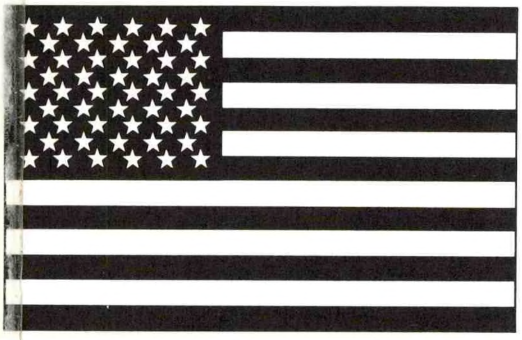

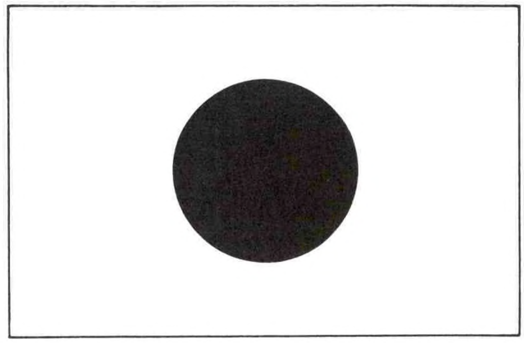

U.S.A.

UJNR

U.S./Japan Cooperative Program in Natural Resources

日本

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16th MEETING of the U.S.-JAPAN MARINE FACILITIES PANEL

September 1989
Conference Record

16th Meeting of the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources (UJNR)

September 1989

Marine Facilities Panel Charter

The UJNR Marine Facilities Panel consists of senior-level engineers, scientists, and managers from the U.S. and Japan who are involved in advanced technology associated with the research, design, development, evaluation, and operation of marine facilities for a wide variety of applications in the assessment, development, utilization, and management of ocean resources.

The scope of technical topics is broad and includes: ocean and coastal engineering; facilities and techniques for ocean resource exploration and development; shipbuilding and marine transportation; undersea systems, submersibles, and remotely operated vehicles; seafloor engineering and offshore construction; port and harbor facility development; ocean environmental measuring and observational systems; and pollution and waste management systems.

Panel members engage in equitable exchanges of technical data and information to avoid unnecessary duplication of ideas; to promote cooperative projects and joint ventures; and to produce mutually beneficial results.

PREFACE

This conference record contains 50 technical papers and special reports presented at the 16th biennial meeting of the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources (UJNR), held September 17-18, 1989, in Seattle, Washington.

From September 14-29, the Joint Panel toured numerous marine facilities along the U.S. West Coast, from Alaska to Hawaii. A final meeting of the Joint Panel was held September 29 at the University of Hawaii-Manoa in Honolulu. A complete schedule and a detailed summary of the meeting and study tour are provided in this report.

The UJNR was established in 1964 to facilitate cooperative efforts and technology exchange in the field of natural resources between key scientific and technical representatives from Japan and the U.S. Seven of the 17 UJNR panels deal with marine science and technology and come under the umbrella of the Marine Resources and Engineering Coordination Committee (MRECC) of the UJNR. The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce is responsible for leading and administering the marine panels. The Marine Facilities Panel has met 16 times, alternating approximately every 18 months between the U.S. and Japan. Each panel meeting has been documented in the form of a proceedings to provide a permanent record and to facilitate wider dissemination of the technical information presented and exchanged at the meeting.

Participating governmental agencies in Japan have included the Science and Technology Agency; Ministry of Agriculture, Forestry, and Fisheries; Ministry of International Trade and Industry; Ministry of Transport; and the Ministry of Construction. Participating governmental agencies in the U.S. have included the Department of Agriculture; Department of Commerce; Department of Energy; Department of the Interior; Department of Transportation; Department of State; Department of Defense; and the Environmental Protection Agency.

Numerous organizations representing private industry and academia have also participated in past meetings. At this meeting, participants from Japan included the Japan Marine Machinery Development Association; Japan Foundation for Shipbuilding Advancement; Mitsubishi Heavy Industries Co., Ltd.; Imabari Shipbuilding Co., Ltd.; Mitsui Engineering and Shipbuilding Co., Ltd.; Japan Marine Science and Technology Center; Coastal Development Institute; University of Tokyo; and Yokohama National University. In the U.S., participants included Westinghouse Electric Corp.; Matson Terminals, Inc.; Tracor Marine, Inc.; Deep Ocean Engineering, Inc.; Marine Development Associates; Engineering Service Associates, Inc.; International Maritime, Inc.; University of Hawaii; University of California; Texas A&M University; Massachusetts Institute of Technology; and the University of Washington.

Special recognition goes to Mr. Richard Krahl, of the Minerals Management Service, U.S. Department of the Interior, for serving as the panel's finance chairman; Ms. Mary Leach and Ms. Lynne Mersfelder, of the International Affairs Branch, National Ocean Service, NOAA, for making the logistical arrangements for the study tour; and to Mr. John Pritzlaff, of Westinghouse Electric Corp., for providing many of the photographs in this conference record.

Pamela H. Rubin
Editor

Table of Contents

Opening Remarks

Eifu Kataoka

Chairman, Japan Panel

On behalf of the Japan Panel, it is a great honor and privilege for me to express our deep appreciation to Mr. Joseph Vadus, Chairman of the U.S. Panel, and to each of the panel members and advisors, for their well-organized arrangements for this 16th joint panel meeting.

Already more than one year has passed since we last met at the 15th joint meeting in Japan.

It is well known that the Marine Facilities Panel is one of the most active panels in the UJNR. Our panel covers a very wide range of technological developments including advanced shipping technology, technology of marine facilities for exploitation of resources, technology for coastal ocean space utilization, and offshore and underwater technology.

To date, through various joint panels, we have been exchanging valuable information and opinions. As important as this information exchange is, however, cooperative programs between the U.S. and Japan should exist also. These must be materialized in the future regardless of whether or not they are undertaken within this panel.

We should also pay attention to the remarks made at the 1973 meeting and other joint meetings: that the scheme of cooperative programs should be positively discussed in the near future. Unfortunately, as far as I know, there has not been much progress because of the various difficulties with respect to research investment and coordination, etc.

We are now seeking opportunities for more cooperation between the U.S. and Japan. I sincerely hope that the U.S. and Japan panels will mutually contribute to the development of ocean technology for the 21st century.

Finally, I would like to extend our cordial gratitude once again to the U.S. Panel members for the preparation of the 16th joint meeting.

Opening Remarks

Joseph R. Vadus

Chairman, U.S. Panel

Konnichi wa, irasshaimase, good afternoon, and welcome. A few of us already had the pleasure of greeting most of the members of the Japan Panel in Alaska. That visit was very interesting and an enjoyable experience.

Now, our entire U.S. and Japan family is together for the plenary session in Seattle. So, on behalf of the U.S. Panel, it is an honor and pleasure for me to extend official warm greetings to Mr. Kataoka, chairman of the Japan Panel, and to each of the members and advisors of the Japan Panel.

After your gracious hospitality at our last meeting and study tour in Tokyo, Kyoto, Osaka and Hokkaido, we are delighted to be your hosts for this 16th meeting of the UJNR Marine Facilities Panel -- our 21st anniversary. We sincerely hope that your visit in the U.S. is interesting, informative and enjoyable.

The objectives of our meetings and study tours are to engage in an equitable technology exchange on a wide variety of topics in ocean engineering research and development, and new advances in

(continued on next page)

marine science and technology; to develop opportunities for closer communications between both sides; and to engage in cooperative projects that are mutually beneficial.

I am grateful to Chairman Mr. Kataoka and to the immediate past Chairman, Dr. Kazuo Sugai, to the Japan Panel, and to Mr. Yukihiro Narita of JAMDA and Mr. Yasukatsu Yamauchi of the Ship Research Institute, for their cooperation in planning and organizing an excellent technical program.

On the U.S. side, I would like to give special recognition to Mr. Richard Krahl, of the Minerals Management Service/U.S. Department of the Interior, for his major effort as Finance Chairman and Chairman of our Alaskan campaign; and to Dr. Jawed Hameedi of NOAA's Alaska office, as Vice-chairman.

Here, in Seattle, the Regional Chairman is RADM Sigmund Petersen of NOAA, and the Vice-chairman is Mr. Edward Early of the Applied Physics Laboratory, University of Washington. Their leadership in coordinating our activities during the Seattle visit and at OCEANS '89 is deeply appreciated.

In San Francisco, the Regional Chairmen are Professor William Webster and Mr. James Wenzel, and in Hawaii, they are Dr. Paul Yuen and Dr. Patrick Takahashi. Their superb efforts are also recognized and equally appreciated.

As you know, our meeting and study tour requires a lot of planning and arrangements. Special recognition is given to Mary Leach and to Lynne Mersfelder of NOAA's National Ocean Service International Affairs office; and to Pam Rubin of NOAA's Office of Oceanography and Marine Assessment for preparing the technical program and study-tour guide.

On a sad personal note, and on behalf of the Marine Facilities Panel, let us join in a small tribute to honor posthumously our dear friend, Dr. Kenji Okamura, who died on January 15, 1989. Dr. Okamura was Special Assistant to the Japan's Minister for Science and Technology, longtime executive with Mitsubishi Heavy Industries Ltd., and a Founding Director of the Japan Marine Science and Technology Center. Among his many accomplishments was his distinguished service and valuable contributions as participant and advisor to the Marine Facilities Panel.

We will always remember Dr. Okamura and will continue to share in his fervent objectives for the development of the oceans for the benefit of mankind.

In his memory, let us share in a few moments of silence.

In closing, I would like to say that the U.S. members and advisors cherish the trust and friendship that these meetings have fostered with our Japanese colleagues; and it is our sincere hope that this spirit of mutual cooperation will become even stronger as we strive together to meet the challenges of the 21st Century.

I wish each and every one of you a pleasant and productive meeting and study tour.

Thank you. Domo arigato, gozaimasu.

A Tribute To Dr. Kenji Okamura

The Marine Facilities Panel, U.S.-Japan Cooperative Program in Natural Resources (UJNR), honors posthumously Dr. Kenji Okamura, who died on January 15, 1989. Dr. Okamura was a Special Assistant to the Minister for Science and Technology, a longtime Executive with Mitsubishi Heavy Industries Ltd., and a Founding Director of the Japan Marine Science and Technology Center.

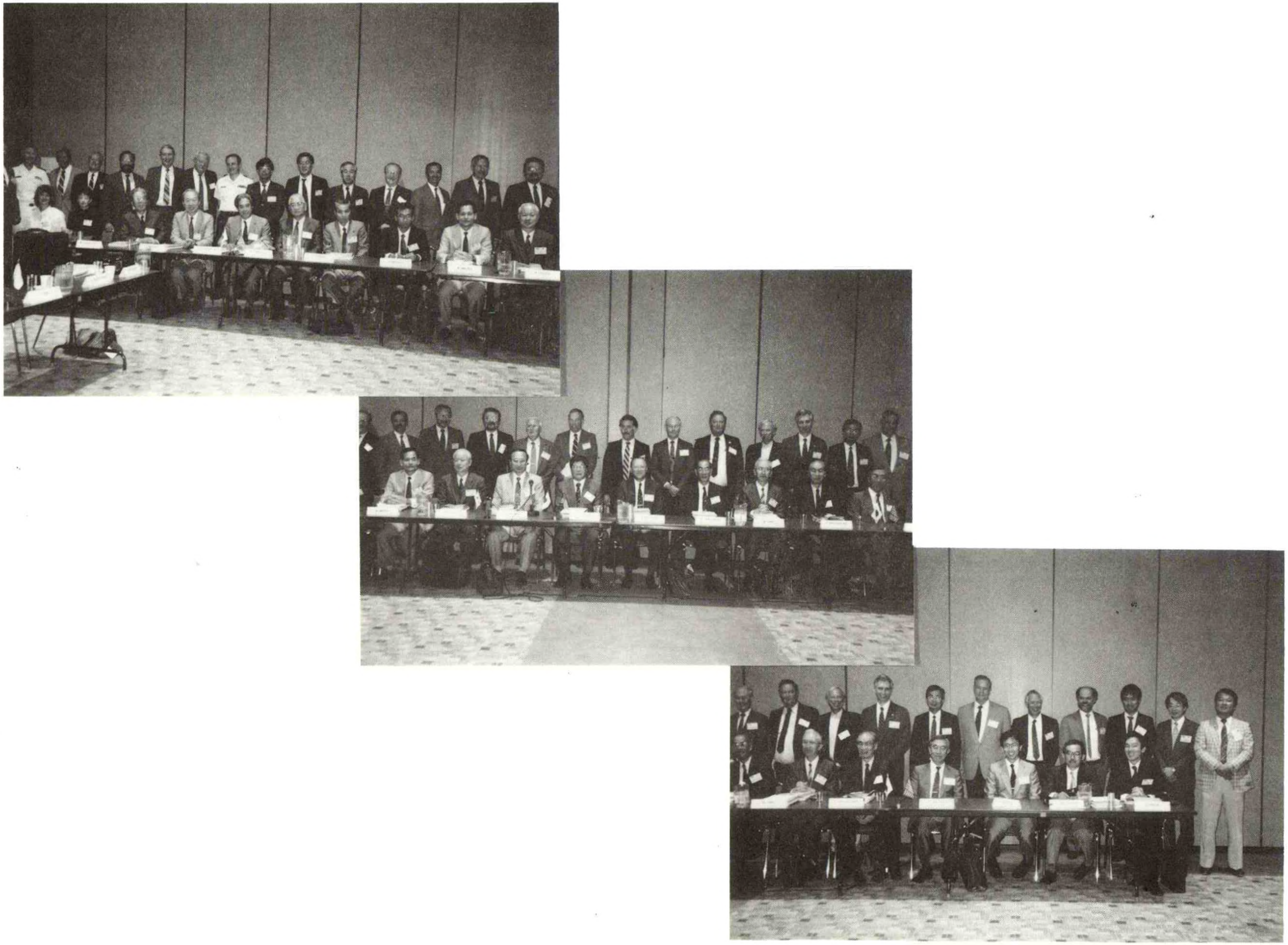
Dr. Kenji Okamura was internationally known and highly respected for his distinguished career and many contributions to the advancement of ocean science and technology for the development and utilization of the oceans and their resources. Among his many accomplishments was his distinguished service and valuable contributions as participant and advisor to the Marine Facilities Panel and other Marine Panels of the UJNR.

We will always remember Dr. Okamura and will continue to share in his fervent objectives for development of the oceans for the benefit of mankind.

Eifu Kataoka Japan Chairman	Joseph R. Vadus U.S. Chairman

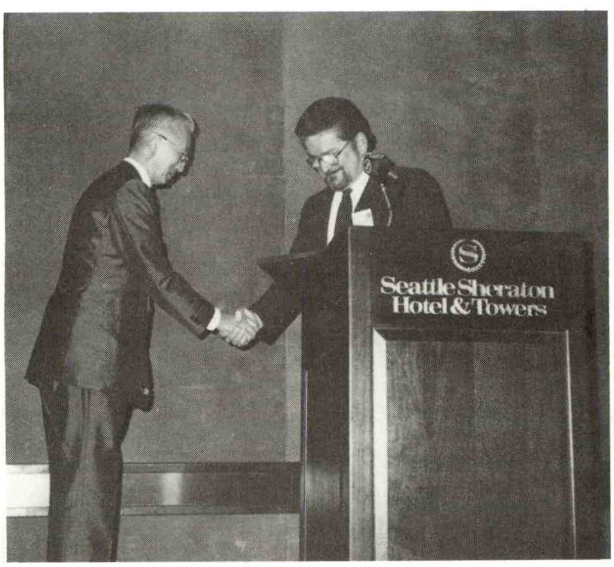
Marine Facilities Panel, UJNR

The entire Joint Panel at the Plenary Session.



Special Recognition

On September 17, 1989, the U.S. and Japan Panels exchanged awards of special recognition. The recipients were acknowledged for their many years of dedicated service and their outstanding contributions to furthering the objectives of the UJNR Marine Facilities Panel.



Clockwise from top left: U.S. Chairman Joseph R. Vadus presents plaques to Japan Panel Chairman, Mr. Eifu Kataoka, Director-General of the Ship Research Institute; Professor Seizo Motora, of the Japan Foundation for Shipbuilding Advancement; and Mr. Masao Ono, of Mitsubishi Heavy Industries Co., Ltd. An award was also presented to Mr. Masanao Oshima, of Mitsui Engineering and Shipbuilding Co., Ltd., one month later in Tokyo.

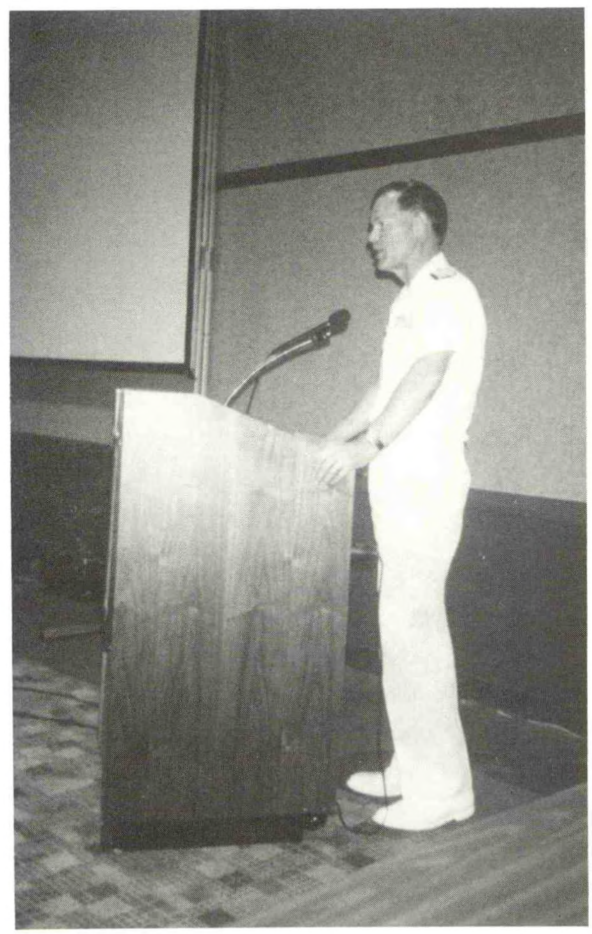
Special Recognition

Japan Panel Chairman Eifu Kataoka presented framed letters of recognition to Mr. Richard Krahl, of the Minerals Management Service, U.S. Department of the Interior; and to Mr. John Pritzlaff, of Westinghouse Electric Corporation.

Plenary Session

The Plenary Session was held September 18 and 19, 1989, at the Washington State Convention and Trade Center in Seattle, Washington.

Following opening remarks by U.S. Chairman Joseph R. Vadus and Japan Chairman Eifu Kataoka, the meeting began with opening remarks from Dr. Robert Wildman, U.S. Chairman of the Marine Resources and Engineering Coordination Committee of the UJNR. RADM Sigmund Petersen, UJNR/MFP regional chairman and director of the NOAA Pacific Marine Center, welcomed the Panel to Seattle.



Left: MRECC Chairman Robert Wildman makes opening remarks. Right: MFP Regional Chairman RADM Sigmund Petersen welcomes the Joint Panel to Seattle.

Keynote Addresses

Keynote addresses were presented by Richard Metrey, Technical Director, David Taylor Naval Research and Development Center; Hisaaki Maeda, Professor, Institute of Industrial Science, University of Tokyo; Charles N. Ehler, Director, NOAA Office of Oceanography and Marine Assessment; and Kazuo Sugai, Managing Director, Technological Research Union of Techno Super Liner. Technical presentations followed.

Top left: Prior to making his keynote address, Richard Metrey (center) presents Chairmen Kataoka (left) and Vadus (right) with a book chronicling the history of the David W. Taylor Model Basin. Top right: Kazuo Sugai's keynote address. Bottom left: Charles Ehler's keynote address. Bottom right: Hisaaki Maeda's keynote address.

Plenary Session

Above: U.S. Chairman Joseph Vadus opens the plenary session of the 16th meeting of the UJNR Marine Facilities Panel. In the foreground is the U.S. Panel. Below: In the foreground is the continuation of the U.S. Panel. On the opposite side is the Japan Panel.

1989 Marine Facilities Panel Participants

United States

Chairman

Mr. Joseph R. Vadus
National Oceanic and Atmospheric Administration

Special Guests

Dr. Robert Wildman
U.S. Chairman, Marine Resources and Engineering Coordination Committee of the UJNR
National Oceanic and Atmospheric Administration

Dr. Richard Podgorny
National Oceanic and Atmospheric Administration

Members

Mr. William Andahazy
David Taylor Naval Ship R&D Center

CAPT Wayne Becker
U.S. Coast Guard

Dr. Eddie Bernard
National Oceanic and Atmospheric Administration

Mr. Charles Bookman
Marine Board, National Research Council

Mr. Norman Caplan
National Science Foundation

Mr. Charles N. Ehler
National Oceanic and Atmospheric Administration

Mr. John Freund
Naval Sea Systems Command

Dr. Jawed Hameedi
National Oceanic and Atmospheric Administration

Mr. Dan Hightower
Naval Ocean Systems Center

Mr. Richard Krahl
Minerals Management Service

Dr. Jerry McCall
National Data Buoy Center

Dr. James Meng
Naval Underwater Systems Center

Mr. Paul Mentz
Maritime Administration

Mr. Richard Metrey
David Taylor Naval Ship R&D Center

Dr. Kilho Park
NOAA Office of the Chief Scientist

RADM Sigmund Petersen
NOAA Pacific Marine Center

Dr. Steven Ramberg
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Mr. Howard Talkington
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Dr. Robert Whalin
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Dr. John Craven
University of Hawaii

Dr. Sylvia Earle
Deep Ocean Engineering, Inc.

Mr. Edward Early
University of Washington

Mr. John Flipse
Texas A&M University

Dr. Ernst Frankel
Massachusetts Institute of Technology

Mr. Christopher Kane
Matson Terminals, Inc.

Mr. Clifford McLain
Marine Development Associates

Mr. John Pritzlaff
Westinghouse Electric Corp.

Mr. Richard Shamp
Engineering Services Assoc., Inc.

Dr. Patrick Takahashi
University of Hawaii

Dr. Don Walsh
International Maritime, Inc.

Dr. William Webster
University of California

Mr. James Wenzel
Marine Development Associates

Dr. Paul Yuen
University of Hawaii

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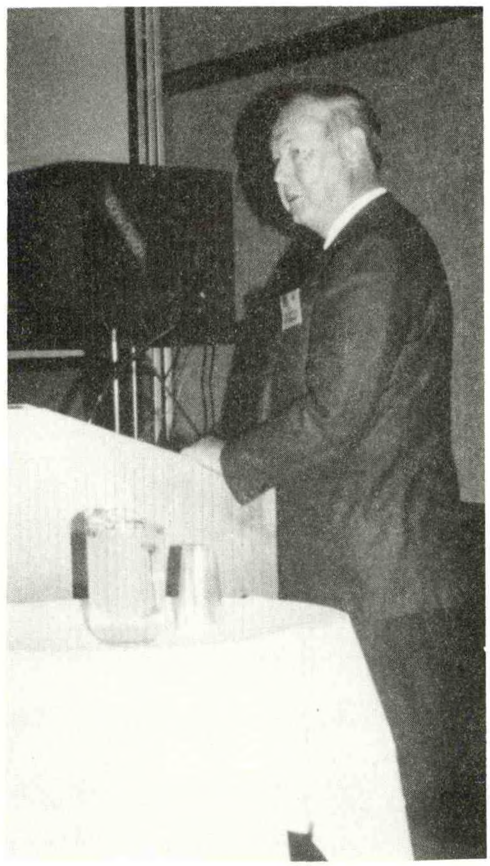
National Oceanic and Atmospheric Administration

Ms. Lynne Mersfelder
National Oceanic and Atmospheric Administration

Ms. Pam Rubin
National Oceanic and Atmospheric Administration



Above: Mr. Howard Talkington.
Left: Mr. Richard Metrey and Dr. Hitoshi Narita.

1989 Marine Facilities Panel Participants

Japan

Chairman

Mr. Eifu Kataoka
Ship Research Institute, Ministry of Transport

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Mr. Takao Hirota
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Prof. Hisaaki Maeda
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Prof. Seizo Motora
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Mr. Hiroyuki Nakato
Japan Marine Science and Technology Center

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Nippon Kaiji Kyokai, Seattle Office

Mr. Tetsuya Shiraishi
Japan Transport Economics Research Center

Mr. Ken-ichi Takahashi
Japan Marine Science & Technology Center

Dr. Iwao Watanabe
Ship Research Institute, Ministry of Transport

Japan Panel members confer at the plenary session. Left to right: Dr. Kazuo Sugai, Japan Panel Chairman Eifu Kataoka, Prof. Seizo Motora, Prof. Hisaaki Maeda.

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The U.S. Reception in the Seattle Sheraton ballroom.

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Above: Members of the Joint Panel dress in survival gear for their helicopter flight and site tour of the Grayling Platform, located in the Cook Inlet near Kenai, Alaska. Standing, left to right: Richard Krahl, Sadao Ando, Takao Hirota, Kazuo Sugai, Jun Obokata, Hitoshi Narita, Hisaaki Maeda, John Pritzlaff, John Flipse. Kneeling, left to right: Tetsua Shiraishi, Yukihiro Narita. Below: The stark beauty of ice floes at Portage Glacier, near Anchorage, Alaska.

1989 UJNR Marine Facilities Panel Study Tour

Thursday, September 14

Kenai Liquid Natural Gas Plant
Phillips Petroleum Company
P.O. Drawer 66
Kenai, Alaska 99611
Telephone: 907-776-8166

Liquid Natural Gas (LNG) is ordinary natural gas that has been reduced in temperature to about -259 degrees F (-161 C) and changed from a vapor to a liquid. This reduces the space required to store or transport the gas from approximately 600 cubic feet of vapor to only one cubic foot of liquid. LNG is colorless, odorless, nontoxic and sulfur-free. As a result, it is a clean-burning, highly desirable fuel.

The North Cook Inlet natural gas field was discovered in Alaska's Upper Cook Inlet in 1962. Because there was only a limited demand for natural gas in Alaska and little or no interest in the "lower 48" states, it soon became apparent that an international project would be necessary in order to commercialize the gas. Two Japanese companies — Tokyo Electric Power Co., Inc. and Tokyo Gas Company, Ltd. — recognized the value of the clean-burning fuel in mitigating their country's growing air-pollution problems. As a result, contracts with Phillips Petroleum Company, as plant operator, and Marathon Oil Company, as operator of the transportation system, were signed in March 1967. Thus began the largest LNG project undertaken until that time.

On November 5, 1969, the Polar Alaska, one of two LNG tankers (the other is the Arctic Tokyo), docked in Yokohama and discharged the first LNG ever exported from North America — and the first ever imported into Asia. Each tanker has a capacity of 71,500 cubic meters and makes 17 or 18 round trips each year.

Left: The Joint Panel attends a briefing in the control room of the Kenai Liquid Natural Gas Plant.

Right: Panel members stand on the shipment dock for liquid natural gas tankers in Cook Inlet.

The Grayling Platform
Cook Inlet
Kenai, Alaska
Helen Oradei, contact person
Minerals Management Service
949 E. 36th Ave. , Suite 614
Anchorage, AK 99508
Telephone: 907-261-4065

The Grayling Platform was designed by Brown & Root Company of Houston, Texas, in 1965. The platform was built in Vancouver, Washington, and the jacket was ocean-towed to Alaska in the spring of 1967.

The platform is located in 125 feet of water (the tidal variation is approximately 30 feet). Its height from the ocean floor to the top drilling is 421 feet. The deck size is 114 by 120 feet, with a 47-by-60-foot subdeck. There are 48 drilling slots, 12 in each leg. The jacket weight (steel only) is 3,547 tons. The total platform weight, including equipment and supplies, is 23,680 tons.

Two 10-inch-wide pipelines transport oil and gas 6.04 miles under Cook Inlet to the beach. Currents in the inlet reach a speed of eight to nine knots, and the air-temperature variation is from 70 degrees F to -22 degrees F.

Visitors to the platform are advised to wear warm, layered, casual clothing and a head covering. Following lunch on the Platform, the Minerals Management Service of the U.S. Dept. of the Interior will give a presentation on cold-weather work. The day's activities will include a visit to a pump station of the Trans-Alaska Pipeline System.

Left: This view of the Grayling Platform was photographed from the helicopter that transported the Joint Panel to the facility.

Right: Panel members attend a briefing at the Grayling Platform.

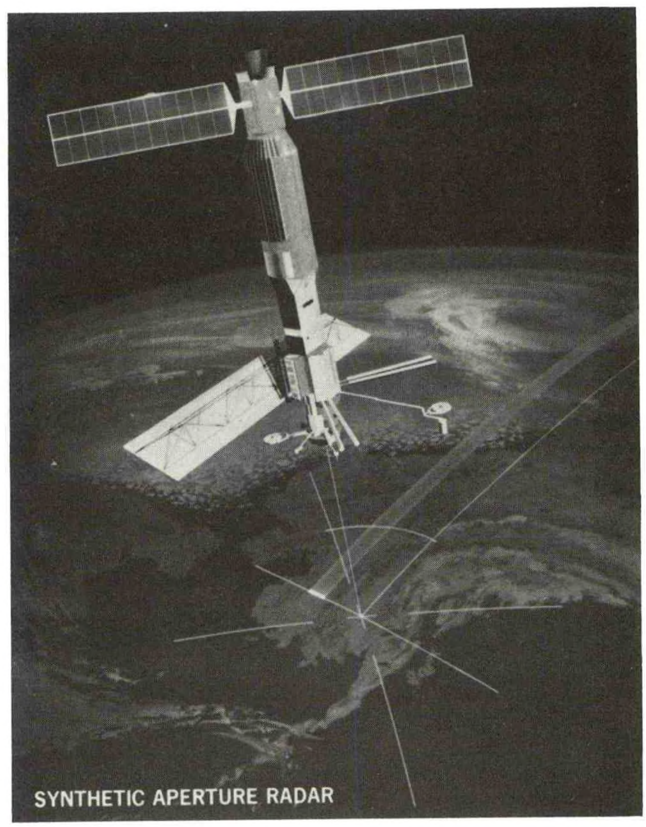
Friday, September 15

The Geophysical Institute
University of Alaska Fairbanks
Fairbanks, Alaska 99775-0800
Syun Akasofu, Director
Telephone: 907-474-7558

Research at the Geophysical Institute focuses on high-latitude geophysical phenomena. Established by Congress in 1946, the institute is dedicated to teaching, research, and public service at the University of Alaska Fairbanks. The institute's proximity to both the Arctic and North Pacific Oceans makes it an important base for studies in these regions.

Research findings are applied in such areas as communications, space programs, and national defense; weather and climate; transportation and economic development; natural resources and environmental preservation; and the prediction and detection of geophysical hazards. The institute is primarily funded by research grants from the National Science Foundation, the National Air and Space Administration (NASA), and other federal agencies.

Institute scientists actively participate in formulating state, national, and international research policy for the Arctic region. The institute's human and technical resources are particularly well-suited to address such scientific issues.



Above: Panel members attend a demonstration and briefing at the Alaska Synthetic Aperture Radar Facility. Right: The Geophysical Institute's SAR Facility will manage data from synthetic aperture radar satellites similar to this one.

Alaska Synthetic Aperture Radar Facility (SAR)
University of Alaska Fairbanks
Fairbanks, Alaska

Remote sensing from space platforms is very important to scientific research in remote and inaccessible regions of Alaska and the Arctic. In 1987, NASA and the University of Alaska Fairbanks established the Alaska SAR Facility in order to gather data from a new generation of satellites with synthetic aperture radars (SAR). These satellites, to be launched in the early 1990s, will receive, analyze, store and distribute data, substantially extending the scope of northern research. Sea ice and oceanographic studies will benefit greatly from SAR data, as will research in glaciology, geology, and botany.

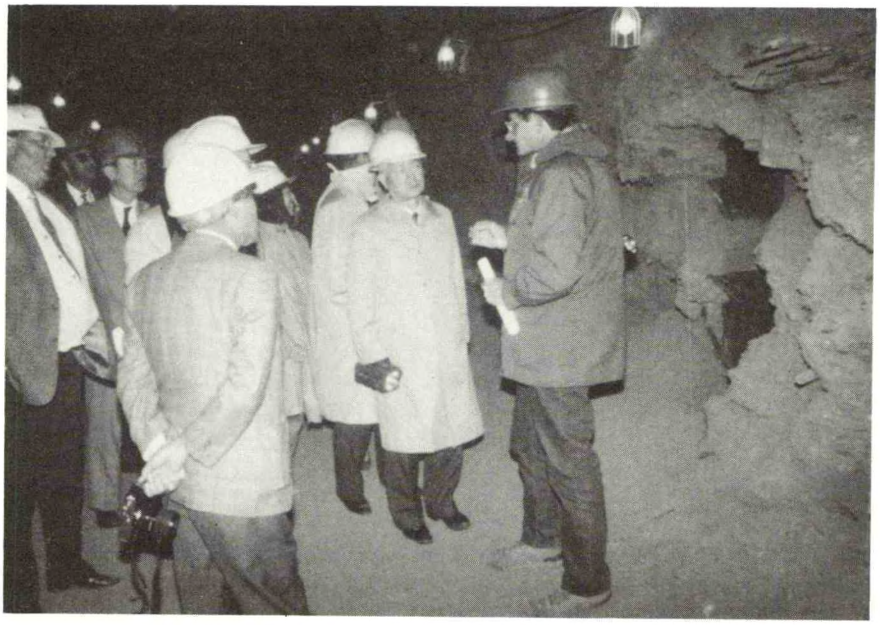
One of three such stations in the world, the Alaska SAR Facility will operate in conjunction with SAR stations in Kiruna, Sweden and Ottowa, Canada. In time, the three stations will provide nearly complete coverage of the Arctic Ocean.

Permafrost Tunnel
U.S. Army Corps of Engineers and
The University of Alaska Fairbanks
Fox, Alaska
Jawed Hameedi, contact person
Program Manager NOS/NOAA
P.O. Box 56
Anchorage, AK 99513
Telephone: 907-271-3618

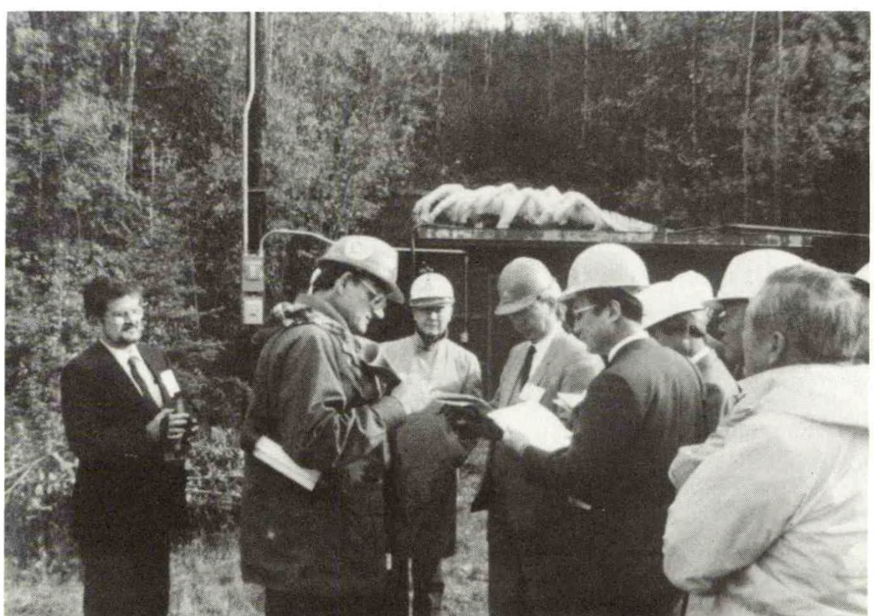
More than half of Alaska is underlain by permafrost (perennially frozen ground), which poses challenging scientific and engineering problems related to human activity throughout the region. In 1965, the Cold Regions Research and Engineering Laboratory (CRREL) of the U.S. Army Corps of Engineers built the first permafrost research tunnel in the western world at a site in Fox, Alaska, about 10 miles north of Fairbanks.

CRREL and the University of Alaska Fairbanks now jointly maintain the tunnel for permafrost studies and demonstration purposes. The geological exposures in the tunnels provide a unique opportunity to observe ice structures some 30,000 to 40,000 years old, as well as ice-saturated soils common to permafrost. These ice structures are responsible for most of the engineering problems associated with construction in frozen soils.

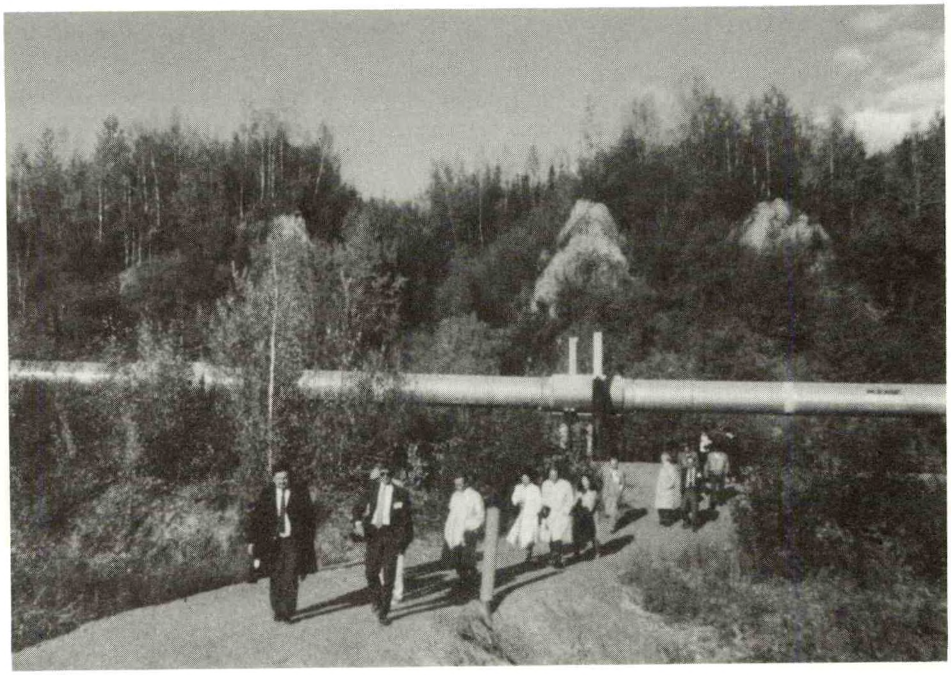
The distinctive odor in the tunnel is common to most permafrost excavations in the region. The odor results from the oxidation of organic materials found throughout the exposed silt. This organic material originated from prehistoric plants and animals that once populated the valley.



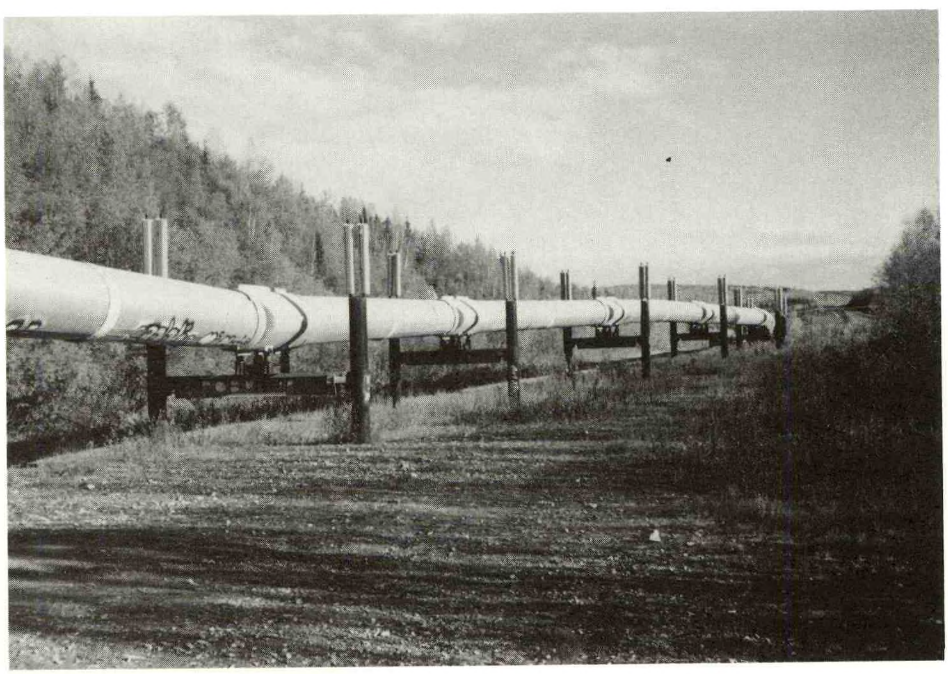
Left: Inside the Permafrost Tunnel, a guide explains some of the engineering problems unique to the Alaskan region. In the middle of the photo is Dr. Kazuo Sugai, former Chairman of the Japan Panel. At the far left is Richard Krahl of the Minerals Management Service, U.S. Dept. of the Interior.



Right: The Panel receives a briefing before entering the Permafrost Tunnel. The large pipes on top of the tunnel entrance (background) help to keep the entrance cold.



Before departing for Seattle, the Panel visited the famous Trans-Alaska pipeline.



Tuesday, September 19

OCEANS '89 Conference
Washington State Convention & Trade Center
Robert C. Spindel, Chairman

"The theme of this conference is 'The Global Ocean' — global in its earth-girdling extent, global in influence on our planet's environment, and global in promising opportunities," writes Conference Committee Chairman Robert C. Spindel, professor of applied physics at the University of Washington. "The global ocean initiatives of today will tomorrow provide profound new understanding of the forces that shape our future. I cannot imagine a more challenging, exciting or opportune time for those of us in the 'ocean business.' We embark on a voyage of discovery made possible by the products of technology which allow us, for the first time, to view our planet and its seas in toto."

Plenary session: On Tuesday morning, leaders from industry, government and academia will address global ocean issues to provide a framework for the 2-1/2 days of technical sessions that follow.

Technical sessions: Beginning Tuesday afternoon, 102 sessions will feature more than 400 technical presentations.

Exhibition: Also beginning Tuesday afternoon, more than 100 exhibitors will display the latest ocean technology products and services available from industry, government and academic institutions.

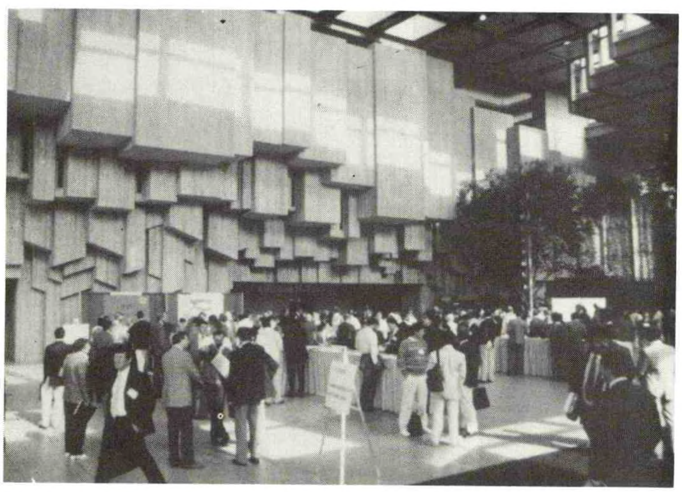
Visiting vessels: Two vessels are scheduled to be moored at NOAA's Pacific Marine Center on Fairview Avenue East in Seattle at the time of the conference. The UJNR/MFP Panel has been invited to tour the NOAA Ship Rainier on Thursday, September 21. The research vessel William A. McGaw, owned and operated by Ocean Enterprises, Ltd., will be open throughout the conference.

Wednesday, September 20

OCEANS '89 Conference
Washington State Convention & Trade Center

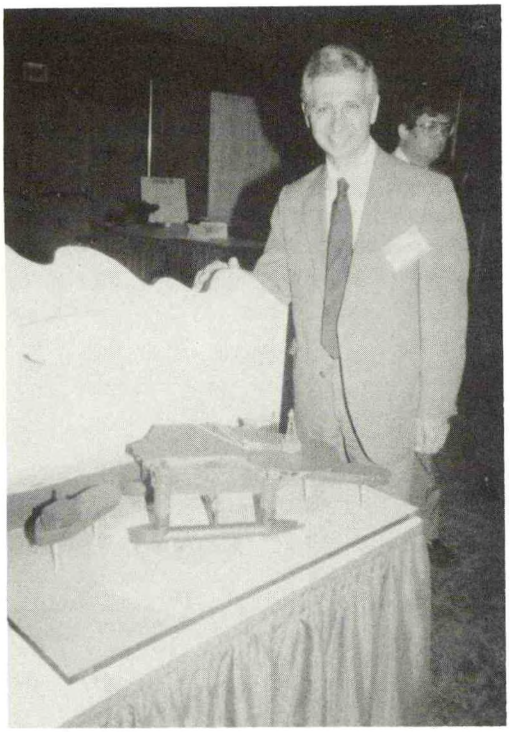
In addition to the OCEANS '89 technical sessions, which will continue throughout the day, the following OCEANS '89 activities will be offered:

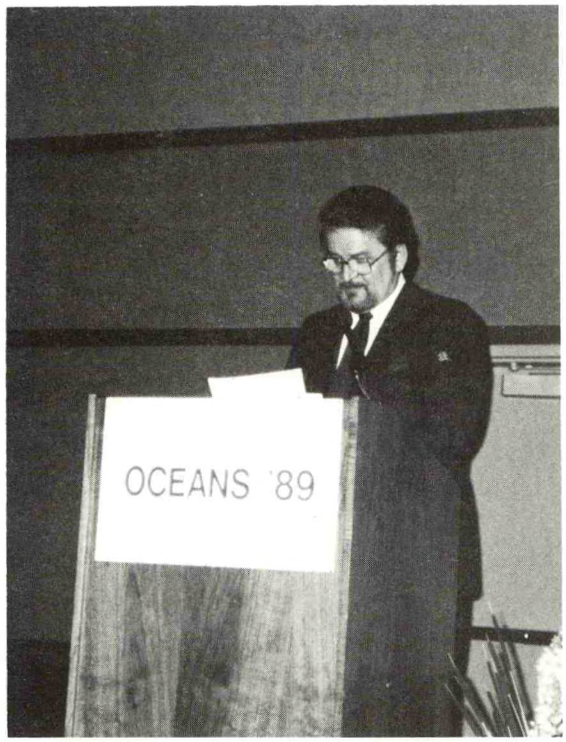
Poster session: On Wednesday afternoon, graduate and undergraduate students from U.S. Sea Grant Colleges will present their findings on more than 20 international oceanographic projects.



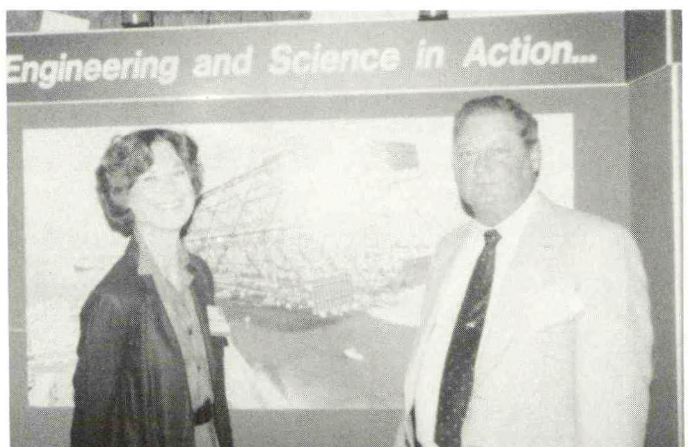
Left: Opening day of OCEANS '89 at the Washington State Convention & Trade Center.

Right: The Joint Panel joined other OCEANS '89 participants on a cruise through scenic Elliott Bay to Blake Island in Puget Sound. The Seattle skyline can be seen in the background.





The Joint Panel participated in a variety of activities at OCEANS '89. Clockwise from top right: The U.S. Panel sings at the U.S. reception. U.S. Chairman Joseph Vadus serves as Master of Ceremonies at the evening banquet. Richard Krahl speaks with a representative from the Minerals Management Service at the MMS exhibit. The Japan Panel sings at the evening banquet. Richard Metrey visits the exhibit of the David Taylor Naval Research and Development Center.



<u>*Thursday, September 21*</u>

Lake Washington Ship Canal and
Hiram M. Chittendon Locks
U.S. Army Corps of Engineers
P.O. Box C-3755
Seattle, Washington 98124

The eight-mile-long Lake Washington Ship Canal winds through Seattle's Ballard, Fremont, Wallingford, University, and Montlake Districts, linking Puget Sound and Shilsole Bay with the fresh waters of Salmon Bay and Lakes Union and Washington. Here, commercial and pleasure craft are free from tides and strong currents.

Before the canal and Hiram M. Chittendon Locks and Dam were built early in this century, no direct navigable connection existed between these waters. Currently, about 100,000 commercial and pleasure vessels navigate the locks each year. Cargo and logs passing through the locks average more than two million tons annually.

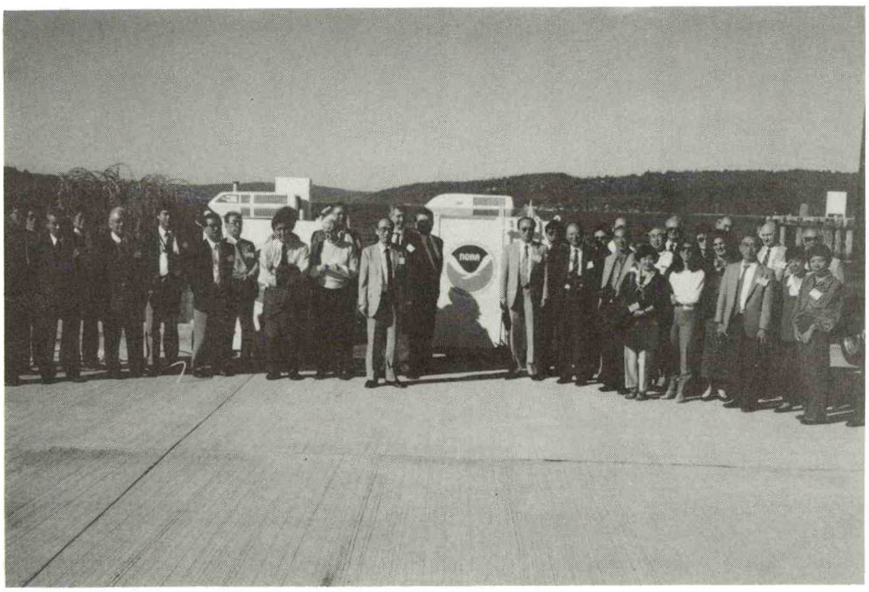
A park ranger explains operations at the Hiram M. Chittendon Locks.

The eight-mile-long Washington Ship Canal protects pleasure and commercial craft from tides and strong currents.

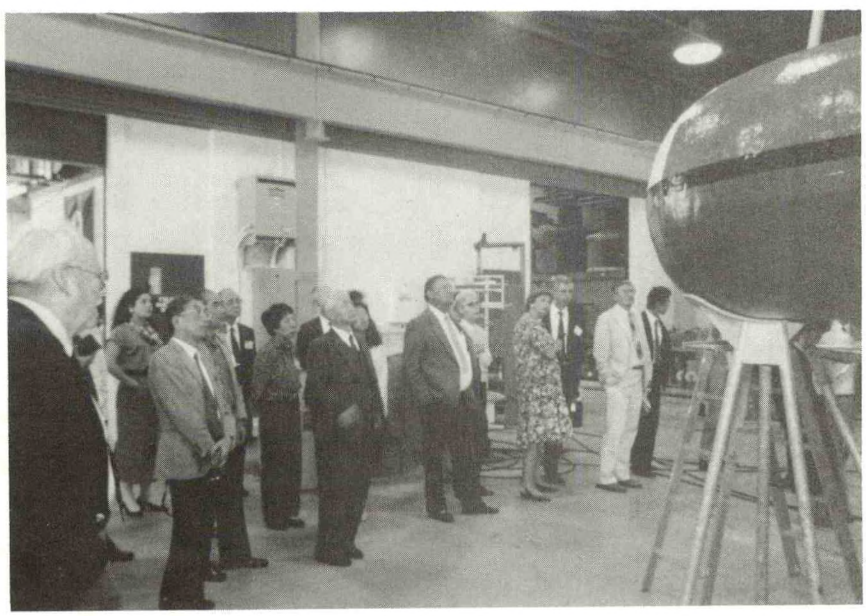
__Thursday, September 21__

Pacific Marine Environmental Laboratory
Office of Oceanic and Atmospheric Research
National Oceanic & Atmospheric Administration
7600 Sand Point Way NE
Seattle, Washington 98115
Dr. Eddie N. Bernard, director
Telephone: 206-526-6800

The Pacific Marine Environmental Laboratory (PMEL) conducts oceanographic and meteorological research throughout the Pacific to improve our understanding of marine geochemistry, ocean circulation, and ocean-atmosphere interactions. The Marine Assessment Division studies physical and geochemical processes that determine the health of the ocean system and its ability to withstand potential pollutants, in order to help policymakers balance economic development and environmental conservation. The Ocean Climate Division studies the processes of heat, moisture and momentum exchange between the ocean and atmosphere, including the large-scale transport of heat by the ocean and atmosphere, to predict both short- and long-term climatic change. The Marine Sciences Division investigates ice dynamics and thermodynamics, as well as coastal winds, waves, and tsunamis, to improve information, forecasts, and warnings regarding possible environmental hazards to people in U.S. offshore and coastal areas. The Marine Resources Division researches the oceanographic effect of seafloor spreading processes, such as high-temperature fluids venting from geologically active areas of mid-ocean ridges.



The Joint Panel at the NOAA Pacific Marine Environmental Laboratory in Seattle.



The Panel attends a briefing and demonstration in PMEL's manufacturing and assembly facility.

Pacific Marine Center & NOAA Ship Rainier
National Ocean Service
National Oceanic and Atmospheric Administration
1801 Fairview Avenue East
Seattle, Washington 98102-3767
Rear Admiral Sigmund R. Petersen, Director
Telephone: 206-442-7656

The Pacific Marine Center (PMC) operates the 12 NOAA vessels stationed on the U.S. West Coast. Nine of these ships, which range in size from 86 to 303 feet in length, have their home port on Lake Union in Seattle. (California, Hawaii and Alaska host one vessel each.) These 12 ships serve as the "working platforms" for NOAA bathymetric surveying and other oceanographic and fishery research throughout the Pacific. KVJ, the PMC radio station, provides daily radio communication with the fleet.

The NOAA Ship Rainier, which will host a late-afternoon reception for the UJNR/MFP Panel, is one of the vessels that operates from the PMC. The 231-foot vessel was commissioned in 1968. Commanding Officer John C. Albright supervises 10 officers and 42 crew members. The ship is currently engaged in hydrographic surveys on the south side of the Alaska Peninsula. These surveys will be used to update and maintain NOAA nautical charts.

Left: The Panel is briefed in the control room of the NOAA ship RAINIER. Below: the NOAA Pacific Marine Center in Seattle.

Left to right: former Japan Panel Chairman Dr. Kazuo Sugai and Mrs. Sugai; U.S. Panel Chairman Joseph Vadus; Mrs. Motora and Prof. Seizo Motora; and Captain Wayne Becker of the U.S. Coast Guard.

Following the day's site visit, the NOAA Ship RAINIER (below) hosted an afternoon reception for the Joint Panel. Right photo, left to right: Japan Panel members H. Yamashita, H. Nakato, and E. Kataoka with NOAA Corps Rear Admiral Sigmund Petersen .

Friday, September 22

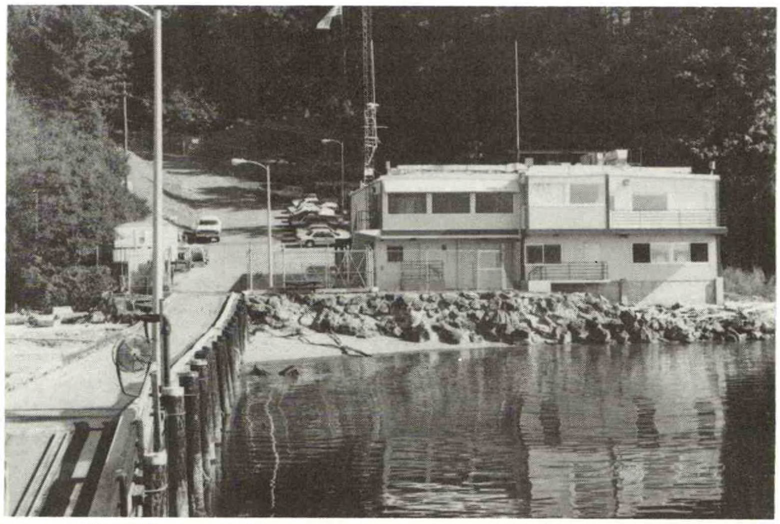
Carr Inlet Acoustic Range
Department of the Navy
David Taylor Research Center Detachment,
Puget Sound
Bremerton, Washington 98314-5215
C.P. Henson, Director
Telephone: 206-476-4335

The Carr Inlet Acoustic Range (CIAR) was established in 1953 to conduct research and engineering studies in the areas of underwater acoustics and ship silencing. The facility, located in southern Puget Sound near Tacoma, Washington, is used to support both the Surface Ship Silencing and Submarine Noise Reduction Programs. The operations center is located on Fox Island.

CIAR has the unique capability to suspend a submarine in free water while supplying up to 2,400 amperes (amps) of shore power for special tests. This capability maximizes the efficient use of time and minimizes crew fatigue during acoustical trials, since the ship is always in the measurement area and is not required to maneuver between test runs. In addition, the ship's propulsion and power-generating plants can be shut down while operating on shore power, thus enabling engineers to evaluate the effects of individual auxiliary systems or components of the ship's noise signatures.

CIAR has a bottom-mounted tracking system for submarine maneuvering and positioning, along with state-of-the-art systems for data acquisition, processing and analysis.

The Carr Inlet Acoustic Range (right) is located in southern Puget Sound near Tacoma, Washington, where the Joint Panel posed for a group photo at Tacoma Boatbuilding Company (below).



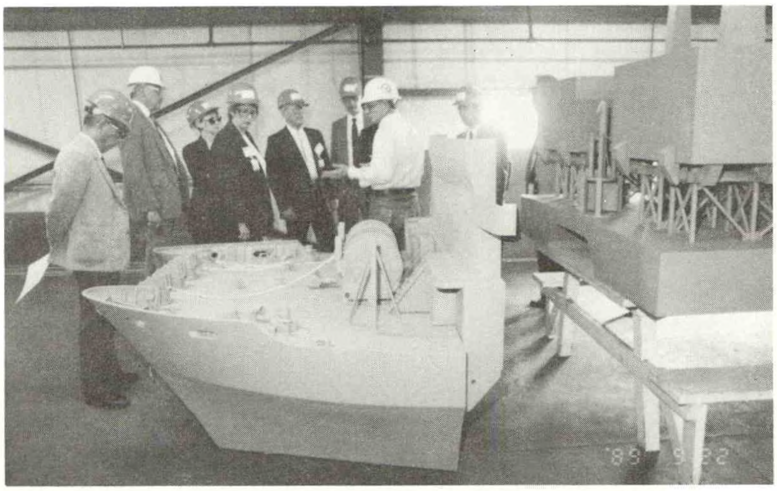
U.S. Naval Ship Hayes
Tacoma Boatbuilding Company
Tacoma, Washington
Charles Henson, contact person
Dept. of the Navy
DTRC Detachment, Puget Sound
Bremerton, WA 98314-5215

In 1986, the United States Navy proceeded with plans to develop an Acoustic Research Ship (T-AG 195). According to the plan, the T-AG 195 would be required to meet stringent, self-generated underwater noise specifications in order to measure vessel-generated underwater noise in support of the Submarine Noise Reduction Program. The T-AG 195 would also be used to further research and development of advanced acoustic sensors and related equipment.

Converting an existing ship was the most cost-effective way to meet the T-AG 195 Program requirements, so the Naval Sea Systems Command (NAVSEA) chose to convert the USNS Hayes. The conversion is designed to meet commercial specifications and standards, and will be certified by the American Bureau of Shipping, the United States Coast Guard, and other regulatory bodies. The converted ship will be operated by a Military Sealift Command civilian crew, which will support a research team composed of civilian scientists from the David Taylor Naval Ship Research and Development Center (DTNSRDC). These scientists will be responsible for performing the mission measurements.

In February 1987, NAVSEA awarded the conversion contract to Tacoma Boatbuilding Company of Tacoma, Washington. The project is being administered by the USN Supervisor of Shipbuilding, Conversion and Repair in Seattle. An on-site Noise Control Team, staffed by DTNSRDC personnel, is responsible for ensuring that the ship's critical design elements meet the specified noise criteria.

The U.S. Naval Ship HAYES (below) is currently undergoing conversion to become an Acoustic Research Ship (T-AG 195). At right, members of the Joint Panel study a model of the ship.



Monday, September 25

San Francisco Bay-Delta Tidal Hydraulic Model
U.S Army Corps of Engineers
2100 Bridgeway
Sausalito, California 94965
Telephone: 415-332-3871

The San Francisco Bay and Sacramento-San Joaquin Delta is a complex estuarine system. To increase our knowledge of this system and to develop information to assist decision makers on planned water projects, the Corps of Engineers constructed the San Francisco Bay-Delta Tidal Hydraulic Model. All important features of the Bay and Delta are represented, including ship channels, rivers, creeks, sloughs, canals, fills, major wharves, piers, slips, dikes, bridges and breakwaters.

Although the Model does not look exactly like the Bay or Delta, its action is similar. It reproduces (to the proper scale) the rise and fall of tide, water flow and currents, salinity distributions (the mixing of salt and fresh water), and indicates trends in sediment movement. This enables engineers, scientists and planners to analyze problems that can't be resolved through textbooks, experience or mathematical models alone. Engineers are able to examine, in a laboratory setting, the effects of change on the physical forces of the Bay and Delta.

The original Bay Model was constructed in 1956-57, and the Delta portion was added in 1966-69. Operated by a Hewlett Packard minicomputer system linked to such automated instruments as water-level detectors, conductivity/temperature meters and velocity meters, the Model approaches the technological state of the art.

Top left: The Golden Gate Bridge in a classic San Francisco "fog bank." Top right: A Sunday afternoon barbecue at the home of U.S. Panel advisor James Wenzel. Bottom: The Joint Panel visits the San Francisco Bay Model.

Deep Ocean Engineering, Inc.
1431 Doolittle Drive
San Leandro, California 94577
Telephone: 415-562-9300

Deep Ocean Engineering, Inc. (DOE) is a privately owned corporation founded in 1982 by Graham Hawkes and Sylvia Earle to design, manufacture, and operate equipment for use in underwater and other "hostile" environments. Products include modular sensory manipulators and control systems, remotely operated underwater vehicles (ROVs), manned submersibles, and a wide variety of instruments, tools and accessories.

More than 150 of DOE's portable PHANTOM ROVs have been used worldwide for research, military applications, police search and recovery operations, pipeline surveys, dam and oil rig inspection, recreation, use in nuclear power facilities and other applications. DEEP ROVER, a one-man submersible designed and built by DOE, has been used in various commercial and scientific research applications in depths to 1,000 meters.

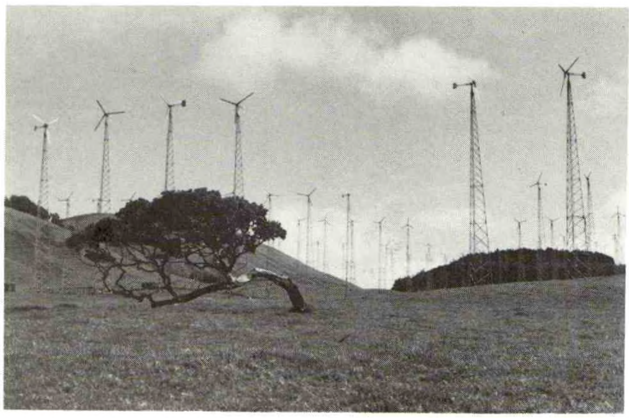
DOE received the Marine Technology Society's 1988 Compass Award for its "outstanding contribution to the advancement of the science and engineering of oceanography and marine technology."

Top left: Dr. Sylvia Earle holds a toaster to compare its size to that of Deep Ocean Engineering's FIREFLY ROV (remotely operated vehicle), held by Mr. Yukihiro Narita. Top right: Dr. Earle briefs the Joint Panel. Below: The Phantom DS4 is one of DOE's latest models. Below left: Mr. John Pritzlaff operates the Phantom 300.

Wednesday, September 27

Kahua Ranch Wind Farm
P.O. Box 837
Kamuela, Hawaii 96743
H. Monte Richards, manager
Telephone: 808-889-6464

Located in the North Kohala District of the Big Island of Hawaii, the Kahua Ranch is one of the largest "wind farms" in the state. The ranch itself owns three Jacobs wind machines, and private investors have installed 198 more Jacobs and six Carter machines. As a result, the ranch is capable of providing approximately four percent of the Big Island's peak late-afternoon electrical needs.



Above: At the Kahua Ranch Wind Farm, a lone tree stands as testimony to the natural energy being harnessed there. Right and below: The OTEC (ocean thermal energy conversion) project at the Natural Energy Laboratory of Hawaii was of great interest to the Joint Panel, which received a lecture on the topic at the Keyhole Point facility on the Big Island.

Natural Energy Laboratory of Hawaii (NELH)
OTEC and Mariculture Facilities
P.O. Box 1749
Kailua-Kona, Hawaii 96720
Claire Hachmuth, contact person
Telephone: 808-329-0648

The NELH Kona Seacoast Facility, nicknamed "OTEC," is located on 322 acres of oceanfront property at Keahole Point, adjacent to Keahole Airport, on the Big Island of Hawaii. This site is deemed to be one of the best in the world for conducting research on ocean thermal energy conversion (OTEC).

The facility is unique in its ability to continuously supply large volumes of both warm surface seawater, at 24-28 degrees Centigrade, and cold, deep seawater (from a 600-meter depth) that is colder than 10 degrees C. The cold, deep water is nutrient-rich and relatively pathogen-free, providing an excellent environment for marine culture. Salmon, trout, Maine lobster, nori (Japanese seaweed), abalone, kelp, clams, and blue-green algae have all been successfully cultured ashore at NELH.

Thursday, September 28

Hawaii Volcanoes National Park
U.S. Department of the Interior
National Park Service
Hawaii 96718

Located on the Big Island of Hawaii, the Hawaii Volcanoes National Park encompasses the volcanic mountains of Mauna Kea, Mauna Loa and Kilauea. Measured from the ocean floor, Mauna Kea and Mauna Loa are considered to be the greatest mountain masses on Earth. Mauna Kea rises 4,205 meters (13,796 feet) above sea level, and Mauna Loa follows closely at 4,159 meters (13,667 feet). Kilauea, too, is an impressive shield volcano, rising about 6,700 meters above the ocean floor and more than 1,200 meters (4,000 feet) above sea level.

Mauna Kea lies dormant, but Mauna Loa and Kilauea are counted among the Earth's most active volcanoes. Nevertheless, their eruptions are relatively gentle. Violent outbursts — characterized by tremendous explosions, destructive earthquakes, clouds of poisonous gases, showers of hot mud, and rains of erupted rocks — have occurred only twice in recorded history. Both occurred at Kilauea, one about 1790, the other in 1924.

In general, however, Kilauea's eruptions are mild, and by far the greatest part of the material it releases appears in the form of slowly moving lava flows. The lava, gases, and cinders issuing from the vents can be dangerous, of course. Lava flows have destroyed forests, crops, houses and other property on occasion.

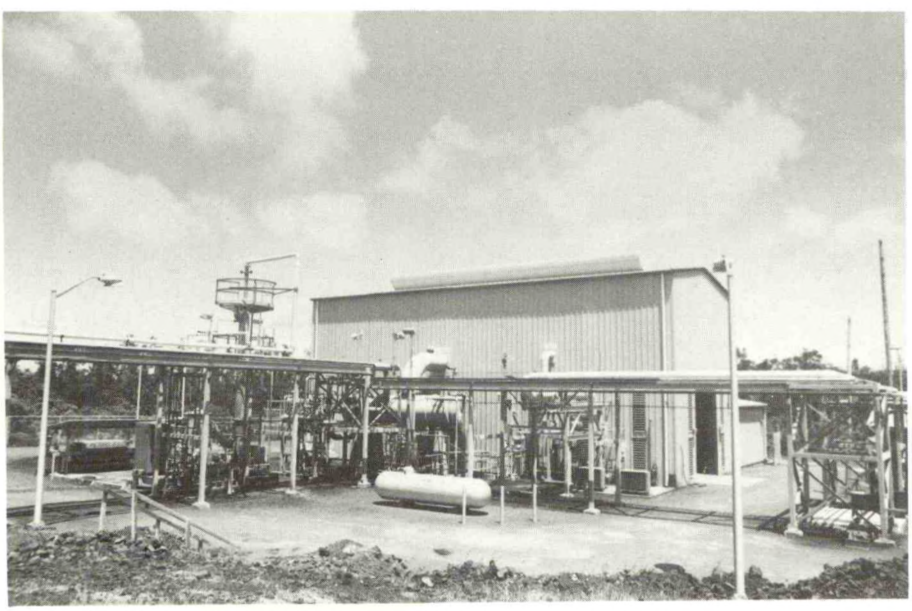
NELH-Puna Geothermal Facility
P.O. Box 2172
Pahoa, Hawaii 96778
Roy Nakanishi, operations manager
Telephone: 808-965-9699

The NELH-Puna Geothermal Facility is located near Kapoho, approximately 12 miles from Hilo in the Puna District of the Big Island. The facility is comprised of the HGP-A power plant and the Noi'i O Puna (Puna Research Center), a research laboratory for both electrical and nonelectrical applications of the geothermal resource.

With Federal, state, county and private funding, a well named HGP-A was drilled to a depth of 6,540 feet (1,966 meters). The project began in December 1975 and was completed in April 1976. With a bottom hole temperature of 358 degrees Centigrade (676 degrees Fahrenheit), HGP-A is one of the hottest geothermal wells in the world. The resultant 3.0-megawatt HGP-A power plant has operated since early 1982, demonstrating that electricity produced from the geothermal resource in the Kilauea East Rift Zone is technically, economically and environmentally viable.

Research projects utilizing the Puna Research Center include papaya-powder drying, plant propagation, cloth drying and lumber drying.

At the Puna Geothermal Facility in Pahoa, one of the hottest geothermal wells in the world provides the energy for a 3.0-megawatt electric power plant.



Friday, September 29

Matson Terminals, Inc.
Pier 51B
P.O. Box 899 Sand Island Rd.
Honolulu, HI 96808
Christopher A. Kane, Vice President, Industrial Engineering
Telephone: 808-848-1211

Matson Terminals, Inc. operates on a 108-acre site on Sand Island, a few miles east of Honolulu and directly off the island of Oahu. The terminal is illustrative of the vital role of ocean transportation in serving a vibrant island economy. Matson is proud to have served as the major carrier between Hawaii and the U.S. mainland for more than 107 years. The terminal also serves as the principal point of entry for the significant amount of general cargo that arrives from Japan and other points in Asia and Oceania. Cargos bound for the neighboring Hawaiian Island ports depart five times a week on Matson-owned barges, and another barge, bound for the Marshall Islands, leaves each month. In addition, the terminal serves as the departure point for twice-monthly service to the Far East and monthly service to Australia, which are offered by independent shipping lines.

The terminal includes storage space for containers, trailers and automobiles, a six-floor control tower, a container freight-station warehouse and a maintenance complex. The facility consists of three berths. Piers 52 and 53 provide a berth length of 1,736 feet. Pier 51-B is 656 feet long. The gate is generally open from 6 a.m. to midnight, five days a week, with weekend shifts and extended operations available at customers' request.

Left: The Joint Panel is briefed on the activities of Matson Terminals, Inc.

Right: The terminal, located on a 108-acre site on Sand Island, serves as the principal point of entry for general cargo arriving from Japan and other points throughout Asia and Oceana.

University of Hawaii at Manoa
2540 Dole Street
Honolulu, Hawaii 96822
Telephone: 808-948-7727
Lunch and briefing on university programs by
Dr. Paul Yuen, Vice President for Academic Affairs

The University of Hawaii consists of nine campuses which are located throughout the islands. More than 50,000 students attend the University, with the main campus at Manoa having the largest enrollment.

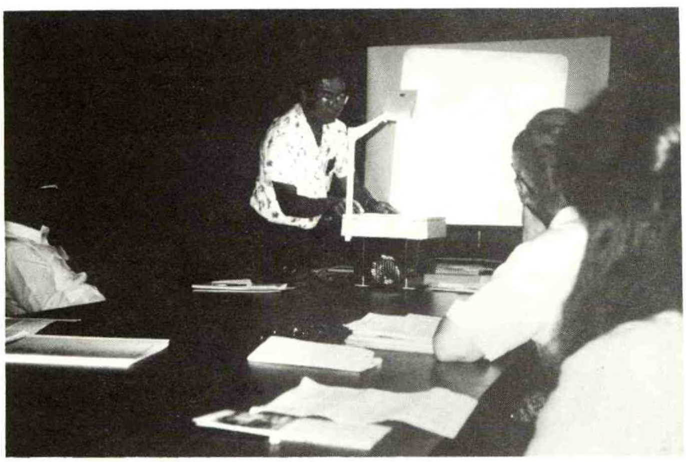
Hawaii, being surrounded by the ocean, naturally evolved into a center for marine research. The University's involvement in ocean-related areas is extremely diverse. In 1988, the School of Ocean and Earth Science and Technology at UH Manoa was established to link all marine activities. The school is comprised of the Hawaii Institute of Geophysics, the Hawaii Institute of Marine Biology, the Hawaii Natural Energy Institute, and the Sea Grant College Progam.

The University's programs and facilities for ocean-related research are extensive. Studies in oceanography, ocean engineering, geology and meteorology focus on such areas as resource management, minerals assessment, renewable energy, seafloor surveying, aquaculture and coastal activities. Research vessels, laboratories and pilot plants are among the facilities that support the University's extensive marine efforts.

University of Hawaii
Briefing on the Pacific International Center for High Technology Research (PICHTR) by Dr. Patrick Takahashi, Director, Hawaii Natural Energy Institute and PICHTR Vice President of Development

The Pacific International Center for High Technology Research is an applied research and development center serving government, industry, universities and peoples of the Pacific. PICHTR brings people together to advance technology, and transfers technology by integrating research results, education and training. PICHTR's five divisions — Energy and Resources, Education and Training, Information Technology, Technology Transfer, and Biotechnology — direct their resources toward meeting the needs of the Pacific and Asia.

The Energy and Resources Division works on a variety of ocean-related projects, among them OTEC systems, seabed minerals development, desalination, and tuna assessment/restocking. Researchers in the Information Technology Division utilize computer-based technology to study natural language processing, computer vision, robotics, expert systems and other topics applicable to ocean-related activities.



Dr. Patrick Takahashi gives a briefing on the Pacific International Center for High Technology Research (PICHTR), for which he serves as the Vice President of Development.

The Joint Panel held its final meeting at the University of Hawaii-Manoa. Dr. Paul Yuen (center) is flanked by the Japan and U.S. chairmen.

Summary of the 16th Meeting

Chairmen Eifu Kataoka and Joseph Vadus prepared this final summary of the 16th UJNR Marine Facilities Joint Panel Meeting.

1. Overview

On September 17-18 the plenary sessions were held at the Washington State Convention and Trade Center in Seattle. Total MFP attendance was 64; 40 from the U.S. (20 members, 15 advisors, 3 members of the Executive Secretariat, and 2 observers), and 24 from Japan (3 members, 12 advisors, and 9 observers). Other attendees included special guests Dr. Robert Wildman, U.S. Chairman, Marine Resources and Engineering Coordination Committee (MRECC) of the UJNR; and Dr. Richard Podgorny, Chief, International Affairs Staff of the National Ocean Service, NOAA. Mr. Richard Krahl and Mr. John Pritzlaff were honored to receive letters of recognition from the Japan Panel; as were Japan Chairman Eifu Kataoka, Prof. Seizo Motora, Mr. Masao Ono, and Mr. Masanao Oshima, who received testimonial plaques from the U.S. Panel.

From September 14-29, the study tour proceeded from Kenai (on the Cook Inlet, near Anchorage), to Fairbanks, Alaska; Seattle, Washington; San Francisco, California; the Big Island of Hawaii; and Oahu, Hawaii. The Panel visited about 20 marine facilities operated by government, industry, and academia, including laboratories, factories, port and harbor facilities, and construction sites.

The final meeting took place September 29 at the University of Hawaii-Manoa in Honolulu on the island of Oahu.

The 16th UJNR MFP Joint Meeting was quite informative and successful. While valuable technical information was exchanged at the plenary session and during the study tour, perhaps equally valuable were the many informal meetings and information exchanges that took place during luncheons, receptions, breaks, and while the members and advisors were en route to various site visits.

2. Plenary Session

The U.S. and Japan Panels each presented two keynote addresses. Keynote speakers for the Japan Panel were Dr. Kazuo Sugai, whose paper was entitled "Advanced Ship Technology in the 1990s"; and Prof. Hisaaki Maeda, whose paper was entitled "The Current Progress of Ocean Research and Development in Japan." Keynote speakers for the U.S. Panel were Mr. Richard Metrey, whose paper was entitled "Marine Facilities: The Key for Moving from Research to Reality"; and Mr. Charles Ehler, whose paper was entitled "Drowning in Data, but Learning to Swim". The broad range of themes explored in these keynote addresses set the tone for the technical presentations that followed.

A total of 52 papers were prepared for the meeting, 14 of which were reference papers. Thirty-four papers were presented (U.S., 20 and Japan, 14), in addition to the four keynote addresses.

The 52 papers were divided into the following categories for presentation:

1. Marine Facilities and Systems for Resource Development and Environmental Conservation
2. Advanced Ship Technology Development

3. Offshore and Undersea Technology Systems
4. Coastal Ocean Space Utilization
5. Ocean Measurement, Assessment and Environmental Protection.

All of the papers were well prepared and the presentations, usually accompanied by excellent visual material, were smooth and punctual. Discussions following the papers were interesting and, at times, lively.

Chairman Vadus noted that he received many supportive comments regarding the decision to limit the presentations to 10-minute summary reports and allow more time for discussion. "The summaries are very good," he said, "because each paper provides the objectives and principal findings of the activity, and the short reports are interesting to everyone, even if the topic is not closely related to their speciality."

The proceedings of the 16th UJNR MFP joint panel meeting and study tour will be published and forwarded to the Secretary of the Japan Panel and the Editor of the U.S. Panel.

3. Proposal for the Next Joint Meeting

Chairman Kataoka offered the following proposal for the next joint meeting:

"Regarding the 17th Joint Meeting in Japan, I now tentatively propose the following plan. The meeting will be held for about two weeks in April or May 1991, and this will be arranged just before or after the 25th anniversary of the UJNR. The meeting will be held in Tokyo, followed by a study tour which will include a visit to Okinawa, including the Okinawa Marine Park, a hydroelectric power station, an artificial coral reef, and beautiful seashores; and then to Kyushu, including a visit to a floating oil-storage facility [editor's note: the world's largest]; then to facilities in Nagasaki and other coastal citites on Kyushu."

"In addition to the Japanese proposal, Mr. Vadus gave us a suggestion to include the Palau Islands in the study tour. We will further discuss the possibility of this plan."

Chairman Vadus made the following comments:

"Upon examining my suggestion about the Palau Islands, it occurs to me that it may be difficult for logistical reasons to include a visit to Palau. This proposal was mainly centered on the idea that the Palau Islands -- just like Okinawa and some of the U.S. islands in the Pacific -- are of interest to us on the Marine Facilities Panel. For example, 85 percent of the U.S. Exclusive Economic Zone is in the Pacific, and there are many resources there in food, energy, minerals, and so forth. So my thought was to be able to make a first-hand assessment of the island's activities and potential resources to see how we could include them in our furture ideas and developments."

"I have made inquiries there, and learned that there is a marine laboratory on Koror which has been funded by Japan and the U.S. They also have some mining operations there. But, Palau may be a bit too remote to include in our visit to Japan, so we do need to discuss it further. However, it will be very interesting and worthwhile to include Okinawa and the southern part of Kyushu."

4. Future Activities

Regarding continued cooperation, Chairman Kataoka said: "I believe that the information we have exchanged will help both the U.S. and Japan to promote the development of research work for marine facilities. As I mentioned earlier, I hope that many cooperative programs will soon flow from the papers that we have discussed at this meeting."

Chairman Vadus added, "At this time I'd like to mention a proposal for a special cooperative project under the umbrella of our joint activities in the UJNR MFP. We have been discussing for some time an ocean space utilization symposium. The First International Symposium on Coastal Ocean Space Utilization was held in New York May 8-10, 1989, and at that time I participated with others in discussions with Mr. Furudoi, at that time the Director of the Ports and Harbours Bureau of the Ministry of Transport. There were agreements made that we should continue. While in New York, we visited the U.S.-Japan Foundation, and they also expressed interest in our proposal. Dr. Moto, the new Director of the Ports and Harbours Bureau, and I decided to explore the possibilities of a joint U.S.-Japan symposium/workshop on coastal ocean space utilization, and we have agreed to be the organizers."

"The symposium approach would be to feature invited papers and have panel discussions and workshops. Perhaps the second day would be regional workshops, where, for example, participants from the New York-New Jersey Port Authority and the Tokyo Port Authority could discuss problems of mutual interest. And similarly, for example, the Ports of Los Angeles and Yokohama. We would then have a panel discussion to address pressing problems that are of interest to such cities, and finally a summary on the results of the symposium/workshop. Those are our preliminary thoughts, and we will explore them together."

Chairman Katoaka, Director-General of the Ship Research Institute, Ministry of Transport, and Richard Krahl, of the Minerals Management Service, U.S. Department of the Interior, discussed pursuing cooperative research activities on the impact of floating ice floes on offshore structures. A further exchange of correspondence between Mr. Kataoka and Mr. Krahl was planned.

Editor's note: Since the 16th meeting, Mr. Krahl has made arrangements to meet with Mr. Kataoka in Tokyo in February 1990, at the time of his planned participation in the 5th International Symposium on the Okhotsk Sea and Sea Ice and the International Workshop on Okhotsk Program, to be held in Hokkaido, Japan in February. Also, Mr. Kataoka later reported that he and Dr. Akasofu of the University of Alaska are exploring the possibilities of a cooperative project on arctic research. Additionally, the Ship Research Institute is interested in exploring the possibilities for collaboration with the U.S. Maritime Administration (Mr. Paul Mentz) in regard to ship maneuvering standards and research.

Dr. Iwao Watanabe, Director of the Wave Force Section, Ship Dynamics Division, SRI, MOT, requested the following information from the NOAA Oceanographic Data Center (NODC):

1. Meteorological data reported by ships to NOAA in areas of the northeast Pacific (i.e., east of 170 E and North of 0, from 1974 to the latest year available in the form of magnetic tape.

2. Discus Buoy data derived in the North Pacific, from 1974 to the latest year available in time-sequence form (not the statistically analyzed result).

Chairman Vadus agreed to contact the NODC in order to facilitate Dr. Watanabe's request. Editor's note: Since the 16th meeting, Ms. Pam Rubin assisted Dr. Watanabe in obtaining the information he needed from NODC.

Cooperation in ocean engineering research between the U.S. National Science Foundation and Japan's Science and Technology Agency, first reported at the 15th MFP meeting, has advanced to the stage of conducting program development workshops. The first workshops, scheduled for October 1989 in Tokyo, will cover Autonomous Underwater Vehicles, and Very Large Floating Platforms and Artificial Islands for Ocean Space Utilization. The second workshop, planned for March 1990 in Hawaii, will cover Deep Ocean Upwelling for Open Ocean Mariculture, and

Remote Imaging Techniques for Seafloor Surveys. Several members and advisors from the Marine Facilities Panel are involved in the workshops.

Mr. Howard Talkington, Deputy Technical Director of the Naval Ocean Systems Center, informed the panel that PACON 90 -- the Pacific Congress on Marine Science and Technology -- is scheduled to be held in Tokyo in July 1990. Since the UJNR MFP is very involved in the Pacific, he encouraged the members' and advisors' participation and invited them to submit scientific papers.

Chairman Kataoka concluded, "In Japan we have a small land area with a large population, especially in the coastal area, so the importance of correctly utilizing our waterfront is well understood. We anticipate that the demand for marine facilities will increase remarkably in the near future. Under these circumstances, we recognize the importance of the role of this panel."

5. Acknowledgments

Both chairmen extended appreciation to NOAA and the Ministry of Transport, the organizations that supported the planning and arrangements for the 16th meeting; and to the University of Hawaii, which hosted the final meeting.

Chairman Vadus stated: "I would like to express our appreciation and thanks to Chairman Kataoka and the members and advisors of the Japan Panel for their valuable technical contributions and personal efforts in making this meeting and study tour a great success. Also, I would like to thank Mr. Yasukatsu Yamauchi and the SRI staff, and Mr. Yukihiro Narita of JAMDA, for their assistance in planning and coordination. On the U.S. side, I would like to especially thank Mr. Richard Krahl, the U.S. finance chairman, for all of his efforts toward this conference, as well as all of the regional chairmen: Mr. Krahl, for Anchorage; Dr. Jawed Hameedi, of the NOAA Office of Oceanography and Marine Assessment, for Fairbanks; RADM Sigmund Peterson, Director of the NOAA Pacific Marine Center, and Mr. Edward Early, of the University of Washington Applied Physics Laboratory, for Seattle; Dr. William Webster, of the University of California Dept. of Naval Architecture, for San Francisco; Dr. Paul Yuen and Dr. Patrick Takahashi, of the University of Hawaill College of Engineering, for Hawaii. Thanks also to Ms. Pam Rubin, who coordinated the technical program, and to Ms. Mary Leach and Ms. Lynne Mersfelder, who made all of the logistical arrangments and coordinated the study tour."

Chairman Kataoka stated: "I am deeply grateful to Mr. Joseph Vadus, Chairman of the 16th MFP meeting, and to all the other members and advisors for their excellent organization. I would like to express our thanks to all of you for the success of this 16th joint meeting. I am also grateful to the executive secretariats of both the U.S. and Japan Marine Facilities Panels, who completely arranged this meeting and study tour."

"We are looking forward to seeing all of you in Japan in two years' time," Chairman Kataoka concluded.

List Of Technical Presentations

Note: (R) denotes a reference paper.

Keynote Addresses

The Current Progress of the Ocean Research and Development in Japan

Hisaaki Maeda

Institute of Industrial Science
University of Tokyo

INTRODUCTION

Importance of Ocean Development

The mission of the Ocean Development for Japan is to contribute to the progress of the society and economy of our union. Since the last Oil Crisis, it has been impossible for Japan to continue to expect enough low price resources and energy from abroad which supported the country's development at the fastest rates, to depend on the large scale development of coastal real estate, and to continue to pollute the environment due to the priority of economy. From where we can get resources, energy and real estates in future is one of the most concerned subjects. The best solution for this problem is the ocean which gives us the infinite number of opportunities and possibilities of development and utilization of resources, energy and space. The ocean is the objectives for which we should concentrate ourselves for Japan where is surrounded by coast lines.

The natural environment of the vast ocean is affected by the social and economic activities of increasing humankind. Those may destroy the self-purification of the environment. Therefore we require the global, systematic and consistent program for the ocean development which is closely connected to ocean environmental protection.

Moreover the United Nations Convention on the Law of the Sea was adopted in April 1983, codifying a new order of the sea and launching ocean development upon a new era of international cooperation. Specifically, cooperation in international subjects such as ocean observation, ocean environmental protection, protection for ocean living resources, international management of resources in open sea and etc. is expected to gain momentum, and Japan, as a maritime nation, believes in being flexible and positive in adapting to this new age.

Ocean Development Program in Japan

The ocean development diverges to various fields. Not only individual development of fundamental technology, but also global development which corresponds to each individual development are required. Since the ocean is vast and the environmental conditions are very severe, the data base of ocean observation is not enough, and ocean development faces some big problems which can not be solved only by the extension of the present technology. The problems come from shortage of data base for ocean observation, very severe environmental conditions which refuse the establishment of safety, and many conflicts among ocean utilization fields.

Therefore in order to make the future ocean development effective, it is important to proceed the main program of ocean development which includes R & D of ocean science and technology globally, effectively and powerfully.

The council for Ocean Development is an advisory body to the Prime Minister which deliberates basic and comprehensive matters relating to ocean development. In this capacity, the council is the only body of its kind in

Japan.

The council issued a two-part report in August 1979 and January 1980 in response to a request from the Prime Minister for a basic program and method for promoting ocean development to the year 1990, based on a long-term outlook. The program contained the 200 mile fishery exclusive zone utilization, ocean environmental protection, survey of ocean bottom minerals and so on. It is now almost in the 1990's. The Prime Minister requested the next vision of ocean development in the 2000's to the council at February 3rd, 1989. It is considered that the council will treat the 200 mile economic exclusive zone (EEZ) utilization, coastal zone development as marine leisure and development of small scale coastal cities, international cooperation on ocean observation from the earth science standpoint and so on. The report will be issued in May, 1990.

In Japan the R & D in the field of ocean development is supported strongly by the government because there is no big oil field around Japan and ocean industries are not strong enough for business wars except shipping, shipbuilding and fisheries. Japan's ministries and agencies are concerned with all the fields of ocean development, either carrying on their own works or taking necessary measures to realize their own particular goals, but always with the cooperation of other ministries and agencies.

In this regard, the Liaison Committee for Ocean Development was established in 1980 in order to direct development efforts by ministries and agencies in an effective and systematic fashion. The committee, which represents eleven ministries and agencies, is responsible for formulating its annual Ocean Development Promotion Program. The committee covers a diverse range of nine fields such as marine living resources, sea water and marine mineral resources, ocean energy, ocean space utilization, total technology for utilization of sea area, marine environmental protection, ocean observation, fundamental and common marine science and technology, and international cooperation in marine science and technology.

R & D Expenditure

These nine fields are all equally necessary for the ocean development in Japan, though the amount of R & D expenditure for each field fluctuates every year. In 1987 fiscal year, the R & D expenditure is larger in the field of sea water and marine mineral resources, marine living resources and fundamental & common marine science and technology than in other fields(see Table 1). The total amount of expenditure for ocean field is about 500 million dollars(the exchange rate is 125 yen per one dollar), while the expenditure for aerospace and aeronautical field is about twice of that for ocean field. Besides these R & D expenditure spent by the government, some amount of R & D money is expended by private sectors for the water front developments in large city areas such as Tokyo, Osaka or Kobe.

In the following sections, some topics among nine fields are selected and described briefly as the examples of the recent progress in R & D on ocean technology in Japan.

Those topics are the research on an ocean-based mariculture experimental facility of a deep sea water supply system in the field of Marine Living Resources, the research on development of manganese nodules, the research on the technology of development of marginal oil field in the field of Marine Mineral Resources, the R & D on construction standards for offshore structures , a large scale floating oil storage system, Kansai International airport of an artificial island in the field of Ocean Space Utilization, the research vessel,"HAKUHO MARU" in the field of Ocean Observation, manned submergible "SHINKAI 6500", the research on advanced robot technology in ocean and the research on the underwater inspection robot "AQUAROBOT" in the field of Fundamental and Common Marine Science and Technology.

There are many other interesting topics which the author would like to introduce, but those have to be omitted because of the limited pages of this paper.

MARINE LIVING RESOURCES

Research Project of Deep Sea Biology and Its Support Technology

It is well known that the cold deep sea water contains nutrients which can be used to sustain mariculture operations. The sea areas where natural upwelling of deep sea water occurs good fishing banks.

The R & D project in which the effect of artificial upwelling of nutrient-rich deep sea water on the enhancement of marine bio-productivity is evaluated has started in 1986 and will continue for five years. This project is carried out by Science and Technology Agency as a national project due to the Special Coordination Funds for Promoting Science and Technology. There are two systems in the project which are an ocean based mariculture system and a land based system. This project is also to research the OTEC system to supply energy to the self-sustaining ocean based mariculture system.

The ocean based mariculture system consists of a platform, CWP, water handling, mooring, and OTEC experiment facility. The platform made of steel is 25m in length, 11m in breadth, 2.5m in depth and 1.3m in draft. The platform was constructed in Toyama Bay, in the middle of Japan along the Japan Sea in 1988. The motion of the platform will be measured. A CWP is vertically hung up by a tower located at the center of the platform through a moon pool. The intake depth of cold sea water is about 300m, where the content of nutrients is much more than that in surface layer according to the investigation of vertical profile of nutrient in the bay. The CWP consists of two pieces of 10.5m flexible hose and the other, the steel pipe joined by a 11m rigid piece. The diameter of the CWP is 0.45m which allows either max $0.3m^3/sec$ of the flow rate or 1.9m/sec of the deep water velocity flow in CWP. The deep sea water is mixed with surface sea water in order to stay longer in euphotic zone and to reduce the lag period of phytoplankton growth, which is longer in the case of pure deep sea water than that in the case of the mixed water by the laboratory test. The lag period is defined as the duration time from the start of culture to the day when the logarithmic growth curves crosses with the minimum phytoplankton concentration. A two point catenary mooring system is applied and about 150m excursion circle is expected by about 40 ton initial tension for the line. The distance between two anchors is about 2,400m, the each anchor is installed at about 320m and 250m in depth respectively. Each catenary line has a 20 ton mooring buoy for easy operation for relief and re-mooring of the removable platform without anchoring works. While non experimental term, the platform does not locate at the site, the CWP is hung up by the supporting buoy.

In order to establish the optimum design method to adapt the ocean based OTEC-driven mariculture system in Toyama Bay, the experiment on a 5kw class OTEC power system, which represents a scale-down version of a commercial OTEC plant, is planned to be achieved in the project. The principal components are the evaporator, turbine generator, condenser, ball cleaning system, biofouling monitoring system and data acquisition system. The designed overall temperature difference is 20^0C.

The land based mariculture system was designed on the basis of the performance requirements and the estimated maximum wave height. The main design specification of this system are as follows: depth of deep sea water intake, 250m; length of the pipe, 2,650m; inner diameter of the pipe, 125mmd; pipe material, high density polyethylene with steel wire armor; pump installation height, 2.7m below water level; pump material, polyvinyl chlorides, pump power, 7.5kw. The fast and accurate reel-barge method was used for laying the deep sea water pipe. The construction of the system was completed in 1988. The site is in the southern part of Japan.

MARINE MINERAL RESOURCES

Manganese Nodule Mining System

Manganese nodules contain rare metals such as manganese, nickel, copper, and cobalt which are indispensable to the poor-in-resource Japan because they are to secure stable mid-and long-term supplies.

The development of manganese nodules consists of three stages such as investigation, mining and refining. Since manganese nodules deposits are found in 4000m to 6000m deep water, new mining technology is required to be developed.

This R & D project on manganese nodule mining system started in 1981 and will continue till 1991. The total R & D expenditure is about 154 million dollars. This project is conducted by Agency of Industrial Science and Technology of Ministry of International Trade and Industry.

The mining system being developed in this project is a hydraulic mining system in which manganese nodules are collected by a towed vehicle on the ocean floor and lifted to a surface ship by the hydraulic lift system using hydraulic pump and / or air lift pump through a long pipe of several thousands meters.

This mining system consists of five subsystems such as collector, material lifting, machinery handling, electrical control and data assembling, and the total system. At the final stage of this project, the pilot mining test is scheduled to be held in the manganese nodule province in the Pacific Ocean combining these systems in order to establish a commercial extraction system for manganese nodules by matching collectability, reliability and harmonization of subsystems with each other.

The current progress of subsystems such as collector subsystem, lift subsystem, machinery handling subsystem, and measurement and control subsystem are as follows. Regarding the collector subsystem, the target is to develop a nodule collector capable of collecting manganese nodules from the ocean floor of 4000m - 6000m deep water efficiently and supplying them to lifting pipe strings. In order to develop a high performance nodule collector, basic research has been carried out on the mutual dynamic relationship between sediments and nodule collection simulation analysis of nodule collection characteristics performance tests of collector motions, and simulation analysis of collector motions.

Research in connection with the lift subsystem involves developing the pipe strings for transferring collected nodules to the test ship; and slurry pumps of the pump lift and air lift type. The pipe strings involve many technical elements demanding development which lead to the requirement of selection test, and performance verification tests, as well as simulation analysis for nonlinear behavior and stress of pipe strings. These tests have been conducted in connection with their individual materials, structure, connection methods, etc. The research on the pump lift type slurry pump system is in progress for developing a highly reliable high head submerged pump and a submerged motor resistant to water pressure. The selection test of pump lift equipments simulation analysis of pump lift characteristics have been conducted.

Various kinds of tests are in progress in connection with the air lift type slurry pump system,including verification tests of air lift equipments and simulation. Basic research is also in progress with regard to the nodule lifting characteristics of a two-phase, solid/liquid flow system and a three phase, solid/liquid/gas flow system.

The machinery handling subsystem involves the development of a system for lowering and recovering underwater equipments safely, accurately, and speedily, and motions compensator for preventing the ship's motions from being transmitted to the pipe strings. The corresponding equipment tests and simulation analysis have been conducted and a scale model of a derrick system has been fabricated.

The measurement and control subsystem is to adjust and coordinate the measurements as well as to control the items involved in the total system and respective subsystems in order to conduct integrated ocean mining tests smoothly and effectively. The corresponding tests of selection and performance verification have been conducted in connection with the optical/electrical umbilical cable, connectors and data terminals.

The initial design of the total system and subsystems in connection with the pilot model, at-sea experimental facilities has been done by 1985, and the experimental apparatus for flow characteristics of air lift pumping system which has 200m depth was completed. The lifting experiment of both pumping system and air lift system has been successful.

Research on the Offshore Technology for Marginal Oil Fields Development

Recent development for offshore oil fields moves towards not only deeper but more harsh environments while discovered reservoirs are getting smaller. These small reservoirs are called as "marginal oil fields" due to the fact that optimized development planning is the key factor to make the development system feasible both technically and economically.

JNOC (Japan National Oil Corporation) has executed the five year research project, named "Offshore technology for marginal oil fields development" since 1985 featuring the floating production system in cooperation with the several private companies. To meet the technical requirements, several joint research projects are on progress.

One of the main objectives of this research is to develop the assisting tool program for the user's decision making, which technically evaluates the applicability of each element for the offshore oil fields development system and selects the most economical system among many candidates. Another software approach is to develop the optimization program for the floating production system which enable the motion analysis, mooring analysis, riser analysis, working ratio and fatigue analysis, and the analysis on the performance of the processing unit in motion.

As a national organization, JNOC has also an intention to promote the private sector's technology, especially in the offshore hardware industry. Verification tests of the high pressure multipath riser swivel joint, turret mooring system, and fiber optic-umbilical riser system were performed individually simulating the actual operating conditions. Excellent characteristics to meet our expectations were confirmed. Furthermore other four joint research projects for the development of the hardware technology are being carried out focusing on the subsea control system, flexible production riser system, submudline christmas tree/underwater inspection device, and heavy duty paint.

OCEAN SPACE UTILIZATION

R & D on Construction Standards for Offshore Structures

Japan surrounded by sea has been utilizing ocean in order to expand the living space by developing shipping, fisheries and artificial islands. The exploitation of not only coastal zone but also deep seas over 20m depth will begin to be opened on the utilization of ocean space. The ocean space utilization is one of the most important subject for Japan which has little flat lands.

Innovative and advanced technologies are required in order to construct large scale offshore structures subject to harsh natural environmental conditions. The R & D of this kind of offshore structures has been carried out in the north sea but only few published data of full scale experiment have been opened. Therefore the Ministry of Transport started the five year project of the R & D of offshore structures in deep seas since 1986.

The contents of the project are classified into three themes. These are the R & D on observation techniques of oceanography, the R & D on floating offshore structures and the R & D on fixed type structures.

The final objective of the project is to identify effective ways to use calmed sea areas on the landward side of such structures.

The R & D on meteorological observation includes those of 2-D wave measurement technology and coastal wave forecast which are carried out by the Office of Meteorology. Fixed type structures are being developed by the Research Institute of Port and Harbor which concerns design technology and practical application. The fixed structures are assumed to be built in up to 50m water depth. The full scale test of cell type structures of vertical circular cylinder will be carried out in 1989.

The R & D on floating type structures is conducted by ship Research Institute which concerns design technology, construct- ability, safety, reliability of mooring system and maintainability.

The prototype model of this floating structure is a column footing type one which has twelve columns, which is named as POSEIDON and operated at real sea since 1987. The test site is located in the northern part of Japan along the Japan Sea where the weather and sea condition are very severe in winter time. The size of the POSEIDON is 30m deck length, 20m deck width, 11m column length and 530 ton displacement, and considered as a small portion of an expected or imagined huge structure and is about 1/3 scale ratio to the elementary floating body so that the environmental condition at sea could correspond to the severest sea state for the full size offshore structures.

This at-sea experiment of the POSEIDON has following many measuring items ; environmental conditions, the high and low frequency motions of the structure, strength of the structure, mooring line tensions, and corrosion and paints. Among twelve columns, one column is made of RC concrete and the other eleven columns are made of steel. The steel columns are painted separately by eleven different painting companies respectively which means that the comparison test for anti corrosion and anti biofouling is being carried out.

The interim report of this at-sea experiment of the POSEIDON was already presented at the last Joint Meeting UJNR Marine Facilities Panel.

Floating Oil Storage System

The Kamigoto Oil Storage Facility, constructed in the bay of the Goto islands in the southern part of Japan, is the first floating oil storage facility in the world, and uses a new type of floating storage system. This system is managed by The Kamigoto Oil Storage Corporation.

After the oil crisis in 1973, Japanese Government decided to achieve the storage of 90 days worth of oil, and farther 20 million kiloliters.

If this large amount of oil is to be stored in conventional land tanks, it will require much flat space, which in Japan is extremely insufficient. Several types of new oil storage systems have, therefore, been proposed, including underground storage and offshore storage.

Floating storage system was proposed and developed as a new method for stockpiling emergency oil reserves since 1974. This system has also the following advantages besides unnecessity of much land space.

(1) Storage of oil in floating barges is earthquake-proof.
(2) Storage barges eliminate the possibility of inclination due to differential settlement of a tank.
(3) Construction period is shorter as compared with land storage system.

The whole system was completed at the end of September, 1988.

The system consists of oil storage barge, mooring system, floating oil fence, multipurpose floating bank for oil spilling and collision protection, wave breaking revetment and so on.

The area of the site for oil storage barges is 40ha where five barges are moored.

The principal dimensions of oil storage barges are as follows; length of 390m, breadth of 97m, depth of 27.6m, draft of 24.5m, and oil tank capacity of about 880,000kl.

Oil storage barges are moored to mooring dolphins and loading dolphins set up around the oil storage barges via buckling type rubber fenders. In deciding the mooring system, model tests and simulation calculation were carried out to confirm the safety of the system even in rough sea condition.

Kansai International Airport of an Artificial Island

Since the surrounding area of Osaka International Airport has been so developed that the operating hour for the airport is limited, due to the environmental problem of aircraft noise, the demand for air transportation is not fulfilled now. In order to improve this condition, 24 hour open offshore airport was planned to be constructed 5km off the Osaka Bay middle part of Japan which would be free from noise problem and could be enlarged according to the demand.

The construction started in 1987 and will be completed in 1992. The construction, maintenance and administration will be operated by The Kansai International Airport Corporation as the third sector the capital of which is invested by the Japanese Government, local selfgoverning bodies and some private companies. The total expenditure is about 8 billion dollars the details of which are 6.4 billion dollars for construction, and 1.6 billion dollars for others. This expenditure is excluded from Table 1. The rough specification of the airport is as follows. The location is 5km off the coast of Senshu, the south-east of Osaka Bay. The area is 511ha and length of landing path is 3.8km. The maximum number of landing and take-off is 160 thousands per year. The access from the coast depends on the 3.8km length bridge for railway and road and on high speed access boats.

The construction schedule is as follows. At the first stage the 11km length breakwater revetment is constructed along the outer surroundings of the airport artificial island. The compacting of soft and weak sediments for the breakwater revetment, sand mound and rubble mound were conducted subsequently. The upper part of the breakwater revetment was seen completely out of water in two years. As soon as the improvement of the foundation for the breakwater revetment is completed, the compacting of sea floor foundation for the main artificial island will start and then the artificial airport island will be constructed. The access bridge will be built at the same time. The landing path, terminal buildings and appendage facilities will start to be constructed subsequently on the just completed artificial land.

The construction of the main airport island is summarized as follows. The sea site for the airport is 18m water depth, 20m soft clay formation lie under the sea bed and under diluvial formation of 400m thickness lie down. The differential settlement of the surface of the reclaimed land could not be allowed since the large scale 511ha artificial island reclaimed in deep water depth is used as an airport. The whole foundation of an airport island protected by the breakwater is filled with about one million sand piles by using sand drain construction method, and about 150 million m^3 of sand and gravel are placed on and made flat with several layers. Observing the settlement, the mound was constructed up to 30m from the sea floor which is almost the same height as a nine floor building. This is the first example in the world in which so huge amount of sand and gravel is used for the reclamation within the limited construction period. In order to conduct the construction safely and economically, the construction schedule and the construction control system are made rational and computerized as much as possible.

The Kansai international airport is an reclaimed artificial island, however, at the initial planning stage a floating type airport was proposed as an alternative which was concluded as feasible. Concepts of a commuter airport or heliport are now proposed, though a floating type airport has not been realized except an aircraft carrier yet.

OCEAN OBSERVATION

Research Vessel "HAKUHO MARU"

A research vessel "Hakuho-maru" was completed on May 1, 1989 to replace the old Hokuho-maru built in 1967. Several requirements for up-to-date ocean research have been properly accommodated; (1)Adoption of dual propulsion system composed of diesel-CCP for high-speed cruising and diesel-electric for precise maneuvering together with 3 thrusters. (2)Shape of ship was carefully designed so that acoustic instruments on its hull have no bad effect of bubbles caused during cruising. (3)Underwater noise is kept minimum to insure proper operation of acoustic observation. Best skewness of propeller was decided to reduce cavitation noise. (4)Local area network (LAN) using optical fiberscope connecting navigation bridge, 10 laboratories and data processing computer room is equipped to facilitate data communication, real-time logging and processing on board the vessel.

The main research and observation facilities are as follows; Weather Satellite Receiving System, Multi Narrow Beam, Acoustic Biomas Investigation System, Precision Depth Recorder, 3.5KHz Sub Bottomprofiler, Acoustic Transponder System (SSBL,LBL), Air Gun and Compressor, Gravity Meter and Precise Gyro Compass, Marine Meteorological Observation System, Doppler Sonar Water Current Meter, Super Deep Sea CTD System, Proton Magnetometer, Oceanfloor Imaging System.

The principal particulars of the vessel are as follows; Length Lpp=90.0 m, Breadth B=16.2 m, Depth D=8.90 m, draft d=6.00 m, Gross tonnage=3980 ton, Maximum speed =18.74 knots, Cruising speed =16.0 knots.

This vessel belongs to Ocean Research Institute of the University of Tokyo which is open to scientific community nationwide. The cost of the vessel is about 80 million dollars which is excluded from Table 1.

FUNDAMENTAL AND COMMON MARINE SCIENCE AND TECHNOLOGY

Manned Submersible "SHINKAI 6500"

The manned submersible "SHINKAI 6500" was just completed in 1989. The material of the pressure hull is titanium alloy. The principal particulars are as follows; Length =9.4 m, Breadth =2.7 m, Depth =3.2 m, Dry Weight =25 tons, Maximum Depth Capability =6500 m, Crew = 2 pilots + 1 observer, Payload =200 Kgf.

This submersible belongs to Japan Marine Science and Technology Center. The detail of this submersible was already reported in the Proceedings of 14th and 15th Joint Meeting of UJNR Marine Facilities Panel.

Robot for Oil Exploitation Support

This project is supported by Ministry of International Trade and Industry. Recently oil fields at sea, which account for a third of all oil production, are increasingly being opened up in deep sea and polar regions. As advance work must be performed under extremely harsh conditions, R & D on underwater robots to take over maintenance and inspection work of oil platforms from divers was launched as an eight-year national project in 1983. At present, efforts are focusing on development of (1)technology to give more stable directional movement in tidal and deep-sea currents, (2)technology to enable it to cling to irregular surfaces much as a marine organism does, (3)manipulator technology, and (4)technology to provide the robot with "vision" using soundwaves. The objective is to develop a robot capable of working at a depth of 200 m.

Aquatic Walking Robot for Underwater Inspection

Constructions for artificial islands or port are generally accompanied with underwater works. These underwater works are carried out by professional divers who meet sometimes dangerous situation. In Japan there are about 7,000 professional divers. The age distribution of those divers is 50% younger group and 50% older group. The average age is getting older and the total number is expected to decrease in future.

Though many ROVs have been developed which move suspended in the water, they are weak to keep a stationary position and direction and to measure objects with accuracy. Though there are some vehicles which can crawl on sea bed with wheels or catapilars, they make water so muddy that TV cameras can not be used there. Several types of walking robots have been developed which can walk on irregular terrain, but they are not suitable for watertight designs.

In Japan the R & D for underwater walking robot started in 1985 and a prototype model was completed in 1987 which is the first walking robot in the world that has succeeded in walking on sea bed. This project is conducted by Port and Harbor Bureau and Port and Harbor Research Institute of Ministry of Transport.

The prototype model "Aquarobot" has six legs hexagonal in shape . The size is about 2m in diameter and also about 2m in height. The main material is anti corrosive aluminum. The weight in air is about 700kgf. New type direct current servo drivers are used for articulation. The manipulator has three articulations and the legs have 18 articulations. The sensors used are touch sensors , inclination sensors, a compass and a depth sensor. The underwater TV camera is equipped at the top of the manipulator for observation. The range of rotating angle of the manipulator is +180°. The cable consists of many metal wires and an optical fibers, the diameter of which is 42mm and the tensile strength is 1500kgf. The maximum walking speed is 1.5m/sec at present.

The structure of the Aquarobot control program consists of operating algorithm program and walking algorithm program. The robot operating program receives commands from walking algorithm program and produces detailed command signals for the motor drivers. The walking algorithm program understands the command from human operator and calculates the coordinate values of the points of leg ends.

These programs control the walking mode of the robot. Note that the robot can walk on irregular terrain with the body kept horizontal at a constant level by stopping the lowering of the legs when they touch the terrain surface, according to the information from touch sensors.

The R & D on the underwater inspection robot has been successful up to now, however, there will surely occur plenty of technical problems for the practical use.

CONCLUSION

In the preceding sections, ten topics with regard to the R & D of the ocean development in Japan have been adopted as the current progress. Besides these ten topics there are many other interesting topics left in Japan which are ROV DOLPHIN 3K, ROV DOLPHIN 10K, ROV MARCAS 2500, the mariculture and fish farming project, the new monitoring system in EEZ around Japan, the concept of a floating type atomic power plant and so on. Some of them were reported and will be reported at the Joint Meeting of UJNR Marine Facilities Panel.

In future the R & D on ocean development in Japan tends to progress into the field of ocean space utilization as an artificial island, exploitation of mariculture and deep sea investigation and observation.

Moreover from the stand point of existence of human-being, ocean environmental protection or technology of improvement of ocean environment is getting more important than development of technology of obtaining food, energy and resources from ocean, since green house effect, carbon dioxide are now big problem. And also it is important to foretell a disaster such as an earthquake. Then larger scale ocean observation and monitoring system, for instance, remote sensing in air and in water, is required in future with regard to time and space. In this regard, a big sea-plane may be recommended as an ocean observation scheme.

Oceanic surveillance and research should be promoted through international cooperation not only to enhance their effectiveness but also because they are tasks to be shared by the world, not for the benefit of nations as individuals. Therefore bilateral cooperation and multilateral cooperation through international organizations are very much important.

Finally the author points out the incompleteness of rules for oceans in Japan. There are a lot of conflicts between fishermen and developer of coastal zone. There are many conflicts among regulations of each ministries. Those regulations should be unified or harmonized, otherwise we should develop software of the conflict management.

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Table 1 1987 Expenditure for R & D of Ocean Science and Technology in Japan (1 dollar = 125 yen)

Items	Million Dollars
1. Marine Living Resources	75.90
2. Sea Water and Marine Mineral Resources	102.45
3. Ocean Energy	1.17
4. Ocean Space Utilization	14.16
5. Total Technology for Utilizing of Sea Area	0.76
6. Marine Environmental Protection	18.62
7. Ocean Observation	49.45
8. Fundamental and Common Marine Science and Technology	223.70
9. International Cooperation in Marine Science and Technology	5.21
10. Others	10.69
Total	502.38

Advancement of Ship Technology in 1990's

Kazuo Sugai

Technological Research Asociation
of the Techno-Superliner

An epoch-making advancement in ship technology can be expected in 1990's. In order to meet the new demand in marine activities, such as sea transportation, industry and leisure, many investigations and research programs on fundamental ship technology have been carried out or have started now in Japan. Several projects considered to be interesting in our Panel will be outlined here.

1. High Intelligent Ships

Ship automation means conventionally to control remotely each shipboard instrument, however, this project intends to develop a genuine systematized intelligent ship which can navigate automatically without any human support on board.

As a ship cannot obtain all informations necessary for the navigation, the intelligent ship needs an entire navigation system cooperated with shore based information sites. We call such a system as "Onboard-Shore Integrated Ship Navigation System".

Another important system for the intelligent ship is a set of sub-systems acting for human decision on board. We call it as "Onboard Decision-Making System."

In order to accomplish these two major systems, a leading computer technology, including high-sensitivity sensors and high-density data transmission network is fully utilized. Moreover, skillness of seaman and harbor master is absorbed into the expert system in the computer system.

Since 1983, this big project has been conducted for 6 years, under the cooperation of Japan Shipbuilding Research Association and Ship Research Institute. A general design of "Onboard-Shore Integrated Ship Navigation System" and a prototype of "Onboard Decision Making System" have been completed and now are almost ready for practical use not only in ocean going but also in leaving and arriving at port condition. A computer system for making a real time simulation in various conditions was built newly in the project. The usefulness was recognized to evaluate all kind of computer programs and data bases developed for the navigation system.

2. "Manbou", A Radio-controlled Buoy for Surveying Submarine Valcanoes

There are a lot of submarine valcanoes in the seas surrounding Japan and some of them sre still alive. Not so far as remember the victim of survey ship in the case of Myouzin-Syo explosion, the survey right above a valcano always involves danger.

The Hydrographic Department of Japan has developed recently a radio-controlled unmanned boat named "Manbou" which means a sunfish.

The size is 10m in length and 6.6 ton in displacement and made of FRP. The radio-controlled boat consists of four parts, viz. navigation system, collision avoiding system, data acquisition and transmission system and body of boat itself. The main survey functions are sounding the sea bottom topography and measuring the sea waters. The boat can run around the mother ship at about 6 knots in the maximum range of 120nM.

Recently, the boat has played a remarkable part on the survey of an active submarine volcano which erupted 3km off Ito City, famous hot spring resort near Tokyo on July 13, 1989.

3. Techno-Superliner '93

In order to meet a demand in developing sea transportation in 1990's, an R&D of an advanced high speed merchant vessel has been planned by the Ministry of Transport. The ship named as "Techno-Superliner'93" aims at the capability of 1,000 ton in payload, at 50 knot high speed in the range of 500 nautical miles. The type of ship is supposed to be a kind of hybrid configuration combining properly the bouyancy due to displacement, the lift by hydrofoils and the cushion force by air chambers.

As an R&D nucleus for the ship, Techno-Superliner'93, a research consortium, Technological Research Association of Techno- Superliner(TSL) was established on 4 July with participation of 7 Japanese shipbuilders, namely, Hitachi Zosen Corporation, Ishikawajima-Harima Heavy Industries Co Ltd., Kawasaki Heavy Industries Ltd., Mitsubishi Heavy Industries Ltd., Mitsui Engineering & Shipbuilding Co. Ltd., NKK Corporation and Sumitomo -Heavy Industries Ltd. R&D for TSL is to be promoted by the association under the guidance of the Ministry of Transport.

To realize Techno-Superliner, the following R&D activities will be conducted.

(1)Total system research
(2)Hull form perforomance
(3)Hull structure research
(4)New material research
(5)Propulsion system research
(6)Ship motion and attitude control system research

(7)Model shipbuilding for actual testing in the sea

The R&D period is scheduled to be 5 years and until the last year, 1993, all data to design the actual merchant ship will be prepared. A prototype model ship of some scale ratio will be constructed during the 2 years of R&D period and be subjected to actual navigation tests in the sea.

Japanese shipbuilding industry expects earnestly a success of the Techno-Superliner which will be superior in terms of economic efficiency, safety and maintainability as a dreamful merchant ship in 1990's.

4.Maritime Access Ship to Kansai International Airport

Kansai International Airport is now under construction to begin its service in 1993. The airport is located on an artificial island in Osaka Bay at comparatively long distance from the big cities nearby, Osaka and Kobe, by way of coast routes.

A plan to access to Kansai International Airport from sea is proposed for avoiding a traffic jam in land. Japan Foundation for Shipbuilding Advancement set up a comittee to study whether the plan feasible and after two years investigation, a final report was completed on the last March.

Mono-hull ships, hydrofoils and catamarans are considered as the candidate high speed ships, however, there are not so much questions about the performance of these ships themselves. Rather important questions are on the items of feasibility. The comittee has focused on six items as requisite studies for such means of transportation; (1)safety (2)swiftness (3)reliability (4)comfortability (5)auxiliary service and (6)economy

Among them, safety is the essential factor required for public transportation. A series of investigations were conducted to varify the safety of access ships, such as a simulation study and a demonstration test on actual seaways. In result, it has been proved that the safety of access ships can be fully ensured, even at high-speed navigation in night time, if proper safety measures are taken.

Another important factor is how the maritime access can be harmonized with activities of the airport as a total system. Through the other five items, investigations were carried put to picture an optimum model of maritime access to the airport.

In the near future, many developments in coastal area, including reclaimed airports and artificial islands,will be planned. This analysis on the maritime access is considered to be applicable into the other cases like as mentioned in the above.

Activities in maritime field are still spreading rapidly in Japan. In responding to the needs and demands of the activities, consistent endeavor should be made for the advancement of new ship technology and that is an only way, I believe, to promote welfare of mankind utilizing marine field.

Drowning in Data, But Learning to Swim

Information for Decisions about the Use of Coastal Ocean Space

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I want to discuss two major problems in managing the resources of the coastal ocean. The first is the fact that the quality of the natural resources of the coastal ocean is deteriorating by almost any indicator measured. The second problem is that we don't appear to be able to do much about it. Decision-makers and their institutions appear to be adrift in an ocean of data and indecision. Furthermore, we're all part of the problem because we rarely put knowledge to practical use. We simply don't allocate enough of our intellectual and financial resources to connecting knowledge to decision-making in the coastal ocean.

Decisions made over the next 10 years about the management of space and other resources of the "coastal ocean" will determine whether this valuable resource base will continue to provide important goods and services into the 21st Century. In the context of this paper, the "coastal ocean" is those waters that extend from the head of tide within rivers and estuaries to the edge of the continental shelf.

The world's coastal ocean and adjacent land drainage areas are being developed at a rate that exceeds the capabilities of governments and industry to make informed and timely decisions that will ensure that environmental quality in these areas is maintained or improved. For example, in the United States, population density in coastal counties (about 270 people per square mile) is six times the density of non-coastal counties (about 45 people per square mile). Coastal population density has increased about 80% over the past 30 years. Along the Atlantic Coast, the population density (435 per square mile) is almost 10 times that of non-coastal counties. By way of comparison, the population density of Japan, which could be considered an entirely "coastal" nation, is about four times that of the coastal United States.

These relatively stressed conditions affect both coastal environmental quality and the coastal economy. The direct environmental effects include (1) a pattern throughout the United States, but especially near the urbanized areas of the Northeastern Coast and West Coast, of elevated levels of chemical contamination in coastal sediments and the living resources that inhabit them, (2) closures of shellfish-harvesting areas due to pollution, (3) closures of marine recreational areas and loss of other recreational opportunities due to pollution, (4) shoreline erosion, and (5) loss of important habitat. Direct economic effects include the loss of millions of dollars of revenues from commercial and recreational fishing and other forms of marine recreation, and significant public investment of billions of dollars in pollution control.

Most nations of the world have come to rely on the coastal ocean not only for transportation, but for energy and food resources. This reliance has increased in recent years, in part because of growing shortages of land-based resources. During the last decade, shortages of domestic energy resources increased the dependence of most coastal nations on imported oil and gas. As a result, development of oil and gas reserves from the coastal ocean of most nations remains a national priority. Interest is increasing in fish as a source of low-fat protein, and people throughout the world are consuming increasing amounts of fish and fish products.

Today, the coastal ocean is a magnet for living and recreating. Frequently, coastal areas are filled to capacity during the summer as more affluent and leisure-oriented societies turn to the ocean. For example, in the United States, Federal, state, and local governments spend over $7 billion each year to create recreational opportunities for the American public. Many more billions of dollars are spent through the private sector.

Major industrial centers and urban population concentrations also are centered in coastal areas. In the United States, over half of our people live and work within coastal counties whose area is less than 10 percent of the land. About 40% of American industry and almost half of Canadian industry is located in the drainage basin of the Great Lakes alone.

In the United States, more than 70% of the commercially important species of fish and shellfish depend on near-coastal waters as habitat. Each year, the commercial and recreational catch of species dependent on these areas contributes over $13 billion to the U.S. economy. The Nation's stake in the coastal ocean is increasing in economic terms, and it is likely to expand.

But despite its high economic and environmental value, the coastal ocean is suffering from declining health. The summers of 1987 and 1988 brought dramatic pollution events to the Atlantic Coast — New Jersey and New York beaches were closed when medical and municipal wastes rode in on the surf. Public concern rose after almost 1,000 dead or dying dolphins washed up on Atlantic beaches from New Jersey to Florida. And despite 15 years of efforts to clean up the Great Lakes, nursing mothers, pregnant women, and children under 15 are advised not to eat lake trout over a certain size because of toxic contamination.

But even more convincing evidence that something serious is happening is emerging from information gathered over the past four years through rigorous, systematic sampling through NOAA's National Status and Trends Program. Analyses from samples taken at sites in estuaries and near-coastal waters have identified places were bottom-feeding fish, bivalves, and sediments show relatively high levels of contamination. They include, along the Atlantic Coast, sites in Boston Harbor, Western Long Island Sound, the Hudson-Raritan estuary, and upper Chesapeake Bay. Individual sites in Tampa, Galveston, and San Antonio bays stand out in the Gulf of Mexico. High concentrations of toxic chemicals in San Diego Bay, at coastal sites near Los Angeles, and in San Francisco Bay and Puget Sound indicate relatively high levels of stress on these systems. Clearly, the scale of the problem is national and, if we looked further, certainly international.

Another NOAA national assessment has identified serious problems in shellfish-harvesting areas of the United States. For example, in the Gulf of Mexico, 61% of waters classified have some restriction on harvest, primarily due to inadequate septic systems, sewage treatment, and urban runoff. Restrictions on shellfish harvest are *both* serious environmental and economic problems.

NOAA research has already documented relationships between liver tumors in fish and the presence of elevated levels of aromatic hydrocarbons. White croakers in San Diego Bay can't spawn because of high levels of DDT. The reproductive success of starry flounders in San Francisco Bay is impaired by high levels of PCB contamination. The DNA structure of English sole from Puget Sound has been chemically modified from high levels of PAHs in sediments. The majority of winter flounder in Boston Harbor shows evidence of lesions. Almost all of the coho salmon in Lake Erie have goiters, have impaired lipid metabolism, and are unusually small. Because of the complexity of the coastal ocean and the multitude of toxic chemicals in it, absolute proof of causal relationships between toxic chemicals and fish tumors and loss of reproductive capabilities in fish and shellfish may never be possible. However, the increasing circumstantial evidence is hard to deny.

Annual production of synthetic organic chemicals in the United States rose 15-fold between 1945 and 1985, far outpacing the overall growth of the national economy. Over 70,000 chemicals are in everyday use, and between 500 to 1,000 new ones are added each year. Pesticide use in agriculture has nearly tripled in the past 20 years, and many of these pesticides are applied directly to land within drainage areas of major coastal areas of the United States.

The Environmental Protection Agency has ranked the waste stream of the organic chemical industry, located primarily in coastal areas of the United States, as especially toxic. While hazardous waste treatment facilities have been constructed throughout the Nation, their waste streams often contain hundreds of chemicals — only 62 of which are regulated by EPA. About one-fifth of the Nation's hazardous-waste stream is discharged to sewage treatment plants and directly into rivers and coastal waters. And despite billions of dollars invested in pollution-control technologies, only a small fraction of the toxic chemicals are treated incidentally through conventional sewage-treatment methods.

EPA has identified nearly 30,000 abandoned hazardous-waste sites in the United States and has placed almost 1,200 on a National Priorities List (NPL) for cleanup action. Nearly half of the NPL sites are located in American coastal counties (132 are on the U.S. side of the Great Lakes drainage basin).

The national economy, and especially the local economies of coastal communities, rely heavily on the environmental quality of the coastal ocean. When beaches are closed and people can't swim in coastal waters because of pollution, when fish and shellfish cannot be sold because of restrictions on their harvest, and when recreational fishing declines, the costs of pollution in the coastal ocean affect us all.

The state of the coastal ocean environment is deteriorating. And it will get worse before it gets better. Intelligent management of these problems requires reliable and timely information. But incidents like the EXXON VALDEZ oil spill in Prince William Sound and medical wastes on East Coast beaches illustrate how unprepared we are to respond intelligently to real or perceived environmental-quality crises.

What's the nature of this problem and what can be done about it?

The Decision-Making Problem

I'd like to identify some "facts of life":

- The coastal ocean is the most productive, most valuable, and most heavily used area of the environment in most coastal nations of the world *— and it is also the area at most risk from human activities;*

- Estuaries, adjacent land-drainage areas, and the coastal ocean are closely linked physical, chemical, and biologic environments that must be managed as *a comprehensive, integrated system. We do not now do this in practice anywhere;*

- Significant gaps exist in our knowledge of the physical, biologic, chemical, and economic characteristics of the coastal ocean. However, *much of the knowledge and information that does exist is not in a form useful to decision-makers;*

- Very little information about the *value of the national resource base* that these areas collectively represent has been made available for decision-making.

And finally,

- Existing resources are, and probably will remain, insufficient at various levels of government in all nations to analyze all areas of the coastal ocean in detail. However, it may not be necessary to do so, if *maximum use can be made of existing information and expertise. Certainly management costs could be reduced if existing information was used more effectively.*

What Can Be Done?

Clearly something is wrong with our current efforts to manage environmental quality in our coastal oceans. If we're going to see any improvements in the current situation then —

1. We must *increase existing efforts to measure periodically the "health" of estuaries and coastal waters* throughout the world, as NOAA in the United States is doing through its National Status and Trends Program — and *measure progress toward improving environmental quality conditions in these areas.*

Each year we spend billions of dollars on water pollution cleanup in the United States and over $125 million on monitoring, and we still don't know if coastal and estuarine waters are getting better, worse, or staying the same!

We have to continue to monitor and identify new pollutants before they reach levels that are a threat to the environment or to humans.

2. We have to *invest in and maintain "early-warning" capabilities that can prevent or reduce the need for "fire-fighting" types of programs* like the Superfund Program in the United States.

3. We have to be *more creative in our application of existing scientific information and knowledge to the management* of the coastal ocean — from the standpoint of allocating increasingly scarce public resources to the most important problems in the most important areas, as well as *identifying management strategies that will produce results,* that is, actual improvements in environmental quality.

Information management, from data collection to information transfer, is an integral component of the complex process that generates new knowledge and understanding about the coastal ocean. Efficient and effective management of information is especially critical in a world in which satellites and computers generate, each day, oceans of data about selected conditions of the planet, but in which, at the same time, some of the most basic information and fundamental knowledge needed to solve serious problems are lacking.

At least three user communities, (1) *the scientific community,* (2) *the decision-making community,* and (3) *the general public,* need improved access to information. Each of these groups has different requirements for information, depending on the time and space scales of the coastal ocean problem upon which it is focusing. For example, dealing with emergency situations such as toxic chemical spills or red-tide outbreaks requires near real-time information with detailed spatial resolution about a particular place. At the other extreme, writing national legislation and implementation strategies to address coastal pollution problems often requires information about conditions over a long time period throughout entire nations. A great challenge facing all of us is the improvement of our collective abilities to provide *appropriate* information to decision-makers in a more *timely* and *accessible* manner.

The difference between "data" and "information" is important to recognize. Data are individual facts. They are highly valued by the scientific community and necessary for hypothesis-testing, analysis, predictive modeling, and other research activities. Information is data that has been processed, organized, quality controlled, and synthesized for a purpose. Only through this process can data become information useful for decision-making in a management context.

If the complexities of the coastal ocean are to be understood, including the effects of pressures and changes that are the result of both human activities and nature, then sophisticated data-processing facilities, detailed information, and expert knowledge will all be needed. But the new technology is not a panacea that will cure overnight our current limited abilities to apply what we know to solving problems in the coastal ocean. Past experience has shown clearly the dangers of overselling technology, particularly if the technical "solutions" have been developed without a clear appreciation of needs and priorities.

NOAA Computer-Based Capabilities

A key to developing useful information and practical assessment capabilities is to recognize that a number of factors, many for which knowledge is incomplete and highly uncertain, affect almost every resource-use decision in the coastal ocean. In this decision-making context, where incomplete knowledge and uncertainty exist, assessment capabilities are required that enable the analysis of different assumptions, about both the state of scientific knowledge and alternative management strategies. New NOAA information bases and assessment systems are being designed and implemented to apply these capabilities to resource management decisions in the coastal ocean.

The concept of geographical information systems, or "geosystems," is particularly relevant. They are being used today in government and industry to do everything from finding oil to selling hamburgers! Within NOAA, we have four new geographical information systems in use or under development:

1. **Geo-COAST** (Geographical Coastal Ocean Assessment System and Technology), a state-of-the-art, microcomputer-based GIS for coastal ocean assessment and planning at the state and national level;

2. **Cmas,** a Computer Mapping and Analysis System of the biogeography of coastal ocean living marine resources;

3. **COMPAS** (Coastal Ocean Management, Planning, and Assessment System), a user-friendly, microcomputer-based GIS for use at the state and local level; and

4. **CAMEO** (Computer-assisted Management of Emergency Operations), a user-friendly, microcomputer-based GIS for hazardous-materials planning and response at the local level, in use by over 3,000 fire departments in the United States and currently adapted and being used in the Exxon Valdez spill response.

An innovative feature of these capabilities is their emphasis on building "expert systems" that use available information and knowledge in an efficient and easily understood manner. The operating principle is to guide users through "menu-driven" computer programs that logically organize various levels of details and combinations of data aggregations and graphic presentations. Another important feature is the emphasis on an explicit "audit trail" capability so that the quality of the information itself can be evaluated.

Each of these NOAA information systems is organized geographically so that characteristics can be compared, computer-mapped, and assessed across combinations of spatial units, for example, the entire exclusive economic zone, areas within the EEZ such as the Gulf of Mexico or the Gulf of Alaska, or estuarine systems that drain into the coastal ocean.

No Shortcuts

Development of a body of information on the coastal ocean and operational capabilities to use it intelligently has been under way in NOAA for over 10 years. Among the lessons that we have learned is that there are simply no shortcuts to developing these capabilities systematically and carefully. The operational task of integrating disparate data bases and analytical capabilities is a difficult one requiring creativity, consistency, and continuity. The analytic capability to combine, compare, analyze, and portray information about the coastal ocean in a comprehensive manner provides the marine, scientific and resource-management communities with a basis to organize information on the effects of alternative policies and communicate it in a timely manner.

Until the introduction of the compass by Portuguese mariners in the 13th century, navigation was based primarily on courage and luck, with a little bit of knowledge of landmarks, winds, and currents thrown in. For a long time after its initial introduction, however, the compass was a pretty poor instrument, poorly used. Often the ship's master took a reading that, with a rough approximation, either confirmed or denied what he had already guessed through other means.

In many ways, today's decision-makers are in the same boat. Many important decisions that affect coastal ocean environmental quality are made on no better basis than courage or luck, with a little bit of experience thrown in. We move from decision to decision with little or no information about where we are, where we've been, or where we're going. Like the ancient mariner, we need to make and learn how to use new tools to provide better information for decision-making. *And we have to be prepared to use that information to act.*

When over 10 million gallons of crude oil from the EXXON VALDEZ spilled into Alaskan coastal waters, it caused some obvious, but many still unmeasured, environmental and economic damages. But perhaps even more importantly, the most significant long-term damage is the accelerated erosion of public confidence in our institutions, both public and private, to deal with coastal ocean environmental problems. If public confidence is to be restored, then we have to make fundamental differences in the way we think and decide about strategies for dealing with these problems. This meeting can lead hopefully to some of these fundamental changes.

MARINE FACILITIES: THE KEY FOR MOVING FROM RESEARCH TO REALITY

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Introduction

Man has used his instruments and tools to probe the unknown for insight into possible new futures. The instruments and tools of the maritime sciences are usually large in scope and extremely capital intensive and benefit greatly from a collaborative approach as embodied by our cooperative program. Carefully planned and integrated into future requirements and imperatives, these tools can provide invaluable technical insight for the design and development of future vehicles and systems At last year's meeting in Tokyo, Dr. Kazuo Sugai and Mr. Joseph Vadus, in their keynote addresses, provided an excellent overview of ship technology and marine facilities required for the 21st century. This year I would like to describe the initiatives taken by one laboratory, the David Taylor Research Center (DTRC) to provide world-class tools and facilities that I feel would be required to fulfill that vision. This paper does not intend to diminish the many excellent facilities available throughout the world in the marine engineering and sciences field. Its purpose is to highlight recent facility upgrades and the introduction of brand new facilities at the David Taylor Research Center that represent a significant step forward in this field.

Some of the systems envisioned for the future exploit such technologies as the rapidly emerging development of Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) and include

- bottom survey and mapping
- ocean systems and monitoring
- inspection, maintenance and repair of underwater equipment
- operations in deep water and under ice
- oil and gas pipelines
- marine mining
- fish finding and classification
- scientific and engineering research
- environmental monitoring

At another extreme of the maritime activities is the emerging role of offshore installation with the following possible range of missions:

- maritime mining facilities
- mining of vital strategic materials
- mariculture, aquaculture and artificial reefs
- incineration at sea for waste
- scientific and engineering research
- floating cities
- megasize floating islands or naval bases
- energy conversion systems
- environmental pollution monitoring

These challenges require careful design and adaptation of our planned and proposed marine facilities. I would like to provide an overview of the David Taylor Research Center's effort to prepare for these challenges.

The David Taylor Research Center is a complex of 2800 people and facilities located throughout the United States as shown in Figure 1. Its mission is to be the principal Navy RDT&E center for naval vehicles and logistics and for providing RDT&E support to the U.S. Maritime Administration and the maritime industry. The latter responsibility, namely support in the private sector, goes back to the Laboratory's inception in the late 1800's and was enacted into law by Congress. In support of that mission the Center's technical program encompasses a wide range of maritime sciences, including concept innovation, acoustic and magnetic silencing, hydrodynamics, structural mechanics, aerodynamics, radar and infrared signature control, mathematics and computer science, materials development, energy conversions and propulsion, pollution abatement and environmental sciences, logistics, submarines, submersibles, surface ships and amphibians. The existing facilities, many of which are unique in the free world, are located in 225 buildings in 10 locations on a total of over 400 acres of land and represent a capital investment valued at over $2.5B.

Fig. 1. DTRC Detachments and Facilities

During the four year period from 1988 to 1992, DTRC will undergo a significant expansion in facility capabilities with the development of two more detachments and an investment of over $350M. These new facilities will provide an expanded and unique capability to develop the maritime systems of the 21st century. The development and modification of these facilities to accommodate these future imperatives will be described. These facilities and the thrust of their development or upgrade is summarized below and each is briefly described.

Facility	Enhanced Capability
• Large Cavitation Channel (Memphis, Tennessee)	• Improved evaluation of hull-propulsor interaction and acoustics
• Large Scale Vehicle (Bayview, Idaho)	• Autonomous underway vehicle (AUV) research platform
• South East Alaska Acoustic Facility (Ketchikan, Alaska)	• Improved acoustic/magnetic signature evaluation/ characterization of underwater vehicles
• USNS Hayes (Cape Canaveral, Florida)	• Improved at-sea acoustic/magnetic research platform
• Maneuvering & Seakeeping Basin (Carderock, Maryland)	• Improved laboratory evaluation of platforms in extreme sea states
• Pressure Tank Laboratory (Carderock, Maryland)	• Improved capability to evaluate deep-sea structures/vehicles under cyclic pressures
• Deep Ocean Research Island (Gulf of Mexico)	• At-sea platform for multi-disciplinary research

Large Cavitation Channel

The Large Cavitation Channel (LCC) is presently under construction in Memphis, Tennessee, with final acceptance in late calendar year 1990 (approximately Dec. 1990). The LCC is the largest recirculating water tunnel of its kind in the world. Figure 2 shows a model of LCC, and Figure 3 shows it under construction in Memphis. It is approximately 240 feet (74 meters) long by 65 feet (20 meters) high and has a maximum diameter of 24 feet (7.4 meters). The tunnel is set in a body of water contained in a large concrete trench. The pump is driven by a 14,000 hp cyclo-converter controlled motor and is designed to be noncavitating over its entire rpm range. The flow through the channel is controlled by specially designed cast acoustically treated turning vanes coupled with flow straighteners and honeycombs. All portions of the tunnel in contact with the water are stainless steel.

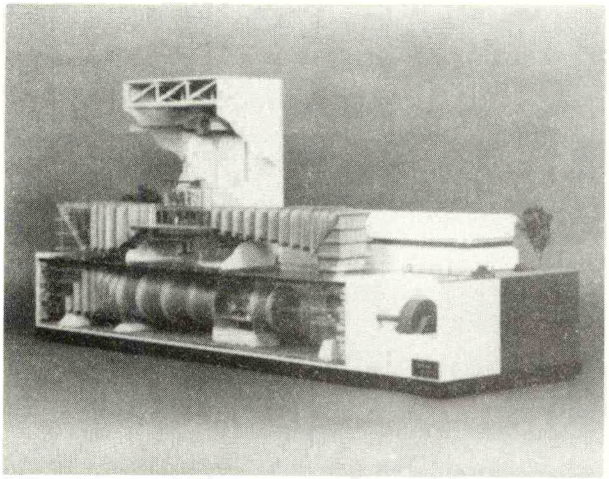

Fig. 2. Model of Large Cavitation Channel

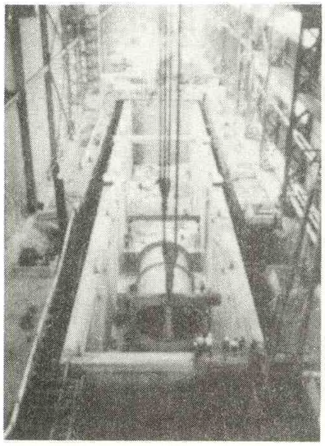

Fig. 3. Large Cavitation Channel Under Construction

The test section is 10 foot by 10 foot (3 meters square) by 43 foot (13 meters) length and is capable of handling both ship and submarine models up to 40 feet (12.3 meters). The test section environmental parameters include fluid velocities up to 30 knots (15.6 meters/sec) with pressures between 0.5 psia and 60 psia.

The dynamometer system will be capable of handling contra-rotating, dual, and single propeller systems. Each dynamometer motor has a maximum rating of 680 hp or a combined rating of 1360 hp. The maximum 6000 rpm system will have a capability of measuring up to 1200 lb of thrust and 320 ft-lb of torque for a 10-inch, 25-lb propeller. The maximum 3000 rpm system will have a capability of 3600 lb of thrust and 1000 ft-lb of torque with a 15-inch, 75-lb propeller.

The data acquisition system will be capable of handling 64 channels of analog and 32 channels of digital data with 16 discrete channels per digital word with a maximum A/D sampling rate of 1000K samples per second. There will be 14 analog tape channels. For data portability, in addition to the analog tapes, two 9-track digital magnetic tape recorders will be available. The magnetic recorders will have selectable recording densities of 1600 or 6250 bpi and speeds of up to 120 ipa and will use 0.5-inch tapes on 10.5-inch reels.

Cavitation and flow characteristics will be examined using a combination of Laser Doppler Velocimeter, photographic, and acoustic systems. The acoustic transducers will be a combination of wide band and highly directional systems using beamforming techniques.

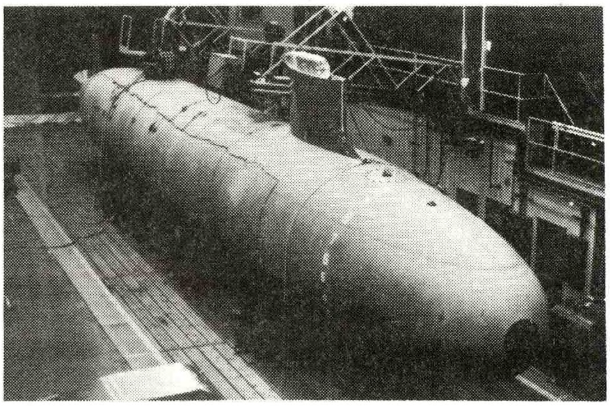

Fig. 4. Large Scale Vehicle at DTRC's Acoustic Research Detachment

Large Scale Vehicle (LSV)

The Large Scale Vehicle (LSV), nicknamed "KOKANEE", is a quarter-scale, free-running unmanned vehicle developed specifically to support the evalution of future submarine technology and propulsors. A paper describing the plans for this program was presented at our meeting in Tokyo last year. The LSV, shown in Figure 4, was operational early this year at DTRC's Acoustic Research Detachment (ARD) in Bayview, Idaho. The detachment is located on Lake Pend Oreille, which is an 1150-feet (350 meters) deep fresh water lake located in northern Idaho.

The LSV is a battery-powered, direct-drive dc-motor driven, scale model of a full-sized submarine. All onboard systems are operated by a ship control computer (SCC); all operations are conducted within a radiated noise range and controlled by an acoustic tracking and communication systems (ATACS). An onboard instrumentation system records a variety of important parameters: forces, vibrations, strains, pressures and pressure distributions, cavitation, and airborne noise. Acoustical range instrumentation allows for recording and analyzing radiated noise emanations from the LSV. Future capabilities may be provided for determining target strength characteristics, wake surveys, and video monitoring the LSV while surfaced and submerged. For the next several years, the LSV will serve primarily as a platform for testing performance-enhancing hardware being developed for the new design attack submarine. As the new submarine enters the Fleet, the LSV will increasingly become more available for other projects relating to future submersibles. These projects may include Navy and private sector as well as foreign ventures.

The LSV hull has the requisite fairwater and other control surface appendages, which are removable. The pressure hull contains the batteries, propulsion system, auxiliary systems, onboard instrumentation, and the SCC. The fore and aft non-pressure hulls house the ballast tanks, high-pressure air flasks, ATACS transducers and instrumentation, and control and monitoring systems for the propulsor. The hull is approximately 88 feet (26 meters) long , 10 feet (3 meters) in diameter, and displaces 155 tons.

The propulsion system consists of main- and loiter-propulsion motors, a drive train, shaft seals, and the propulsor. The system provides propulsive means ranging from a loiter condition to flank speed. The loiter-propulsion motor minimizes drain from the batteries at low transit speeds and proves a backup in case of main motor failure. Motor speed varies from 350 to 600 rpm. The aft fixtures for the attachment of the propulsor to the non-pressure hull are designed to allow relatively easy replacement of alternate propulsor candidates. The main propulsion motor is rated at 3000 hp.

South East Alaska Acoustic Facility (SEAFAC)

We have just started the construction of a new acoustic and magnetic range for static and dynamic evaluation of undersea vehicles. This has been necessitated by the increased amount of ambient noise level at our two west coast detachments in Washington and California. This new range will be located in southern Alaska in a deep fiord called Behm Canal, as shown in Figure 5. The underway site will be located in

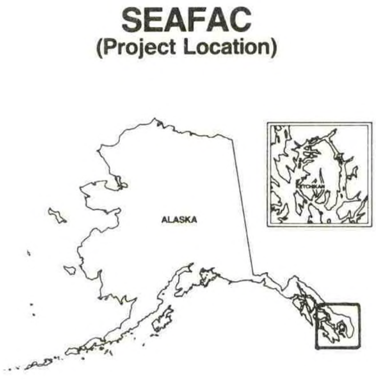

Fig. 5. Location of South East Alaska Acoustic Facility

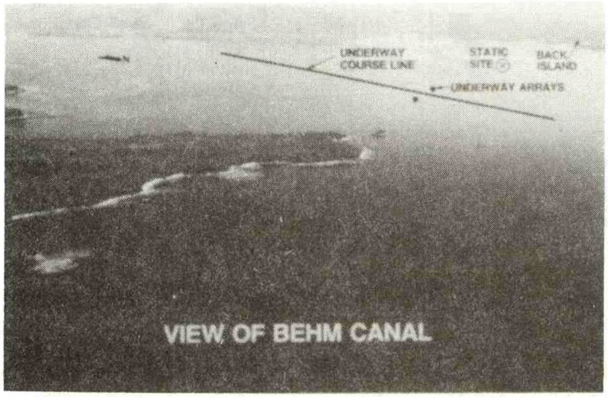

Fig. 6. SEAFAC Facility and Course

1320 ft (402 meters) water depth and will consist of an instrumented zone 500 yards (457 meters) wide and 20,000 yard (18.9 kilometers) long with two 1500 yard (1372 meters) maneuvering zones for course reversals. Figure 6 shows the course in relationship to the general terrain. SEAFAC will also include a static site for signature measurement of full scale submarines suspended at depth (Figure 7). When completed SEAFAC will be one of the Navy's most capable west coast acoustic measurement ranges and diagnostic tools.

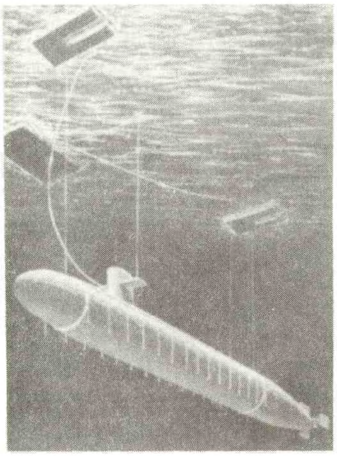

Fig. 7. Artist's Concept of a Recent Submarine Suspension Test

USNS HAYES

To provide the Center with a state-of-the-art, at-sea mobile acoustic and magnetic measurement capability we are modifying a catamaran-hulled ship with an overall length of 246 feet (75 meters) and a displacement of 4037 long tons, Figures 8 and 9. The USNS HAYES will replace our existing Mobile Noise Barge (MONOB), 1390 long tons, and will operate in the quiet environment of Exuma Sound, Bahamas. When completed in 1990, the HAYES will be one of the quietest measurement platforms in the world carrying heavy deck equipment capable of permitting rapid deployment and retrieval of large measurement arrays. Laboratory space will be provided for current and future measurement objectives. HAYES will be configured to maximize the advantages of a shipboard surface deployed system, including mobility and minimal shore support, deployment of a wide variety of specialized systems on an as-needed basis, and ease of upgrading, modification and repair of in-water components. Additionally, HAYES will provide underway measurements through the use of a towed array and target strength measurements through the use of a special system for these measurements.

Fig. 8. USNS Hayes Underway Prior to Modification

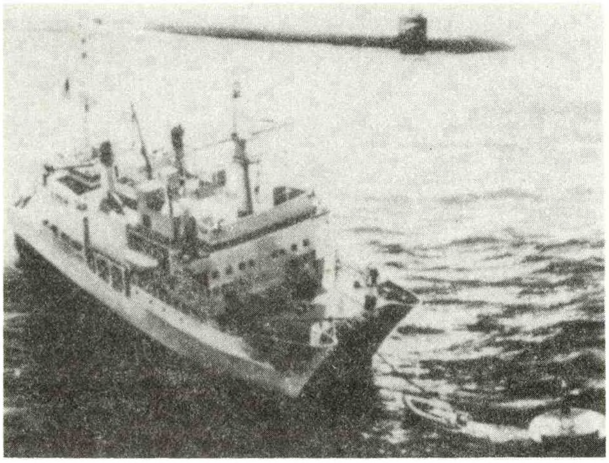

Fig. 9. Artist's Concept of USNS Hayes When Completed

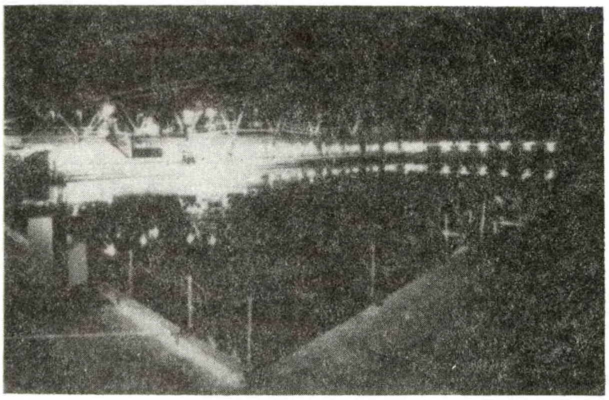

Fig. 10. Maneuvering and Seakeeping Basin at DTRC

Maneuvering and Seakeeping Basin (MASK)

The Maneuvering and Seakeeping Basin shown in Figure 10, built in the 1960's, has become one of our most versatile and heavily used facilities due to a number of recent additions of new capabilities. Its primary characteristics along with DTRC's other basins are shown in Table 1. The primary use of the MASK is to predict the full scale performance of ships, platforms and mooring systems in realistic waves which can simulate the ocean up to sea state nine. We are currently replacing all the wavemaking equipment and installing a new control system to provide us with better frequency control and better wave spectrum shaping. This will improve our ability to evaluate at-sea structures, and advanced ship hull forms.

In addition to the enhancement in the sea state simulation capability, we have also installed an underwater 3-D tracking range to provide a capability to evaluate and characterize the maneuvering characteristics of underwater vehicles.

Table 1. DTRC Basin Characteristics

	Length (ft)	Width (ft)	Depth (ft)	Volume (gal)	Wavemaking Capability Length (ft)	Wavemaking Capability Height (in)
Shallow Water Turning Basin	1,192	51	10-22*	8,870,000	—	—
Deep Water Basin	1,886	51	22	15,820,000	5-40	4-24
High Speed Basin	2,968	21	10-16**	6,310,000	3-40	2.5-24
Maneuvering & Seakeeping Basin	360	240	20-35	12,210,000	3-40	0-24
Rotating Arm Basin	260 (dia)	—	20	7,940,000	—	—
140 ft Basin	140	10	5	52,000	2-13	1-7.5
Miniature Model Basin	40	2	2	1,500	—	—

* 10 ft for one-quarter of Basin length, 22 ft remaining length
** 10 ft for one-third of Basin length, 16 ft remaining length

Pressure Tank Laboratory

The Pressure Tank Laboratory, located at Carderock, Maryland, is used primarily in connection with the submarine structures program. Examples of its uses are:

- Hull design research (complex hull collapse)
- Large-scale design confirmation models (TRIDENT, SEAWOLF, Shinkai 6500)
- Evaluation of military and civilian submersibles and devices.

The complex consists of five large tanks and numerous small tanks. Several of the tanks feature the multilayer design concept; the tank shells are made up of a number of thin layers rather than a single thick layer. The size and operating pressure for each of the five major tanks are indicated below.

Diameter (ft)	**Length** (ft)	**Pressure** (psi)
13	40	3,000
10	sphere	10,000
6	21	6,000
5	9	17,000
4	20	15,000

Each tank is vertically oriented and buried in its own vault with only the head exposed on the test floor. This reduces potential hazards to operating personnel. Also, handling of the heads and models is much easier with the vertical arrangement; it is possible to open or close any tank in less than one hour, thus facilitating model examinations.

The number of pressure tanks in the United States with a working diameter of four feet or greater is in excess of thirty. However, the tank complex at Carderock possesses the finest overall capability. Only one tank, in Portsmouth, New Hampshire, is larger, but it has a lower operating pressure. Only one, at ITTY Research Institute, has a higher operating pressure.

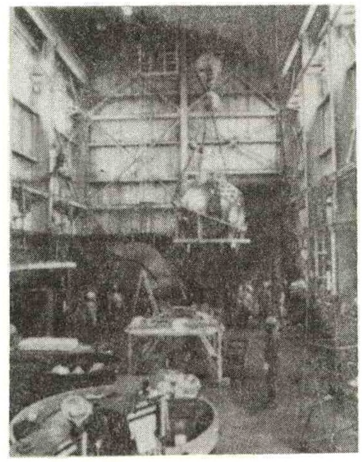

Fig. 11. The 25-ton titanium-hull submersible in DTRC Pressure Laboratory

During 1988, the five large tanks were used for a total of 350 hours. In addition, the time the models are being instrumented and hooked up and the time the tanks are tied up while plumbing is being changed from one test setup to another is about twice as long as the actual usage.

In 1988, the Japanese Marine Science and Technology Center (JAMSTEC) tested their titanium-hulled, deep-sea Shinkai 6500 in the 10-foot spherical pressure tank, see Figures 11 and 12. Four hundred strain gauges were installed by the builder, Mitsubishi Heavy Industry, prior to its shipment to DTRC. To test it, the sphere was filled with water and immersed in the tank filled with oil. The hull was tested to 10,639 psi and showed zero water leakage at maximum test depth.

While not described here, the Center also has a series of horizontal pressure tanks, shown in Figure 13, at our Annapolis laboratory. The tank shown is 10 feet (3 meters) in diameter by ft in length with a maximum pressure capability of 12,000 psi.

Deep Ocean Research Island

The Deep Ocean Research Island (DORI) is the most recent addition to the Navy Laboratories' research fleet. DORI is a 19,000 ton, self-propelled semisubmersible that will be deployed

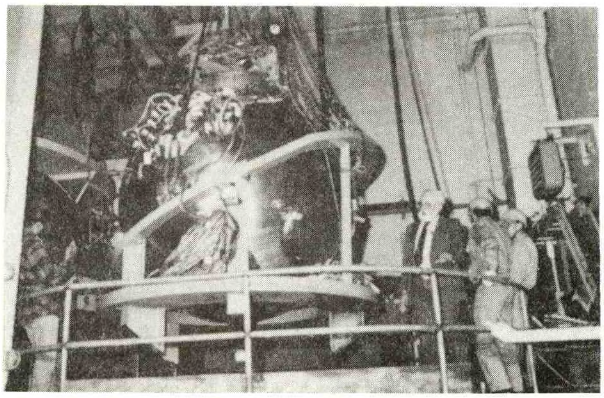

Fig. 12. Shinkai 6500 in 10,000 Spherical Pressure Tank

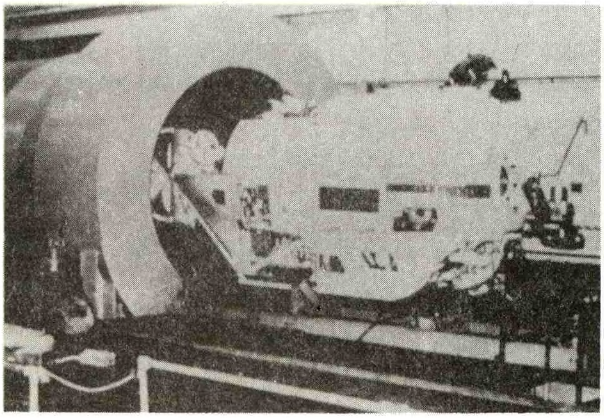

Fig. 13. Semi-Submersible Being Tested in DTRC's Horizontal Pressure Tank

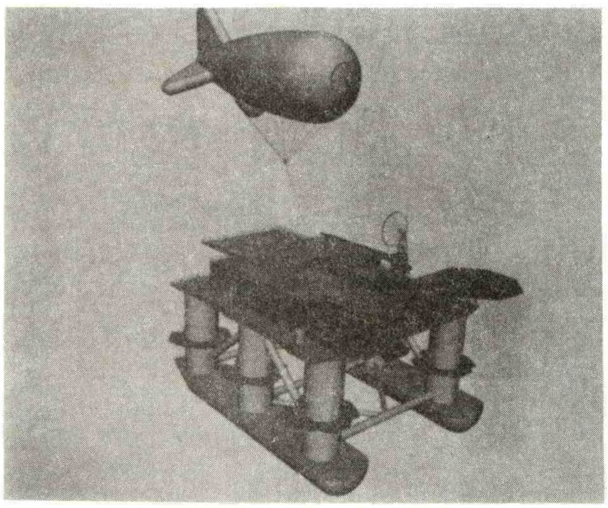

Fig. 14. Artist's Concept of Deep Ocean Research Island (DORI)

in the Gulf of Mexico next year. With over 60,000 feet of usable deck area and three decks of laboratory space, DORI will serve both a surveillance role for the U.S. Defense Department and multiple research functions for the Navy's seven other R&D centers. Because the David Taylor Research Center is chartered to serve the private sector, this asset will be available for a wide range of projects. The platform, shown in Figure 14, will provide full support for an aerostat-borne radar system that will allow full frequency evaluations of ships operating in well developed seas. Subsurface facilities will be used to support the Navy's deep ocean structural and shock evaluation needs into the 21st century. DORI will also provide the Navy with an at-sea corrosion laboratory, materials evaluation center, Unmanned Underwater Vehicle (UUV) test/evaluation site, and a potential service facility for acoustic and magnetic ranges. The multiple research and development missions anticipated, coupled with the flexibility of this platform, makes the Deep Ocean Research Island one of the most attractive new assets for the Navy's future. The David Taylor Research Center will own and operate DORI for the common benefit of all Navy research needs in the deep ocean.

Conclusions

The David Taylor Research Center has undertaken a broad base program to modify and develop its marine facilities in an attempt to anticipate the future needs and imperatives. The continued cooperative use of these facilities by innovated agencies and industry, both U.S. and foreign, are vital if we are to move the key marine technology from the research laboratory to reality.

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Marine Facilities and Systems for Resource Development and Environmental Conservation

FLOATING DISPOSAL SYSTEM FOR WASTE FRP BOATS

BY

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1.INTRODUCTION

Plastics have excellent characteristics, including lightness, corrosion resistance and colorability. Since their appearance in the 19th century, they have been used in fields ranging from toys to ships, where they replace wood and metal. One kind of plastic, glass fibre reinforced plastic (GFRP, or simply FRP) is used in Japan, mainly as a strucural material for small boats, such as small fishing boats or leisure boats. About 30,000 FRP boats are built each year.

For boats built 30 years ago are now at the end of their lifespan and it is necessary to break them up. The difficulty of disposal is also another problem. Fig.1 shows a flow chart for processing waste FRP boats. Presently after breaking-up and crushing, since a recycling method for FRP has not been established economically they are disposed of by burying.

According to a study by the Ministry of Transport, the breaking-up and crushing of FRP is technically quite possible. However, the breaking-up and crushing costs are more than ¥150,000 per ton. By adding to this the transportation cost, the total disposal costs of FRP amount to more than ¥200,000. Moreover, as the cost-sharing rule on this matter has not yet been established, there is a great possibility of illegal abandonment.

To overcome these difficulties, a method of disposing of waste boats without any preprocessing or transportation costs is proposed. It is also proposed that a ship is used exclusively for offshore processing of waste FRP boats. Then:

① to save on the preprocessing costs such as crushing, it is suggested that shaped materials as large as possible are utilized, if possible, original size, therefore not requiring any breaking-up or crushing prior to thermal decomposition.

② To solve the problem of transportation, constructed the recycling factory including the thermal decomposition furnace on a ship. Thermal decomposition would then enable recovery of the oil, gas and glass fibres.

To promote the above plan, a series of thermal decomposition experiment are being done as fundamental background research. The results to date of this thermal decomposition experiment and an outline of the offshore processing ship are introduced in this report.

2.RECOVERY TECHNOLOGY FOR OIL AND GASES BY THERMAL DECOMPOSITION

2.1 EXPERIMENT

Results of thermal decomposition experiments on FRP will be investigated with the view of utilizing in offshore processing factory ship. There are 3 stages in the thermal decomposition experiment.

① The fundamental experiment. Analysis

of the gases, oil and residues obtained after thermal decomposition of FRP. The fundamental thermal decomposition fFurnace is schematically shown in Fig.2.

② Development of a thermal decomposition furnace using a self-sustaining combustion system. In order to dispose of the scrap materials generated while building new FRP boats, this thermal decomposition furnace must be capable of processing materials above 1 to 2 m^3, and must use continuous combustion to improve efficiency. The thermal decomposition furnace for continuous, self sustainig combustion is shown in Fig.3.

③ Development of a batch type thermal decomposition furnace for shaped materials (self-sustaining combustion system) which is capable of thermal decomposing 15m long FRP boats of full size. The thermal decomposition furnace for shaped materials is given in Fig.4.

Stage ① and ② have already been completed.

2.2 RESULTS AND DISCUSSION

2.2.1 RECOVERY EFFICIENCY

Table 1 shows the recovered quantity in the fundamental thermal decomposition experiment. 90.7 ℓ of gas, 344 g of oil and 524 g of thermal decomposed residue were recovered from a supply of 1,000 g FRP. Since the resin contents of the FRP used for thermal decomposition is 60% by weight, the recovery rate of oil from resin is 57%. Since the decomposed residue of FRP consists of glass fibre and carbon, and the content of the glass fibre is 40%, the carbon content is estimated at 124g.

Scrap materials were used as fuels to supply heat for thermal decomposition during the thermal decomposition experiment by the continuous combustion system. The recovery rate was reduced by the amount of resin used for combustion. Actual broken-up materials of volume of 1 m^3 were used for this experiment. Since the FRP shell plate of the waste boat is of the sandwich type structure of FRP where the core is plywood, a considerable amount of plywood becomes incorporated with the scrap materials. Thus accurate weight measurements of the FRP content were difficult. Approximately 2.5 tons of oil and 5 tons of glass fibrs plus carbon residue were recovered by thermal decomposition for about 10 tons of FRP. In the initial stages, there was great concern about a drastic decrease in the recovery rate, but the oil recovery rate from the resin was maintained at a level of 40%, compared with 57% in the fundamental thermal decomposition experiment.

Since whole boats cannot be bepacked togather for thermal decomposition by the self-sustaining combustion system for shaped materials (Fig 4) as compared with the more tightly packed FRP that has been broken-up and placed in a continuous combustion furnace, a further decrease in the recovery rate is expected. The results of estimated calculations are indicated in Fig.4. The recovery rate of 30% from resin is economically viable and should be possible to maintain.

2.2.2 ANALYSIS OF THE RECOVERED GAS

Table 2 shows a chromatographic analysis of the gas recovered during thermal decomposition. 8,939 kcal/Nm^3 of the gross heat of combustion of the recovered gas is almost as high as natural gas and has enough heating value to be used for fuel. However, the recovered gas obtained in this experiment includes 41.8% carbon dioxide which means that less than 60% is combustible gas. This carbon dioxide must be separated so the combustible gas with main components of carbon monoxide and hydrogen can be used for gas engines even though they have low gross heat of combustion. Presently, it is not reasonable to use this gas for Diesel engines because of the high ignition point of these two main component gases; namely carbon monoxide with an ignition point of 651°C and hydrogen of 585°C.

Although an increase of carbon dioxide content is inevitable while doing thermal decomposition by a self-sustaining combustion system because of the air blown into the furnace, this gas can be utilized, provided that it is separated from the carbon dioxide.

2.2.3 ANALYSIS OF THE RECOVERED OIL

Table 3 shows a characteristic analysis of the recovered oil. The results show clearly that the recovered oil is extremely acidic and has a viscosity equivalent to polymerized naphtha (comparing with petroleum fuel). It is highly inflammable, having a flash point close to gasoline. The fluid point and the carbon content indicates that it is different from petroleum. The composition ratio of carbon to hydrogen is approximately 10:1, and it has a greater carbon content than the regular fuel oil , the ratio of which is 6:1. Improvement in the combustion system may be necessary since it requires more air for combustion than petroleum. However, a strong point is that it does not produce sulfuric acid corrosion in low revolution or low-power engines, since its sulfur content is only 0.10% by weight.

According to a detailed analysis of the contents, it is assumed that the acidity of the recovered oil is attributable to either the sulfuric or the chlorine compounds. Those can probably be neutralized by some chemical process. Also it contains a considerable amount of aromatic compounds which have high octane values and these should therefore be fully usable for internal combustion engines if they are mixed with other oils.

Although there are some problems in the recpvered oil as described above, the recovered oil is able to be used as fuel for engines provided that it is further processed by redistillation until it has enough heating value.

The contents of the recovered oil by thermal decomposition of the self-sustaining combustion system are basically same as for the oil in the fundamental thermal decomposition experiment.

2.2.4 RECOVERED RESIDUE

The residue of the FRP thermal decomposition process, after oil and gas were recovered, consists of glass fibres adhering to carbonized resin. The glass fibres can be recovered in their laminated state without reducing the volume. Table 4 shows the compositions of the glass fibres specified for FRP production. They contain more than 50% Si, and could be used in cement. The glass fibres also have an increased insulating capacity because of the carbon between the laminated layers and use is envisaged as a core material for various insulation materials. These are considered to be effective methods of recycling.

2.2.5 SUMMARY

It has been found that the oil and gas recovered by thermal decomposition of FRP have sufficiently high heating values to be used as fuels. Further the glass fibres in the residue may be used as insulating materials. In the future, it is proposed to continue with the final stage of the thermal decomposition experiment i.e. for shaped materials and study whether thermal decomposition by a self-sustaining combustion system can be utilized where the boats do not need preprocessing.

3 CONCEPTION FOR OFFSHORE DISPOSING OF WASTE FRP BOATS

3.1 OUTLINE

As described above, research is ultimately aimed at the thermal decomposition of waste boats where there is no preprocessing. However, beside the processing cost that of the transportation a major expense. The transportation expense is considerable since the waste materials consists of either the full size boat or scraps, both of which are quite bulky. One method for cutting the transportation costs is to salvage and transport these boats by ship. If the recycling factory is situated on the shore, the waste FRP boats need firstly to be salvaged by ship, then transported to the port and transported to the factory on the land. The cost of this is significant. Processing directly on the salvage ship can solve the problem. This is outlined in the following.

3.2 RECYCLING FACTORY SHIP

The features of this ship are as follows:

① This is a factory ship, a major part of which is a thermal decomposition furnace. It is equipped with a thermal decomposition furnace, recovery equipment for oil and gas, and a crane and other necessary breaking-up equipment.

② It requires sufficient space for laying out waste boats or recovered materials.

③ A low speed of 8 knots/hour is sufficient for cruising.

④ Stability is essential since there is a factory on the ship.

⑤ The fuel for cruising should be supplied from the recovered gas and oil from thermal decomposition, if possible.

⑥ It must be capable of processing wastes boats where demands may be variable.

Considering the above features, a pin-joint ship with a side thruster, shown in Fig.5 is deemed most suitable. Then a barge which holds the waste boats can be connected to the rear of the ship. Several of these barges would located as shown in Fig.6. The owner then disposes of his boat on one of these barges. The recycling ship then travels from one area to another according to the shipping schedule, collectioning and concurrenrly processing waste boats. Thus it circles around the whole country, continuously processing waste boats.

3.3 SHIPPING SERVICE FOR THE RECYCLING SHIP

A round trip following the coast line of Japan is about 6,400km as shown in Fig.6. It takes 19 days to complete the circuit with a cruising speed of 8 knots/hour. To sustain 8 knots/hour the side thruster drive motor power required is 3,600 ps.

Calculation of the drive motor power produced when using a turbo generator run by steam generated by the recovered oil from thermal decomposition is as follows:.

The number of waste boats in Japan during 1995 is estimated to be 36,500 boats, i.e. 18,250tons FRP. Assuming that the ship makes 3 circuits of the country in a year, it needs to process 6,080 tons per circuit. The processing quantity per hour will be 13.3tons if thermal decomposition is continued during the 19 days of cruising. Even in the case of thermal decomposition of shaped materials, 2.66tons of the recovered oil is assured since a minimum of 20% of the FRP weight can be recovered as oil. The recovered oil has a minimum gross heat of combustion of 8,500 kcal/kg.

The steam generation rate Gx is obtained from the following equation.

$$Gx = \frac{Foc \times Lcv \times \eta b}{\iota - \iota o}$$

$$= 27301 \text{ kg/hour}$$

where

Foc: processingquantity 2,600 kg/hour

ι : entahalpy of steam 667.1 kcal/kg

ι o: entahalpy of feedwater 60 kcal/kg

Lcv: gross heat of combustion 8,500 kcal/kg

η b: conversion efficiency 0.75

Therefore the output of the turbo generator Po is 3,412kw(27301/8). Assuming 3,000kw is available for driving and the efficiency is 0.95, the drive motor power will be 3.876 ps (3000×0.95kw). This exceeds the 3,600 ps which is required for cruising at 8 knots/hour. The gas generated by thermal decomposition is naturally available in addition to this.

4 CONCLUSION

The disposal of waste FRP boats is difficult because of the high cost. To solve this, offshore processing of waste FRP boats has been proposed, which has almost no operational costs. This is an effective method from the view point of waste disposal administration. However, development of a technically superior method of recycling the resultant gases, oil and glass fibres is needed to make this business viable, since the construction cost of this system is enormous.

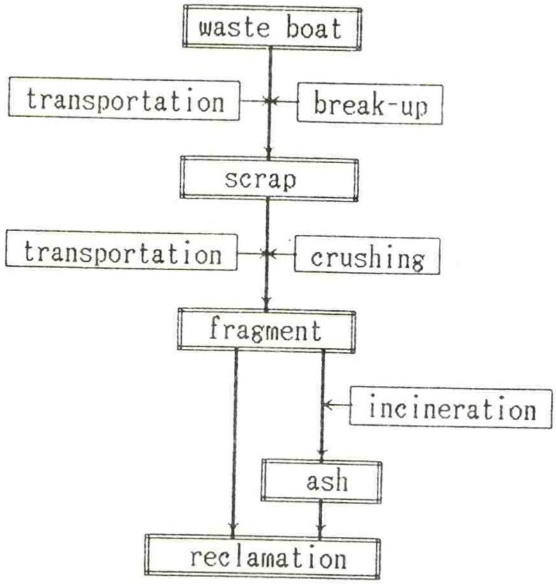

Fig.1 Flow Chart for Processing Waste FRP Boats

Table 1 Recovered Quantity (per 1,000g FRP)

Component	Contents
gas	83.8ℓ
oil	344g
residue	524g

Table 2 Chromatographic Analysis of Recovered Gas

Component	Contents %
Oxygen	0.2
Nitorogen	0.8
Hydrogen	14.2
Methane	7.4
Carbon Monoxide	20.2
Carbon Dioxde	41.8
Acetylene	0.05
Ethylene	3.6
Ethane	3.9
$C_3 \sim C_5$	3.9
$C_6 \sim C_8$	1.1
Gross Heat of Combustion Kcal/Nm^3	8939

Table 3 Chracteristic Analysis of Recoyered Oil

Specific Gravity (15℃)	0.9556
Flash Point ℃	- 0.5
Kinematic Viscosity (50℃) cSt	0.966
Pour Point ℃	< -65
Gross heat of combustion kcal/kg	9240
Conradson Carbon Contents wt%	1.12
Ash Contents wt%	0.01
Water Contents wt%	0.60
Surfer Contents wt%	0.10
Water plus Sediment Contents vol%	0.30
Carbon wt%	75.6
Hydrogen wt%	7.2
Chlorine wt%	0.10
Nitrogen wt%	0.08

Table 4 Composition of Glass Fibres

SiO_2	52~56%
Al_2O_3	12~16%
CuO	12~25%
Na_2O, K_2O	0~ 1%
MgO	0~ 6%
B_2O_3	8~13%

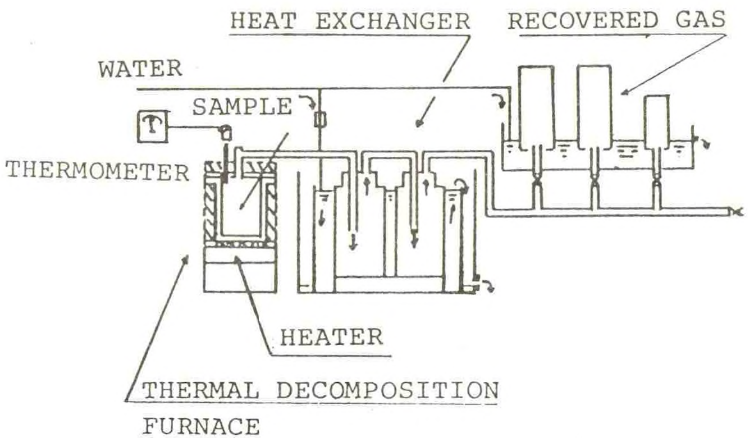

Fig.2 The Fundamental Thermal Decomposition Furnace

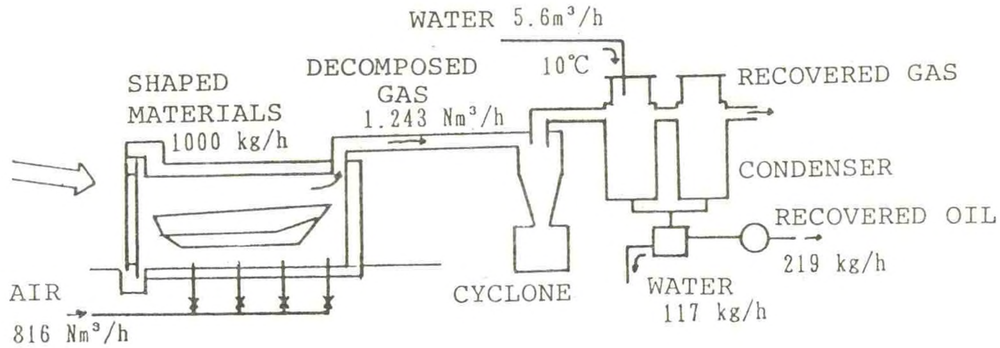

Fig.4 The Thermal Decomposition
for Shaped Materials

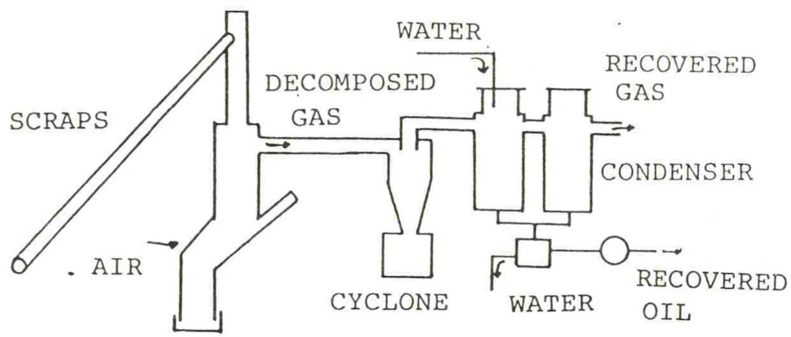

Fig.3 The Thermal Decomposition Furnace
by the Continuous Self-Sustaining Combustion

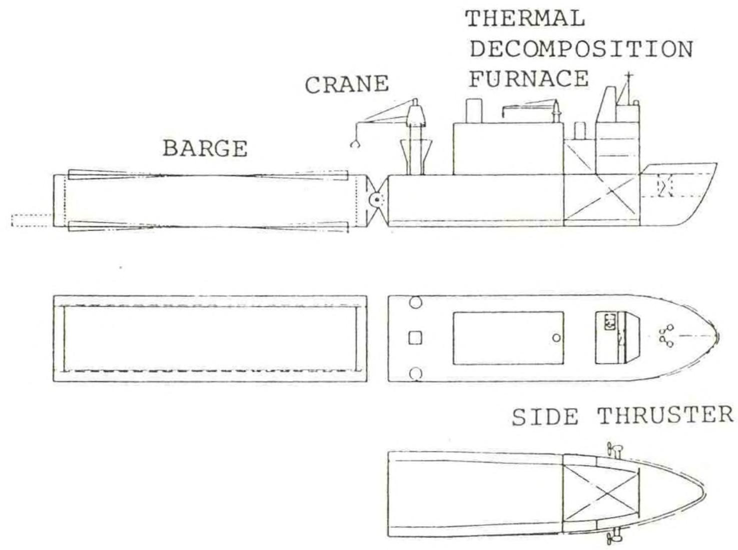

Fig.5 General Arrangement of Offshore
Factory Pin-Joint Ship

Location of waste boat yards	Number of waste boats	Amount of waste FRP	Distance from yard to next one
A	4,000	2,000 tons	500 km
B	3,500	1,700	500
C	4,500	2,250	400
D	4,000	2,000	500
E	3,000	1,500	400
F	3,000	1,500	400
G	2,000	1,000	900
H	1,000	500	600
I	4,000	2,000	600
J	3,000	1,500	600
K	2,500	1,250	500
L	2,000	1,000	500
total	30,500	18,250 tons	6,400 km

Fig.6 Location of Waste Boat Yards

THE FLOATING TERMINATOR TYPE WAVE POWER DEVICE

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INTRODUCTION

The floating terminator type wave power device is one of the most effective wave power absorbing device. Its first principal mechanism of wave power absorption is due to the oscillating water column type [1] which is adapted to several devices for practical use in the world. And, second of it is the floating device like the floating breakwater.

The device which we described in this paper has good performance of dissipation of waves and absorption of wave power.

When this device is placed at the offing of seashore, where wave power is too high to utilize its area for fishing, transportation and amusement, it will be very effective for significant multiple development of the coastal zone.

JAMSTEC has been developing the attenuator type floating wave power device from 1975 and many effective results and experiences were obtained.[2][3][4]

By the way, JAMSTEC started to study on the floating terminator type wave power device, but fundamental study from 1986 [5]. Until now, we could obtain some principal results of this type device.

These are, (1)high efficiency of wave energy absorption, (2)wide frequency range of high efficiency region, (3)ability to reduce the transmitted wave height, (4)comparatively low mooring force. The outline and discussion of this study are described in this paper.

FLOATING TERMINATOR DEVICE

The floating terminator has several air chambers which has a bottom-plate, projecting walls and an orifice on the top of the chamber respectively as shown in Fig.1 and some floating chambers. And the air turbine and the generator are equipped on the orifice for electrical generation.

The oscillating water column (OWC) is a mass of water in the air chamber as shown by oblique lines in Fig.2. The OWC is oscillated by incident waves and it makes air go into and out through the orifice and rotate the air turbine. That is the transformation from wave energy to electrical energy and its ratio is the efficiency of wave power absorption. In such condition, a bottom plate and two projecting walls are effective to the efficiency [5].

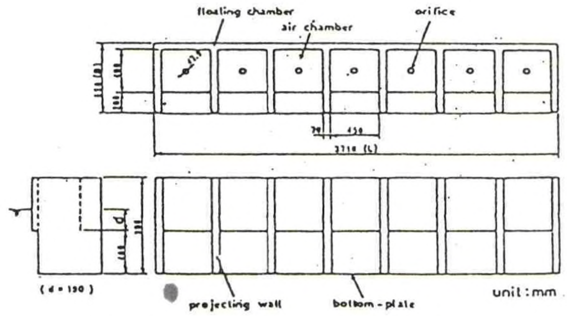

Fig.1 Principal Dimension of the Model

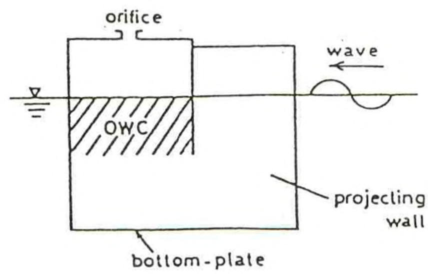

Fig.2 Section of the OWC Type Wave Power Device

The floating terminator is moored by some mooring lines in such a way that the longitudinal center line of the device is paralell with wave crest line like the breakwater.

WAVE POWER ABSORPTION in WAVES

(a) In Regular Waves

When the wave power device which has energy absorbers of N units, that is the air chamber for OWC type device, is placed in the regular waves, the absorption energy per unit length Ea is estimated by following equation.

$$
\begin{aligned}
E_a &= \frac{1}{T}\int_0^T W dt\,\bar{\eta} \\
&= \frac{1}{8}\rho g n H^2 C_g \bar{\eta} \\
&= \frac{\rho g}{32\pi} H^2 T \bar{\eta}
\end{aligned}
\qquad (1)
$$

where, ρ ; density of seawater
g ; gravity acceleration
H ; wave height
T ; wave period
N = Cg/C
Cg; group velocity
C ; celerity

$$\bar{\eta}=\frac{1}{N}\sum_{i=1}^{N}\eta_i(f) \qquad (2)$$

a; wave energy absorption efficiency of a unit of number i
f ; wave frequency

Consequently, we can estimate the value of Ea if we can grasp only the characteristics of wave energy absorption against wave frequency for each unit.

(b)In Irregular Waves

The absorption energy in uni-directional irregular waves is estimated by following equation.

$$E_a=\rho g\int_0^{\infty}S(f)\,C_g(f)\,\bar{\eta}(f)\,df \qquad (3)$$

where, S ; wave power spectrum

By the way, wave energy absorption efficiency $\bar{\eta}$ is affected by incident angle between the longitudinal axis of the device and direction of incident waves [7]. When the device is fixed in uni-directional irregular waves, the wave energy per unit length of wave in the direction of device depend on only the angle θ as following equation.

$$E_a=\rho g\int_0^{\infty}S(f)\,C_g(f)\cos\theta\,\bar{\eta}(f)\,df \qquad (4)$$

So, Ea in multi-directional waves is estimated by the following equation.

$$E_a=\rho g\int_{\theta 1}^{\theta 2}\int_0^{\infty}S(f)\,G(f,\theta)\,C_g(f)\cdot\cos(\theta_m+\theta)\,df\,d\theta \qquad (5)$$

where, G ; directional spreading function
θm; leading direction of multi-directinal waves
θ1, θ2; lower and upper limit of integration

But, in the case of the floating device, the wave energy absorption efficiency must depend on not only wave frequency but also on wave direction because of the oscillation of 6 modes responding to waves. So, the following equation is obtained.

$$E_a=\frac{1}{N}\sum_{i=1}^{N}\left\{\rho g\int_{\theta 1}^{\theta 2}\int_0^{\infty}S(f)\,G(f,\theta)\,C_g(f)\,\eta_i(f,\theta)\,df\,d\theta\right\}$$
$$=\rho g\int_{\theta 1}^{\theta 2}\int_0^{\infty}S(f)\,G(f,\theta)\cdot C_g(f)\,\bar{\eta}(f,\theta)\,df\,d\theta \qquad (6)$$

As shown in eq.(4), we must investigate on the efficiency of each unit η_i or averaged efficiency of total units $\bar{\eta}$ against to wave frequency and direction.

OPTIMAL TERMINATOR

The terminator type wave power device will be set up near seashore as described above, so its directivity to incident wave should be narrower than that of the device which is set up at the offing far from seashore. Because, narrow directivity is good at wave energy absorption for such terminator type device because of two dimensional oscillation of OWC in the air chamber with bottom-plate and projecting walls.

But, the leading direction of waves change sometime by weather condition in spite of unchangeable direction of the device by mooring. And the device is not able to be set up adjusting the direction of it to wave direction because of topography of sea floor, fairways, fishing area and etc.. So, we will have to design the optimal dimension of a device adapting to wave condition at the expected area for setting up.

The wave energy absorption efficiency of the terminator type device depends on wave frequency and incident angle as shown in eq.(6). And the change of incident angle is considered to be the change of frequency of incident wave neglecting the exact solution.

The characteristics of wave energy absorption of the floating terminator depends on pitching motion around the longitudinal axis x mostly, as shown in Fig.3. When the wave comes from the oblique direction of θ as shown in Fig.3, the device oscillates responding to the apparent frequency f_a which is converted by following formula using incident wave frequency f_w.

$$f_a=f_W/\cos\theta \qquad (7)$$

By the way, the behavior of pitching depends on GM of the device, and it depends on the moment of inertia of section, and finally the breadth of the device briefly speaking.

Consequently, when we try to design the device, we must correct the peak frequency of efficiency using the leading incident angle of incident waves, and decide the optimal breadth using this correction.

MODEL TEST

The model test was carried out at 2 and 3 dimensional condition, regular and irregular, uni and multi directional waves in order to confirm the principal behavior described above.

The dimensions of the scale model is shown in Fig.1, and the principal particular of this model is shown in Table 1. And, the model was moored by 4 chain lines as shown in Fig.3.

By the way, we measured incident waves, transmitted waves, pressure in the air chambers, motion of the device and mooring forces. Each data were recorded by analogue recorder and digital recorder, and these data were analyzed.

Table 1 The Principal Particulars of the Device

Length (L)	3.71 m
Breadth (B)	0.65 m
Depth (D)	0.90 m
Depth of the Curtain Wall (d)	0.19 m
Weight	191 kg
GM	0.043m
Natural Period of Pitching	7.6 sec

WAVE ENERGY ABSORPTION EFFICIENCY

The behavior of wave energy absorption efficiency at head sea (θ=0°) against wave length ratio, that is also related to wave frequency, is shown in Fig.4 and Fig.5. In these figure, the breadth B of the model is shown in Fig.1 and the value of efficiency of absorption is obtained by averaged air power divided by wave power per length of a unit air chamber.

Fig.4 is a result obtained at the condition of two dimensional condition. This test was carried out in the wave tank which is 4 m in width and 2 m in depth, so there would be little effect from both sides of the device.

In this test, all orifices were opened and absorbed the wave power evenly. So, the peak value of the efficiency of absorption is only about 30 %. But when some orifices were closed, every other orifices for example, the peak value of efficiency per unit air chamber which has opened orifices exceed 50 or 60 % [5] because of the interaction between neibouring air chambers which have closed orifice.

By the way, the performance under 3 dimensional condition is shown in Fig.5. This test was carried out in the wide basin which has about 36m in width but about 1.2 m in depth. So, it was considered that the three dimensional effects were produced in such condition. But, there was a little difference between results obtained under 2 and 3 dimensional condition.

Consequently, we can find that the terminator type wave power device with bottom-plate and projecting walls has good directivity and good performance for wave energy absorption compared with the attenuator type device [8], and the behavior obtained under two dimensional condition is effective for the open sea also.

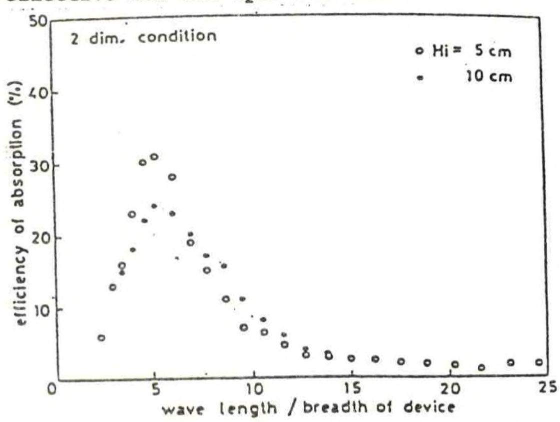

Fig.4 Performance of the Wave Energy Absorption in Regular Waves under the 2 Dimensional Condition

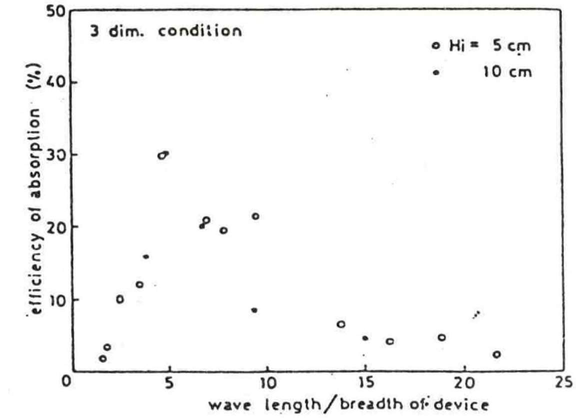

Fig.5 Performance of the Wave Energy Absorption in Regular Waves under the 3 Dimensional Condition

BEHAVIOR in OBLIQUE WAVES

The behaviors of the device on the absorption efficiency in oblique regular waves is shown in Fig.6. In this figure, the incident angle of incident waves is θ in Fig.3 and λ is wave length. And the curve in this figure is the fair curve drawn by an author.

When the breadth of the device is fixed, we can find the optimal angle θ_o against incident waves of frequency using eq.(7) and the peak frequency f_W in Fig.4 as follows;

$$\theta_o = \cos^{-1}(f_W/f_p) \tag{8}$$

As f_p is about 0.685 Hz in the scale model, the estimated value of θ_o becomes about 16 degrees as shown in Fig.6 by an arrow. The peak value of the curve is not precise in this figure, because the peak frequency of efficiency in head sea (θ=0°) is not so different from the wave frequency of this test in oblique waves. But, the arrow points almost at the peak of the curve , so it is confirmed that eq.(8) gives good estimation.

By the way, the behaviors of wave energy absorption in multi-directional irregular waves is shown in Fig.7. In this figure, the horizontal axis is the parameter of concentration which is used to express the directional distribution of multi-directional waves as follows;

$$G(f,\theta) = G_o \cos^{2s}\left(\frac{\theta}{2}\right) \tag{9}$$

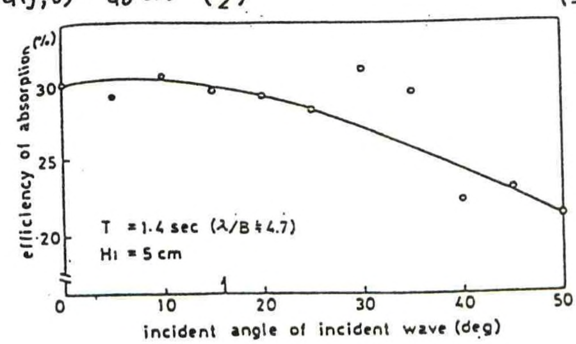

Fig.6 Performance of the Wave Energy Absorption in Oblique Regular Waves

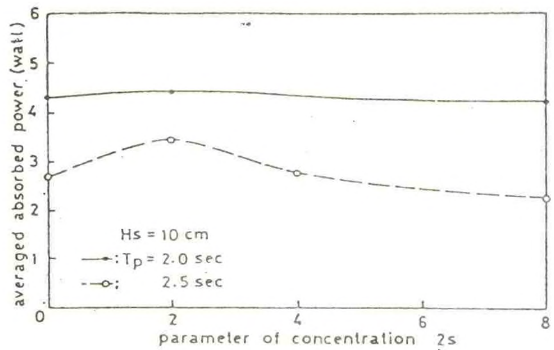

Fig.7 Performance of the Wave Energy Absorption in Multi-Directional Irregular Waves

The vertical axis is the time averaged air power of the device (7 air chambers) which is not dimensionless. And, Hs is the significant wave height and Tp is the peak period of the spectrum. Each curves are faired by an author.

We could obtain following consideration by this results. Since this model shows the effect of its best performance in oblique waves, it ought to apply to the multi-directional waves. But, the directivity of the device is distinguished as described above, so the performance must be reduced when the wave directional distribution becomes wider and wider. Consequently, the optimal condition must exist for each device.

In this case, we could find the optimal condition is 2s=2, and we can observe such phenomenon near seashore always.

Furthermore, We will have to study on this optimal condition with a high accuracy qualitatively and quantitatively hereafter.

DISSIPATION OF WAVES

Since the wave power device absorbs the wave energy, wave height behind the device ought to be reduced by the corresponding amount of absorbed wave energy. The results obtained in 2 and 3 dimensional regular waves are shown in Fig.8 and Fig.9. In these figures, the vertical axis is the ratio which is the value of the transmitted wave height divided by the incident wave height. And, in Fig.8, Hi is the incident wave height.

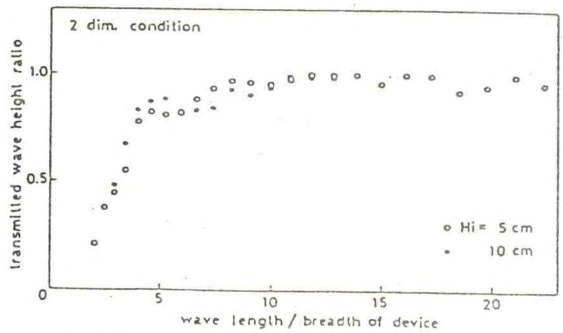

Fig.8 Performance of the Dissipation of the Waves in Regular Waves under the 2 Dimensional Condition

We could find that the effect by this device is not so clear in both conditions. But, since this behavior depends on the oscillation of the device responding to waves, it will not be difficult to improve this. The performance of dissipation in 3 dimensional condition is not so good at the short wave length especially because of the diffraction waves from both sides of the device. We must consider this phenomenon in open sea, and try to study on the optimal arrangement of number of devices.

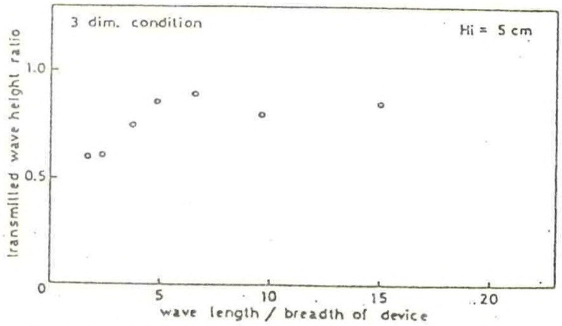

Fig.9 Performance of the Dissipation of the Waves in Regular Waves under the 3 Dimensional Condition

MOORING FORCE

Maximum mooring force which occurred on a weather side mooring line as shown in Fig.3 in regular waves of 5 cm in wave height Hi is shown in Fig.10. In this figure, the vertical axis is the ratio of maximum mooring force Fmax divided by the wave force.

As you can find that the mooring force of this device is not so large except in the condition of the short wave length. The reason of this phenomenon is caused by the reflected waves which causes the drifting force of the floating structure. So, the other way, the behavior of dissipation of waves is not good under the condition of the long wave length.

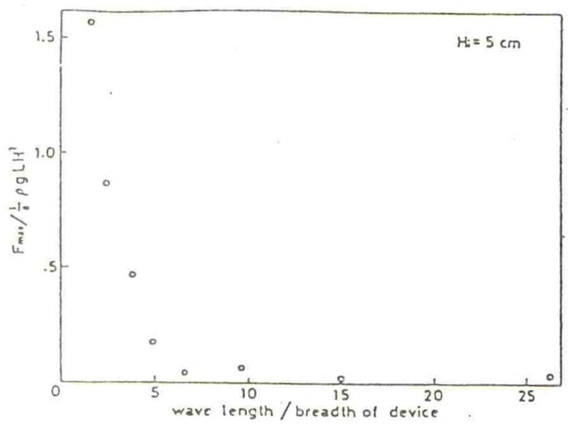

Fig.10 Behavior of the Maximum Mooring Force Acting on a Weather Side Mooring Line

Furthermore, when the wave length is short, the wave height is not so high because the wave gradient is not so different at any area near seashore. So, the value of the maximum mooring tension on one line occurred in actual condition will be in the order of 100 tons if the scale of this model is assumed about 1/20.

COST FOR ELECTRICAL GENERATION

Using some results of the test, we tried to estimate the total quantity of generated electrical power Eg during its life as follows;

$$E_g = E_w L \eta_a \eta_g X \tag{10}$$

where, Ew ; wave power per unit length
ηa; averaged efficiency of conversion from wave power to air power
ηg; averaged efficiency of conversion from air power to electrical power
X ; total operating hours during the life

When we assumed Ew=10kWh/m, L=60m, ηa=30% and ηg=50% and X=306600h (=24h*365d*35y), Eg becomes about 27.6 GWh during 35 years.

By the way, the cost of the device with 7 air turbines was estimated as shown in Table 2. And, the operational cost which included running cost, maintenance cost and others [8] was estimated using the cost of Table 2 as shown in Table 3. Finally, the total amount of cost for this generation system during 35 years became about 1.36 billion yen, that is about 7.7 million US dollars in the rate of 133 yen corresponding to one dollar. Consequently, we can find the cost for generation by this device is about 35.7 yen/kWh, that is about 0.28 US dollar/kWh.

In conclusion of this estimation, the floating terminator type wave power device is effective to user at isolated area and islands for practical use as shown in Fig.11.

Table 2 Facility Costs of the Device (unit ; million yen)

Hull of Device	139
Turbine and Generator	201
Mooring Equipment	90
Design and Engineering	4
Installation and Construction	18
Total	452

Table 3 Operating Costs (35-Year Service Life) (unit ; million yen)

RUNNING COST	
Personal Cost	70.0
Maintenance	146.3
Fixed Asset Tax	79.1
Other	31.6
REPAYMENT COSTS	709.0
TOTAL	1,036.0

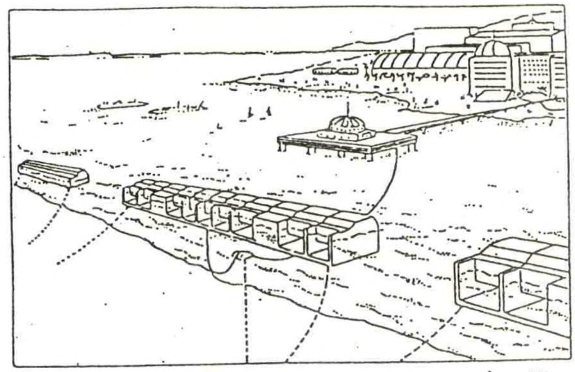

Fig.11 A Conseption of the Installation of the Floating Terminator Type Wave Power Device

CONCLUSION

Following conclusions were obtained by this study.

(1)The floating terminator type wave power device has good directivity and high efficiency for the behavior of wave energy absorption compared with the attenuator type device.

(2)The effect by 3 dimensional condition in open sea is not so evident because of the directivity of the device with harbour and projecting walls.

(3)When the device does not show its best performance in head sea ($\theta = 0°$), it will be improved by the change of its direction because of its behavior in the oblique waves.

(4)This type device shows good wave energy absorption but performance of dissipation of waves is not so good. The mooring force acting on the mooring lines is not so large, and it is enough for practical use.

(5)The cost of electrical generation by this type device becomes about 35.7 yen/kWh, that is about 0.28 US dollar/kWh. So, we propose the device as a useful generation system for the isolated islands.

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STATUS ON OTEC TECHNOLOGY RESEARCH AND DEVELOPMENT IN JAPAN

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1. INTRODUCTION

Recently it has been recognized that ocean thermal energy is very attractive because of the vast amount of resources,the stable energy source and the minimal ecological impact from the view points of global environmental problems which are of green house effect, acid rain,and so on, and of the inevitable finiteness of fossil fuel resources.

Since 1974 Japan has been one of countries with government-sponsored OTEC research and development programs.Additionally,the private sector also made an effort to progress OTEC technology through the preliminary design work on several land-based closed cycle prototype plants, one-year demonstration test of a 100kW closed cycle OTEC pilot plant in Nauru in 1982, two-year demonstration test of a 50kW closed cycle OTEC system in Tokunoshima in 1984 and so on. Moreover, academic sector supported the progress of OTEC technology from the basic research such as an enhancement of heat transfer and analysis of ocean structures.

In Japan the drop of oil prices of 1985 and the variation of exchange rate resulted in a lowering of political pressure to develop alternative energy sources such as solar energy,geothermal energy and so on. OTEC research and development became thin. However,some OTEC R&D programs were not interrupted ,and on the contrary new R&D activities have been started. Japanese efforts were almost oriented in the past toward developing a large scale closed cycle OTEC power plant. Recently the R & D trend has changed to consider the possibility of an open cycle and multi-purpose OTEC system including mariculture.

In this paper,three OTEC R&D activities which are presently active in Japan are overviewed.They are in Sunshine Project ,Agency of Industrial Science & Technology,MITI, in Special Coordination Funds of the Science & Technology Agency and in Ocean Thermal Energy Conversion Association of Japan established by the group of private sector.

2. RESEARCH AND DEVELOPMENT ACTIVITIES

2.1 Basic Research in the Sunshine Project [1)]

Basic research on OTEC technology has been carried out in the Sunshine Project promoted by Agency of Industrial Science and Technology, Ministry of International Trade and Industry since 1974. Three national research institutes (Electrotechnical Laboratory, Government Industrial Research Institute:Chugoku and Government Industrial Research Institute:Shikoku) and one nonprofit organization (Engineering Advancement Association of Japan) have joined. The objectives of the OTEC research in the Sunshine project are to achieve the enhancement of system performance and to clarify various uncertainty or unknowns in OTEC technology including the evaluation of environmental impact in order to develop the 1000kW class OTEC pilot plant with high performance, high reliability and moderate cost in the future.

Power System

In order to develop the enhancement of system performance the basic study of a nonazeotropic mixture working fluid cycle and an open cycle has been carried out from the point of more efficient use of overall temperature difference.

Based on the experimental results of both natural convective and forced convective condensing heat transfer performance for single vertical tube and the theoretical model analysis for various types of heat exchangers as the parameter using various mixed ratios of a nonazeotropic working fluid, the design and construction of the 10 kWt class heat loop test facility has been completed in order to study the variation of the heat transfer performance along the length of heat exchanger and the system charateristics. The test condenser was the plate type, which has the fluted surface with titled drainge gutters. A smooth surface was also provided as the reference. In the water side there is no enhancement treatment. The material of the plate was aluminum alloy. The nominal heat transfer area is $0.47m^2$ (0.12mx0.98mx4 plates). The cross sectional area at the water side was $3.48x10^{-2}$ m^2. The overall water flow rate was 6.3 t/h at the mean flow velocity of 1.0 m/s. Two types of the evaporators were provided. One was pressure-distributed and spray-pool boiling type evaporator originated by ETL. Another was a plate type evaporator which was the same constitution as the condenser. In the plate type evaporator the forced convective type heat transmission would be expected. The working fluid could be selected R114, R112, and R21 adapting for the experimental purposes. The nominal working flow rate was 3.3 l/min. in R12, and 2.0 l/min. in R21 respectively.

An open cycle OTEC system, in which warm seawater is directly used as the working fluid, can produce both electricity and fresh water. Fresh water is very valuable for tropical islands. At present there are several unknowns to evaluate the detail performance of an open cycle system. Those are the characterisitics of a large size turbine driven with low pressure difference and low vapor density, and the behavior of noncondensable gas dissolved in warm seawater mainly. Hence, in OTEC the research on the behavior of noncondensable gas has been started experimentally and theoretically. A small scale heat loop experimental facility was designed and constructed as shown in Fig.1. The test facility was equipped with both a direct contact evaporator and a shell-and-tube type condenser. In order to clarify the optimum removal of noncondensable gas for an open cycle system the preliminary estimation was carried out. In the analysis the effect of the concentration of noncondensable gas on the condensing heat transfer performance and the condensing temperature was estimated based on the existing experimental data. And the exhaust pumping power was represented the function of removal rate. The net power output per unit warm flow rate was obtained as the function of removal rate to determine the maximum net power output condition.

Material research including biofouling countermeasure has been achieved to establish th e high reliability and to reduce cost. The fracture behavior in liquid ammonia is investigated to elucidate an effect of carbon dioxide on stress corrosion cracking susceptibility of aluminum alloy (A5052 and A7075). It was found that the maximum stresses for both specimens became equal to or slightly larger than those obtained in pure liquid ammonia, and that according to the surface observation after fracture these specimens had no pits, which were observed in the case of those in pure liquid ammonia and liquid ammonia contained small concentration of oxygen. This information suggests the , method to prevent from pitting corrosion.

For the prevention of micro biofouling by using the lytic activity of bacteriophage, an effect of bacteria other than host-bacteria on the lytic activity of the bacteriophage was investigated. According to the experiments bacteriophages didn't effect the number of bacteria in environment where the density of the host bacteria was low, and for the complete lysis of host bacteria higher density of bacteriophage had to be added than estimated in the initial research stage.

Ocean Structure

Behavior of the platform and the cold water pipe in wave and current are tested at tank by models of the platform and cold water pipe of 1,000kW plant.

The behavior has been also calculated by the simulation computing programs which are developed by ENAA. The calculating result shows good conformity with the experiments, thus the designing tool of the floating platform, cold water pipe and mooring system are prepared.

Two types of flexible joint for cold water pipe are designed and tested by models of 1 m diameter. Towing and installing the cold water pipe are tested at sea by connecting 1 m diameter steel pipes to one of the said flexible joints.

A joint between the platform and the cold water pipe of the 10,000kW plant is designed. A 1/15 scale model of plastics is used for the confirmation of its function.

In order to develop the suitable deep sea mooring system for OTEC, the strength characteristics of compound mooring lines which consists of steel wire ropes and solid rubber as shown in Fig.2, is researched with numerical simulation and small scale tank tests.

Environmental Assessment

Dispersion mechanism of cold seawater discharged from an OTEC plant and current induced by intake of warm seawater for the plant are clarified through hydraulic tank experiments in density-stratified stream. It became clear that the spreading of the discharged water jet, which came into collision with the interface and mixed with ambient seawater, was classified into three types of flow pattern : these are (1)jet flow type, (2)weak top hat type and (3)top hat type. These flow patterns depend on the overall Richardson Number.

By the effect of the earth's rotation, a large quantity of discharged water forms a water plume with time. In order to clarify the formation of water plume, a rotating experimental basin was contructed and the preliminary experiments were achieved in uniform ambient water.

2.2 Research on Mariculture-OTEC System [2,3]

Since 1986 a five-year research and development program has been carried out under the auspices of Science and Technology Agency.

An ocean-based mariculture-OTEC project, which is included in that program, has been achieved by Japan Sea Regional Fisheries Research Laboratory, Electrotechnical Labolatory and so on.

The objectives of this five-year project (FY 1986- FY 1990) are to evaluate the effect of artificial upwelling of nutrient-rich deep seawater on the enhancement of marine bio productivity for an ocean-based system and to verify the co-existence of between mariculture system and OTEC system to supply energy to mariculture system self-sustainingly. The ocean-based mariculture -OTEC pilot plant named "HOUYOU", which means "Fertile Sea", was completed the fabrication and deployment off Himi, Toyama Bay, the Sea of Japan on July 11, 1989. The site is lacated at 36°57′ in north latitude and 137°06′ in east longitude, approximately 5km off Himi, where is the highest latitude of OTEC experiments which have ever been carried out. The experiment will be carried out from July 17 until September 5 1989 for this time.

The ocean-based mariculture-OTEC pilot plant consists of a barge (25mLx11mWx2.5mHx1.3mDraft, 343 ton), a 250m-long steel cold water pipe of 0.45m in diameter, water-spreading system driven with diesel engine and a small scale OTEC experimental facility, as shown in Fig.3.

The water-spreading system intakes cold depp seawater of about 3 °C in temperature and 0.3 m^3 /s in flow rate and warm surface seawater of about 22- 25°C and 0.6m^3/s. It spreads the mixed seawater on the surface layer through the spray header. The piping & instruments diagram of the ocean-based mariculture-OTEC experimental facility is shown in Fig.4.

The OTEC experimental facility represents a scale-down version of a commercial OTEC plant for a self-sustaining ocean-based mariculture-OTEC system. The power output of this facility is about 3.5kWe in electricity in the design that the cold and warm water flow rate are 0.03m^3/s and the temperature difference between inlet warm water and inlet cold water is 20 ° C. The piping & instruments diagram of OTEC experimental facility is shown in Fig.5 and the specifications of major components are shown in Table 1.

For past three years(1986-1988), the characteristics of seawater in Toyama Bay and in the Sea of Japan from the physical, chemical and biological points were investigated by Japan Sea Regional Fisheries Research Laboratory, Toyama Prefectural Fisheries Experimental Station, Maizuru Meteorological Station and Hokkaidou University. The depth and regional profile of temperature, salinity, current, dissolved nutrients, dissolved oxygen and so on, seasonal variations of them and potential resource of deep seawater were investigated. The small scale simulated mariculture experiments using sample of deep seawater taken from 300m deep were carried out to detect the growth characteristics of phytoplankton by JAMSTEC. The development of the heat transfer performance was achieved in OTEC side by ETL. The biofouling characteristics were measured using coastal seawater at Toyama Bay by ETL. Moreover, the behavior of discharged plume was analysed with the numerical simulation by ETL.

2.3 Feasibility Study of OTEC System by Private Sector

Ocean Thermal Energy Conversion Association in Japan (OTECA) was established in February, 1988, which is constituted with 25 private companies and one national laboratory (ETL). Its aims are to coordinate OTEC activities, mainly by promoting R & D and plant construction, and furthering international cooperation in related engineering area.

In order to achieve the objectives the one-year feasibility studies are completed now. Main results are summarized hereafter : site selection, power plant design, seawater intake system, and multi-purpose utilization of cold deep seawater.

Sites selection

26 sites in 24 countries in the Pacific area were selected in consideration of the seawater temperature at surface layer and 500m-deep layer, oceanographical and meteological factors, geological factors, population, land area, GNP and diplomatic relations. Moreover, 5 sites in 26 sites as more appropiate sites were selected to satisfy the following additional conditions:

(1) The minimum temperature difference in a year should be more than 20°C.

(2) The horizontal length of cold water intake in 600 m deep should be less than 2 km.

They are ① Male, Moldive , ② Ciemas and Bali, Indonesia, ③ Aiwo, Nauru, ④ Tarawa, Kilibati and ⑤ Funafuti, Tuvalu.

Power plant design

Studies were conducted on both open and closed cycles. In the latter two cases of ammonia and R-22 as the working fluid were evaluated. The rated gross power output is 1000 kWe based on the temperature difference of 20°C. The surface temperature is 28 °C, the deep seawater temperature is 8°C at the inlet of condenser. The efficiencies of closed cycle turbine and open cycle turbine are assumed 82 % and 75 % respectively. The seawater pump efficiency is 74 %, and the working fluid pump efficiency is 65 %. The results of the system calculations are shown in Table 2. The most efficient system was concluded a closed cycle OTEC system using ammonia as the working fluid. In an open cycle the estimation of the parasitic power contains some uncertainty because of scarcity of technical experiences.

Seawater Intake System

Seawater intake system for a land-based OTEC total system which produced 1000 kW gross power output and utilizes cold seawater as the mariculture, fresh water production and air conditioning system was studied. From the view point of reliability two-line CWP system was adopted. The comparison study of pipeline system was carried out as shown in Table 3. At present from the view points of applicability and reliability the bottom-laid system at shallow zone, in which concrete-covered steel pipe was laid on the sea bottom, and the multi-points mooring system, in which high density polyethylene pipe was moored by chain and wire mooring lines placed at a distance, were recommended.

Multi-purpose utilization system

The deep seawater is cold, nutrient-rich and clean. These characteristics are very useful to apply to the aquaculture, agriculture, desalination and air conditioning system. Using 250 kW electricity, 11,000 m^3/h surface seawater of 24.0 °C at the outlet of the evaporator, and 9000 m^3/h deep seawater of 12.8 °C at the outlet of the condenser, a multi-purpose utilization system was designed. The species for aquaculture were selected in consideration of the effect to the native-born fishery. The resultant production plan is shown in Table 4. The coldness of deep seawater can be used the air conditioning of 2700 m^2 in floor area of the building by means of 52 m^3/H in cold water flow rate and 76 kW in electricity for fans and pumps.

3. CONCLUDING REMARKS

In Japan both government and private sector are interested in OTEC technology as one of alternative, clean energy resources from the global points of view. The national research institutes such as Electrotechnical Laboratory, Government Industrial Research Institutes, Chugoku and Shikoku, and Japan Sea Regional Fisheries Research Laboratory have achieved basic research on power system, ocean structure, environmental assessment and mariculture. The private sector, which has concentrated to OTECA, has investigated the feasibility of state-of-the-art small scale(1000 kW class) OTEC system to apply to the total system at tropical zone, where is the best site for OTEC system.

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Table 1 Specifications of OTEC Experimental Facility

Evaporator	Shell :520 x4,350 l Tube :Small piramid fins & porous coating fluted tube,21.5 OD(16.0ID)x 3,500 l 150 tubes Aluminum alloy
Condenser	Shell :500 x4860 l Tube :Spiral drainage fluted tubes with drainage gutters ,21.5 OD(16.0ID) x 4000 l 140 tubes Aluminum alloy
Turbine	Single stage axial flow Rated speed 1,500 rpm PCD 400mm Sectional area pf nozzle $2.03\times10^{-3}m^2$(12ϕx18holes)
Generator	Synchronous generator,separately exited type three-phase alternating current 200 V ,50Hz
Load	Resistance 20-60Ω 5Ω intervals Three-phase balance adjustment , 5Ω each phase
Working Fluid	R114 ($CClF_2$-$CClF_2$)
Pumps	Volute type
Cleaning System	Sponge ball cleaning method for only evaporator Natural sponge rubber $18mm\phi$

Table 2 Preliminary design evaluation of three options for 1000 kWe OTEC system

case	A	B	C
cycle	NH_3-Closed Cycle	R22-Closed Cycle	Open Cycle
Evaporating Temp.(°C)	22.8	22.8	22
Condensing Temp.(°C)	14.2	14.2	14
Warm Water Flow Rate (m^3/h)	10,750	10,750	12,400
Cold Water Flow Rate (m^3/h)	8,760	8,760	9,900
CWP Dia.(m)	1.4	1.4	1.5
No. of CWP	2	2	2
Turbine Type	Radial/Geared	Radial/Directly Connected	Axial/Directly Connected
Rotar Size (m)	0.6	1.0	3.0
Heat Exchanger Type	Shell/Plate	Shell/Plate	Shell-Plate
Heat Transfer area (m^2)			
Evaporator	6,250	6,970	-
Condenser	6,150	11,700	7,500
Pump (kW)			
Cold Seawater	225	209	235
Warm Seawater	207	199	230
Working fluid	38	119	12
Vacuum Compressor	-	-	156
Net Power Output(kW)	530	473	307

Table 3 Evasluation of various types of CWP for land based 1000 kWe class OTEC system

Sections	Cold Water Deployment System	Pipe Materials			
		Steel pipe with concrete	High-density poly-ethylene pipe	FRP pipe	Rubber Pipe
Gently-sloped Section (0-150m)	Bottom-Laid System	◉	◉	▲	▲
Steeply-sloped Section (150-500m)	Inverted Catenary System		◉	□	□
	Multi-points Mooring System		◉	□	□
	Supported System	▲	▲	▲	▲

◉ :Very good □ :Good ▲ :Not good

Table 4 Concept and production estimation of mariculture using half amount of deep seawater intaken for 1000 kWe OTEC system

DEPART-MENT	SPECIES	AREA	ANNUAL PRODUCTION AMOUNT
COMMERCIAL FARMING	JUMBO TIGER PRAWN	30.0 ha	63 t
	MILK FISH		96 t
JUVENILE CULTURE	MILK FISH	8.0 ha	$1.4x10^{6}$
	SEA BASS	7.2 ha	32.4 t
PILOT CULTURE	BROWN-SPITTED GROUPER	0.4 ha	1.8 t
	PEARL-SPITTED RABBIT FISH	0.4 ha	1.8 t
	FLAT FISH	0.9 ha	50.0 t
LARVAL REARING	JUMBO TIGER PRAWN	-	$12x10^{6}$
	SEA BASS	-	$10x10^{6}$

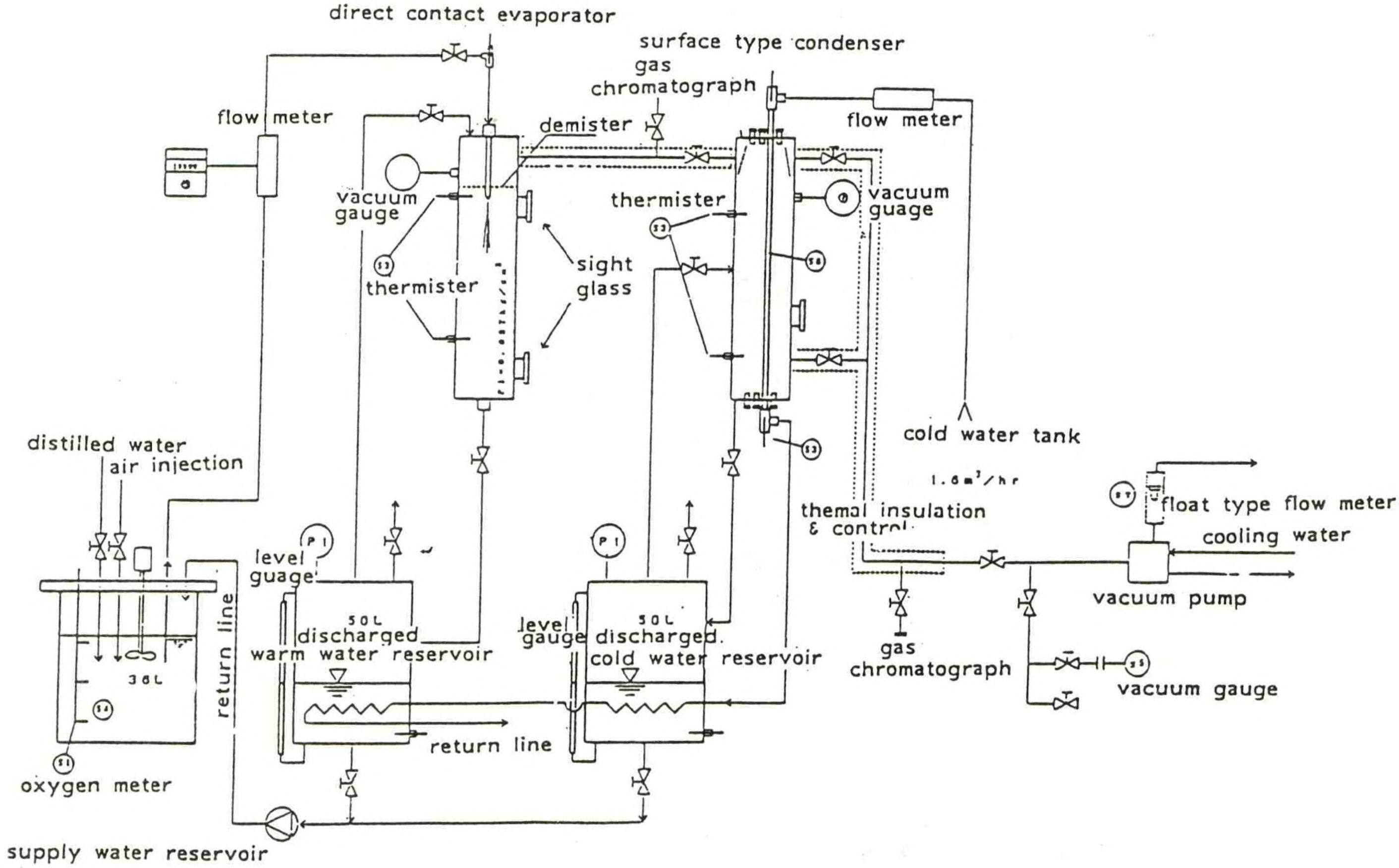

Fig.1 Piping & Instruments diagram of open cycle OTEC heat loop to investigate the behavior of dissolved gases in warm seawater

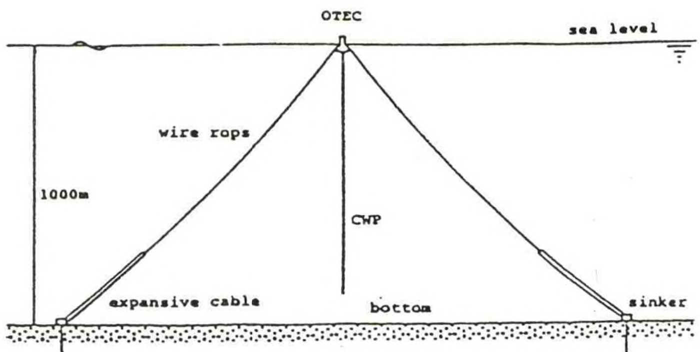

Fig.2 Concept of combination of compound mooring cables

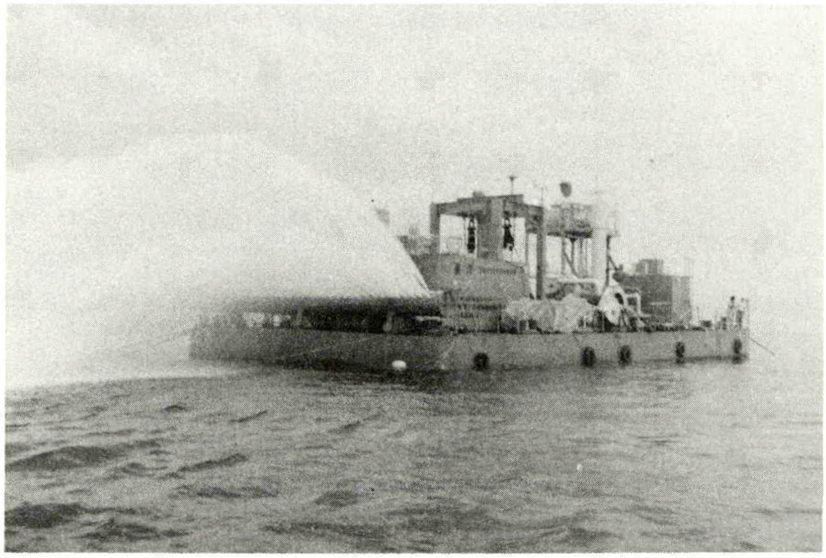

Fig.3 Ocean based mariculture-OTEC pilot plant "HOUYOU" in operation off HIMI, Toyama Bay

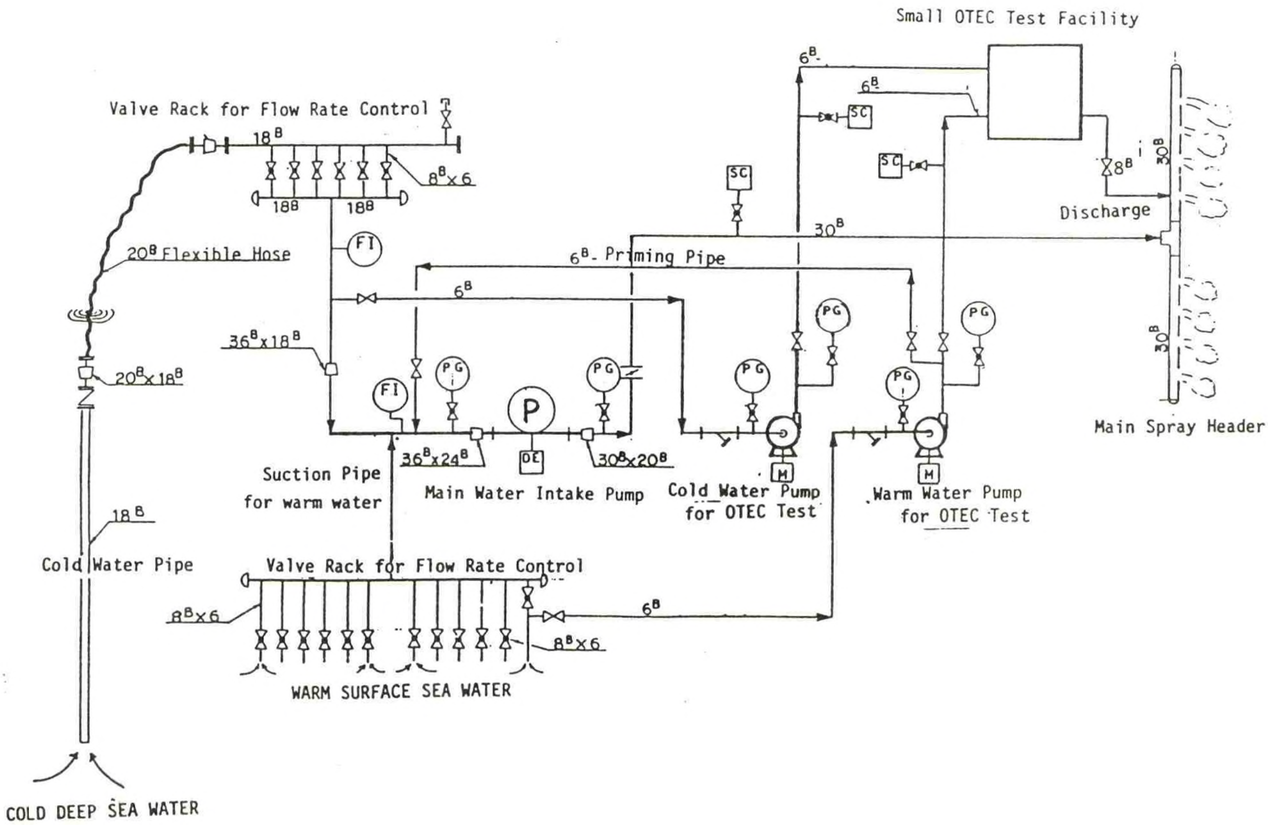

Fig.4 Piping & Instruments diagram of ocean based mariculture-OTEC pilot plant "HOUYOU"

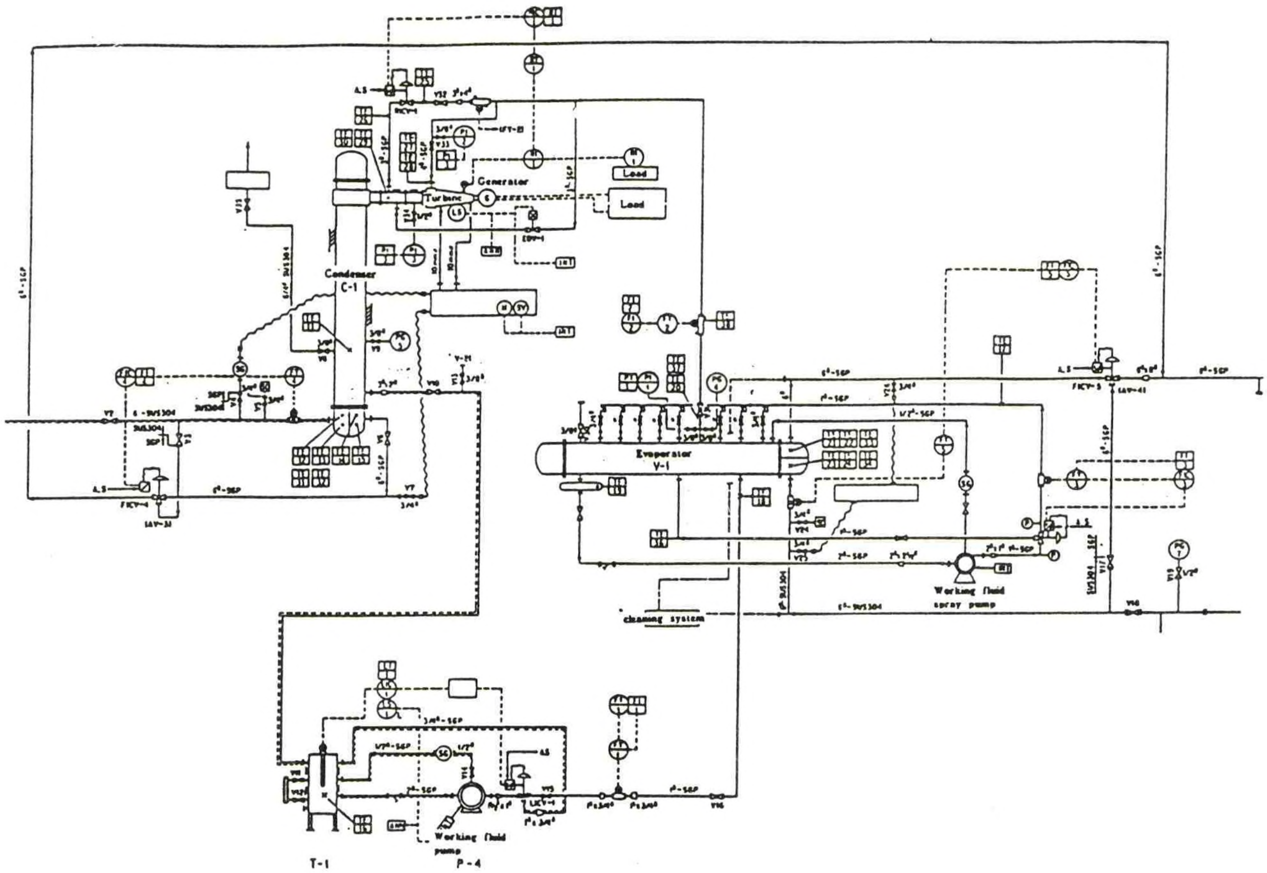

Fig.5 P&I diagram of OTEC experimental facilty on HOUYOU

OFFSHORE STRUCTURES FOR DEEP OCEAN AND ARCTIC OIL AND GAS OPERATIONS

by

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ABSTRACT

The United States is placing an increasing reliance on offshore oil and gas operations to supply the growing need for energy. This paper reviews some of the major developments in both the deep ocean and Arctic and the technological evolutions to safely and efficiently develop resources in these severe environments. Experience derived from numerous installations in shallower water and recent activities in Arctic waters of Alaska and Canada coupled with extensive research provide a solid basis for future operations in these frontier areas.

INTRODUCTION

The adequacy of technology for use in areas that have yet to yield a potential resource (but may in the future) is an elusive concept. It is difficult to demonstrate adequacy before there is a specific need for the technology or before there is significant experience with the technology to develop a useful data base. The petroleum industry has shown in the past, as the search for oil and gas moved further offshore and into the hostile regions of the Arctic, that it has the ability to conduct operations in a safe and reliable manner. Economics, not limitations on technology, has usually determined when a field could be produced. However, the development of petroleum basins in the deep ocean and Arctic will involve new concepts and technologies that will be used for the first time. Various aspects of these new technologies remain to be proven and considerable research and development funds are being expanded to develop safe and reliable structural concepts.

The development of future structural concepts will depend a great deal on the consistent progressive application of today's technology as well as on the assessment of rewards and benefits to be achieved by advancing the state-of-practice. However, technology is not only the acquisition and possession of scientific-engineering knowledge but also the application of that knowledge. To demonstrate the current state-of-practice for frontier oil and gas operations several recent deepwater and Arctic projects will be reviewed, along with plans for future expansions and the technological concerns relating to those developments.

DEEPWATER OPERATIONS

Innovative and cost effective production techniques are the major factors that have encouraged deepwater drilling activity. Examples of these innovative concepts include Shell's single piece steel jacket platform in 1,350 feet of water, Conoco's tension leg well platform, which is currently being installed in 1,760 feet of water, and Placid's conversion of the Penrod 72 to a floating production system to develop a field in 1,500 feet of water. Each of these projects will be reviewed to illustrate the innovations that led to their installation.

On May 31, 1988, Shell Offshore Inc. launched the Bullwinkle platform, the tallest manmade offshore structure in the world, 150 miles southwest of New Orleans. The platform, with the deck and drilling rigs installed, stands 1,615 feet above the seafloor. Figure 1 provides the height and weight of the platform components and the wind, wave, and current criteria assumed in the design of the structure. Figure 2 illustrates the relative height of the platform as compared with several well known land based structures.

The platform took 3 years to construct, and the total structural weight is over 77,000 tons, consisting of the jacket at 49,375 tons, the piles at 10,500 tons, the conductors at 12,760 tons and the deck modules at 2,300 tons. It is designed to resist hurricane forces that include a 140-MPH wind and a 72-foot wave. During this maximum hurricane, the top will sway about 6 feet.

The Bullwinkle base, 408 feet by 487 feet, covers about 4.5 acres. It tapers up to a 162 x 140 foot jacket top on which rests a 205 x 185 foot deck structure having a 60-well capacity. Typical braces are 30 to 40 inches in diameter, while the 12 legs vary from 120 inches at the bottom to 54 inches in diameter at the top of the jacket. The 28 skirt-pile sleeves (seven at each corner of the platform) are about 90 inches in diameter. These sleeves connect the structures via grout to 84-inch diameter piles that are 460 to 540 feet long and weigh about 400 tons each.[1]

At a total cost of only $500 million, excluding lease bonus costs of $34.5 million, Bullwinkle is scheduled to reach full production in 1992 to produce 50,000 bbl of oil a day plus 90 million cubic feet of natural gas. Of the total cost, approximately 50 percent was spent to build and install the platform and to equip it in preparation for development drilling. The other 50 percent of the cost will be spent for development drilling, permanent production facilities, and a pipeline system. McDermott

International installed a 7.5-mile oil pipeline in a water depth of up to 1,350 feet to connect the Bullwinkle production platform to Shell's existing Boxer platform. This pipeline is one of the deepest in the Gulf of Mexico.

The design, construction, and installation employed many innovative concepts. Fabrication of the jacket involved the use of both conventional and novel assembly and erection techniques. The jacket was launched as a single element from a barge at the installation site and upended to a vertical floating position by controlled flooding of members near the lower end of the jacket. The piles were installed in one piece, eliminating the need for offshore welding and were driven with an underwater hammer through open pile guides. In recognition of its size and many advances in offshore technology, the Bullwinkle platform received The Outstanding Civil Engineering Achievement Award of 1989 from The American Society of Civil Engineers.(1)

The first Floating Production System (FPS) in the Gulf of Mexico was installed on Placid's Green Canyon Block 29. Placid's FPS uses the converted drilling rig Penrod 72 as shown in Figure 3. The systems consist of a subsea template, subsea trees, production riser, the floating drilling/ production facility that includes permanent moorings, and the deepest pipelines in the Gulf of Mexico. The floating facility, located in 1,520 feet of water, will not only accommodate the processing function of production, but also the drilling, completion, and servicing of all the template wells. In addition, it will support the production riser and controls for all the subsea units and will perform all the necessary marine, service, and safety functions. It is designed to be permanently moored without disconnect for 15 years and will process 40,000 bbl of oil and 120 million cubic feet of dehydrated gas per day.(2)

The subsea template is actually a multipurpose structure. Its main function is the foundation for the development wells, but it also serves as the anchor point for the production riser, a pipeline manifold for future oil and gas pipeline connections, a connection point for satellite wells, and a landing base for the subsea controls. The template is 87 feet wide, 165 feet long and weighs 1,280 tons. It was set in February 1987 and is secured to the seafloor using eight piles, which were driven by an underwater hammer.(3)

The most innovative parts of the concept are the self-supporting rigid riser, the deepwater satellite well completions, and the deepwater pipeline installation technique. Much of the equipment used is similar to that of other developments; however, the overall scope and water depth exceed anything done to date.

The rigid riser extends from the template at the seafloor to 150 feet below the water line as shown in Figure 4. It is designed for a 20-year life that includes remaining in service during a Gulf of Mexico 100-year storm. From top to bottom, the riser is composed of an upper riser connector package, twenty-five 50-foot and one 34-foot riser sections, and a titanium joint/bottom connection assembly at the template. At the top, flexible flow-line jumpers connect the upper riser connector package with the permanently moored semisubmersible. Six tensioners on the rig apply load to the riser's top to keep it in position and reduce the possibility of damage to the flexible flow lines.[4]

Both fixed and variable buoyancy make the riser self-supporting. The fixed or syntatic foam modules give each riser segment slightly negative buoyancy in water and allow for a simplified installation procedure. The upper flotation tanks provide additional buoyancy at the top and help achieve the required design life by keeping the stresses at acceptable levels for fatigue. After the riser was installed, the individual production and annulus lines were installed through fiber glass guide tubes within the foam modules.[4]

On May 5, 1989, Placid Oil Company brought on stream its Green Canyon 31-6 satellite well in 2,243 feet of water, tying the world water depth production record set last year by the companion Green Canyon 31-4 satellite well.[5] The previous world record was 1,613 feet offshore Brazil. The basic operating system used for the template wells are used for the satellite wells. A flowline bundle containing the production, annulus, and control lines connects the satellite trees to the template. Because the satellite wells are offset from 1 to 8 miles from the template, they were provided with additional hydraulic controls as well as a flushing system to clean their control lines.

The pipeline fabrication and installation included the placement of two bundled export lines of 14 and 16 inches in diameter, 8.45 miles long and three bundled flowlines, 1 to 7 miles in length. The project provided many technical breakthroughs that dramatically reduced the costs associated with deepwater pipeline installation.

The pipe sections were assembled on the Matagoroa Peninsula, 80 miles southwest of Houston, in single lengths. They were launched laterally through the surf zone and towed some 450 nautical miles on the Gulf's bottom, through water as deep as 2,500 feet, to the Placid site, approximately 100 miles southwest of New Orleans. The pipe ends, with connection tow sleds, were placed in precise target areas and the last 2,000 feet of each section was floated off the seabed, deflected, and connected "diverless" to the well heads and template.[6]

Conoco's Tension Leg Well Platform (TLWP), as shown in Figure 5, is a lightweight version of the tension leg platform producing for the company in the North Sea's Hutton Field. It will have a displacement of 18,000 tons (compared with the 65,000-ton displacement at Hutton), no drilling rig, and limited processing capabilities. The TLWP will be equipped with a workover rig, but most processing equipment will be located on a fixed, steel jacket platform in shallow waters in Green Canyon Block 52. The TLWP will be installed in 1,760 feet of water in the southeast corner of Green Canyon Block 184.[7] An artist's concept of the Conoco installation is shown in Figure 6.

The Jolliet development, named after the French explorer Louis Jolliet, will cost $400 million. This amount will be split--30 percent for drilling and completing wells, 20 percent for pipelines, and 50 percent for building and installing the TLWP and the fixed production platform. The initial capacity of the production platform will be about 35,000 bbl of oil and 50 million cubic feet of gas per day. However, the unit, intended to serve other facilities in the area, will be designed with sufficient deck load capacity to process 100,000 bbl of oil per day.[8]

The mooring system for the TLWP will consist of twelve 24 inch diameter tendons, three at each corner, connecting the four hull columns to the template on the seafloor. The 24 risers will consist of a 9 5/8-inch casing string, tensioned at the TLWP deck level and will extend from the template to christmas trees located on the TLWP.

Five major pipelines are part of the project. Separate pipelines for oil, gas, and water injection will connect the TLWP with the fixed production platform that is located in 600 feet of water, 10 miles north of the Jolliet field. Production will move through a 30-mile oil pipeline and a 17-mile gas pipeline from the production platform to existing offshore gathering lines.[8]

Two other platform types have received considerable attention for deepwater operations; the compliant tower and an extension of the floating production systems, the Ocean El Dorado. Those innovative concepts are helping to achieve the goal of maximizing the cost-effectiveness of deepwater developments. Today's offshore projects are driven by economics. Less expensive, reliable ways to develop and produce oil and gas in deepwater are more than a challenge; they are a necessity.

Whereas the Placid FPS used a converted semisubmersible drilling unit as the production platform, Ocean Drilling and Exploration Company (ODECO) engineers have designed a purpose built semisubmersible platform which is touted to be a considerable improvement over converted drilling units. Shown in Figure 7 the "Ocean El Dorado" is a symmetrically shaped, six column semisubmersible designed to economically operate in water depths ranging from 1,000 to 8,000 feet. The unit operates at a deep draft of 180 feet and has a displacement of 112,558 tons and a top deck elevation which is 262 feet above the bottom of the pontoons. The deck shape is a 12 sided polygon measuring approximately 340 feet across the flats. Depending on site specific design considerations, the mooring system will consist of 24 to 36 chain/wire mooring lines and will use anchors varying from 65 to 35 tons. With an air gap of 60 feet, the Ocean El Dorado is designed to safely withstand the passage of a 90-foot high wave in conjunction with a 162-knot wind and a 2-knot current. Further, given that the unit has been designed specifically for the purpose of oil and gas production, its deck load capacity, floating stability, and motion characteristics are claimed to be far superior to those of semisubmersible drilling units. Having been provided with full drilling capability, simultaneous drilling and production operations are possible on the Ocean El Dorado.

Typically, drilling would be done using a conventional subsea stack lowered through the moonpool. The vessel would first position itself vertically over the well location using the mooring system and set a permanent guidebase on the seabed. It would then drill the well using a subsea stack and a drilling riser. After the 7-inch production casing is set, the stack and drilling riser would be removed and the well tied back to the vessel's tensioning system using a 9 5/8-inch riser enclosing the 7-

inch protective casing. Approximately 30 wells could be individually drilled and tied back in this manner, thus eliminating the need for a massive seabed template. All completion and workover operations would be at deck level using conventional surface controls.

Compliant towers are an extension of conventional fixed platform technology and provide a strong option for transition depths between fixed platforms and floating systems for very deep water. It is similar to the guyed tower, but has no guylines. The loads are resisted and compliance is provided by attaching extensions of the foundation piles to a point about midway up the structure as shown in Figure 8. Major cost advantages for the compliant structure relate to its lateral support system. The primary applications for the Gulf of Mexico are in 1,000-3,000 foot water depths, for a moderate to large number of wells and for moderate to large deck pay loads. Due to the low production rates of most single wells in the Gulf of Mexico and many producing wells and injection points are needed to produce an average field.[9,10]

Just as earlier offshore economics drove industry to fixed, self-contained platforms, the economics of deep water operations have driven the industry to consider a broad class of new concepts. For marginal fields, the use of satellite wells with subsea completions may prove to be the most technically and economically feasible. The production could then be located on a shallow-water platform or even a floating facility. Today's subsea technology provides a capability far beyond what has been done. The concept of single satellite wells has given way to clusters, multiwell templates, subsea manifolding, and even subsea multiphase pumping to reduce the incremental cost of subsea completions.[11]

ARCTIC OPERATIONS

Potentially great sources of oil and natural gas are contained within the Arctic offshore regions of North America. To tap these reserves will require the design, construction, installation, and maintenance of structures that can withstand the harsh conditions imposed by the Arctic environment. A wide variety of structures has been installed or proposed for exploration or production activities off the coasts of Alaska and Arctic Canada as shown in Figure 9. Although exploration wells have been drilled from coastal barrier islands and from manmade structures in fairly shallow water, recent lease sales have added large regions in the Chukchi and the Beaufort Seas that have both deep water and heavy ice. In such locations, the engineer is confronted with classes of events, ice features, and other environmental conditions that he has not had experience with previously.

The unique Alaskan Arctic offshore environment poses significant technological and economic barriers to developing their oil and gas resources. The combination of severe weather, destructive forces from moving ice and large waves, and unstable terrain contribute to the high risks and high costs for future developments. Such uncertainties, the expected high costs, low oil prices, and the fact that no large commercial fields have been discovered offshore have limited current industry participation in the Arctic. Given current technology, offshore fields smaller than 500 million barrels may not be developed unless advances are made to decrease the risks and costs of Arctic production and transportation.[(12)]

Offshore drilling activity in the Alaska Beaufort Sea has proceeded at a very cautious pace for the past several years. The wells that have been spudded have been drilled from a variety of exploration platforms as shown in Figure 10. A list of the artificial islands used for exploration in Federal waters is provided in Figure 11. The specific location of some of the most recent drill sites is given in Figure 12.

The Minerals Management Service (MMS) held two OCS lease sales in 1988. The fourth Federal sale in the Beaufort Sea, Lease Sale 97, was held in March 1988 and offered leases covering the entire Beaufort Shelf from the U.S./Canadian border to the Chukchi Sea, just west of Barrow. A total of 202 tracts were leased by industry, generating $118 million in revenues for the U.S. Federal Government. Sale 97 leases are, for the most part, further offshore, characterized by deeper water (up to 330 feet) and more severe ice conditions.

The second sale, Chukchi Sea Lease Sale 109, was held in May 1988. This was the first lease sale within the Chukchi Sea planning area and included lands of the northwest coast of Alaska west of the Beaufort Sea area to the U.S.-USSR boundary. Industry leased 339 tracts generating more than $475 million in revenues. Shell Western Exploration and Production, Inc. (Shell) was the most active bidder, acquiring 164 leases and spending almost $370 million. The Chukchi Sea is characterized by severe environmental and logistical restraints: water depths ranging up to 250 feet, distances from industry infrastructure at Prudhoe Bay up to 400 miles (up to 250 miles from Barrow), and moving pack-ice conditions.[(13)]

The current Department of the Interior 5-year OCS leasing program has two OCS Arctic sales scheduled for 1991: Sale 124, the fifth lease sale in the Beaufort Sea planning area, and Sale 126, the second Chukchi Sea sale. The leasing process for both sales has been initiated.[(13)] Figure 13 shows the designated lease sale areas offshore Alaska.

Drilling activities at three locations have occurred since November 1987. Tenneco completed operations at the Aurora Prospect on August 30, 1988, after drilling for 10 months. Drilling commenced on November 2, 1987. The well was drilled in 66 feet of water, approximately 3 miles offshore of the Arctic National Wildlife Refuge (ANWR) Coastal Plain, 22 miles east of Kaktovik, and approximately 130 miles east of Prudhoe Bay. Tenneco drilled the well using the Canmar SSDC/Mat as shown in Figure 14. No well results have been released to the public.[(13)]

In September 1988, Amoco spudded the first well in their Eastern Beaufort Sea Belcher Prospect, located 50 miles northeast of Kaktovik in 167 feet of water. The well was spudded on September 5, 1988, using the BeauDril Kulluk, shown in Figure 15, a conically shaped drillship. Operations were suspended on October 17, 1988. In order to drill the well, which is located in the Sale 87 area, Amoco requested, and received, an exception to the Seasonal Drilling Restriction (SDR), which prohibits downhole exploratory activities during fall bowhead whale migration, generally August 1 through October 31.[13]

Chevron U.S.A. spudded their first well into the Karluk Prospect in February 1989. The well is located in the Sale BF lease area, just east of the Endicott Field. Chevron constructed a spray-ice island in January 1989 in 22 feet of water. The spray-ice island is the second of its kind used for exploratory work in the U.S. Beaufort Sea (the first being Amoco's Mars OCS-Y 0302 Prospect). Although the Karluk No. 1 well has a surface location on a State lease, the MMS assumed joint jurisdiction with the State because of Chevron's intent to drill Karluk No. 1 as an undirected wellbore into Federal Lease OCS-Y 0194. Chevron commenced drilling at the Karluk location on February 19, 1989, and plugged the well on April 6, 1989. Future operations at the Karluk Prospect are uncertain.[13]

In September 1988, the MMS approved an Exploration Plan (EP) for Amoco's Eastern Beaufort Sea Sale 97 Galahad Prospect, located approximately 50 miles northwest of Kaktovik in 170 feet of water. The plan calls for drilling up to 14 wells using either the Kulluk or one of the Canmar Explorer drillships. Location for the first well is proposed to be on Lease OCS-Y 1092, the high bid lease for Sale 97 at $23.4 million.[13]

Development and production activities at the Endicott Field, a gravel island connected to the mainland by a gravel causeway as shown in Figure 16, have continued since 1987, including the completion of three producing nonconventional directional wells (80 to 90 departures from vertical). The nonconventional wells were drilled to alleviate gas-coning problems and increase well productivity. The Endicott Field located in Alaska State waters continues to be the only Beaufort Sea offshore producing field. Endicott was discovered in 1987 and began production in 1987 with 40,000 barrels of oil per day. Current field production is approximately 100,000 barrels of oil per day. Cumulative production to date has been approximately 50 million barrels of oil. According to the Alaska Department of Natural Resources, total anticipated recovery is 330 million barrels of the 1.5 billion barrels in place, making it one of the 10 largest producing oil fields in the U.S. and the largest U.S. offshore oil field.[13]

The MMS has recently approved two exploration plans for Shell for exploration drilling in the Chukchi Sea Sale 109 area. Shell submitted separate plans for their Near Offshore Prospects and their Remote Offshore Prospects separated because of significant environmental differences between the two areas and the close proximity of several prospects to the designated bowhead whale spring migration corridor. The Remote Offshore Prospects have been identified by Shell to have a higher priority for exploration. Shell has identified 11 Remote Offshore Prospects and five Near Offshore Prospects, using names like Klondike, Burger, Crackerjack, Praline, Baby Ruth, Nacho Supreme, Blizzard, Bearclaw, Bagel, Taco, Burrito, Eclair, Napoleon, Ceveza, Popcorn, and Kolache, to identify the prospects. Drilling of a 15,000-foot well began in July 1989 on the Klondike Prospect (part of the Remote Plan--see Figure 12), which is 200 miles from Pt. Barrow and in 140 feet of water. Shell is using the Canmar Explorer III drillship supported by two ice-class vessels and one icebreaker. A top drive system and Shell's communications equipment were installed in Victoria, B.C. during the winter for Shell's program. Shell has estimated seasonal costs to drill in the Chukchi Sea to be $60 to $70 million. Because of the remoteness of this area and logistics associated with their drilling program, Shell will be using a dedicated spill response/ storage barge.[13]

In Canada, industry has drilled a total of 239 exploratory and delineation wells and found 49 significant oil and gas discoveries. Figure 17 shows the significant discoveries and possible pipeline locations in the Canadian Mackenzie Delta-Beaufort Sea areas.

In the Canadian Beaufort Sea two major conditions influence the choice of structures for drilling: the water depth which ranges from 0 to 650 feet in the exploration area and surface ice, which can be either land-fast or moving. Table 1, taken from reference 14, lists the type of structures that have been used in the Canadian Arctic. These same structures are now being employed on the U.S. side of the Beaufort Sea.

Offshore exploration started in Canada from sacrificial sand and ice islands and then from a Canmar Drillship. Since those initial efforts, caisson retained islands and the conical drilling unit have been used more frequently. Given the excellent record of discoveries in the Canadian Arctic in water depths of 30-100 feet, it is likely that these two types of units will remain very active in the near future. For production, it is anticipated that typical gravity type structures being proposed for the Arctic will be used.[14]

CONCLUSION

The growing need for new energy sources has provided the necessary encouragement to explore the frontier regions of the deep ocean and the Arctic. The capability to drill exploratory wells in 7,500 feet of water in the Gulf of Mexico and in depths up to 200 feet in the Arctic has been proven. Production in these areas have been negated more by the lack of commercial, economical discoveries than by technology. The experience derived from the current exploration efforts, coupled with the extensive research being conducted by both Government and the industry, should provide a solid basis for safe and environmentally cognizant developments in the deep ocean and the Arctic.

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Table 1. Typical Arctic Facilities For Drilling

Drilling System	Characteristics	Water Depth	Capability in ice
Sprayed Ice Island	Thickened ice pad rests on seafloor. Winter season only.	0-7 m	In shore-fast ice. Can withstand limited ice movement.
Man-made Sand Island	Usually built in summer and drilled in winter. Protected with sand bags, plastic sheets or tubes, gravel.	0-15 m	In shore-fast ice. Can withstand limited ice movement.
Caisson-Retained Island (Molikpaq, SCRI, SSDC)	Sand-filled or concrete-reinforced caisson, set on sea floor berm. Placed in summer. Year round operations.	5-20 m (no berm) to 30+ m (with berm)	Designed to withstand moving ice in transition zone.
Conical Drilling Unit (Kulluk)	Circular unit designed to resist moving ice from any direction. 12 anchors. Summer season to mid-November with good ice management.	25-300 m	Designed to work in moving ice. Needs icebreaker support.
Drillship, Ice-Reinforced (Canmar Explorer)	Shipshape, rig mounted mid-ship. Anchored on location. Summer season, mid-July to November.	25-180 m	Can withstand small floes and thin ice only. Needs icebreaker support.

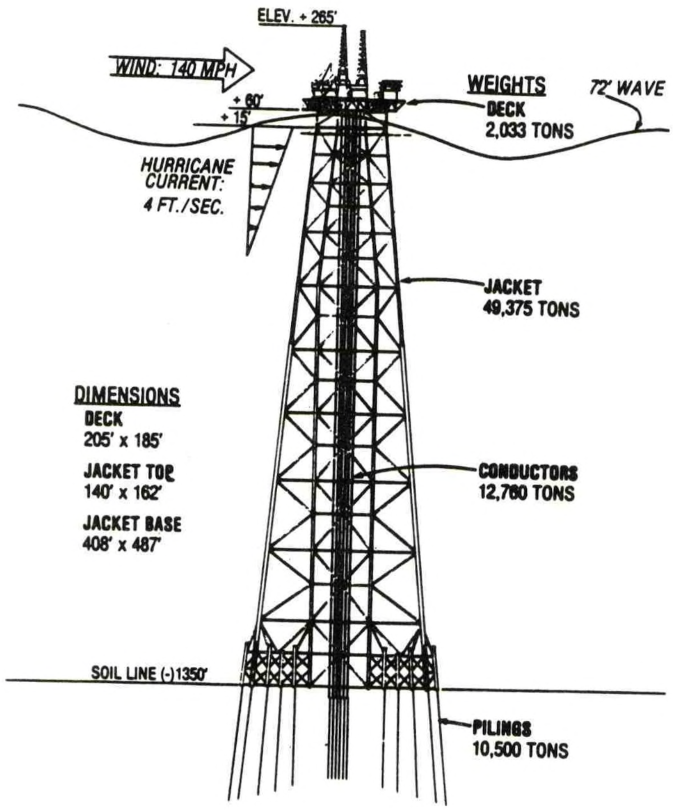

Figure 1. Component weights and environmental design criteria for Shell's Bullwinkle platform.

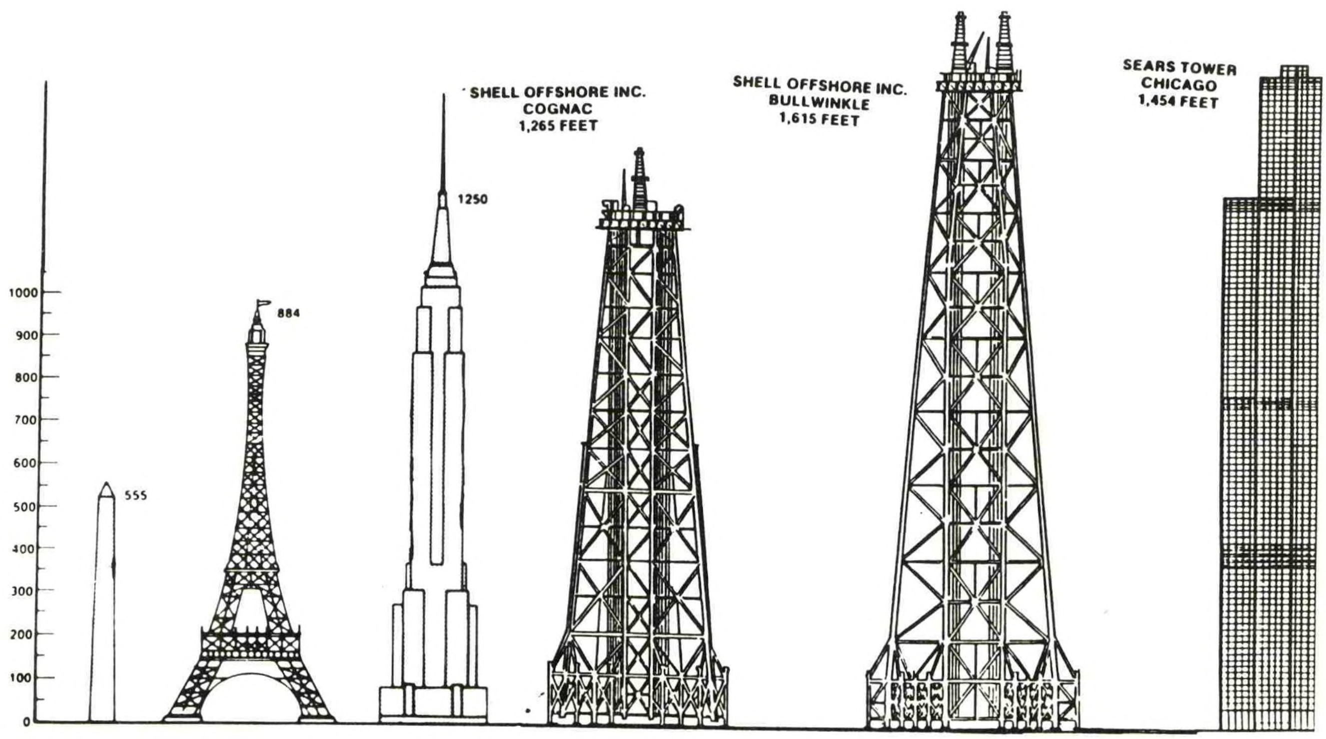

Figure 2. *Comparison between the height of Shell's Bullwinkle platform and other noteworthy structures.*

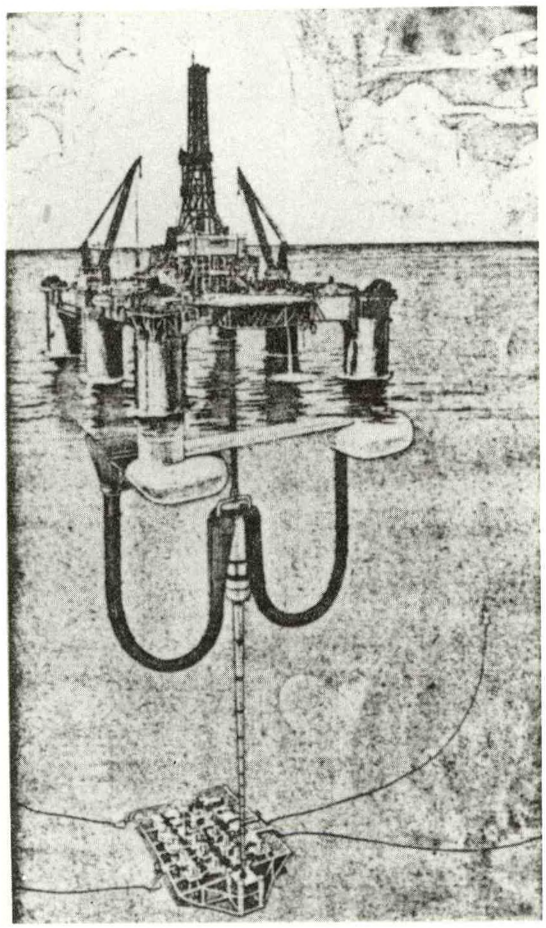

Figure 3. Placid's Penrod 72 floating production system.

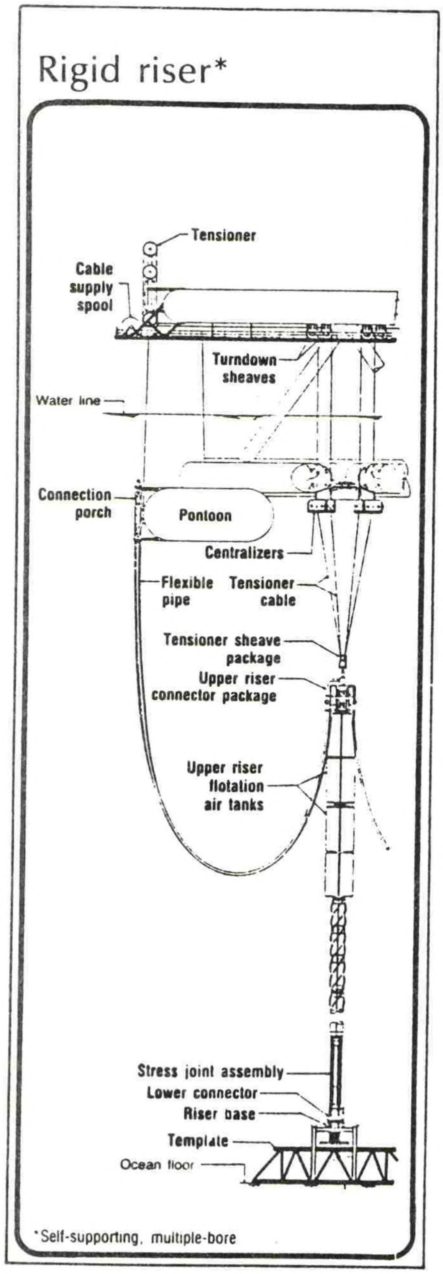

Figure 4. Riser assembly for Placid's floating production facility (taken from reference 4).

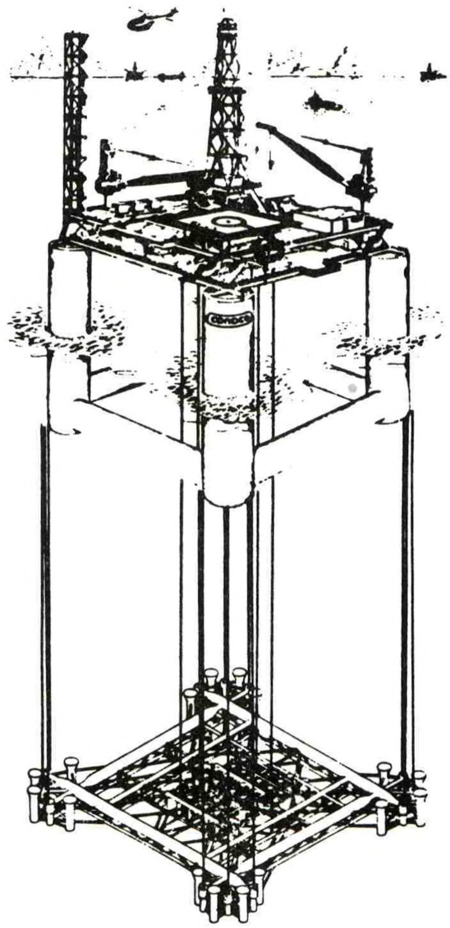

Figure 5. *Conoco's tension leg well platform.*

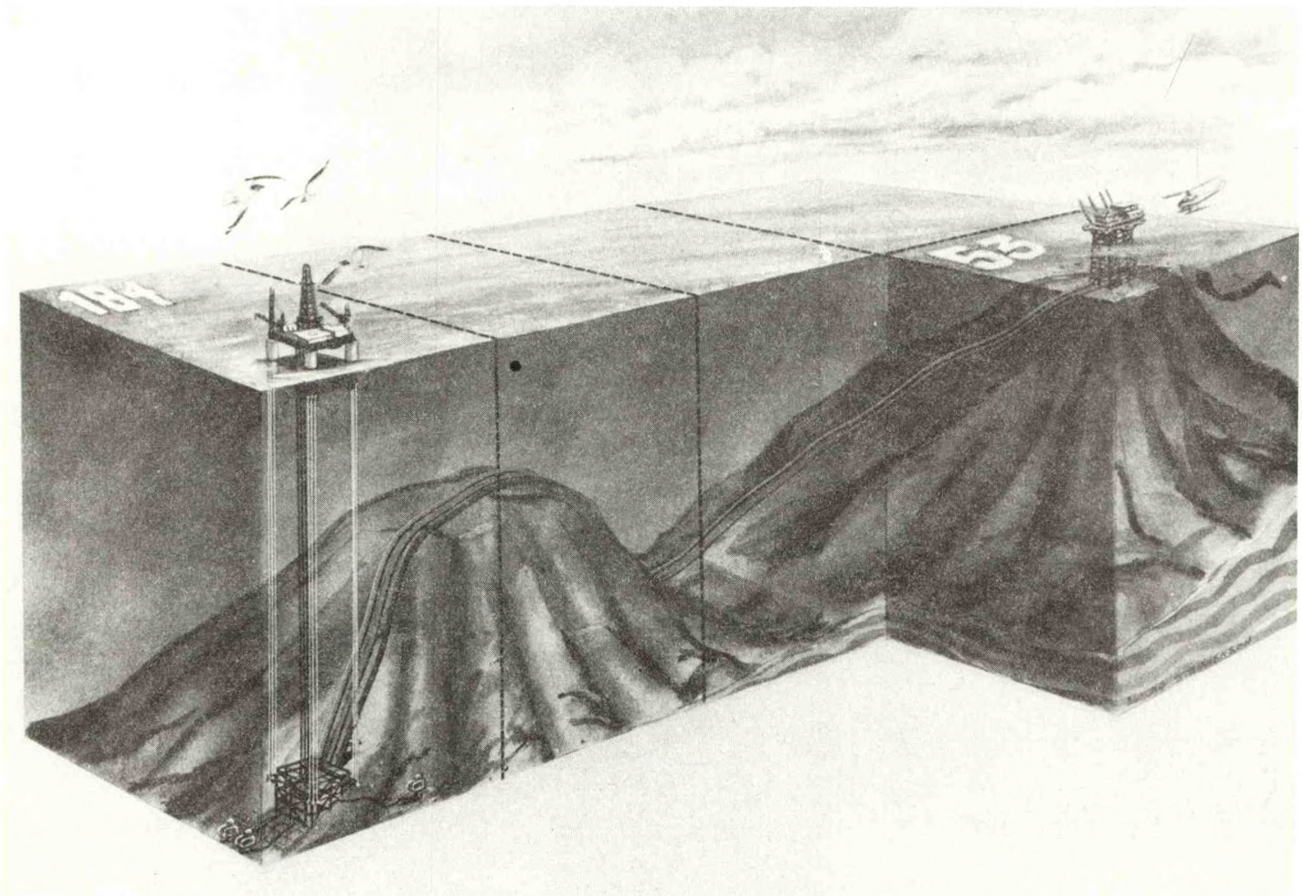

Figure 6. *Artist's conception of Conoco's Jolliet TLWP and the pipeline to the fixed proauction platform in relatively shallow water. (NOTE: The production platform is actually in Block 52 not Block 53.) (Taken from reference 8.)*

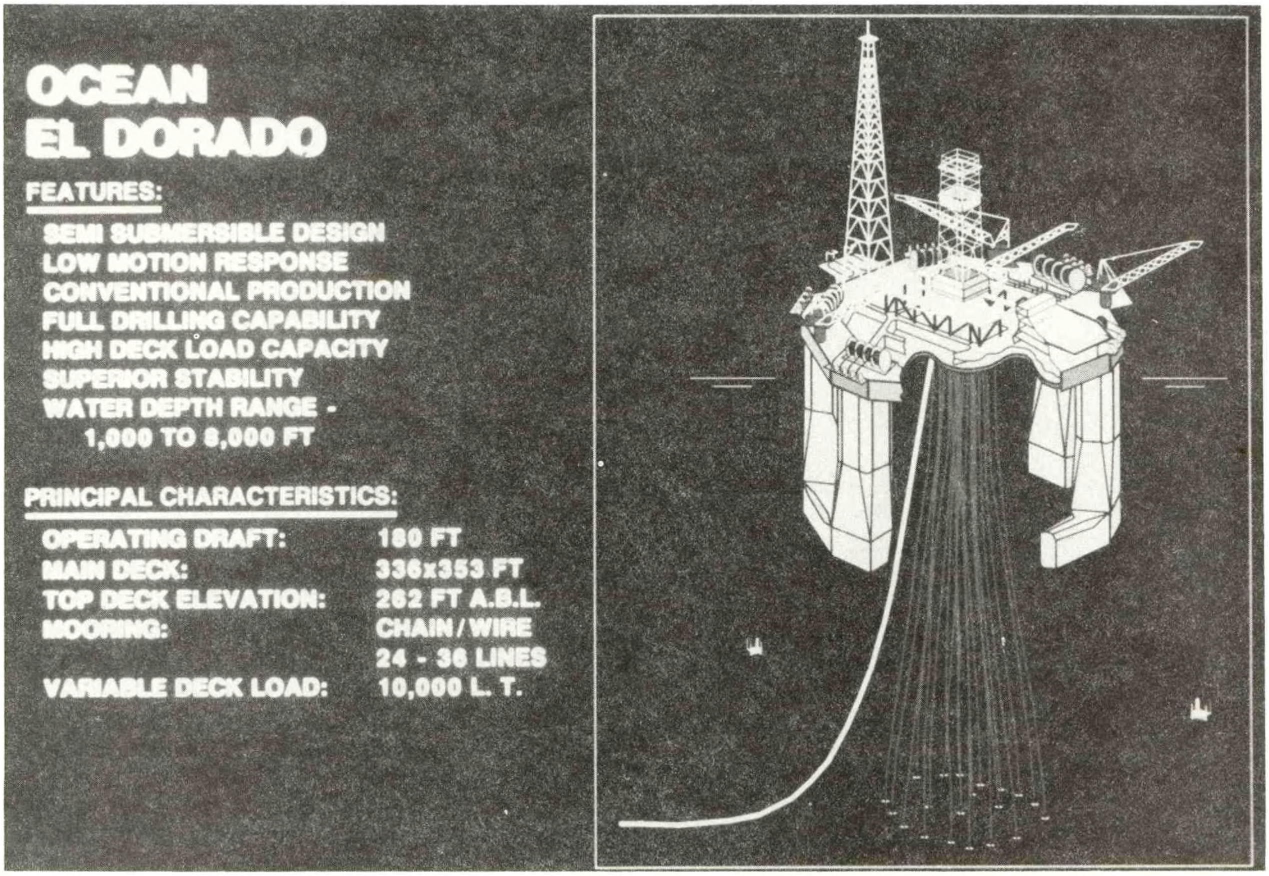

Figure 7. ODECO's Ocean El Dorado column-stabilized semi for drilling and production.

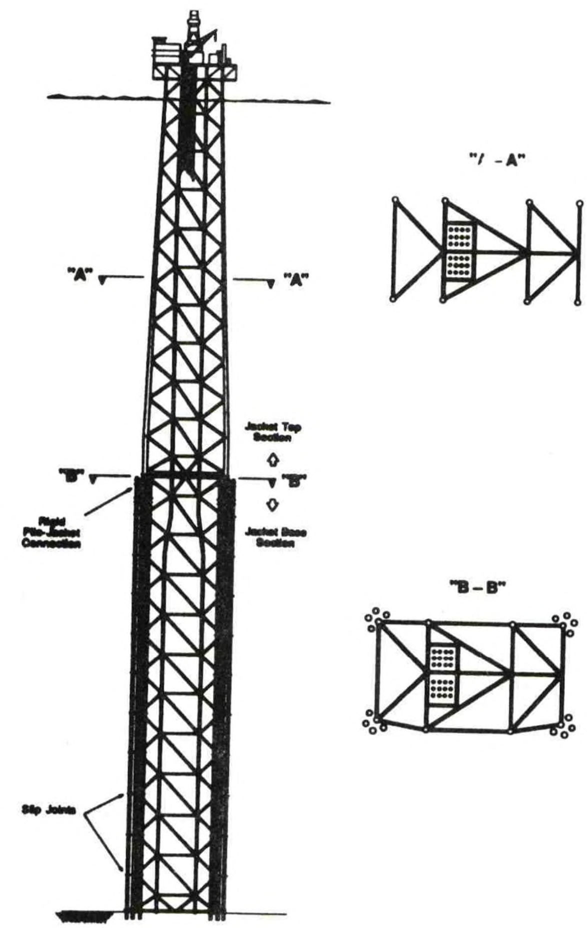

Figure 8. *Typical compliant tower structure.*

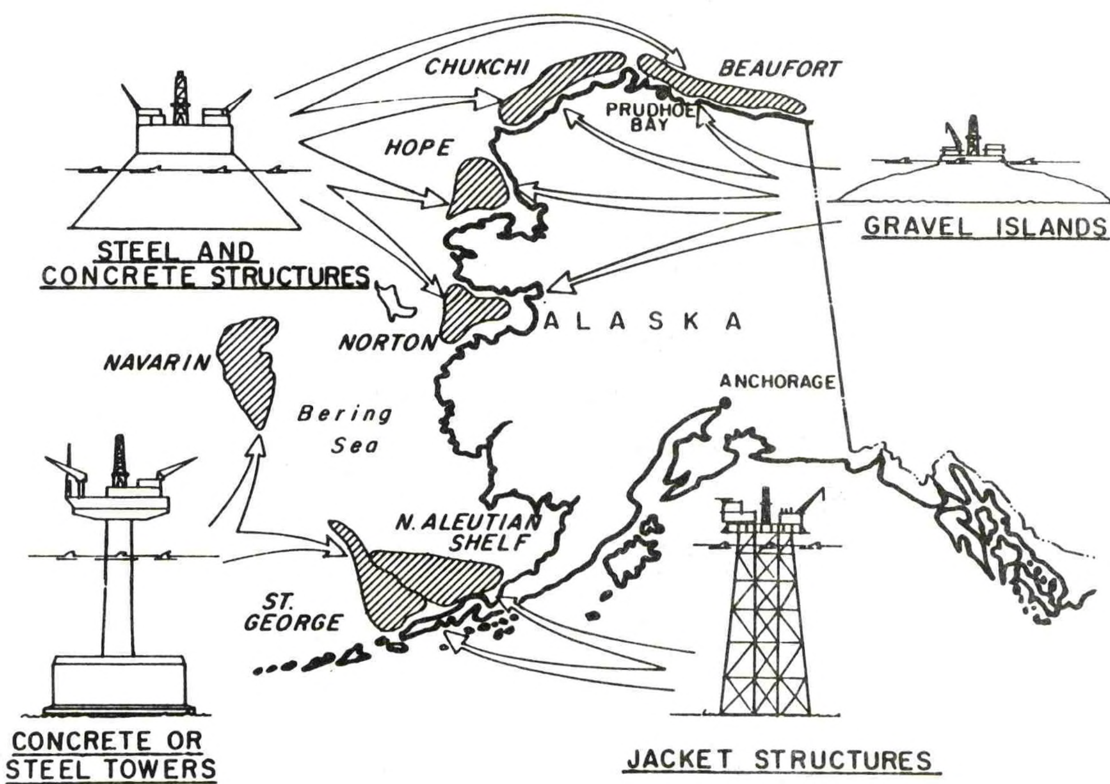

Figure 9. Structures proposed for Alaskan Arctic basins.

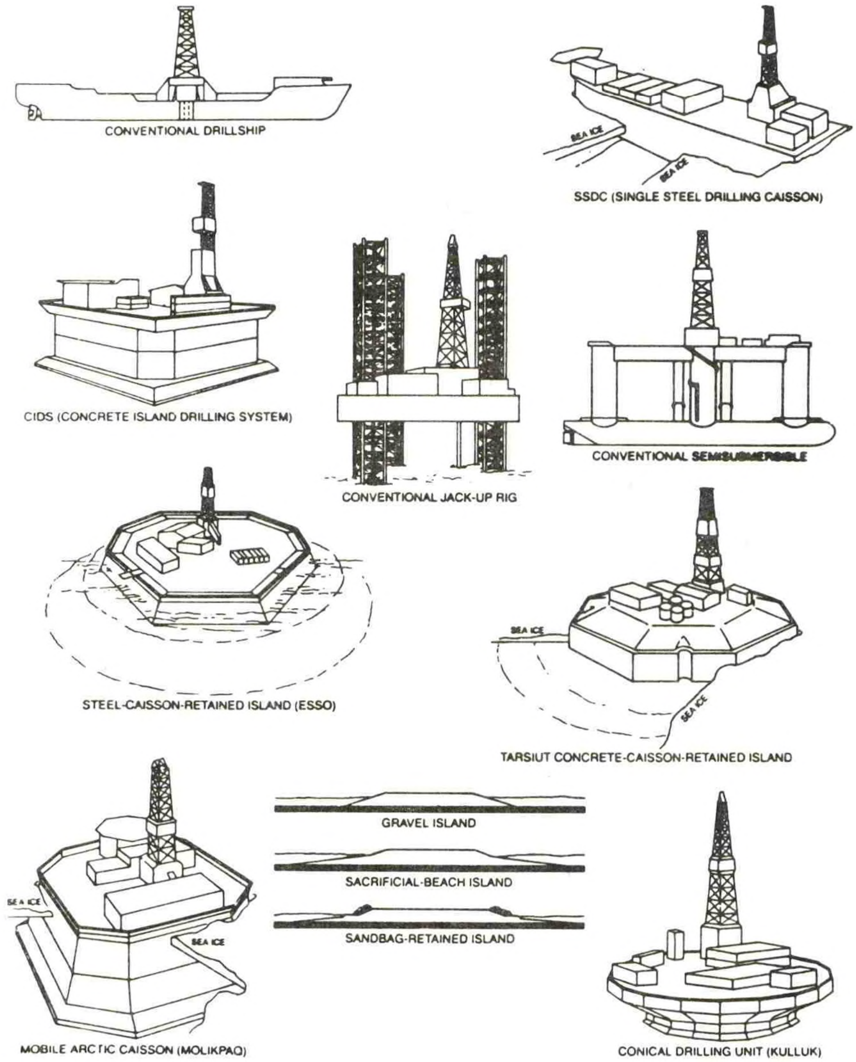

Figure 10. *Structures that are currently employed for exploration drilling in the United States and Canadian Beaufort Sea.*

ARTIFICIAL ISLANDS USED FOR OCS ACTIVITIES

COMPANY	SALE AREA	ISLAND NAME	TYPE	YEAR	WATER DEPTH FT	CONSTRUCTION TECHNIQUE	FILL VOLUME (MMCY)	COST (MM $)
EXXON	BF	BF-37	GRAVEL	1980-81	20	TRUCK	0.31	20
SWEPI	BF	TERN	GRAVEL	1981-82	21	TRUCK	0.31	18
SWEPI	BF	SEAL	GRAVEL	1981-82	39	TRUCK	0.7	26.2
BPX	71	MUKLUK	GRAVEL	1982-83	48	BARGE	1.35	100
SWEPI	71	SANDPIPER	GRAVEL	1984-85	49	TRUCK	0.81	27
AMERADA HESS	BF	NORTHSTAR	GRAVEL	1984-85	45	TRUCK	0.87	25
AMOCO	71	MARS	ICE	1985-86	25	SPRAY ICE		8
CHEVRON	BF	KARLUK	ICE	1988-89	22	SPRAY ICE		

Figure 11. Artificial islands used for exploration in the Alaskan OCS.

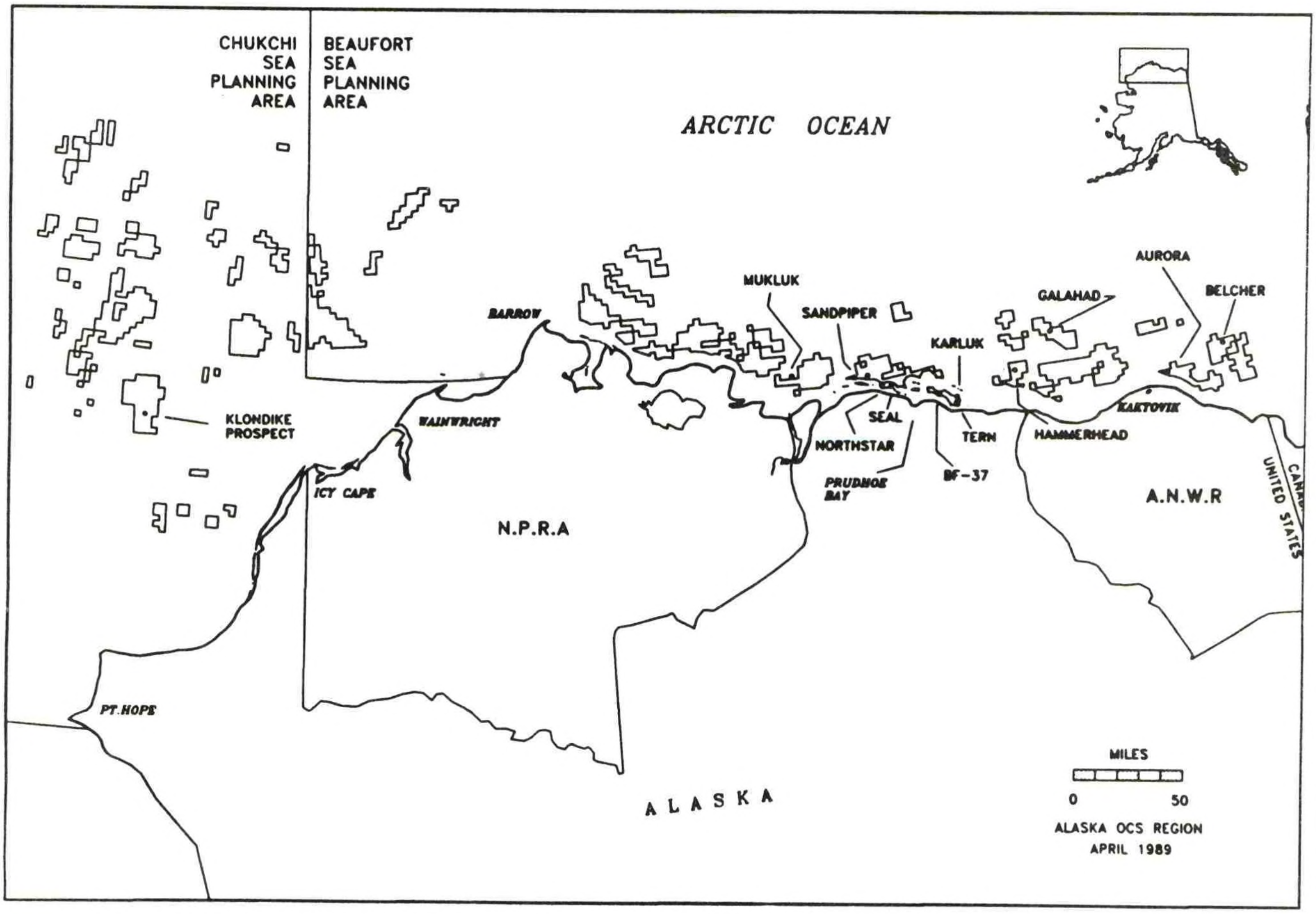

Figure 12. Exploration wells in the Chukchi Sea and Beaufort Sea planning areas.

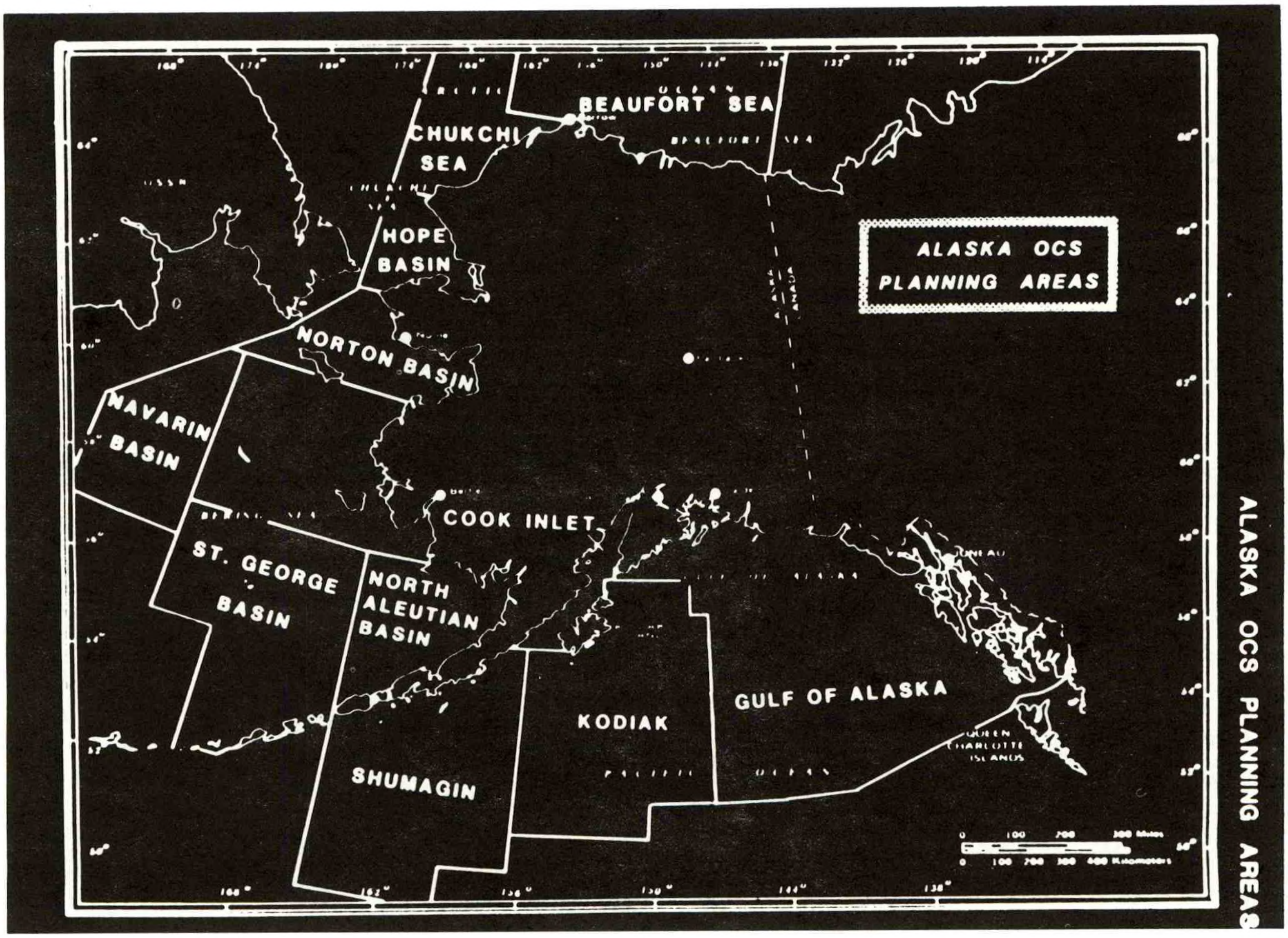

Figure 13. Boundaries of Alaska OCS planning areas.

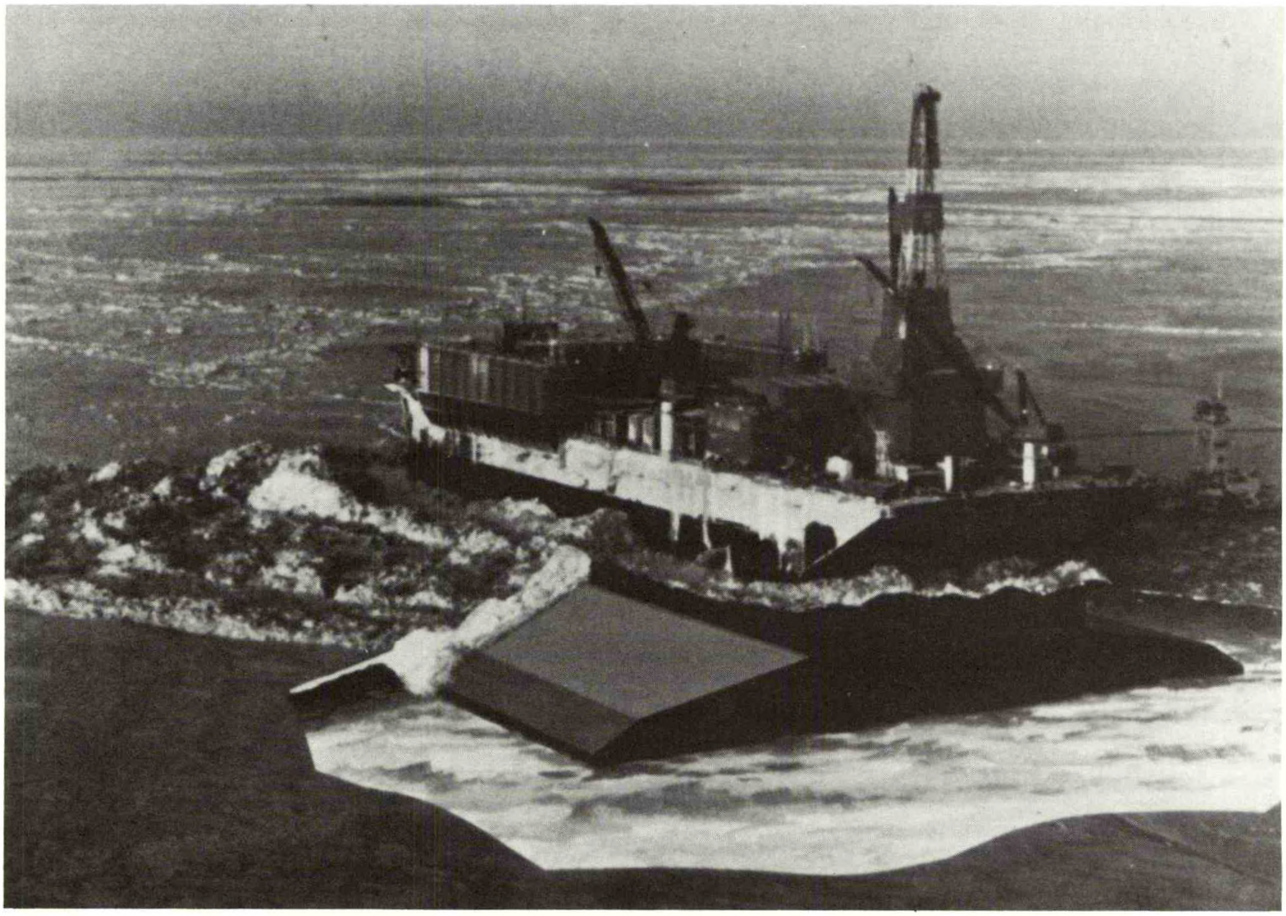

Figure 14. *Canmar Single-Steel Drilling Caisson (SSDC) showing artist version of the steel subbase mat.*

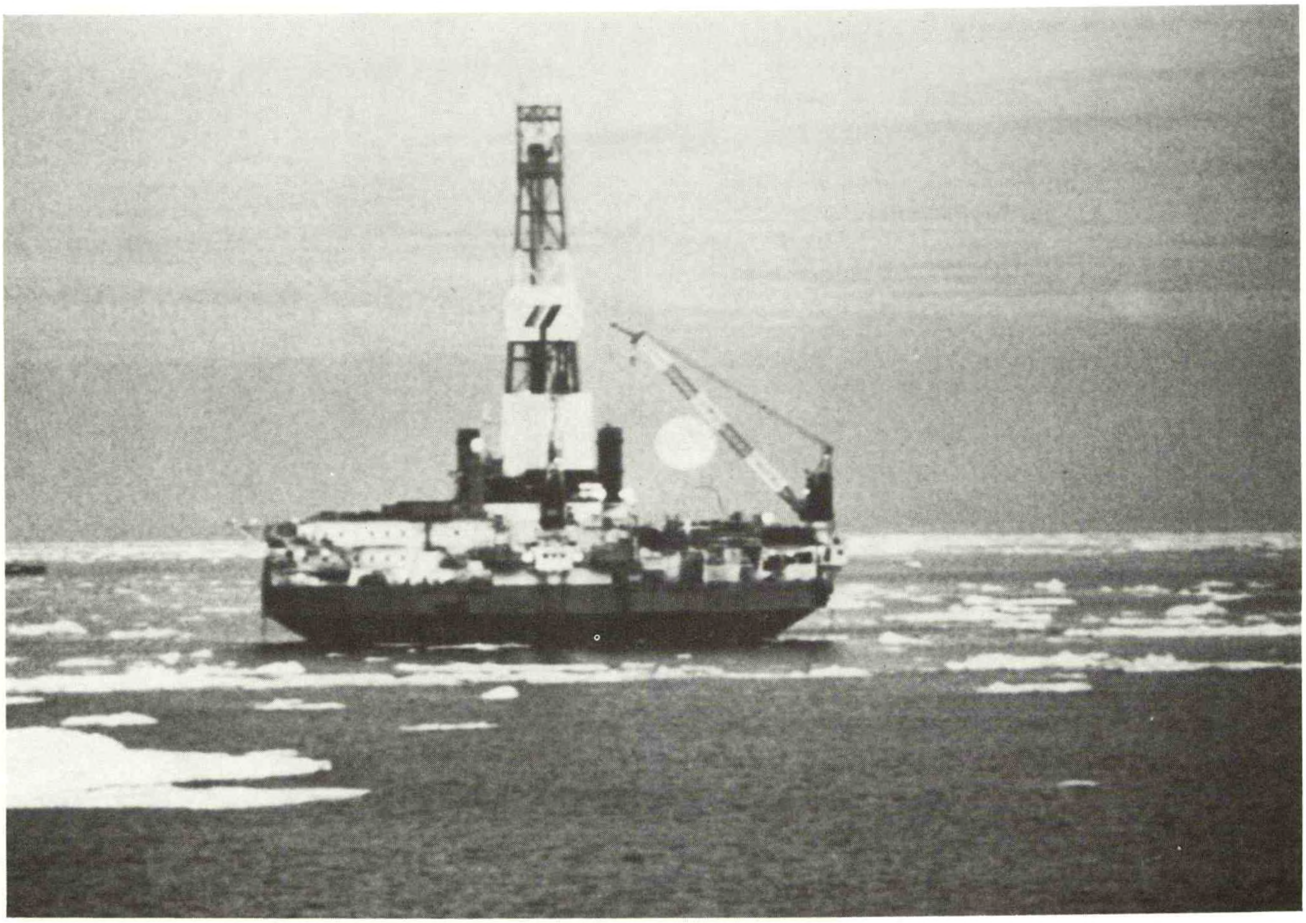

Figure 15. *Beaudril Conical Drilling Unit (Kullur) at Amoco's Belcher wellsite.*

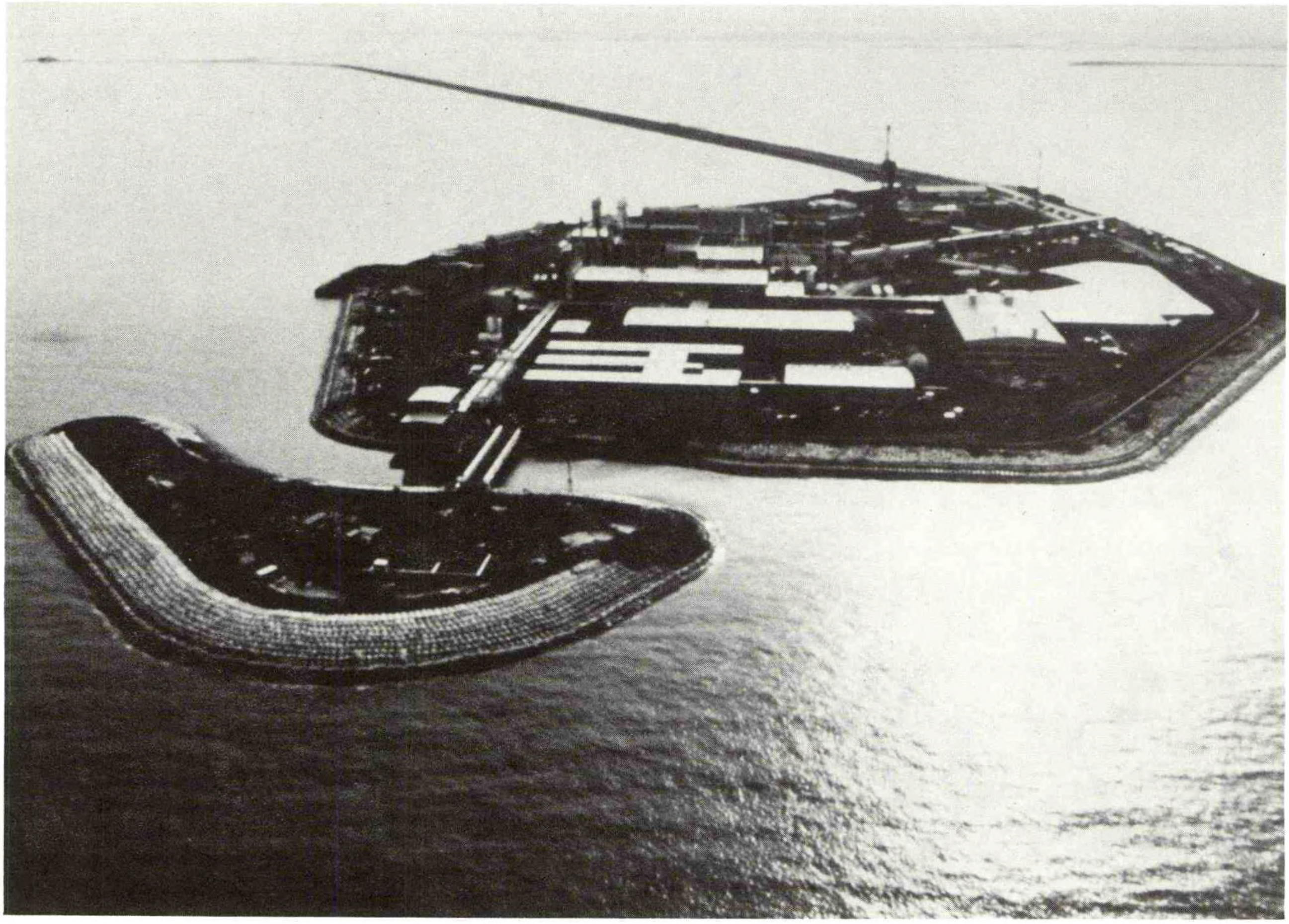

Figure 16. *Endicott production island.*

MACKENZIE DELTA – BEAUFORT SEA
SIGNIFICANT DISCOVERIES

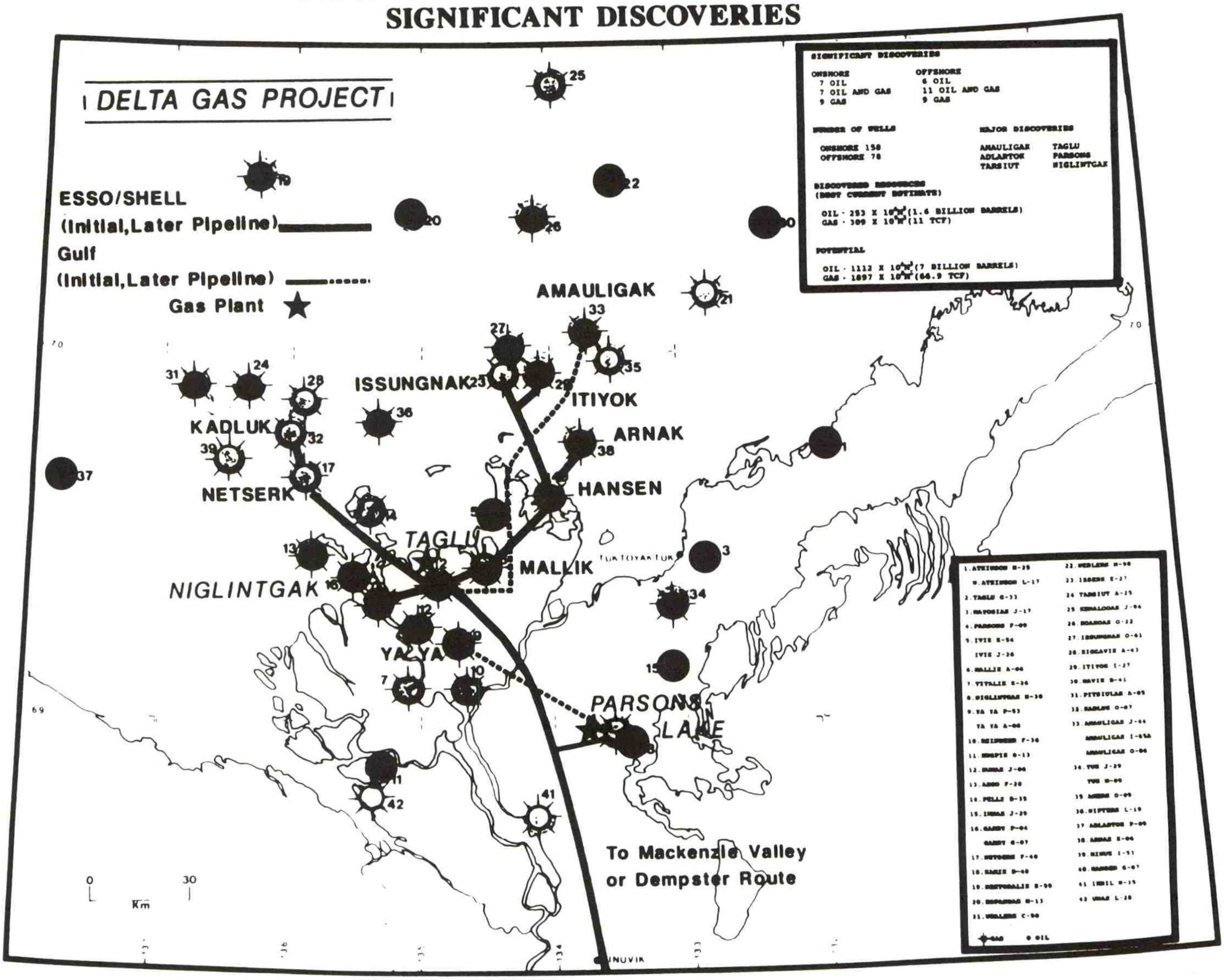

Figure 17. Canada Beaufort Sea/Mackenzie Delta exploration area.

OCEAN RESOURCE DEVELOPMENT IN HAWAII

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Introduction

When the President of the United States in 1983 proclaimed the national Exclusive Economic Zone (EEZ), he nearly tripled the jurisdictional area of the nation and made Hawaii, in combined land-ocean domain, the second largest state in the Union. In the six year period since this historic act, the State of Hawaii has taken major strides to build the technological base to develop the immense potential of the seas.

Five significant meetings and publications well summarize the plan for ocean resource systems development in the Hawaiian EEZ:

1. Results of the conference on "Engineering Solutions for the Utilization of the Exclusive Economic Zone Resources," hosted by the University of Hawaii College of Engineering and sponsored by the National Science Foundation, October 19-21, 1986. (1) The International Ocean Technology Congress (IOTC) was born at this meeting.

2. Proceedings of the Governor's Symposium on Ocean Science and Technology—Exploring and Applying Hawaii's Great Ocean Resources, November 14, 1986. (2)

3. June 1987 issue of SEA TECHNOLOGY, a special report focusing on the critical role played by ocean engineering in developing the national EEZ. (3)

4. The series of Pacific Congresses on Marine Science and Technology (PACON) in 1984, 1986 and 1988.

5. First International Ocean Technology Congress, held in Honolulu January 23-26 earlier this year. (4)

In parallel, several important ocean resource developments have been initiated:

1. The Pacific International Center for High Technology Research (PICHTR) was created in 1983 to coordinate international cooperation in advanced technologies for the Pacific, with a major portion of funding being placed on ocean resources. PICHTR is now the foremost engineering organization for ocean thermal energy conversion.

2. On a total of 867 acres at Keahole Point on the Big Island, the Natural Energy Laboratory of Hawaii (NELH) has gained maturity as the preeminent field laboratory of its kind, initiating experiments in various facets of ocean energy and aquaculture, and the Hawaii Ocean Science and Technology (HOST) Park has been dedicated to commercialize the fruits of NELH research. This combined development represents an investment in excess of $30 million, a key feature being the availability of 20,000 gallons/minute of deep ocean cold water from five pipes, the largest having a diameter of 40".

3. The Hawaii State government has reported that the local ocean industry is already a major revenue producer, bringing in more income than sugar and pineapple combined.

4. The University in 1986 created the Center for Ocean Resources Technology, which in

1988 was selected by the Department of Interior to become the national ocean basin Marine Mineral Technology Center. (5)

5. The University of Hawaii established a School of Ocean and Earth Science and Technology in 1988, and secured funding for a $42 million Pacific Ocean Science and Technology building now being designed for occupancy by 1992.

The story behind this development is presented in the following sections. Ocean resources provide the brightest hope for new industries in the Pacific, and the plan of action provided outlines a blueprint for building the fundamental infrastructure for such an endeavor.

History and Background

Hawaii is the newest of the 50 United States. The islands of Hawaii extend north as far as Kure Atoll, with an EEZ strategically occupying more than 849,000 square miles in the middle of the Pacific Ocean (Figure 1). The Pacific Ocean itself is more than twice the size of the Atlantic, washes the coastline of nations representing two-thirds the world population, and accommodates trade more than 25% greater than the Atlantic with a disparity that is growing.

Hawaii is geographically the hub of the Pacific, representing an ideal mix of Occidental, Pacific and Asian cultures. Blessed with favorable climate, desirable living conditions, stable government and progressive economy, Hawaii is recognized as the international center for cooperation. The capital, Honolulu, means "the gathering place" in Hawaiian, a most appropriate name for the home of the ocean resource program being advocated, for international cooperation is at the heart of the plan, and Hawaii offers the ideal environment to advance research and development in these fields.

The Hawaiian EEZ (Table 1), which is 29% the size of the Continental USA, is unique and advantageous for the following reasons:

1. Ocean thermal energy conversion potential (OTEC) is the best among the 50 States.

2. The harvesting of cobalt-rich crusts offers an attractive option. As the USA imports 95% of cobalt, 90% of platinum group metals and 75% of nickel, much from countries such as South Africa, Zaire and the Soviet Union, international politics of which we have no control could, and would almost be expected to, trigger a critical shortage of these strategic minerals by the turn of the century. Interestingly enough, palladium,

Table 1. Size of the Hawaiian EEZ

CONTINENTAL USA AND HAWAII EEZS	AREA (square miles)
Gulf of Mexico	365,625
West Coast	426,563
East Coast	487,500
Hawaii	**849,000**
Size of Continental USA	2,962,030

Adapted from Ehler, C. and D. Basta. "Strategies Assessment of Multiple Resources—Use Conflicts in the U.S. EEZ," EXCLUSIVE ECONOMIC ZONE SYMPOSIUM FROM OCEANS '84 CONFERENCE PROCEEDINGS, Rockville, Maryland

Figure 1. Hawaii Exclusive Economic Zone

possibly an important element for cold fusion, is found in seabed ores.

3. Ocean ranching, whether through land-based aquaculture using OTEC cold water, or mariculture from induced artificial upwelling provided as a by-product of the OTEC process, is a growing industry. It is conceivable that mega-OTEC pods in the open ocean could furnish the source from which new fisheries can be created with the possible added benefit of greenhouse warming mitigation.

4. Hawaii has the only deep ocean site in the nation for R&D on ocean resources. PICHTR has proposed the design and construction of prototypes which can bridge the gap between R&D and commercialization. Included among these pre-commercial experimental advancements are the Sea Rancher (floating platform for induced upwelling), Ocean Miner (to harvest seabed crusts) and a series of open and closed cycle OTEC facilities. (6)

5. The Naval Ocean Systems Center, Center for Ocean Resources Technology, College of Engineering, and Natural Energy Laboratory of Hawaii, in combination with the undersea vessels of the Hawaii Undersea Research Laboratory, offer facilities and capabilities unmatched for ocean resource research.

By the mid-80's, when the University of Hawaii began a campaign to support ocean resource technology research, however, a major problem loomed. While the National Science Foundation was providing an annual $150 million sum for the marine sciences, the Engineering Directorate effectively did not have an ocean engineering program. The National Oceanic and Atmospheric Administration had backed away from research, the Energy and Interior Departments were reducing their research efforts in this area, the Department of Defense kept virtually everything proprietary, and there was no viable ocean industry to cost match, provide encouragement or otherwise participate in federally funded programs which required private sector involvement. What there was of a marine commercial community had to do with recreation, offshore oil or defense.

THE PLAN

While on initial superficial analysis one could well have been discouraged to embark on any grand mission to develop the EEZ, the opportunities created by the above conditions were, in fact, ideal for building an ocean resource systems program. A comprehensive initiative that took the baton from the sciences, considered the total system of co-products, stressed economic development, and was sensitive to the environmental, sociological and non-technical factors... was in desperate need of leadership, as the world is always looking for future sources of energy, metals, food and pharmaceuticals, and the ocean is the final and greatest untapped reservoir on Earth.

The national and local legislative bodies could appreciate the economic potential and the strategic defense implications of having this capability. As no university, no state, and no nation had a monopoly on developing EEZ resources, the strategic plan developed by the University of Hawaii in partnership with various governmental and academic organizations attracted considerable interest.

The plan was relatively simple: establish an international center for ocean resource R&D. Almost by default, but certainly because of a compelling list of advantages and universal local support, Hawaii became this center. In so doing, there was good reason to expect that marine industries would be spawned, international cooperation would be promoted and the world, including Hawaii, would benefit. The key to success...the basis for cooperation...was the Hawaiian EEZ.

NATURAL ENERGY LABORATORY OF HAWAII

The Natural Energy Laboratory of Hawaii, where the Seacoast Test Facility (STF) is located, is able to provide cold, deep seawater (6-8°C) as well as warm surface seawater (24-28°C) for different applications. The facility includes a large laboratory for indoor experimentation and wet chemistry, an outdoor wet laboratory, a large concrete pad for outdoor investigations, an administration building, backup power supply, and a large area for open experimentation and expansion.

Research in ocean thermal energy conversion (OTEC) has been on-going for many years at the facility. Closed-cycle OTEC research examines the corrosion and biofouling aspects of seawater on OTEC heat exchangers. Open-cycle OTEC experiments focus on heat and mass transfer experimentation on the properties and effectiveness of evaporators and condensers. The mist lift cycle has also been investigated.

Aquaculture development from the discharge of the OTEC plant is economically beneficial. The deep, cold seawater has the unique qualities of being nutrient-rich and pathogen-free which allow for monospecies development in aquaculture. See Table 2.

The list of aquaculture crops include trout, salmon, abalone, oyster, nori seaweed, lobster, giant clam, algae, and others. Cold seawater is being used in agricultural applications to culture fresh strawberries, lettuce, and flowers, which require cold to control soil temperature and provide atmospherically condensed irrigation. Included in the list of other research experiments are environmental measurements, deep sea cable corrosion, aluminum corrosion, solar ponds, and materials science.

Among the operational support capabilities and advantages of NELH include:

1. Environmental Monitoring
   - Wind, Temperature, Rainfall
   - Solar Insolation
   - 3 Multichannel Data Loggers

2. Permits in Place
   - Approved Offshore Research Corridor
   - Conservation District Use Permit for Coastal and Submerged Land
   - Special Management Area Use Permit for Coastal Lands
   - DOT Harbors Division Shore Waters Construction Permit
   - Environmental Impact Statement/Environmental Assessment for the Whole Facility
   - NPDES Discharge Permit for Seawater Effluents
   - United States Army Corps of Engineers Permits
   - Federal Aviation Administration Permits

3. Security
   - Fenced Research Compound
   - Guard Service Off-hours and Holidays

STATUS OF THE HAWAII OCEAN RESOURCES SYSTEMS R&D PROGRAM

The two organizations spearheading much of the ocean resources systems and technology activities are the Pacific International Center for High Technology Research (PICHTR) and the University of Hawaii (UH). PICHTR serves as the technology transfer bridge between UH research and the marketplace.

The Energy and Resources Division of PICHTR, College of Engineering and the Center for Ocean Resources Technology (CORT) of the UH work very closely together on projects involving ocean thermal energy conversion (OTEC), marine algae, ocean minerals, tuna assessment and development, mitigation of greenhouse warming, and marine materials. The field laboratories used are primarily the Natural Energy Laboratory of Hawaii and the James Look Ocean Engineering Laboratory.

PICHTR plays the lead role on OTEC. A cooperative program is being conducted with the U.S. Department of Energy, Solar Energy Research Institute and Argonne National Laboratory on open cycle OTEC research. The five year goal is to design and build an advanced OTEC experimental plant capable of producing 165 kilowatts and fresh-

Table 2. NELH WATER QUALITY DATA

Seawater as Delivered to the Laboratory by 12 inch Diameter System
(Weekly samples 1982 - 1986)
(Values shown are average ± standard deviation)

Parameter	Warm Seawater	Cold Seawater
Temperature °C	25.99 ± 0.93	8.91 ± 0.95
Temperature °F	78.79 ± 2.82	48.04 ± 5.12
Salinity (°/00)	34.816 ± 0.172	34.298 ± 0.033
pH	8.227 ± 0.049	7.563 ± 0.040
Alkalinity (meg/1)	2.318 ± 0.020	2.354 ± 0.021
$NO_3 + NO_2$ (micromolar)	0.20 ± 0.08	38.97 ± 1.19
PO_4 (micromolar)	0.16 ± 0.04	2.96 ± 0.08
Si (micromolar)	2.98 ± 1.53	74.59 ± 4.36
NH_4 (micromolar)	0.36 ± 0.21	0.19 ± 0.20
Dissolved Organic N (micromolar)	4.34 ± 0.71	1.78 ± 0.61
Dissolved Organic P (micromolar)	0.24 ± 0.05	0.05 ± 0.06
Dissolved Oxygen (mg/1)*	6.98 ± 0.33	1.21 ± 0.19
Total Organic C (mg/1)	0.77 ± 0.33	0.36 ± 0.14
Particulate Organic C (micromolar)	2.88 ± 0.85	0.96 ± 0.35
Total Suspended Solids (TSS-mg/1)	0.61 ± 0.52	0.25 ± 0.13

Intake Locations

Warm Water: 303' (92.4m) Offshore Water Depth 65' (20m)
20' (6.1m) above Seafloor; 45' (13.7m) below Surface

Cold Water: 4650' (1417m) Offshore Water Depth 1995' (608m)
70' (21m) above Seafloor; 1925' (586m) below Surface

*Dissolved O_2 data from 1985 only (most reliable data) water. In this regard, the Hawaii State Legislature this spring provided \$4 million over the next two years to accelerate this effort, and an additional \$5 million to install a second 40" cold water pipe system.

Another joint effort is funded by the Japanese Ministry of Foreign Affairs to assess the South Pacific market for OTEC and plan towards megawatt-size open cycle OTEC powerplants. Developmental programs in open and closed OTEC are being discussed with Taiwan, Papua New Guinea, Tonga and various nations of the Pacific. PICHTR, in March of 1989, completed a strategic plan for Taiwan to commercialize OTEC.

The multi-product nature of open cycle OTEC, with potential for electricity, air-conditioning, freshwater, food, pharmaceuticals and induced open-sea upwelling conditions, makes this concept particularly attractive throughout the Pacific. PICHTR has determined that virtually every site in the South and Central Pacific region shows promise for OTEC. The three cornerstones of technology transfer, economic development and education are being laid to nurture this option.

CORT oversees the ocean basin division of the Department of Interior Marine Mineral Technology Center. Technology for seabed mining and ore transportation and processing are being developed. However, an equally important factor is the combination of environmental, sociological and related factors that needs to be included in the overall analysis. As in the OTEC project, the total system must be considered.

A growing concern is the greenhouse effect. PICHTR and the UH have formed an international team to initiate a mitigation program where renewable energy and the ocean are offered as important solution elements. Funding is expected from the National Science Foundation, Environmental Protection Agency and Electric Power Research Industry in the USA, and equivalent organizations throughout the world. The ocean represents a great unknown. There is very little data about how the seas affect the effect. Interestingly enough, the ocean could well become a significant reducer of carbon dioxide if major OTEC development occurs around the world where the deep, cold, nutrient rich waters are dispersed in such a manner that marine algae and the full chain of aquatic growth can be supported. There are uncertainties with respect to the chemical balance, but strategies are being developed to spur mitigation.

In the long term the hydrogen economy appears to be the ultimate savior for a sustainable society. In this regard, research is being supported on developing biological and catalytic methods to convert seawater to hydrogen and oxygen using sunlight. An international team has been brought together to assist in engineering a technological breakthrough. Three workshops have been held involving key researchers from around the world, and a pivotal decision-making session will be held in July of 1990 when Hawaii hosts the 8th World Hydrogen Energy Conference.

The Hawaii EEZ resource development program thus features internationally cooperative projects for the benefit of mankind. The Hawaiian EEZ offers a clear natural advantage for this purpose.

CONCLUSIONS

The sea around us will someday provide energy, freshwater, a greater abundance and variety of food, and pharmaceuticals. For Hawaii, so dependent on tourism and defense, the ocean shows promise for providing a much stronger economic base. The Exclusive Economic Zone will serve as the research environment for this development, and the Hawaiian EEZ has become the international laboratory for this monumental undertaking.

In each of the technologies described above the resources of the EEZ—warm surface and cold deep waters, seabed minerals, maricultural products—provide the natural conditions from which economic value can be engineered. These technological alternatives only hint at what could become the next industrial frontier.

It is particularly gratifying to note that in each case international partnerships are desired and might even be necessary for success to be maximized. Hawaii is ready to play this critical role of marshaling world cooperation. The key to bridging the gap leading to ocean enterprises might well be the catalytic efforts currently blossoming in the middle of the Pacific.

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A Promising Resource of the EEZ

The Oregon Black Sands

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For us in U.S. Industry, that have long been pursuing the exciting challenges and long-range growth potential of Ocean Mining, major consideration has been required in our business planning for U.S. strategic material needs, the import-export unbalance, international markets, and the problems associated with the Law of the Sea (LOS). Collapse of the metals markets, and the disasters in deep-sea minerals aspects of the LOS, essentially destroyed U.S. Industry private investment interest in ocean mining, which had developed so strongly in the 1960-70s time period.

With establishment of the U.S. Exclusive Economic Zone (EEZ), most of the international legal issues diminished in significance. The parallel aggressive actions of the U.S. Governments Geological Survey, Bureau of Mines, the Minerals Management Service, and the Governments of several States, has sparked some returning excitement, and potential research activity for both Universities and Industry. In addition we have seen some significant improvement in metal markets.

In this paper, I would like to (1) Review the rationale and background of Industry interests in ocean mining; (2) Take a brief look at the deposit characteristics of the Oregon black sands; (3) Summarize the technology / development requirements; and (4) Examine the concerns and opportunity present for this aspect of ocean mining.

Industry Investment Criteria

To present a brief summary of an Industry viewpoint on status, needs and concerns relative to ocean mining, one needs to first look at the mandatory business factors, followed by a review of the business environment in which the mining venture must operate. A simplified version of such a summary is shown in Figure 1. It is not meant to be complete, since every development opportunity has many important, and sometimes unique, facets affecting investment decisions. However, the messages from the chart are clear.

If we focus on the relationship of business factors to deposit location, namely on the continental shelf or in deep water, it becomes clear that Industry near-term investment interest must focus on shallow water. Sand and gravel for construction is the major existing Industry activity, with economic viability depending on the local construction needs, availability of on-land deposits, and transportation costs. Placer deposits, including precious metals in Alaska, the multiple mineral products in Oregon black sands, and some East Coast deposits are very attractive. Some are in production, and others are technically feasible now.

Deep water deposits, on the other hand, present far greater risks. It is interesting and important to note, that the development of the manganese nodule deposits, over which we have the greatest knowledge of deposit characteristics, and available exploration, mining and processing system technology, was stopped cold regarding private capital investment, by market conditions and their impact on venture economics. Today, the most promising deep water deposits are the high-cobalt manganese crusts, in the

Hawaiian/Pacific atoll areas, where we also have some very challenging and interesting technology development tasks. However, the investment risks are such that U.S. Industry activity will be limited primarily to activity where government support can be obtained, an area being focussed by the Dept. of Interior's Marine Minerals Technology Center.

The most attractive near-term Industry investment opportunities are therefore in the placer deposits associated with precious metals, the black sands, and gravel deposits. The most significant Industry concerns, regarding these deposits, are those of the Government/Industry interface, and particularly on the lack of ocean policy regarding environmental requirements, development, and the assurance of investment return proportional to risk. Some of these will be addressed later in this paper.

Oregon Black Sands - Deposit Characteristics

When we look at the composition of the black sands placer deposits off the coast of Oregon, we find that they are enriched in the heavy minerals ilmenite, chromite, and zircon, as well as magnetite, garnet, and significant quantities of gold and platinum. As shown in Figure 2, these materials have broad Industry applications for pigments, titanium and zircon alloys, stainless steel and abrasives. We have significant strategic needs for chemically resistant, high strength, light weight alloys, and most of these materials are currently imported, as defined here by the U.S. Bureau of Mines. Since there are presently no cost effective substitutes for titanium dioxide in pigments, or for chromium in stainless steel production, and with these deposits located well within our 200-mile EEZ, the value to the U.S. is significant.

Sources of these economic heavy minerals deposits have been traced to metamorphic and ultramafic rocks of the Klamath Mountains of northern California and of the southern Oregon Coast Range. Rivers draining such sources undoubtedly supplied placer minerals to ancient beaches on the Oregon continental shelf during lower sea levels (Figure 3), at water depths varying from 18 to 105 meters of water, as well as to the now uplifted terraces. These features are in some instances associated with magnetic anomalies, leading Kulm, in 1968, to postulate the existence of heavy mineral placers on these submerged terraces. Surface samples, box cores, and piston cores recovered by marine geologists of Oregon State University and the U.S.G.S., have furnished supporting evidence. Conceptual diagrams of the source, transport and formation of mineral placers on the shelf, as shown here, were given by Bowman in 1972.

During the late Wisconsin regression, sea level was approximately 120 meters lower than today, and rose to its current level about 3000 years ago. Three large submerged banks are present on the Outer Continental shelf and were exposed during the low sea level stands.

Dispersal patterns of sand-sized sediments show that the dominant direction of the littoral transport has been to the north, at least during the past 18,000 years. Sands were transported by energetic storm waves approaching shore from the southwest, driving strong longshore currents that carried both light and heavy minerals to the north. Smaller fair-weather swells from the northwest would have driven lower velocity longshore currents to the south, providing a sorting action, and leaving the heavy minerals behind.

Significant advancements in understanding of the formation and potential characteristics of these deposits have been provided by Peterson, et al, of Oregon State University. Studies of the two Pleistocene terraces near Bandon, Oregon (Figure 4), the Pioneer and the older Seven Devils terraces, were made. These terraces were mined for gold and chromite during World 11. Field observations and sampling of these terraces, were analyzed together with extensive bore hole data taken previously in 1945-56, by private interests, and by the U.S. Bureau of Mines in 1978, and were published by Peterson in 1986. These analyses showed that the areal distribution of placer sands on these terraces was much broader and far more continuous than had previously been supported. The Seven Devils terrace was observed to extend about 6 km. south from the Cape Arago headland and nearly 3 km. in breadth at its widest point. These dimensions were determined from concentrations of heavy minerals greater than 50 percent by weight in layers of at least 1 meter in thickness.

Typical ore body cross sections (Figure 5) obtained from the bore hole data, indicate that the Seven Devils terrace deposits varied in thickness from the one meter up to 15 meters thick. Using estimates of explored placer ore reserves above the 3 % Cr_2O_3 cut-off (greater than 6 % chromite) and the corresponding ore body surface area, Peterson calculated the original Seven Devils placer probably accumulated at least 16 million metric tons of placer ore.

Another key deposit characteristic found in the study, is shown in Figure 6. Total heavy-minerals abundance varies almost directly with grain size. Total heavy minerals abundance in the two deposits varied from 90-100 percent, at the bottom of the deposit, to about 20 percent from 3-6 meters above the bottom. Therefore, the highest concentrations of economic chromite, ilmenite, gold and platinum, will generally be found near the bottom of the stratigraphic sections, due to current sorting. This will be significant in estimating overburden considerations in subsequent mining operations.

Based on seafloor surface (grab and box core) samples taken in the late 1960s by the U.S.G.S., heavy mineral concentrations offshore Oregon and northern California were defined by Peterson, Kulm, et. al., as shown in Figure 7. Much of this "halo" (surface) data has been analyzed by Oregon State University. Using models related to the magnetic anomalies, and a Heavy Minerals Model, volumes of the total heavy minerals contained in specific deposits were estimated. These estimates showed volumes of large deposits ranging up to 400 million to 2.67 billion metric tons of heavy minerals. Although the volumes of these deposits need to be verified by deep vibracore measurements, the estimates of quality and size, truly indicate the potential presence of World-class mines.

Technology and Development Assessment

When one looks at technology and development considerations (Figure 8), it is clear, as stated earlier, that risks associated with deep ocean minerals are very significant, with fundamental engineering research required in most areas, including new exploration tools. However, when we look at the Continental Shelf deposits of construction materials and placers, we see a different picture, demonstrating the basis for potential U.S. Industry interest in these opportunities in the EEZ. The technology and tools for exploration and mining are state-of-art, with relatively low risk.

Exploration

Relative to exploration, definition of deposit size and mineral characteristics need to be confirmed for specific mine site economic analyses. Due to the importance of proving environmental compatibility of mining operations with those of living resources, aggressive gathering of pertinent baseline data is required during the exploration operations.

Mining

Although the mining task can be done with existing dredge concepts, a significant amount of innovative engineering will be required to optimize the dredge/platform and at-sea transfer for operation in rough seas. The highly dynamic sea conditions, which have concentrated the placer deposits, must be dealt with, in design, to assure adequate operations time and platform stability.

Processing

A development constraint, as shown in this chart, exists in selecting the appropriate mineral concentration equipment, in order to maximize the degree that such operations can be conducted on-board the dredge. The problem is to mechanically, or magnetically, separate the highly-rich heavy minerals, with minimal loss of fine grain precious minerals, and permit replacement of the unwanted sands back to the seafloor. Such separation equipment exists, but needs to be carefully selected and scaled-up for production operations. It is important to minimize the quantity of dredged material that is brought to shore, in order to increase the flexibility in plant site selection.

Ocean Policy - Concerns and Opportunities

Although we do not have time to discuss all of the ocean management and policy matters related to ocean mining and Industry, we can touch the subject. Perhaps the greatest ocean policy concerns for offshore mineral resource development, is the highly emotional public response to the serious environmental impact of oil spills. Although heavy mineral sands and petroleum are totally different in character, public reaction and the outcries by policy activists, view such offshore development as the same nemesis. I was very distressed during participation in a U.S. Ocean Policy Workshop, held recently in California, to hear nationally-recognized "experts", calling for banning both offshore oil and ocean mineral development, in the same breath, and with so little understanding of the differences.

The heavy black sands are non-toxic, sink rapidly to the seafloor, naturally shift on the seafloor in high currents, and have been an integral part of the living resource environment for millions of years. Dredging disposal studies, conducted by the U.S. Corps of Engineers at a site (Figure 9) located one mile from the Coquille River exit, showed a negligible impact of the disposal operations on the benthic community. Over 2.4 million cubic yards of placer sands from the river exit and harbor had been disposed on the site since 1920, with a maximum annual quantity of 115,000 cubic yards. In this area of intense activity of living resources (Figure 10), no diminished values of abundance and diversity of benthic infauna were found. These reports and data need to be studied and play a significant role in the development of a viable ocean policy regarding these strategic mineral resources.

To focus this discussion, the most significant unknowns for Industry lie in the area of undefined policy for environmental requirements associated with potential deposit development. Initially, Industry must assess the risks associated with such requirements, define the biological research required to perform such risk assessment, establish its cost and determine the impact on a logical development schedule. The concern is risk assessment and management, as well as venture economics. A responsible mining and fishing Industry, as well as policy makers, the environmental community, and the public, need to know and understand the impacts, in seeking policy and regulation requirements for mineral resource development. Also, in the areas of environmental unknowns, Industry and Government need to cautiously learn together.

In this regard, the heavy minerals resources of the Pacific Northwest present an exciting opportunity. The black sands deposits are highly attractive, the technology is essentially in hand, and the strategic value of the minerals are strong incentives for development.

Since its formation in 1984, Marine Development Associates, Inc. has pressed hard for an effective "partnership" between State and Federal Governments, the resource Industry, State Universities, Environmental groups, the Fishing Industry, and other users of the waters, in carrying out effective EEZ management planning. In these days of pressing national and local economic needs, the importance of treasured public values, and environmental hazards of World-impact magnitude, we need to set an example of cooperation and effective resource development for satisfying our needs.

It has been most encouraging that the State of Oregon, where emotions and State actions on environmental matters run high, has taken key steps to set up an Ocean Management Plan under such a "partnership" approach (SB-630). Legislation encouraging mineral resource development (SB-606) has also been passed. A special Task Force, established by the Governor, is struggling with the creation of an effective EEZ Ocean Management Plan. The task is not easy, and the problems are difficult, but are being effectively addressed in an open manner. Success will set an example for the Nation, and set the stage for intelligent development of the highly promising placer deposits within the State coastal waters.

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Figure 1

Ocean Minerals - Criteria for Industry Investment

	Shelf Deposits		Deep Water Deposits		
	Sand & Gravel	Placers	Manganese Nodules	Hi-Cobalt Crusts	Polymetalic Sulfides
Business Factors					
• Probable Mineable Deposits	■	■	■	■	□
• Adequate Technology	■	■	■	▨	□
• Existing Markets	■	■	□	▨	□
• Favorable Economics	▨	■	□	▨	□
• Manageable Risks	■	■	▨	▨	□
Industry/Government Interface					
• Investment Protection (Preference Right)	■	■	■	□	□
• Predictable Rules of the Game	▨	▨	▨	▨	▨
• Cooperative Environment	▨	▨	■	▨	▨

■ Attractive/Existing ▨ Partial/Problems □ Major Deterrent/Unknown

Figure 2

Uses and Foreign Sources of Selected Placer Minerals

Material	Uses	Foreign Sources	Mineral / Metal Substitutes
Ilmenite & TiO_2 Slag	Pigments Synthetic Rutile Titanium Alloys	Australia (63%) Canada (26%) South Africa (13%)	In Pigments** Rutile Clay, Carbonate, Zinc Oxide
Zircon	Foundary Sand Refractories Ceramics Zirconium Alloys	Australia (63%) South Africa (27%)	In Foundary Sand: Chromite In Ceramics: Titanium, Tin In Alloys: Titanium, Stainless Steel
Chromite	Stainless Steel Plating Refractories Pigments	South Africa (61%) Turkey (10%) Zimbabwe (10%) Yugoslavia (5%)	In Alloys: Boron In Plating: Nickle In Pigments: Iron
Garnet	Abrasives Filtration	Australia (100%)	In Abrasives: Diamonds, Silicon Carbide, Aluminum Oxide In Filtration: Ilmenite, Magnetite

** All data from Bureau of Mines, 1988
There are presently no cost effective substitutes for titanium dioxide in pigments or for chromium in stainless steel production.

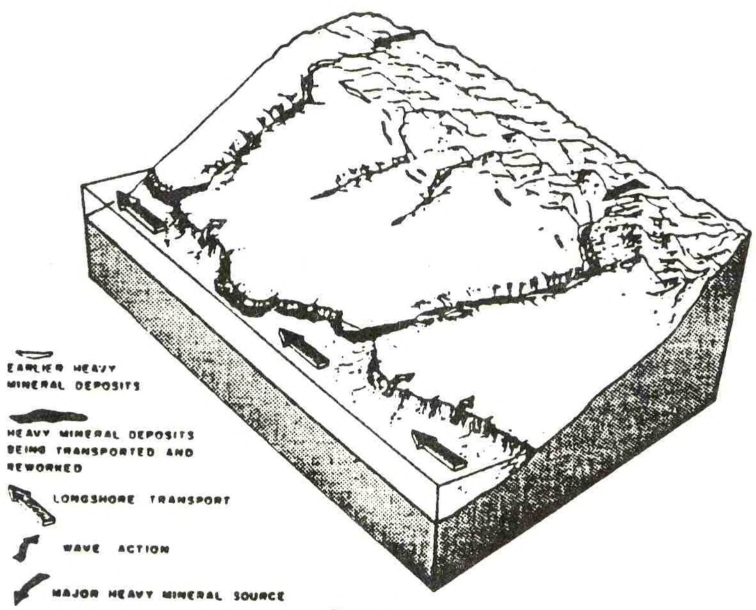

Figure 3

CONCEPTUAL DIAGRAM OF SOURCE, TRANSPORT AND DISTRIBUTION OF HEAVY MINERALS AT LOW STAND OF SEA PRIOR TO HOLOCENE TRANSGRESSION

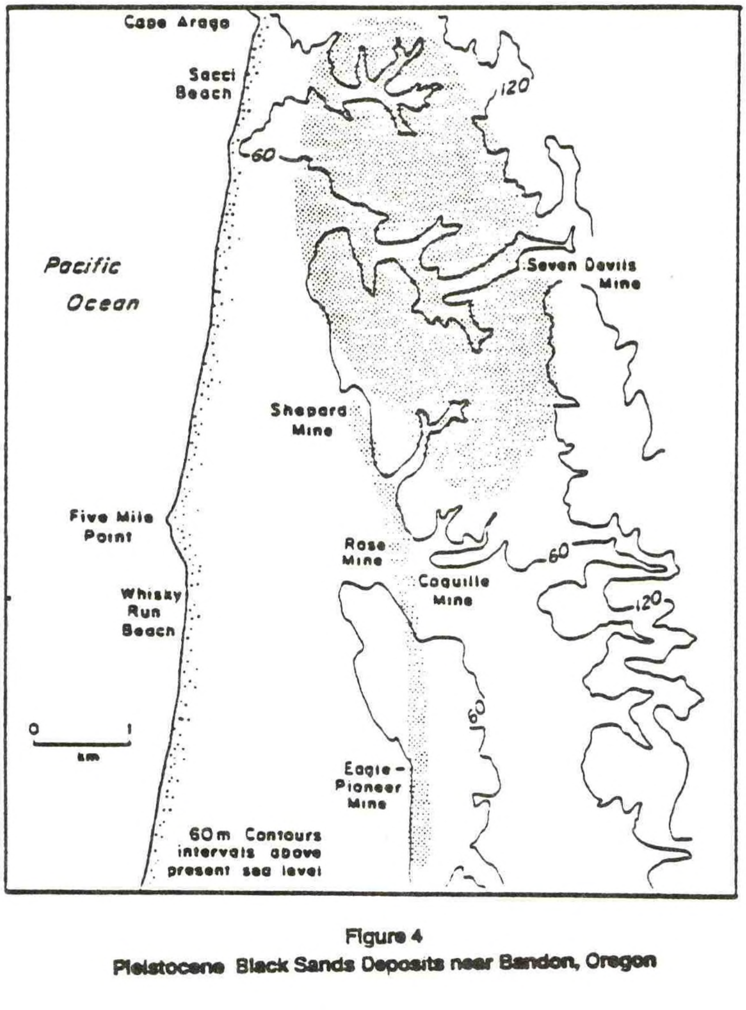

Figure 4
Pleistocene Black Sands Deposits near Bandon, Oregon

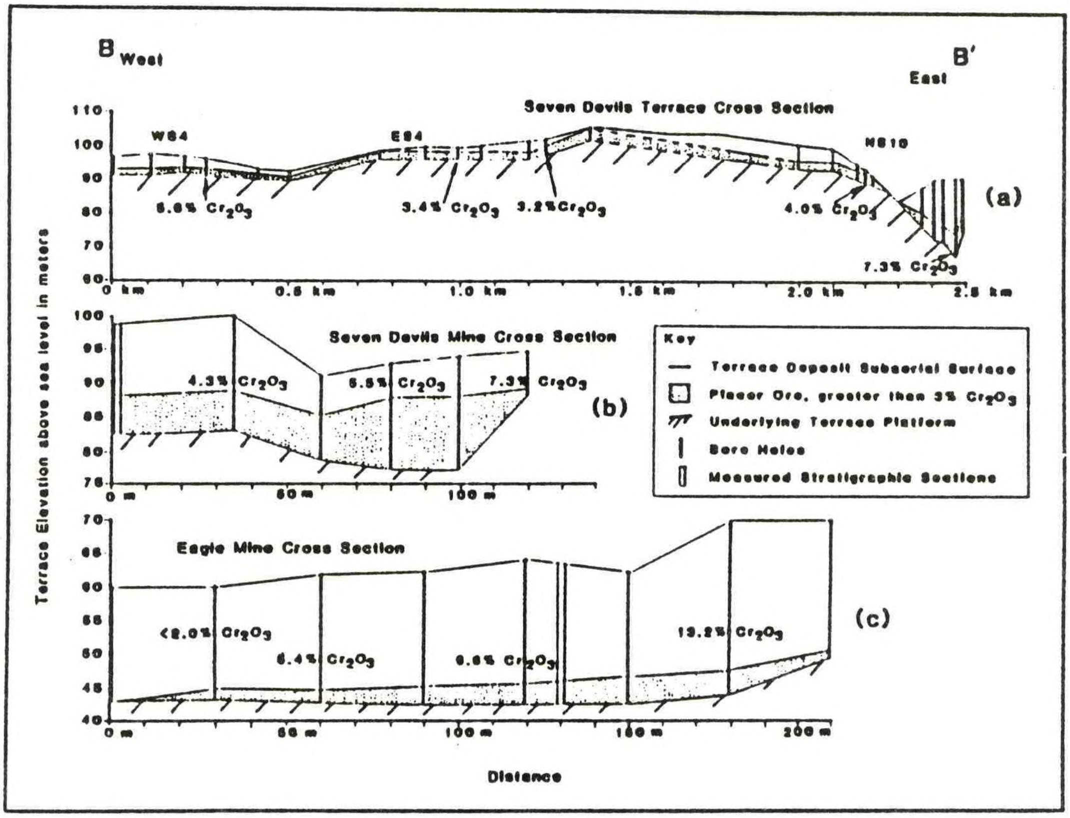

Figure 5 Placer Deposit Cross Section

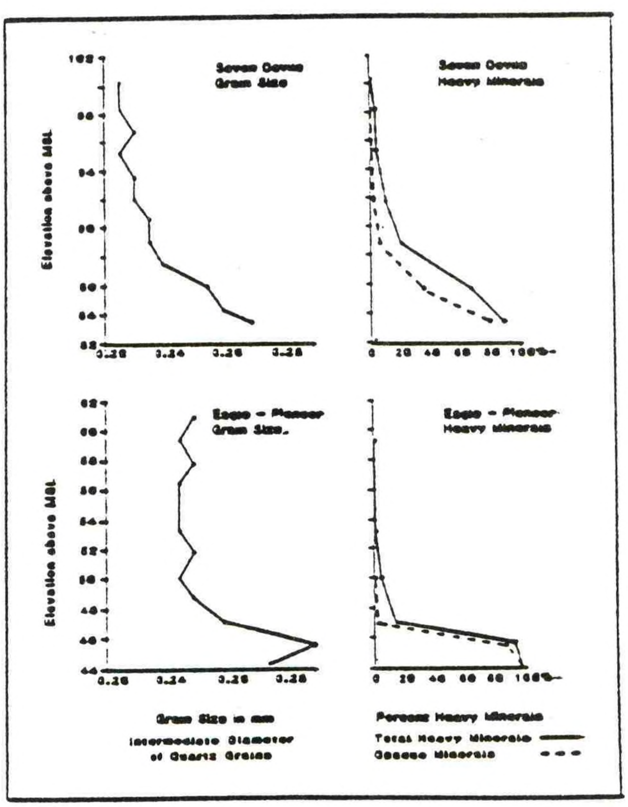

Figure 6 Grain Size & Heavy Minerals Composition in Bulk Samples

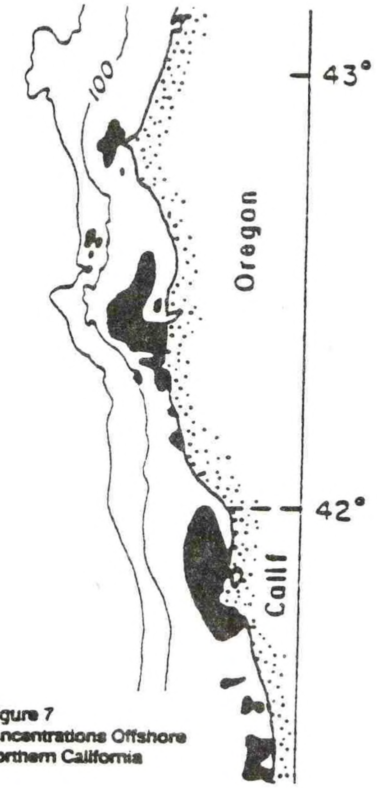

Figure 7
Heavy Mineral Concentrations Offshore
Oregon & Northern California

Figure 8

Ocean Mining Development Constraints

Resource	Technology Assessment					
	Exploration		Mining		Processing	
	Tools	Deposit Definition	Components	Systems	Process	Waste Mangm't
<u>Continental Shelf</u>						
• Sand & Gravel	-	-	-	-	-	-
• Placers						
• Precious Metals	-	-	-	-	-	-
• Heavy Metals	-	■	-	-	■	-
<u>Deep Water</u>						
• Phosphorites	-	■	■	-	-	-
• Metalliferous Muds	-	■	-	-	■	-
• Manganese Nodules	-	-	-	■	-	■
• Polymetallic Sulfides	■	■	■	■	-	■
• Manganese Crusts	■	■	■	■	-	■

■ Indicates Significant Market or Fundamental Technology Constraint

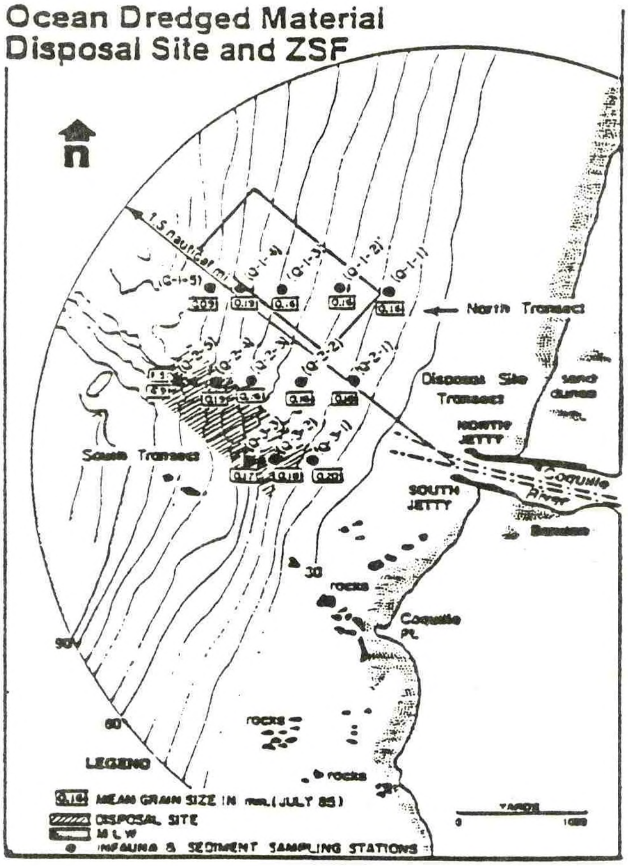

Figure 9 Sampling Sites

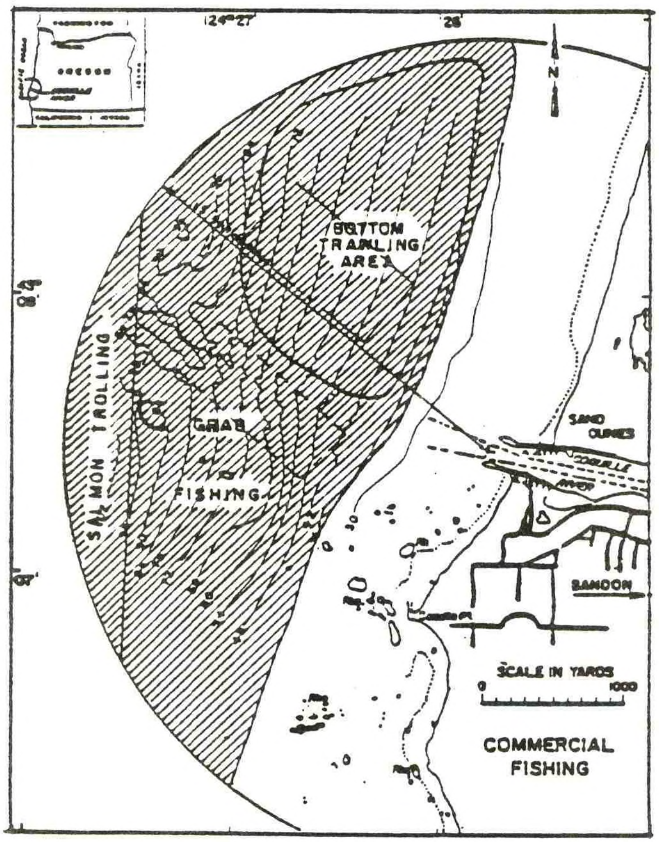

Figure 10 Commercial Fishing Areas

THE TECHNICAL PROGRAM OF THE
OFFSHORE TECHNOLOGY RESEARCH CENTER

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and Center Director
Texas A&M University
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Introduction

It was our pleasure in 1988 to present a paper at the 15th meeting of the UJNR/MFP describing the National Science Foundation sponsored Offshore Technology Research Center, a joint venture of Texas A&m University and the University of Texas. This paper will describe in some detail the technical program and the direction pursued during the Center's first year.

We have been extremely pleased with both the scope and progress of the research and the strong support provided by the international offshore industry. Although the first year is not complete at the time of this writing, our first annual report has been made and a favorable review conducted by the National Science Foundation.

The Research Thrusts

The several thrust areas reported in the 1988 paper continue to be the focus of the technical program of the Center. These thrust areas are: hydrodynamic loadings in deepwater, structural integrity of deepwater systems, materials for ocean applications, foundation/seafloor engineering, subsea work systems, and new production system concepts. These closely inter-related research areas form a coherent integrated research program requiring the attention of researchers from different disciplines with different backgrounds and expertise. Of the thrust areas mentioned above, work has started in the first four and planning is underway to begin work in the last two, subject to the availability of funding.

As previously reported, two very large potential petroleum provinces are believed to exist in the deep Gulf of Mexico. A research program which would permit their economic development within a decade is the long term objective of the current Center research effort. It is interesting to note that in the March 1989 lease sale in the Gulf of Mexico, half of the acreage bid upon was at depths of 1800 meters or more. The current research thrusts focus on problems whose solution would also be useful in extending the current working depth of platforms from 600 meters to say 1000 meters over the next 2 to 5 years. The following material describes our first two year research projects in each of the thrust areas.

Hydrodynamic Loadings In Deepwater

Offshore structures in very deep water require nonlinear analysis. 3Dimensional nonlinear diffraction theories must be further developed for multi-body large floating structures in non-Gaussian random seas. Slowly varying drift forces strongly effect structure motions which, in turn, modify the forces. Additional investigation is also required in nonlinear interactions between hydrodynamic loadings on slender bodies and their dynamic responses. Breaking wave and wind loads are also problems of concern.

In all of the above studies, advances in nonlinear signal processing, advanced computational techniques, and advanced numerical techniques to model transient and experimental studies must be developed. Physical models undergoing complex nonlinear hydrodynamic phenomena are required to verify the analytical and numerical results. Such tests, in turn, require advanced digital signal processing as well as improved sensors and data handling.

Our objectives are to develop an efficient 3D nonlinear hydrodynamic model for large floating structures, to examine the effects of multi-directional non-Gaussian seas on nonlinear hydrodynamic forces, to develop an approach whereby model tests and field data may be systematically and quantitatively analyzed for both linear and nonlinear phenomena, to investigate breaking waves and wave impact forces and to develop predictive models for design application and to improve the accuracy of predicting hydrodynamic forces on slender bodies. Projects have been undertaken in these areas by principal investigators, or teams of principal investigators, supported by graduate students and monitored by industry practitioners.

Four major projects are now underway. First, a project to determine the significance of quadratic nonlinear loading effects on structural response including slow drift oscillation of moored structures and high frequency induced fatigue of members. The second project concentrates on the development on a technique for generating and synthesizing extreme breaking waves in the laboratory to investigate fluid particle kinematics. The interactions of the extreme waves with fixed floating structures and wave impact forces is a topic of great concern. To support the physical model studies, an advanced numerical simulation technique is being developed. The third project will develop better computational tools to estimate hydrodynamic loads on slender structures. Several fundamentally different approaches are being used. The fourth project focuses on the development of finite element and boundary element algorithms to model the propagation of nonlinear free surface waves and wave structure interactions using a vertex spline method.

Accomplishments to-date include a model test of a tension leg platform to demonstrate how digital polyspectral analysis techniques allow one to decompose the structural response into its linear and nonlinear components. Advanced finite element and boundary element algorithms using vertex splines have been developed to model nonlinear hydrodynamics for large floating structures. Software and instrumentation have been developed for the generation and monitoring of multiple waves in a 2D tank to study slow drift forces. Techniques for generating breaking waves have been successfully demonstrated. Numerical techniques are being developed for the study of 2D flow around slender structures. They include the Navier-Stokes equation and the vorticity transport equation.

Structural Integrity Of Deepwater Systems

The successful design of tension leg platforms or other compliant structures requires accurate estimation of the motions of the structures under dynamic excitation such as wind, currents and wave action and the resultant stresses. The analysis is complicated by the fact that the components of these structures vary greatly in size. The hull of the structures are large while tethers, mooring lines and risers are very slender bodies. The simplified analysis of these structures using existing linear equations are likely to result in severely over-designed components.

Research is needed to improve the reliability of structural analysis, the drag and hydrodynamic damping forces associated with body motions, and the validity of current techniques for estimating forces on slender bodies and flow induced vibration. While many of these questions are being addressed in the hydrodynamic loads thrust area, the structural integrity investigations must provide techniques for using the results of the hydrodynamic research and means to analyze the structural loads produced.

The overall objective of this thrust is to enhance current knowledge and understanding of the behavior of deepwater marine structures in all aspects pertinent to their design thereby minimizing the uncertainties and permitting reduced costs in their construction. Four research projects were selected for emphasis during the first two years, they include dynamic response of tendons and risers, response and stability of deepwater tubular structures under combined loads, non-Gaussian stochastic structural fatigue, and dynamic behavior of nonlinear offshore systems.

The first project is intended to provide the analytical and computational support needed in other projects and thrust areas. It includes the development of a sophisticated formulation for the nonlinear analysis of slender bodies, the development of nonlinear finite element programs for stress analysis of risers or tendons under combined axial force, bending and pressure to predict buckling, and finite element programs for nonlinear analysis of pilings used in the foundations or anchoring of compliant structures. The second project concentrates on the detailed analysis of the nonlinear response and identification of structural instability of tubular structures under combined pressure, tension and bending loads.

The third project addresses the area of fatigue with basic analytical studies of fatigue life under random non-Gaussian histories of stress and an experimental study of strength and fatigue of members welded using new techniques. The last project in the first two year program addresses the area of the motions of structures. It includes basic research in nonlinear dynamics and chaotic movement in order to provide an understanding of the conditions or types of structures for which dynamic instability or chaotic motions can develop. The combination of these four projects cover the basic steps of structural analysis and design and tie in well with projects in the other thrust areas.

Materials For Ocean Applications

The economic production of oil at great water depths will require the application of new material systems or appreciably more sophisticated utilization of conventional materials. Weight and reliability of the risers and structural attachment from the floating structure to the seabed will have a tremendous impact on the design and cost of deepwater oil production facilities. The materials thrust area focuses on the possible application of high performance composite materials in combination with conventional materials fabricated in novel ways that will enhance the economics of construction and maintenance of these complex structures.

Primary application of high performance composites has been in the aerospace industry where their cost is secondary, hence the long term durability of such materials in saltwater must be explored. We know that all polymeric materials absorb moisture when immersed in water. The extent and the result in damage to the materials must be determined. Deep petroleum resources pose a significant challenge in the construction of seabed pipelines, risers and other flow component structures. The complexity and time required for welding steel members in deepwater applications appear to be prohibitively high. Techniques must be developed to provide resistance to hydrogen-assisted cracking and fatigue due to wave and current forces. The seawater itself at depths of 1800 meters can be quite different than in shallower depths resulting in a need to analyze and test deep ocean use of materials in the deep ocean environment.

The materials research effort involves the use of composite materials for risers or tension legs, the use of organic fiber ropes for moorings and tension legs, the coupling of composite tubular goods, the welding of pipe structures for offshore deepwater applications, and deepwater corrosion and corrosion fatigue of steel structures.

Three projects have been undertaken for the first two years that cover these areas of concern. The first project combines the development of screening tests to evaluate the degradation of composite materials in saltwaters with fundamental studies of the nature of degradation using real-time fracture studies in the scanning electron microscope. The second project evaluates the suitability of homopolar welding as a new fabrication technique for tubular goods. This novel technique involves the joining of two pipe sections by means of a forge weld assisted by the application of a very high amperage electrical current for a very short period of time. The resulting weld includes no added material and no phase change in the crystalline structure of the base metal. Its suitability to the welding of offshore structures and pipelines is to be determined. The research includes a parametric study of the sensitivity of this process to poor fit up using workpiece pairs with controlled angular and axial misalignment and dimensional mismatch. The third project includes the combined effect of temperature and oxygen concentration on the corrosion and corrosion fatigue behavior of structural steel in seawater.

These several projects are pertinent to the development of tension leg or riser systems which would consist of long sections of composite cylinders joined together with metal couplers. Couplers would be bonded metallic inserts that would be attached during the manufacturing of the tubular goods. Inserts would then be homopolar pulse welded during installation. The corrosion studies are to determine the corrosion fatigue resistance of homopolar welded materials in both shallow and deep seawater.

Foundation/Seafloor Engineering

As the search for hydrocarbons has extended from the Continental Shelf to the slope, two problems are being identified which preclude mere extrapolation of shallow water techniques. The foundations required for deepwater compliant structures are in many cases different in nature and the seafloor environment can be startlingly different. The traditional offshore structures have produced downward vertical loads. Tension Leg platforms, on the other hand, produce varying tensile loads resulting in the need for long piles or anchors involving collateral piling or clump-weight applications. The varying repeated loadings caused by wave action are a unique problem.

The formation of ice in the form of gas hydrates has been observed throughout the Gulf of Mexico in water depths greater than 500 meters. Hydrates in the foundation bearing zone introduce significant problems in foundation integrity. The risk of hydrate melting due to repeated motion or heating from the presence of nearby hot oil in conductor pipes is a threat. The growth and dissipation of gas hydrates in the deep ocean sediments is not understood and their effect on foundation and bearing capacity is unexplored.

The objective of this thrust area research is to solve the unique problems associated with deepwater foundations and unusual seafloor behavior.

Two major projects have been undertaken. In the gas hydrates area, techniques must be developed to determine their presence and extent. The first approach is the development of a probe utilizing standard geotechnical boring procedures. Limitation of the probe to specific sites and the expense of drilling in the deep seabed suggests new techniques must be developed for extending hydrate detection. One approach involves the enhancement and interpretation of standard acoustic data available from shallow seismic surveys. Computer simulations of the acoustic returns are being core-ducted to replicate real data in gassy sediments and hydrates. This fundamental study will result in methods of "seeing through" the loss of signal that occurs in acoustic records due to gas in the sediments. Another approach is the analysis of seismic surface waves propagated from the seafloor using spectral analysis techniques. This involves the development of a theoretical model for the propagation of surface waves in sediments overlain by water and an experimental program to develop data with which to verify the theoretical models. A collateral investigation is being made to determine pore pressures and fracture gradients of hydrated sediments.

The second major project involves both theoretical and experimental research in the bearing capacity of piles under combined static and cyclic loading, both lateral and tensile. This work will be extended to include pile groups, piles in sand, and grouted piles.

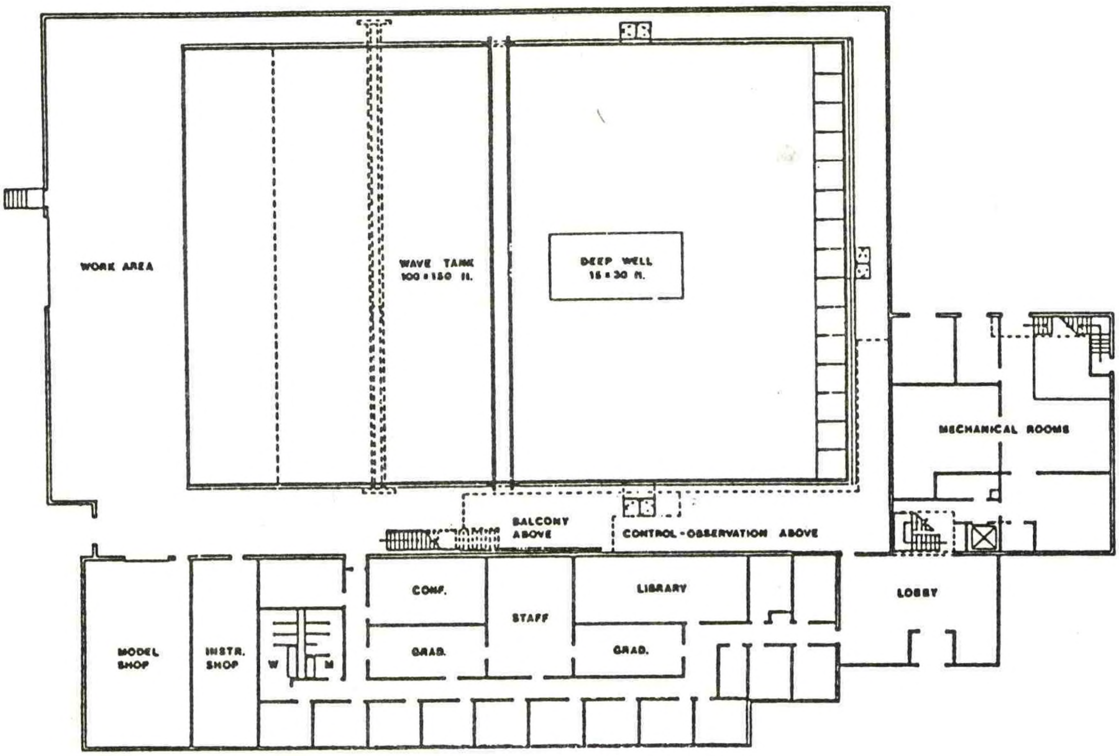
The Offshore Test Facility

A key element in the establishment of the Offshore Technology Research Center on October 1, 1988 was the establishment of a world class seakeeping and 3D wave basin. The design of the basin has changed from that reported in the 1988 paper to a 30 meter wide by 50 meter long by 6 meter deep tank with a 15 meter deep pit near the center of the basin. The size increase will permit generation of deepwater waves 1 meter high. The multi-segmented directional wave generator control system has been upgraded from an analog system or an analog-digital combined system to a fully digitized system which permits the integration of the data taking and analysis computers with the wavemaker controls.

The facility is a major, superbly equipped modern 3D wave basin in a setting where skilled scientists and engineers can, on a continuing basis, develop and test the theories and mathematical models necessary for determining nonlinear hydrodynamic loads on offshore structures. Its location at a major university assures the training of the next generation of users and researchers. The equipment of the basin takes advantage of recent developments in Europe and Canada as well as the United States. The facility is planned so that it can be expanded to an L-shape wavemaker configuration and increased basin length which will permit the testing of offshore multiple module floating platforms. The facility is a unique asset for our offshore educational and research program and should prove useful to the industry's development program of complex deepwater offshore structures. The floor plan and section below illustrate the major features of the facility which will be ready for service in October 1990.

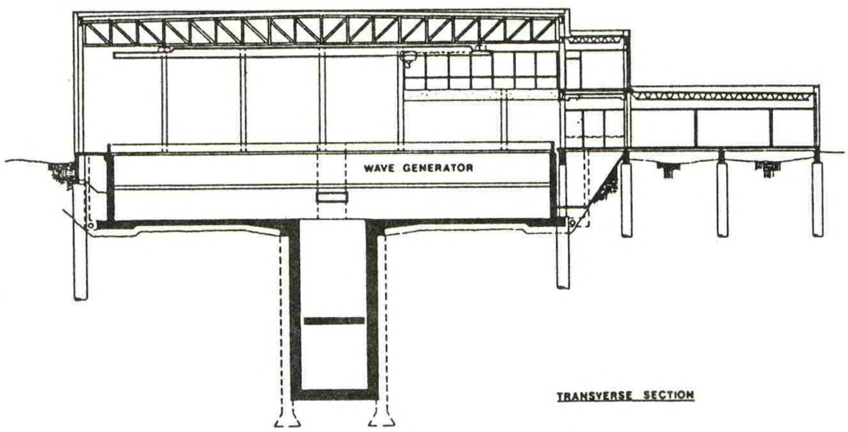
Conclusion

The rapid development of the Offshore Technology Research Center's research program and the very strong support supplied by the petroleum and offshore industries clearly indicates the importance of deep ocean resource development to our nation and the world. The support of the National Science Foundation and the more than 30 companies of the United States, Norway and France listed below suggest that the Center's program is properly focused in both research and academic areas. The effective transfer of the technology is assured by the close association of our teachers, researchers and industry practitioners. We look forward to continued growth of the program and the opportunity to contribute to the development of international offshore natural resources.



OFFSHORE TECHNOLOGY RESEARCH CENTER WAVE TANK FACILITY

Figure 1



OFFSHORE TECHNOLOGY RESEARCH CENTER WAVE TANK FACILITY

Figure 2

OFFSHORE TECHNOLOGY RESEARCH CENTER
INDUSTRY SUPPORTERS

Company Name & Location

ARCO Oil and Gas Co.
Dallas, TX

BP Exploration, Inc.
Houston, TX

Brown & Root, Inc.
Houston, TX

Cameron Offshore Engr., Inc.
Houston, TX

Chevron Oil Field Research Co.
La Habra, CA

Columbia Gas System
Wilmington, DE

Dow Chemical USA
Freeport, TX

Elf Aquitaine Petroleum
Houston, TX

Exxon Production Res. Co.
Houston, TX

FMC Corporation
Houston, TX

Fugro-McClelland Inc.
Houston, TX

Hudson Engineering Corporation
Houston, TX

Institut Francais du Petrole
Paris, France

International Underwater Contractors, Inc.
City Island, N.Y., N.Y.

Mobil Exploration & Producing Serv., Inc.
Dallas, TX

Mobil Research & Development Corp.
Dallas, TX

H.O. Mohr Research & Engineering, Inc.
Houston, TX

National Oilwell
Houston, TX

Omega Marine
Houston, TX

OXY USA Inc.
Houston, TX

Pyramid Manufacturing
Houston, TX

Reading & Bates Drilling Co.
Houston, TX

Shell Oil Co.
Houston, TX

Statoil
Stavanger, Norway

Tenneco Inc.
Houston, TX

Tenneco Gas
Houston, TX

Texaco USA
New Orleans, LA

Unocal Corporation
Brea, CA

Vetco Gray Inc.
Houston, TX

June 8, 1989

Advanced Ship Technology Development

PRESENT STATUS OF THE JAFSA'S MHD PROPULSION SHIP PROJECT

by Seizo Motora, Setsuo Takezawa, and Hiroshi Tamama
Japan Foundasion for Shipbuilding Advancement

Introduction

As it was presented at the 15th Marine Facilities Panel of UJNR, Japan Foundation for Shipbuilding Advancement has been promoting a project to construct a MHD propelled experimental ship which is expected to be completed at the end of 1989 fiscal year with Mr. Yohei Sasakawa as the leader of that project.

The project is progressing almost as scheduled, and MHD thrusters and relating machineries have almost been constructed and are now at adjusting stage.

The ship itself will be constructed from November this year at Kobe shipyard of Mitubishi Heavy Industries Co. Ltd., and equipment of MHD thrusters and machineries will be finished by the end of March 1990.

1. MHD thruster using superconducting magnetic coils

A set of MHD thruster consists of six dipole unit coils of which inner diameter is 0.360m, length is 3.90m and magnetic flux density at center is 3.5T. These six unit coils are arranged so as to form a ring so that leakage of the magnetic flux outside the thruster set is very small, and due to superposition effect, magnetic flux density at the center of each coils becomes to be 4.0T.

Two sets of MHD thrusters are constructed, one by Mitsubishi Heavy Industries Co, Ltd. and the other by Toshiba Corporation with a little different practice, and will be installed on port side and starboard side of the ship respectively.

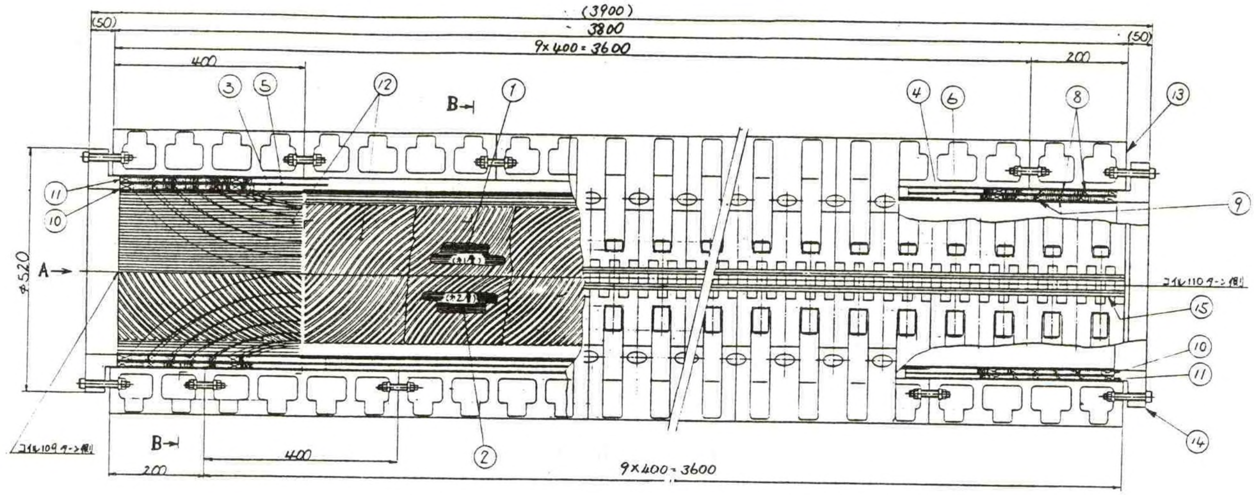
The Total Lorentz force generated by two sets of the thrusters is 16,000N, and the thrust to be generated is expected to be 8,000N.

1) Unit dipole coils

Unit dipole coils consists of stainless steel (SUS 316L) inner tube, a pair of two layers dipole coils so as to generate uniform magnetic flux perpendicular to the axis of the inner tube, and coil collars. The water duct made of FRP is placed inside the inner tube, so as to generate electric current perpendicular to the magnitic flux. Dimensions as well as the arrangement of each coils are as shown in Table 1 and Fig.1.

Table 1 Particulars of the unit coil

Inner diamenter of the coils	0.360 m
Inner diamenter of the duct	0.240 m
Length of the coil(total)	3.70 m
Length of the coil(parallel part)	3.00 m
Number of turns	220 ×2 layers×2 poles
Normal electric current	4,600 Amp
Magnetic flux density at center (for single unit)	3.5 T



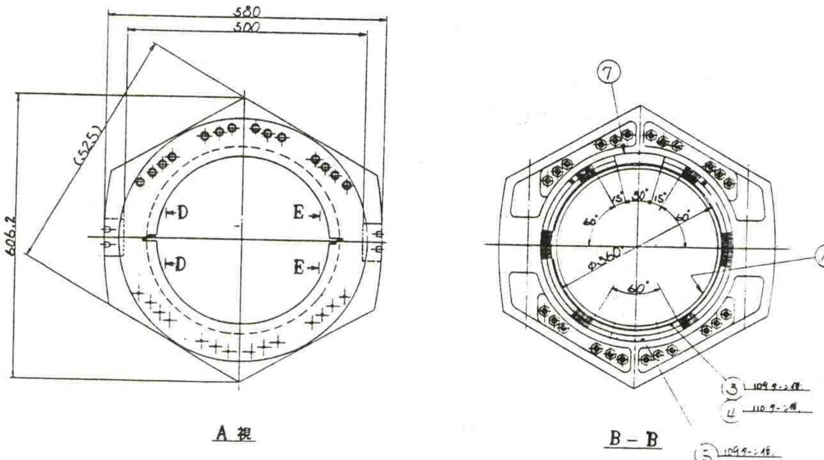
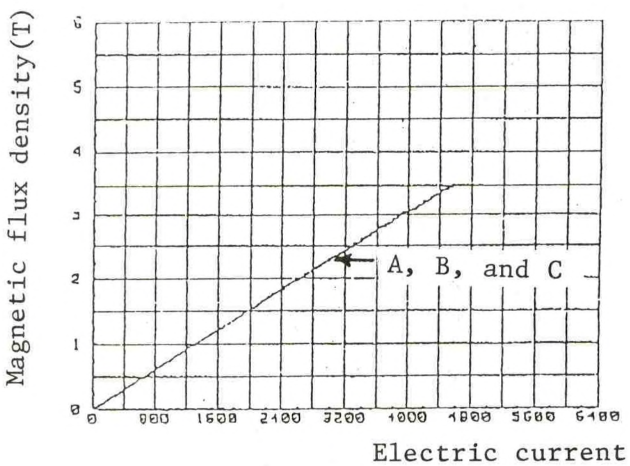


Fig. 1 Unit superconducting coil.

1 coil (1st layer)
2 coil (2nd layer)
3 coil key
4 "
5 "
6 "
7 "
8 coil spacer
9 "
10 coil end plate
11 "
12 coil cover
13 coil suppresser (Collar)
14 end plate
15 key
16 inner tube of cryostat



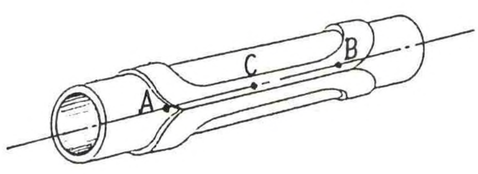


Fig.2(a) Measured magnetic flux density

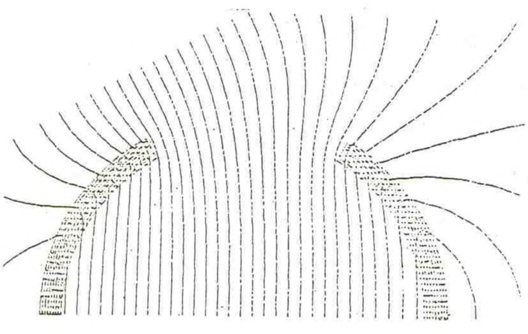


Fig.2(b) Equi-potential line of magnetic field

To wind up dipole coils of complicated configuration at an uniform tension, a special apparatus was developed.

Each coil was energized and trained by progressively increasing electric current experiencing some quenchings, and finally it was ascertained that a stable densigned magnetic flux density was obtained by the designed operational current. Measured magnetic flux density at the center and both ends of the parallel part of the unit coils showed practically the same value. Therefore it was ascertained that an uniform magnetic field was generated all over the parallel part of coils. An example of result of the test is shown in Fig.2.(a).

Distribution of magnetic flux density was also analysed. Result of calculated equipotential line shown in Fig.2(b) showed that uniform distribution of magnetic flux all over the section of the inner tube by the unit dipole coils was attained.

Strain of the coil collars was measured at typical points and compared with calculated value by FEM. It was found that measured strain agreed well with calculated value but the former was about 12% less than the latter.

2) MHD thruster set

A MHD thruster set consists of 6 unit dipole coils which are arranged to form a ring around a core tube. All coils are contained in a cryostat and kept at 4.2K by liquid Helium. At the center of each six coils, FRP tube is provided to form a duct through which sea water is driven.

A set of electrodes are provided inside the duct to generate electric current in sea water perpendicular to the magnetic flux. Six ducts protruding the cryostat are connected to inlet and outlet through disintegrating and integrating branch.

Helium refrigerator and Helium reservior are attached to each thruster set.

Particulars and arrangement of the MHD thruster set is as shown in Table 2 and Fig.3.

Table 2

Compound Magnetic flux density at center	4T
Electrode current (normal)	2,000 Amp
Lorents force	8,000 N/set
Thrust	4,000 N/set
Weight	18 t/set

3) Persistent current switch

In practical operation, coils are cooled down and energized at the base on land, using Helium refrigerator and electric source provided in the base, then switched to a permanent current by permanent current switchs provided in the ship. Thermal type switches are adopted.

3. Electrode current source

Electrode current source is practically the power source for propelling. Since large direct current at comparatively low voltage is required alternative current generated by a generator driven by a high speed diesel engine is rectified by diodes and supplied.

To avoid vibration of electrodes and to avoid probable quenching induced by ripple current, electrode current is flattened by an inductance to decrease ripple ratio down to 3%. Particulars of the electrode current source is shown in Table 3.

1 vacuum container
2 upper vacuum container
3 LHe container
4 LHe resavour
5 80k shield
6 LHe tube
7 attachment to the hull
8 shield supporter
9 tension member
10 coil suppresser
11 inner tube of the cryostat
12 center column
13 thrust bearing beam
14 L. He anti-sloshing plate
15 support
16 bellows
17 "
18 protective resistance
19 permanent current switch
20 superconducting coil

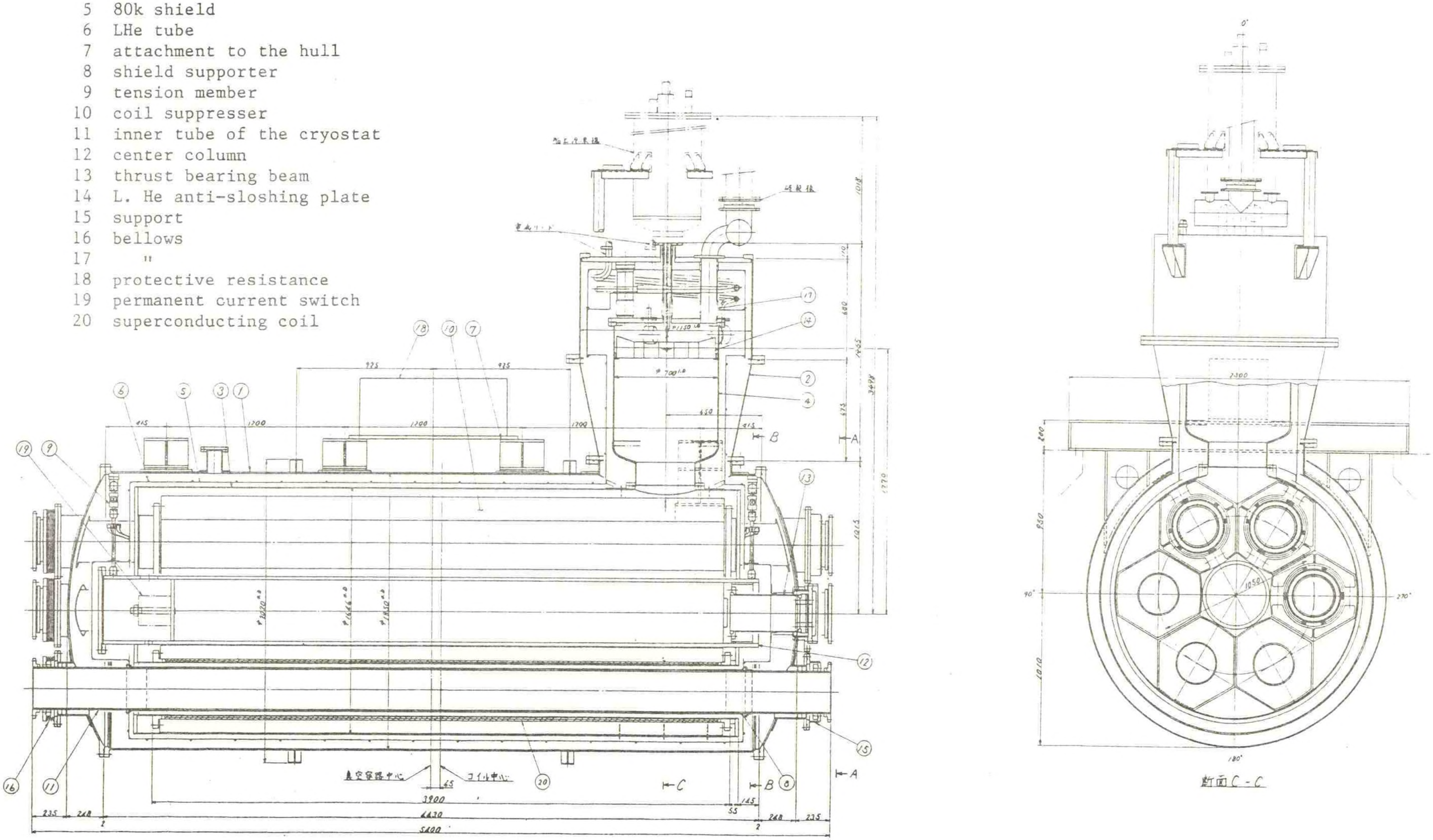


Fig. 3 MHD thruster set

Table 3

Generator	370V, 90Hz, 1,800rpm×2
Engine	2030KW MTU high speed engine×2
Electrode current	2,000Amp
(for a pair of electrodes)	
Voltage between electrodes	150V
(for a pair of electrodes)	
Ripple ratio less than	3%

Three pairs of electrodes out of twelve pairs of electrodes are connected in series, and four such groups are connected in parallel.

4. Electrodes

For material of the electrodes, Titanium coated by an oxide will be used tentatively.However other material which generate much less chlorine is now under development.

5. Helium refrigerator

To minimize consumption of helium on board the ship, a compact expansion turbine helium refrigerator, capacity of which is just about to cover the heat leaks into the cryostat, was developed by Kobe Steel Ltd.. Particulars of it is as shown in Table 4.

Table 4 Particulars of the He refrigerator

Diameter of rotor	6.00 mm
RPM of rotor	636,000
Power absorbed	10W (at 4.4K)
Weight	100 kg

These machineries and apparatus are almost completed and are now at adjusting stage, and will be equipped on the experimental ship at the beginning of the next year.

Total weight of the propelling machineries including thrusters, generators, diesel engines, refrigerators, stwichboard etc is about 130t.

6. Ship hull

The size of the ship somewhat has increased from the initial design as the propelling machineries actually constructed, and weight and necessary space became clear. The final particulars of the ship is as shown in Table 5.

Table 5. Particulars of the experimental ship

Length overall	30 m
Length between perpendiculars	26.4 m
Breadth(molded)	10.39 m
Depth(max)	3.69 m
Draft(max)	2.69 m
Displacement	185 t
(including water in the ducts)	
Speed	about 8kts
(at Lorents force 16,000N)	
Material of the hull	Aluminium
Number of person	10 including 3 crew

Outside view and general arrangement are shown in Fig.4 and Fig.5.

The ship is expected to be completed by the end of March 1990, and after some adjustment and trials of machineries on land, sea trial will be strarted from June, 1990.

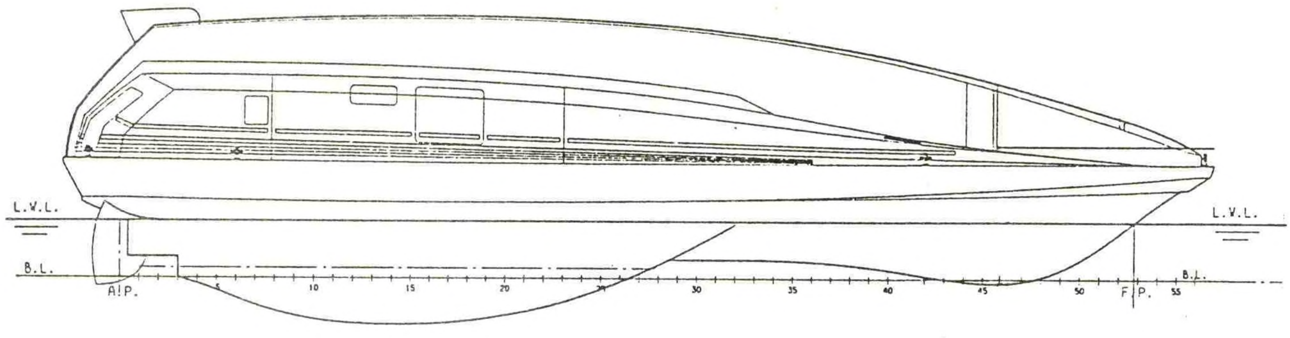


Fig. 4 Side view of the experimental ship

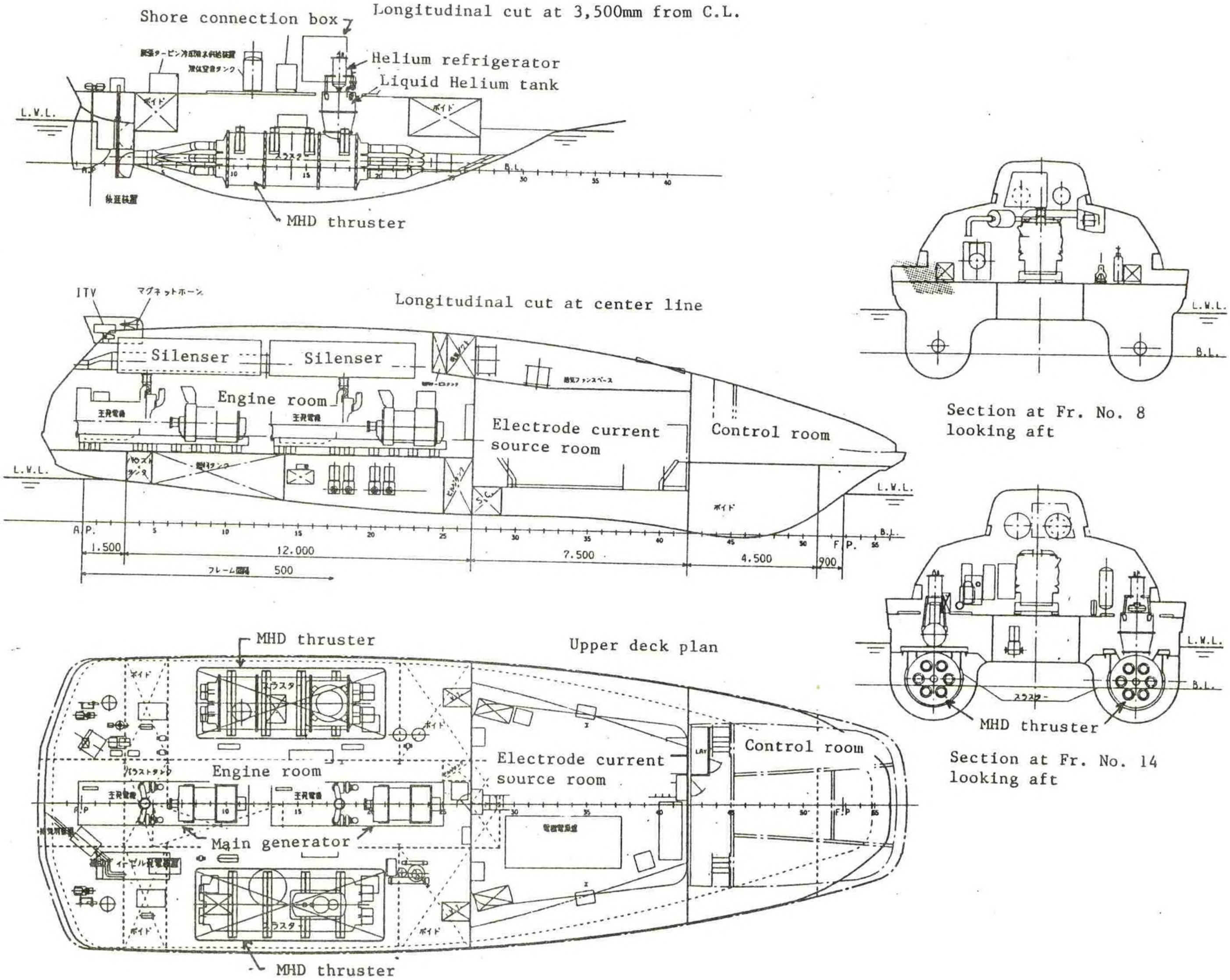


Fig. 5 General arrangement of the experimental ship.

System Design and Decision Making System of Intelligent Ship

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1.Introduction

An attempt to develop highly automated ship which navigates automatically without support by human onboard, has been performed by the Japan Ship Builders mainly. Such ship is called "Intelligent Ship". To realize the Intelligent Ship there are many difficulties to be solved. In such difficulties social one and technical one are included.The main of social difficulties is to get social consensus and this is cannot be reached in short time. But in contrast with this technical difficulties are rapidly being solved by leading edge technologies as high-sensitivity sensor high-density data transmission network etc.

Today on ship navigation, ship and several shore based sites must cooperate exchanging necessary informations. It is because a ship cannot obtain all informations necessary for navigation itself. So intelligent ship must cooperate with shore based sites. Considering such conditions, the design of intelligent ship is included in the design of entire navigation system composed of ships and shore based sites. We call such system named "Onboard-Shore Integrated Ship Navigation System.

In intelligent ship there are several kinds of automation sub- systems of navigation. The most important and difficult systems to realize of all sub systems are the systems to act for human decision, which are supervisery system and judgement system. We call them "Onboard Decision-Making System"

In this paper a general design of "Onboard-Shore Integrated Ship Navigation System" is presented in chapter 2, and an example of "Onboard Decision-Making System" is shown in chapter 3.

2. General System Design

In "Onboard-Shore Integrated Ship Navigation System" it is a important probrem how assign navigation tasks ship and shore based sites. Considering the principle of freedom at sea and the right of concerned parties , it is reasonable to assign navigation tasks as present. If the assignment would be done as present, the greater part of navigation tasks must be done by intelligent ship. So ability of onboard systems of intelligent ship must be very high.

Considering above-mentioned things the general design of "Onboard-Shore Integrated Ship Navigation System" is performed as shown in Fig.1. The design is presented by the reference(Nagata,1987) and which is generally agreed in Japan Ship Builders.

2.1 Onboard Navigation System

Several tasks must be performed which are position fixing, course setting, motion control, collision avoidance, communication with other ships and shore based sites,berthing etc.···. by intelligent ship. If one computer performs all tasks, when the computer would be troubled, navigation is stopped. So it is better method that one computer performed one work and supervisory computer(named "Onboard-General Control System" in Fig.1) control such computers. When one of them is troubled the supervisory computer take the backup action. Consequently onboard system of intelligent ship is distributed system which several computers are connected through network.

2.2 Shore Based Systems

2.2.1 Vessel Traffic Management Center

Vessel Traffic Management Center is to manage vessel traffics in its management area in order to control mainly each ship's incoming time into the area, and to be capable of digitally encoding about the same amount of information that is currently handled by the existing Vessel Traffic Management Center for transmission to ships brought up electronically to a high level of intelligence and also to be capable of communicating to Vessel Traffic Control Center personnel through display on CRT etc. digitally encoded messages transmitted from the intelligent ships.

The functions and equipment which each Vessel Traffic Control Center should have are indicated in Fig.2.

2.2.2 Shore Information Support Center

Shore Information Support Center is to support navigation of each ship in order to inform necessary information as the berth for arrival,and to be capable of transmitting to the intelligent ships about the same amount of information, in the form ofdigitally encoded messages, that is currently handled by the ship operators' agents and also to be capable of decoding the digitally encoded messages transmitted from each of the intelligent ships and communicating the decoded messages to the personal of each responsible agent by teletyping, etc.

The functions and equipment which Shore Information Support Center should have are indicated in Fig.3.

3.Onboard Decision-Making System

3.1.Modeling of Onboard Decision-Making System

The total judgment process by human seems to have multiple levels. The top level process judges the global matters and checks the consistency from the macroscopic viewpoint. It makes principal decision and offers guidelines for the judgment in the lower level. The lower level judgment,on the other hand,judges matters and situation for a restricted region,and makes decision in detail. Generally a process of judgment and decision-making can be modeled as the following sequence seen in Fig. 3(Fuwa,1989).

After examination of informations collected,the real state of the situation is estimated.This is the stage of the judgment and understanding of the situation. Sometimes the estimation is information itself or state of the situation desired in future. The estimation is defined by the amount and accuracy of information,the way of inference etc.,and it depends on an amount of experiences and knowledge of the ship operator or system designer. Secondly,it is determined what to do and not to do in the situation based on the aim,principle and strategy of the system.This is the stage of decision-making.In this stage the experience and knowledge are also utilized. Thirdly the best plan and optimum procedure are made out if it is required. This is the stage of planning. Lastly commands for the actions are ordered just on the time necessary according to the action plan.

Usually these stages are repeated iteratively, and sometimes they are repeated like a trial and error manner in assumption before the actual judgment or decision is obtained. When interactions or conflicts have happened during the process, another knowledge for the resolution is recalled and applied. The iteration loop can be in the upper or meta level as well as in the same level.

3.2 Computer Model of Onboard Decision Making System

A new computer model for the judgment and decision-making process in ship operation is proposed. It performs several kinds of tasks. It is composed of a hierarchical structure and hybrid of different styles in algorithm presentation and programming. The top and higher level of the hierarchy take roles of understanding and judgment for working situation and make a plan and guidelines of the tasks. The lower level is corresponded to the judgment in narrower range of the tasks as collision avoidance, finding out of suitable way of action etc.

3.2.1 Implementation by a Knowledge based System

A practical modeling of the judgment and decision-making process shown in Fig. 4 is proposed on the analogy of the human judgment. The feature of the model is its hierarchical structure and application of knowledge based system in the top and higher levels of the process.

The top level judgment responds to informations from the lower level judgment and other information as well, and performs in the global or macroscopic view by knowledge in the knowledge base. The knowledge is expressed as production rules. Inference based upon the IF___THEN___RULE is performed by ready-made inference engine (called "ART"). General judgment and understanding of the situation, and decision-making are the two major subject of the top level judgment process.

The top level judgment performs is final judgment and decision-making for the whole voyage plan and actions. The judgment, however, will not give command of action directly but supervision only. Usually it shows the results of judgment and understanding for the situation or gives guidelines for action.

The supervising function is realized in two ways. One is an explicit supervision in the form of command to the lower level, which is realized as the assertion of Fact in the knowledge base. The other is implicit supervision which indirectly affects to the whole of the knowledge base by means of special Fact handling named Control Fact. The higher level judgment, which includes the management of the judgment process in the lower level and some judgment and decision-making in the level, is also a knowledge based system. The ordinary judgment has a role of judgment and decision-making after a well defined sequential procedure, and orders the processes of action by commands. The knowledge based system works one of an asynchronous processes in the multi-process type simulation system.

Rules in knowledge base is classified in two categories. One is rules for system management of judgment, such as data handling with other simulation processes programmed in LISP or FORTRAN, timing management and flow control of the interface. Other is rules for the expression of the knowledge in the real world. According to the modeling of judgment ship navigation and decision-making shown in Fig. 3, rules for the knowledge in the real world are classified with four groups.

Of course it is possible to build up either whole process of judgment from primitive to the top, or whole of the simulation system as a knowledge based system (Jin,1987;1988). Different style of system design is chosen here in order to realize a real time simulation system in a large scaled multi-process system. A lot of existing software programs in FORTRAN are utilized, and CGI system on advanced graphic workstations in the computer network is built up easily by means of the hybrid style.

3.2.2 Hierarchy in Knowledge based System

It is not procedures but knowledges that are expressed and programmed in the knowledge based system. The flexibility is a remarkable feature and an advantage of the knowledge based system which has plenty of possibility in new practical domain and offers much freedom for the system design.

In some cases needless freedom for a well defined problem spoils an easiness in the system design. A knowledge based system is designed after the hierarchical modeling of the judgment process but deferent from the viewpoint of system freedom.

A Control Fact system is introduced after the two stand points. One is management in the kind of task and another is control for the level of

the situation. Level of the situation has essential meaning but kind of task is only for the convenience of the system management and system design. These control facts are governed by the top level judgment process. The top level judgment can select the kind of work or restrict of the judgment in lower level by the management of the Control Fact. In other words the total inference is affected and controlled by the final judgment and understanding of the top level judgment process for the ship situation.
Each rules of the production system has three layered context in its IF_part as shown in Fig. 5. The first is conditions for the system management, the second for the Control Fact,i.e.,for the control of inference by higher level through the control fact management, and the last is for ordinary conditions of knowledge expression.
By this way ordinary knowledge based system designed by segment according to the kind, is put in the hierarchy and unified. As the results the knowledge based system has wider range of validity. The hierarchy is also helpful for the management and handling of the total system.

3.3 Results of Computer Simulation and Discussion

A data centered and scenario driven type of computer simulation system is built. (Fuwa, 1987a;1987b) It is easy to carry out simulation in various kind of condition by the system.

In this chapter an example of simulation results at emergency condition that fire occured in which condition the action of developed "Onboard Decision-Making System" is clearly observed is shown.
Fig.5 - Fig.7 show the results of simulation for the navigation in emergency condition. Time histories of state variables; ship velocity, course angle, rudder angle, revolution of propeller are shown in Fig. 5 Trajectories of ships are shown in Fig. 6 with corresponding marks to the time history of state variables for own ship. Fig. 7 indicates the flow of the judgment by the knowledge based system.
This is a scenario for entering to Tokyo Bay and an accident is happened onboard of the ship. The following sequence is seen in Fig. 7 .
When the ship is running in Uraga Suido Traffic Route, a fire is broken out at time 1. A trouble or accident is noticed by the alarm, and a necessary check is requested by the judgment process. The accident is confirmed to be a fact and reported to the top level judgment process. The top level judgment recognizes that a fire onboard. Then the top level gives necessary orders to the lower level judgment processes as the supervision. A command of speed reduction to the three quarters is sent to the navigation system. When results of the checks and other related informations are brought to the top level by the management function of judgment for the trouble and emergency, the top level understands the scale and position of the fire, works for fire etc., and ship navigation conditions. The judgment decides to go out side of the traffic route for the safety of other ships and continue the work for fire. Various commands are ordered one by one , and the top level alters the level of situation to sever one for the supervision of the lower judgments. At time 4 the top level gets sufficient informations about the accident and fully understand the situation. By the supervision of the top level it is decided to stop the ship. At time 5 the fire is put off by the work and the extinction is reported to the top after confirmation. The top level judgment declares that the fire is over ,and the judgment sets the level of the situation to the ordinary level. The various tasks, which have been suppressed during the fire, begin to be performed again. The ship starts again and returns to the original reference course by means of a new by-

pass route.
Knowledge for the emergency increased their importance in the knowledge base by the functions of supervising rules in the top level of the judgment when they are expected. Therefore dynamic tuning of the knowledge-based system is performed by the event and design of the process structure.
Though it is a prototype of the system, the simulation results seem promising. Speed of inference, is a key point for real time system and some treatment in the simulation management might be required.
Knowledge-base is, as its nature, easy to be built and extend their range of availability by the additional knowledge. And only the application for various kinds of problem improve the system. So it is difficult to judge the complication of the system.
The knowledge based system works asynchronously to the other processes in the simulation system. Command and information exchange is modeled as data exchange by calling functions or writing data in common data area. The top level judgment works with the other part of simulation and affect the inference results indirectly. Performance speed of inference depends on Facts, rules and CPU.

4. Closing Remarks
The following remarks are presented.
(1) General design of "Onbord-Shore Integrated Ship Navigation System" is presented and according to the design desirable composition of onboard navigation system of intelligent ship is proposed which is distributed system.
(2) A hierarchical model for "Onboard Decision Making System" is proposed and a prototype is programmed in the multi-process type of simulation system for the automatic ship navigation. The top and higher level of the judgment processes are realized as a knowledge based system.
(3) The top level judgment process, which plays a role of supervision and managements of the lower level judgment, is also expressed as in the form of IF___THEN___RULEs in the knowledge base by the introduction of FACTs for RULE control. The hierarchical structure in the knowledge based system is useful and seems to be plenty of applications in practice.
(4) It is shown that the real time simulation is possible with the knowledge based system. Results obtained by means of a realistic simulation for ship navigation in emergency, are quite reasonable and promising. Advantages of knowledge-based system are confirmed by means of computer simulation.

Acknowledgment
The simulation system used in the present study is constructed under the cooperation of Japan Ship Research Association and Ship Research Institute. Authors are grateful to Japan Ship Research Association for its cooperations.

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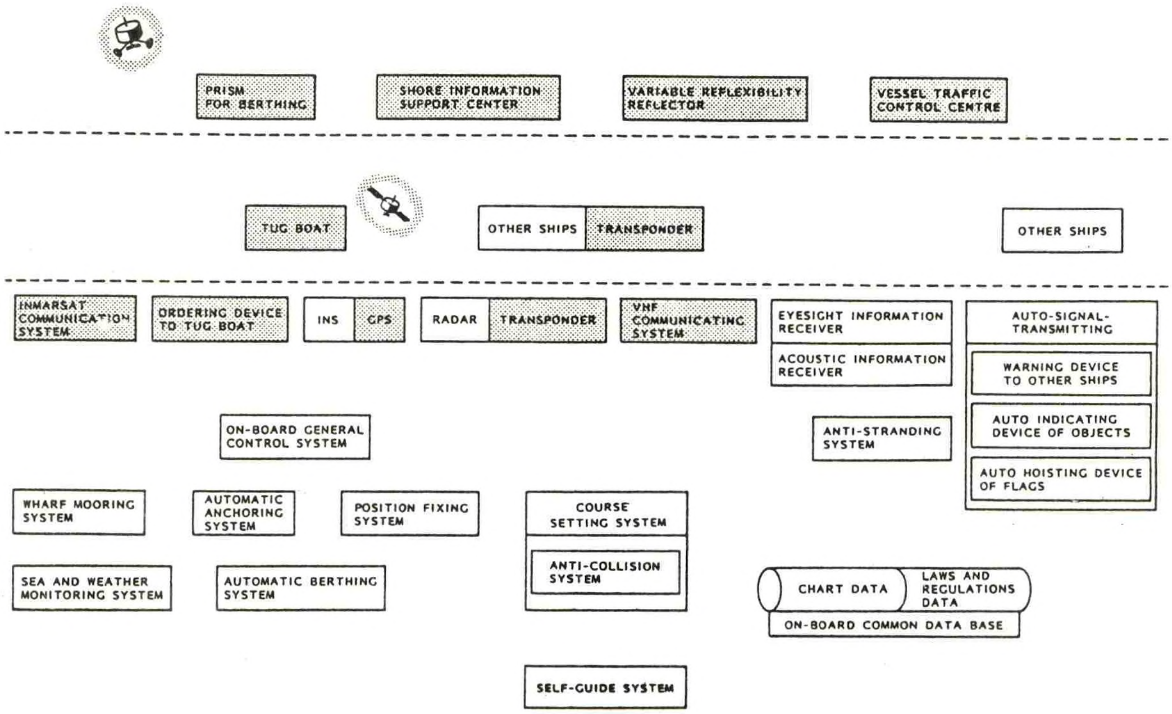


Fig.1 General Design of Onboard-Shore Integrated Ship Navigation System

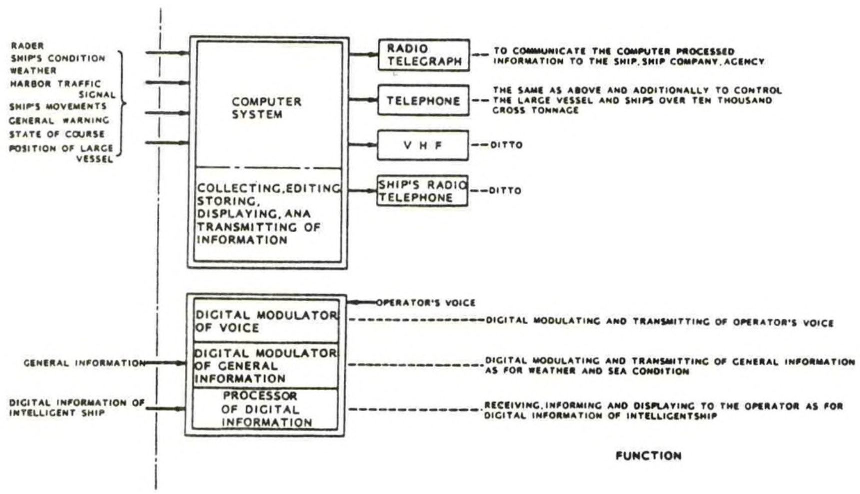


Fig.2 Vessel Traffic Management Center

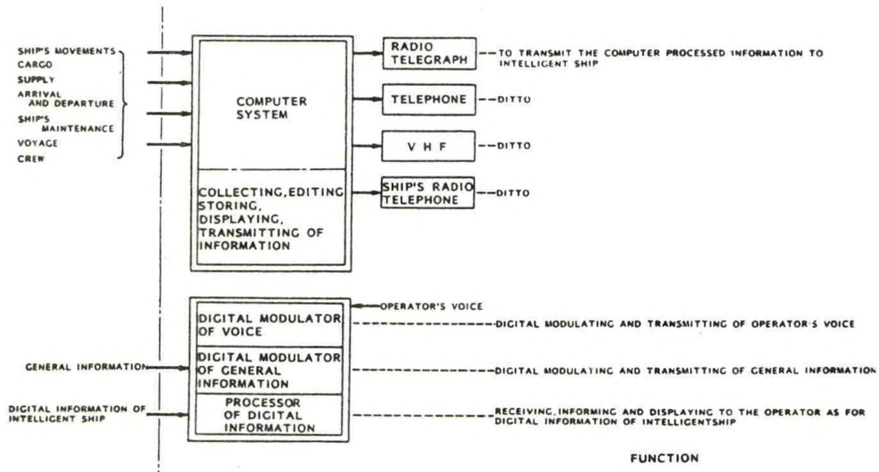


Fig.3 Shore Information Support Center

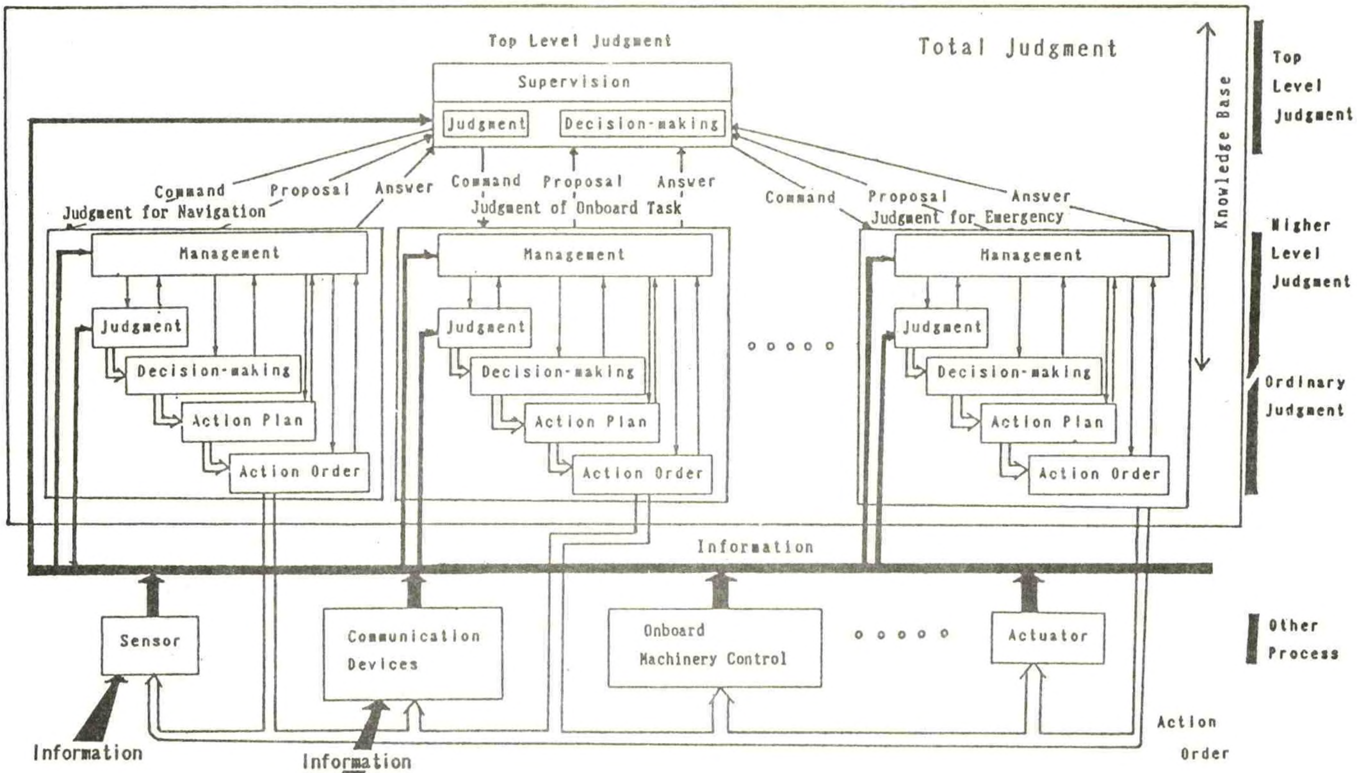


Fig.4 Structure of Onboard Decision-Making System

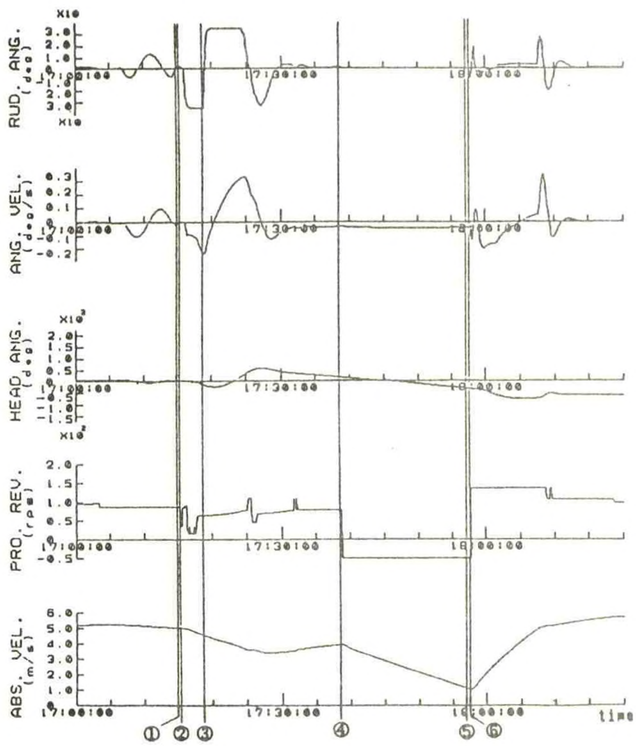


Fig.5 Simulation Result(Time History)

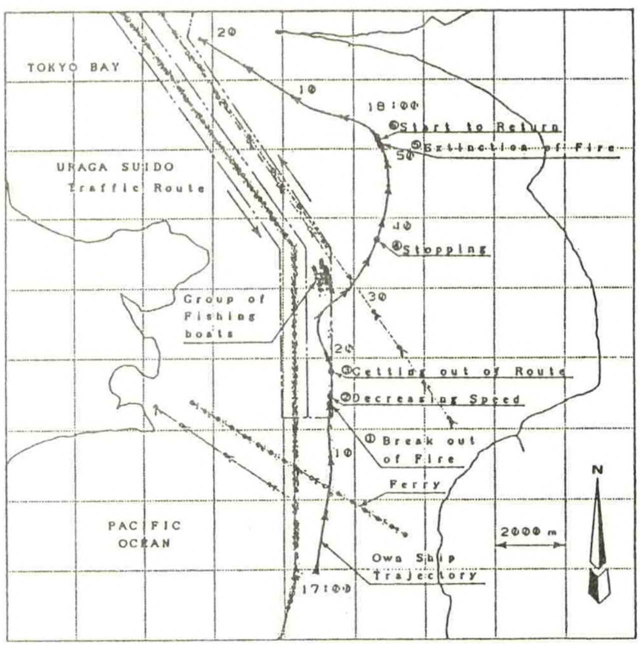
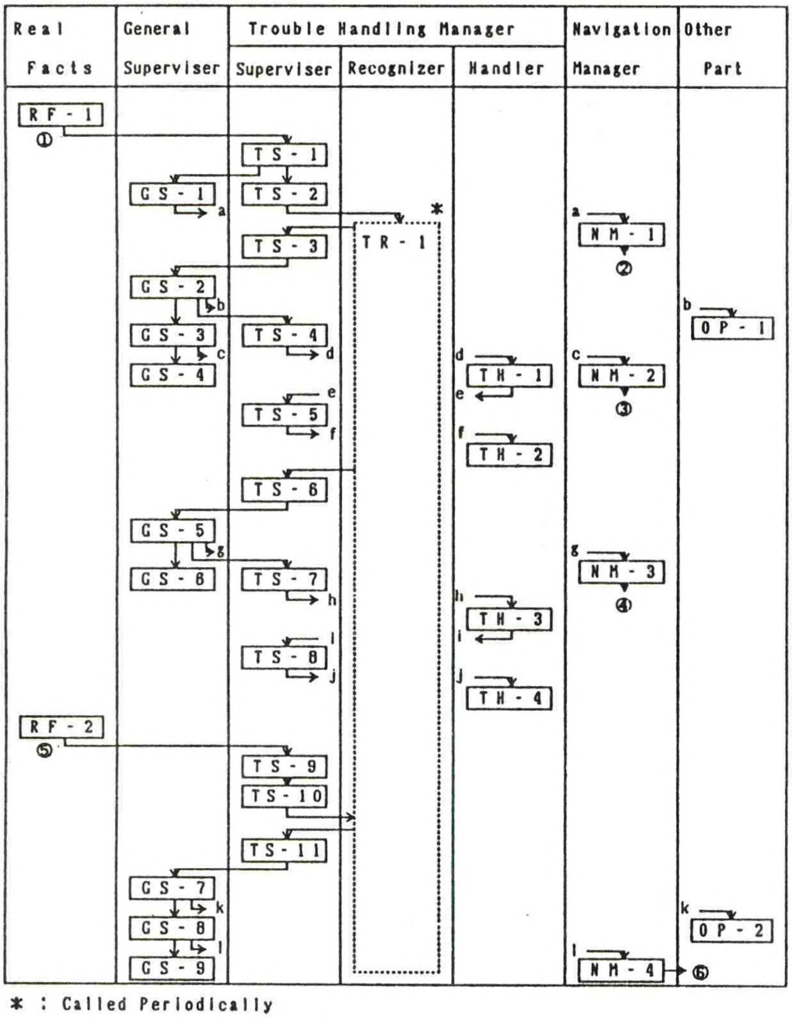


Fig.6 Simulation Result(Ship Trajectories)



RF-1 : Break out of trouble (fire)
RF-2 : Trouble repaired (Extinction of fire)

GS-1 : Order emergency action 1
GS-2 : Declare trouble
GS-3 : Order emergency action 2
GS-4 : Change mode
GS-5 : Order emergency action 3
GS-6 : Change mode
GS-7 : Declare end of trouble
GS-8 : Order recovery action
GS-9 : Change mode

TS-1 : Detect trouble
TS-2 : Order Diagnosis
TS-3 : Recognize trouble
TS-4 : Order making plan-1 of trouble handling
TS-5 : Order trouble handling (1)
TS-6 : Recognize change of level of trouble
TS-7 : Order making plan-2 of trouble handling
TS-8 : Order trouble handling (2)
TS-9 : Detect end of trouble
TS-10 : Order verification of end of trouble
TS-11 : Recognize end of trouble

TR-1 : Diagnosis trouble (kind and level) and verification of end of trouble

TH-1 : Making plan-1 of trouble handling
TH-2 : Trouble handling (1)
TH-3 : Making plan-2 of trouble handling
TH-4 : Trouble Handling (2)

NM-1 : Order decreasing speed
NM-2 : Order getting out of route
NM-3 : Order emergency stop
NM-4 : Order of start to return

OP-1 : Inform break out of trouble to VTS etc.
OP-2 : Inform end of trouble to VTS

Fig.7 Flow of Judgement of Onboard Decision-Making System

An Outline of Research into Maritime Access Ship for Kansai International Airport

Takeo Koyama

University of Tokyo

Kansai International Airport is now under construction to begin its service in 1993. This airport is located on an artificial island in Osaka bay about 40km,30km,70km respectively the ports of Osaka, Kobe and Shikoku. To this end, Japan Foundation for Shipbuilding Advancement (JAFSA, Chairman: Mr.Ryoichi Sasakawa) set up a Committee on Maritime Access Ship for Kansai International Airport chaired by Prof.Takeo Koyama of Tokyo University, and began in April 1987 a two-year research into access ships, focusing on six items as requisite for such means of transportation: (1)safety (2)swiftness (3)reliability (4)comfortability (5)auxiliary service and (6)economy.

Among these, safety is the essential factor required for public transportation. A series of investigations were conducted to varify the safety of access ship, such as a simulation study on occurrence of ship congestion in Osaka Bay; an experiment to avoid interception of seaways by use of operation simulators; a demonstration test on actual seaways using jetfoils and other advanced seacraft, and fact-finding overseas. In result, it has been proved that the safty of access ships, even in high-speed night navigation, can be fully ensured, if proper safty measures be taken.

As for the other five items, investigations were carried out to picture an optimum mode of maritime access to the Airport. A one-way trip in an access ship from Kobe to the Airsport is estimated to take 30 minutes, and the total time required for the access, including land trips, will be 30 to 40 minutes shorter than that for conventional land transportation. From an economic point of view, a round trip at a fare lower than that of land transportation will be possible on the Kobe route, if the route is used by about 6,000 passengers a day; and round trips on the Takamatsu route and Tokushima route will pay, should passengers number 1,330~1,360 and 1,420 respectively a day.

Based on the results of these investigations, the Committee has worked out measures to be taken toward realization of safe, comfortable maritime access.

1. SAFETY

The Committee conducted a wide range of quantative evaluation of access ships, such as a simulation study on occurrence of ship congestion; an experiment to avoid interception of seaways by use of operation simulators;

and a demonstration test on actual seaways, and studied safety measures for high-speed night navigation. The result is that the safety of access ships can be ensured, if safety measures should be taken properly, such as installation of raders, dark-field monitoring equipment, automatic rader plotting aids, and flashing light; the institution of rules on separate sea-lane navigation and earliest course alteration to prevent collision; educational training for crew members, and construction of on-shore control centers. Moreover, we have proposed that new concepts of high-speed seacraft be studied.

2. SWIFTNESS

High-speed access ships will cover the distance from Kobe to the Airport and vice versa in half an hour. The total time of the Kobe route access including land trips will be reduced to about an hour, promising an arrival at the destination about 40 minutes earlier than by travel over land.

3. RELIABLE SERVICE

Although access by sea is free from such traffic congestion as on land, it is essential to develop seaworthy ships less subject to the affect of weather and to make up versatile sailing schedule. While access ships are expected to ply frequently between the Airport and coastal cities, prompt notice must be given through mass media and alternative means of access be secured in case of cancellation.

4. COMFORTABILITY OF TRAVEL

Much attention must be paid to amenities and service which will excite a traveler's emotion, such as commodious passenger cabins of refined design; special hull structure limiting rolling and vibration to a minimum; easy transfer at a railroad terminal; baggage handling service, of which the last is dispensable with high-speed limousine ferries because a direct connection to limousines is available.

5. AUXILIARY SERVICE

Access ships are to shuttle between the Airport and coastal cities at an optimum interval, so as not to make passengers wait too long before embarkation. It is desirable that buses send passengers to and pick them up at main hotels and railroad stations. Up-to-the-minute information should be provided on flights and sailing schedule.

6. ECONOMIC CONSIDERATIONS

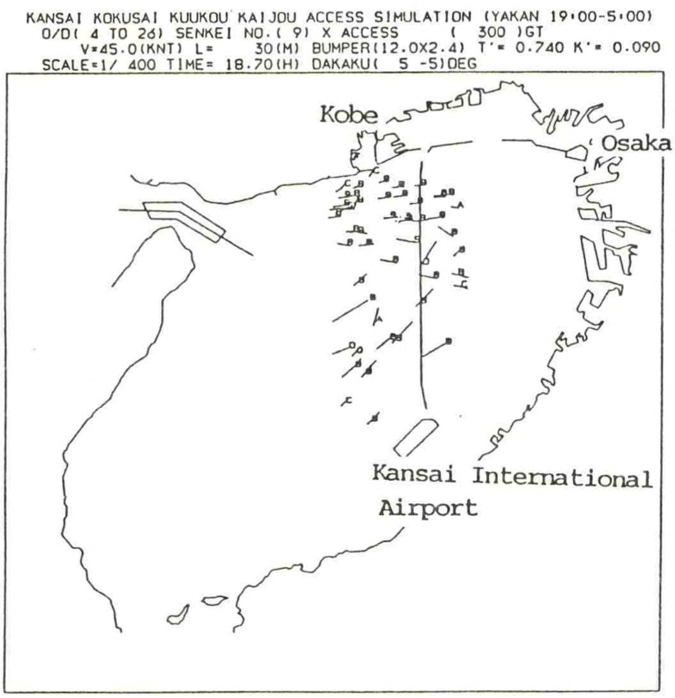
To take a round trip on the Kobe route for example, it will be less expensive than land transportation, if 6,000 passengers use the route a day. Round trip service on the Takamatsu route and Tokushima route will be profitable, if passengers number 1,330~1,360 and 1,420 per day respectively.

	high-speed navigation	night navigation
B. detector		
・detector		
dark-field monitoring equipment	—	◎
raders	◎	◎
anti-collision ancillery equipment	○	○
searchlight	—	△
・correspondence between ships and ships		
V H F	○	○
ship telephone	△	△
marionet telephone system	◎	◎
C. rules on navigation		
・flashing light	—	◎
・separate sea-line navigation	◎	◎
・course alternation to prevent collision	◎	◎
・wide separated distance	○	○
D. crews		
・working conditions	○	○
・an increase of the staff	○	○
・training	○	◎
E. and so on		
・land control system	◎	◎
・head phone	△	△
・voice recorder	△	△
・seat belt	○	○

Fig.1 Safety measures list of access ship

◎ it is expected to be very effective safety measures
○ it is expected to be effective safety measures
△ it is expected not to be very effective safety measures

(1) front range of vision
ships in 45 degree



(2) ships which alter the course
to prevent colligion

Fig.2 a route model by navigation simulation
in Osaka Bay

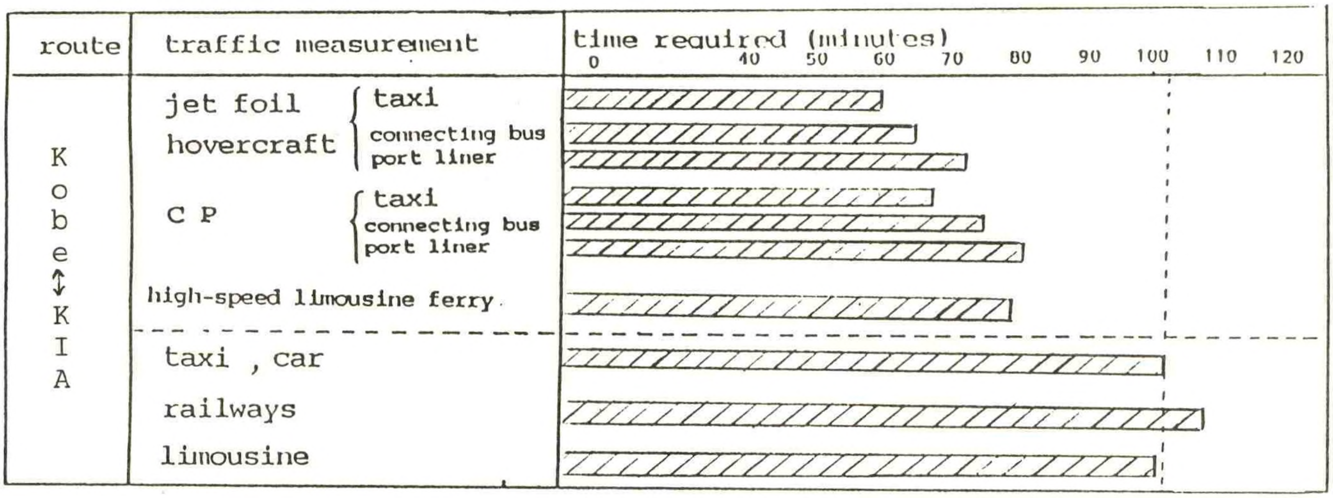


Fig.3 comparison between land access time and maritime access time

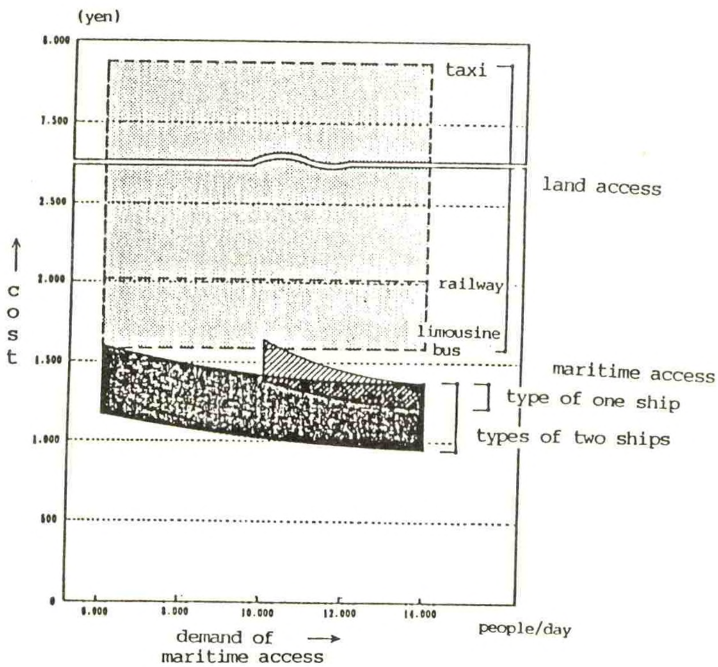


Fig.4 comparison between land access costs and maritime access costs

RECENT TECHNOLOGY DEVELOPMENTS IN THE U.S. MARITIME COMMUNITY

APPLICATION OF ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS TO SHIPPING OPERATIONS

Henry Chen - Ocean Systems, Inc.
Jeffrey Dillingham - JAYCOR
John Dumbleton - U.S. Maritime Administration
Martha Grabowski - Rensselaer Polytechnic Institute
Kevin Logan - MACSEA, Ltd.
Paul Mentz - U.S. Maritime Administration

Introduction and Background

The United States depends on its domestic and international commerce as a vital element in its economic infrastructure. Our nation's diverse capabilities are dispersed throughout fifty states and its products must be collected and distributed through an efficient national transportation system. Likewise, our country's well-being is intertwined with that of the rest of the world, resulting in substantial commodity exchange or trade which depends upon responsive international transportation services.

In both the domestic and international areas, a choice of transportation modes is usually, although clearly not always, available. When available, however, waterborne systems often offer the most flexible and efficient services among the alternatives. Ships, ferries, tugboats (or towboats) and barges, and other marine craft are an indispensable part of our nation's domestic and international transportation services, along with the necessary ports and waterways to support such services from shallow rivers to deep oceans.

This conclusion is further developed in Title I - Declaration of Policy of the Merchant Marine Act of 1936 (as amended). An edited version is as follows:

It is necessary for the national defense and development of its foreign and domestic commerce that the United States shall have a merchant marine....owned and operated under the United States flag by citizens of the United States....constructed in the United States and manned with citizen personnel....sufficient to carry its domestic waterborne commerce and a substantial portion of the waterborne export and import commerce of the United States.... and capable of serving as a naval and military auxiliary in time of war or national emergency.

This clearly stated goal has always been difficult to attain and has become increasingly so in recent years. Yet the need now seems greater than ever.

It is generally concluded that action is necessary to (a) encourage capital investment in U.S. maritime enterprise through the restructuring of promotional policies, and (b) encourage greater innovative productivity and competitiveness in the ocean shipping and shipbuilding industries of the United States. Of the many areas of technological innovation that are being explored to assist in meeting this latter objective, artificial intelligence and expert systems are among the more intriguing and exciting. This paper will describe some of our recent experiences in this regard.

AI/ES State of the Art

Definitions of artificial intelligence cover a wide spectrum; here are three that have been provided by the authors of some well known AI textbooks: "Artificial intelligence is the study of ideas which enable computers to do the things that make people look intelligent"-- Patrick Winston (Massachusetts Institute of Technology)

"Artificial intelligence is the study of how to make computers do things which, at the moment, people do better"-- Elaine Rich (University of Texas)

"Artificial intelligence is the study of mental faculties through the use of computational models"--Eugene Charniak (Brown University) and Drew McDermott (Yale University)

Whereas the first two definitions make the essential point that AI is concerned with making computers perform in a human-like way, the third definition is aimed at the research side of AI; i.e., what is human thought? The point of view that AI is a research discipline is borne out by the fact that commercial applications of AI have only recently come to fruition with commercial development unheard of before the late 1970's.

By far, the single most developed part of AI is that of Expert Systems (also called knowledge-based systems and deductive reasoning systems). Although attempts have been made to commercialize other elements of AI (natural language processing, intelligent vision and speech, and intelligent robots), the greatest emphasis has been on expert systems.

An expert system can be characterized as nothing more than a unique type of computer program. Perhaps the best way to describe an expert system is to compare it with the traditional algorithmic program. In the algorithmic program, the knowledge of how to solve a particular program is encoded explicitly and permanently into the program in the form of procedures or algorithms. Such a program is capable of receiving input data, processing it in some fixed way, and outputting some useful information. The main distinguishing feature of the expert system is that the knowledge about a specific problem may be stored separately from the program itself. The file containing the knowledge is known as a knowledge base. The program which processes this knowledge base is often referred to as the inference engine. The inference engine and the knowledge base together comprise the expert system.

The evolution of expert system hardware, programming languages and software tools (commonly called "expert system shells") has been nothing short of phenomenal. Whereas only five years ago, the only way to develop meaningful expert system applications involved using special purpose LISP machines and expensive shells at very high cost, today there are major applications being developed at a fraction of the cost on PC's and general purpose work stations. As a result, we are seeing more affordable applications being developed in an integrated manner with ongoing operations.

AI/ES in Shipping Operations

Since 1969, the Maritime Administration has sponsored a cooperative program with the U.S. flag shipping industry to apply leading edge computer technology to the operations and management functions of ship operating companies. When the program first began, most shipping companies did not even own computers. As a result, the early program was revolutionary in that it was largely responsible for bringing about the computerization of the basic functions that shipping companies perform today; cargo documentation, financial control, and container management.

During the period which followed, many innovative results have been accomplished, including:

a. Development of software modules for all functions of shipping company operations.

b. Satellite communications for ship-to-shore voice and data communications.

c. Electronic data interchange for exchange of data from one company's computer to another company's computer.

d. Extensive use of personal computers aboard ship and in the office.

The next major innovation that we are seeing in the area of computer technology for the shipping industry is in the field known as "artificial intelligence" or AI. Although AI has been studied and researched by academia for over 30 years, there was little commercialization of the technology until the early 1980's. So, in 1985, the Fleet Management Technology program embarked on a dedicated effort to explore the potential and pitfalls of this emerging technology.

In the summer of 1985, MARAD issued a request for proposals for cooperative research projects with the U.S. ship operating industry. The emphasis was on the application of artificial intelligence technology to appropriate problems in maritime operations, both shipboard and shoreside. As a result, several contracts were awarded to conduct exploratory research in a number of areas. Highlights of these projects, several of which will be described in detail later in this paper, are as follows:

1. <u>Application of Artificial Intelligence in the Maritime Industry: Problem Definition and Analysis; University of Michigan</u>

This was a survey project whose objective was to examine the technology of artificial intelligence (as well as the predominant subset of this technology which was being commercialized, i.e., Expert Systems) and to evaluate how it could best be applied to the problems of the shipping industry. The major products of this research were a cost/benefit analysis of the more significant potential applications in marine operations, a more detailed assessment of two of these applications (containership stowage planning and shipboard performance monitoring), and a review of hardware and software tools available at the time. The report (1) of the project results provides a good reference for evaluation of future applications.

2. <u>MEMEX: An Expert System for Vessel Energy Management; Ship Analytics Incorporated and University of Connecticut</u>

A prototype expert system was developed to reason about problems related to energy management as they apply to the maintenance of medium speed diesel engine propulsion plants. The system consisted of three major components: a knowledge base of rules, an inferencing system, and a natural language interface. The system, developed on a Digital Equipment Corporation VAX 11/780 minicomputer in a FRANZ LISP programming environment, was successfully demonstrated. Although a shipboard version of the system was never developed, the project yielded significant results which are currently being utilized in the development of a real time system for a diesel engine (low speed) performance analysis and diagnostic system. Results of this project are documented in a two volume report (2).

3. Expert System for Diesel Engine Maintenance; American President Lines and MACSEA Ltd.

This project is currently at its midpoint and will result in an operational system installed onboard the APL vessel President Harding. The system will operate in real time, with sensor data being acquired from the engine performance monitoring system and the engine combustion analyzer. The operation of the system centers around an IBM - PS/2 microcomputer which acquires and analyzes the performance data, reasons about the conditions that it observes, and makes appropriate recommendations to the Chief Engineer to optimize performance and reliability. The project is being conducted with the participation and assistance of American MAN B&W (engine manufacturer) and Veritas Petroleum Services (fuel analysis vendor). In addition, Lykes Brothers, who is chartering the vessel to APL, is observing the activities of the project. Development of the system is planned to be completed during the fall of 1989.

4. Piloting Expert System; Rensselaer Polytechnic Institute

This project has addressed the problem of piloting a large vessel in a restricted waterway. As in many decision-making under uncertainty scenarios, deck officers and pilots engaged in piloting are inundated with information and are required to make crucial decisions in a brief time interval. As vessels become larger, cargoes more hazardous, and the waterways more congested, decision aiding technology will become more and more important. The Piloting Expert System will allow users to mentally rehearse various piloting transits before making the actual voyage. This project incorporated the Rules of the Road and specific piloting recommendations from Sandy Hook pilots for a transit through New York Harbor. The system was developed using a Symbolics Lisp machine and the Knowledge Engineering Environment (KEE) expert system development tool. Next steps include incorporating real-time position information through interfaces with bridge navigation equipment, the coupling of electronic charts within the system, and porting of the system to general purpose PC's or workstations. The project results are documented in a Technical Report and User's Manual (3).

5. Prototype Expert System for Containership Stowage Planning; Arctec Offshore Corporation, Farrell Lines, and JAYCOR.

This project developed a prototype system to provide advice for stowing containers on a large, modern, containership. The system was written in Turbo Prolog, a PC software package which has many of the capabilities of the popular AI language, Prolog. The system which was developed, called STOW, is a combination expert system shell and data management system, which is specifically designed to handle the stowage planning problem. In addition to developing the prototype system, the project included an evaluation of four test cases in order to evaluate its performance. The project also described further development required to provide an operational system. The development has recently been completed, and the results are documented in a Technical Report and Users Manual. (4)

In the next part of this paper, details will be described for three of the foregoing projects, as well as a fourth project which is a follow-on to an earlier MARAD project. This will be followed by a synopsis of other applications which are being developed for the area of shipping operations.

Discussion of MARAD Sponsored AI/ES Applications

A. Piloting Expert System

A considerable change in the size and structure of marine traffic has taken place during the last two decades. From 1960 to 1980, the number of tankers doubled and their tonnage increased sevenfold. Quick turnaround container ships evolved and numerous structures for oil and gas production have been erected in inland waters, complicating marine traffic flow. These changes make the pilot's and ship's officers' task of safely navigating vessels in congested waterways considerably more complicated. As vessels become larger, cargoes more hazardous, and waterways more congested, decision aids have been developed to improve the safety of navigation.

Much work in developing navigational decision aids has focused on standalone systems, not integrated with existing bridge designs. With the vast array of navigational aids provided on the bridges of even small ships, the requirement to make the information available easier to assimilate and use effectively is pushing the move to consolidate displays and the number of 'boxes' aboard ship. Systems engineering approaches to integrated bridge designs support the consolidation, as the decision-making requirements of future ship's bridges are determined, and integrated, rather than ad-hoc, functional architectures incorporating the use of decision aids are recommended.

One example of a navigational decision aid developed with the systems engineering approach to assessing pilots' decision-making requirements is the Piloting Expert System, a prototype expert system developed for the U.S. Department of Transportation, Maritime Administration. The system provides decision support to masters, mates on watch, and pilots in congested waterways by capturing the decision-making expertise of the local pilot and providing recommendations to the user. The system also allows users to mentally rehearse piloting transitsbefore making actual voyages. The Piloting Expert System is presently a standalone system, but is also fully integrable with future and existing bridge designs because of the systems engineering principles applied during its construction.

Expert Systems (ES) are computer programs which solve problems in a narrow domain of expertise using facts, beliefs, and heuristics. Unlike traditional information systems, expert systems solve problems associated with "intelligent" behavior, primarily non-numeric processes involving complexity, ambiguity, and uncertainty, for which algorithmic solutions do not exist. These solutions are knowledge-based, invariably require search, and heuristics to guide the solution process (5). Expert systems attempt to emulate the reasoning processes of human experts, who use domain knowledge and heuristics to "see" things about a problem that are unclear to a layman. Like human experts, expert systems rely on the interaction between knowledge and heuristic reasoning to solve problems.

With the Piloting Expert System, users can receive on-line piloting recommendations to support particular piloting passages, or they can use the system off-line, as a voyage planning or mental rehearsal tool. In mental rehearsal mode, users go through the thought processes associated with piloting, navigation, collision avoidance, restricted visibility, and emergency procedures before encountering these conditions on watch. The system provides a planning and rehearsal capability that mirrors the way senior deck officers and pilots encourage their junior deck officers to plan prior to assuming a watch or making a transit.

1. System Description

The Piloting Expert System was developed using the Knowledge Engineering Environment (KEE), an Intellicorp product (6), (7). The system incorporates both frames and rules in its knowledge base. Frames provide the structure for describing and classifying the objects reasoned about in the piloting domain- -ships, buoys, lighthouses, channels--into hierarchical classes and subclasses. For instance, the class of SHIPS in the piloting knowledge base is broken into the subclasses VERY.LARGE.SHIPS, LARGE. SHIPS, and SMALL.SHIPS, and further subdivided into CONTAINER.SHIPS, TANKERS, OBOS, FREIGHTERS, and ROROS. Each of the members of the SHIPS class has qualities of "breadth," "draft," "height," and "compass.bearing," each of which are reasoned about in the second half of the PILOTING knowledge base, the rules. Rules represent procedural information about how objects in the domain behave and provide the mechanism for reasoning about both the declarative and procedural information in the system's knowledge base.

2. Building the Piloting Expert System

The Piloting Expert System was constructed in accordance with standard systems engineering precepts. First, a piloting requirements analysis was conducted. Since the system was built in cooperation with the United New York-New Jersey Sandy Hook Pilot's Association, the requirements detailed were those of the Sandy Hook Pilots'. A model of piloting information and decisions was then developed, and edited by the piloting experts. This edited "reasoning hierarchy" was then used as a basis for filling in the objects to be reasoned about in the Piloting Expert System's knowledge base. The objects in the knowledge base were the objects in the piloting domain--SHIPS, SHIPPING.CHANNELS, HARBORS, VISIBILITY.STATES, etc.--and attributes or qualities were attached to each object. Similar objects (LNG.SHIPS, BREAKBULK.SHIPS, and TANKER. SHIPS) were grouped under a common parent (the generic class of SHIPS).

Once the pilots' requirements and the objects to be reasoned about were identified and categorized, a task analysis was conducted to determine which of the piloting tasks were to be supported with the expert system to be developed. A man-machine tradeoff study delineated the breakdown between the required tasks, and a software analysis determined which of the machine tasks were best suited for expert systems implementations. The hardware design followed, which deter-mined what the development and delivery platforms ought to be.

Once the objects and reasoning mechanism were established, rule classes, which grouped rules solving similar problems, were constructed. The system "reasons" by gathering information about the local environment and processing it to determine the implications of the new information. Processing the data is accomplished by moving "forward" through the piloting objects and the rules which govern the behavior of the objects. This process is known as "forward chaining".

The Piloting Expert System was developed as a standalone system, but because of the way in which it was constructed, it is easily integrated into future and existing bridge designs. The system presently runs aboard the Symbolics 3600 family of LISP processor, but can be ported to a more familiar 80x86 or 680x0 implementation. Thus, the systems engineering approach allows the development of a modular, integrable expert system, which supports the reduction of the number of boxes aboard the bridge and the move to make navigational information easier to assimilate and understand.

3. User Interface

The Piloting Expert System user interface was constructed to facilitate user interaction with the system. A mouse and menus are used to input data to the system. Data input includes visibility, traffic conditions, equipment (navigation, steering, propulsion plant, communi-cations and gyro) status changes, as well as information on changing conditions. Figure 1 gives an example of how inputs to the mouse-and-menus cause new information to be propagated through the system. These cascading menus invoke the forward-chaining reasoning process. Figure 2 provides a close-up of the system's recommendations.

Piloting information needs to be presented in a highly specialized format to be of use (8), (9). Some form of chart representation is often recommended, in order to mirror the user's mental representations of the domain. The left-hand side of the Piloting Expert System (Figure 3) is a digitized chart representation which provides the user with a "you are here" capability. Appropriate ship's courses and salient features of navigational and hydrographic database are represented. Throughout the transit, the user is guided by the digital chart and two sets of piloting recommendations: (1) those particular to the transit leg and (2) those common to all piloting transits.

The right hand side of the Piloting Expert System screen is reserved for access to menus describing changing conditions- changing speeds, restricted visibility, and traffic, for instance. By choosing one of the items on the "Changing Conditions" menu, a series of windows are invoked which guide the user under those conditions. Electronic checklists for emergency procedures, restricted visibility, anchoring, traffic, arrivals and departures are also invoked by menu choices. For instance, the "Preparation for Arrival" electronic checklist reminds the user of important arrival procedures, and allows the user to do voyage planning in real time by responding to questions.

4. Conclusions

Automation and industry structure changes are changing the maritime industry. Ship's crews are becoming ever smaller, more highly trained and specialized, and required to perform increasingly complex functions in constrained time periods. More and more information needs to be absorbed by ship's officers and pilots, who must act quickly and correctly. At the same time, the drive for more efficient ship's operations is leading ship's bridge designers to (1) design integrated, rather than ad-hoc, growth-capable systems, and (2) incorporate decision aids in their functional architectures, in order to enable ship's officers and pilots to maintain a consistent, credible, safe, and efficient level of decision-making.
Many of the earlier navigational decision aids were standalone systems, not integrated with existing bridge designs. Systems engineering approaches to integrated bridge designs offer substantial growth paths for the future, and support the smooth incorporation of previously-standalone decision aids into new functional architectures. Some empirical work evaluating the contribution of standalone and integrated decision aids has been done, primarily through the aegis of "Ship of the Future" programs. It is clear that much more empirical evaluative work will need to be done before sophisticated decision aids become common- place aboard tomorrow's ship's bridges.

B. Expert Seakeeping Guidance System

Knowing the performance characteristics of oceangoing vessels has great implications on the economics of vessel operations. The information is of vital importance to a liner company when making schedules for new deployment. For ship weather routing, accurate predictions of ship position in relation to the major weather system affecting the voyage depends on the accurate estimation of vessel's speedkeeping capability in different wind and wave conditions.

From the marine operations management point of view, performance guarantees on service speeds are often stipulated in charter party clauses. A detailed data base on the vessel's speed and fuel consumption will help to identify trends in performance degradation. Consequently, maintenance schedules on engine, hull and propeller can be optimally planned to minimize operating costs. Real-time measurements of speed and power can also provide information on optimum vessel trim to reduce fuel consumption. The RPM and power data are particularly critical to the diesel engine which could easily operate in a restricted overload region due to high wind and severe waves. Continuous operation in the overload region beyond what was designed as sea margin would reduce the engine life and cause maintenance problems.

Current technology is available to monitor ship performance by measuring the fuel consumption, power output, propeller RPM, speed, vessel draft and trim. However, practically none of the systems available on the market today take ship motion into consideration nor attempts to develop performance characteristics of ships in waves. The problem is very complex and involves both the seakeeping and speedkeeping behavior of the vessel. Seakeeping and ship motion limitations impose constraints on ship's speed under heavy weather conditions. Voluntary speed reduction is frequently carried out by the ship's master in order to reduce excessive motion/stress or for other safety concerns. Added hull resistance due to wind and waves, as well as a less efficient propeller, during heavy pitching also contribute to the speed reduction.

A new approach has been developed to solve this complex problem using state-of-the-art technology to measure and predict seakeeping/ship motion performance. Specifically, data has been recorded by the Expert Seakeeping Guidance System (ESGS) installed on several large container vessels. The data includes engine horsepower, propeller RPM, ship speed and heading, acclerations, roll and pitch amplitude and period along with the observed wind and wave conditions. Empirical relations have been developed by applying naval architecture principles and statistical tools to predict ship speed and power requirements in arbitary wind and wave conditions.

Once the seakeeping and speedkeeping performance characteristics have been developed, the information is used to predict ship motion and power requirements in vessel design studies, as well as for preparing the deployment schedule using past environmental data. The speed performance model is also implemented in a new optimum ship routing system which minimizes the total voyage cost.

1. Real Time Measurements

The real-time ship measurements consist of engine data such as horsepower, RPM, ship's speed and heading, and environmental conditions. Besides the normal data items appearing in the ship's log book, vessel roll, pitch and acceleration information are also monitored by a shipboard microcomputer.

The shipboard system consists of an IBM AT, or compatible microcomputer which performs all the calculations and data acquisition. The ship's motions are sensed by accelerometers and inclinometers housed in a 4X5X6 inch box with a ribbon cable connected to the PC bus. Besides providing an early warning to the deck officer on duty when excessive motion occurs, the software also predicts ship motion at different speeds and heading so that better decisions can be made to avoid heavy weather damage. (10)

Data which can be automatically acquired by the software are saved on disk. Manual input of environmental conditions is carried out by the deck officer every six hours to coincide with the World Meteorological Organization (WMO) observation reports. The parameters of interest are wind speed and direction, height, period and direction of sea and swells, and the corresponding horsepower, RPM and ship speed and heading. At end of voyage, the data is sent back to shore for further analysis.

2. Application Of Speed Performance Model

The speed performance model and related ship motion/seakeeping data bases have been implemented under MS-DOS using Intel's 80286 or 80386 based microcomputers (i.e., IBM/AT or compatibles). Several applications for container ship deployment schedule study and optimum ship routing have been carried out. Other new applications are being developed and refined.

a) Trade Route Evaluation Study

Deployment simulation concerns the scheduling and fuel cost estimation of a proposed route. The result of such study can be used to determine the proforma service schedule for a liner company. The time enroute and expected fuel cost can be used as a basis for voyage chartering.

Naturally, only historical wind/wave data are used in the simulation since the planning usually is months ahead of actual operation. A detailed data base using the analysis of wind and wave directional spectra from the Navy's Global Spectral Ocean Wave Model (GSOWM), (11), has been constructed for the Pacific Ocean. The data base consisting of wind speed, wind direction, height, period and direction of three wave systems, and breaking wave index on a 2.5x2.5 degrees longitude/latitude grid are saved on disk. The wave directional spectra data have been archived by the Navy since GSOWM first went into operation in 1985. The data is continuously archived as it is generated by the GSOWM twice a day.

The unprecedented detail and global coverage provides an ideal data base for voyage simulation using the speed performance algorithm. Proposed routes can be simulated with user specified ship loading condition, motion criteria and fuel price. Statistics are kept on time enroute, fuel burned, average speed, ship motion and other pertinent operational factors.

The scheduled arrival time can be set based on the confidence level derived from the mean and standard deviation of the sailing time. The simulation approach can also be utilized to choose the best route based on the hull geometry, loading conditions and the respective seakeeping/speedkeeping performance characteristics of the candidate vessel.

b) Shipboard Optimum Weather Routing

Instead of using the historical wind and wave conditions, ship routing deals with finding the best route based on the forecast weather information.

Traditional weather routing methodology relies largely on meteorologists looking at weather charts to select a route which avoids storms indicated by low pressure centers. This subjective method has the limitation of not being able to select an optimum route from the overall voyage cost and ship motion points of view. Without the tools and understanding of how specific ships would behave in different loading and wave conditions, he could route a ship into a high pressure area with heavy swells and long periods causing excessive motion and stress on the vessel and cargo. Furthermore, the unnecessary deviation may add extra distance on the voyage thus resulting in increased fuel cost and possible delay from scheduled arrival time.

With the new speed performance algorithm, an intended route can be readily simulated by a microcomputer. The forecast wave data are sent to ship via SATCOM in a cost effective manner (12). Once onboard, Expert Shipboard Weather Station software unpacks the data and creates weather charts in hi-resolution color graphics. The wind and wave data base can be accessed on a 2.5x2.5 degree latitude/ longitude grid. Detailed wind and wave conditions on each grid point can be viewed by simply clicking the mouse.

The theory of minimum cost ship routing was developed more than 10 years ago (13). The stochastic dynamic programming algorithm has now been implemented on a shipboard micro-computer. The Expert Ship Routing System links with Expert Seakeeping Guidance System and Expert Shipboard Weather Station to provide a set of powerful tools for voyage planning, heavy weather damage avoidance and schedule integrity.

Utilizing the speed prediction algorithm described in this paper, various operating parameters such as ship speed, required shaft horsepower under forecast wind, wave and current conditions can be predicted. The resulting fuel cost and estimated arrival time can be compared on alternate routes by the deck officers. Final comparison of ETA, fuel consumption, maximum motions enroute for the standard route, user specified and computer generated optimum route can be ranked by cost or arrival time.

3. Future Challenges

The initial success of implementing the speed performance model on a shipboard microcomputer has established the feasibility of utilizing such sophisticated tools for ship routing and voyage planning purposes. The concept of using a shipboard computer to help deck officers to navigate their ships safely and efficiently are finally becoming a reality with recent advances in computer technology and satellite communications.

One must not forget, however, the results are only as good as the input weather forecast and the skill of the people who use the tools. There are also limitations of the computer models attempting to simulate real world situations with a great deal of uncertainty. The approach presented in this paper is the first step towards developing an accurate prediction of ship speed in realistic ocean environmental conditions. As more feedback from shipboard officers who use the tools to enhance their decision making accumulates, the accuracy of the model will improve. The software will also become more user-friendly with additional features.

C. Expert Diesel Engine Diagnostics System

In June 1987, American President Lines (APL) entered into a cooperative research agreement with the U.S. Maritime Administration to develop an expert system for diesel engine performance diagnosis. The research focused on the use of artificial intelligence technology to develop a practical system for assisting ship engineers in diagnosing existing or impending problems with marine diesel engines. Other participants in the research included American M.A.N./B & W, Lykes Lines, Det Norske Veritas, and MACSEA LTD.

A description is provided of the progress and interim results in the development of a system called the Diesel Expert Test Engineering Reasoner (DEXTER). A description is given of DEXTER in its current state of development. The system automates procedures established by the engine manufacturer for engine performance assessment and trouble shooting, while providing interpretive information to the ship engineer. The expert system is designed to provide automated engine fault diagnosis through an on-line interface with the ship's engine monitoring computers. The knowledge base components include engine shop trials data, model tank test data, ship acceptance trials data, historical ship operating trend data, as well as fault-symptom models for a target set of performance diagnostics.

1. Project Summary

The overall objective of the development was to implement a practical operational system aboard a test ship. The system was to perform the tedious, time-consuming calculations involved with engine performance analysis. It would also provide the shipboard engineers with useful diagnostic information. Engine diagnostics would initially be rule-based and later extended to include more robust diagnostic reasoning techniques. The incremental development approach would allow the users to accept the initial system, assimilate its benefits, and effectively contribute to its extension.

The first project task was to establish an operational data acquisition and analysis system aboard a diesel powered ship. This involved automating the performance analysis procedures recommended by the engine manufacturer. The second major objective was to then develop the expert diesel performance diagnostic system.

a) Conceptual Design

The output of the engine analysis procedures result in a classification of operating trends for key engine performance parameters which are used as input to the diagnostic system. Figure 4 conceptually illustrates the role these procedures play in the overall expert system. The engine evaluation procedures are first applied to service performance data. Reference performance "models" are used to generate diagnostic patterns of deviations from reference normal conditions. The resulting diagnostic pattern is used in conjunction with historical fault patterns to infer fault conditions regarding engine subsystems and components. Alternative fault hypotheses can then be presented to the shipboard engineer, alerting him of a possible engine problem or significant performance deviation.

b) Target Diagnostics and Measurements

The likelihood of building a successful expert system is improved by restricting the problem domain to a small, well-defined set of diagnostics. Once the system has been proven satisfactory for the initial target diagnostics, it can then be expanded to include diagnostics covering a wider domain of ship machinery operations.

The engine manufacturer's recommended performance evaluation procedures (14) establish a basic set of diagnostics covering the major engine subsystems and components. These procedures cover the salient aspects of diesel engine operation and particularly those measurable through existing sensor instrumentation. Areas covered include the main engine and cylinder condition, turbo-charger performance, and air cooler performance.

The initial target diagnostics address engine overloading, even power distribution amongst cylinders, fuel injection timing, turbocharger turbine and compressor fouling, intake air filter fouling, and air cooler fouling.

c) Test Ship Details

The President Harding is a single screw container ship powered by a low speed, two cycle, turbo-charged Mitsui-B&W

9L80MCE marine diesel engine. The maximum continuous rating for the engine is 28,800 BPH at 83 revolutions per minute. The engine has nine cylinders with a single fuel pump and two fuel injectors per cylinder. The engine also has two sets of turbochargers and air coolers, and a shaft generator attached.

The President Harding has an automated engine monitoring and alarm system for unattended engine room operations. This system monitors over 400 analog and digital signals from plant instrumentation, the majority of which involve temperatures, pressures, and various discrete contact points. In August 1988, a cylinder combustion analyzer was installed to provide compression and firing pressures on individual cylinders.

An IBM PS/2 Model 50 computer was installed as the platform for DEXTER development. The system includes one megabyte (MB) of RAM, 20 MB hard disk, 1.44 MB floppy disk, and VGA color graphics. This system was installed in the engine control room and connected to the engine monitoring and cylinder combustion analyzer computers.

2. Engine Diagnostic System Design

Figure 5 illustrates the overall design of DEXTER. The bold outlined boxes represent system modules completed under the current development phase.

a) Data Acquisition Module

Plant performance data is supplied to the system under the control of the data acquisition module. This includes special software interfaces for data communications with the engine monitoring and cylinder combustion analyzing computers. It also includes special data processing of measurement inputs, such as averaging functions. Unvalidated measurement information is supplied to the sensor diagnostic module.

b) Sensor Diagnostics Module

Consistency checks are applied to the unvalidated measurements supplied by the data acquisition module. Consistency is established on the basis of both direct and analytically redundant measurements of engine parameters. Sensor faults are identified and validated estimates of engine parameters are computed, using consistent subsets of redundant measurements. Sensor fault information is archived into the knowledgebase and the validated estimates are supplied to the performance fault monitor.

c) Performance Fault Monitor

Using the set of validated engine parameters supplied from the sensor diagnostic module, reference performance parameters are established and compared to operating data. A current deviation pattern is formed by transforming parameter deviations into qualitative measurements reflecting normal or abnormal behavior.

The current deviation pattern is archived into the knowledgebase to record a history of such patterns.

d) Temporal Reasoning

Historical deviation patterns are examined for significant trends over pre-established intervals of engine running hours. Trend information is generated on each performance parameter for both short-term and long-term intervals.

e) Rule-based Diagnostic Reasoning

Current and historical deviation patterns, as well as trending results, are used to diagnose possible engine performance problems. Reasoning is based on a compiled knowledgebase of rules. Historical trending information lends evidential support to diagnostics based on the current deviation pattern. The result of the rule-based reasoning is a candidate set of fault hypotheses.

When this set includes multiple hypotheses, fault resolution proceeds through the structural reasoning module.

f) Structural Reasoning

The fault hypotheses generated by rule-based diagnostics involve certain engine subsystems or components. The set of candidate faults is expanded through a structural enumeration of possible fault paths connected to the identified components. The result of structural reasoning is a list of suspect components whose malfunction could describe the observed performance of the engine. The suspect components are those occurring along paths of structural connectivity with those components associated with the initial set of fault hypotheses.

g) Temporal Maintenance Reasoning

Given an input set of suspect components, this module assesses historical maintenance records and component specifications to determine the most probable faults within the candidate set. Historical records provide information on when specific components were last replaced, repaired, or inspected, based on engine running hours. Component specifications provide information on expected time between overhauls or mean time between failure. Based on this information, the suspect component list is used to statistically derive the most likely failure candidates.

h) Maintenance Advisory

The results of temporal maintenance reasoning are output to the user through the maintenance advisory module. The user is able to inquire about supporting and contradictory evidence, as well as paths of reasoning, for each conclusion reached by the system.

The advisory function can be extended to provide maintenance instructions and parts requisition lists associated with each maintenance activity. Maintenance instructions include step-by-step work procedures to be executed by the repair staff. Parts lists include a listing of necessary replacement parts taken from inventory for each maintenance activity.

i) Maintenance Activity Feedback

As maintenance activities are performed, the maintenance history database is updated to reflect recent repairs and inspections. This provides a feedback loop of information flow for subsequent cycles in the diagnostic process.

3. Conclusions

The resulting diagnostic system can provide a base level of consistency in marine diesel engine performance monitoring, with less reliance on the varying analytical skills and motivations of the ship engineer. Practical benefits expected from the use of the expert system are:

- Indication of deviations in overall engine performance and subsystem/component processes from the manufacturer specified reference normal condition,
- Reduction in the occurrence of off-design engine operation, thereby improving individual component and overall system reliability,
- On-line detection and diagnosis of controllable losses in engine performance to aid in minimizing fuel consumption, and
- Prediction of specific maintenance actions which will improve performance and avoid catastrophic engine failures.

Engine maintenance and repair costs may be reduced through a comprehensive scheduled maintenance program, coupled with an expert system for condition monitoring and diagnosis.

In order for engine performance diagnostics to succeed, sensor measurement accuracy must be assured by a sensor diagnostic and monitoring function. Diagnostic reasoning can be improved by representing a combination of functional, structural, and compiled or rule-based knowledge constructs within the expert system.

D. Expert System for Containership Stowage Planning

The objective of this project was to determine the feasibility of utilizing modern artificial intelligence methods to improve the speed and accuracy of cargo stowage planning. The target machine was a desk-top PC. A prototype expert system program, called STOW, was developed with assistance from an experienced stowage planner. STOW combines data base management with intelligent decision support. A test case for STOW was devised using realistic input data obtained from Farrell Lines Inc., and several stowage plans were generated by the program. A discussion of the results is presented, along with information on processing time, pitfalls and general usefulness of this method.

1. The Stowage Planning Problem

Figure 6 shows a typical container ship. When the ship enters a particular port, it is the goal of the stowage planner to decide how to arrange the containers which are being loaded so as to maximize the profit overall. This is accomplished by (a) maximizing the number of containers which can be loaded and (b) minimizing the handling costs. Objective (a) is achieved primarily by maximizing vessel stability by placing heavier containers near the bottom. Objective (b) is achieved primarily by minimizing overstows. An overstow occurs when a container is placed below some other container which is destined for a latter port. The result of overstows is that some top containers will have to be offloaded temporarily to "dig out" lower containers. The cost of "rehandling" the top containers can be substantial. The planner must consider the effect of his stowage plan at subsequent ports, and must therefore have an understanding of the port sequence as well as some knowledge of what outbound containers are expected to be waiting at each of the subsequent ports.

Besides maximizing profits, the planner must observe many physical and regulatory constraints. Physical constraints include container size and weight, vessel stability, vessel trim and heel, deck strength, lashing strength, hull bending moment and power requirements for refrigerator containers. Regulatory constraints primarily dictate placement of hazardous cargo.

The literature on the container stowage problem is fairly small. Early reference to the problem may be found in Webster (15), and Scott and Chen (16). The most advanced work has been done by Shields (17) and Saginaw (18), (19).

Primarily, the reason the stowage planning problem is a suitable AI application is that there are so many possible ways to stow a typical containership that the optimization problem cannot be solved exactly by conventional techniques, even with the most powerful computers available. This is referred to as the problem of combinatorial explosion. On the other hand, people do a reasonably good job of stowage planning using purely manual methods by applying experience and rules of thumb to guide the search for a solution and to limit the number of possibilities which are investigated.

In the containership stowage problem the search for the optimum solution must be limited by the use of heuristic rules, or rules of thumb, similar to those which a human planner uses. In the jargon of AI, the collection of possible solutions to the problem is described as a search tree, and the process of limiting the number of possible solutions which are actually tested is known as "pruning the search tree". Developing a good method for pruning the search tree is really the core of this problem. The rules perform the difficult task of dictating how the tree will be pruned as well as the relatively easy task of verifying that all physical and regulatory constraints are satisfied.

2. Program Design

STOW is a user-friendly decision support tool which runs on an IBM-PC or compatible computer. It is written entirely in the PROLOG language. The data base which STOW uses is read from a standard ASCII file in a very simple format which reflects the structure of the PROLOG language itself. This data file could be generated by making minor additions to existing data-base management programs.

STOW accesses data records extremely quickly. This capability is important, since it allows the system to answer questions such as: "Is there a container on the inbound vessel whose length is 40 feet and whose weight is 15 tons and whose origin port is Alexandria?" Such questions arise repeatedly as intermediate steps during the processing of chains of rules. To locate a single data record in a file of 2000 records, matching up to 14 parameters in each record requires approximately 0.005 seconds on an IBM-AT compatible machine.

STOW is primarily rule-based. Unlike most expert systems, in which the rules are stored external to the rule processor, the rules in STOW are encoded directly in the PROLOG language, which greatly increases the processing speed. Rules are used to (a) impose restrictions on where containers may be placed based on regulatory or physical constraints, (b) make tentative choices of which containers to move and where to place them and (c) evaluate the tentative decisions to determine acceptability and desirability. Figure 7 shows an example of a rule written in PROLOG, along with its English translation.

STOW generates suggestions which are container-specific. The data base management system keeps track of individual containers rather than just matching port-pair combinations to locations on the vessel.

STOW is highly interactive. The user can interrupt the system at any time during the planning process and override or revoke suggestions which STOW has made. It is intended to be primarily a decision support tool rather than a totally automated system, although it can run unattended.

Stow is graphically oriented. Pop-up windows show sectional views of the inbound vessel stowage and the current outbound plan. During automated stowage planning, each of the suggested container movements is displayed graphically as the decisions are made.

STOW contains approximately 2200 lines of PROLOG source code and 26 loading rules.

3. Conclusions

The performance of STOW has been assessed on the basis of faults which were observed in the computer-generated stowage plans. Since these errors are quite obvious, it is fairly easy to measure the quality of a stowage plan after it is generated, even though it may be very difficult to generate a plan from scratch.

Although the plans actually produced by the program showed many overstow faults, it was found that most of these could be corrected easily by minor manual post-processing. This points out the need for either a post-processing algorithm or modification of the rules so that containers can be moved by the program after they are initially stowed.

Overall, the performance of the system was good when the rules sufficiently described the solution procedure. Proper consideration of the hatch cover locations will require further knowledge engineering and more rules. The complexity of these additional rules will probably not be excessive, however the processing time may increase significantly, since many more slots must be searched to test for overstows. Addition of rules for dealing with hazardous cargo, refrigerators containers and other minor restrictions will also increase processing time.

The methods used in this prototype have produced a code which is efficient and compact. This is largely due to the characteristics of the PROLOG language, which is well suited to this type of problem due to its refined internal pattern matching and searching capabilities. PROLOG is a very efficient language for implementing an intelligent data base management system of this type. Some speed improvement might be realized in the future by translating portions of the program into the C language. This would also facilitate transporting the software to larger machines.

Considering the time constraints associated with stowage planning, the low-end personal computer will probably not have enough speed to be truly useful after all of the necessary rules are incorporated. With the use of a small minicomputer or workstation, the methods used in this prototype have potential to perform the stowage planning task with speed and accuracy exceeding that of a human planner.

Based on our experience, an expert system approach is a feasible and practical one for solving this type of problem. The rule-based structure, combined with an inexact reasoning strategy facilitates program development and clarity.

Few rules are required to describe the stowage optimization task in heuristic terms. Probably no more than 50 - 100 rules will ultimately be necessary to achieve useful performance levels.

Other Applications in Shipping Operations

There are of course many application areas that have been examined and are reported on in the technical literature. It is not the authors intent to reiterate this information since the reader can obtain copies of these references from the Maritime Technical Information Facility (MTIF), located at the U.S. Merchant Marine Academy, Kings Point, NY. However, there are two very interesting applications which have been investigated in the area of container handling that have not been reported on in the literature. These applications are briefly described as follows:

a. Stowage of Containers

In order to minimize shipping costs, shippers of containerized goods want to maximize the amount of cargo that can be placed into a container. While weight is sometimes a limiting factor, the primary factor is space. Shippers must determine how to best load the cargo to take full advantage of the space inside a container. With the large variety of container configurations available today, this is not always a simple task. Complicating matters further are the variety of rules that must be followed when shipping refrigerated cargo.

Sea-Land Corporation, in conjunction with August Design and Development Company, has created an Expert System called Sea-Stow. Sea-Stow, which runs on an IBM-PC compatible equipped with a graphics adapter, advises shippers on efficient methods to load containers.

In operation, the user enters a Sea-Land container number and the dimensions of the cargo boxes to be shipped. Sea-Stow then accesses its built-in data base to determine the type of container and the interior dimensions of the container. If the container is a refrigerated type, Sea-Stow asks the user a few questions such as whether or not the cargo is chill-sensitive. Combining mathematical algorithms with a number of expert rules, Sea-Stow determines the optimum cargo pattern and graphically displays the pattern on the screen and printer.

For refrigerated containers, the system arranges the cargo for the best air flow, while avoiding interior refrigeration mechanisms and providing air channels through the cargo as necessary. Sea-Stow automatically "pinwheels" palletized cargo, yet allows the user to view non-pinwheeled configurations. Sea-Stow is also used by Sea-Land engineers in evaluating container designs.

b. Positioning Containers in a Stacked Container Yard

The stacking of containers in a terminal improves the efficient land use of a yard, but detrimentally affects the throughput. In a chassis operation, all of the containers are equally accessible; however, in a stacking situation a container at the top of a stack is much more accessible than a container at the bottom of the stack. Costly rehandling is necessary to access containers in the lower tiers of stacks.

Sea-Land, in conjunction with August Design and Development and Haewon Enterprises, has developed an Expert System for the placement of containers in a stacked terminal environment. Simply put, the primary goal of the system is to always have the container that is needed next, at the top of a stack. In the real world, this goal is impossible to reach, but experiments currently being conducted indicate that the Expert System provides great improvement over existing methods.

In developing the system, Sea-Land commissioned extensive mathematical studies of the problem to establish the theoretical limits and to identify effective algorithms. Sea-Land then sent knowledge engineers to interview experts in the U.S., Hong Kong, Korea, Japan, and England. The methods these experts use to organize shipping terminals and provide safe and efficient operation were carefully documented. By combining the theoretical with the practical knowledge of experts, a number of rules were developed and the Expert System software was written.

The current version of the program is written in Pascal and runs on an IBM-PC compatible. The program employs a local data base that is organized in the physical image of the yard. The data base contains the location and details (container number, weight, type of container, destination, origin, vessel, owner, etc.) of each container in the yard. Via a micro-to-mainframe communications link, the system also can gain access to Sea-Land's mainframe computer. In this way, ship schedule, stowage plans, ship manifests, cargo bookings, etc., can be taken into consideration by the system in making its recommendations.

Whenever a container enters the yard, either from the gate, ship, rail, or other source, the serial number of the container is entered into the system. Pertinent data regarding the container and shipment is automatically accessed from the central data base. The system then evaluates every possible candidate location for placement of the container into the yard, by searching through the local data base and applying the expert rules. Each location is given a score representing how well the match of the container and the candidate location suits the rules. At the end of the evaluation, the Expert System identifies the location that has scored the highest and the container is placed in that location.

There are about 50 rules in the current system. Separate rules exist for inbound and outbound containers. Refrigerated containers and dangerous cargo have special subclasses of rules. The primary outbound rules involve destination and weight. In simplified terms, the heavier containers should be placed so they can be loaded into the lower portions of the ship for stability. In regard to destination, the containers are arranged in the yard assuming the ship is loaded in a last in first out manner (LIFO). Other rules involve such parameters as safety, stacking compatibility, and current location of the container handling equipment.

A major feature of the system is flexibility. The system can be easily adapted to any container terminal and configuration. The system also has the capability of automatically seeking the optimum rule configuration and adapting to changing situations such as port modifications and seasonal changes in operation. Sea-Land plans to perform detailed experiments with the adaptive nature of the system in the future.

Currently the system has been designed and tested for Sea- Land's GRAIL, an experimental high density/high productivity overhead rail system. Versions of the Expert System for Sea-Land's Transtainer yards and its bridge crane facility in Hong Kong are in development and are expected in the field in the near future.

Conclusions and Recommendations

In order to attain its national goals, the United States must continue to define and develop advanced shipping systems for its domestic and international commerce and trade. We believe that artificial intelligence and expert systems will be important elements of such capabilities, particularly for international ocean shipping. Due to the many complexities of the global maritime arena, constant challenges exist to our ability to offer international transportation services commensurate with our nation's needs.

We are pleased to share some of these challenges and opportunities with you under the Marine Facilities Panel of the United States-Japan Cooperative Program in Natural Resources. It is recommended that we continue to do so in the future. The long term health and well-being of our two countries will benefit from these activities.

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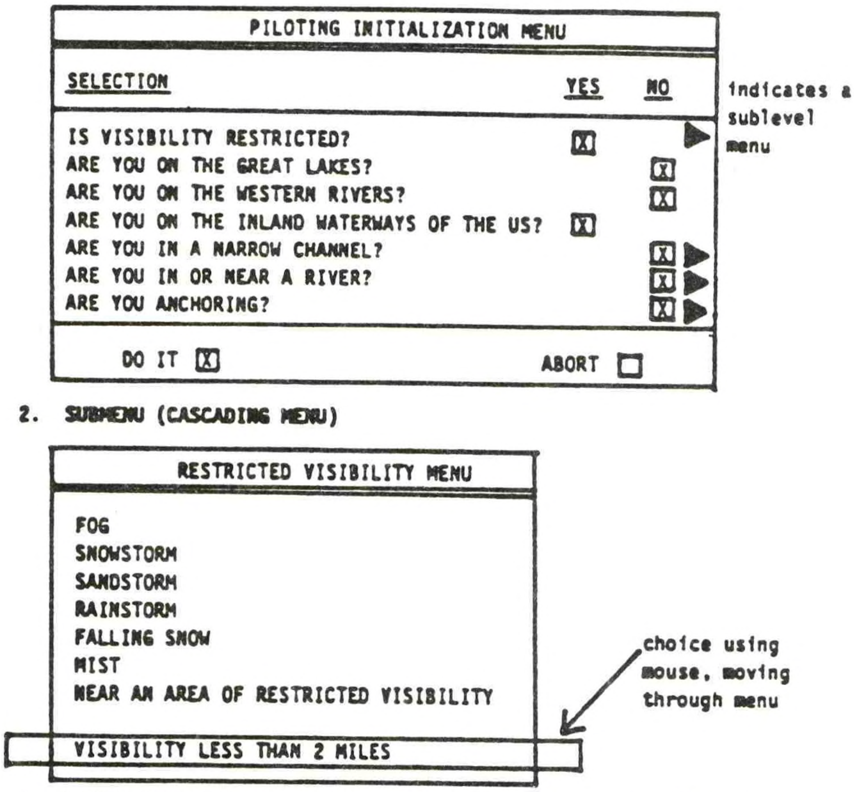
FIGURE 1

MENU DRIVEN USER INTERFACE

1. INITIALIZATION MENU



3. IMPACTED RULE PREMISE - CONDITIONS INDICATED ARE ASSERTED IN KNOWLEDGE BASE
- ONE OF MANY IMPACTED RULES

```
WHISTLE.RULES.FOR.RESTRICTED.VISIBILITY.FDV.RULE 35A
  (IF (   (?ANY.SHIP IS IN CLASS POWER.DRIVEN.VESSELS)
     AND  (VISIBILITY.STATE OF ?ANY.SHIP IS IN CLASS            ASSERTED
               RESTRICTED.VISIBILITY.STATES)
     AND  (VESSEL.STATE OF :ANY.SHIP IS IN CLASS UNDERWAY.STATES))
     THEN ((WHISTLE.ACTION.TAKEN OF ?ANY.SHIP IS BLOW.ONE.PROLONGED.BLAST)
          (WHISTLE.INTERVAL OF ?ANY.SHIP IS NOT.MORE.THAN.TWO.MINUTES)))
```

FIGURE 2

SAMPLE OUTPUT FOR LEG D, INBOUND NY

Eventual input from SATNAV or other electronic navigation systems

PILOTING RECOMMENDATION

Latitude 39-XX.XN   Longitude 73-XX.XW
Course 346°
Speed 11.2^{K}

Based on the information provided,

* Recommend course 347° for 1.94 miles
  Half Ahead (60 RPM's)

  Until pass buoys 13, 14 ←O→ (N. end, Ambrose channel)

Coney Island Light Ø's	013°
West Bank Light Ø's	092°
Great Kills Light Ø's	264°
Old Orchard Shoals Lt. Ø's	247°

* Then A/C to 348°, for 2.3 miles

* If visibility closes (expected weather),

  - reduce speed accordingly
  - sound appropriate whistle signals
  - notify docking master of delayed arrival.

* To make gangs at 0800, you must pass Stapleton Anchorage by 0615

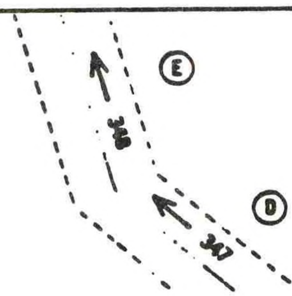


FIGURE 3

PILOTING EXPERT SYSTEM DISPLAY

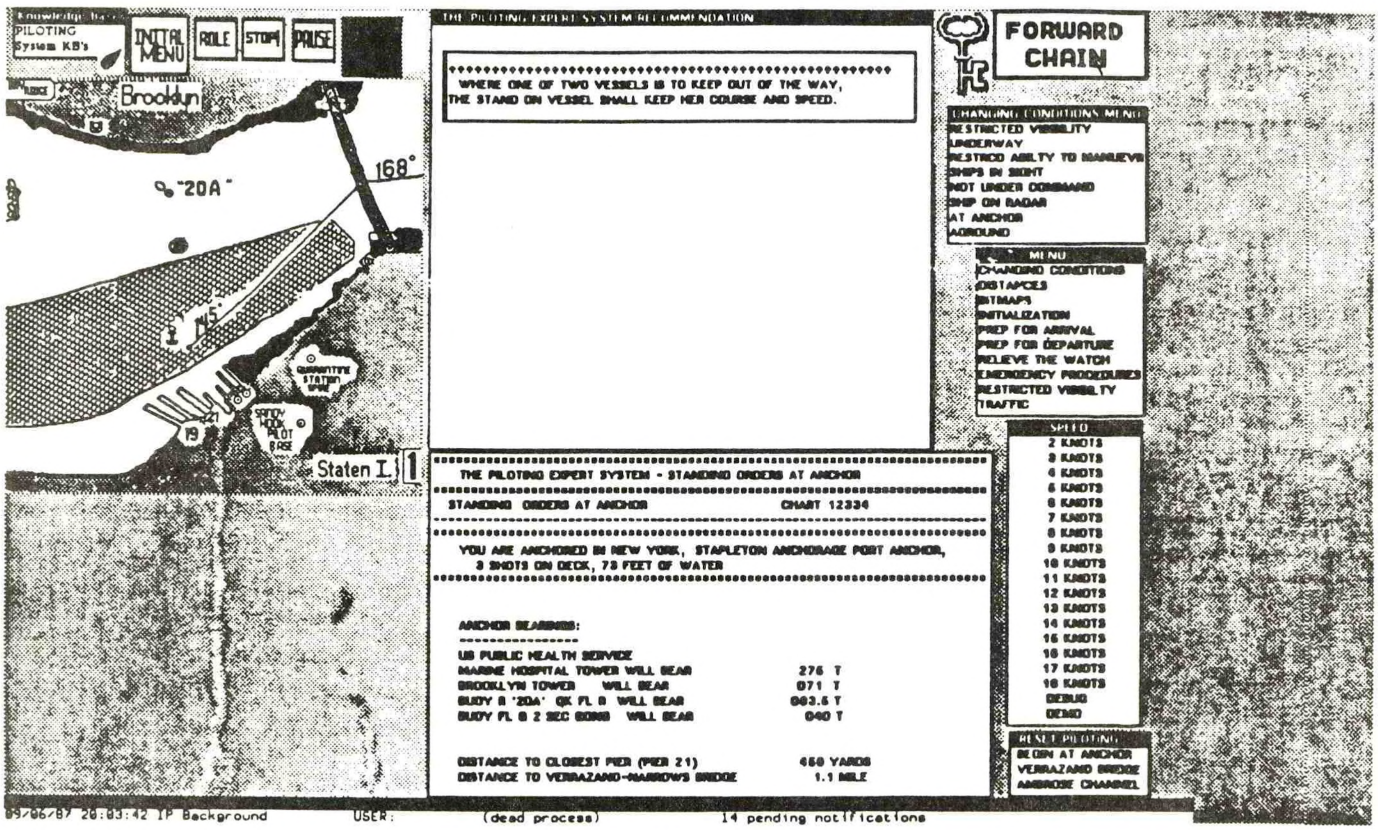


FIGURE 4

DIAGNOSTIC EXPERT SYSTEM CONCEPTS

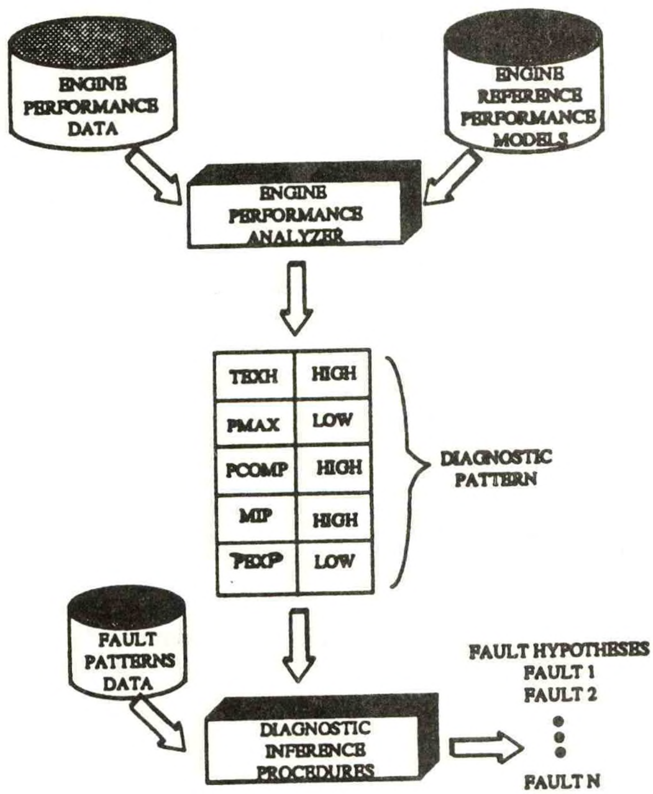


FIGURE 5

OVERALL DEXTER DESIGN

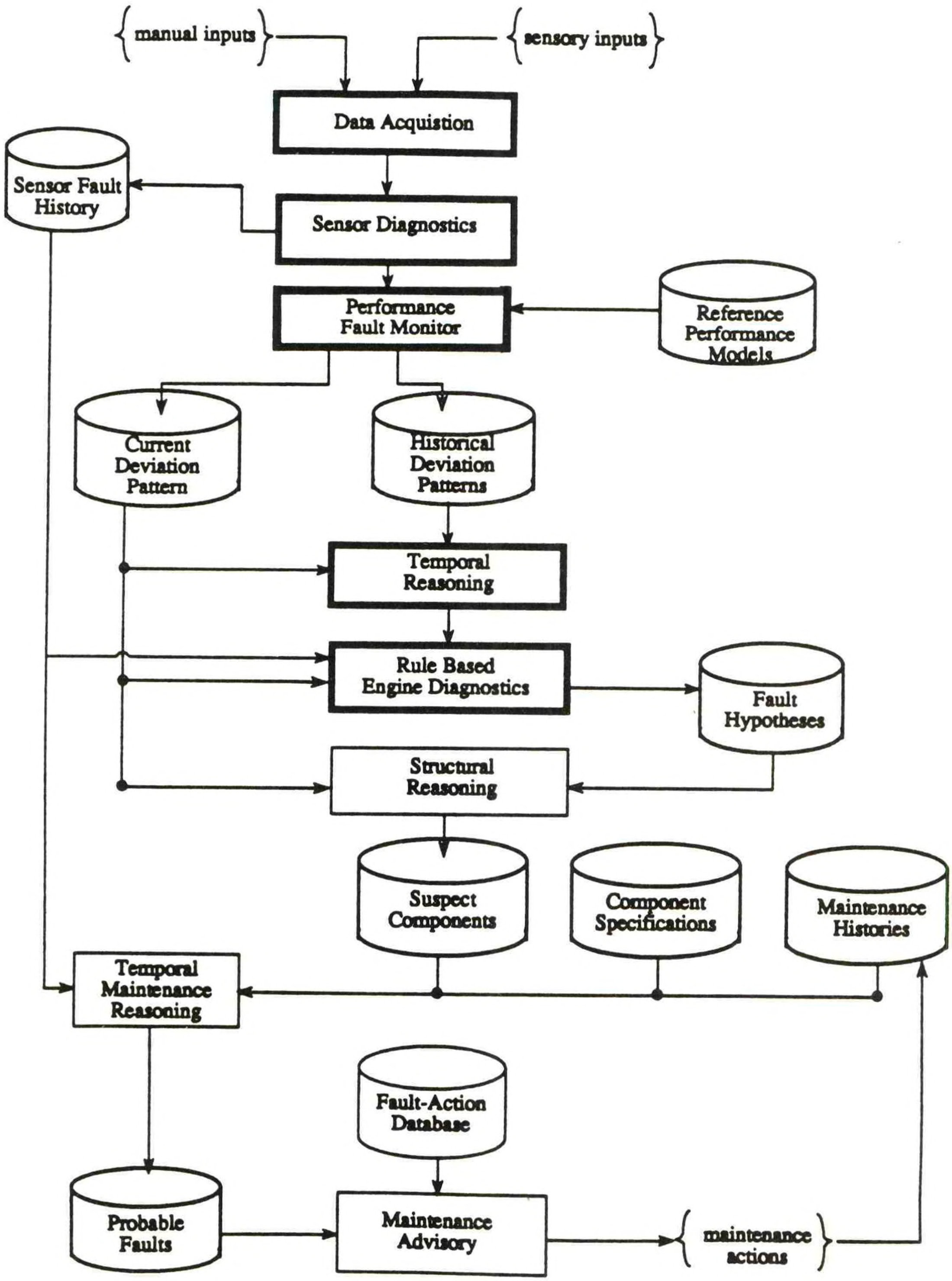
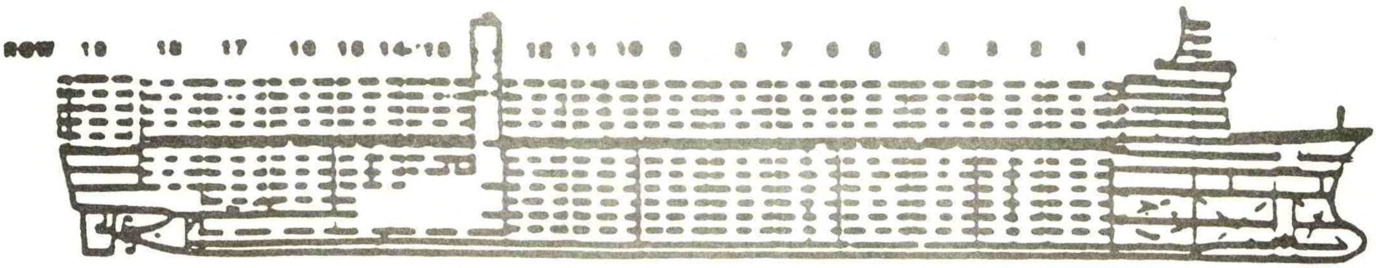
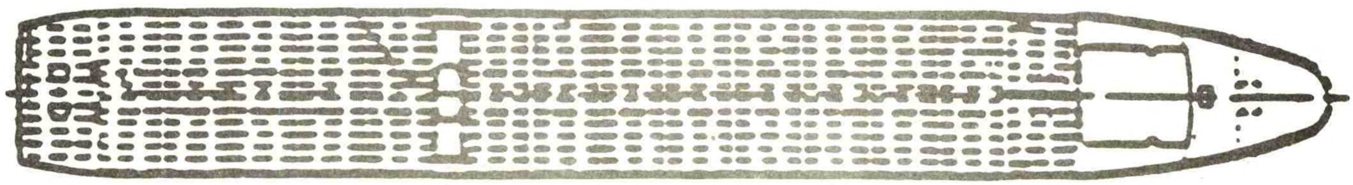


FIGURE 6

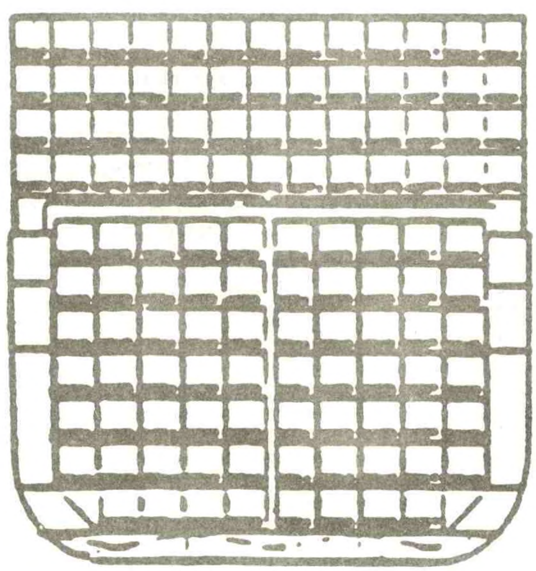
TYPICAL CONTAINERSHIP CONFIGURATION



INBOARD PROFILE



PLAN VIEW-WEATHER DECK



SECTION

FIGURE 7

EXAMPLE OF RULE WRITTEN IN PROLOG

RULE

```
rule_target_bay_cell(Baynumber,Cellnumber,0.8):-
   suggestion(source,ori(Originport),_),
   backload_port(Baynumber,Cellnumber,Originport).
```

TRANSLATION

The certainty factor is 0.8 that

the target bay is Baynumber
and
the target cell is Cellnumber

if

the source container originates from port Originport
and
cell Cellnumber in bay Baynumber is a backloading cell for Originport

COMMENTS

This rule gives preference to trying to load containers from a certain port into backloading space for that port. Backloading space is space which is made available for backloading containers after the unloading is completed for that port. Thus NY backloading space is space which is empty after the ship is unloaded in NY. Empty in this case means the entire cell must be empty all the way to the bottom (i.e. there must be "bottom space"). The fact that the certainty factor is 0.8 means roughly that the consequent of the rule (the statement preceding the "if") should be true most of the time if the antecedent of the rule (the statements following the "if") is true. A certainty factor of 1.0 would mean the consequent must be true, while a certainty factor of -1.0 would mean the consequent must be false.

Integrated Electric Propulsion

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Introduction

Electric drive systems for ship propulsion have been recognized as providing many benefits not achievable with mechanical propulsion systems.[1,2] The major source of these benefits is the flexibility of propulsion machinery arrangement and the flexibility of operation allowed by an electric drive system. This flexibility, in turn, enables the realization of other benefits to the ship, provided that other technologies are developed in parallel with electric drive. An extension of this idea is that other seemingly unrelated technologies, when combined with electric propulsion, can provide an integrated ship machinery system with far reaching advantages. If chosen properly, the benefits of an integrated machinery system, with electric drive as the center-piece, will provide benefits greater than the summation of benefits expected from each technology above. We have designated such a synergistic collection of technologies a "cluster."[3] The remainder of this paper will describe such a machinery cluster and indicate its advantages.

Electric Propulsion

The U.S. Navy has already begun the development of an electric propulsion system for future ships. This system is based on the extension of alternating current (a.c.) synchronous drive technology to provide a 25,000 horsepower per shaft test system illustrated in figure 1. The key components of this system include a.c. synchronous motors and generators with liquid cooled stator windings to reduce size and weight. Static power supplies provide field excitation via rotating brushless exciters. Control of motor speed is accomplished with a solid state frequency changer located between the motor and generator. Input power will be provided by gas turbines operating at a maximum of 3600 revolutions per minute (rpm). Motor output speed is presently set at a maximum of 3600 rpm. The motor drives the propeller at a much lower speed (yet to be determined) through an epicyclic gearbox, which will be developed as part of this system.

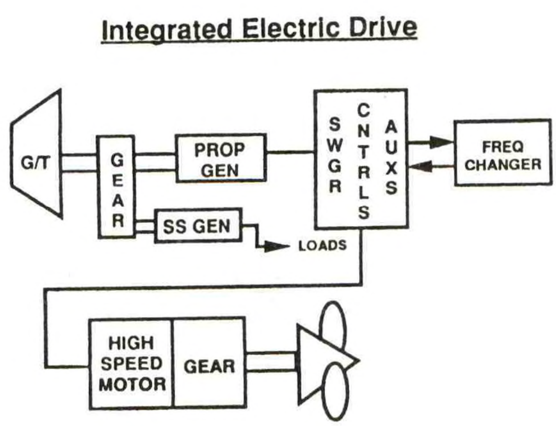

Figure 1. Near Term Electric Drive System

Although this system requires a reduction gear, it retains the essential elements of flexibility which make electric drive attractive. The advantages provided by this system alone are indicated in figure 2.

Ship Flexibility

Turbine/Generator Independent of Motor/Propeller	>---<	Alignment Free Arrangement Reduced Shafting Reduced Ducting Small Diameter

Operating Flexibility

Turbines Selectable Cross Connectable Rapid Reversal Rapid Acceleration	>---<	No Gears No Clutches No CRP Low Noise

Fuel Economy

Continuously Variable Reduction Ration	>---<	Match Propeller/ Turbine Opertion Minimize Fuel Consumption

Figure 2. Electric Drive Advantages

In previous papers, electric drive systems based on the use of superconducting motors have been discussed.[2,4] Indeed, superconducting machinery will provide many benefits beyond those indicated above. In particular, size, weight, efficiency, and noise improvements would be expected. Therefore, superconducting electric drive remains the long term goal. However, the U.S. Navy has chosen to start full scale development with a low risk approach which will provide the essential electric drive benefits at the earliest date possible. Research targeted toward superconducting electric drive critical technologies[4] will continue in parallel with the near term system development.

Integrated Electric Propulsion and Propulsion Derived Ship Service

Deriving ship service electric power from the propulsion prime mover has long been recognized as a means for saving both fuel and machinery volume and weight.[1,5] Application of this idea to some commercial cargo ships in the form of shaft driven generators is straightforward, since engine speed can be held nearly constant. In military and some commercial applications, a wider variation in propulsion engine speed must be taken into account.

A propulsion derived ship service (PDSS) system, in which the prime mover speed is allowed to vary, requires some type of variable speed - constant frequency generator system.

There are two basic means of achieving a constant output electrical voltage and frequency from a variable speed shaft. The first method is to use a continuously variable mechanical speed changer such as a bi-conical drive, or to use a differential gear train with hydraulic or electrical feedback. In both cases, the "gear ratio" of the device is adjusted continuously to provide constant output speed to a synchronous generator regardless of input speed. The second method is to drive the generator at a variable speed dictated by the propulsion system and to press the output power through a solid state frequency changer to provide constant output frequency. Both of these methods have been successfully used in both aircraft and marine applications.

The use of propulsion derived ship service technology with electric drive has been given the designation of "integrated" electric drive as indicated in figure 1. The key to maximizing the benefit of a PDSS system is the flexibility of operation of the propulsion plant that electric drive provides. The larger the prime mover speed range over which the PDSS system must operate, the larger and less efficient the PDSS equipment becomes. By exploiting the fact that electric drive allows the prime mover speed to be largely independent of propeller speed, the range of PDSS speed can be minimized, consistent with propulsion system optimal performance. Naturally, if the two systems are "integrated" during design, an optimal overall system is much more likely to emerge, consisting of the minimum number of prime movers and generators necessary to meet the ship mission.

Related Technologies

Over the past several years, the David Taylor Research Center has estimated the overall ship impact of many technologies, both singularly and in combination. These analyses, as well as others, have consistently shown integrated electric drive, i.e., electric drive combined with propulsion derived ship service, to be of substantial benefit in terms of performance, and economics. In addition, a set of related technologies has also emerged which, when combined with integrated electric drive, provide additional performance and economic benefits. It is important to note that these benefits are aimed toward meeting the performance and affordability goals projected for the 21st century Navy.

The four primary and two secondary technologies, combined with integrated electric drive, as indicated in figure 3, have been designated Cluster "A."

Primary

- **Integrated Electric Drive**
- **Advanced Propulsor System**
- **Intercooled, Recuperated (ICR) Gas Turbine**
- **Integrated Electrical Distribution System**
- **Machinery Monitoring and Control**

Secondary

- **Advanced Auxiliary Systems**
- **Loiter/Take Home Power Systems**

Figure 3. Cluster "A" Machinery Technologies

Advanced Propulsor System

Electric drive makes possible machinery arrangements which are difficult, if not impossible, to achieve by other means. One such arrangement is to locate the final drive (motor, gear, shafting and propellers) in an external podded arrangement as indicated in figure 4.

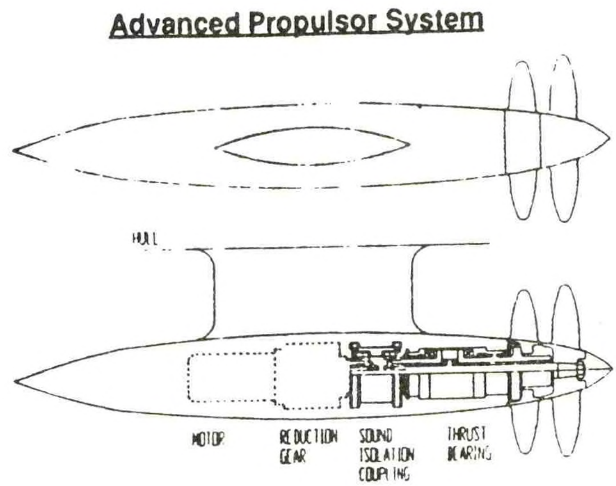

Figure 4. Advanced Propulsor

This advanced propulsor arrangement, enabled by electric drive, has hydrodynamic and other architectural benefits. Among these are the elimination of internal shafting and machinery, providing for more flexible use of machinery space. A major benefit is the removal of restrictions on propellor placement and angle of attack. With the propeller facing forward, perpendicular to the inflow, and with no struts or appendages disturbing the inflow, much improved hydrodynamic performance is expected.

Several variations of this arrangement are being considered, including the use of contra-rotating propellers. As recently demonstrated on a Japanese bulk carier, an epicyclic gear driving a contrarotating propeller can increase efficiency up to 15%.[6]

ICR Gas Turbines

The relatively poor part power fuel consumption of simple cycle propulsion gas turbines can be partially overcome by electric drive through its ability to cross connect and run multiple shafts from a single engine at low speeds. This, of course restricts the degree to which other aspects of electric drive may be exploited. This poor part power performance of gas turbines can be improved by recuperating the exhaust energy from the turbine and using it to preheat the combustion air. Efficiency can be further improved by cooling the inlet air between the low and high pressure compressor stages, reducing the compressor loading as shown in figure 5.

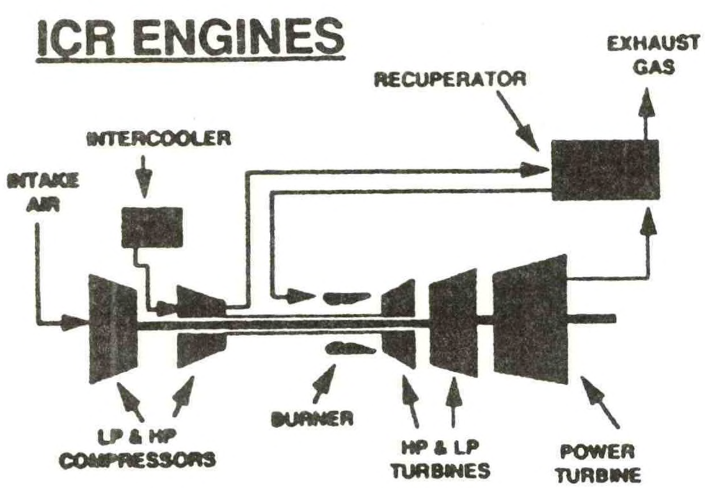

Figure 5. ICR Engine

The net result of recuperation and intercooling is to both lower and flatten the specific fuel consumption curve of the gas turbine as shown in figure 6.

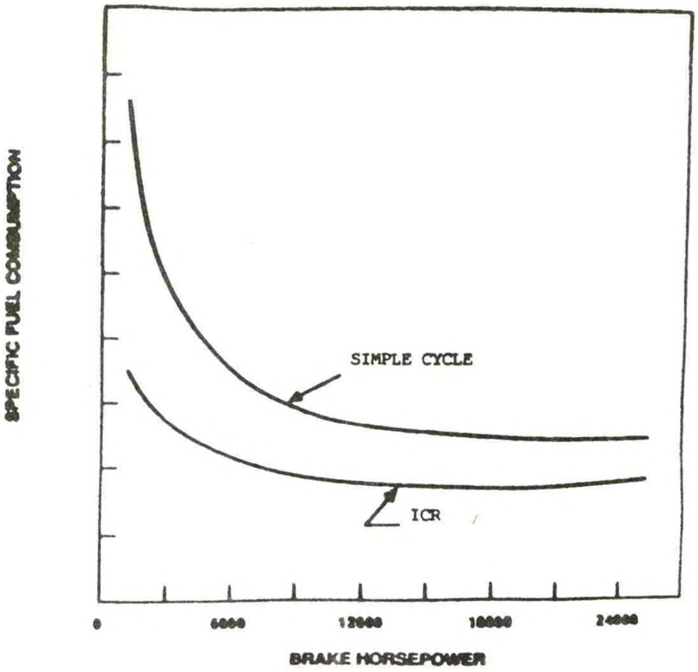

Figure 6. ICR Engine Fuel Rates

Integrated Electrical Distribution System

The growing demand for electric power; the increase in non-linear loads; the need to provide high quality, continuous power to vital systems; and the emergence of new power sources such as propulsion derived ship service; are cause for renewed interest in the ship electrical distribution system. Goals of an integrated electrical distribution system will be to provide adequate power of the proper quality to each user aboard the ship, according to priority of need and with a minimum of installed generation capacity and fuel consumption.

Heretofore, some of these goals have been met by sacrificing others. Presently we assure that adequate power is available by allowing generous margins in equipment ratings including redundant reserve equipment, and by providing special power systems for vital combat system loads. For the 21st century Navy, more creative approaches are provided by solid state power device technology and system control, including control over the distribution of propulsion derived electrical power. Future electric distribution systems will rely on constant monitoring and control of the sources of electric power, the distribution network, the needs of the various loads on the system and priorities set by the tactical situation. Size, weight, and efficiency improvements are expected due to reduction in distribution equipment size and weight, better matching of capacity to load demand, and more efficient use of fuel in the power generation process. Performance in terms of reliability and survivability will improve due to the ability of this future system to be fault tolerant, respond to faults or transients more quickly, and to reconfigure itself through control and redundancy to accommodate damage.

Machinery Monitoring and Control

The machinery monitoring and control system serves the functions analogous to the body's nervous system. As envisioned, this system will increase readiness and survivability while reducing manning. Readiness will be assured by constant monitoring of machinery and electrical equipment condition, and automatically signalling when maintenance is required. This condition-based maintenance, along with the automation of the machinery monitoring functions will lead to reduced manning. Embedded training, made possible by the distributed architecture and software capability of this system will increase the readiness of operators as well as reduce the requirement for off-board training facilities and manpower. Survivability of the ship and its subsystems will be enhanced by faster and more informed response to damage and automatic reconfiguration of energy or data links to vital equipment such as fire pumps, controls or defensive systems. Reconfiguration of auxiliary systems, as redundancy allows, to respond to damage or failures will also enhance survivability. The key technologies required for this system are advanced distributed architecture; survivable signal processing and data communications systems; sensors and knowledge for machinery condition monitoring; and expert system technology for rapid decision making.

Such a monitoring and control system will be necessary to assure that electric drive equipment in remote locations such as propulsion pods is operating properly; that most efficient use is made of the installed integrated propulsion-ship service generation system; that the integrated electrical distribution system can respond appropriately to rapidly changing requirements, and that the advanced auxiliary systems and emergency power capabilities are most effectively utilized

Advanced Auxiliary Systems

Auxiliary machinery, e.g., heating, ventilation, and air condtioning (HVAC), hydraulics, fluid systems, steering, represent a large fraction of the internal ship load. Incorporating modern technologies such as composite materials, high efficiency compressors and pumps, compact heat exchangers, etc., can reduce the size, weight, and power consumption of the auxiliary machinery system substantially, leading to lower cost ships. In addition, survivability can be enhanced by dispersing the auxiliary systems and enclaving so that damage to a single compartment does not propagate to others. Integration of these concepts with the monitoring and control system will assure that optimal use is made of all auxiliary machinery assets under all conditions.

Take Home/Loiter Power

Take home/loiter power can be provided by an independent power source (e.g., a turbine generator set) and a lower power propulsion system, located well away from the primary machinery spaces. Such a system would provide both emergency ship service power as well as emergency propulsion when all other sources are inoperable for any reason. In addition, for certain ship missions calling for extended periods of low speed operation, this system could be employed in lieu of operating the large propulsion turbines. The resulting benefits to survivability and fuel savings are evident. This emergency power system provides a needed backup to the integrated electric drive power system, while serving the independent function of a secondary propulsion system. The key technologies to be developed here are a lightweight emergency propulsor such as an extendable outboard motor or waterjet, and an efficient power source such as a small ICR gas turbine or lightweight, quiet diesel engine.

Conclusions

The U.S. Navy electric drive program is underway with development of a near term a.c. synchronous system. Far term plans include eventual development of a superconducting d.c. system.

A cluster of machinery technologies has been identified for development, which, when combined with electric drive, will help the Navy to meet its projected performance and affordability goals in the 21st century. These technologies are: Propulsion Derived Ship Service, Advanced Propulsors, ICR Engines, Integrated Electrical Distribution, Machinery Monitoring and Control, Advanced Auxiliary Systems and Loiter/Take Home power system. The interrelationship between these systems is such that, the level of performance and value of each, depends to some extent on the existence and performance of the others. Thus the benefits of the entire cluster of technologies is expected to be greater than expected from the summation of the benefits of each part individually. This approach to ship machinery system design implies that the integrated electric drive and its associated cluster of technologies should be pursued together, in a coordinated fashion to reap the maximum benefit from the investment.

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MAGNETO-HYDRODYNAMIC PROPULSION FOR SHIPS
A REPORT ON
U.S. PURPOSE AND PLANS

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Background

The 15th meeting of the UJNR exposed the members and perhaps others of the UJNR Study Group to the reality of magneto-hydrodynamic (MHD) propulsion by demonstrating through a scale model the potential for radical departure from conventional ship propulsion by advancing an old idea with new technology. The old idea, MHD Propulsion, is a phenomenon that has been explored for several decades for its practicality as a prime mover for a number of vehicles. The new technology is superconductivity, which can make practical MHD seawater propulsion systems by increasing the strength of the magnetic field needed for these systems. In short and for review, MHD is the phenomenon of the generation of a Lorentz Force normal to an applied magnetic field and an electric current flowing through a conducting media. The force generated pushes a ship through the water without need for a propeller or rotating machinery drive train.

Currently the practical applications of MHD have been limited to electromagnetic pumping of high conductivity liquid metals and electrical power generation caused by forcing hot ionized plasma through a powerful magnetic field. Similarly, although somewhat in contrast, magneto-hydrodynamics for seawater propulsion is also another potential application concept.

MHD experiments in seawater were performed as early as 1966 when Stewart Way demonstrated a ten-foot model with conventional magnets, and in 1976 by Iwata with a similar model. Both models achieved a velocity of approximately 1.5 knots with magnetic field strengths of two tesla or less.

There has been consistent agreement from Soviet, American, and Japanese researchers who have advanced the technology the farthest, that MHD seawater propulsion is technically feasible. The disagreement among researchers has been about whether MHD seawater propulsion is desirable. In fact, assessments by international researchers indicate that the extreme low efficiency of MHD systems heretofore prevented any advancement of the technology from those early experiments of the 1960's. Thus it was that the U.S. members of the UJNR were favorably surprised that researchers at the Japan Foundation for Shipbuilding Advancement (JAFSA) had again pursued MHD propulsion with renewed vigor and with advanced technology. The Japanese team demonstrated in operation an actual large-scale model of a surface ship utilizing a single MHD duct surrounded by a superconducting dipole or racetrack magnet in which they had obtained favorable performance results. Still more impressive is the next generation experimental MHD ship, *Yamato I*, which will utilize a six-barrelled Lotus design to assist in controlling extraneous magnetic fields. Although Japanese accomplishments and planned advancements are no doubt impressive, the efficiency, the major issue of MHD, is still only of the order of 1%. Clearly, if this technology is to move forward profitably, efficiency values must be improved significantly. The proposed 10% efficiency target of the planned *Yamato II*, if achieved, may uncover key directions of future research in which commercial profitability may have some gleam of hope with future designs.

Current Assessment

Work by Japan, the U.S., and the U.S.S.R. confirm that by increasing the magnetic field strength and/or the volume (e.g. length and diameter) of the thrusters that the efficiency can be increased. It could be called "economy of scale." To achieve the appropriate magnetic field, the principal engineering problem is to make lightweight, high field strength superconducting magnet systems (i.e. including the refrigeration, structures, and cryostats). Achieving large volume can be an expensive proposition, because very large test apparatus or actual boats must be built. Hence, potential payoffs must be identified more clearly to justify the large R&D investment.

U.S. Issues

The U.S. faces a number of significant problems for both the production of future naval ships as well as ships for domestic use. Paramount is a declining maritime industry caused by lack of innovation and ability to compete internationally. Another issue is limited public funds for acquisition of future naval ships on which existing U.S. shipyard rely. Therefore, two critical R& D issues that will fashion and form the underpinnings of future industry directions are improving affordability and increasing performance. Put more simply, Navy-procured ships and submarines of the future must have superior performance in terms of speed, quietness, and payload and must achieve these characteristics at or below current cost figures, which in the case of submarines and Navy surface ships is about $100,00/metric ton.

On the commercial side, pursuit of new technology must be weighed in terms of contributing to its potential to help revive the U.S. maritime industry. Presently, a rather bleak picture exists where in the past decade we have witnessed a veritable decimation of the U.S. shipbuilding industry. Since 1978, numerous shipyards have closed, and an increasing number of companies are operating under Chapter 11 of the bankruptcy laws. As we speak, there are <u>no</u> commercial vessels on order or under construction in the United States. The shipbuilding industry argues that the causes are rooted primarily on government subsidies of other nations, but it is suggested that a lack of R&D investment of the past may also contribute to the U.S. inability to keep technology working on its side to make ships more affordable with high payoff performance. I do not suggest that MHD is the answer to these complicated industry problems. But I do contend that it is the bold approaches by nations on behalf of their essential industries to undertake new technology development to preserve their industrial vitality, or, in the case of the U.S., to ensure an industry for national defense and provide a foundation for which commercial markets can again be competitive. Recent actions by the U.S. Congress, which increases funds for research and development, hopefully will lead the way for opportunities for advanced ship technology. Likewise, actions by the Congress to initiate programs to explore advanced Hull, Machinery, and Electrical (HM&E) technology for submarines again will improve opportunities not only to develop advanced new hull materials, electrical systems, and hydrodynamic designs, but also to find ways to improve total system performance, including advance propulsion technology, potentially using superconducting motors as well as MHD. The U.S. views MHD technology as a means to eliminate classical ship and submarine propulsion train equipment that includes thrust bearings and foundations, shaft seals, shafting, couplings, and rotating propulsors. At first assessment these simplifications could indeed reduce system weight and potentially cost , both acquisition and life cycle. But MHD has its own suite of technology that must be added and includes at least the following: electric current generators, switchgear, MHD propulsors (magnets, cryostats, hydrothruster ducts) and refrigeration equipment. These issues must be addressed in any systems concept.

There are many different types of MHD concepts for ship propulsion, including clustered dipole, double solenoid and toroidal hull type thrusters, each using a different type of superconducting magnet. Comparisons of the weight and volume of MHD propulsors against mechanical or electrical drives that are also available will be highly dependent on the MHD concept selected. MHD propulsion systems at first approximation will be larger and heavier than mechanical or electrical drives if the maximum speed of a ship is held constant for all three systems. It is hoped that MHD technology will eventually provide high quiet speed and be less costly.

Since the U.S. has shown an initial interest in investigating the potential of MHD, the UJNR forum has created an opportunity for advancements made in Japan to be discussed and shared with U.S. counterparts to allow a framework for advancing the work on a number of important issues. The following are a few performance characteristics that the U.S., and other nations for that matter, view as issues that must be addressed:

- Efficiency: Determining economy of scale
- Size and Weight: Practicality of MHD magnetic system and associated propulsion equipment
- Environmental Effects: Potential hazards of gases generated at the electrodes
- Acoustic Characteristics: Bubble formation and collapse, vibration, etc.
- Corrosion-Erosion: Material concerns with electrolytic and cavitation-flow effects
- Cost: R&D, acquisition, life cycle, support, logistics, facilities, etc.
- System Interfaces: Control system, mission packages, auxiliary system
- Safety: Electromagnetic, electric
- "ilities": Reliability, maintainability, etc.

In October 1988, a team of U.S. scientists visited Japan hosted by Dr. Seizo Motora, that included a visit to the test facility at the Tsukuba Science City. During the visit, frank and open technical discussions ensued. Technical papers were presented in Tokyo by both U.S. and Japan technical representatives.

The visit also included a side trip to the magnetic levitation train train in Miaysaki where a large scale use of superconducting magnets was demonstrated in a future commercial high speed transportation application.

As a consequence of the visit to Japan a new direction for the U.S. effort was developed with the hope that either the Japanese would join in the experimental effort participating on the U.S. side, or that the U.S. would produce data of some scientific consequence and value that could be shared with the Japanese. Presently no plan is in place for any joint effort because of the disparity of objectives and applications and uncertain long-range funding commitments.

U.S. Plan

Concern with efficiency seems to prevail with the U.S. investigation of MHD propulsion. Perhaps justifiably so, in view of some exciting alternatives being advanced in the U.S., such as superconducting electric drive. Skepticism and competition for scarce R&D funds prevent anything as adventurous as the *Yamoto I* from being pursued in the U.S. at this time. Therefore, large-scale "mock-up" type experiments were selected as a means of assessing efficiency potential and several of the key downside problems such as bubble noise, magnetic field effects, and corrosion as well as evaluating the performance of MHD thrusters in seawater.

The Defense Advanced Research Projects Agency (DARPA) program, teamed with several contractors, and the Navy have designed and will build a "Global Model" that comprises computer representations of hydrodynamic flow control, electrode systems, magnetic systems, and cryostats. Hardware scaling experiments will be undertaken using an existing large field magnet with a variable 1 meter opening, 3.6 meters in length. The magnetic field strength is nearly 6 tesla. The objective will be to show a thrust flow of 10 m/sec (80-100 kL/min) representing about 22 knots ship speed. Transient behaviors and thrust reversal will also be demonstrated. The ability to vary the orifice opening from 0.2 m to 0.5 m will be present. Gas measurements, acoustics, efficiencies and corrosion effects of electrodes will be monitored. More specifically, the program plans to concentrate on the following:

- Efficiency/size of magnets - program will look at an order of magnitude reduction in size and weight while increasing power densities
- Gasless electrodes - elimination of environmental effects, hydrogen sulfides and chlorides, bubble effects
- Magnetic field cancellation - elimination of extraneous high magnetic fields that may impact sensors, displays, automation equipment, and potential biological hazards
- Conductivity enhancements - methods to seed the conductive media
- Potential design considerations - propulsion configuration in a whole ship architecture

One area of particular interest in this last study topic is a combination of power systems that increases the net overall system efficiency. As an example, it has been proposed by some in the U.S. that a fuel cell/MHD power plant combination may be possible where the fuel cell provides the low voltage high current electrode power plus the required magnet support power, thus taking advantage of the high efficiency fuel cell to offset the lower efficiency MHD propulsor. The overall system efficiency thus may be raised. This combination could provide a totally electro-mechanical system that would "lock-in" the advantages of the MHD propulsion listed previously. Thinking in terms of power building blocks could help to make the end product more attractive and justify a greater investment in R&D.

The current U.S. program is now underway with participation by universities (MIT, Univ. of Tenn.), industry and government (Navy, Argonne National Laboratory). The purpose of the work is to give some answers to the question of "why MHD for ships." The set up of Figure 1, using the large superconducting magnet at Argonne, is expected to be operating by July/August 1990 with testing to continue for approximately one year leading to a decision on feasibility for future development.

Interest has been intense since the time of our visit to Japan. In addition to the DARPA planning effort, a comprehensive workshop was conducted at the Naval Underwater Systems Center to pull together the U.S. experts who could make a significant contribution to this scientific area and to help determine the case for U.S. investment.

Conclusion

It is clear that interaction between the JAFSA scientific team and U.S visitors and by the informative presentations and tours helped significantly to form and galvanize the U.S plan for further research and potential large-scale development. Still, the problems are many and may take the combined inventiveness of the Japanese and U.S. researchers to eventually solve them.

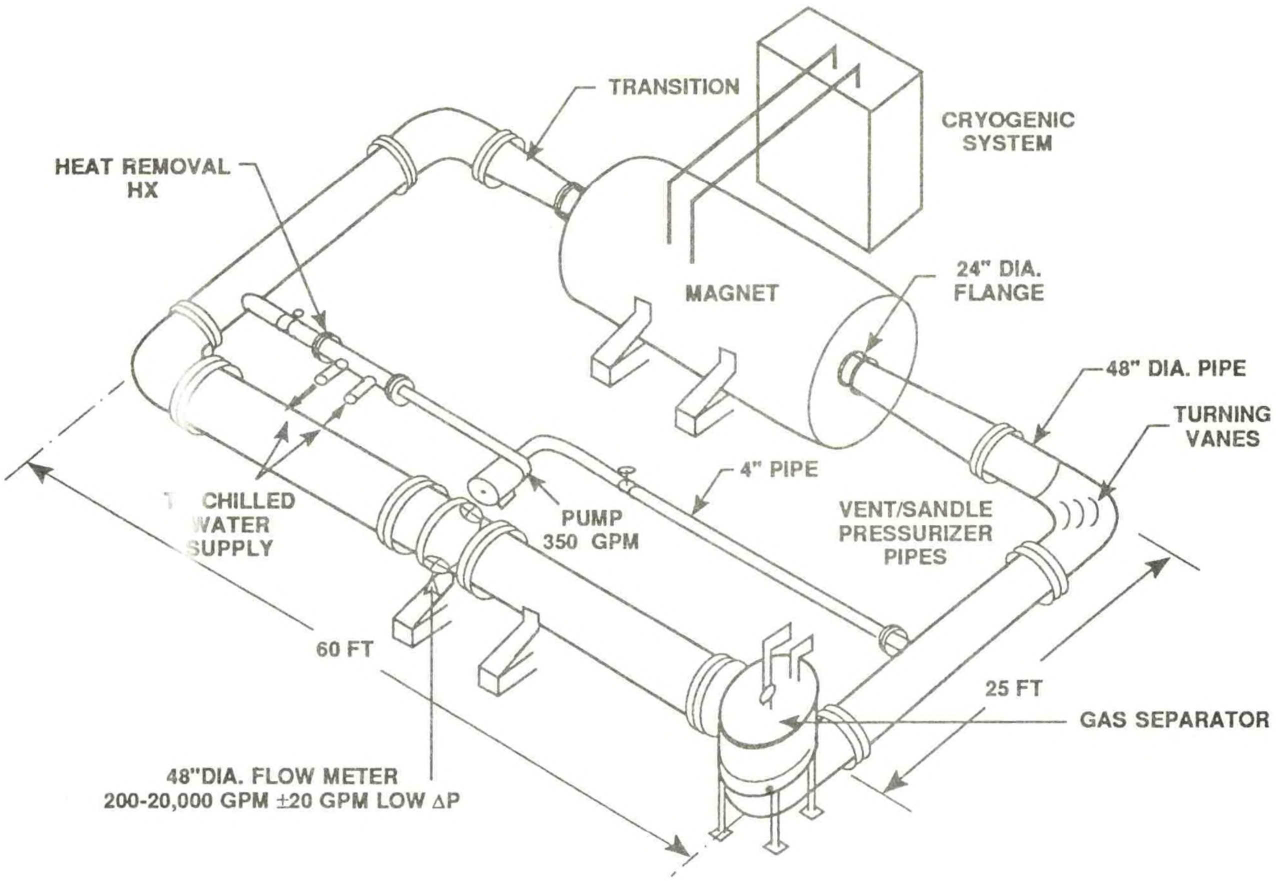

Fig. 1. MHD propulsion test facility flow loop arrangement and geometric patterns

Therefore, translation of technical reports to provide greater detail of work efforts as well as a willingness and an openness to discuss successes and failures experienced in both countries' programs will do much to advance this difficult, yet promising, propulsion technology. The forum of the UJNR has offered a unique opportunity for its members to continue technical dialogue at the "cutting edge" of engineering science for our mutual benefit and future directions.

WATERWAY DESIGN: REDUCING RISK OF MARINE NAVIGATION

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One of the Coast Guard's responsibilities is to provide an aids-to-navigation system that ensures safe and expeditious passage of deep draft vessels in restricted waterways. Nearly 21% of the Coast Guard operating budget is used to support this mission. The aids-to-navigation system must support a wide variety of users, from recreational boaters to large tankers, each with different navigation requirements. More than 40,000 aids to navigation are currently operated and maintained by the Coast Guard. The selection and placement of these aids to navigation is critical for safety in the ports and waterways of the United States.

In the past, the design of an aid-to-navigation system has been subjective, being guided by previous practice, preferences of professional mariners and intuition. Until recently, few quantitative methods existed for selecting and placing aids to navigation to account for channel size, turn angles, environmental factors, vessel maneuverability and traffic density.

The approach to waterway design has changed in recent years as a result of U.S. Coast Guard research. This research, which has been active for more than 12 years, has used man-in-the-loop simulations to study the effects of the waterway, the vessel and the environment on piloting performance. The program has led to a methodology for quantifying the level of risk associated in transiting a particular channel in a particular vessel under specific environmental conditions. This risk analysis is used to design new aids systems, improve the safety of transiting an existing channel and guide Captains of the Port in determining conditions for passage.

Background

The Coast Guard research program, initiated in 1976, recognized the need to examine and measure the relationships between aids to navigation and navigation performance. Ship Analytics, Inc., the prime contractor for this work, was awarded the contract based on their marine experience, as well as their approach in using marine simulation. Ship Analytics, a small company in North Stonington, Connecticut, has many highly skilled technical personnel in marine engineering, human factors engineering, and experimental psychology. The company designs and builds marine simulators for customers around the world. Their expertise in both the hardware and software sides of simulation has proved to be an asset for development of the risk assessment methodology.

Most of the data that were used for the risk model were obtained on shiphandling simulators, though substantial data were obtained at sea to validate those data obtained on the simulators. Shiphandling simulators provide a full-size ship's bridge, typically 180 degree or more of horizontal field of view, computer generated color images of the view out of the bridge, and complex hydrodynamic models that accurately simulate the motion of numerous types of vessels under various environmental conditions (e.g., wind, current, bottom effects).

Simulators have the advantage that precise control can be exercised over the type and size of a vessel, the placement of navigational aids and the environmental conditions, unlike measurements at sea. These conditions can be duplicated so that performance of many mariners can be studied under identical conditions. Furthermore, precise data can be obtained on ship's position within the simulated channel, the number of engine and rudder orders, the time of occurrence of these orders, and the pilot's behavior. In the twelve years of this program, Ship Analytics has conducted more than twenty simulator-based experiments, examining many variables that affect ship handling. Table 1 lists many of the variables that have been examined.

Waterway Design Program

Ship tracks provide the basis for much of the analysis. Professional pilots, serving as test subjects in the experiments, were directed to keep the ship on the centerline of the channel, deviate from the centerline when required to prepare for the turn, and return to the centerline after completing the turn. Most experiments were done on a simulated 150-meter wide channel with a 35 degree turn.

Through careful analysis of vessel tracks and pilot's behavior on the bridge, both on the simulator and at sea, critical waterway regions were defined that affect the quality of the maneuvering in the channel. For purposes of analysis, channels were divided into three regions: turn, recovery, and trackkeeping.

The turn region requires the most severe maneuvers, requiring the pilot to make rapid and frequent judgments of the ship's alongtrack and crosstrack position and velocities. The recovery region, the area where a pilot "sets up" for a turn or pulls out of a turn, must provide precise information about the edges of the channel and the ship's relationship to them. The trackkeeping region, the straight portion of the channel, encloses the channel segment in which the pilot is satisfied with the ship's track and has no intention or need to leave that track. He does not need precise information about the channel edges, and relatively few aids to navigation.

Measures of trackkeeping are sensitive to changes in the variables listed in Table 1.

TABLE 1

VARIABLES THAT AFFECT SHIPHANDLING ABILITIES

I. Ship Design/Ship Operations

a. Ship size, maneuverability
b. Height of ship's bridge
c. Speed

II. Waterway Design

a. Channel width
b. Turn Angle
c. Turn radius
d. Channel depth
e. Closeness of landmass

III. Aid Configuration

a. Aid placement
b. Aid density
c. Types of aids (fixed, floating, radio aids, radar reflectors, etc.)
d. Accuracy of aid placement
e. Radio aid accuracy

IV. Environmental

a. Wind
b. Current
c. Visibility
d. Day/Night
e. Traffic density

Some sample findings include:

- Trackkeeping is better when buoys are gated than when they are staggered.

- Trackkeeping is better if buoy spacing along channel is 1150 meters rather than 2300 meters.

- Performance in turns is best when three buoys mark the turn.

- Landmass near the channel edge aids mariners if buoy density is low.

These sample findings are incorporated into a risk assessment model for waterway designers. A quantitative measure, called the Relative Risk Factor (RRF), reflects the probability of grounding or collision in a particular waterway. The relationships between RRF and the variables listed in Table 1 were derived and used as inputs to the model.

A waterway designer can analyze the design of a particular waterway with a software package written for the purpose. Design considerations are entered, including the size of the ship for which the channel is being designed. The output is an estimate of the relative risk of transiting that channel during day, night, low visibility, and with meeting traffic.

Since 1987 aids to navigation offices throughout the Coast Guard have been conducting analyses of waterways to determine which waterway regions have unnecessary risk. In many cases, plans for reducing this risk have been implemented. The general approach is to make risk in all the channels in a particular harbor as uniform as possible. The waterway designer, for example, may calculate relative risk factors for all turns in a channel, select the turn with the lowest RRF and then redesign the other turns so that their RRF's approach that of the best turn.

We are continuing to update and extend this risk assessment system to include information about radionavigation accuracy. The use of Loran-C and the nearly operational Global Positioning System (GPS) make harbor transits possible when visual aids are obscured by fog. The accuracy of the radionavigation signal has an impact on a mariner's ability to navigate in the absence of visual aids. We are currently determining how accurate the radionavigation information must be for successful navigation and evaluating the risks associated with different levels of accuracy. This information will eventually guide the Captain of the Port in traffic control schemes for low visibility conditions.

The goals of reducing risk and providing a system for expeditious passage of vessels are being met. The analyses of U.S. waterways have resulted in improvements that reduce the risk of groundings and collisions. Our knowledge of the factors that affect the movement of ships has enabled us to design a system that is tailored to the needs of the users.

Offshore and Undersea Technology Systems

CONSTRUCTION TECHNOLOGY OF HUGE FLOATING OFFSHORE PLATFORM

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The utilization forms of the ocean at present are classified into following groupes.

① Ocean space utilization for production, living, traffic or transportaion, recreation, waste and storage

② Utilization of ocean energy such as wave and current and thermal energy

③ Development of marine bio-resources such as marine ranch, consolidation of fishing ground and culture fishery

④ Development of ocean mineral resources such as seabed petrouleum, natural gas and seabed resources

The marine structures, which can provide these utilizations, have various kinds such as floating type, jack up type, bottom supported type, fixed type, etc. In this paper the trend of the technological development in Japan especially about the floating offshore platforms out of many kinds of marine structures will be described.

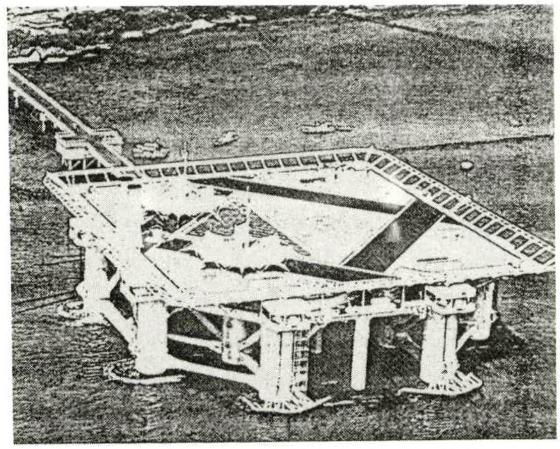

Photo 1 AQUAPOLIS

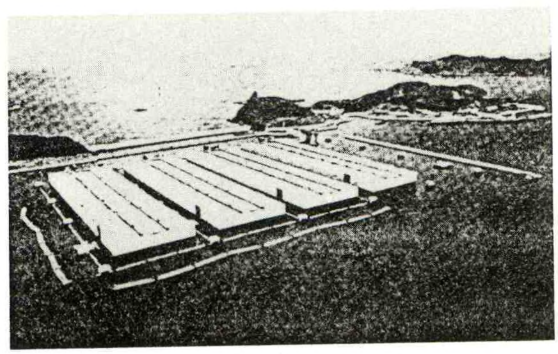

Photo 2 Oil stock base

EXAMPLES OF THE FLOATING OFFSHORE PLATFORMS

There exists rather small offshore platforms, but the size of most of the structures are less than 100m. Most of the floating offshore platforms of medium size of larger than 100m are the rigs for the exploitation of the submarine mineral resources. Further, there are only two other examples. One is marine artificial island "AQUAPOLIS" (length;104m, breadth;100m, see Photo 1) which was constructed as the symbol of the Okinawa international marine exposition in 1975. And the other is the Kamigoto island oil stock base (5 storage ships,length;390m, breadth;100m see Photo 2). Although 20 years has passed since the marine resources development actually began in Japan, non-floating type of marine structures has the leading part in the ocean utilization. The realization of ocean utilization by the use of floating offshore platforms is still expected to come true at present. Therefore, the enlightenment of the floating offshore platforms as well as the improvement of economy and the development of technology is keenly necessitated.

CONCEPT OF HUGE FLOATING OFFSHORE PLATFORMS

The social structure, economic structure and national land structure are expected to be greatly reformed up to 21st centuries due to the liveliness of economic activities, expansion of domestic demand, improvement of living standard, increase of leisure time, society full of communications and informations, insufficiency of the offices and the housings around the capital area accompanied with the substantialness of the basis of the economic society. Therefore, the multi-purpose utilization of the ocean space in the 21st century will be rapidly accelerated while the new structure of society has been groped.

Floating offshore platform has the following fundamental characteristics.

① High freedom to the direction of the sea depth and ability to utilize on the sea surface, in the sea and the sea botttom

② Less effect to the ocean environment.

③ Movement, expansion and reduction is easy to cope with the change of social circumstances and the construction period is short

④ Superiority in the earthquake-proof

Various concepts utilizing the floating offshore platforms as the form of ocean space utilization have been published officially. The representative examples are "FLOPORT" (length; 1020m, breadth; 80m, Photo 3), floating commuter airport presented by Japan Shipbuilding Industrial Association, "Floating airport and city" (length; 5000m, breadth;1900m, Photo 4) presented by Japan Ocean Development and Construction Association and the "Floating Artificial Island" of multiple purpose by Japan Industrial Machinery Association.

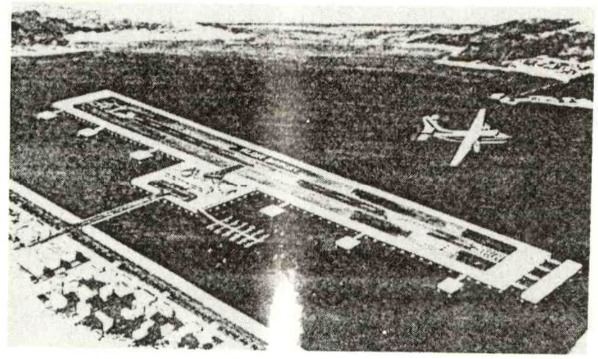

Photo 3 FLOPORT

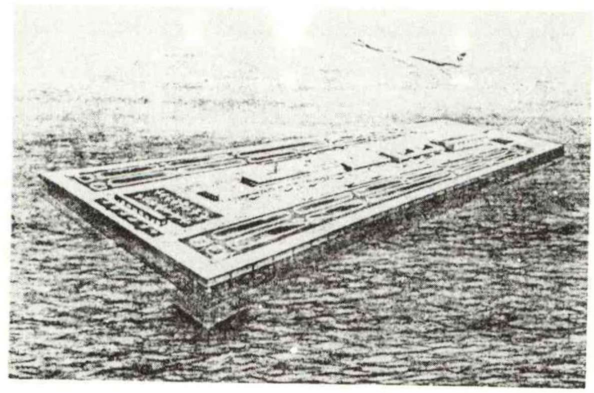

Photo 4 Floating airport and city

ITEMS FOR TECHNOLOGICAL DEVELOPMENT CONCERNING HUGE FLOATING OFFSHORE PLATFORMS

The items for element technologies can be listed up as follows about the plan, design, construction, setting and operating conditions of normal floating offshore platforms.

1) Circumferential conditions

① Regulations and standards (design and construction, management, formation of consensus, compensation, etc.)

② Natural environmental conditions (prediction techniques, data analysis, data collection, long term measurement at the sea area, etc.)

③ Sea area investigation (water depth, sea bottom, soil quality, earthquake, tsunami, etc.)

④Plant on board (measures against the damage from the salt water, arrangement, anti-motion and vibration characteristics, etc.)

⑤Access (helicopters, transport vessels, bridges, submarine pipelines and cables, submerged tunnels, etc.)

2) Hull construction

①Material (cost, mechanical properties, anti-corrosion, manufacturing, water proof, etc.)

②Structure mode and form (unit pattern, mode, motion characteristics, etc.)

③Management on the progress of construction (process schedule, processing method, etc.)

④Processing (towing, jointing in the ocean, working on board, etc.)

⑤Structural strength (external force, optimum structure mode, structural analysis, fatigue prediction method, vibration analysis, elastic deformation analysis, etc.)

⑥Motion and stability (reduction of motion, security of stability, permissible motion level, etc.)

3) Position keeping

①Method

(1) DPS (weight reduction, reliability, cost down, control system, etc.)

(2) Mooring

a) method of mooring

b) material (cost, mechnical properties, anti-corrosion, abrasion and fatigue prediction method, processing, etc.)

c) processing (adjustment, laying, positioning, seabed basis, etc.)

②Motion control (form of the floating body, external force, wave absorbers, permissible motion level, etc.)

4) Maintenance

①Anticorrosion (material, anticorrosive processing, evaluation method of anti-corrosion, etc.)

②Maintenance

a) inspection (stress monitoring, observation in water, defects inspection in water, working vessels, robots working in water, diving techniques, etc.)

b) repairs and remodelling (working vessels, communication in water, robots working in water, tools used in water, welding in water, diving techniques, etc.)

5) Environment and safety

①Assesment of the environment (effect to the environment, formation of consensus, effect to the ecological system, method of evaluation, etc.)

②Protection against disasters and environment (marine pollution protection, measures against collision and fire, life saving and escape appliances, etc.)

TREND OF TECHNOLOGICAL DEVELOPMENT

In this section, the trend of technological development and actual situation concerning the items of element technologies mentioned in the previous section are described from the view point of the big project of Ministry of Transport, "Research for the development of offshore using the marine structures" or "Research on the safety evaluation in the marine transportation of the marine structures" or "Research on the design of the hybrid marine structures". In these items of element technologies, the item of technology which has been completed or almost completed in the existing rigs and can be adapted to the technology of the huge floating offshore platforms will be excluded.

1) Circumferential conditions

①Regulation and standard

Safety evaluation method adapted to the social circumstances should be establised cosidering the technical innovation and construction quantity. Therefore, these can be changed with the pass of time. The formation of national or world wide consensus and the revision of the law for the fishery compensation are quite important. The measures against them are now been groped.

② Natural environmental conditions

The long term measurement at the sea area where the platforms are supposed to be constructed and set up, is forced to carry out. Therefore, the development of measuring devices, the grasp for the peculiarity of the weather and waves conditions especially the long term component and the improvement of prediction techniques are important. The development of the measuring system of waves and current using the radar, shallow water effect and sheltering effect caused by the islands, the development of prediction techniques of the offshore waves considering the friction at the sea bottom and the shape of sea bottom have been carried out. Further, the measurement of directional waves by the arrangement of 3 points array has been carried out using ultrasonic type probes in the project of "POSEIDON".

③ Sea area investigation

The development of various kinds of measuring devices to improve its performance has been carried out.

④ Plant on board

The improvement of economy as well as anti-corrosion and earthquake-proof is the most important.

⑤ Access

It is impossible to transport humans or goods between land and platform by shuttle using the submerged tunnel, the normal transport vessels or helicopters in rough waves, because the floating offshore platforms experience a dynamic motion due to disturbances. Therefore, the develpment of the flexible tube tunnels, all-weather transport vessels or the new traffic system including the landing place is indispensable. The concept or ideas are now been considered concerning the technological posssibility of success.

2) Hull construction

① Material

The development of concrete of high tension, light weight, high durability, steel of high tension and corrosion resistance, hybrid material and new material is essential from the viewpoint of maintenance or the improvement of economy. The research on the improvement of strength property of hybrid (steel and concrete) structure and the development of techniques of ultrasonic type defects inspection has been going on.

② Structure mode and form

The selection of the best structure mode and form which conforms to the conditions of location considering the economy is quite possible using the existing techniques.

③ Management on the progress of construction

Although the selection of the optimum module, setting the structure and the development of management system of quality and built-up form are very important, the investigation has not been done yet due to prematureness.

④ Processing

The development of automatic construction method, construction by robots, gigantic construction machinery for the operation in the deep sea or in rough waves is significant in order to shorten the construction period. The development of simulation model of the motion of towed body and the towing cable tension when the unit of the huge floating offshore platform is towed in the wind, waves and current and also the technological development on the fatigue of towing cable to the impulsive tension have been in the project.

⑤Structural strength

The establishment of the dynamic structural analysis accounting for the motion, wave-resistant and earthquake-resistant performance of the floating offshore platform has been needed. In order to establish the estimation techniques of structural deformation due to thermal heat, elastic deformation due to waves and the fatigue damage of the structural member, the elastic model tests and the full-scale tests of "POSEIDON" have been carried out.

⑥Motion and stability

The international standard of vibration regulates the loaded equipments concerning the vibration and motion of the platforms. There is nothing more special problem cosidering the past experiences of the rigs. The effect to the human bodies, pleasantness and comfortableness to get on board should fully be investigated because the humans live on board for a long period of time unlike the normal ships. However, those researches have not been carried yet because of the lack of the full-scale plant. As the humans live on board, flooding or list should not be allowed. The existing techniques covers the detection of small quantity of flooding or the system of automatic adjustment of the list.

3) Position keeping

①Method

The techniques to keep positions of the huge floating offshore platform economically in the water depth less than 50m by the use of rubber fender system has been established. If the water depth increases, it is necessary to use the mooring system or DPS which employs the thruster. It may seem that to use both the mooring system and DPS is the most economical as the method for long term position keeping. The durability of cable ropes and chains has been improved, and also the high accurate estimation techniques of fatigue damage, automatic laying system of anchors, cable and chains should be developed. It is indispensable to develop the synthetic fiber ropes, steel cables of high anti-corrosiveness and of durability and new material especially when it comes to the deep sea. On the other hand, DPS needs the development of high efficient thruster and the improvement of lightness of the weight and economy. Those technological development has been carried out in various fields of industries. Moreover, as for the mooring system, "POSEIDON" has been moored for 4 years by 6 slack chain lines. The estimation techniques for the reduction of mooring chain strength due to the lapse of time and the improvement of durability have been developed, while the continuous measurement of the mooring line tension and regular measurement of abrasion and marine growth have been taken. Further, the various at-sea experiments have been carried out in the marine products industries concerning the mooring at deep water depth which reaches about 1000m.

②Motion control

To burden the excessive line tension with the mooring system in order to control the motion of the platforms may be unsuited for the long term mooring from the view point of fatigue property. Therefore, it might be favorable to employ the suitable form and arrangement of the floating bodies, active mechanism and floating breakwater system for the motion control. The simulation experiment for the effect of the arrangement of the floating bodies to the reduction of motion and to the wave breaking have been carried out.

4) Maintenance

①corrosion protection

The development of the long term anti-corrosive paint, that is weather resistant and anti-adhesive free from the stains of salt water and of the economic electric corrosion protection method are important. The experiments of the corrosion protection about concrete and resin mortar or various heavy anti-corrosiveness, etc. have been carried out at "POSEIDON" or experimental tower for exposure. The developmnent of the method of artificial exposure testing which enables the estimation of the corrosion protection in a short period of time in the laboratory. has also been carried out.

②Maintenance

The significant themes are the development of the system for detection in the water, defects inspection and observation, and the system for automatic maintenance, inspection and mending. Only a small part of the technological development such as the robot in water, welding in water, diving and communication in water are now being carried out.

5) Environment and safety

①Assesment of the environment

It is necessary to develop the high accurate monitoring system of environment, the techniques of simulation for the estimation of the effect to the environment and the estimation method which gained a consensus. The effect to the living creatures or the ecological system after the floating marine platform was set up is also important, especially the technological development for making the fish ground or nursery coexist together with the platforms is the most important. It is confirmed that coexistence of fishery is possible in the case of a small-cale or medium-scale of floating offshore platforms.

②Protection against disasters and environment

It is needless to say that the system related to the protection against disasters and life saving is the most important as well as the measures against the marine pollution protection. Those problems cannot be a peculiar technological development theme to the floating offshore platforms if the access to the land is completely equipped or the more appropriate measures are taken like measures on land. Thus, the most important theme is the measure against collision and the actions should be taken on the assumption that the collision necessarily occurs no matter how the navigation of the ships may be regulated, It leads to the necessity of the technological development of the floating fender with the function of breaking waves, preventing oil from spreading and the protection against the ship collisions.

6,500m DEEP MANNED RESEARCH SUBMERSIBLE "SHINKAI 6500" SYSTEM

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ABSTRACT

The construction of the 6500 m deep manned research submersible "SHINKAI 6500" and its support vessel "YOKOSUKA" are nearly completed, with the final dive test to 6500 m deep successfully carried out in August 1989, at the Japan Trench, east of Honshu.

This paper discribes outlines of the submersible and the support vessel and test results obtained upto now.

Main Events

"SHINKAI 6500"		
Launched	January,	1989
Dive to 6500 m depth	August,	1989
Completion	November,	1989
"YOKOSUKA"		
Commencement	February,	1988
Launched	July,	1988
Completion	April,	1990

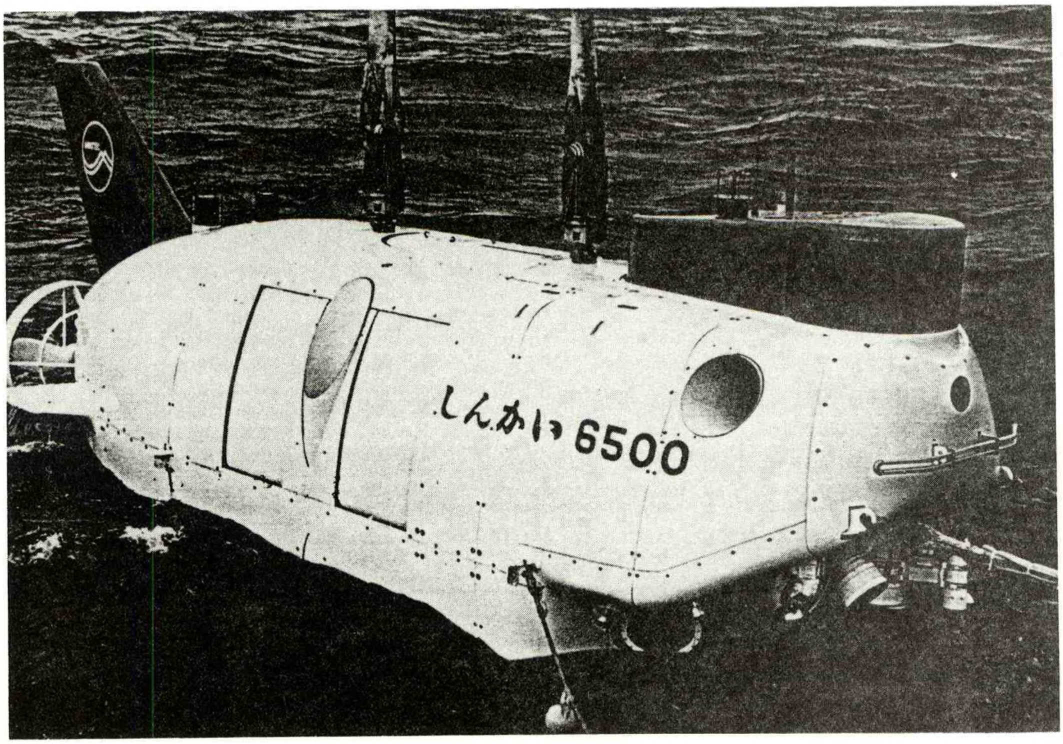

Photo 1.

6500 m Deep Manned Research Submersible
"SHINKAI 6500"

PRINCIPAL PARTICULARS

Length(L_{OA}):	9.5m	Speed:	1kt(Cruise)	Max. Depth	
Breadth:	2.7m		2.5kt(Max.)	Capability:	6,500m
Depth:	3.2m	Crew:	2 Pilots &	Life Support:	
Draft:	2.7m		1 Observer	129hours	
Weight:	ab 26 ton	Payload:	200kgf	=9hours+5days	

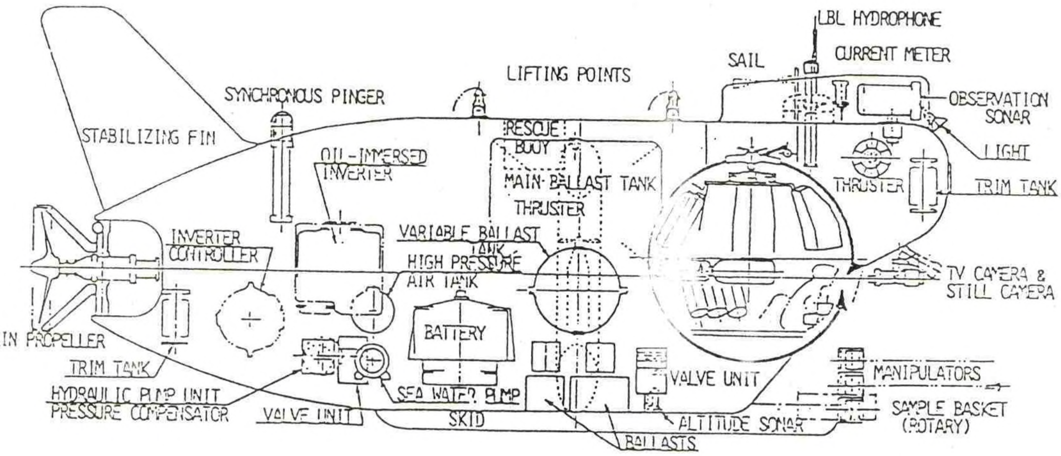

Fig. 1 General Arrangement of "SHINKAI 6500"

FEATURES OF "SHINKAI 6500"

Following are the main features of "SHINKAI 6500";

(1) "SHINKAI 6500" can descend to the 6,500m deep ocean floor in 2.5 hours, by virtue of its elipsoidal sectional form, instead of circular form for "SHINKAI 2000".

(2) The pressure hull is made of titanium alloy (Ti-6%Al-4%V Extra Low Interstitial), and its inner diameter and thickness are 2.0m and 73.5mm respectively. To achieve the purely spherical hull with the aim of weight reduction, the electron beam welding and three dimensional machining were extensively applied. Its pressure proof test charging 1.1 times of the maximum diving depth pressure was carried out at David Taylor Research Center, Maryland, USA, and its integrity was certified.

(3)Newly developed Acoustic Imaging Sonar (Observation Sonar) is installed instead of conventional CTFM Sonar. This is an acoustic TV camera showing frontal, sectional and PPI images of the underwater object on CRT.

(4)Two manipulators are installed. Right hand has 7 degree of freedom controlled by master-slave algorisms and left has 5 degree of freedom controlled by joysticks. The right is dexterous and the left is powerful.

(5)Independent LBL navigation equipment is installed. The system has been so far too large to be installed in the submersible, but the recent technology deveopment on micro-electronics has made the system small enough to be installed in the pressure hull. This acoustic navigation system enables the submersible to locate itself in a good accuracy.

(6)High pressure sea water pump system is installed in order to adjust/ballance weight/buoyancy, by pumping high pressure sea water directly from/to VBT(Variable Ballast Tank).

(7)Oil-filled pressure compensated DC-AC power transistor inverter is installed. The new inverter system requires no heavy pressure vessel, thus contributing to total weight reduction significantly.

(8)Newly developed binary mixture type syntactic foam is adopted as the buoyancy material. The specific gravity is 0.54gr/cm³ and the collapse pressure is more than 1,200kgf/cm².

(9)Machineries are so arranged that emitted noises will not disturb underwater acoustic communications and measurements.

(10)Since acoustic signal attenuates significantly at very long distance, transponders may not respond to the signal approach. Thus the synchronous pingers are adopted to obtain the accurate long-range measurement.

(11)Main batteries, the sole power source of submersible, are composed of silver-zinc cells with excellent property of high energy density and of long serving life. Adoapting the inverters with VVVF/PWM (Variable Voltage and Variable Frequency/Pulse Width Modulation) control algorithms, every AC induction motor equipped is designed to work efficiently.
(12)All of the operation informations from subsystems are graphically displayed and monitored selectively with Integrated Information Display System (IIDS). The useful data for operation and maintenance and supporting data for observation and measurement are automatically logged with IIDS.

PRELIMINARY TESTS OF "SHINKAI 6500"

The primary functions and the performances of various subsystems are tested and evaluated by the preliminary tests.

These tests are composed of three stages; pool test and dock tests, and mating test.

In pool and dock tests, the following tests were successfully conducted in a systematic manner. The function and performance of each subsystem and their integration were compared with their design values and confirmed.

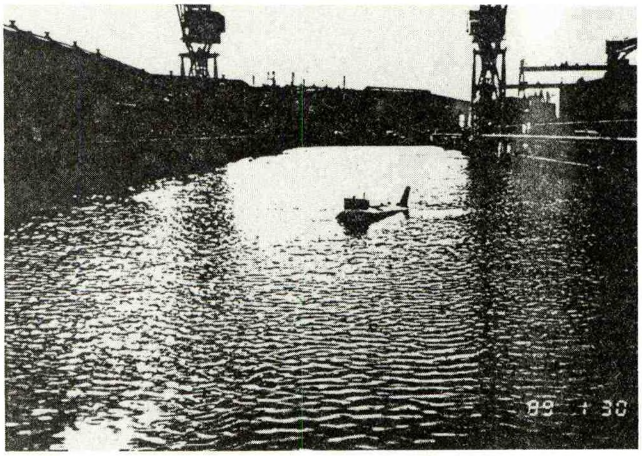

Photo 2. Dock Test of "SHINKAI 6500"

(1)The stability and upright moment of the submersible either in afloat condition or in water were tested in a pool. They were found to be satisfactory.
(2)Reaching and leaving attitude on/off the sea bottom were examined and its excellent maneuverability was recognized successfully.
(3)The noise level emitted from the submersible in different operating conditions were measured and analized to secure enough signal/noise level for any acoustic instrumentations installed.
(4)The jettisonning actuation for ballast releasing mechanics, manipulators system and others were examined individually to secure the emergency buoyancy.
(5)The underwater acoustic equipments such as underwater telephone, altitude sonar/overhead obstacle sonar, acoustic locator (LBL) were tested within their restricted conditions. Their preliminary functions were examined after shooting out some troubles. Performance of the observation sonar promised its future convenience.

After these tests in pool and dock water, several mating tests with the support vessel "YOKOSUKA" were carried out at the builder's pier;
(1)Launching/recovery apparatus and their operation were successfully tested and drilled to ensure enough skill.
(2)The control of charging and discharging current to/from the main battery were examined to get a stable maintenance. And the supply of hydraulic power from the support vessel for checking was also secured.
(3)The semi-automatic fitting of the ballast weight (blocks of steel plates) to the submersible was proved to be quite simple and efficient as a routine work.
(4)Synchronization of the underwater acoustic telemetry equipments was also examined for restricted range.

(5)The power systems such as the main batteries, AC motors, the sea water pump system or hydraulic system were confirmed to work well.

FEATURES OF THE SUPPORT VESSEL "YOKOSUKA"

There are also many unique systems on "YOKOSUKA" [1] (see General Arrangement in Fig. 2).
(1)The hull of "YOKOSUKA" is made as ice-resistant.
(2)Multi-narrow-beam echo sounder is equipped at the bottom of the hull. It can measure the depth of 11,000m ocean floor with ±45° range by 2° increment at 1m depth resolution. This system is used for the pre-survey of the diving point.
(3)A-frame crane system with two points liftings is equipped for launch and recovery operation, under upto sea state 4.
(4)Satellite navigation system using NNSS and GPS and radio navigation system using Loran C and Decca are equipped in order to measure the accurate position of the support vessel on the earth coordinate. They constitute a hybrid system for the accuracy refinement.
(5)Underwater acoustic navigation system using LBL and SSBL is equipped in order to measure relative positions of the submersible and the support vessel with transponders' net developed on the ocean bottom. Positions of both the submersible and the support vessel are shown in graphic displays by relative mode using transponders only or by the earth-coordinate mode combining transponders and satellite/radio navigation systems.
(6)The support vessel has a large void space which can later accomodate the planned 10km-depth ROV.
(7)Underwater acoustic noise emission should be so suppressed that the vessel can use many underwater acoustic apparatus without problem. In order to satisfy this requirement, maximum noise level was determined, taking into consideration the sensitivity of various underwater acoustic devices. Then the prospected noise level was calculated by noise energy flow analysis through the structures, and also the propeller cavitation noises were estimated experimentally. The allowable noise level was determined as by about 10dB less than its sister support vessel "NATSUSHIMA" for the 2,000m manned research submersible "SHINKAI 2000". Using these results, comprehensive countermeasures were introduced such as the adoption of low noise machineries with complete control of fabrication process for the purpose, adoption of elastic supports for vibrating machineries, introduction of vibration restraint material for largely vibrating machineries and adoption of air noise absorbers etc. Combined and preprogrammed control of the propeller shaft revolution related to pitch angle for specially designed skewed twin propellers was also

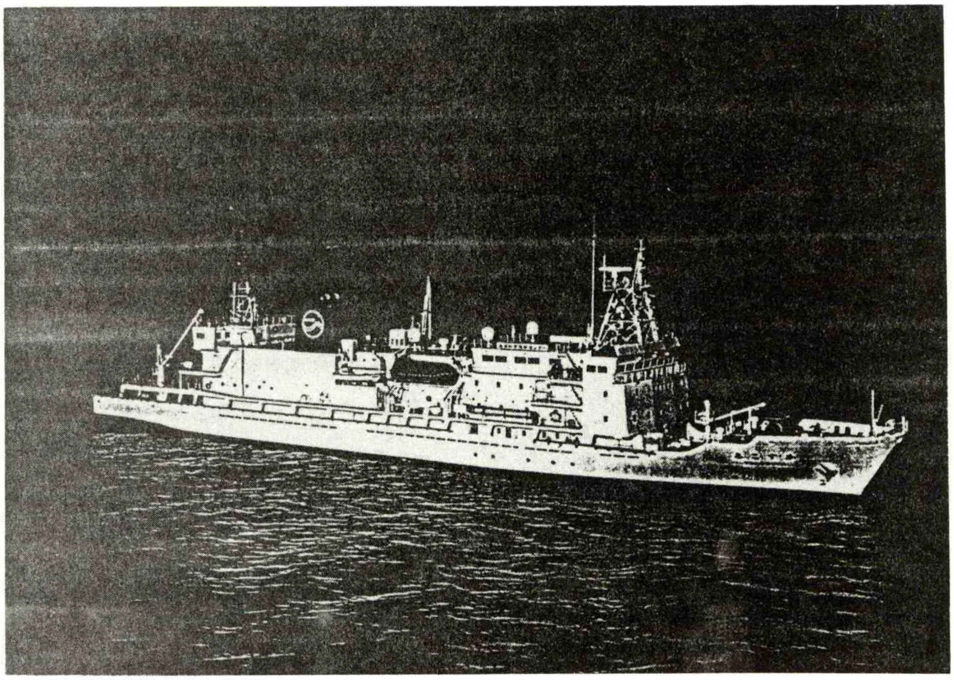

Photo 3. Support Vessel "YOKOSUKA" for the "SHINKAI 6500"

PRINCIPAL PARTICULARS

Type: Monohull
Length (L_{OA}): 105.0m
Length (L_{PP}): 95.0m
Breadth (Moulded): 16.0m
Draft (Moulded): 7.3m
Gross Tonnage: ab4,500tons

Main Engines: 2 sets of 3,000PS Diesel Engines
Propellers: Twin Skewed CPP
Bow Thruster: 1 set with 8 tons Thrust
Electric Power:
3 sets of 740kw Main Generator
1 set of 64kw Emergency Generator

Cruising Speed: 16kts
Cruising Range: 9,000 miles
Endurance: 40 days
Accommodation: Total 57
Officers and Crew: 27
Submersible's Operator: 18
Scientists: 12

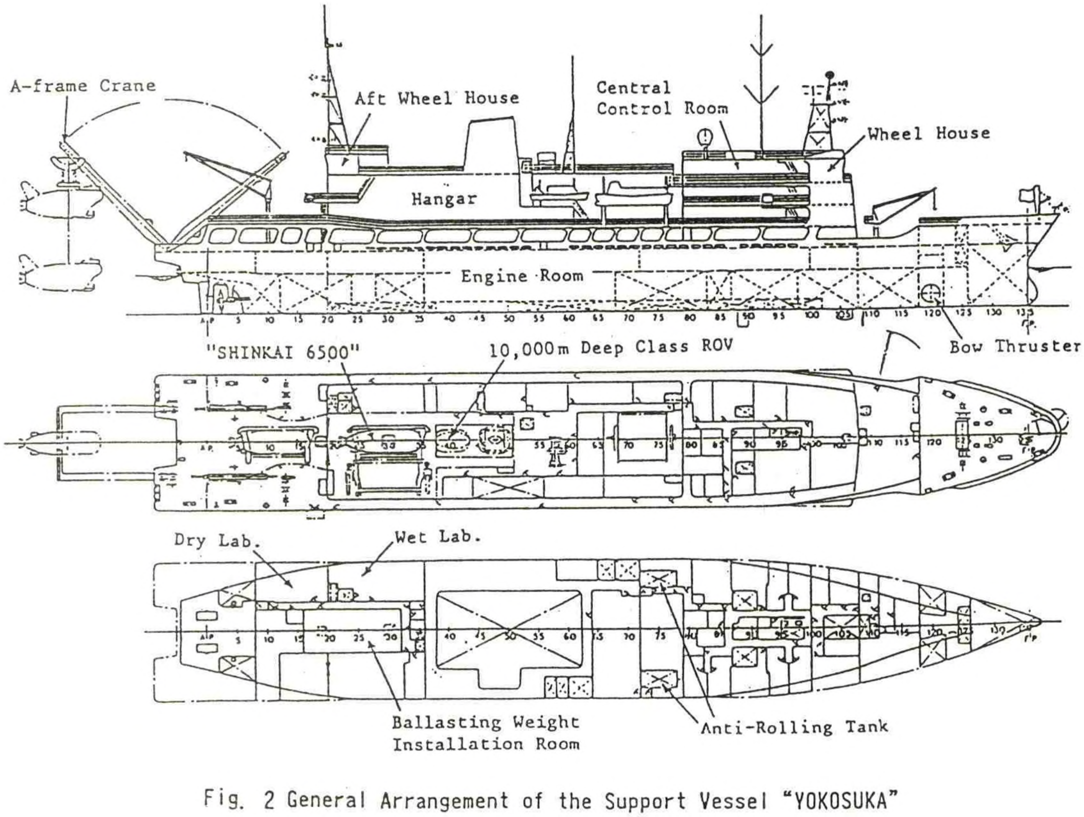

Fig. 2 General Arrangement of the Support Vessel "YOKOSUKA"

introduced in order to suppress the cavitation inception.

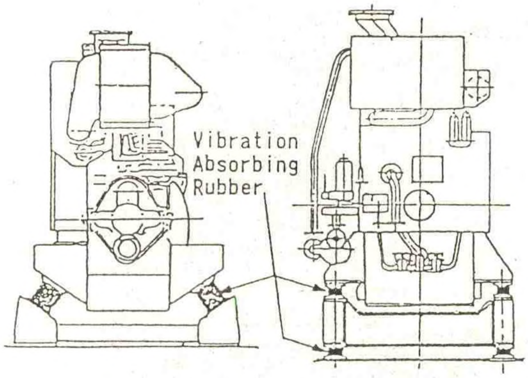

Fig. 3. Elastic Supports of Vibrating Machineries

(8)Laboratories and rooms for researchers are designed considering the convenience for the users in long-term on-board missions. Local area network (LAN) is also installed in researchers' rooms for their convenince.

SEA TRIAL OF THE SUPPORT VESSEL "YOKOSUKA"

After launching, many functions and their performances of "YOKOSUKA" were tested in sea trials.

At first, general tests as a support vessel such as speed trial and sea worthiness measurement were carried out.

Then function of support systems was examined. There are two major kind of support systems: the launch and recovery system and navigation system.

The launch and recovery of the submersible at the rough sea requires the operators to be well trained and accustomed to the work. Therefore a full scale dummy submersible was constructed and used for the training of the operators.

Satellite navigation system, radio navigation system and their hybrid system were tested successfully.

Underwater acoustic navigation system uses transponder net. The LBL operation requires very laborious calibration work on base lines. This new system adopts direct calibration system (depth data is directly informed acoustically from transponders) and makes the work fairly easy. Performance test at sea was quite satisfactory. It is also planned to add other informations such as temperature with the acoustic informations. This transponder system is designed and tested for upto 11,000m depth.

Newly developed multi-narrow-beam echo sounder was also tested. The transducers being fixed at the bottom of the vessel, rough sea may very often disturb the transmission and reception of the signals on account of bubbles covering the surface of the transducers. Since earlier survey of these bubble occurrence had showed that they were produced mainly at the bow-thruster tunnel, "YOKOSUKA" was fitted with bow-thruster cover gates. At the test under rough sea effect of the cover gates was confirmed.

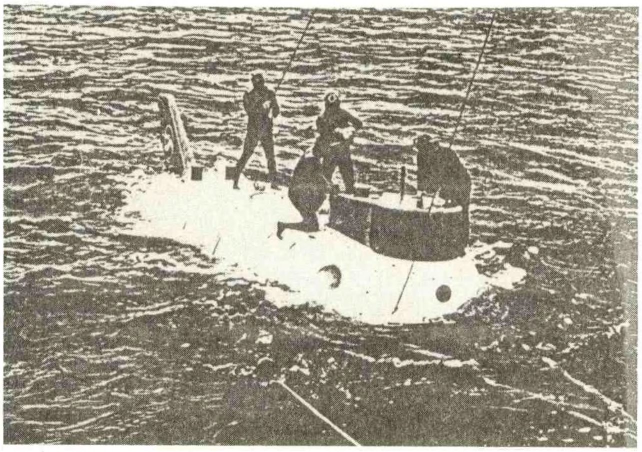

Photo 4. Launch/Recovery Training by Dummy Submersible

The system performance of the multi-narrow-beam echo sounder was also tested at various area. Its performance was confirmed to be very good and also it was found by cruising across the Japan Trench that it could measure the 9,600m depth clearly.

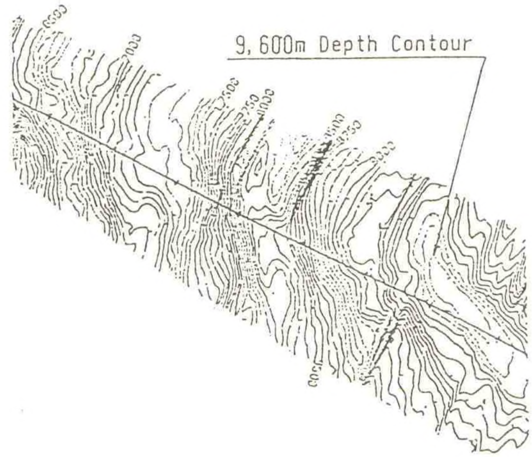

Fig. 4. Example of Sea Floor Contour of Japan Trench

Underwater acoustic noise emission was also measued and examined. There were three kind of tests: measurement at pier, offshore measurement at anchored condition and offshore measurement at cruising condition.

At pierside test, evaluation of the vibrating forces of machineries and of the transmission of vibrations through the ship hull were carried out and the results were found as satisfactory.

At anchored test, measurement of noise intensity distribution was carried out and it was found that elastic supporters for vibrating machineries and vibration restraint materials to suppress the vibration transmission worked effectively.

At cruising test, the propeller pitch and the revolution were controlled in a pre-programmed manner in order to avoid the cavitation noise. Results at this condition were also very satisfactory.

These noise measurements revealed that the new vessel "YOKOSUKA" was very quiet and noise level was as low as the target level.

The noise level was so small that the measurements were often interrupted by other vessels cruising nearby. Even when the other vessel was cruising more than 3 miles away, the measured data was not that of "YOKOSUKA" but that of the cruising one.

These countermeasures were adopted principally against underwater acoustic noise emission, however, noises inside the vessel were so negligible that no one could recognize that the vessel had just started cruising without watching the passing scenery outside.

SEA TRIALS AT COMBINED STATE

Above mentioned tests were carried out operating the submersible or the support vessel independently in order to confirm performance of each ship.

It is the combined state of both ships that the practical condition should be examined and evaluated, debuggings and corrections should be made.

At the combined state, the following items were tested:

(1)Performance tests of the submersible were carried out at various depths. The depth of the first step was 25m, and the depth was increased gradually to the maximum operating depth, 6,500m. In these tests, all systems in the submersible were tested in each depth, such as maneuverability, descending/ascending, ballast jettisoning, sea water ballasting system, sonars including observation sonar, locating by synchronous pinger, LBL navigation/locating system of the submersible, communication system, TV system, manipulators, environment controller in the pressure hull and operationability and others.

(2)Performance tests of the underwater acoustic navigation system of the support vessel especially for tracking of the submersible were carried out at various depths.

The sea trials at combined state have been started since April 1989, and there have been found several bugs both in the submersible and in the support vessel. These initial bugs were carefully surveyed and corrected.

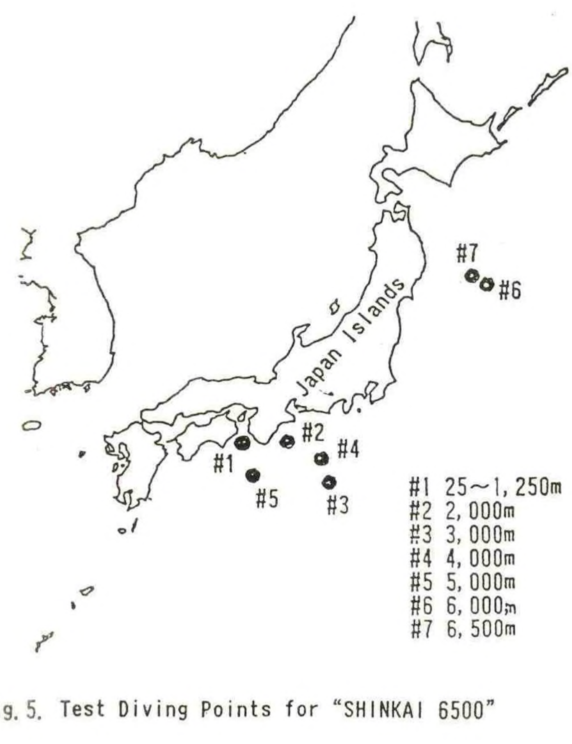

Fig.5. Test Diving Points for "SHINKAI 6500"

PROSPECT

The final dive to 6,500m deep was carried out in August 1989, and after their final maintenance docking, they will be delivered to JAMSTEC. And after one year of training of pilots and crew, mission dives are scheduled to begin in 1991.

The mission dives are expected to give us various and fruitful results on the study on plate techtonics, mechanics on earthquake occurrence and also resources on deep ocean floor, etc.

This system is not that for Japanese only but also researchers of all over the world. Deep ocean floor surveys in international cooperation are also encouraged with the new tool.

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FIBER OPTIC TETHER CABLES FOR DEEP DIVING ROVS

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ABSTRACT

Since 1987, DOLPHIN-3K which is capable to dive depth up to 3,300m has been operated and the total dive numbers are 46 and inwater time exceeds 250 hours. The vehicle utilizes an optical fiber/power line composite cable of 5,000m in length. An experimental cable for the vehicle has been build and tested in 1982. Then, the cable of full length (5,000m) was built and successfully tested at sea in the April 1986. The vehicle was completed and delivered in the summer of 1987 with the cable (No.1) mentioned above and a new spare cable (No.2). 2 cables were used by turn.

Some problems around the cable termination were found but they were improved. A new cable of more sophisticated design is now under fabrication. This paper describes about the comparison of 2 cables mentioned above.

An experimental fiber optic cable for a 10km diving ROV which is now under designing stage was built and tested. The vehicle has no name yet, so the vehicle is temporary called 「10K」 here. This paper also describes about the cable of 「10K」.

The diameter, breaking strength and length of DOLPHIN-3K and 「10K」 cables are 30 and 45 mm, 16.5 and 40 tons and 5,000 and 13,000 (planned) meters respectively.

INTRODUCTION

First use of fiber optics for a ROV might be MARCAS which was developed by KDD Meguro Laboratories (1) and first use of fiber optics for a small ROV might be HORNET-500 developed by JAMSTEC (Japan Marine Science and Technology Center) (2).

Studies of fiber optic cables for ROVs were carried out since 1981 in JAMSTEC. Fiber optics has very superior characteristics such as low signal attenuation, very wide signal bandwidth and no electromagnetic interference.

We first studied the optical loss of optical fibers at high pressure environment. Many kinds of optical fibers such as conventional G.I. optical fibers, special s-glass fiber coated G.I. optical fibers, G.I. optical fibers in loose tube and single mode optical fibers were tested in high pressure test tanks of JAMSTEC.

Through the test mentioned above, it was clarified that almost all of the tested optical fibers withstood pressures up to 1,200 kgf/cm² with very little optical loss except for conventional G.I. optical fibers which withstood 600 kgf/cm² of pressure and gradually increased their optical loss. First fiber optic/power line composite cable for a small ROV HORNET-500 was developed and used. The cable composed of 2 special s-glass coated G.I.optical fibers, 3 rods of carbon fiber as internal strength member, 4 power conductors and 2 contraherically wounded layers of Kevlar as strength member. The cable functioned well. The vehicle was modified as a launcher type in 1988, and the main umbilical and the vehicle tether cables were also developed. The strength member of the new umbilical cable is steel double armour, the strength member of the new vehicle tether is braided Kevlar and optical fibers are loose tube type. The system including those cable has functioned well in tens times of operation depth up to 300 meters.

Since 1986, we have developping Untethered ROV which shall utilize an expendable G.I.optical fiber of 0.9 mm in diameter. The name of the vehicle is 「UROV-2000」 and operating depth of the vehicle is 2000m. Sea going test of the vehicle shall be conducted in the early 1990.

The first experimental cable of the DOLPHIN-3K was built and tested in 1982. The study of fiber optic/power line composite cables utilizing Kevlar 49 as strength member has continued through practical use of the cable of DOLPHIN-3K and test about an experimental cable of 「10K」 was followed. The results of those studies are described in this paper.

SPECIFICATIONS OF THE TOTAL SYSTEM AND OPTICAL FIBER TRANSMISSION OF THE DOLPHIN-3K

The design and specifications of the DOLPHIN-3K, the results of sea going test and succeeding operations were already reported (3), (4), (5).

DOLPHIN-3K is developed for scientific surveys and rescue of the manned submersible 「SHINKAI 2000」 which is owned and operated by JAMSTEC. The system was designed as no-launcher type because the vehicle shoud have broad foot print for scientific surveys. Also, the cable diameter shoud be as small as possible to decrease the cable drag and to increase the vehicle maneuverability.

Main specifications of the system are shown in Table 1.

The general arrangement of the system and path of optical signals are shown in Fig. 1.

The system utilizes the bidirectional PCM transmission with 2 wave division multiplexing via 1 multimode (G.I.) optical fiber of 1 GHz/km bandwidth. The data rate and wavelength of the uplink and downlink are 386.59Mbps, 19.1Mbps and 1.3μm, 0.85μm respectively. High bit rate (400Mbps) and long range (5km) PCM transmission (uplink) is provided by using Lazer Diode (LD) of 1.3μm wavelength which is not limited by mode dispersion noise. Downlink is rather low bit rate, so 0.85 μm LD of proved performance is used. The optical level diagram of the optical transmission system is shown in Fig. 2. Optical margins of uplink and downlink are 13.9dB and 16.9dB respectively. The dynamic loss of the optical transmission system at sea going test is stated later.

TETHER CABLES FOR THE DOLPHIN-3K

The conceptual design of the total system of the DOLPHIN-3K was carried out in 1982 and specifications of the cable were determined by the design. The main specifications of the cable are as follows.

(1) Diameter : 30mm
(2) Length : 5,000m
(3) Breaking strength: 16.5ton or more
(4) Conductors : 2500V, 16A, 3ϕ, 60Hz
: 2500V, 6A, 1ϕ, 60Hz
(5) Number of fibers : 4 (G.I., 50/125)
(6) Attenuation : 1.0 dB/km or less at 1.3μm, 3.0 dB/km at 0.85μm
(7) Attenuation under pressure : 1.0 dB/km or less under 376kgf/cm²
(8) Bandwidth : 1GHz/km (400Mbps, 5km)
(9) MTBF : 7,000hour

The experimental cable was built and tested in early to middle 1983 (6). The final construction and structure of the cable was determined by the result of the test.

The cooperative study about the cable and the optical fiber transmission system was started since 1983 between JAMSTEC, Fujikura Ltd. and MES (Mitsui Engineering and Shipbuilding Co.Ltd.). Fujikura Ltd. is a builder of the cable and the optical transmission system and MES is a builder of the total system. Because the cable and the optical transmission system are the most important subsystem of the DOLPHIN-3K system and technical problems must be solved before construction of the vehicle system. The main purpose of the cooperative study was to built and to test the full length of the cable and the optical transmission system in the sea.

The cable was completed and tested in the sea depth up to 3,300m in the April of 1986. The cable handling system for the DOLPHIN-3K was used to tow the cable and about 1 ton of weight was attached at the top of the cable. The dynamic loss of the optical signal and the bit error rate of the PCM transmission device were measured. Optical transmission loss of the cable including loss of the optical rotary connector was measured by OTDR (Optical Time Domain Reflectometer). Measured optical transmission loss was 0.25 dB to 0.55 dB through 5km of the cable at 3,300 meters of towing depth. Value of optical loss was not changed when the rotary connector rotated at the maximum speed (about 45m/min of line speed). Bit error of the PCM device was below 1 x 10^{-9} at -36.5 dBm of receiving level of O/E device.

Mechanical and high pressure tests using short specimens of the cable were also conducted before the sea going test mentioned above (7). The results were shortly stated below.

(1) High pressure test

Short term, long term and cyclic high pressure tests were carried out using short specimens of the cable. The short term test included pressurizations of 2 x 376kgf/cm², 1 x 513kgf/cm² and 2 x 600kgf/cm². The long term test was carried out during 10 days at 376kgf/cm² and the cyclic test was carried out 200 times by cycling pressure 0 to 376kgf/cm². Those tests did not showed detectable optical transmission loss. Final test was carried out using a 20 m long cable (length of a optical fiber was 80m because 4 optical fibers were linked) and also showed no loss.

(2) Mechanical test

50 cycles of the cable elongation test was carried out, tension between 0 to 15 tons. The elongation of the cable was 0.5 % at 1 ton and 1.18% at 15 tons of tension. The length of the cable tested was 8m and optical loss was almost zero to 0.01 dB. Breaking strength of the cable was tested using 10 specimens and values were between 18 to 20 tons. The maximum elongation of the cable was about 2% at the breaking point and optical fibers and metal conductors were not broken before the cable breakage. The side wall pressure test was also conducted and the oversheave cable life under normal operating load of 1 ton was estimated about 1 million times or more. The life times under 8 and 10 tons of side wall pressure were 2 x 10^4 and 3 x 10^3 times respectively. The same tests mentioned above were also carried out with specimens of the new cable.

The comparison with old and new type of cables is stated below. Fig. 3 and 4 show cross sections of two types of cables. Table 2 shows the construction of two cables. Main differences between 2 cables were:

The old cable has a pressure tolerant optical fiber unit and the pressure tube is mode of Nylon 11. The diameter of the tube is the same as 3 main conductors but the unit is harder and stronger than another 3 main conductors. Therefore, there is some irregularity of strength around the inner core of the cable. The new cable has a small pressure balanced optical fiber unit(Fig. 4) and has uniform mechanical property around the inner core. The new cable has well torque balanced tension member than the old cable. Another most important difference with tension member of 2 cables is the method of winding and the time of hardening of the Kevlar. Both cables utilize a rod type aramid resin fiber(Kevlar) impregnated with unsaturated polyester resin as 2 layers of the tension member. The Kevlar of the old type is hardened before winding and has residual strain after winding. The Kevlar of the new type of the cable is heat treated in the course of winding and hardened by a delayed hardening process just after winding in a special new developed machine. So the strength member of new cable has little residual strain. Outer sheath of the new cable is about 4 times stronger than the old cable in tensile strength.

The new cable is considerably improved and shall be installed in the DOLPHIN-3K system by near chance but the old cable has not a litte problem in present operation and those cables shall be used by turn.

In the practical use, about 400m of the cable from the vehicle is covered by black colored nylon sheath for protection from abrasion and damage and a bell shaped FRP mouth is fixed over the vehicle termination for protection from bending and about 10 meters from the termination is covered with 3 layers of gradually strain reliefing braded Kevlar for protection from twisting. Because the rod type Kevlar is very weak for twisting and bending in a short length. Those protections have functioned well and there was not trouble around the cable termination after improvement mentioned above.

THE EXPERIMENTAL CABLE FOR 「10K」

Specifications of the cable were determined by the result of the conceptual design of 「10K」. The main characteristics of 「10K」 are shown below.

Missions

- o Search and rescue of the manned submersible 「SHINKAI 6500」 depth up to 10,050 meters(collapse depth of manned sphere of 「SHINKAI 6500」).
- o Broad area acoustic and optical surveys by tow mode operation by the launcher without the vehicle and/or the launcher and the vehicle deployed from the launcher, depth up to 6,500 meters.
- o Self propelled mode precise site survey by the vehicle deployed from the launcher, depth up to the bottom of the deepest trench (10,924m).

Specifications (conceptual design)

Vehicle : High quality color TV, color TVs which provide broad angle of view, master slave manipulators (7 d.f. x 2), stereo still camera, CTDV, current meter, 3D sonar, acoustic direction finder, gyro compass, doppler sonar, responder, thrusters
Weight in air: lighter than 5 tons

Launcher: Side scan sonar, bottom sonar, wide angle, long range TV, obstacle avoidance sonar, CTDV, b/w TV, thrusters, cable winch for the vehicle tether cable (250m).
Weight in air: lighter than 5 tons

Deck handling system
: Shall be installed in 「YOKOSUKA」

Control : Shall be installed in the after wheel house of 「YOKOSUKA」

Cable : Fiber-optic-electro-mechanical cable
Length: about 13,000m
Breaking strength: more than 40 tons

The specifications shown above are not fixed and the precise design shall be conducted in 1989.

Main specifications of the cable are as follows:

(1) Diameter : 45mm or less
(2) Length : 13,000m
(3) Breaking strength
: 40 ton or more
(4) Conductors : 6000V, 80KVA, 3ϕ, 60Hz
(5) Number of fibers
: 4 (single mode, 10/125), must be screened by a proof strain test of 2% elongation
(6) Attenuation : 0.2 dB/km or less at wavelength 1.55μm
(7) Attenuation under pressure
: 0.1 dB/km or less at 1,500kgf/cm²
(8) Bandwidth : 1000Mbps, 13km
(9) Mechanical (cable life)
: Bending cycle more than 1 x 10^5 at 12 ton/m of side wall pressure

The cable was designed, built and tested by Fujikura Ltd. The cross section of the cable is shown in Fig. 5. The cable is composed of 3 conductors, 2 earth lines and 1 optical fiber unit which contains 4 single mode (SM) optical fibers and Kevlar strength member. The cable is pressure balanced and the sea water immerse to the outside of the inner sheath, inside void of the inner sheath is filled with water block plastic compound. Contraherically wounded 2 layers of Kevlar strength member are also hardened just after winding under the controlled heat treatment by the same manner as the new type cable of the DOLPHIN-3K. The construction of the cable is shown in Table 3. The construction of the vehicle tether cable is also shown in the Table for reference but the cable is only designed and not yet built.

About 1,100m of the experimental cable was built and high pressure and mechanical properties were tested. The main result of the test is described below.

(1) High pressure test

A preliminary test using the cable without tension member was carried out first. The length of the specimen was 50 meters, each 2 of 4 optical fibers were linked and the total optical loss and distribution of optical loss were measured by optical powermeter and OTDR. 3 cycles of the pressure test were carried out at pressure up to 1,500kgf/cm². The measured optical loss was ±0.01dB/108m (0.09dB/km) and the OTDR also showed smaller optical loss than the specified value of 0.1dB/km

High pressure test of the experimental cable was conducted by using about 200 m of the cable. Optical loss of 1 fiber was not exceed ±0.02dB/km during the test while the other fiber showed an excess loss of 0.28dB/km. Most of the loss was occurred at an epoxy potted feedthru and loss of the fiber inside of the cable was not over 0.02dB/km by means of OTDR.

(2) Mechanical test

120 cycles of cable elongation test was carried out with a cable of 90m length. The cyclic tension was 0 to 20 tons and changes of the cable diameter, cable elongation and angles of cable rotation were measured. The cable diameter was changed from 44.2mm of original value to a minimum value of 43.3mm at 20 ton after 100 cycle. The diameter at 0 ton after 100 cycle was decreased to 43.9mm. The elongation of the cable was changed at first 10 cycle and saturated. The

saturated values were 0.2% at 0 ton and 0.7% at 10 ton and 1.2% at 20 ton of tension. The rotation angle of the cable was also changed at first 10 cycle and saturated. The change is caused by the elongation of the cable mentioned above. The values were 15° at 30m apart from a fixed end and 20° at 60m from the fixed end. The value was not changed after the load was released. The cable rotated in the direction to loosen the outer layer of Kevlar.

Breaking strength of the cable was tested with 6 specimens. Values were ranging from 41 to 51 tons. Except for the lowest value of 41 tons which was broken at the cable termination, the average breaking strength of the 5 specimens was 49 tons. The measured elongation of the cable was 1.25% at 20 ton of tension and the value at 41 tons was extraporated about 2.5% and optical fibers and metal conductors were not broken before the cable breakage. Optical loss was not changed at the test.

The side wall pressure along with S shape bending test was conducted with 3 specimens using a sheave of 1,000mm in diameter, side wall pressures were 20, 30, 40 ton respectively. The change of the resistance of earthlines was monitored in the test. Number of cycles to the change of resisitance were 120, 640 and 7600 times at 40, 30 and 20 tons of the side wall pressure. The appearance of the cables were not changed after the test. The oversheave life of the cable was estimated to 2 x 10^5 times at 12 ton/m of side wall pressure which is related to 8 tons of operational requirement using a sheave of 1,350 mm in diameter.

A self rotation test was carried out with 50m of cable specimen under load. Measured values were 2°, 4° and 7° at load of 2, 4 and 8 tons respectively. The values were considerably smaller than estimated values. The cable also rotated in the direction to loosen the outer layer of Kevlar.

Several electric test were also carried out to know the relation between maximum supply current and the cable heating. The maximum current supply under the specified maximum voltage drop of 10% was 8.9A(6000V, 92KVA) without cooling by water and the value was 9.5A(6000V, 98KVA) with water cooling when 5 layers of cable coiled over a drum. The cable temperature rose to 15°C without cooling and 3°C with cooling over the room and water temperature. The maximum allowable supply power without cable damage were estimated to 139KVA without cooling and 350KVA with cooling.

The experimental cable of 「10K」 showed performance exceeds specifications but studies shall be continued before production of the actual cable.

CONCLUDING REMARKS

The fiber optic power/line composite cable of 「DOLPHIN-3K」 has developed and successfully used in operation by overcome several problems. The new cable which is more sophisticated design than the old one shall be used in near future. The world deepest ROV 「10K」 shall be completed in 1992, more studies must be commemced about the cable and other subsystems.

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(7) Shingo,Y. et.al.,"Development of Optical Fiber/Power Composite Tether Cable for Deep Sea Unmanned Vehicles", Proc. of 37th IWCS, 1988, pp.327-334.

TABLE-1. MAIN SPECIFICATIONS OF THE DOLPHIN-3K

(1)	DIMENSION	285 (L) X194 (W) X196 (H) CM
(2)	WEIGHT	3700 KG (IN AIR) -10 KG (IN WATER)
(3)	OPERATIONAL DEPTH	3300 M
(4)	PAYLOAD	150 KG
(5)	SPEED	DESIGNED MEASURED MAX.
	FORWARD	3 KT 3.3 KT
	REVERSE	2 KT 2.1 KT
	LATERAL	1.5 KT 1.7 KT
	UP/DOWN	1 KT 1.0 KT (UP), 1.3 KT (DOWN)
	ROTATION	30°/SEC. 35°/SEC.
(6)	PROPULSION	
	FOR/REV	2 X 15 HP (11.3 KW)
	LATERAL	2 X 9.5 HP (7.1 KW)
	VERTICAL	2 X 9 HP (6.8 KW)
(7)	HYDRAULIC SYSTEM	HYDRAULIC SYSTEM COMPOSED OF 40KW 2250V 3 PHASE AC MOTOR AND PISTON PUMP WHICH PROVIDES HYDRAULIC POWER TO THRUSTERS, MANIPULATORS, CUTTERS AND PAN/TILT UNITS
(8)	INSTRUMENTATION	COLOR TV CAMERA WITH PAN/TILT UNIT (ENG GRADE) LOW LIGHT B/W STEREO TV CAMERA WITH PAN/TILT UNIT LOW LIGHT B/W AFTER TV CAMERA WITH TILT UNIT 5 X 500W LITHT (2XSPOTLIGHT), 1X250W LIGHT (FOR AFT TV) 35 MM STEREO STILL CAMERA, 150W/S STROBE MASTER-SLAVE MANIPULATOR (7D.F.), GRABBER (5D.F.) CURRENT METER, SHEAR CUTTER, ROTARY CUTTER CTD (SHALL BE INSTALLED IN EARLY 1989)
(9)	NAVIGATION	OBSTACLE AVOIDANCE SONAR (OAS-2), DIRECTION FINDING SONAR, ALTIMETER, GYROCOMPASS, ANGULAR RATE SENSOR, TRIM SENSOR, DEPTH SENSOR
(10)	SHIP BOARD COMPONENT	CONTROL/NAVIGATION VAN, HIGH VOLTAGE TANSFORMER DECK HANDLING SYSTEM
(11)	CABLE	30 MM IN DIMETER, OPTICAL-ELECTRO-MECHANICAL CABLE 5000 M IN LENGTH, BREAKING STRENGTH :16.5 TON
(12)	TOTAL SHIPPING WEIGHT	46~50 TONS

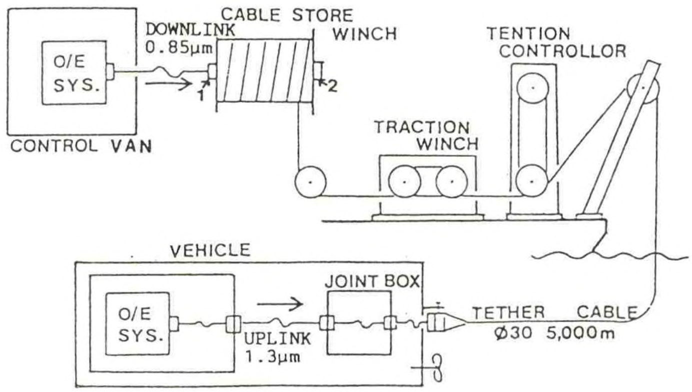

Fig. 1 Arrangement of the total system of the DOLPHIN-3K and the path of optical signals, 1: an optical rotary connector and a high voltage electric slip ring for the vehicle power 2: an optical rotary connector and an electric slip ring for thermisters to monitor the cable temperature.

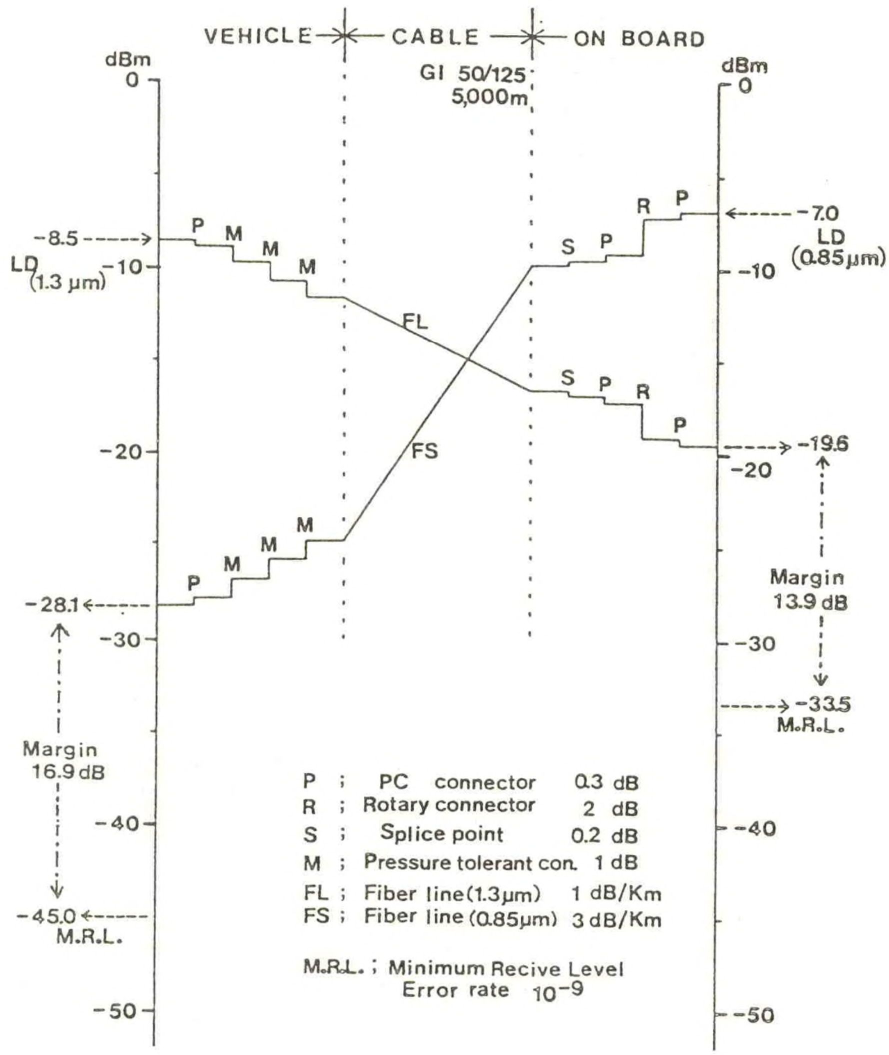

Fig. 2 Optical level diagram of the optical transmission system of the DOLPHIN-3K.

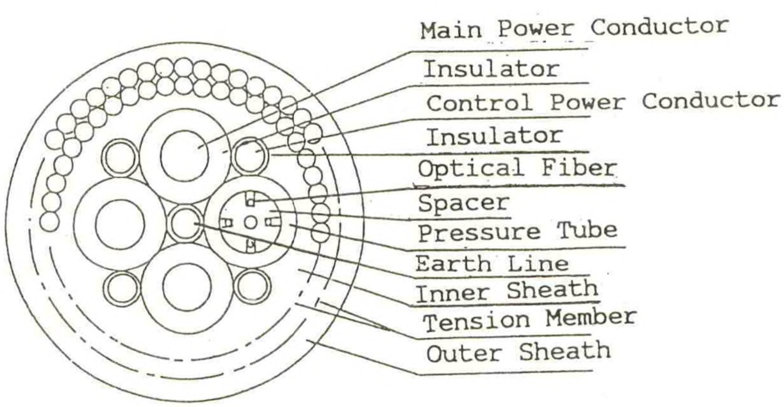

Fig. 3 Cross section of the old type cable for the DOLPHIN-3K.

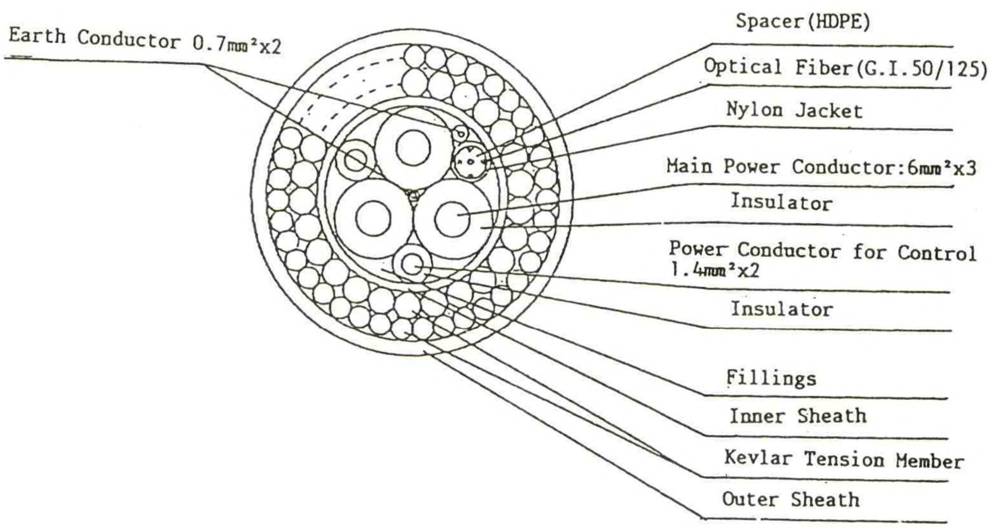

Fig. 4 Cross section of the new type cable for the DOLPHIN-3K.

Table 2. Construction of cables for the DOLPHIN-3K

	Old cable	New cable
Main power conductor	3 19/0.63	3 19/0.65
Control power conductor	4 7/9/0.12	2 3/9/0.26
Earth conductor	1 3/42/0.12	2 23/0.2
Optical fiber (G.I.)	4 in a pressure torelant tube	4 in a pressure compensated tube
Tension member Kevlar 49	33/1.9 (inner layer) 39/1.9 (outer layer)	24/2.5 (inner layer) 35/2.0 (outer layer)
Outer sheath	EP rubber	Urethane
Type of cable	Dry	Dry, pressure compensated
Weight in air	850 (kg/km)	920 (kg/km)
Weight in water	143 (kg/km)	213 (kg/km)
Outer Diameter	30mm	30mm
Length	5,000m	5,000m
Breaking strength	16.5ton	16.5ton

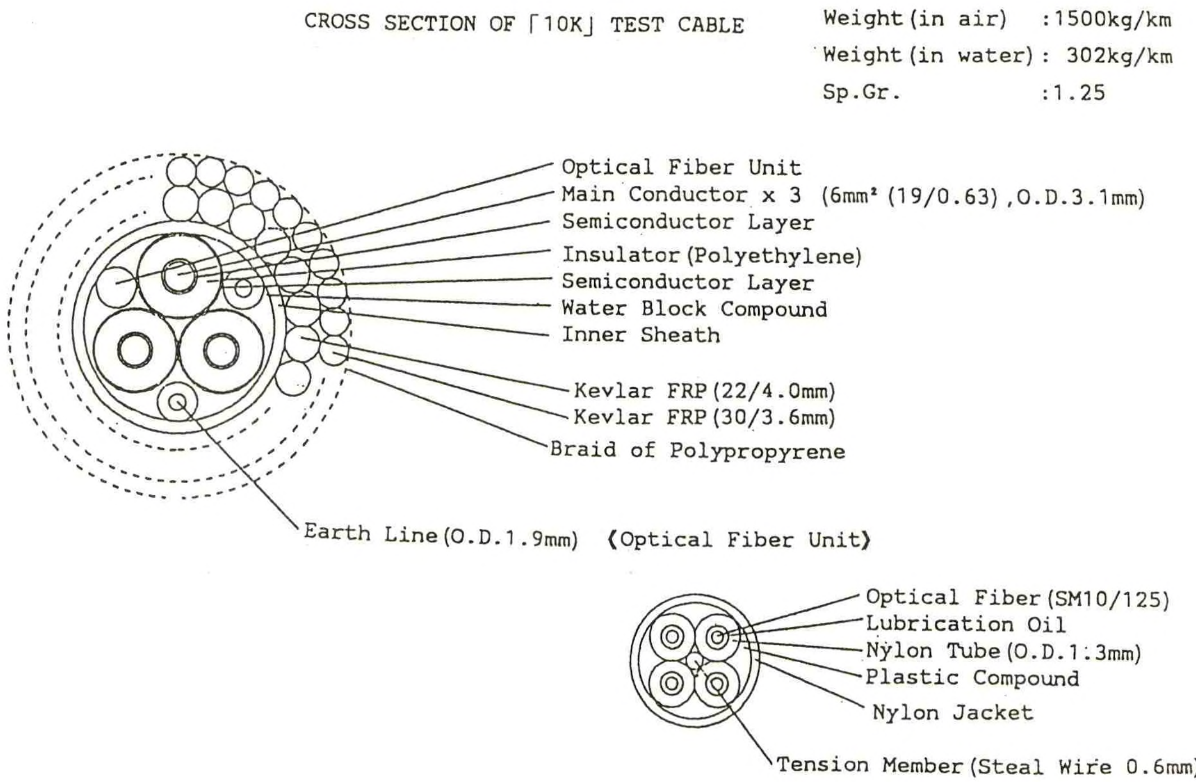

Fig. 5 Cross section of the experimental cable for「10K」.

Table 3. Construction of the cable for「10K」

	Main umbilical	Vehicle tether
Main power conductor	3 19/0.63	3 19/0.58
Control power conductor	- -	2 19/0.5
Earth line	2 3/18/0.18	1 42/0.12
Optical fiber	4 (SM10/125)	4 (G.I.50/125)
Tension member Kevlar 49	22/4.0 (inner layer) 30/3.6 (outer layer)	Braided Kevlar
Outer sheath	Braided nylon	Polyethelene
Type of cable	Wet but inside of inner sheath dry	Dry (neutrally buoyant)
Weight in air	1500 (kg/km)	1010 (kg/km)
Weight in water	302 (kg/km)	13 (kg/km)
Outer diameter	45mm	35mm
Length	13,000m	300m
Breaking strength	40ton	10ton

Autonomous Underwater Vehicle "PTEROA"
for Deep Sea Survey

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INTRODUCTION

The development of an Autonomous Underwater Vehicle (AUV) is highly expected because such vehicle is free from entanglement of umbilical cables and limit of cruising radius, and also danger of human life. But such vehicle has disadvantage of limit of power supply and slow rate of communication between a surface support ship and the vehicle. Therefore such vehicle must be required to be controlled autonomously and have good maneuverability with less energy consumption. The Institute of Industrial Science of University of Tokyo has been developing an autonomous unmanned non-tethered submerged vehicle since 1986 in order to observe the sea bed in the deep water. The project, which was designated "PTEROA project", is supported by the Ministry of Education and Science of Japan. The submerged vehicle descends, glides and comes to a work site autonomously, and sometimes avoids obstacles over the sea floor autonomously. It swims, observes the sea bed, and ascends and homes to a support ship.

The target of "PTEROA project" is the development of free swimming work over the bottom. The mission is illustrated in Figure 1. It consists of three main stages.

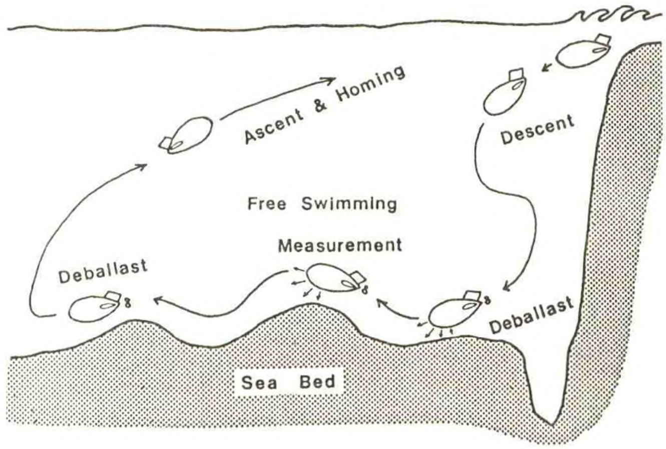

Figure 1 Free Swimming Vehicle in Deep Sea

Descent stage: Gliding descent to the target point without thrust power.

Cruising stage: Constant altitude swimming along a measurement line to the target point after the first deballasting.

Ascent stage: Gliding ascent to the mother ship after the second deballasting.

The research in the Institute is mainly concentrated to the following two items.

(1) Development of hull shape and research on hydrodynamics for maneuvering.

(2) Autonomous control to keep constant altitude on the data of simultaneous sensing of bottom shape.

Vessel Description

The principal dimensions of a prototype vehicle:

Length overall	L = 1.5 m
Beam	Bb = 0.75 m
Height	Tb = 0.45 m
Span of elevator	Boa= 1.2 m
Displacement	W = 0.27 ton
Maximum cruising speed	Vmax= 3.5 knots
Power of thruster	T = 2 x 300 watts

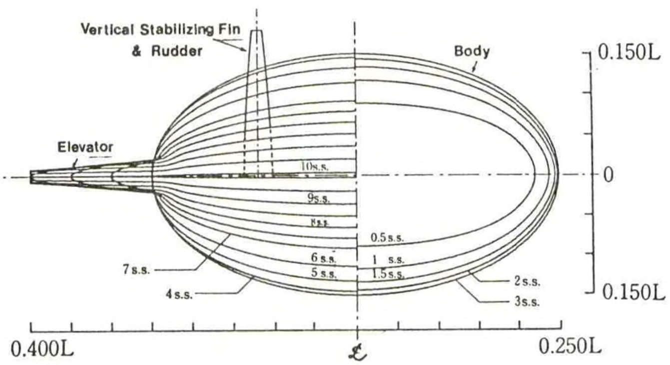

Figure 2 Body Plan of PTEROA Vehicle

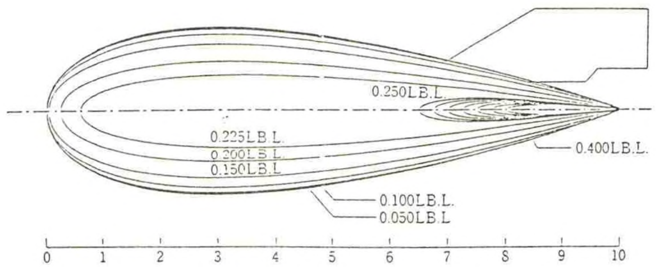

Figure 3 Profile of PTEROA Vehicle

Figure 2 and 3 show a body plan and profile of PTEROA vehicle, respectively. The vehicle consists of a body, a pair of elevator, twin vertical fins and rudders. The longitudinal cross section at the center plane forms NACA0030 and the transverse cross section is approximately elliptic. As the body is not cylindrical as torpedoes but rather a wing type, lift force acts mainly on the body. Elevators enhance good performance of pull-up behavior and stability of gliding. A pair of propeller thrusters are fitted under the vertical stabilizing fins. They can be operated independently to force the vehicle to yaw.

Maneuverability Analysis

Linear terms of hydrodynamic coefficients as stability derivatives of equation of motion of the PTEROA vehicle are determined by PMM (Planer Motion Mechanism) test, oblique test and 3-D source numerical calculation method. It is also proved that some of these derivatives can be derived by so called DATCOM method which is popular in aeroplane design. Nonlinear terms of stability derivatives are determined by identification of free running tests.

Autonomous Underwater Vehicles need to be of low drag and must have good maneuverability to keep away from obstacle in the sea. It is important for the PTEROA vehicle to have good longitudinal maneuverability which is characterized by the gain constant K for turning ability. Figures 4 and 5 indicate the gain constant K versus semispan of horizontal tail and chord length of horizontal tail, respectively.

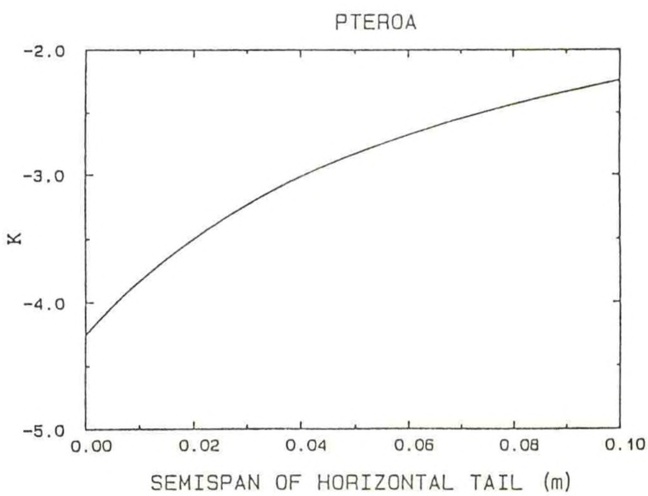

Figure 4 Gain Constant vs Semispan Length of Horizontal Tail

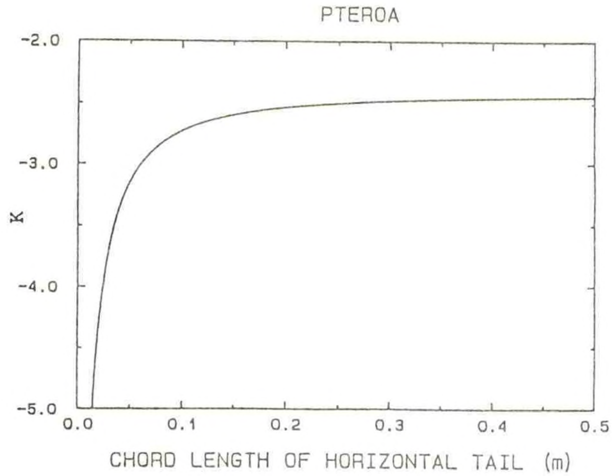

Figure 5 Gain Constant vs Chord Length of Horizontal Tail

Gliding Performance

Figures 6 and 7 show the gliding angle and velocity in steady state swimming, respectively. The buoyancy is slightly negative, that is, 5 % of the displacement. The center of gravity is located at 0.38 L from the front tip.

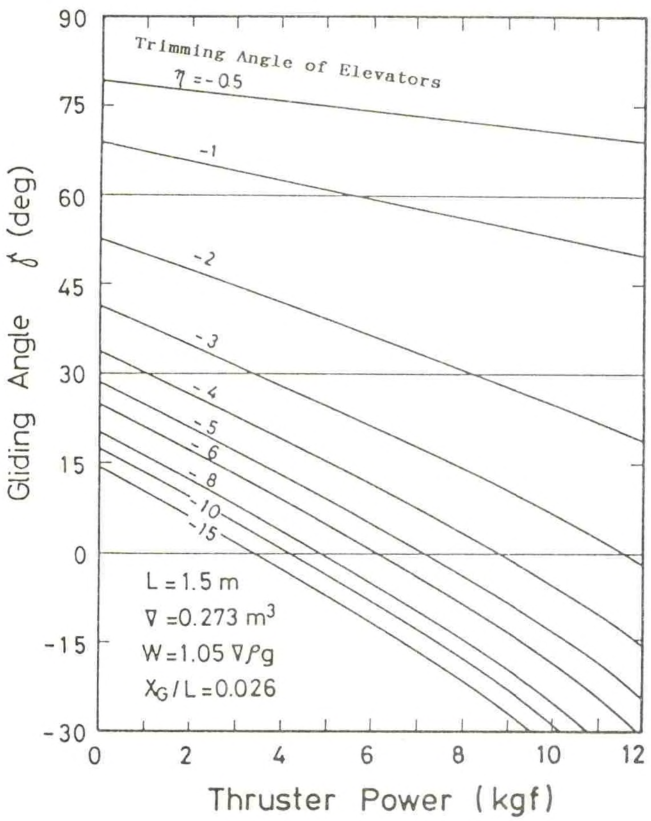

Figure 6 Gliding Angle vs Thruster Power

It is shown that the gliding angle is about 15 deg and the velocity is about 3.3 knots when the elevator trimmed -15 deg. When the depth of descent is 6000 m, this vehicle can arrive in the circle of 22 km radius in four hours. When the trimming angle is -1 deg, the gliding angle and velocity increase up to 69 deg and 7.8 knots, respectively. In this case, the vehicle can reach to the bottom of 6000 m depth in 25 minutes.

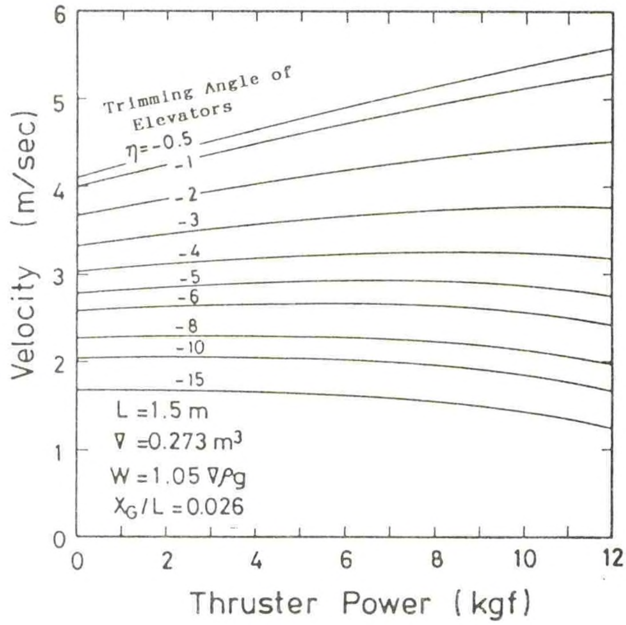

Figure 7 Velocity vs Thruster Power

Longitudinal Swimming

As the vehicle descends to and ascends from the sea bottom with aid of negative or positive buoyancy, and with lifting force on the main body, an investigation of controlling the attitude and the trajectory is one part of the longitudinal plane study. Things of interest include the effects of the trim angle of two elevators, weight and thrust on descending or ascending trajectories of the vehicle. The origin of coordinates is fixed at the center of buoyancy which is located at 5.94 square station on the symmetric planes of the body. At t=0, the vehicle descends vertically downwards. After 20 seconds, it glides in steady state. Figure 8 shows the effect of the trimming of elevators. As the speed increases, the vehicle ascends slightly after pull up maneuvering. Figure 9 indicates that the vehicle gets slow down immediately after deballasting. Figure 10 shows the effect of increase of thrust. As the thrusters are fixed on the horizontal symmetric plane of the body, the vehicle pulls up slowly.

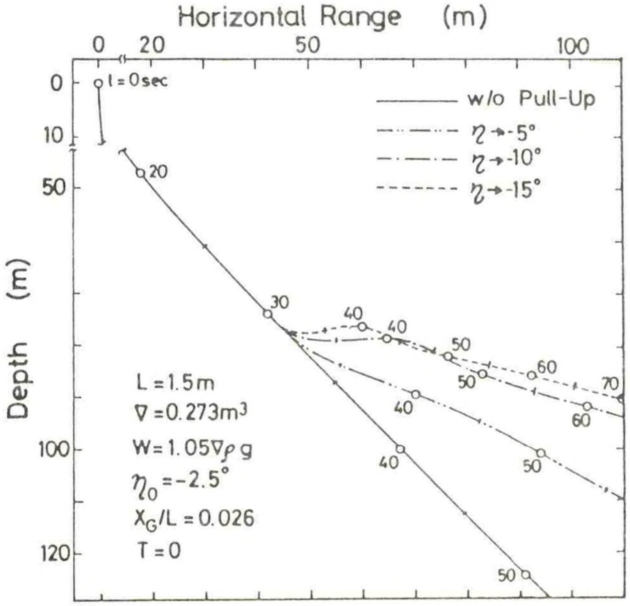

Figure 8 Effect of Pull-up by Trim of Elevator

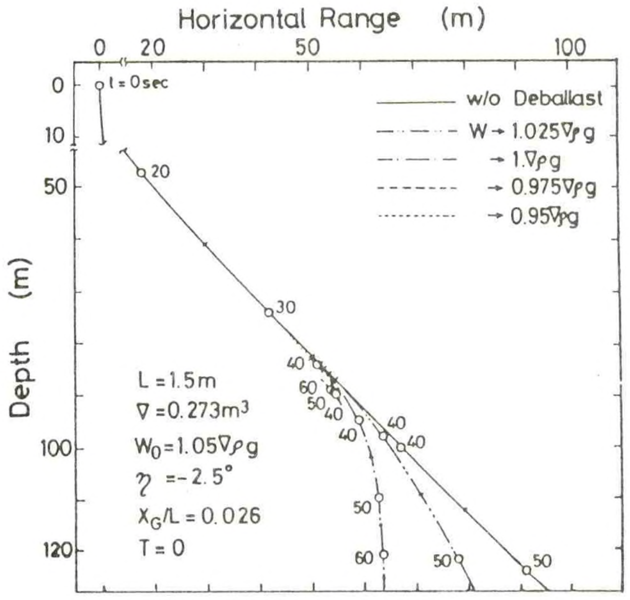

Figure 9 Effect of Deballast

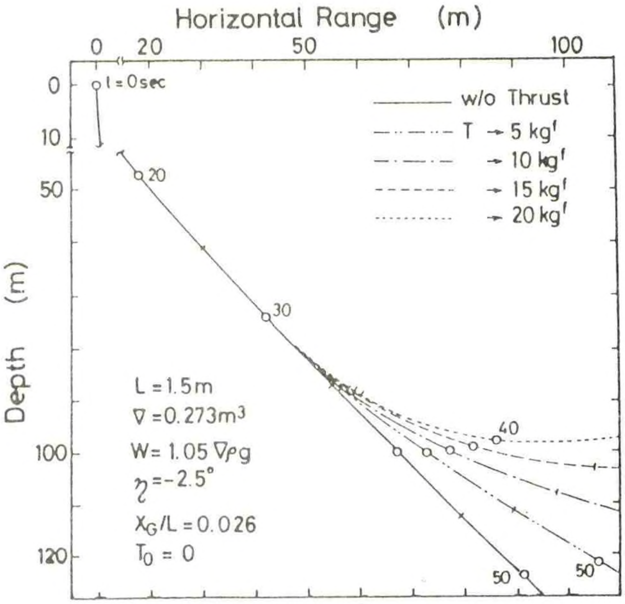

Figure 10 Effect of Increase of Thrust

Autonomous Control System

In order to collect underwater information by using autonomous underwater vehicles, it is required to make the AUV keep low altitude from the surface on the condition that it keeps safety distance. A simplified altitude control system to keep predetermined height is adopted in this study. The control system consists of two hierarchical control blocks, i.e. a guidance block to give attitude reference angle calculated from the observed distances to keep desirable altitude, and a local attitude control block to realize the reference angle keeping the stability of the vehicle. As the attitude control system, a linear feedback elevator angle control system with velocity saturation is adopted, taking account of the system dynamics. In the guidance block, pitch correction angle is calculated from the observed distances. The mixed type filtering is adopted as the algorithm, Non-symmetric smoothing of the correction angle is also introduced to keep the safety distance for rough surface. In order to detect the shape of sea bottom surface for keeping constant altitude, four ultrasonic fan beams to different directions are fitted on the bottom surface of the vehicle. Figure 11 shows the sensing system. Figure 12 illustrates an example of simulation based on the mixed filtering algorithm.

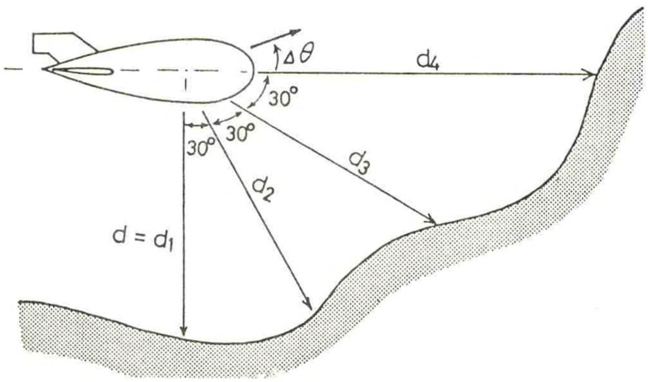

Figure 11 Four Active Echo Sounders

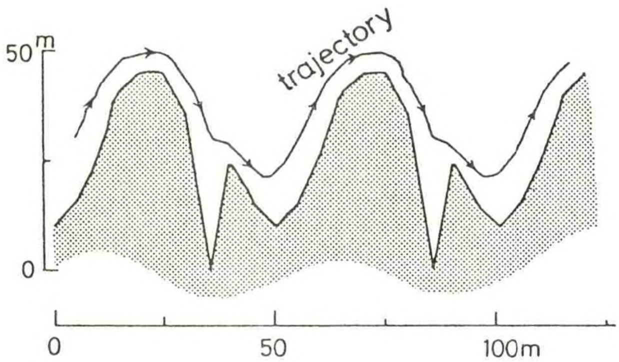

Figure 12 Altitude Control on Irregular Terrain

Design of the Vehicle

The basic sensor suite consists of:

1. A prssure transducer to measure depth
2. An inertia navigation apparatus to measure three-axis acceleration, three-axis direction and three-axis angular velocity
3. Four active echo sounders facing four different directions
4. A transponder to measure the location through SSBL and to be used as an acoustic command link for deballasting in the case of emergency

The vehicle motion is controlled by two thrusters, two elevators and two vertical rudders. The vehicle has two deballastors. The vehicle is propelled by two horizontal thrusters and steered by two elevators and two vertical rudders, and depth is controlled by two elevators. Their actuators are oil-immersed stepping motors, which are driven by CPU and controlled by means of a open loop.

The computer selected is a commercially available single-board computer, based on a 80186 microprocessor. This computer satisfies our requirement that it can be programmed in C language.

The internal arrangement is shown in Figure 13.

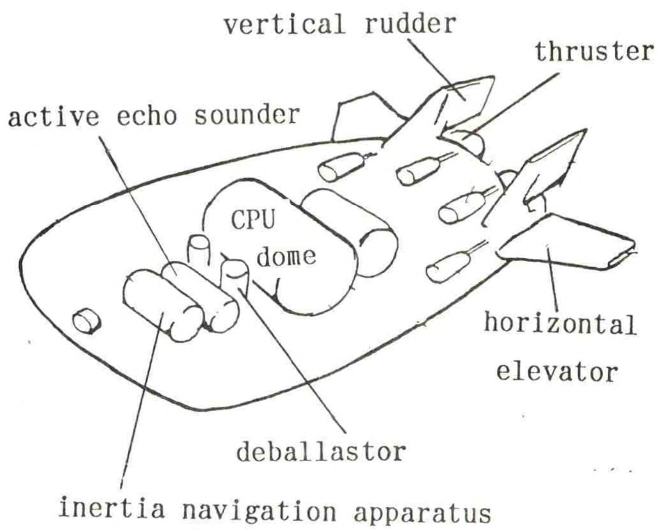

Figure 13 Internal Arrangement

Conclusions

We developed the hull shape and research on hydrodynamics for maneuvering, gliding performance and longitudinal swimming of the AUV "PTEROA". We also developed the main engine of autonomous control system which keeps the vehicle at constant altitude from the sea bottom.

Construction and testing of the vehicle hardware are continuing. We will test the performance of the system of the vehicle in realistic conditions in 1989.

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SEVERAL EXAMPLES OF ROBOT AND AUTOMATION ON THE UNDERWATER CONSTRUCTION WORK

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1. Introduction

Recently, many kinds of robots and automation systems have been developed in the field of the construction work.

Following examples are approaching to practice on the underwater construction work in Japan.

(1) Underwater inspection

The aquatic walking robot for underwater inspection is under development by The Port and Harbour Research Institute MOT.

This robot was informed in form of the paper to The 15th joint meeting UJNR/MFP 1988.

(2) Dredging

(a) Automatic operation system incorporating with fuzzy control for cutter suction dredge

The study for this system was carried on by The Japan Working-vessel Association, PHRI/MOT, and the related companies from 1983 to 88.

This system was loaded on the dredge Chiyoda Maru in the test operation and now it is enjoying good results in practice.

The paper on the development study for this system was presented to The 12th general meeting of WODCON, in May 1989 by JWA.

(b) Submergible walking auto-dredger FUTABA

FUTABA was developed by Penta-Ocean Construction Co.

(3) Underwater rubble levelling

The underwater rubble levelling robot for the construction work in deep sea was developed by POC.

(4) Others

The laser surveying system is very useful to decide the work points of working vessels in offshore construction work.

Connected to the practice, central control systems have been developed in offshore work including sea bottom improve work such as sand drain, paper drain, deep cement mixing method etc.

CRT indicates the results which are measured by many kinds of sensers and computed according to necessity, and supports central operation system.

2. Aquatic walking robot for under water inspection

(a) Outline

The robot is six-legged articulated "insect type" robot known as "AQUAROBOT".

Each leg has three articulations and is driven semi--directly by a DC motor that is built in the leg and have a touch sensor on the foot. The robot can walk on uneven ground and can walk in any direction without changing its quater. There is no difficult for the robot to maintain a stationary position and direction. Then, the robot is good not only on observation with a TV camera but also on measurement of some object with accuracy.

An exprimental model not watertight was built in 1985, and a prototype model watertight in 1987.

(b) Body

The weight of prototype model is 700kgf.

The body is hexagonal in shape and made of anti-corrosive aluminum. The legs are installed on the sides of a hexagonal frame and some sensors installed on the body.

(c) Legs and Articulations

The minimum degrees of freedom to move the point of a leg anywhere is three. Therefor, a leg consists of three articulation. The rotating axis of the first articulation that is nearest to the body is vertical and the axis of the other articulations are horizontal. The foot and leg are linked with a ball joint. A foot has a touch sensor. The length of the thigh and the shank of prototype model are 50cm and 100cm respectively.

The articulations are driven by DC motors with gears.

(d) Motors and motor control system

The motors of robot are driven by 70 volt DC power. Each motor has an encorder that generates 100 pulses per revolution, and harmonic gear with a ratio of 1/150. The two kinds of motors are selected. The motor for first articulation is 40 watt and the motors for others are 70 watt.

A motor driver is used for each motors. The usage changes the DC motor into a pulse motor that can be simple controlled by pulse signals. The motor with the driver can be controled by pulses from a computer.

(e) Sensors

Three kinds of sensors are used for the robot. There are six touch sensors, two inclination sensors and a compass. The robot can therefor walk keeping the inclination and direction of body constant by the sensors.

(f) Cable

A cable of the experimental model is consist of many metal wires. An optical fiber link is introduced in the prototype model. The link improves S/N ratio and makes the cable long. The diameter of the cable is 42mm and the length is 100mm. A pair of opt-electric transform devices are built in the robot body and control box.

3. Automatic operation system incorporating fazzy control for cutter suction dredge

(a) Outline

The purpose of a control system for automatic dredging operation is to realize an unmanned, fully automatic cutter suction dredge capable of greater efficiency than a skilled operator.

To achieve this goal, it was decided to employ a system conbining a conventional sequence control system and a fuzzy control system based on fuzzy inference and the expertise of skilled operators.

Conventional computer control is based on binary logic, with the assumption that everything can be expressed as "1" or "0". However, when the dynamic characteristics of a controlled object cannot be defined with accuracy, as is the case with a cutter suction dredge ordinary computer control and analog feed-back control systems are not applicable. In such a case, it is better to leave control of the machine to an expertise of skilled operator who can combine operational skills with personal judgement. This In control, a stop of the stroke.
produces good results.

A fuzzy control system, however, integrates the expertise of an experienced operator. That is, fuzzy logic, which enables a computer to make quantitative judgements in the same manner as a human is built into the computer control system to offset the demerit of a conventional system. The system is thus able to treat fuzzy judgement like "a little bigger" or "a little to left" based on the know-how of skillfull operators.

Fuzzy logic was first reported by L.A. Zadeh (U.S.A.) in 1965. In Japan, it has been applied to automatic control of subways, water puritication plant, etc., with great success.

In 1983 and 1985, the development committee distributed questionnaires to skilled operators of cutter suction dredges employee by the seven member companies of JWA, togather information on their combined know-how.

In 1986, the committee nomothetically studied the know-how of skilled operators, that is, their responses to the relationships between control situations and control actions, as presented in a 2,000-page report on the questionnaire. They were then able to establish standard control rules (if-, then-) and graphs called membership functions ("a little, larger", "moderate", etc.).

Chiyoda Maru, a cutter sucyion dredge was put to operation at sea to examine the validity of these findings, with skilled operators aboard to offer their opinions.

(b) Field test

Prototype systems and machinery were installed aboad the Chiyoda Maru and put to a series of field test in Shibushi Bay, south Kyushu, as follow:

Test period: Oct. 4–10, 1987

Dredge: 9,500 ps cutter suction
owned by Toyo Construction Co.

Discharge distance: approx. 5,000m

Soil quality: Sanday soil;
N value, approx. 10

Sea condition during test: Wave ht. 1.5–2.0m
Wave pd. 6–8sec

(1) Automatic programmed cutting pattern operation

(a) Swing stroke control

In performing swing stroke control, a stop signal was sent to the swing winches when the cutterhead reached within +/– 0.2m of either of the stroke.

According to the test results, the cutterhead swing 0.2m and 0.7m in excess of the lefthand and righthand limits respectively. These errors were attributed to the influence on the ships hall of wave direction, the direction in which the cutterhead was turning and the effect of the moment of inertia after sending the stop signal.

It can be inferred that better dredging accuracy would have been achieved if the end the swing had been set at

+0.2 to +0.4m for the lefthand stroke and –0.2 to –0.9m for the righthand stroke, insted of +/–0.2m.

(b) Cutterhead depth control

In performing cutterhead depth control, a stop signal would be issued to the ladder winches when the cutterhead was more than 0.2m off the target depth in the hoisting stroke and +0.3m off in the lowering stroke.

According to the test results, the seabed was overcut by 0.0 to 0.3m as against an original target value of tolerance of +/–0.1m. The heavy swell hove the hull up and down, which caused the readings of the cutterhead depth gauge to change. Despite attempts to implement corrective measures, these readings resulted in the cutting errors.

Under normal working conditions, operation would be performed with far greater accuracy.

(2) Control for maximizing dredging production

Chiyoda Maru was operated automatically by the system and also manually by a skilled operator, for comparison.

Mean values of various data obtained by both manual and automatic operation are as follows.

Dredging time for one cutting section (min' sec")	Man.	30'	39"
	Aut.	39'	08"
Slurry velocity in pipe (m/s)	Man.	4.72	
	Aut.	4.82	
Main dredge pump load	Man.	43.24	
	Aut.	43.01	
Cutter load (A)	Man.	344.01	
	Aut.	314.66	
Concentration by volume in situ (%)	Man.	14.50	
	Aut.	13.49	
Production per unit time (m^3/h)	Man.	1088	
	Aut.	1034	

The normal production capacity of the dredge is 1,200 m^3/h. Despite poor sea conditions and soil conditions, test operation successfully achieved production of 1.034 m^3/h in automatic mode, which compared well with 1.088 m^3/h in the manual mode as performed by a skilled operator.

Initially, 246 control rules were prepared for the controls for dredging production cutting pattern and forward shift. For the purpose of the field tests, however, these were reduced to 69, due to the sea conditions and soil conditions.

It has hitherto been considered difficult to automate dredging operations. Our system, however, demonstrates the feasibility of fully automated dredging of efficiency comparable to that achievable by a skilled operator.

In the future, fuzzy control will be applied not only to cutter suction dredges but also to other work vessels.

In addition, this automatic operation capability can be used to record and store important operational expertise of experienced operators, which can then be used in the training of inexperienced operators.

4. Submergible walking auto-dredger "FUTABA"

Usually, large waves and high currents can make dredging difficult and new technology to combat these problems is urgently required.

It is the main component of a fully-automated dredging system "SWAD" (Sumergible Walking Auto Dredger) which is remotely controlled from land. "FUTABA" walks along the sea-bed carrying out unmanned dredging operations. The system avoids the need to resist high waves and currents, so that high capacity, safe and cost effective operations are achieved.

By means of cable remote control from land, the robot can walk forward, backward and sidewards automatically at a maximum depth of 15m underwater. All the movements, such as horizontal control or modifying direction etc., are fully computerized and controlled through optical-fiber communication cable.

Dredging can be carried out safely under severe maritime conditions such as maximum wave height 2.8m and maximum wave current 2 knots. The robot uses submarine and floating hoses for discharge line, as they can drift and rids on the waves with less wear and tear.

The robot has a high efficiency disk-cutter, which is able to deal with any kind of soil, from slit to sand, in forward or backward dredging. The dredging does not cause any turbidity in the surrounding sea. The dredging pump is a high efficient, high pressure type, which contributes greatly to the robot's high dredging capacity.

The up to date optical-fiber communication system interfacing with computers allow all the dredging operations to be handled by only one man.

The depth sensor mounted on the robot and the auto tracking laser survey system on land, which catches the reflected beam from the laswer reflector on the robot's staff, enables precise dredging positioning and depth measurement to the nearest centimeter. Four echosounders located just above the cutter measure the sectional shape of the dredged sea bed accurately.

This new dredge control system has been developed through a variety of experiences and accumulated know-how. Thus, the operator can monitor precise information of all dredging situations.

The robot can submerge or surface to and from a depth of 15m by intaking or exhausting air into/from its ballast (floating) tank, without the aid of a floating crane. It also can control the contact pressure of its legs with the sea bed, so dredging can be carried out even in a soft sea bed area.

5. Underwater rubble levelling robot

This 8-legged walking UNDERWATER RUBBLE LEVELLING ROBOT moves freely in all directions, striding over uneven sea bed and carrying out rubble levelling work.

All of the underwater movements, walking and levelling works, are carried out safely and are accurately controlled by one operator using a computer.

Deep (–30m) sea works can be carried out with no loss of time from the pressurization required in diving operations.

Large-scale underwater works can be performed quicker than manual labour performed by divers.

Precise adjustment of levelling height and the work by rake and compact-roller provide accurate smoothness of the underwater mound.

The unique sliding mechanizm enables the robot to walk in forward, back, right, and left directions, and it can make a spot turn.

The data from the ultra-sonic topographic measurement device is continuously displayed and plotted on the X-Y recorder.

Two float tanks enable the robot to submerge and surface. The robot is then towed from one job site to another.

The ultra-sonic topographic-sounding device replaces traditional optical methods for work in turbid water.

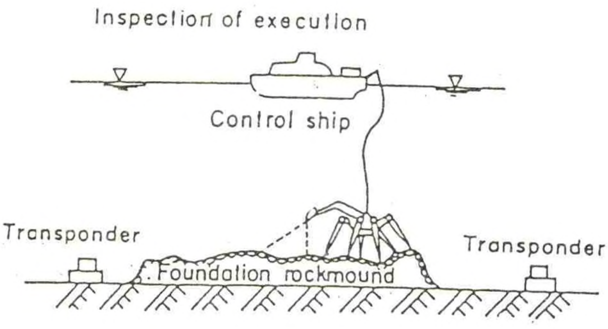


Fig. 1 Underwater operation of the robot

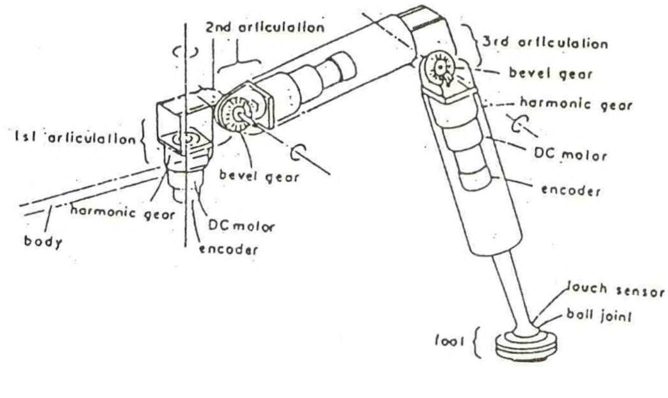


Fig.2 Stracture of a leg

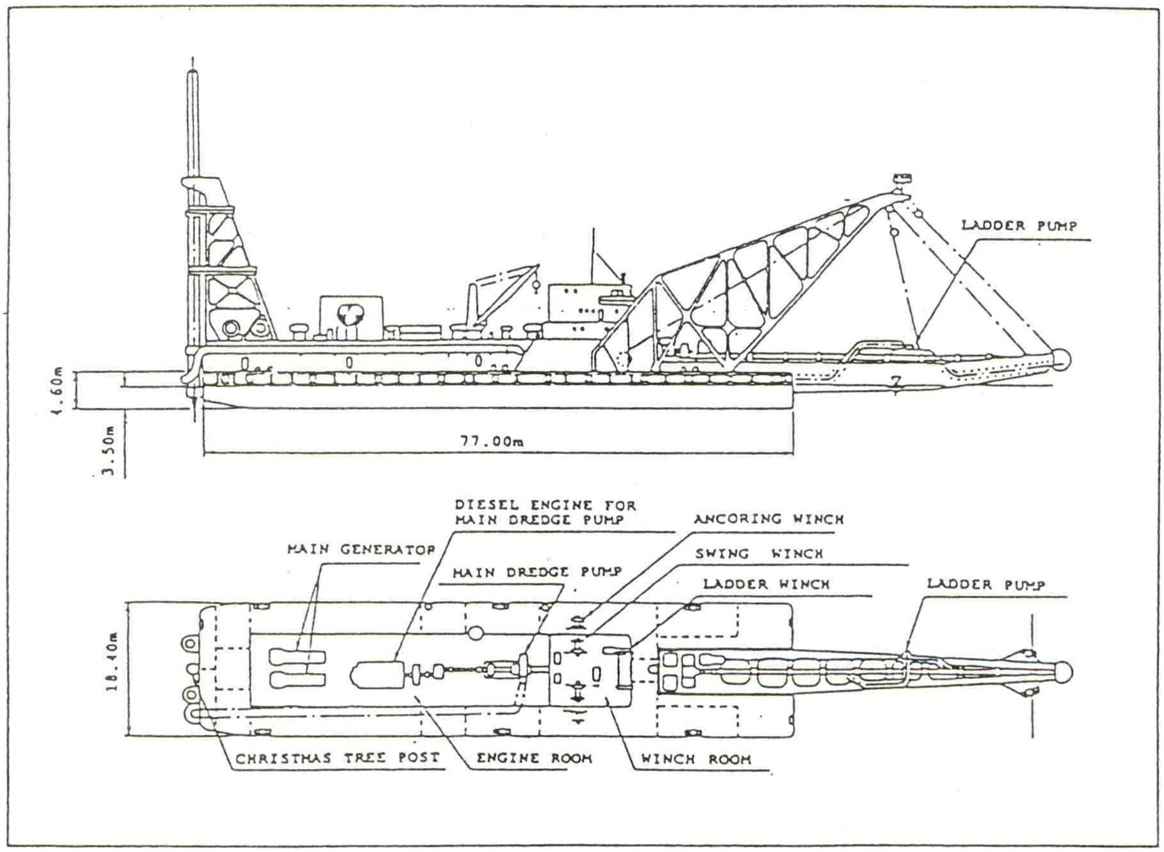
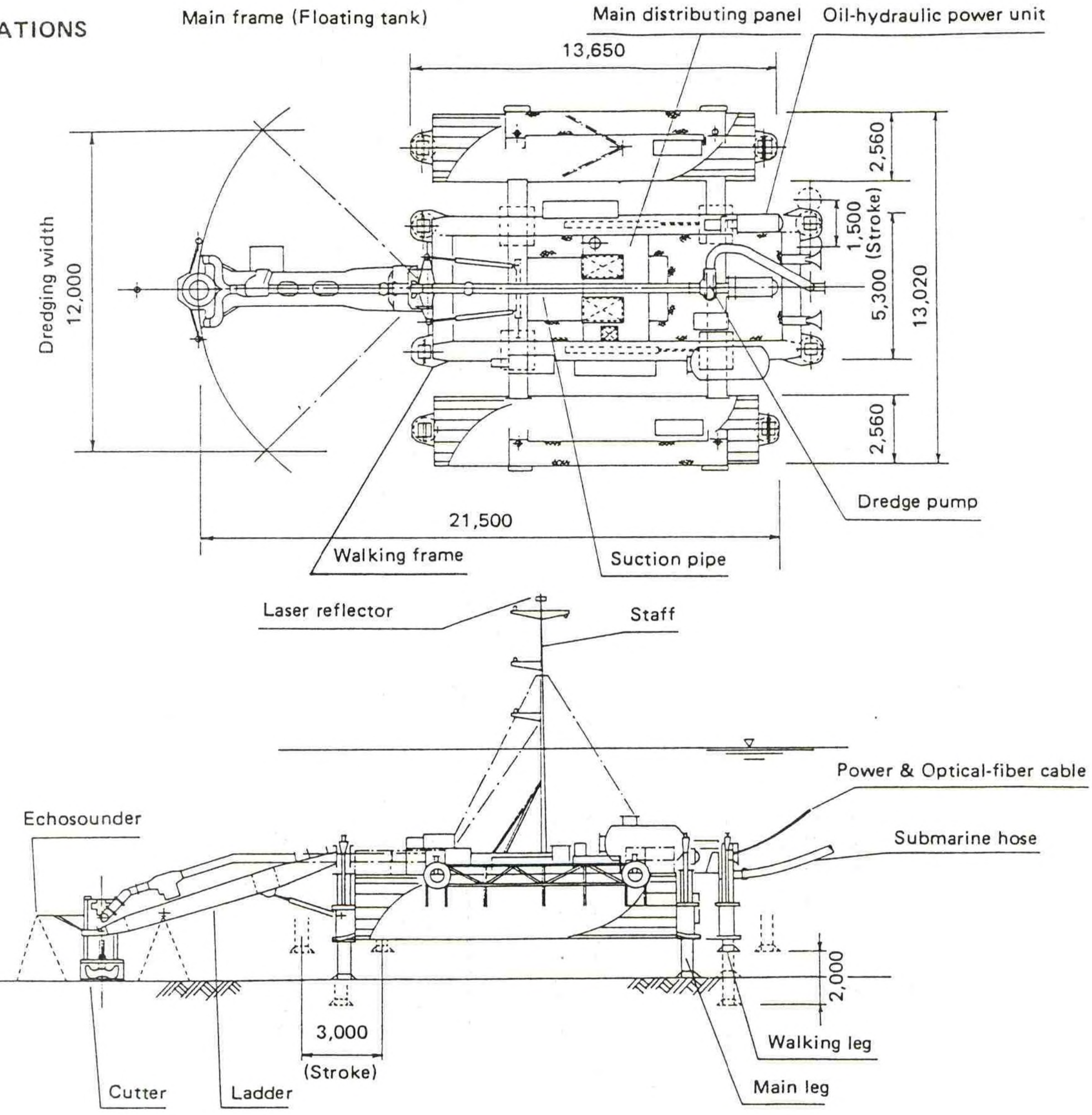


Fig. 3 General arrangement of the dredge "CHIYODA-MARU" used for dredging test

SPECIFICATIONS



Type

Body:	Fully submersible 8-legged walking type
Driving:	Submersible electric motor
Operation:	Cable remote control system
Dredging:	Disk cutter dredge pump system (Forward & backward dredging possible)

Dimensions & Weights

Overall length:	26.5 m
Width:	13.0 m
Height:	5.1 m (Exclude post)
Weight:	150 tons (In air)
	70 tons (Underwater)

Walking Faculties

Extension stroke of legs:	2.0 m
Forward & backward sliding stroke:	3.0 m
Sideward sliding stroke:	1.5 m
Directional modifiability:	±2.0 deg.

Main Machineries

Dredge pump

Motor power:	320 kW
Capacity:	800 m^3/h (Water)
Total head:	70 m
Inlet/outlet dia:	300/300 mm

Oil-hydraulic power unit

Motor power:	150 kW
Capacity:	550 lit/min.
Rated pressure:	210 kgf/cm^2

Cutter

Oil-hydraulic motor:	120 ps
Outer dia.:	1200 mm
Revolution:	0 ~ 30 rpm

Control Monitors

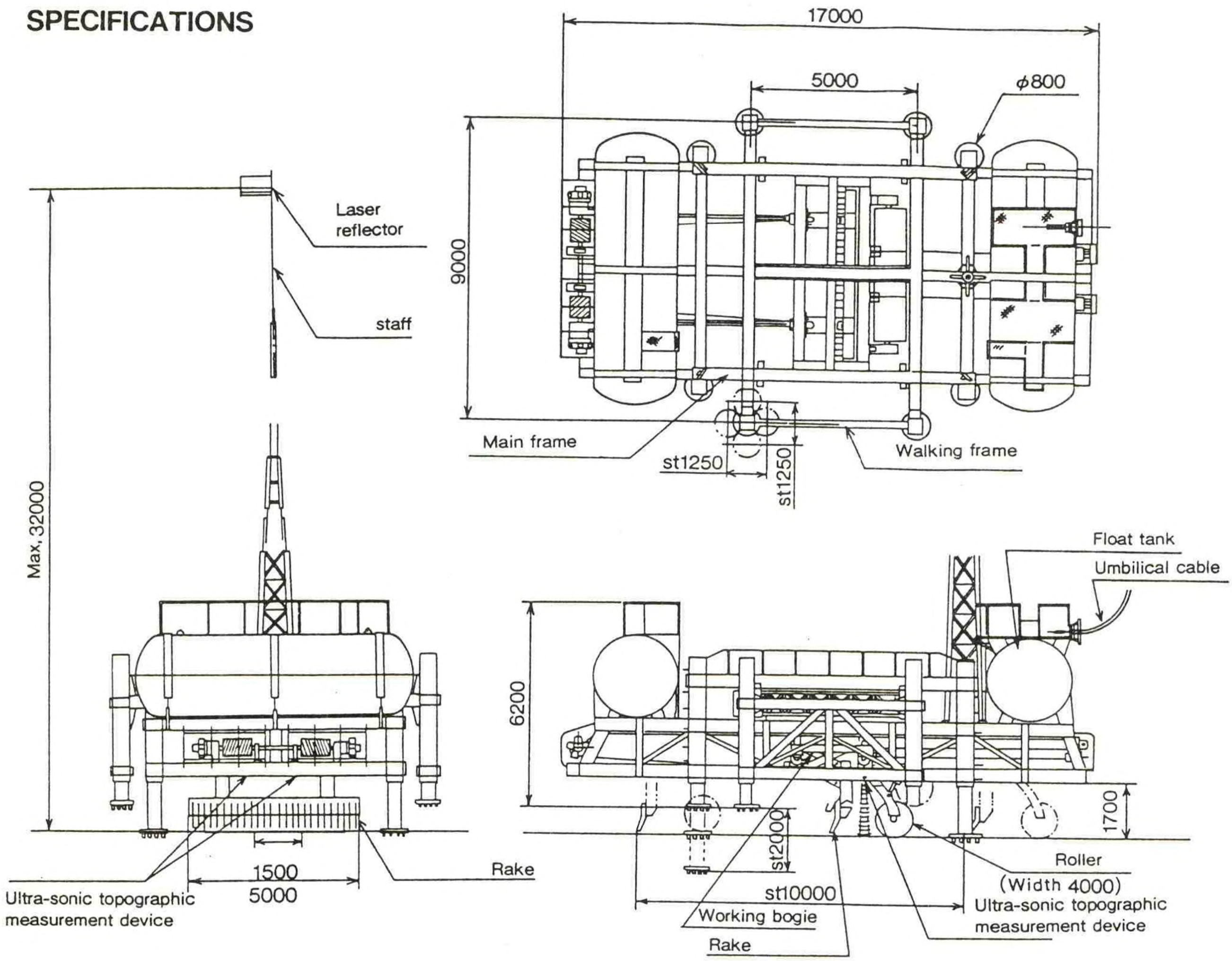
Surveying:	Auto tracking laser surveying system
Walking:	Auto walk control monitor system
	Auto horizontal control monitor system
Dredging:	Dredge control monitor system
Direction:	Gyro-compass
Depth:	Pressure compensated depth measurement apparatus

Submerging/Surfacing Faculties

Remote controlled self submerging/surfacing

Fig. 4 Submargible walking out dredge "FUTABA"

SPECIFICATIONS



NOMINAL WORK RATE	200m²/DAY
ULTRA-SONIC RECORDER	2 lines of 10m length
MAXIMUM WORKING DEPTH	-30m
RUBBLE STONE SIZE	10~200kg/pc.
ACCURACY OF SMOOTHNESS	±5cm (under 100kg/pc.) ±10cm (under 200kg/pc.)
WEIGHT	83ton (IN AIR) 63ton (UNDER WATER)
DIMENTION L×W×H	17×10×6.2m
LEG	STROKE 2.0m
WALKING STROKE	1.25m (BACK, FORTH & SIDE DIRECTIONS) WALKING SPEED 25m/h
WORKING BOGIE	WORKINB STROKE 10m LEVELLING FORCE 20t

RAKE (TEETH)	WIDTH×PITCH ×5.0×0.24m
ROLLER	WIDTH×DIA 4.0×1.0mφ COMPACTING FORCE 20ton
HORIZONTAL POSTURE	WITHIN ±0.14deg.
MOTOR	UNDERWATER MOTOR (OIL IMMERSED)
OPERATION	
AUTOMATIC WALK	REMOTE COMMAND
〃 HORIZONTAL POSTURE	〃
〃 LEVELLING	〃
〃 SPOT TURN	〃
RUBBLE LEVELLING	REMOTE OPERATION

Fig. 5 Underwater rubble levelling robot

AN OUTLINE OF POWER SOURCES FOR THE UNDERWATER VEHICLES

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1. Introduction

More than 2000 unmanned underwater vehicles have been utilized for search of the natural resources in the sea. The thrusters and other devices of these vehicles are almost transferred the driving energy from the mother ship by using untethered cable. The maneuverability on those systems is considerably limited to the depth of shallow water.

In the future development, the autonomous type of the unmanned and manned underwater vehicles will be needed particularly in deep water. The power sources for deep underwater vehicles can be classified into following groups; chemical battery, fuel cell, internal and external combustion engines, radio isotope and nuclear energy

Objective of this paper is to survey what kind of power source exhists, how large power output can be taken, and what sort of utilization has been conducted. Radio isotope and nuclear energy were excepted in this paper.

2. Environment of Underwater Power Sources.

Since air solution in sea water is extremely small (0.019 cm^3 air/cm^3 of H_2O at 20 °C and 1 atm), air breathing type of power sources used in land service or on sea surface is unavailable without any improvement added. On account of the difficulty of fuel charge in the sea, the power source carried loading fuel is limited to the short range of operation. Because of extremely high water pressure, the very careful design is needed for the compartment of the main body of power source and auxiliary. In the case of combustion engine, difficulty exists to exhaust working gases from the vehicles to outer high pressure circumference due to large power losses. Those mentioned above are negative factors for the underwater power source.

The electric conductivity and thermal conductivity of sea water are relatively large. Active use of these physical properties makes positive factors. If specific weight of power machinary and auxiliary as well as vehicle body is designed near sea water, power needed for vertical movement can be decreased by the influence of buoyant force. This is the most different point from the surface ship.

3. Chemical battery [1]

3-1. Primary Battery

The primary battery is in one shot use. Longer endurance, simplicity and low cost are important. Representative primary batteries are shown in Table-1.

(i) Lithium - oxygen ($Li-O_2$) battery has higher cell voltage and specific energy than other batteries. This results in a small package volume and a reduced weight. Long endurance missions are capable of mechan-

Table-1. Primary Battery for Underwater Vehicle

Type	Specific Energy (Wh/kg)	Cell Voltage (volt)	Operating Temperature (°C)
$Li-O_2$	2400	2.1-2.4	30-45
Al-AgO	160	1.5-1.7	60-80
$Mg-H_2O$	1300	0.7-1.1	

ically recharging the consumed reactants after each use. However, gaseous oxygen must be supplied from the external container in which oxygen is stored at a high pressure gas, or a cryogenic liquid or hydrogen peroxide state. Aqueous lithium hydroxide electrolyte also must be recirculated in a close loop. A heat exchanger and other auxiliary systems are needed to remove the waste heat and reaction products. 5 kW, 32 volt battery operating for 6 hours is under development.

(ii) Aluminum - silver oxide (Al-AgO) battery is rapidly activated by flooding seawater at the pressure of the surrounding. This system also needs auxiliary equipments to recirculate the electrolyte of sodium hydroxide and to remove excess heat and reaction products. The development has been originally conducted for power sources of torpedoes. 120 kW power output for 10 minutes duration system has been tested on U. S. Navy programs. This battery is considered useful in underwater vehicles for emergency power and auxiliary power to perform a specific task.

(iii) Magnesium - seawater ($Mg-H_2O$) battery is a high specific energy, as with lithium - oxygen battery. This battery does not require a pressure housing, since the battery is pressure balanced seawater flooded at all depths. Auxiliary systems do not need and only consumable material is an inexpensive magnesium alloy. At present, comparatively low power density of $5W/m^2$ is produced by electrodes exposed to seawater, therefore being desirable for a long power endurance energy source.

3-2. Secondary Battery.[1],[2]

The most important chemical battery is the rechargeable secondary battery. The important performance required for this battery is high cycle life in charge and discharge alternation, and the discharge depth. The specification such as larger power, lighter weight, smaller volume, and longer life time is also needed as a matter of course. Deterioration of secondary battery arises from droping out of active materials from the electrode or deposition of impurities on the electrodes. Atractive secondary batteries for underwater vehicles are shown in Table-2.

(i) Lithium alloy - iron sulfide (Li-FeS) battery operates with high temperature molten salt electrolyte. This battery has high energy density which results in a small package volume and high specific energy. These are useful for reducing overall underwater vehicle size and

Table-2. Secondary Battery for Underwater Vehicle

Type	Specific Energy (Wh/kg)	Cell Voltage (volt)	Operating Temperature (°C)
Li-FeS	85	1.1-1.25	450
Ag-Zn	80-110	1.5	60-110
$Pb-PbO_2$	15-30	2.0	room

weight. High cycle life has been obtained at 500 cycles in 100% deep depth of discharge, 800 cycles in 80% DOD, and 1200 cycles in 40% DOD, respectively. To use the battery, it is heated first to the operating temperature of 450°C by using the resistance heaters powered from an external electrical source. Thermal insulation container is needed.

(ii) Silver - zinc (Ag-Zn) battery has the best specific energy. This battery is well suited for use as a primary battery when the full discharge is allowed such as an application to power source of torpedoes. When used as a secondary battery, 50% DOD is considered to be the best compromise in order to get a life of 80 - 100 cycles at 10 hours rate. However, the specially designed secondary battery has been developed in which over 200 cycles over periods of 30 months have been achieved. The energy output of this battery is 80 - 110 Wh/kg and 150 - 195 Wh/ℓ as much as 220 Wh/kg and 610 Wh/ℓ in certain models. The alkaline KOH electrolyte is normally used .

(iii) Specific Energy, Cycle Life and Depth ofDischarge.[3]

Fig.-1 shows the relation between the usable percentage of capacity versus constant rates of discharge of the secondary batteries. It can be seen that the capacity of Ag-Zn battery is hold at 100% upper region of discharge rate of 2 hours. By contrast, the capacity of lead-acid batteries is rapidly decreasing with shortening discharge rate.

The specific energy is reduced with increasing cycle life

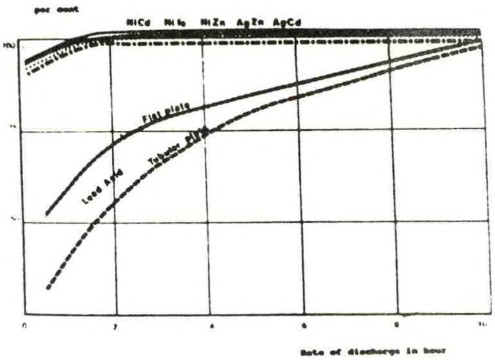

Fig.-1. Usable Energy vs. Rate of Discharge.

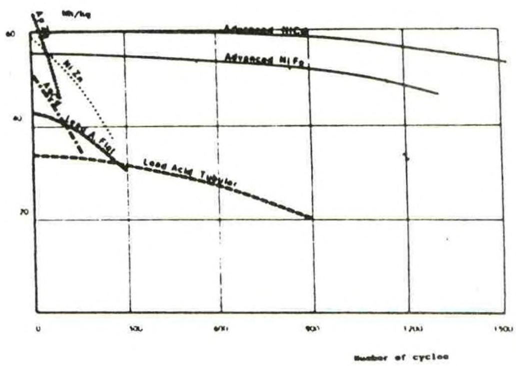

Fig.-2. Specific Energy vs. Cycle Live

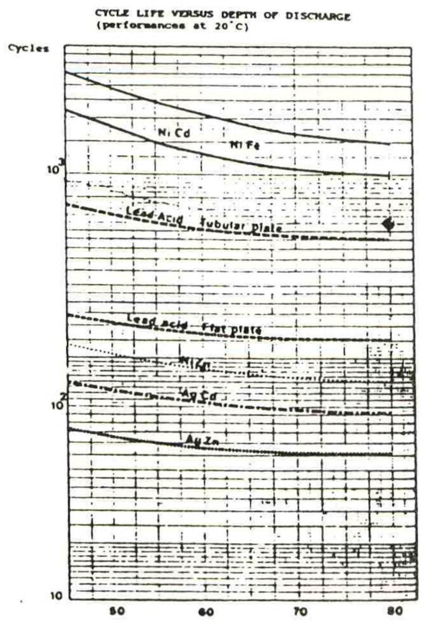

Fig.-3. Cycle Life vs. Depth of Discharge as illustrated in Fig.-2. Although the specific energy of Ag-Zn battery is better than lead-acid batteries, the weak point of this battery is shorter cycle life.

The tendence of curves shown the relation of cycle life and discharge depth of the Ag-Zn battery is similar to lead-acid batteries on the semi-logarithmic coordinates, as seen in Fig.-3. However, it can be also found from this figure that the cycle life of the Ag-Zn battery is lower.

4. Fuel Cell[4]

Fuel cell is a device which directly converts chemical energy into electrical energy. Low, medium and high temperature fuel cells exhist. The hundred or thousand-kW class fuel cells for onshore use are gradually coming out in markets.

It can be considered that the fuel cell is a primary battery in which the fuel and oxidizer are stored external to the battery and are fed to it when needed. Therefore, when the fuel cell is utilized for a power source of underwater vehicles, the duration time in a mission depends upon the capacity of the external storage tanks of the fuel and oxidizer. In the applied experience of U.S. Navy, in which a 700 kW alkaline electrolyte fuel cell successfully powered a Lockheed submersible, gaseous hydrogen and oxygen were stored at 200 bars pressure in high strength steel spherical vessels. The energy system generated 220 Wh/kg and 176 Wh/ℓ. This is significantly superior to lead acid or Ag-Zn batteries and established a 42.9 hrs. underwater endurance record for a nonnuclear powered submersible.

Since the fuel cell utilized an alkaline eletrolyte requires pure reactants in order that the performance of KOH electrolyte is decreased by the effect of impurities, the acid fuel cell is said more appropriate. The fuel cell composed of solid polymer electrolyte (SPE) named as "Nafion" and phosphoric acid is reported to be capable of specific energy of 90 - 140 W/kg., while estimated to yield 40 W/kg. including pressure vessels for future utility applications.

Another SPE fuel cell of 310 kW output for 30 day mission is proposed by the U. S. Navy as shown in Fig.-4. In this case, methanol is reformed in a

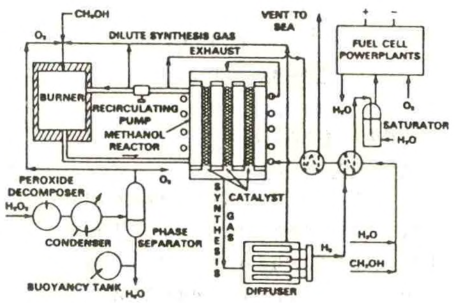

Fig.-4. Methanol Fuel Cell.[4]

reactor to carbon monoxide and hydrogen. Oxygen is supplied from a peroxide decomposer. The total weight and volume included all machinaries and reactants with 30% excess fuel and oxidants are 621,285kg and 580 m^3, respectively.

The West German Navy was reported to have a fuel cell for a submarine on board, in november, 1987, after 350 hours on shore test. The hydrogen absorbed in a metal hydride and liquid oxygen are utilized in this system (Fig.-5).

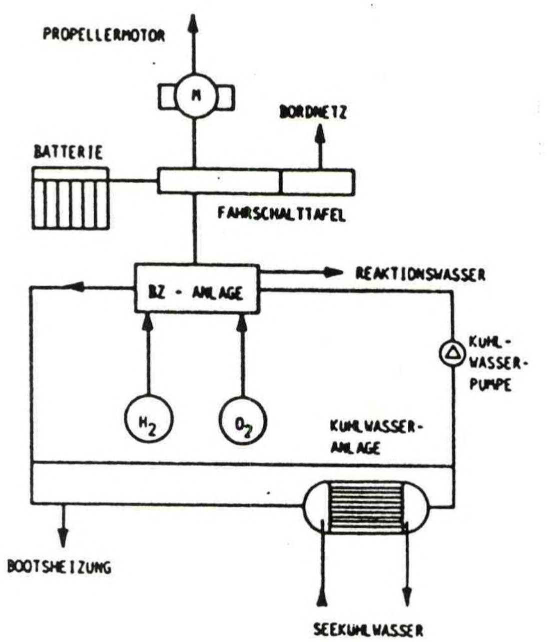

Fig.-5. Fuel Cell for Submarine.[5]

5. Thermal engines

5-1. Diesel Engine.[6]

The defect of internal or external combustion engines is that the engine performance is strongly affected by environmental pressures. In shallow water, combustion gases can be directly exhausted from the engines into water without large power losses. However, in deep water, utilization of a closed cycle system is forced to adopt.

A 22 kW(30PS) diesel engine "HIRUP-30E" was actually tested offshore at 100 m depth as a power source of 16kW electric lighting devices and tools, by Japan Marine Science and Technology Center, under cooperating the engine maker; Hitachi Zosen Co.(ship builder, Japan). This enine was supplied air and oxygen from each external cylinder, in which 400 ℓ gases was stored at 150 atg. Combustion gases were recirculated after cooled down from 600°C to 135°C by water injection and adjusted oxygen consentration to 34 vol%. Excess gases were pushed out of the test cell by a compressor. The specific fuel consumption (sfc) was reported to be 522g/kW/h and specific oxygen consumption(soc) was 2.01 kg/kW/h.

After HIRUP-30E, a 27.4kW (37.3PS) closed cycle diesel engine as shown in Fig.-6 was tested on land. On this test, oxygen was supplied from the same cylinder as mentioned above CO_2 and N_2 in the exhaust gases were recirculated, while an excess gas of CO_2 was absorbed by using a scrubber in which 40% aqueous monoethanolamin $H_2N \cdot CH_2CH_2OH$ was contained as an absorbent. The sfc and soc were 233 g/kW/h and 1.07kg/kW/h, respectively. The absorption ability of other absorbents such as diisopropanolamin,

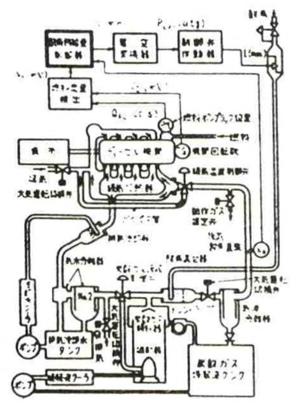

Fig.-6. Closed Cycle Diesel Engine[6]

5-2. Stirling Engine.[7]

Although this engine is given chemical energy of fuel by external combustion through a heat exchanger, a matter involved in applying to power sources of underwater vehicles is considered to be similar to internal combustion engines, as was seen in the diesel engine. However, the diving depth without a gas compressor seems to be more deeper than the case of diesel engines, by the reason of higher pressure of working gases. One of the applied examples is 75 kW closed cycle Stirling engines developed by the Sub Power workshops in Sweden, which had four new A17-class submarines of the Swedish Navy on board (Fig.-7). In this case, diesel fuel and liquid oxygen are used. It is reported that the engine can operate at water depths of 300 m without the need for exhaust gas compression or a dissolving system.

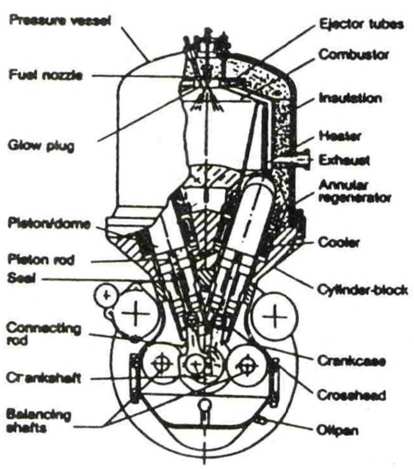

Fig.-7. Stirling Engine for Submarine.[7]

5-3.Continuous Combustion Engine

(i) Reciprocating Engine.[8]

Fig.-8 shows other system of internal combustion engines which had been developed as the power source of torpedoes by the Japanese Navy, for 1916 - 1932, and used until 1945 with continuous improvement. Pure oxygen stored in a 980 ℓ storage tank at a pressure of 225 atg.

First of all, the engine is started by using air stored at 235 atg in a 13.5 ℓ cylinder and kerosine fuel, in order to avoid

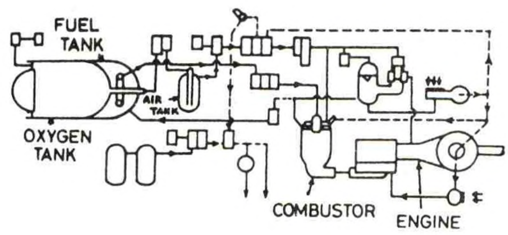

Fig.-8. Reciprocating Engine.[8]

the explosion that easily be happened by a mechanical shock of components in the oxygen and fuel mixtures. After starting, the engine automatically changes air balanced pressure to oxygen. The mixture of kerosine fuel and pure oxygen is burned in the combustor at a pressure of 20 atg. Cooling water passes in a double wall of combustor. and is injected along the inside surface of the combustor to achieve film cooling. The temperature of combustion gases is about 1200°C in the combustion zone and 900°C at the outlet. The combustion gases are supplied to reciprocating engines. The total output of this system is about 1177 kW (1600PS)/kg/s of oxygen.

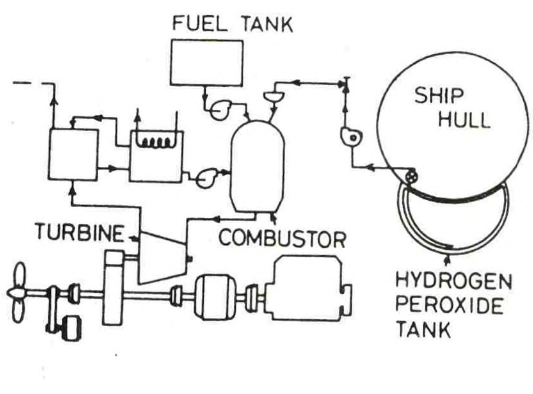

Fig.-9. Walther Turbine.[8]

(ii) Turbine Engine. Fig.-9 shows a Walther turbine engine developed by the German Navy as a power source of the submarine U-793, 795 and others, in 1945. Oxygen decomposed of 80 - 90% hydrogen peroxide and diesel fuel were burned in the combustor. The hydrogen peroxide was stored in pressure-compensated bladder type tanks[9].

Fig.-10 is another system which is considered as a power source for deep underwater vehicles in a feasibility study. Liquid hydrogen and oxygen are reactants in this case. Thermal efficiency obtained at 1000 kW output is estimated 45% at 1.5 MPa of supplied reactant pressure, and 800°C TIT. The excess product is only water wich can be easily pushed out of vehicle hulls without large power losses in deep sea.

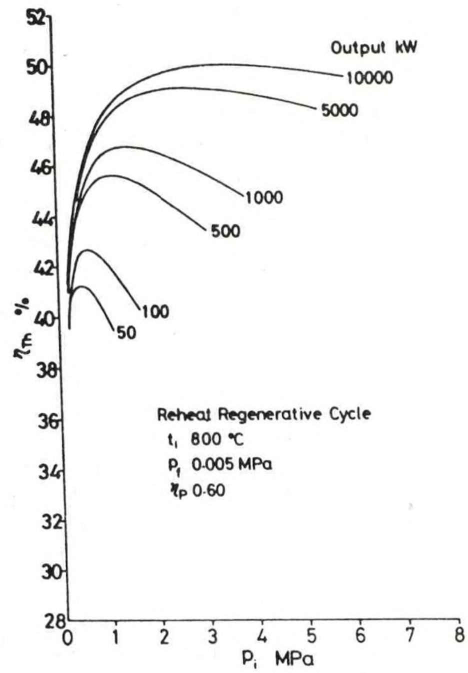

Fig.-10(b). Performance of Power System Shown in Fig.10(a)

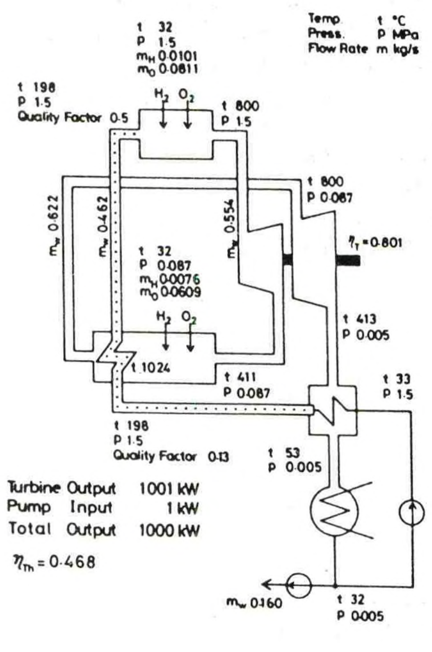

Fig.-10(a). LH_2/LO_2 Power System.[10]

According to a result of oxidants selection on reactant system weight and volume at a fixed output energy, it is obvious that liquid oxygen has a significant advantage under the present technology (Table-3).

	LIQUID OXYGEN		90% H_2O_2		70% H_2O_2	
	TONS	m³	TONS	m³	TONS	m³
OXIDANT*	129	–	306	–	392	–
OXIDANT TANKAGE	60	130	46	245	59	340
METHANOL*	84	–	84	–	84	–
METHANOL TANKAGE	13	117	13	117	13	117
BUOYANCY TANK	10	106	5	56	5	56
TOTAL	296	363	453	418	553	513

*BASED ON FUEL CELL EFFICIENCY OF 57.5% AND 30% EXCESS REACTANTS.

Table.-3. Weight and Volume of Oxidants and Reactants.[4]

There is no choice of storage methods for liquid fossil fuels. In comparison with them, hydrogen has three choices; gas, liquid and metal hydride. Liquid hydrogen has a better energy density , but not tolerated for long storage time. As for duration of storage, metal hydrides have a good characteristic equal to a cylinder gas. The storage quantity of hydrogen in the metal hydrides is larger than the amount in the storage cylinder as shown in Table-4.

Hydride	H_2 kg*	Weight Ratio**
$LaNi_5H_6$	46	0.0137
LaH_3	30	0.0210
TiH_2	16	0.0393
MgH_2	8	0.0787
(GH_2 cylinder		0.0117)

* Absorbed hydrogen weight.
** Adsorbed hydrogen weight/hydride weight.

Table-4. Hydrogen Weight Adsorbed in Hydrides.

6. Conclusion.

There are many types of candidate chemical batteries, which did not mentioned in this paper, as shown in Fig.-3. Since chemical batteries are superior to others in no affection of higher pressure of deep water, but hevy and bulky, yet. Stronger future developments are expected. Internal or external power sources are usable, particularly, for a large power needed. However, some amounts of power losses arise to manage exhaust gases. Fuel cell is also a hevy and bulky energy source. As well as battery systems, stronger future development of fuel cell systems are expected.

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Measures for safety of submersible carrying passengers

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If we try to operate the submersible carring passengers in our country, the operations would be regulated by such laws and ordinances, related to safety of submersible, as Ship Safety Law which the writer takes charge of, Marine Transportation Law, Mariner's Law, Law for Ships Officers, Law for Preventing Collisions at Sea, Port Regulation Law and so on.

The regulation of laws and ordinances, however, has accomplished just a little part in keeping the marine safety and as a matter of fact, in order to keep safety operations, safety operations can't be accomplished until a ship yard, owners of ships, and operators unite their will and effort.

Specifically,Submarsibles carring passengers are designed in consideration of many conditions of operations as I have explained above, therefore, in order to avoid accidents it is indispensable for operators to pay close attention to maintaining safety and to practice certain and reasonable operations.

Then, the safest management of operations should be done such as adjustment of management system of operations, training and maturing the crews, adjustment of surrounding facilities, careful investigation and selection of the water area for entiring service, operations for breaking in their ships before opening the business, and after opening the business, habitual grasp of weather and sea conditions, suspending operations in response to these conditions, a habitual inspection of machinery, suspension of operations at the time of the machine's being out of order, appropriate ballast adjustment related to the number of the passengers, inspections before the operations, certain enforcement of a supply, reasonable sailings, proper operations of leading passengers etc.

On the other hand, shipbuilding companies which build submersibles are responsible not only for keeping the safest designs in mind grasping the actual condition of operations but for a habitual inspection and adjustment, offering services such as supply of parts, informations which are necessary for operators to keep safty , for example, a precondition of design, matters that demand special attention to operations, the advice for peculiates of submarine passengers, the counsel for adjustment of surrounding facilities and plans of operations, processes of managing the ships, a point of management etc.

The writer himself is at present in charge of safety regulation, but safety regulation by laws and ordinances does not essentially regulate the nation's activities but it aims to keep the minimum safety. So it does not mean to deny the cruising form of new vessels like submersibles carring passengers.

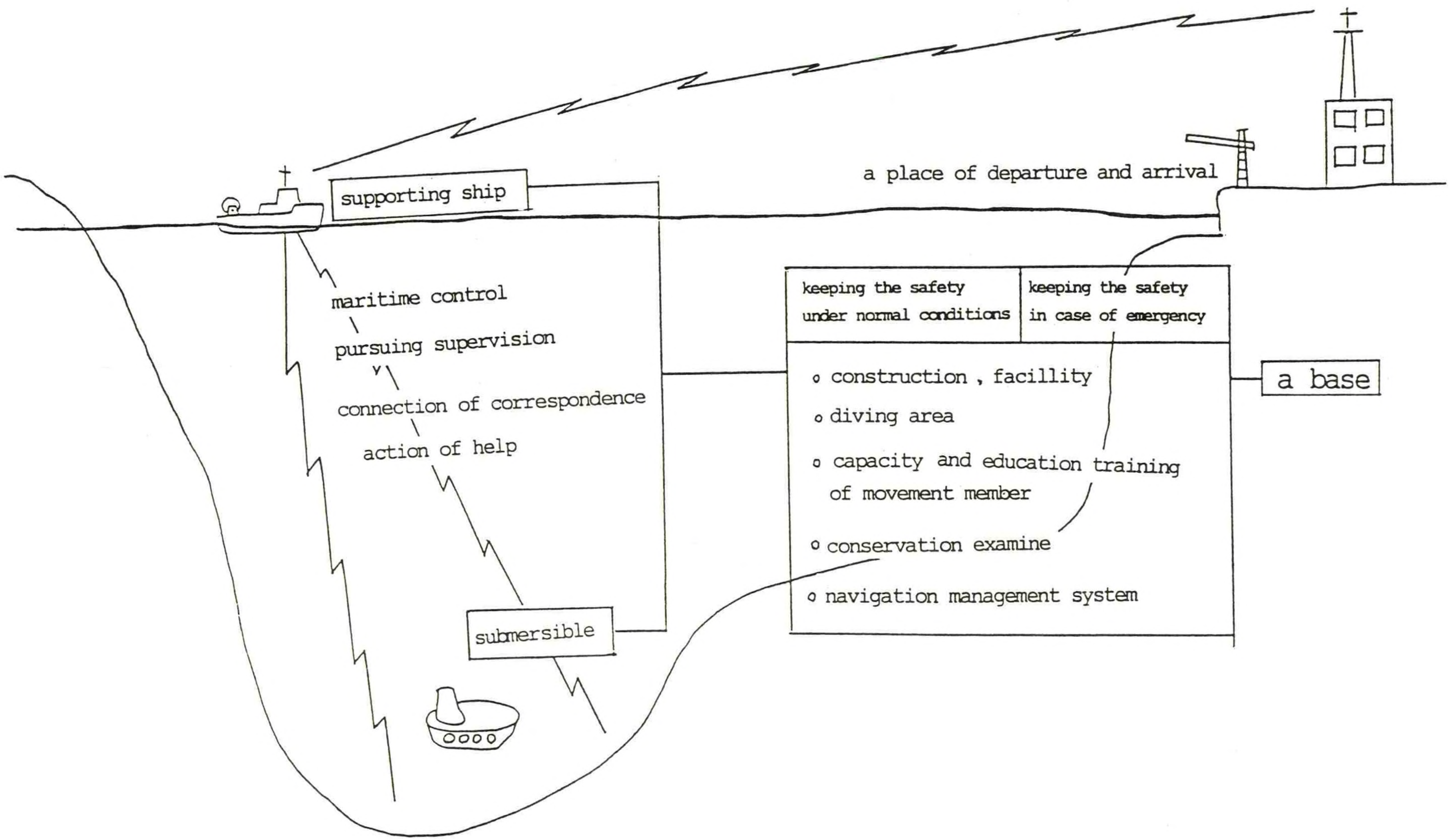
We hope that small bud grows soundly and it helps us to expand the dream of future development of the ocean.

In this sense, we consider that all the parties concerned including the administration should tackle with the safety control and should not end in failure.

The press has reported as safety standards for submarsibles carring passengers are not provided, drawing doesn't proceed at all. In writer's opinion at this point, if the administration in charge of safety regulation would provide the standard onesidedly, it would cause restricting creativity of designers. So, it is needless to do so.

We are ready to comply immediately with concrete consultation and also respond flexibly to various means of safety control.

"keeping the safety of submersible carring passengers"



TOURIST SUBMARINES: CURRENT STATUS AND FUTURE DIRECTIONS

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I. INTRODUCTION

This brief review is derived from a four volume, worldwide tourist submarine market opportunity survey done by International Maritime Incorporated (IMI). This study was begun two years ago and is maintained up to date for our clients through the use of a computerized data bank.

Since it is difficult to describe such a complex field in just a few pages, I will attempt to limit my presentation to only a few key areas such as present (1989-1990) construction and operational plans; profile of the business side of these operations, and new development trends. I note that John Pritzlaff's paper has given you some historical background on the development of tourist submarines and describes some of those presently in service. Therefore I will not repeat this information again but will try to complement the useful information he has presented.

II. NEW SUBMARINES COMING INTO SERVICE: 1989-1990

At present there are 14 built-for-the-purpose, and 4 converted offshore workboat type submersibles in passenger carrying service. These are summarized in Table 1.

During the current year and through the end of 1990 there will be from 10-13 submarines added to the worldwide fleet. These are summarized in Table 2. Please note that some of this data is IMI's estimates based on market growth and the demonstrated success of some of the builders. Of the maximum number of 13 submarines, 2 of these exist as completed hulls (LG-50-3 and ODYSSEY) while 3 others are virtually completed (Mitsubishi, PC- 1202 and ATLANTIS VI). The remaining submarines are newbuilds.

Nevertheless, the fact that the world fleet could nearly double in the next 16 months is a strong indication of the inherent strength of this new marine-related recreational market. However the opportunity is not unlimited nor is it easy to capture.

III. THE BUILDERS: MOST ARE NO LONGER IN THE BUSINESS

Despite the rapid growth in the submarine population the number of builders has dramatically decreased. The current fleet of 13 built-for-the-purpose submarines were constructed by three companies: Sub Aquatics Development Corporation (Canada, 6 ATLANTIS class), Fluid Energy Ltd (Scotland, 2 LOOKING GLASS class) and Wartsila-Laiveostillius (Finland, 4 MARIEA class). Of these three companies only Sub Aquatics remains in business, over the past year the other two quit. Fluid Energy went into receivership and Wartsila, a successful shipbuilding company, determined that their profit margins too small in the submarine business.

At the time of its termination, Wartsila's tourist submarine group spun off two new companies, SubMarine Oy and W Sub Oy. SubMarine Oy is perfecting and marketing the SM-100 tourist submarine design which began

TABLE 1: SUMMARY OF TOURIST SUBMARINES CURRENTLY IN SERVICE

NAME	BUILDER	YEAR BLT	PASS	LOCATION	OPERATOR
ATLANTIS I	Sub Aquatics Development Corp.	1985	28	Grand Cayman Island	Atlantis Submarine (Cayman) Ltd.
ATLANTIS II	Sub Aquatics Development Corp.	1987	28	Georgetown Barbados	Atlantis Ltd.
ATLANTIS III	Sub Aquatics Development Corp.	1987	46	St. Thomas, U.S. Virgin Islands	Atlantis Submarines Inc.
ATLANTIS IV	Sub Aquatics Development Corp.	1988	46	Oahu (Waikiki), Hawaii	Atlantis Submarines Hawaii, L.P.
ATLANTIS V	Sub Aquatics Development Corp.	1988	46	Apra Harbor, Guam	Atlantis Submarines Guam
ATLANTIS VII	Sub Aquatics Development Corp.	1989	46	Kona, Island of Hawaii	Atlantis Submarines Hawaii, L.P.
CORAL ADVENTURE (RS-250-4)	Wartsila Laivateollisuus	1988	46	Amami Oshima, Kyushu, Japan	Coral Marine Co., Ltd.
DEEPSUB (PC-1202)	Perry Offshore	1975	10	Cozumel, Mexico	Del Mar Deep Sub
DOLPHIN I	Plongee, Inc.	1987	8	Curacao, N.A.	Plongee, Inc.

TABLE 1: (CONTINUED)

NAME	BUILDER	YEAR BLT	PASS	LOCATION	OPERATOR
ENTERPRISE (LG-50-2)	Fluid Energy Ltd.	1988	48	St. George, Bermuda	Looking Glass Tours Ltd.
GOLDEN TROUT (RS-250-2)	Wartsila Laivateollisuus	1988	46	Lake Simojarvi, Finland/Tennerife , Canary Islands	Finnish SubmarineTours Inc./SUBTREK S.A.
LOOKING GLASS (LG-50-1)	Fluid Energy Ltd.	1988	48	St. Thomas U.S. Virgin Islands	Submarines Tours Ltd. of St. Thomas
MARIEA I (RS-250-1)	Wartsila Laivateollisuus	1987	46	Saipan, Territory of N. Marianas	DOSA Sub-Sea Co., Ltd.
MARIEA III (RS-250-3)	Wartsila Laivateollisuus	1988	46	Cheji-do, Korea	Daekuk Subsea Co.
MARIEA V (RS-250-5)	Wartsila Laivateollisuus	1989	46	Palma de Majorca, Spain	(unknown)
PAU PAU (PC-1201)	Perry Offshore	1975	2	Rota Island, Territory of N. Marianas	Micronesian Investment Corporation
PC-1205	Perry Offshore	1978	2	Grand Cayman, BWI	Research Submersibles Ltd
PC-1802	Perry Offshore	1978	3	Grand Cayman, BWI	Research Submersibles Ltd

TABLE 2: TOURIST SUBMARINES WHICH WILL GO INTO SERVICE 1989-1990

NAME	BUILDER	YEAR BLT	PASS	LOCATION	OPERATOR
ATLANTIS VI	Sub Aquatics Development Corp.	1989	46	Bahamas, BWI	Hotel Corporation of the Bahamas (owner)
ATLANTIS VIII	Sub Aquatics Development Corp, Canada	1990	46	Aruba, N.A.	(unknown)
ATLANTIS IX	Sub Aquatics Development Corp, Canada	1990	46	Tenerife, Canary Islands	(unknown)
MERGO 10	Malmari & Winberg, Finland	1990	10	Sharm ash Shaykh, Egypt	(unknown)
Mitsubishi (UNNAMED)	Mitsubishi Heavy Ind.	1989	40	On'na Village, Okinawa	Japan Submarine Tourism Co., Ltd.
ODYSSEY I	International Submarine Engineering, Canada	1989	36	Sint Maartens, N.A.	Submarine Safaris of Alberta
SEAMAID	Bruker Meerestechnik AG, W. Germany	1990	48	Cancun, Mexico	(unknown)
SEAVIEW	Sea View Enterprises, USA	1990 (if acylic hull is approved)	10	Hawaii	Sea View Enterprises
SEEVIEW	Perry Offshore (PC-12), USA	1990	6	Key Largo, Florida	Subsee Tours, Inc.

TABLE 2: CONTINUED

NAME	BUILDER	YEAR BLT	PASS	LOCATION	OPERATOR
SM-100	SubMarine Oy/FRABECO, Finland/Belgium	1990	48	Eilat, Israel	SCANDIVE (Norway)
SM-100	SubMarine Oy/FRABECO, Finland/Belgium	1990	48	Tenerife, Canary Islands	Finnish Submarine Tours
SPT-16	Sulzer Brothers, Switzerland	1989-90	16	Swiss lakes	Deep Line AG

Note: This listing is based on best information available at the time this paper was written (August, 1989).. Each company has been contacted to confirm the information presented here. However, the fast changing nature of this business results in changes that are difficult to track. Therefore this table should be used as a guide to the dynamics of the tourist submarine sector rather than an absolute forecast of what will happen in 1989-1990.

as the Wartsila VENTURE class. While no VENTURE submarines were built, SubMarine Oy is currently building two SM-100's in Belgium for investor groups. Both should be launched in 1990.

W Sub Oy has taken over the after-sales support of the four Wartsila MARIEA (RS-250) class submarines, which are operating in four countries including Japan (Amami Oshima). In addition, at the time of its formation, the company acquired a completed hull for a fifth RS-250. This submarine is currently being completed in Spain.

The other major Finnish shipbuilder, Rauma-Repola, for about a year offered its RR-49 design tourist submarine through their subsidiary, Malmari & Winberg. No sales materialized and in October, 1988, Malmari & Winberg bought itself out from Rauma-Repola. M&W continues to offer the submarines as the MERGO class and it has been reported that a 10 passenger MERGO 10 is now under construction. In Switzerland, Deep Line AG is completing the construction of the SPT-16 tourist submarine at the Sulzer Brothers fabrication facililty in Winterthur. This 16 passenger submarin should be operational by the end of 1989. At this time they do not have any additional orders.

International Submarine Engineering (ISE) in Vancouver, Canada has had the completed hull for the ODYSSEY submarine in their shop for several months. The hull has been pressure tested at 1.5 times operating depth but construction is not being completed pending refinancing of the owner/operating company, Submarine Safaris of Alberta. IMI has heard that this may be accomplished shortly.

In Japan, Mitsubishi Heavy Industries managed to surprise tourist submarine business observers by actually constructing a submarine with very little public notice until the project was well advanced. This 40 passenger submarine will be put into service at Okinawa in October, 1989. The project is a joint venture of MHI, Japan Airlines and the Japan Travel Bureau plus smaller shares held by three other investor groups.

With the exception of SubMarine Oy (2 SM-100's under construction), each of the companies listed above is only building one submarine. The only company with tourist submarines in serial production is Sub Aquatics Development Corporation in Vancouver. ATLANTIS VI is in the final stages of assembly at Vancouver while ATLANTIS VIII & IX have been ordered by investors. Construction on these two will begin in 1989 with completion early next year. In 1990 construction will begin on ATLANTIS X and possibly XI.

Although most of the new capacity to be added in 1989-90 will be built-for-the-purpose submarines, there is one conversion of a Perry PC-12 industrial submersible that will be operated in the Florida Keys. Built and certified (ABS) for 1200 foot operating depth, this was orginally a diver lockout submersible. By modifying the lockout chamber into a passenger cabin, the SEEVIEW will be able to 6 passengers. All design and conversion work is being carried out under ABS supervision.

A final note on the companies that manufacture submarines. First, most of them are not conventional shipyards. The labor and overhead rates at most shipyards are simply too big to provide the shipyard builder with a reasonable profit. Second, as long as the plans and construction meet classification standards and appropriate government regulations, then the submarine can be made in almost any fabrication facility. Understandably the lowest cost facility will offer the highest profit margins for the designer/builder. And third, the real profit in tourist submarines is not in their construction but in their operation. This is the reason that some of the designers/builders have developed a franchise type arrangement where they become equity partners with the operators for the life of the submarine.

IV. THE OPERATORS: MOSTLY DOING WELL

Since this business was started in the mid-1980's by Research Submersibles Ltd. (RSL) in Grand Cayman nearly one million people have safely enjoyed tourist cruises underwater. RSL specialized in using former industrial submersibles to take no more than 2 passengers to depths as great as 800 feet and more than seven thousand people have enjoyed this experience at a ticket price of $200 each. However, nearly 70% of the million passengers have been carried in the six ATLANTIS class submarines now operational.

At present tourist submarine operations are being conducted at 12 sites in 8 countries. The 1989-90 forecast of new operations adds another 7 countries. Seven of the current submarine operations are in areas under U.S. jurisdiction: U.S. Virgin Islands (2), Hawaii (2), Guam, Saipan and Rota Island. For this reason the U.S. Coast Guard has been working diligently over the past year to develop rules and regulations for passenger carrying submarines. Existing rules and regulations, developed for surface vessels, do not adapt well to submarine operations.

Business failures among the operators have been less frequent than for the builders. In fact, only one operator (Looking Glass Tours in St. Thomas, U.S. Virgin Islands) has left the business. This occured in early 1989 when their submarine, YELLOW SUBMARINE (Fluid Energy LG-50-1) was seized by creditors. YELLOW SUBMARINE may be the first built-for-the-purpose tourist submarine to enter the secondary (i.e., used) market. The current disposition of this submarine is unknown but it is certain that it will eventually be sold to help satisfy debts incurred by its operating company.

IMI estimates that during 1989-90 at least two more submarines will enter the secondary market due to business termination by their present operators. These 1-3 submarines should be available at lower costs than a new-build since most will be sold to satisfy debts against the operator. This extra supply on the market will provide some sales competition for the builders of new tourist submarines. In some cases the builders may even be competing in the market against their own, previously-built, products.

Most the of the business failures can be associated with poor selection of the operating site, weak marketing, and cash flow difficulties. These problems can traced to poor planning during the startup stages of the project where business plan development was not thorough.

V. NEW TRENDS

While the worldwide market for the larger tourist submarines will continue to be attractive, the full capacity will probably be in the order of 50-80 submarines. In this market sector the larger the submarine the greater the profit for the operator. This because the per seat construction cost of tourist submarines is non-linear. That is a 50 seat sub does not cost twice as much as a 25 seat; the cost factor is more like 1.4 times. Therefore, a large submarine will be more profitable if the selected operating site can handle the seat capacity.

Nevertheless there is a considerable market niche for small (6-25 passengers) built for the purpose submarines. There are many locations throughout the world that could support a full time tourist submarine operation if the sub could operate profitably with fewer passengers. Simply downsizing existing designs will not work as the cost per seat will not permit a decent return on investment. However, designs specialized for this capacity range could be successfully employed at smaller resorts and locations which could not profitably support a large submarine. Several designers are working on plans for small submarines but only Deep Line's 16 passenger

SPT-16 is the only one currently under construction.

The market for these smaller sized submarines eventually could be considerably greater than for the larger 40-60 passenger models. The technical problems in designing and building a cheap, small passenger carrying submarine are formidable but they can be solved.

Another new trend is that use of massive acrylic cylindrical sections for the actual pressure hull of the submarine. The present classification rules for manned submersibles only consider plastics as materials for windows, viewing ports and hemispheric closures at the end of conventional steel pressure hulls. Classification societies such as the American Bureau of Shipping (ABS, who have classed virtually all existing tourist submarines), Lloyds Register and Det Norske Veritas do not have rules for massive acrylic pressure hulls. In addition, the U.S. American Society for Mechanical Engineers (ASME) "Pressure Vessel for Human Occupancy" (PVHO) standard which is often accepted for the design of submersible hulls, does not have standards for cylindrical plastic hull sections greater than 30 inches in diameter.

This is not to say that hulls of this material cannot be classed, it says that to achieve new rules a considerable investment will have to be made in the testing to failure of full sized hull sections. This will be costly and time-consuming; so far no one has initiated the process. Nevertheless, in the past two years, three companies have proposed plastic pressure hull designs to ABS for preliminary review.

Why plastic? The primary answer is visibility. The submarine with an all plastic hull will afford the passengers an 'infinite window' experience. Since the index of refraction of acrylic is about the same as seawater, the effect inside the submarine is one of being inside a hole in the ocean. Also, scratches in the hull material will not be apparent as long as the submarine is in the water.

The question is whether or not such submarines can be approved, built and put into service before most of the prime locations have been populated by the conventional steel hulled submarines.

The third new trend will be for built for the purpose submarines which can go to deep depths. At present this role is being filled by former offshore industrial submersibles which have been adapted to carry from 2-6 passengers to depths as great as 1000 feet. These are mostly submersibles in the Perry (USA) PC series.

However, it would not be difficult to build a 40-50 passenger tourist submarine that could dive to 500 plus feet. The major problem would be the provision of a recovery system since operating depths would be well below those where divers could assist. Either a second submarine or a remotely controlled vehicle (ROV) will be required to satisfy this requirement. Most national regulatory authorities, such as the U.S. Coast Guard, will require recovery systems for the deep submarines.

The market for the deep diving experience will probably be small and limited to the type of person who enjoys adventure type recreation. About 75% of all marine life can be found in the first 30 feet of ocean depth and here the penetration of sunlight can show actual colors of marine flora and fauna. This is the region currently being served by existing design tourist submarines. In most oceans, by the time you reach 500 feet all light from the surface has been extinguished and the submarine must use power consuming lights to illuminate the viewing area.

Nevertheless people will want to experience the primary submarine variable: depth.

VI. SUMMARY

The tourist submarine business is a permanent sector in the marine recreation market. In a little over four years a great many people have been exposed to undersea cruises and there have been no serious accidents. In the span of less than the next 18 months the number of these submarines will nearly double.

Many of the early technical and business mistakes have been overcome. It is clear that there is excellent potential for those companies and investor groups who take the trouble to study and understand this market before investing in it.

As this business sector evolves we can begin to see sub-sectors developing. Examples of these are: greater depth, smaller capacity submarines and use of transparent hulls.

The basic elements of a successful program will be determined by careful analysis on the part of the potential operator. This is best done by working with the submarine builder who can bring to the process his past experience with submarines he has built and set up at various sites.

TOURIST SUBMERSIBLE SAFETY

By John A. Pritzlaff, Program Manager
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The tourist submersible industry had its modern day start in 1964 with the operation of the Auguste Piccard in Lake Geneva carrying thousands of visitors on excursion dives as part of the 1964 Swiss National Fair (Figure 1).

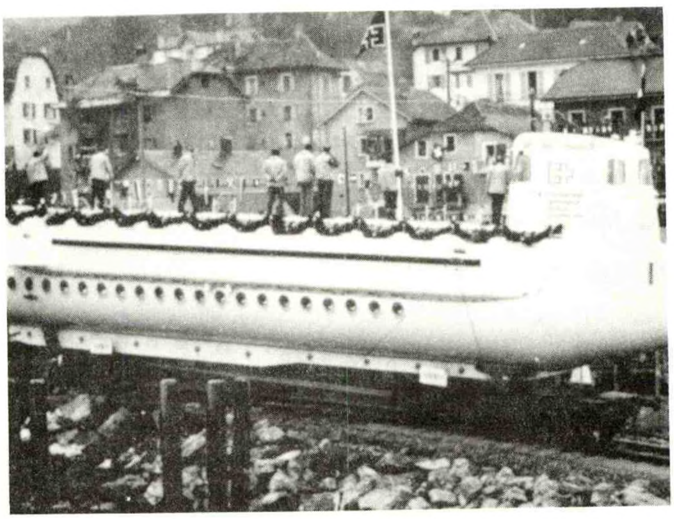

Figure 1. Auguste Piccard
Length 28.5M; Displacement 222 Metric Tons; Passengers/Crew — 40/4

Since that time there was no significant activity until the early 1980's when Research Submersibles Ltd.. of Cayman Is. BWI. began taking down tourists in small numbers in several reworked Perry Submersibles (PC-8, PC 1202, etc.).

Most recently, (1987/1988) Fluid Energy Corp. of Inverkeithing, Scotland has produced two "Looking Glass" tourist submersibles (Figure 2) and Sub Aquatics Development Corp. of Vancouver, Canada has produced five "Atlantis" tourist submersibles (Figure 3), with the first one being placed in service in 1985. The Wartsila shipbuilders of Finland have produced four of the looking glass type of tourist submarine under the Mariea (RS-250) name (Figure 4).

These eleven submarines are the only "large" tourist submarines that are currently in operation. Some of these may be temporarily out of service due to financial and/or operational problems.

There are several other companies that are starting to produce or are able to produce similar tourist submersible.

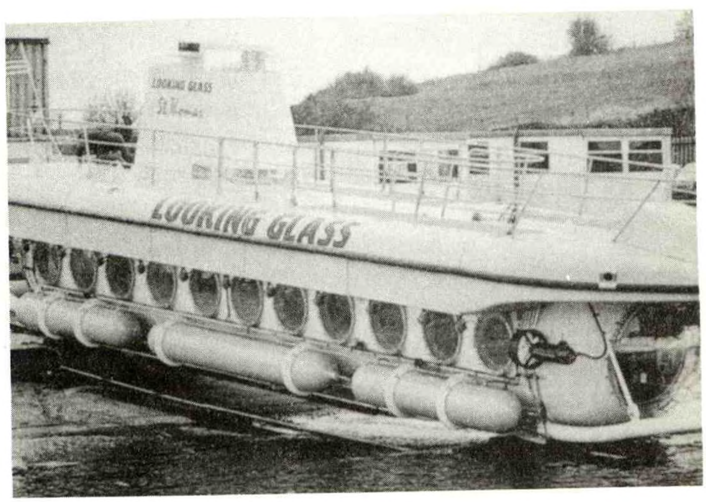

Figure 2. Fluid Energy's "Looking Glass"
Length 19.5M; Displacement 106 Tons; Passengers/Crew — 48/2

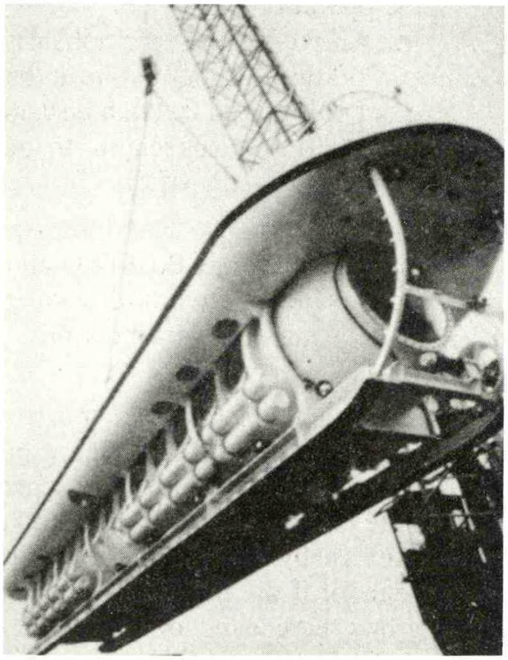

**Figure 3. Sub Aquatics' "Atlantis V"
Length 20M; Displacement 80 Tons;
Passengers/Crew — 46/3**

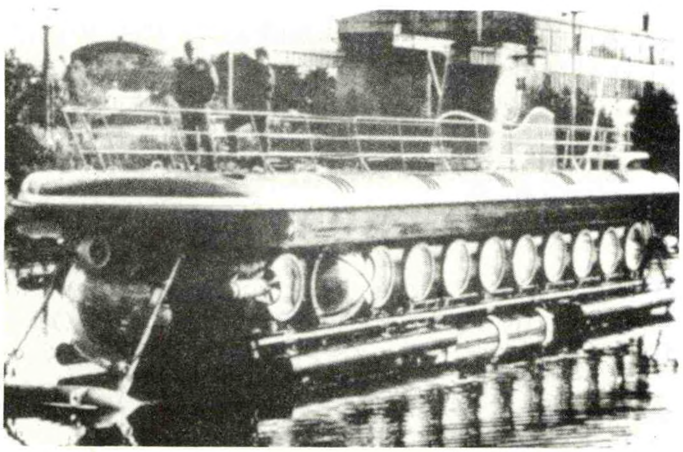

**Figure 4. Wartsila's Mariea Class
Length 19.5M; Displacement 106 Tons;
Passengers/Crew — 48/2**

Typical of this type of submersible is the the Malmari-Weinberg OY (Helsinki, Finland) design of the RR Sub 49. This is a 120-ton craft that can carry 49 passengers and a crew of 3 to depths of 100 meters. Figure 5 shows an external view of this type of submersible as seen in model form.

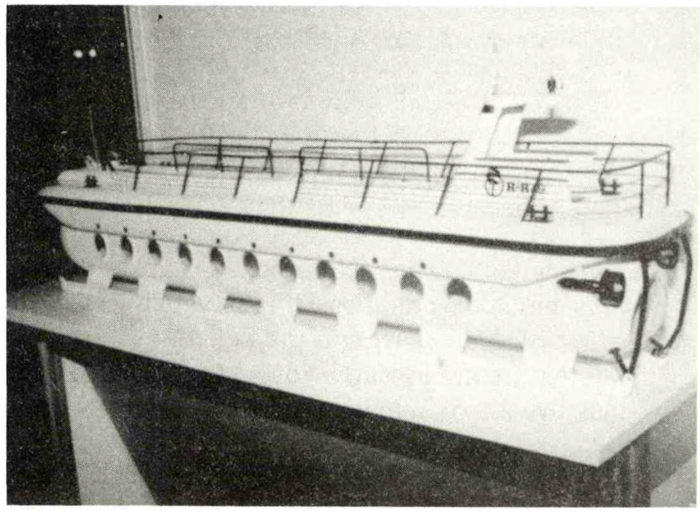

**Figure 5. Display Model of the
Malmari-Weinberg OY Tourist Submersible
RR Sub 49**

The purpose of this paper is not to discuss the technical details of the various classes of tourist submersibles, but to discuss their operational safety and in particular what is happening in the United States with respect to tourist submersible safety.

There have been some 15 tourist submersibles in operation on a worldwide basis (11 large, 4 small). Several of these are operational in U.S. waters where the U.S. Coast Guard has legal responsibility for maritime safety.

Under Title 46 of the U.S. Code, 46 CFR Subchapter T covers the U.S. Coast Guard mandate to regulate and control the design and operation of ships under 100 gross tons carrying more than 6 passengers for hire. Most of the current tourist submersibles currently operating fit into this category even though it was not specifically intended for submersible craft.

If the craft is larger than 100 gross tons its regulation falls under 46 CFR Subchapter H for passenger ships. If less than 6 passengers are carried for hire the craft falls under 46 CFR Subchapter C for uninspected vessels.

While the U.S. Coast Guard has a legal responsibility to regulate tourist submersible activity in U.S. waters, it also has the desire to see that this regulation is carried out in a timely, sensible and cost effective fashion.

Since the various subchapters of the U.S. Code do not specifically cover tourist submersibles, the Coast Guard has initiated work in various marine safety sectors to define the specific hazards that may impact on tourist submersible designated operations.

During 1988 a Tourist Submersible Safety Project was initiated by the Coast Guard with the Department of Transportation (DOT), Transportation System Center in Cambridge, Mass. This project has five major activities:

1. Define and document the constraints of a Tourist submersible System, i.e., "System Definition."
2. Generate a "Preliminary Hazard Analysis."
3. Generate a set of most likely "Hazard Scenarios."
4. Generate a set of "Fault Free Analyses" for specific hazards.
5. Document this work in a "Final Report" to be delivered to the U.S. Coast Guard in early 1989 (March/April).

Several of these documents can be seen in their report form in Figure 6.

In addition to this 1988 Transportation Systems Center work, the U.S. Coast Guard has in 1989 tasked the Marine Board of the National Research Council to establish a Tourist Submersible Safety Review Committee.

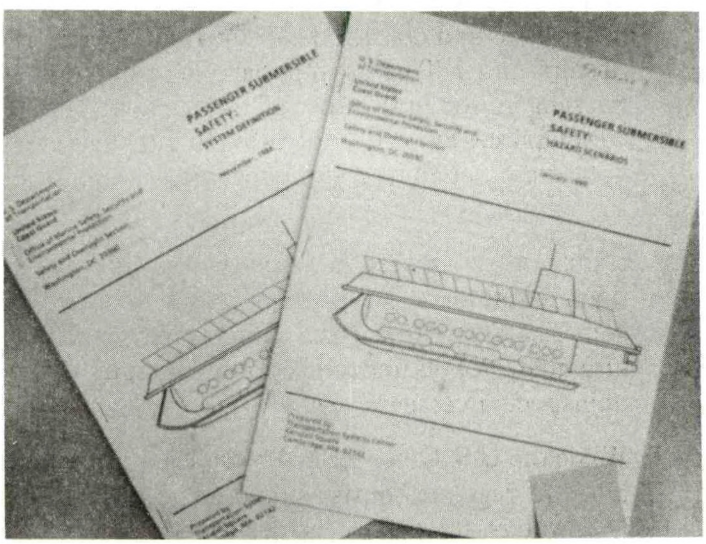

Figure 6. DOT Transportation Systems Center Tourist Submersible Safety Documents

The focus of this committee will be to analyze and review the operational safety of tourist submersibles. This activity will be accomplished through a series of working meetings on site at tourist submersible operations and through discussion with experts in the various fields relating to tourist submersible operations and safety.

The output of the Marine Board's committee will be a report to the Coast Guard making specific safety improvement recommendations.

The builders and operators of tourist submersibles also have a very real mutual responsibility and interest in the safety of their product. The responsibility stems from the need to produce a safe product for use by the public. The interest is a financial one for if the product is safe and the industry grows there is money to be made. If, however, one tourist submersible has a significant accident — say entrapment below, the near instantaneous worldwide publicity will be harmful to the entire business and all of the builders and operators will feel the impact of reduced acceptance by the public. The news media, newspapers, radio and television react with such enthusiasm to a life threatening accident (i.e., entrapment) that worldwide notification and minute by minute follow of rescue events will ensure that "the public" knows what is happening and its outcome be it good or bad.

In an effort to further look into the various aspects of Tourist Submersible Safety, the SNAME OC-6 Submersible Panel (J. Pritzlaff, Chairman) and the MTS Undersea Vehicle Committee (R. Cook, Chairman) have joined forces to explore what role can be played by the volunteer expert members of these two technical societies.

One approach that is currently being pursued is to hold a small Technical Workshop with attendees from tourist submersible builders, owners, and operators. The workshop would focus on what policy, procedure and safety resources the various industrial attendees would be willing to share with each other such that the overall safety of their operation would be improved for everyone.

It maybe that one operational group has a particularly good pilot training program that they would be willing to share with their counterparts. One or more builders may have a good inspection program or a maintenance procedure that could be modified by the various groups to fit their specific operation and thus possibly improve the safety of the entire industry.

In this safety context what is good for one is good for all and if anything bad happens to one it is bad for all. Thus, it is to the industry's mutual advantage to work together in this safety arena.

The SNAME/MTS safety workshop initiative was documented in two small (approximately $10K each) proposals submitted to SNAME and to the U.S. Coast Guard for joint funding of the expected travel and living expenses associated with an industry/technical society tourist submersible safety workshop to be held in sometime in late 1989 or early 1990.

It is hoped that the workshop can identify industrial safety resources that can be made available to the Coast Guard and the Marine Board such that any Tourist Submersible Safety recommendations generated can be implement or acted upon in a timely fashion.

If workshop funding is not available from SNAME or the U.S.C.G. due to budgetary limitations, the SNAME/MTS workshop initiative will be carried forth to the various international ship classification societies and to the industry itself.

As a follow on to the U.S. Coast Guard initiative, the Marine Board Committee recommendations and an Industry SNAME/MTS Workshop, it is felt that generation of a set of "Operational Safety Guidelines" for use by the industry and regulatory/classification/insurance groups would be a worthwhile and important contribution to be made by the technical societies. To this end the SNAME Submersible Panel and the MTS Undersea Vehicle Committee are committed to an ongoing safety activity in the tourist submersible area.

It is felt that continuing dialog with the builders, owners, operators, and regulatory/classification groups will be desirable and that a series of Working Safety meetings should be held throughout the 1990 and 1991 time frame. These meetings might be held in conjunction with other ocean related activities or might be stand alone meetings depending on the time, place, interest and need for such activity.

As stated earlier, with respect to safety what is good for one (builder, owner, operator, U.S. Coast Guard, and the Ship Classification Societies) is good for all, i.e., the worldwide public who will use, enjoy, and benefit from a first hand excursion to the undersea wonders of our water plant.

DEEP UNDERWATER MUON AND NEUTRINO DETECTION STATUS AND PLANS

Howard R. Talkington

Naval Ocean Systems Center

with
excerpts from
University of Hawaii DUMAND Office
DUMAND II Proposal

Introduction

DUMAND, the acronym for deep underwater muon and neutrino detection, is a project started by a group of U.S. physicists to produce a detector large enough to detect a significant rate of very high-energy natural neutrinos. This project will permit the study of elementary particle interactions in cosmic rays at energies beyond those available from contemplated future particle accelerators. It may also allow the observation of extraterrestrial and possibly extragalactic sources of neutrinos.

For elementary particle research, the energies sought—10^{14} eV (100,000 billion electron volts) and above—are necessary to probe the structure of particles on the minutest possible scale and to test our presently emerging picture of the fundamental forces of nature. A very large detector is also necessary to make high-energy neutrino astronomy a reality, because of the background of terrestrial neutrinos made by cosmic-ray protons in the earth's atmosphere. At very high energies, the flux from beyond the earth will surely dominate. If the sources that we believe exist do produce an observable flux of extraterrestrial neutrinos, we shall have begun a new field of science and opened a new window upon the universe.

The techniques available for detecting high-energy neutrino collisions in the ocean utilize either the light flash that the particles produce (Čerenkov radiation) or the acoustic pulse they emit (by instantaneously heating a tiny volume of water). The ocean is simultaneously our target detection medium and our shield from external disturbances. The ultimate detector configuration, at 4.8 km depth, may consist of a volumetric array of 22,680 sensors evenly placed on a three-dimensional grid at spacings of about 40 m (130 ft). This detector configuration is presently envisioned as a group of vertical strings of sensors, anchored to the bottom and kept in near-vertical orientation by high tension provided by excess buoyancy at the top of each string. Initially, primary detection will be concentrated on the optical signals, and the sensors optimized for the optical phenomena. The initial array to be installed beginning in 1991 will consist of 216 optical modules, 9 laser calibrators, and 9 environmental sensor packages.

The placing of large numbers of optical sensors in calibrated positions near the sea floor in depths to 4.8 km, with the connecting instrumentation cabling, and the 40-km long cable run to the shore station, is a major ocean engineering challenge of the 1990's; and is of direct vital interest to the engineers and scientists of the UJNR Marine Facilities Panel. During the development of the DUMAND detector system, the engineering of many portions will require using the "cutting edge" of technology. The following items will be heavily technology-dependent:

- Fiber optic and power undersea cables
- Underwater connectors
- Optical and acoustic sensors
- Precise position monitoring
- In-situ signal processing
- Power supplies and distribution
- Pressure-tolerant electronics
- Lightweight structural frameworks
- Special materials
- Special anchoring

In addition, procedures must be validated for deploying very large arrays in deep water; large quantities of data will be processed in situ to reduce bandwidth for cable economies; unmanned vehicle expertise for inspection and repair of sensors and cabling systems in deep water will be developed; and, finally, procedures must be developed for installing and maintaining deep-sea cables and investigating structural response in long, undersea sensor strings.

The first stage of the DUMAND project has been completed, culminating in successful operations of a Short Prototype String (SPS) of detectors operating at depths to 4000 m. The project is now ready to proceed to the development, installation and long-term operation of an array of multiple strings of optical detectors.

DUMAND Stage I Operating Results

To test our concept and design of components for the future DUMAND project, the Short Prototype String (SPS) experiment was carried out in the Pacific Ocean about 35 km west of the island of Hawaii, during November 1987. The primary purpose of this experiment was to develop the prototype components and then to demonstrate the feasibility of detecting muons in the deep ocean. Seven Čerenkov light detector modules, two calibration light source modules, one environmental sensor module with a sensor unit, two hydrophones, and a String Bottom Controller (SBC) were used for the experiment. The detector modules were attached to the string on a 5.1-m spacing; the whole string stretched about 50 m vertically. Figure 1 shows the actual configuration of the SPS detectors as deployed from the Naval Ocean Systems Center (NOSC) SSP *Kaimalino*. This Small Waterplane Area Twin Hull (SWATH) type craft proved ideal for this type of deployment due to its ultra stability in medium sea states.

The modules and the SBC were deployed from a ship using an electro-optical cable of 7.9 mm diameter. We used a data-taking scheme as close to the real DUMAND scheme as possible. Namely, all the data coming from the modules are sent to the SBC, digitized and multiplexed there, and then sent up to the ship through an optical fiber cable at 50 Mbaud. The data were decoded, processed, and recorded on magnetic tapes onboard the ship. The electric power for all the components was sent from the ship through the cable with a sea water power return. The whole system was controlled from the ship through a 300-baud, slow speed communication link superimposed on the power line.

The data were taken at depths from 2000 m to 4000 m in steps of 500 m. In total, we gathered data for more than 35 hours in real observation time and acquired 1.2 million triggers of cosmic ray muon data, as summarized in Table 1. Along with these data, we obtained much information on the environment of the deep ocean, including the attenuation length of light in the deep ocean.

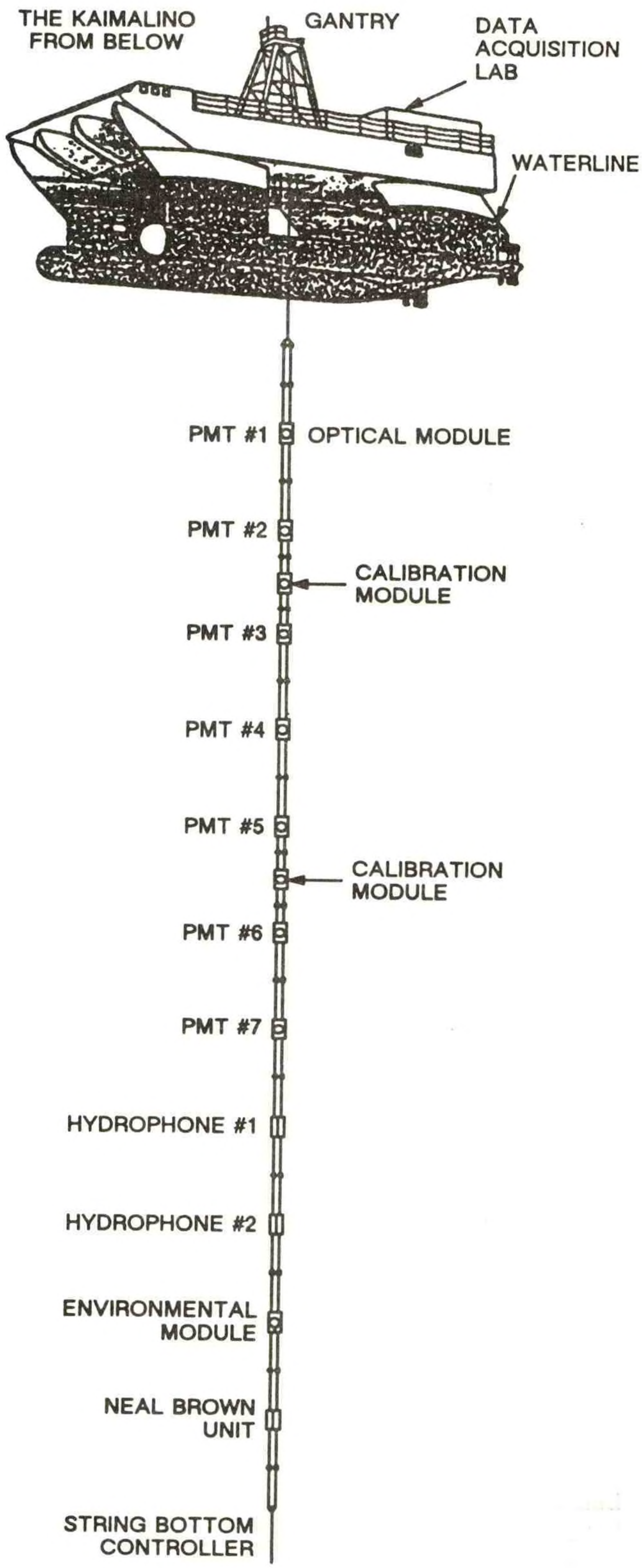

Figure 1: Layout of the short-prototype string, deployed from the SSP Kaimalino.

Table 1. Observing time of the SPS string, at different depths and space conditions.

Depth (m)	# of OMs	Total # Triggers (k)	Total observing time (hr:min)
2000	5	106	5:00
2000	7	26	1:28
2500	7	103	4:31
3000	6	249	5:53
3500	7	277	4:10
4000	7	451	14:10

DUMAND II

DUMAND II is a project to build a deep underwater laboratory for the study of various areas including

- high energy neutrino astrophysics, principally the detection of galactic and extragalactic point sources of TeV neutrinos;
- particle physics, via indirect observations of Ultra High Energy (UHE) hadronic interactions in astrophysical objects as well as more direct observations of terrestrial interactions;
- cosmic ray physics, mostly relating to muon and primary composition studies; and, incidentally,
- geophysics and ocean science.

The second stage of the DUMAND project is a 20,000 m^2 effective area, deep ocean neutrino detection laboratory. We use the term laboratory to emphasize that we are not proposing a single purpose experiment, but the construction of a facility to initiate research in a new domain, that of High Energy Neutrino Astrophysics. The international DUMAND collaboration, from the USA, Japan, and Europe, plans that this first long term deep ocean emplanted array be constructed and deployed over a period of 3 years, at a cost of about $9M, with the beginning of regular neutrino astrophysics observations in the early 1990's.

The international DUMAND collaboration consists of the following people: P. Bosetti - Technische Hochschule Aachen, West Germany; P.K.F. Grieder - University of Bern, Switzerland; B. Barish and J. Elliott - California Institute of Technology, USA; J. Babson, R. Becher-Szendy, J.G. Learned, S. Matsuno, D. O'Connor, A. Roberts, V.J. Stenger, V.Z. Peterson, and G. Wilkins - University of Hawaii, USA; O.C. Allkofer, P. Koske, M. Preischl, and J. Rathlev - University of Kiel, West Germany; T. Kitamura - Kinki University, Japan; H. Bradner - Scripps Institute of Oceanography, USA; K. Mitsui, Y. Ohashi, and A. Okada - Institute of Cosmic Ray Research, University of Tokyo, Japan; J. Clem, C.E. Roos, and M. Webster of Vanderbilt University, USA; U. Camerini, M. Jaworski, R. March, and R. Morse - University of Wisconsin, USA.

The proposed location, size, and configuration for the laboratory have been chosen after extensive analysis and experimentation as the simplest and least expensive technique which can do unique and important high energy neutrino physics and astrophysics. In addition, it will have a significant capability in high energy cosmic ray physics and ocean science. The design is intentionally flexible, and can be expanded as the science warrants, with the long range goal of achieving an array of $\sim$1 km^3.

The site proposed for the array is almost directly west of Keahole Point on the island of Hawaii, in a subsidence basin, the "Kahoolawe Deep," at a depth of 4.8 km, 35 km from shore. The array cables will emerge from the ocean directly at the Natural Energy Laboratory of Hawaii (NELH), a State of Hawaii facility at Keahole Point. The DUMAND shore lab will be located at NELH, which already has adequate power and lab space. The Keahole Airport, which serves the nearby Kona resort area, is a short distance away on the same point of land. Nearby is Kawaihae Harbor, with full container facilities. The location is ideal, shielded from the prevailing winds by the island, with very moderate swells and little currents. The site has been extensively explored over the last decade, and has been found to be adequate to our needs (water quality actually better than first expectations). Early concerns about biofouling and bioluminescence have been investigated and we have found that neither presents a serious problem.

The overall concept of the experiment is illustrated in Figure 2. A schematic view of the proposed array is pictured in Figures 3 and 4. Its main properties are summarized in Table 2. Basically, the proposed design consists of 9 vertical strings, each with 24 photomultiplier detectors spaced 10 m apart along the string vertically for 230 m, and with the strings spaced 40 m apart horizontally in an octagonal configuration. This gives a total of 216 detectors and a neutrino-induced muon detection solid angle area of 148,000 m^{2}sr and contained mass of 1.8 megatons.

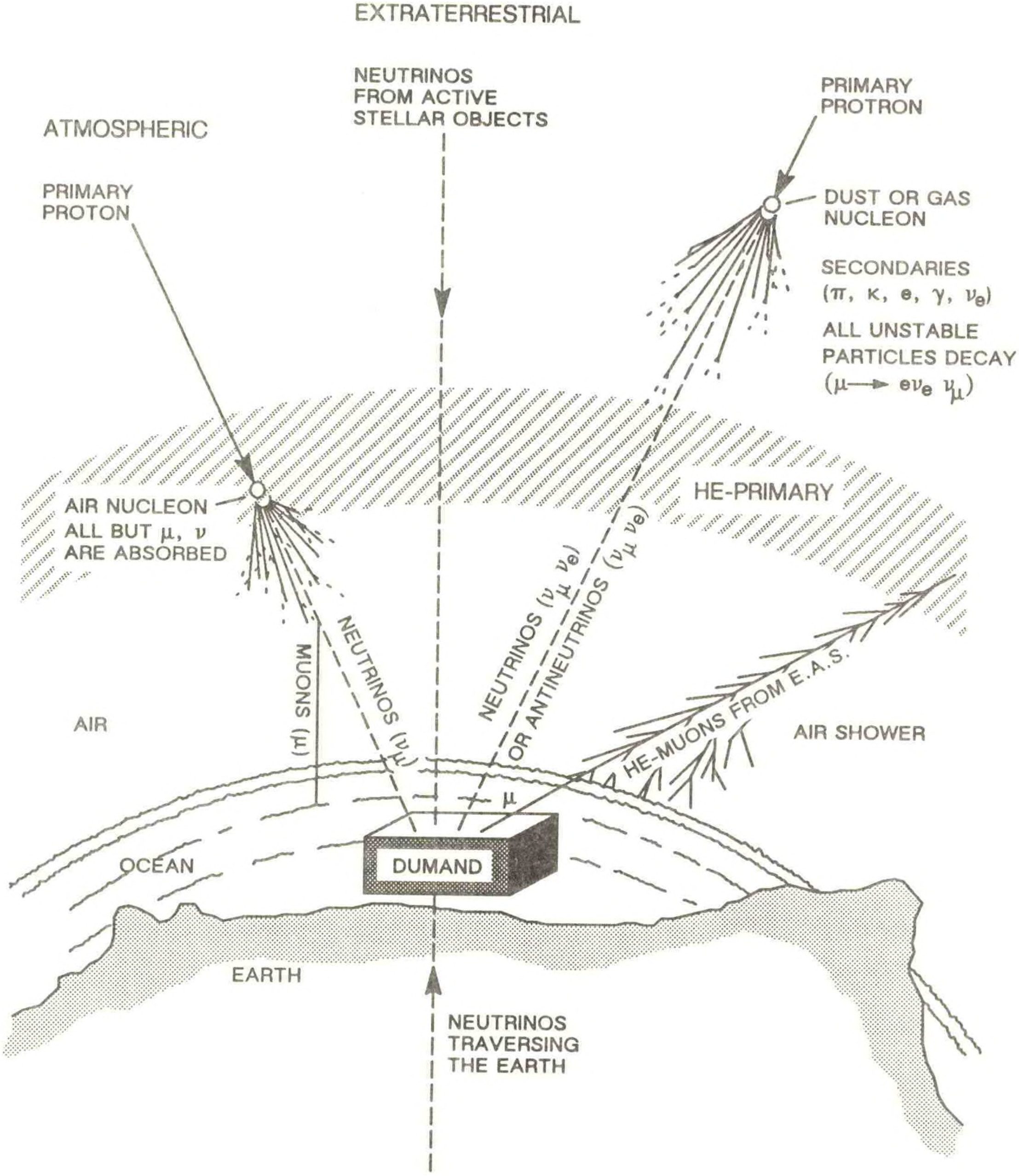

Figure 2: DUMAND experiment concept. Cosmic ray protons (or other nuclei) of very high energy strike matter, either in the earth's atmosphere or elsewhere in the cosmos. The resulting hadronic secondaries decay into neutrinos which penetrate to the DUMAND array and are detected. Down-going muons produced in the atmosphere with energy greater than ~ 3 TeV can also be detected and analyzed.

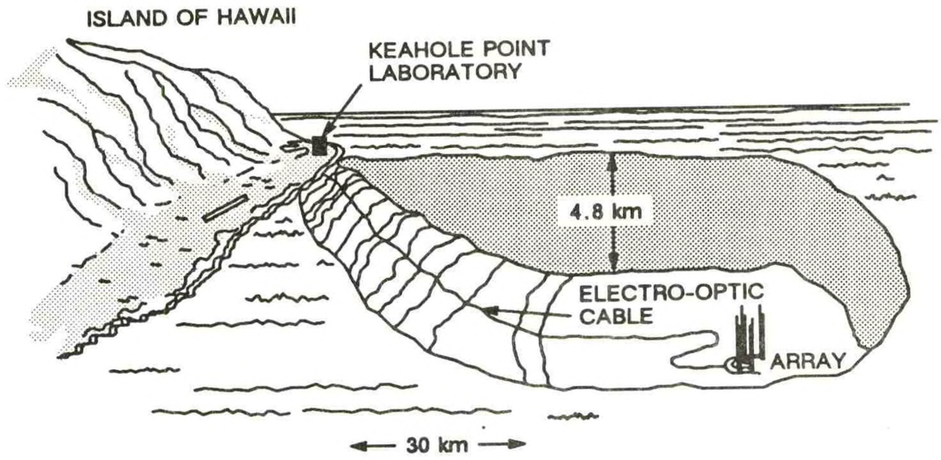

Figure 3: Disposition of the DUMAND detector at 4.8 km depth in subsidence basin ~ 35 km off Keahole Point, island of Hawaii. Armored cables carrying power and fiber-optics communication connect DUMAND to the shore station.

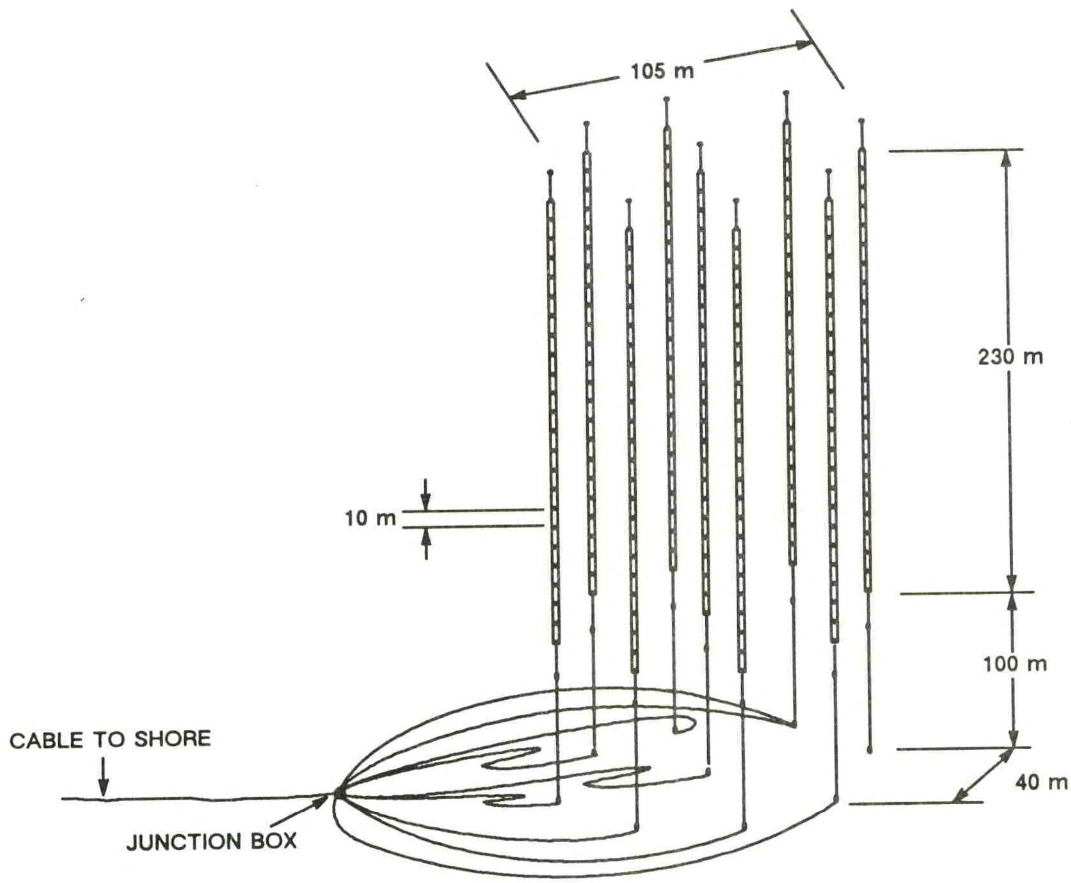

Figure 4: The DUMAND Octogon Array. There are 9 strings, each anchored at the bottom, and held taut by a float. They are spaced 40 m apart on the perimeter, with a ninth in the center. Along each string are 24 detector modues spaced 10 m apart. The strings are independent – they are connected at the bottom.

Table 2. Summary of the physical characteristics of the array.

Property	Characteristic
Array dimensions	100 m diameter × 230 m high
String spacing	40 m side
Number of strings in array	8 in octagon, 1 in center
Sensor spacing along strings	10 m
Number of optical sensors/string	24
Total number of optical sensors	9 × 24 = 216
Height of first sensor above bottom	100 m
Depth of bottom	4.8 km
Sensor pressure envelope	17-inch (43.2 cm) O.D. glass sphere
Optical sensor	16-inch photomultiplier
Volume of array, contained	$1.8 \times 10^6 m^3$
Target area for through-going muons	23,000 m^2 horizontal, 7,850 m^2 vertical up-going, 25,500 m^2 downgoing
Effective target volume for 2 TeV muons	$1.0 \times 10^8 m^3$
Effective target volume for 1 TeV cascades	$7.0 \times 10^5 m^3$
Muon energy threshold	20 to 50 GeV
Track reconstruction accuracy	0.5° - 1.0°
Cascade detection threshold	~1 TeV
Downgoing muon rate	3/minute
Atmospheric neutrino rate for throughgoing muons	3500/yr
Atmospheric neutrino rate for contained events above 1 TeV	50/yr
Point source sensitivity	4 to $7 \times 10^{-10} cm^{-2} sec^{-1}$ in a year above 1 TeV
Contained event sensitivity	$1 \times 10^{-8} cm^{-1} sec^{-1}$ in a year above 1 TeV

The array design being proposed has been optimized for the detection of high-energy muons from neutrino interactions. Calculations indicate that this gives us the best opportunity for detecting extraterrestrial neutrino sources. The detector spacings, 40 m horizontally and 10 m vertically, ensure that muons with energy ≥50 GeV which pass through from outside, will be detected with high efficiency and reconstructed in direction with better than 1-degree accuracy. (The original neutrino direction will be within this error for neutrino energies above about 1 TeV. Moreover, the relatively flat spectrum sources observed in VHE and UHE gamma rays imply mean observed neutrino interaction energies greater than 1 TeV.) Further, the chosen dimensions allow a significant effective detector volume to be achieved with a modest number of photomultiplier tubes, and thus to have a useful event rate and adequate sensitivity to detect extraterrestrial sources at their expected flux level. A closer spacing—of the order of a few meters—would have been appropriate had we wished to optimize for the detection and reconstruction of lower energy hadronic and electromagnetic cascades. However, future expansion could easily incorporate strings with smaller detector spacing.

No present or planned underground detector is large enough to have a good chance of seeing high energy extraterrestrial neutrino sources. The second stage of DUMAND will be about two orders of magnitude more sensitive than previous detectors underground.

Basic to the DUMAND system is the light detector modules. We have developed a Čerenkov light detector module for deep underwater use. We converged on a module design which was successfully used in the Short Prototype String (SPS) experiment. The module employs a 15-inch (382-mm) hemispherical photo multiplier tube (PMT) as a Čerenkov light detector, which is enclosed in a 17-inch (432-mm) Benthos pressure housing along with special electronic circuitry. The module has been satisfactorily tested in the ocean down to 4000 m depth.

The cross-sectional view of the detector module used for the SPS experiment is shown in Figure 5. All circuit elements are located on a two-tier mount consisting of two annular circuit boards around the neck of the PMT. DC-DC converting power supplies which generate ± 5 V and ± 15 V from the +48 V input are on separate boards attached to the periphery of the larger circuit board. The output pulse of the module is sent through the optical feed-through shown at the right hand side in the figure. The power for the module is supplied along with a communication line and a ground line through the electrical feed-through shown at the left hand side of the figure.

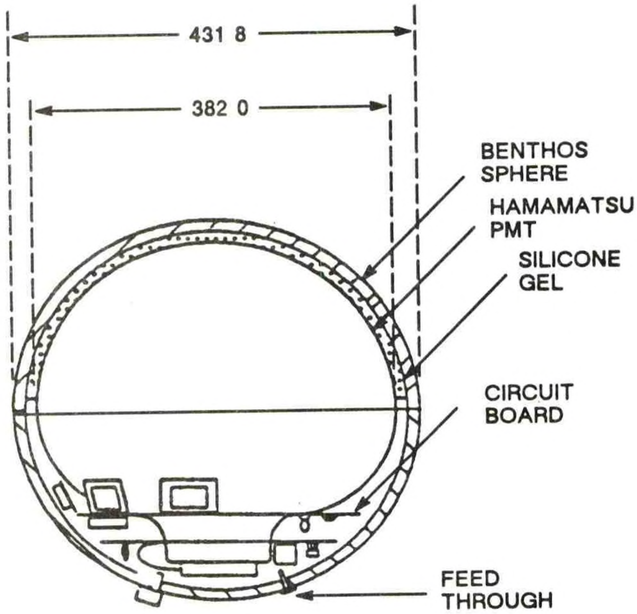

Figure 5: Cross-sectional view of the DUMAND optical module.

The basic tasks of the detector module are listed here:

1. Detect Čerenkov light generated by a muon in the water.
2. Convert the Čerenkov light signal to a semi-digital pulse to be sent through the fiber optic cable.
3. Monitor the counting rate, and supress output during periods of high bioluminescence.
4. Respond to control and monitoring commands from outside via a communication link.

Conclusion

This project should be of particular interest to the group of engineers and scientists of the UJNR Marine Facilities Panel. We are all involved, in one way or another, with marine facilities. This array is to be deployed in the mid-Pacific area, and operated by a collaboration including many USA and Japanese scientists. The design, development, test and installation is a tremendous challenge to the undersea engineers. Following the development and deployment of the Stage II DUMAND array will be a most interesting exercise for us, and many of us will be called on to assist as consultants, applying our knowledge and experience in the field of deep ocean engineering and marine facilities.

Status and Trends in Autonomous Underwater Vehicles (AUV) Research and Development in the U.S.A.

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Busby Associates, Arlington, Virginia

Joseph R. Vadus
National Oceanic and Atmospheric Administration
Rockville, Maryland

1.0 INTRODUCTION

Over the last 20 years, the trend in undersea vehicles has progressed from manned submersibles to Remotely Operated Vehicles (ROVs) to Autonomous Underwater Vehicles (AUVs). In essence, the progression has been toward minimizing the need of man's physical presence and intervention underwater. A self-contained, preprogrammed, decision-making AUV, independent of external control, is the objective of that trend, in that man is in the loop only to initiate or launch the mission, and at the end to collect the results. In some cases, there may be some intermediate actions such as transmitting the data while the system is underway, or accepting signals for a mid-course redirection.

Though technology is advancing toward unmanned, untethered, preprogrammed underwater vehicles, it is important to state that both manned and unmanned vehicles will be needed and used in the future, depending on the specific application or mission.

Another AUV vehicle concept being considered is Multiple Autonomous Underwater Vehicles (MAUVs), where one vehicle emanates from the mother vehicle to perform an assisting function such as closeup or "shadow-effect" lighting. Also, mother-daughter systems, enabling an AUV to egress from the mother vehicle or submarine to perform special functions not possible by the larger mother vehicle, have great promise for the future. One example of a mother-daughter vehicle is the ALVIN submersible and JASON JR. (ROV) demonstrated during the TITANIC exploration. Instead of an ROV, an AUV might be used to avoid a long tether or one that may become fouled.

AUVs with subsea robotics capability provide a great challenge and opportunity for automating many of the present underwater vehicle applications, such as: resource survey and assessment, seafloor sampling, object recovery, bottom survey and mapping, environmental monitoring, inspection, maintenance, and basic underwater work functions. Operations in deep water, under ice and for long endurance are possible with AUVs. Future AUVs will require advances in such areas as: high resolution, 3D imaging systems; computer aided vision systems; artificial intelligence/knowledge-based computer systems; satellite-subsurface acoustic-laser telemetry systems; highly dextrous, autonomous, two or three arm munipulator systems to duplicate man's manipulative skills; and especially lightweight, high-energy and high-density power sources.

2.0 R&D BACKGROUND

At present, there are some 36 different U.S. organizations conducting research and/or development projects pertaining to underwater vehicles. Twenty-six of these projects reported activities concerned with AUVs. The main source of funding for this AUV R&D is the Department of Defense (mainly Navy and DARPA), who are responsible for funding 18 of the 26 AUV-reported projects and account for probably 90% or more of the total funds.

The first reported AUVs were developed over two decades ago (in 1963) by the Applied Physics Laboratory of the University of Washington. These were the SPURV vehicles, and for nearly 15 years they were the only representatives of this class. Although a few Navy activities were involved from time to time, it was not until the mid-1980s before development began in earnest.

In 1988, The Defense Advance Research Agency (DARPA) initiated a project with the Draper Laboratory for two AUVs (DARPA prefers the term Unmanned Underwater Vehicle, or UUV) at a total cost of $23 million. Also in 1988, DARPA initiated a project at Martin Marietta for $14.8 million to develop intelligence for the UUVs to conduct certain tasks without human intervention. In June 1989, DARPA announced another solicitation, entitled "Prototype Development of a Mine Avoidance Unmanned Undersea Vehicle, Capable of Autonomously Detecting Mine-Like Objects."

Non-DOD efforts account for less than about $500,000 per year. Military and Civil oriented programs are described below. Chronological development of AUVs worldwide is presented in Table 1.

3.0 AUV RESEARCH PROGRAMS

3.1 GOVERNMENT-MILITARY

DAVID TAYLOR RESEARCH CENTER (DTRC)

Through the Naval Systems Research and Development Center (NSRDC), one of its laboratories, DTRC is conducting R&D efforts in two major areas: hull technologies and propulsion and auxiliary machinery technologies.

DEFENSE ADVANCED RESEARCH PROJECT AGENCY (DARPA)

A brief description of the two DARPA-funded projects mentioned in "R&D Background" follows.

The Draper Laboratory Effort

The UUV shape will be that of a submarine. The physical characteristics of the vehicles are consistent with the low drag needed for minimum propulsion power. The UUV will weigh 6,800 kg in air. Operational goals include: a maximum speed of 10 knots; acceleration from 0 to 10 knots in 44 seconds; depth control within +/- 1m at speeds greater than 3 knots; and navigational accuracy about 0.2 nautical miles per hour. A silver-zinc battery will provide power and will comprise about one-third of the vehicle's weight, about 2,300 kg.

The Martin Marietta Effort

All aspects of this project are classified. The overall objective is to assess capabilities and limitations of AUVs. Some of the tasks being considered include planting submarine detection sensors on the seafloor, surveying and mapping minefields, towing hydrophone arrays and serving as long-range weapons platforms.

OFFICE OF NAVAL RESEARCH (ONR)

Through the Naval Research Laboratory (NRL), ONR is funding development of several AUV capabilities, including long-range navigation and fuel-cell power sources.

The objective is to develop a technique that will provide accurate navigational capabilities beyond 100 nautical miles from a starting point.

The goal of the fuel-cell program is to develop a power source for a small, unmanned observation vehicle (UOV). It will use proton exchange membrane technology. The researchers hope to develop a fuel cell (an oxidizer and fuel) that will not exceed the same space that is now taken up by silver-zinc batteries.

OFFICE OF NAVAL TECHNOLOGY (ONT)

In 1987, ONT funded Texas A&M University via the Naval System Warfare Center (NSWC) for AUV research and development. The current work is directed at controllers for AUVs. Applications for these AUVs are classified.

NAVAL OCEAN SYSTEMS CENTER

The Naval Ocean Systems Center (NOSC), San Diego, California, has been a pioneer in the field of Remotely Operated Vehicles since the early 1960s with development of the CURV, and is involved with AUVs. AUV activity began in the early 1980s with development of the Advanced Unmanned Search System (AUSS) for operation to 6,000 meters' depth.

In May 1989, NOSC announced that the AUSS will be going back to sea in 1990 after it is refurbished and upgraded. The vehicle was originally developed as a search and survey vehicle. Future improvements to AUSS have not yet been revealed.

Another recently developed AUV at NOSC is the Free Swimming Mine Neutralization Vehicle (FSMNV). A new processor has been developed, and a planned executive/control system and a cable detection/tracking system have been demonstrated.

3.2 GOVERNMENT-CIVIL

NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION (NOAA)

Sea Grant Office

The Sea Grant Office funded the Massachusetts Institute of Technology to develop a lightweight, low-cost autonomous vehicle. The vehicle, called SEA SQUIRT, is intended to be a platform for testing artificial intelligence algorithms. No communications link between the submersible and the operator is provided beyond an acoustic recall signal. A layered control approach to artificial intelligence is used to give the vehicle the ability to respond to unanticipated circumstances and environments. The vehicle will be capable of operating in previously uncharted areas, avoiding danger and investigating interesting phenomena in a controlled, adaptive manner.

NATIONAL SCIENCE FOUNDATION

University of New Hampshire

This research project pertains to the design of real-time, expert systems for autonomous vehicles. This involves developing methods for interaction between tasks that are represented symbolically and numerically and are running concurrently. Means to quantify symbolic processes, including measurement of system performance, are being investigated. This project will also assess some of the problems in utilizing knowledge-based systems in real-time operations. Since AUVs can operate a great distance away, human intervention adds another level of complexity to be considered.

Florida Atlantic University and Carnegie-Mellon University

This joint research program pertains to development of an underwater, three-dimensional vision system for intelligent autonomous underwater vehicles. Algorithms will be developed to process signals from a multiple element sonar array to generate a grid representation of the ocean bottom terrain, and the development of map building algorithms to generate a coherent map of the terrain. The goal of this research is to develop the capability to produce a high-level, three-dimensional world model image required to support underwater surveying and sensor-based navigation.

Woods Hole Oceanographic Institution

This project involves the design and construction of an unmanned, untethered vehicle for performing and servicing long-term, deep ocean benthic experiments. This vehicle, called the AUTONOMOUS BENTHIC EXPLORER, can be launched from any oceanographic research ship and will remain on site for several months. During this period it will periodically move about in its acoustic navigation net, taking photos and making a variety of scientific measurements. At the end of its mission, it can be recovered on command by an available ship.

3.3 INDUSTRIAL ACTIVITIES

BOEING AEROSPACE

A long-endurance underwater power system has been under development since 1985. The objective is to develop a power system capable of providing at least 1,000 kilowatt-hours of energy and capable of operating continuously for more than 10 days.

ELTECH RESEARCH CORPORATION

ELTECH has developed an aluminum air fuel cell--an electrochemical device that continuously converts the chemical energy of aluminum and oxygen into electrical energy. Electricity is generated by the dissolution of the aluminum anode into the caustic electrolyte and by the reduction of oxygen. The oxygen can be provided by air or other oxygen sources such as hydrogen peroxide, sodium chlorate, cryogenic or compressed gas. The fuel cell is said to be "mechanicallly rechargeable" in that it is restored to full charge by replacement of the aluminum plates, removal of the discharge product (alumina) and addition of water.

The energy yield of the aluminum air cell is 200 to 300 kilowatt-hours per pound (including the oxygen supply). The oxygen efficiency is reported as twice that of a hydrogen/oxygen fuel cell. Currently, silver-zinc batteries provide about 100 kilowatt-hours per pound.

WESTINGHOUSE ELECTRIC CORPORATION RESEARCH & DEVELOPMENT DIVISION

a) Silver-Iron Batteries for Submersibles

A silver-iron battery has been developed for use in special applications where high-energy, high-density systems are required. Research to improve utilization of the silver and iron active materials has resulted in volumetric and gravimetric energy densities similar to those of the commonly used silver-zinc battery.

b) Laminar Flow Drag Reduction for UUVs

The Oceanic Division of Westinghouse, Annapolis, Maryland, has been examining various mechanisms for extending laminar flow on underwater vehicles. One aspect of the project is to examine the savings in the vehicle's stored energy source brought about by vehicle drag reduction. Reductions in propulsion resulting from increasing drag reduction are said to range from as much as 50% to 90%.

MARTIN MARIETTA AERO & NAVAL SYSTEMS

a) Flight Testing of a Sliding Mode Control Autopilot for an Unmanned Underwater Vehicle

Martin Marietta is investigating the design of a UUV flight-control system. This research includes in-water testing of a nonlinear control technique known as sliding mode control (SMC). A UUV test bed developed at Martin Marietta is used. SMC is designed to provide a theoretical framework for the design of controllers that are robust and are able to adapt to varying payloads.

b) Intelligent Waypoint Transiting in Complex AUV Environs

Martin Marietta has developed an approach for planning and executing waypoint transiting in a complex and dynamic ocean scene. Missions anticipated for an AUV will require the vehicle to arrive at specified points at designated times, and the execution of various activities at certain times or places, or under certain conditions. To accomplish such behaviors, the high-level controller will pilot the AUV through potentially complex and uncharted obstacle fields and terrain features. In the course of traversing an area, the high-level controller will be able to "learn" its environment for future use, should it be required to retraverse the same area.

HONEYWELL, INC., SYSTEMS & RESEARCH CENTER

This project pertains to AUVs with complex capabilities and intelligent software for multi-mission capabilities. As a result, programming an AUV for a particular mission promises to be an increasingly formidable task, even as it increasingly needs to be programmable in the field by operational personnel, not computer scientists. This project involves the development of a three-level approach consisting of: 1) onshore development of operational tactics: 2)predeployment programming by operational specifications, and 3) real-time, dynamic determination of the current situation and appropriate response within the desired operational constraints.

HUGHES AIRCRAFT COMPANY, GROUND SYSTEMS GROUP

This program involves a multi-year effort encompassing all aspects of Unmanned Underwater Vehicle (UUV) technology. The emphasis of the program is to develop a real-time system with intelligent planning. The design includes an intelligent planning function that is programmed within a map system. A graphic human interface facilitates operator entry and allows quick examination of mission progress. The required intelligent behavior has been demonstrated using a simulator.

3.4 ACADEMIC INSTITUTIONS

CARNEGIE-MELLON UNIVERSITY

According to the investigators, the main task of perception for autonomous underwater vehicles is to build a representation of the observed environment in order to carry out a mission. Terrain modeling, the geometry of the environment observed by the vehicle's sensors, is crucial for autonomous underwater exploration. The objective of the research is to analyze the components of the terrain modeling task, to investigate the algorithms and representation for this task, and to evaluate them in the context of real applications.

CALIFORNIA STATE UNIVERSITY /FULLERTON

The development of fully Autonomous Underwater Vehicles (AUVs) for deep ocean scientific and commercial applications is being investigated. The main goal is the design of feedback-control systems for AUVs for automatic depth and attitude control.

The emphasis in this research is focused on the derivation of a stochastic dynamic model of the AUV and a performance index which weights the tradeoffs between errors in vehicle trajectory and expenditure of control effort to correct these errors.

WOODS HOLE OCEANOGRAPHIC INSTITUTION-ADVANCED ENGINEERING LABORATORY

A new system for communication with untethered underwater vehicles is being developed. The system is centered around sophisticated digital signal-processing units which perform signal coding, waveform generation, FFT demodulation, adaptive equalization and date decoding.

The objective is to develop a powerful and flexible architecture for underwater acoustic communication and other functions such as vehicle control and video data compression.

4.0 REFLECTIONS/DIRECTIONS

Underwater vehicle technology is advancing toward AUVs on a worldwide scale. This paper describes some of the AUV related R&D in the U.S.A. and doesn't pretend to include it all. As with early manned submersible and ROV development, the Department of Defense provides the major funding for AUV development. As civil needs develop and economic advantages prevail, more R&D will be undertaken by the private sector.

Though this paper focuses on U.S. activities, it is important to note that there is substantial foreign R&D under way, as noted in Table 1. For example, it is reported that Japan has budgeted approximately $43 million for AUV technology. In Europe, there are several joint R&D efforts under the EUREKA initiative, with budgets totaling about $60 million over the next five years for AUV and advanced ROV technology.

This paper was not able to cover each of the critical technologies and make projections on future needs. However, based on the present status and trends, it is the authors' perception that some of the research priorities that are important for the future advancement of AUV technology include:

• Compact, lightweight, high-energy and high-density power sources for reliable, long-endurance operation

• Accurate long-range navigation and precise positioning at target location

• Fusion of sensors for 3D environmental modeling and scene perception for positioning and manipulation

• Automated task planning for task execution and adaptiveness

• Compact, high-capacity computers and parallel processing for the interaction of functions responding to sensory numerical data and knowledge-based systems; storage capacity for acquired data.

• Application of knowledge-based systems in real-time operations.

Lastly, and eventually most important, will be: the reliability of the system; the probability of mission success; and the economic factors to achieve cost-effectiveness for multi-user acceptability.

TABLE 1. AUV CHRONOLOGICAL DEVELOPMENT

YEAR	VEHICLE	PURPOSE	DEPTH (M)	DEVELOPER
1963	SPURV 1	Water Measurements	6000	Applied Physics Lab. U. of Washington
1972	UARS	Under-ice Mapping	457	Applied Physics Lab. U. of Washington
1973	SPURV 2	Water Measurements	6000	Applied Physics Lab. U. of Washington
1975	SKAT	Ocean Research	NA	Inst. of Oceanology Moscow, USSR
1979	EAVE EAST	Testbed	914	Mar. Sys. Eng. Lab. U. of New Hampshire
1979	EAVE WEST	Testbed	610	Naval Ocn. Sys. Ctr. San Diego, CA
1979	RUMIC	Mine Countermeasures	NA	Naval Coastal Sys. Ctr Panama City, FL
1980	PINGUIN A1	Search	200	MBB GmbH Bremen, West Germany
1980	CSTV	Submarine Control Tests	NA	Naval Coastal Sys. Ctr Panama City, FL
1982	ROVER	Structure Inspection	100	Heriot-Watt Univ. Edinburgh, Scotland
1982	ROBOT II	Bottom Survey	91	Mass. Inst. of Tech. Cambridge, MA

1982	B-1	Drag Characteristic Studies	90	Naval Underwater Sys. Ctr., Newport, R.I.
1983	TELEMINE	Vessel Destruction	150	Teksea Lugano, Switzerland
1983	TM 308	Sturcture Inspection	400	Techomare, S.p.A. Venice, Italy
1983	AUSS	Search	6000	Naval Ocean Sys. Ctr. San Diego, CA
1983	EPAULARD	Bottom Photography/Topography	6000	IFREMER Paris, France
1984	ARCS	Under-ice Mapping	400	ISE, Ltd. Port Moody, BC Canada
1986	ELIT	Structure Inspection	1000	IFREMER/COMEX France
1986	(No Name)	Feasibility	NA	Simard Subsea A/S Horten, Norway
1987	LSV	Submarine Testing	NA	Naval Coastal Sys. Ctr. Panama City, FL
1988	XP-21	Testbed	610	Applied Remote Tech. San Diego, CA
1988	MUST	Testbed	610	Martin Marietta Baltimore, MD
1988	SEA SQUIRT	Testbed	61	MTI Sea Grant Cambridge, MA

1988	RUV	Krill Research	250	U. of Washington Seattle, WA
1989	UUV (I)	Testbed	NA	Draper Laboratory Cambridge, MA
1989	FSMNV	Mine Neutral- ization	NA	Naval Ocn Sys. Ctr. San Diego, CA
1990	UUV (II)	Testbed	NA	Draper Laboratory Cambridge, MA
1991	AROV	Search and Map- ping	NA	SUTEC Linkoping, Sweden
1992	MINE AVOID- ANCE AUV	Mine Counter- measures	NA	Not yet selected
1993	ARUS	Bottom Survey	NA	EUREKA (European Consortium)
1992	DOGGIE	Bottom/Sub-Bot- tom Surveys	6000	Yard Ltd. Glasgow, Scotland
1992	DOLPHIN	Temp./Sal./Depth Monitoring for 30 day periods	6000	Yard Ltd. Glasgow, Scotland

Coastal Ocean Space Utilization

Public Water Reclamation Act
and
Coastal Development in Japan

by
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Introduction

Japan is a country of islands. Most of the densely populated islands have only limited plane land but hills and mountains. From ancient time, people sought new farm land and new town space by filling or draining the surrounding sea. That was as though old-time American sought frontier at West.

Legend tells about creation of the land by a couple of Gods. It explains that the Gods created the first island of Japan by means of somewhat dredge and fill manner in the sea. Later, other Gods continued efforts to expand the land by various means including towing scattered islands together into a larger consolidated land mass.

After medieval age, efforts to reclaim the land from the sea to expand farm lands and towns were accelerated. Most part of the downtown areas in Osaka and Tokyo were all filled land out of the sea in the period of the latest five centuries.

Public Water Reclamation Act of 1920

Even after establishment of modern legal system in the late 19 century, the land development at the sea by filling and drainage were widely encouraged.

The Public Water Reclamation Act of 1920 determined legal procedures of the land reclamation by filling or draining of the Public Water such as the sea or the lakes.

Applications for a reclamation were approved as long as the applications were not conflicting with other public interests such as flood control and irrigation systems, navigation and other national development plan and activities. If the applied site was within the harbor limit, the application was examined whether it would not disturb existing and the future port activities and plans.

The grant or license for reclamation was issued by the central government. In practice, however, the actual control was delegated to the hands of prefecture governors who exercise the power on behalf of the Minister of Interior.

One of the important differences of the legal system for the coastal management between Japan and U.S.A. is that the land at shore, beach and sea bed or wet land, and water area are, in principle, is not permitted to establish private ownership on them. They are considered to be public assets. While the immediate water front land and beach belong to the National Treasury, the sea bed and the water belong to the Nation but not treated as ordinary property. They are treated as if they are air or water. Which means the Public Water is the common asset for the people and nobody can claim its exclusive right until it is filled or drained to a dry land.

Therefore, the Act defines the reclamation of the Public Water as transfer of the sea into the land and a public asset into a private property. The applicant can acquire the land title only when the reclamation has finished and the land emerged from the sea either by filling or draining.

Buoys, pontoons piers on piles and other structures, which permit free water under the structure, are considered to be structures rather than reclaimed land. Applications for such construction or installation are permitted, in case of within a port limit, by the port authority. Permission of the Coast Guard, in view of navigation safety, is also required regardless of its location (inside or outside of a harbor). Other relevant governmental authorities' approvals, e.g., laws related to beach erosion control, natural park, building code etc., are also needed, if applicable.

Rapid expansion of the reclaimed land

Since 1960's, large scale industrial development and farm land reclamation became active. During the period of 1945 to 1985, the total area of 127,000 hectare of sea was reclaimed. Enclosed sea as Tokyo Bay, Osaka Bay and Setonaikai (Inland Sea) had relatively shallow and calm water. Reclamation works at such water could be done at relatively low cost; which resulted in concentration of large scale reclamation for industry sites to such waters. Most of the industry site developments were made within the port limits (during 1945 to 1985 approximately 57,000 hectare of land was built in the port limits).

Large scale reclamation activities during 1960's caused reduction of shallow water area and increase of discharge from the industries, thus resulted in deterioration of the water quality and other environment conditions at the closed sea areas.

In 1973 the Government changed policy on reclamation from promotion in principle to 180 degree direction toward strict restriction.

Public Water Reclamation Act of 1973

According to the revised Public Water Reclamation Act of 1973, reclamation for mere acquisition of land is not permitted. The applicant of reclamation must submit concrete plan of the land use for himself upon its completion.

If the application is approved, the applicant, other than public organization, cannot change its land use or cannot sell the land or right of the reclamation to others within the period of 10 years after the completion of the reclamation.

In order to obtain approval of reclamation, environment assessment is required in addition to the previous required conditions. The environment assessment should include not only impact analysis on the surrounding water and oceanographic environment but also the impact of the proposed industry and other facilities, including air, noise, discharge of water and traffic etc..

The result of the assessment must be submitted to the competent authority and the document must be exhibited to the public in the office for a specific period. Whoever has an objection to the application, he can present his point to the authority. If necessary, public hearing will be held.

The application for a reclamation containing environment assessment are examined at the immediate competent authority. The application for more than certain magnitude of reclamation, however, must be circulated to all the related authorities and ministries and be examined from every aspects.

Competence for approval of reclamation belongs, if it is within a port limit, to the Minister of Transport, if it is within a fishing port, to the Minister of Agriculture Forestry and Fishery, and other areas belong to the Minister of Construction. The Minister of Environment, however, is in the position to check and give his opinion on its environment impact of above certain scale of reclamation.

Reclamation of the sea by filling as well as installation of piers, other structures at the sea are also examined from the view point of navigation safety. Approval by the Coast Guard is also required regardless to its jurisdiction for reclamation approval.

Reclamation of the sea within the area of Setonaikai and a part of Osaka Bay is relatively restricted by the Setonaikai Environment Control Act of 1973. Within this area, reclamation is normally not permitted unless it has less environment effects and/or it will contribute to the protection or improvement of the environment.

Reclamation of water at enclosed sea as Tokyo Bay, and Ise Bay are not so strictly restricted as at Setonaikai. However, the total environment limit for specific location are given and which restrict additional discharge or emission of pollutant to the environment by the new reclamation or activities on the newly reclaimed land.

Application for reclamation must give sufficient proof indicating that the new reclamation will not cause any excess or saturation of such environment limit to the area. For example, if the applied site has NOx gas density to near its limit, additional NOx gas generated from the new reclaimed land should not exceed the total ceiling value of NOx whatever it is originated.

Dumping of dredged materials and wastes

Dumping of oil, chemical and other waste materials into the sea is strictly controlled according to the Marine Pollution Control Act. Dredged materials from navigation channel and harbor may not be dumped in the sea freely, unless permission is obtained from the Coast Guard and agreed by the fishing right holders. Some areas are also restricted for dumping by the Minister of Environment. Soil and waste with certain category can only be dumped at the designated area along the coastal water.

Nature of the most of dredged materials are harmless and permitted to dump at the sea at the designated area. Most of the cases, however, the hauling distance to the dumping site from the dredging site is prohibitively long and uneconomical for transportation. Therefore, dumping of dredged material is not normally made to outside of the harbor as other countries' practice but most of the cases are only to dump at the dike enclosed water area which eventually become a filled land. Muddy suspension in the water caused by dredging often become a source of trouble.

In order to prevent dispersion of muddy water, silt protectors are often used either around the filling site or around the dredger. Overflow dredging operation by a trailing suction dredger is getting difficult in ordinary cases.

Wastes generated from cities are prohibited to dump into the sea except for at the designated area. Usually dumping of wastes at the designated area is not practiced because of its hauling distance. Accordingly, dumping at the land or filling in reclamation sites is almost only solution for the final stage of wastes treatment. Most part of city wastes are debris or excavated earth related with construction works. They seldom contain harmful materials as heavy metals, P.C.B. etc.. Some waste materials, which can be incinerated, are incinerated at city plants and ash are sent to the reclamation areas. Inflammable wastes such as metals and glass are recycled as much as possible. Other inflamable wastes as plastic or some flammable wastes which overflowed from the incinerator plant due to insufficient capacity are also dumped at reclamation sites.

Water areas near big cities as Tokyo Bay and Osaka Bay have now less reclamation works for industrial development or wharf construction. Instead, more filling works as waste disposal sites are increasing. Even in the Port of Tokyo, some 2,500 hectare of reclamation was made during '61 to '85 and these fillings include approximately

110,000,000 cubic meter of excavated soil from building sites and other city wastes.

Dumping of these city wastes at the land will become more and more difficult in the future. Therefor, local governments and port authorities along the Bay coast jointly negotiate to create joint dumping sites at reclaimed lands. At Osaka Bay, a plan called "Phoenix Plan" started in 1986 to build reclamation sites to receive city wastes from surrounding cities.

At Tokyo Bay, Haneda Airport expansion project also receives a large quantity of city wastes besides the reclamation sites in the Port of Tokyo. A total volume of city wastes of 27,000,000 cubic meter will be dumped at Haneda Airport. And with these materials some 800 hectare airport space and related land will be created.

Even if the primary purpose of the reclamation is waste disposal or wharf construction, procedure for environment assessment is same as other's and must be cleared before beginning of the construction works. If any harmful substances are contained in the disposed materials and potential hazard by seepage of such substance from the filled sites are anticipated, the dikes or bulkheads for the reclamation and, if necessary, the bottom of the sea bed, must be made as impermeable in order to prevent such materials dispersion into the environment.

Typical example of such reclamation is in the Port of Minamata. The sea bed of Minamata harbor was polluted by mercury contaminated discharge water from a chemical plant located at the vicinity of the harbor. Most of such poisonous water discharged from the factory during 1940's. Many people customarily fed by fishes from this harbor were died with poisoning or damaged their health.

According to research works, removal of mercury contaminated silt at the sea bed would eliminate harmful effects to fauna in the area, and the fishes would again become edible. A part of the harbor basin with an area of 58 hectare was closed by dikes and 111,500,000 cubic meter of silt, which contained more than certain limit of mercury content, was dredged from the sea bed into the enclosed dikes. The filled area was covered by clean sand to make the site harmless. The filling work started from 1981 and will be completed in 1989. The filled land will be used as ferry terminals, water front garden etc..

The total cost spent for the reclamation work at Minamata was 48,500,000,000 yen. Thirty seven percent of the cost was funded equally from the central and local government. The remaining 63 percent was charged to Chisso Co., which was the primarily responsible party of this pollution. Because of this pollution, the factory had stopped previous plant and had changed its activities to harmless process. The company, however, had become near bankruptcy at the time but continuation of its activities had been rather encouraged in order to secure such compensation fund raising. The charged cost was permitted to repay in long term installment. The company also had to pay enormous amount of compensation and medical expenses to people who were died or damaged their health.

<u>Prospect of reclamation in Japan and coastal development</u>

Owing to change of the policy on reclamation from previous encouragement in principle to more environment conscious after 1973, reclamation of the land at the sea by a private speculator disappeared. At the same time development of heavy industry sites also declined thus the total inclement of reclaimed land in the country had greatly decreased.

In the mean time, construction of necessary infrastructures as ports and airports have been continuing such as Haneda airport expansion, New Kansai International Airport and Second Port Island at Kobe etc..

Lack of dumping sites of construction waste and earth and rise of the land price at major cities have added pressure to expand the land space by reclamation of the sea. Unit cost of the reclaimed land at Tokyo, for example, will be only one fiftieth to one tenth of the unit price of the land in the vicinity.

While improving environment of the sea, multipurpose reclamation plans have been made and discussed by the relevant authorities partly to respond to demand of the land and partly to receive wastes and earth.

Even though with such great demand for the land is existing, application for mere short term profit seeking reclamation as experienced in the past will no longer be approved. The Public Water Reclamation approval system requires adjustment of all kinds of interests including various planning, environment evaluation and public and private rights etc.. It also requires consultation among competent Ministries and other authorities. According to these guidelines, the competent Ministers evaluate and control all the applications for reclamations through local governors.

Water areas, where demand for reclamation are heavily concentrated, are vicinity of big cities. These places are generally designated as the port limit of major ports. Within the area of major ports, the competent Minister to approve reclamation is the Minister of Transport thus he has the largest power and responsibility in relation with present heavy demands for the reclaimed land.

Mooring of pontoons or other floating facilities in the sea is relatively easily approved compared with reclamation. Therefore, floating office or floating mariners have been built recently. Much larger scale floater is contemplated to create a floating city.

Floaters, piers and other intermediate type of structures are proposed and studied. Such structures are advantageous for deep water area or water area with very weak earth foundation. Unlike filled reclamation, these types would not disturb or obstruct water circulation and give less impact on the water environment.

Closed water areas such as Setonaikai, Tokyo Bay and Osaka Bay are already heavily utilized and not much rooms for further reclamation are left. Other than closed water areas, the sea around Japanese islands are rough open seas. Demand for the land in Japan is large and desire for calm water for aqua culture and marine recreation are strong.

Research for creation of offshore type artificial islands at open sea to create lands as well as calm water areas for multi purpose use are undergoing.

When the research will be completed, an artificial off-shore island will be created for super sonic aircraft as well as high speed land and water transport terminals. At the same time the water space behind the island will be effectively used for aqua culture center and marine recreation.

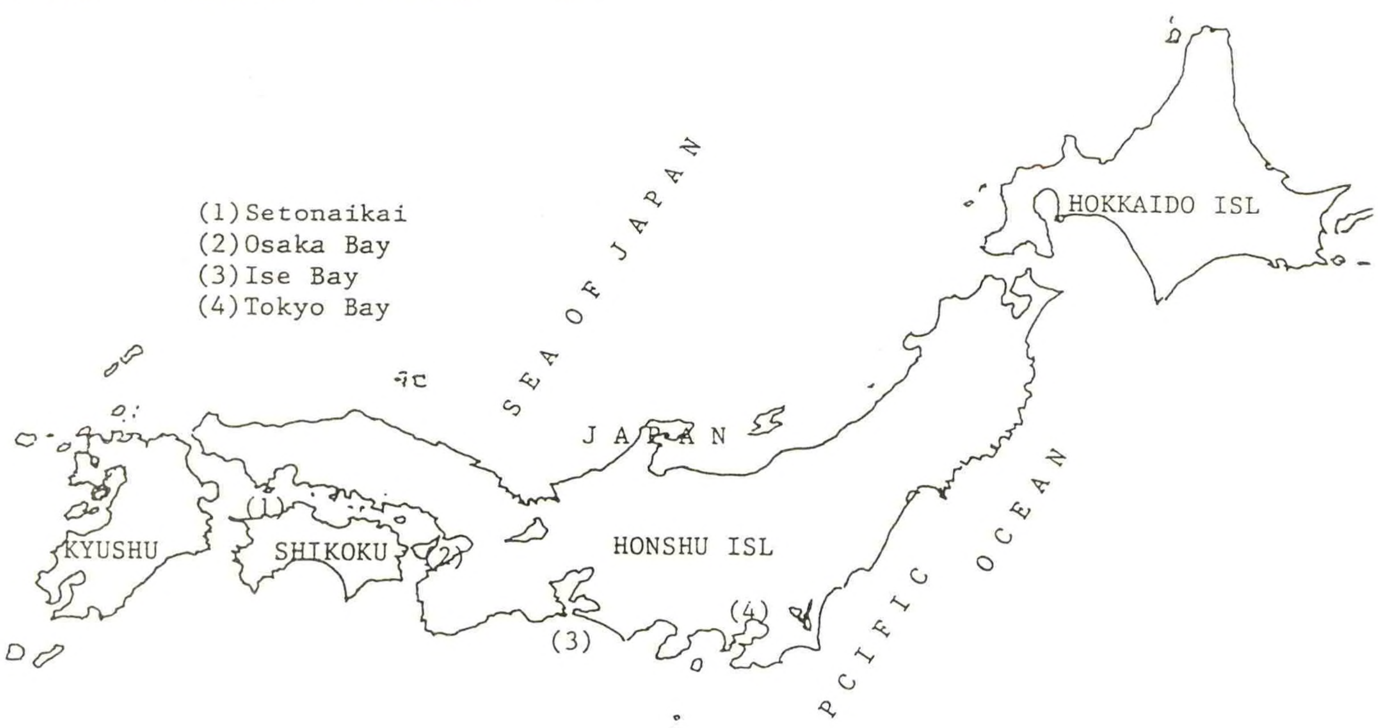

FIG. 1 ISLANDS OF JAPAN

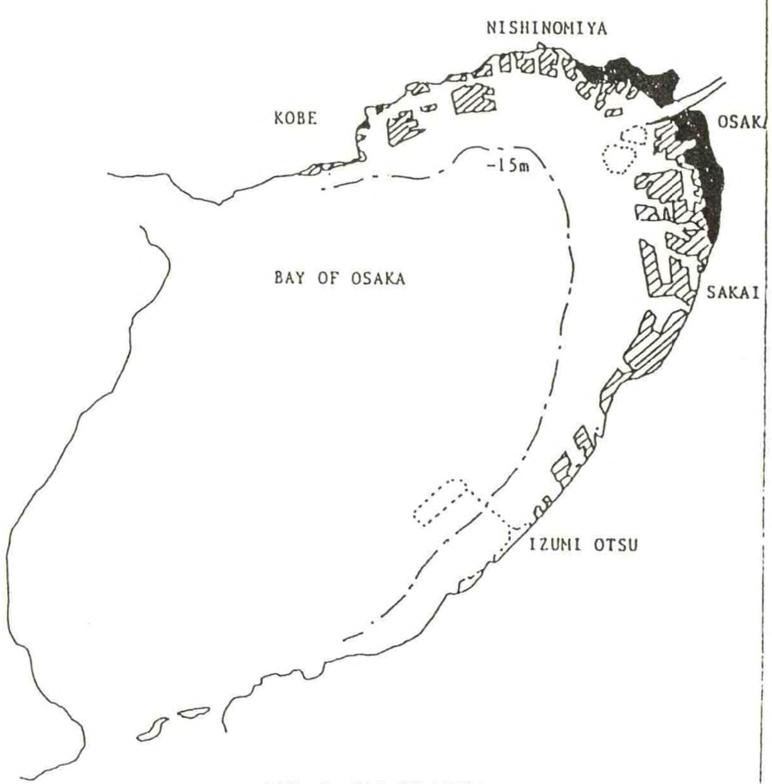

FIG. 3 BAY OF OSAKA

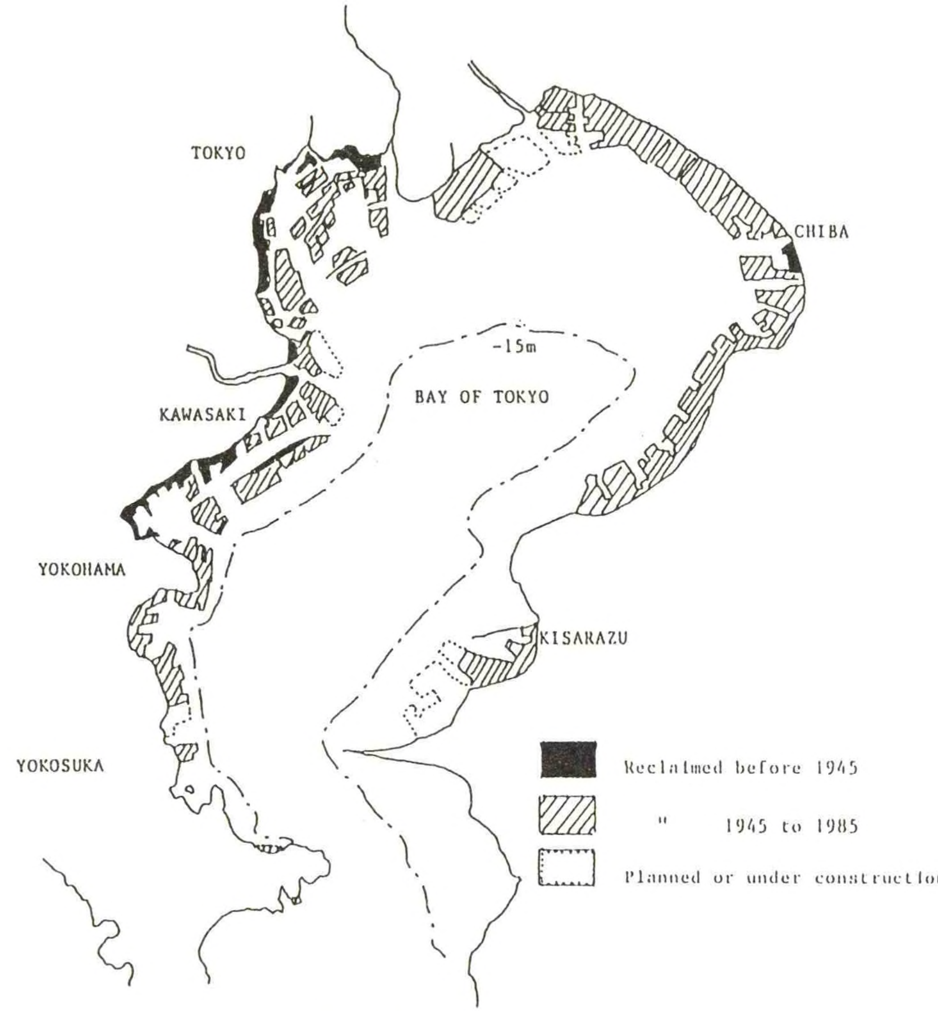

FIG. 2 BAY OF TOKYO

TREND OF WATERFRONT AREA DEVELOPMENT TECHNOLOGIES

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1. Change of Social Demands Connected with Waterfront

It may be said that Japan is at a turning point at present. The nucleus of the industries is changing from the heavy, thick, long and large type to the processing and assembling type, especially to advanced frontier technologies. The siting conditions of the industries have also been changing enormously. In the field of physical distribution, along with the change of the industrial structure, the growing ship sizes, the mechanization and automation of cargo handling, and the increasing import and export of high added value products have been brought about. They are bringing about large changes in the sizes and the forms of port facilities. The location of the central functions of physical distribution at ports is changing from the inner harbor to the outer harbor. Farthermore, the progress of urbanization and the advancement of the industrial structure are raising the living standards and increasing the leisure time. There changes are diversifying people's values and increasing the expectations for more comfortable and tasteful living. The Japanese society has caught up, with the advanced European and American countries and has entered the state of the qualitative improvement of social infrastructures. There are similar demands for the waterfront.

The demands for the waterfront have been diversified along with these social trends. Mary project have already appeared at various places. They have the following characteristic trends. There are many projects connected with recreations and resorts, represented by marinas. There also are mary projects for utilizing coastal and ocean spaces, represented by artificial islands and fishery promotion. Electric power plants are the main projects in the energy field, while roads having bridges and tunnels are the main projects in the transportation field at ports. New port and harbor improvement projects have also become necessary in order to cope with the changes of the import/export structure and the internationalization. A large variety of new technologies must be developed for promoting these projects smoothly.

The governmental, private and academic sectors must comprehensively promote the technological developments by assuming respective roles of each sector. Especially, there are large expectations for technological developments by the private sector. Therefore, we investigated the waterfront development technologies which the private sector owns or is developing. We selected those technologies, products and knowhows which will specially be utilized in the future. Here, waterfront technology is interpreted in its wide sense, namely, "all the software and hardware technology that is necessary for developing ports and coastal areas and the technology which enables to improve whole areas comprising ports and coastal areas."

The trends of technological developments for waterfront developments which were grasped on the basis of the results of the present survey will be described. Various measures which must be taken for directing technological developments adequately and for developing better technologies will be introduced.

2. Trends of Waterfront Development Technologies by Private Sector

2-1 System of Technologies

The waterfront development technologies were systematized on the basis of the result of the questionnaire survey. The result is shown in Figure 1. (Figure 1 gives the number of technology items of each minor category obtained by the questionnaire survey.)

2-2 Content of Individual Technologies

An evaluation value which was obtained by dividing the total number of technology items belonging to one major category by the number of minor categories belonging to the same major category was calculated. It was found that "technology for creating waterfront space" was the largest. "Technology for waterfront utilization" and "technology for waterfront maintenance and prevention" were disaster nearly the same. "Technology for project management of water front development" was the smallest.

Than, the medium categories were compared on the basin of similar evaluation values. It was found that "construction technology" is by for the largest. It was followed by "technology for ocean resource utilization" and "technology for traffics and physical distribution" and then, by "technology for ocean survey and forecasts" and "technology for leisure and resort." It may be considered that technological developments are relatively active in these fields. On the other hand, "knowhow and techniques for development planning" and "technology for information and communications" are not active.

Future technological development are expected in these fields. Finally, the minor categories were compared. It was founds that "construction materials" was the largest. It was followed by "land reclamation," "seawall and quay" "wave control structure," "technology for foundation," "floating structure" etc. The fields which are relatively inactive are "ocean energy utilization," technologies connected with beautification, such as "space design" and "green area improvement," technologies connected with leisure and resort, such as "construction and improvement of marina" and "facility layout planning" and "traffic flow planning."

The characteristics of individual technologies are summarized below.

(1) Technology for creating waterfront space

1) Technology for ocean survey and forecasts:

This category comprises the technologies of meteorological, hydrographic and terrestrial survey and environmental assessments. Generally, computerized systematization is in progress. Efforts and being made to increase the precision, to obtain real time information and to expand ranges.

2) Construction technology: (Construction materials" has the largest number (1,30) of technological developments. Regarding the wave control structure, there is active development of the technologies of the hybrid structure, the pile and block combination, the submerged structure, the membrane structures etc. Concerning construction methods, computerized construction management systems are being developed and applied for practical use. The technological developments connected with the utilization of

Major groups	Subgroups	Small classification (Items)	
I. Technology for creating water front space	1. Technology for ocean survey and forecast	1) Oceano-graphic survey	6
		2) Meteorological survey	3
		3) Topographical and geological survey	46
		4) Environmental assessment	20
	2. Construction technology	1) Wave control structure	62
		2) Seawall and quay	87
		3) Land reclamation	105
		4) Use of wastes for reclamation	21
		5) Floating structure	40
		6) Construction materials	130
		7) Construction craft	35
		8) Technology of foundation work	56
	3. Renovation technology	1) Repairing of structure	26
		2) Renovation of structure	11
		3) Preservation of historical facilities	1
	4. Landscape technology	1) Space designing	8
		2) Structure and facility design	12
		3) Green area improvement	7
		4) Water front improvement	8
		5) Space production	5
II. Technology for water front utilization	1. Technology for leisure and resort	1) Construction and improvement of marinas	6
		2) Marine facilities and equipment	20
		3) Marine leisure equipments and tools	7
		4) Construction and improvement of lodging facilities	
		5) Construction and improvement of commercial facilities	7
		6) Construction and improvement of related recreation facilities	12
	2. Technology for ocean resource utilization	1) Ocean energy utilization	7
		2) Cultivation and harvesting aquatic resources	37
	3. Technology for traffics and distribution	1) Construction and improvement of traffic and transportation facilities	55
		2) Development of traffic and transportation means	11
		3) Advancement of distribution	8
		4) Storage and custody	11
	4. Technology for information and communication	1) Construction and improvement of information and communication infrastructure	10
		2) Utilization of information on marine leisure	1
		3) Utilization of traffic and distribution information	2
III. Technology for water front management	1. Technology for structure and facility maintenance and management	1) Diagnosis and evaluation of soundness of structures	15
		2) Maintenance and management of structures and facilities	23
	2. Technology for preservation and control of environment	1) Purification and control of water quality	19
		2) Purification of sea-lottom sediment purification	10
		3) Sea surface cleaning	3
		4) Preservation and restoration	5
	3. Technology for safety and disaster prevention management	1) Countermeasures against high tide and waves	1
		2) Countermeasures against earthquakes	29
		3) Safety and disaster prevertion measures for ships	10
IV. Technology for project management for development	1. Knowhow and techniques for development planning	1) Facility layout planning	5
		2) Flow planning	1
		3) Scenario and production planning	1
	2. Knowhow and techniques for business operation system		12

Figure 1 System of Water Front Development Technologies

used hulls, PC pontoons, hybrid pontoons, new mooring methods and floating structures are actively being promoted.

3) Renovation technology: Concrete and steel repairing material are being developed for reproducing aged facilities. The static destruction technology for reinforced concrete structures and the cutting technology for underwater structures are being developed for renovating structures. For preserving historical structures, the investigation, diagnosis, designing and operation techniques are being developed.

4) Landscape technology: Scenery simulation systems and CAD systems are being developed. Artifical be aches and terrace blocks are being developed for constructing attractive water front having access to the water.

(2) Technology for waterfront utilization

1) Technology for leisure and resort: The technologies of various leisure facilities, such as marinas, machinery, submarine sight-seeing boats, cruisers, water coasters, underwater observatories and underwater promenades are being developed.

2) Technology for ocean resource utilization: Ocean energy utilization technologies, such as wave activated generatiŏn ocean thermal energy generation and tidal curreat generation are being developed. Artificial fishing reefs and artificial upwelling and many other technologies to be used for growing and catching fishery resources are being developed.

3) Technology of traffics and physical distribution: In the field of traffics, tunnel and bridge construction technologies, new traffic systems and high- speed boats and being developed. In the field of physical distribution, the development of distribution system which connects transportation, storage, cargo sorting and packing by a computer network should be notes.

4) Technology for information and communication: geographical information systems, communication system for leisure boat personal-computer communication system for use between ship and shore etc. are being developed.

(3) Technology for waterfront maintenance and disaster prevention

1) Technology for structure and facility maintenance and management: Equipment and systems to diagnose the soundness of structures are under development.

2) Technology for preservation and control of coastal environment: The technologies for purification of water and soil and for maintaining and recovering ecology are being developed.

3) Technology for safety and disaster prevention management: Measures to cope with liquefaction, antiressmic designing of buried pipelines and disaster information transmission systems etc. are being developed.

4) Technology for project management of waterfront developments Manly banks and trade companies indicated the knowhow of project coordinations, project execution methods, incomes expenditure.

2-3 Trends of Water Front Development Technology

(1) Characteristic Technological Development Fields

When the technologies obtained by the present questionnaire survey are studied in comparison with the port and coastal technologies accumulated in the part, some characteristics are found in the purposes and objects of technological developments or in the uses of technologies.

The first characteristic in that the technological development for relatively shallow see areas are active. It is true that the technologies connected with the construction and utilization of structures (artificial offing islands in deep sea areas and in the o offing and also being developed. However, the technologies in shallow sea areas are being developed and even those which seem to have been established are restudied from a new viewpoint.

For example, a breakwater is becoming not simply a structure for preventing waves, but also a structure for controlling wares to facilitate their use. Efforts are being made to design good-looking breakwaters. Sea walls are coming to be used and developed as multi-function and multi-purpose facilities.

The second characteristic in the technological development of material. Materials themselves are being developed. Technological innovation is in progress. Durable and anticorrosive materials or light and strong materials obtained by technological development and innovation are used as construction materials. By applying such materials to staircase-shaped blocks, structures that harmonize with-the surrounding landscape can be created. A new structural style can also be created through composite use of these materials The third characteristic is the development of maintenance and management technology. The aging of port and harbor facilities has been increasing the importance of the technology of maintaining facilities, the technology of repairing and renovating them and the technology of destroying them and constructing new ones. The construction technology for narrow and small places and the construction technology of decreasing the influences on the surrounding area are also being developed. The fourth feature of newly emerging technology is the variety of developments related to floating structure. The uses of floating structures were limited in the past and the fours of technological developments was m and by related to ships. It present, flouting structures of various sizes, from small ones to large ones (artificial floating island), and of various purposes are being developed. It with occupy an important position among the waterfront development technologies in the future.

(2) Directions of Technological Developments

In order to grasp the trends of technological developments in general on the basis of individual technologies, I attempted a cross sectional study by paging attention to the directions of the technology. The trends can be expressed generally with the following key words. 1) Systematization, 2) mechatronics, 3) multi-functions, 4) sofwrare, 5) hybrid, 6) sategrates engineering They are described hereinafter.

1) Systematization: Various steps are packaged into a system to increase the precision and to rationalize operations. The systems which are being developed include not only telecommunication systems and experimental date analysis systems, but also in integrated systems of surveys, tes data summary and analysis. Water front facility development system (integrated system from planning to construction). are also developed.

2) Mechatronics, Robots for underwater geological survey, dredger robot and mechatronic machines for forming rubble mound are being developed. Various technologies are being studied and developed to cope with the increasingly large water depth, large underground depths and large sizes of developments.

3) Multi-functions: Multi-function terrace sea walls and environmentally desirable sea alls are being developed in order to meet the diversification of social needs and the need for protecting and fostering natural environment. Multi purpose and multi function facilities are forming a new trend. For example, machinery using wave energy are attached to a breakwater.

4) Software: The technology of green area improvement and landscape design for improving amenity is actively developed. The technology of conceptual work for planning in also being developed though not in a large number.

5) Hybrid; Hybrid structures which are constructed with the materials developed in the petroleum, chemical and steel industries are actively being developed. The examples include hydrid caissons and hybrid floating structures which utilize the advantages of both steel and concrete. Not only composite materials, but also composite structures are being developed.

6) Integrated engineering: Different industries and different technologies are compounded. There is a tendency that various technologies are compounded or technologies are developed jointly by different industries. For example, technologies are developed jointly by a chemical enterprise and a contractor on the basis of the technologies accumulated by the clemical enterprise. Technological cooperation among industries will be promoted in the future.

3. Government Assistance for technological Developments by private Sector

For the smooth promotion of these technological developments by the private sector and by the development of higher technologies, the Ministry of Transport takes various governmental measures. They are briefly introduced hereinafter.

. Experimental sea area offering system: Field verification tests must be carried out in a real sea at the final stage of technological development. An enormous amount of data must be collected for selecting a place of experiment. This is not easy for the private sector. There is a problem of making coordinations with related organizations after a selection of a place. This system was started in the fiscal year of 1987 in order to solve these problems and to facilitate the selection of a place for experiment.

Evaluation system of Port and harbour technology developed by private sectors: The government adequately guides the development of port and harbor technology by private enterprises by announcing new technological development themes which are necessary for port and harbor improvements. The accomplishments are evaluated by governmental port and harbor engineers and university professors who have specialized knowledge and sufficient expersences. The assessment results are announced publicly in order to promote the smooth spread of outstanding technologies and to contribute to the construction of high-quality social infrastructures at ports and herbors.

. Joint development system of echnology: Previously, technological developments were led mainly by the Government. However, the technology of private enterprises have recently made great progress and numerous technological developments have been accomplished through the accumulation of field experiences. It is important to utilize active private sectors' ability for technological developments, Under this system, the Government and the private sector work jointly to utilize private sectors' abilities. The joint technological developments and researches conducted at Port and Harbor Research Institute, Ministry of Transport, are listed in Table 1.

. Various kinds of aid and loan system for private sector: For promoting the development of new port and harbor technologies, the Government mediates Japan Development Bank's low interest rate loan system for technologies promotion and Japan Shipbuilding Industry Loundation's aids.

4. Postseript

The forms of waterfront utilization are undergoing large clanges in Japan as the result of the changes of the industrial structure and social reeds. Many waterfront development projects, such as artificial offshore islands, resort facilities and port and harbor redevelopment, are appearing at various places throughout the country. New technologies are necessary for smoothly implementing these projects. The present survey of the technological developments by private enterprises leaves a strong impression that technological development have never been as active as now. It can be expected that the future developments will not be limited to the extention of the previous technology. It can be anticipated that new labor-saving, cost-saving and multi-function products and technologies will be developed on the basis of the technological innovation of electronic and new materials.

The measures which support private technological developments must be improved further and the linkage with fundamental researches and application researches being conducted at universities and governmental research institutes should be strengthened. We also feel the need to improve the onservative attitude toward the actual application of new technologies and to reform the awareness for adopting good technologies flexibly.

Table 1 Examples of Joint Technological Development and Researches (Port and Harbor Research Institute)

Name
Research on Semicircular Breakwater
Research on surf Zone Environment and Aquatic Ecology
Research on Development of Hybrid Wave Gauge
Research on Asserrment Method of Accumulated Ground Constructed with Improved Soil
Research on reliability Improvement of Rather Long Period Components of Strong Motion Seirmograph Recording
Research on Sea Water Resistance of Concrete
Research on Corrosion Prevention of Steel Pipe Piles
Research on Structures Using Fiber Materials for Tension
Research on Lift-up of Prestressed Concrete Pavement Plates
Research on Development of Seabed Roughness Meter
Research on Vibration Shape of Penetration Steel Plate Cells
Research on breaking Wave Force Response Characteristics of Pile Type Sea Berth

DEVELOPING INNOVATIVE LEISURE FACILITIES IN SHELTERED OCEAN AREAS

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1. Introduction

Observing Japan from a socioeconomic perspective reveals several prominent trends: the country is shifting toward an economically stable yet highly diverse society; the average age of the population is on the increase; and information access has greatly expanded. In particular, the industrial foundation of the country is accelerating in the direction of service industries, a post-industrialization phenomena. In response to these trends, plans for waterfront and harbor redevelopment have been proposed.

In this socioeconomic scenario, the prospect of increased leisure time and indeed, changing views toward leisure are imminent. This study will lay out a scheme for creating recreational facilities through developing marine environments—in unique projects tapping the resources of technology and nature. These recreational developments could take place in oceas sheltered behind artificial islands or break water.

2. Outline of The Study

Fig. 1 is a flow chart intended to illustrate the procedure used in researching this report. Although this study originally consisted of the following five projects, only two of them, namely (2) creating new types of marine recreation and (3) proposing a large-scale marine recreation base will be introduced here on account of the space available.

(1) Studying literature on the current situation in regards to development of facilities in sheltered waters, and the trend of marine recreation activities.

(2) Creating new marine recreation facilities based on natural sources of interest in the sea.

(3) Proposing a large-scale marine recreation project, based on plans for developing calm sea areas and establishing leisure facilities there.

(4) Outlining the design of facilities in a marine recreation complex.

(5) Clarifying the technological problems of realizing the scheme.

3. Possible new Forms of Marine Recreation

As will be mentioned in detail later, this study lays out a scheme to secure an extensive, sheltered coastal area facing the open sea and to create a novel marine recreation base in this zone. The various recreational activities available there could be completely unconventional and novel.

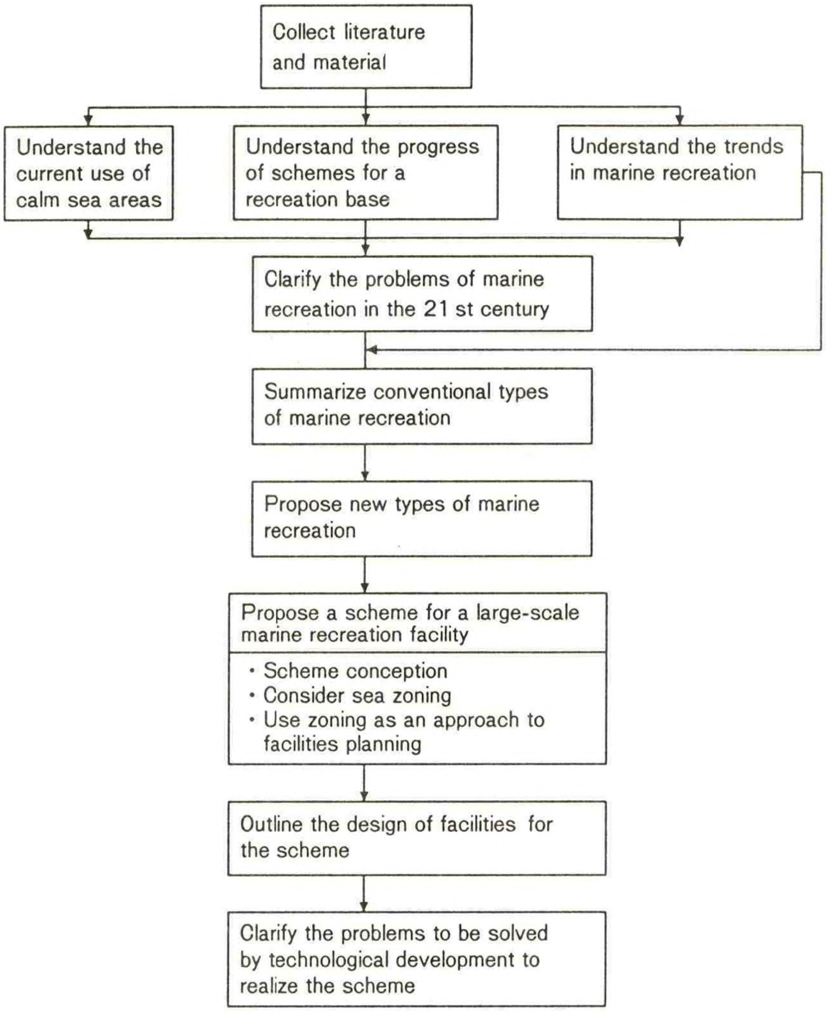
Harnessing natural phenomena of the sea (Table 1) could supply a means for creating new and imaginative marine recreational activities.

Some of the activities proposed in the following paragraphs are not necessarily feasible at this moment—in terms of technology and cost—but are rather potentially viable recreatinal alternatives for the near future.

Table 1 Characteristics of the Sea

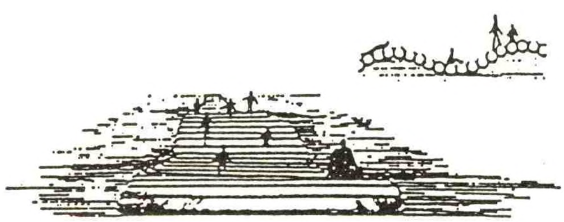
·Waves	(surge)
·Current	(tide, ebb and flow)
·Pressure	(water pressure, buoyancy)
·Sea water	(density)
·Space	(surface, underwater, seabed, topology of seabed)
·Oceanic life	
·Water quality	(transparency, luminous intensity, color)
·Others	(water temperature, wind darkness)

Fig. 1 Flow Chart of This Study



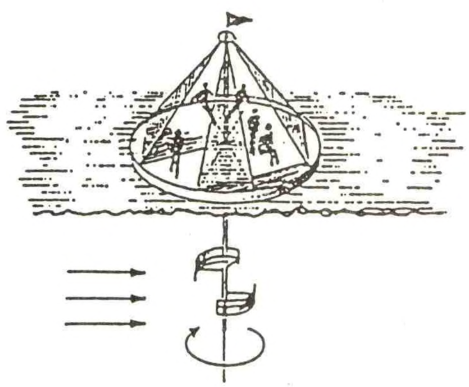
Floating promenade

A floating promenade could be constructed on the sea's surface. Designed so it would move with the waves, visitors would feel as if they were walking on a swinging suspension bridge. Visitors would also have the sensation of walking on the surface of water because the promenade would be slightly lower than the level of the sea.



Drifting Carousel

A circular floating-platform, with a vertical shaft at its center reaching deep below the water surface, would rotate as currents flowed past blades attached to the shaft.



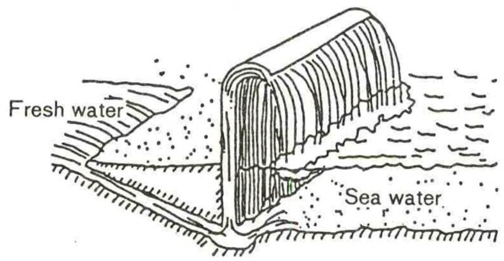
Underwater Promenade

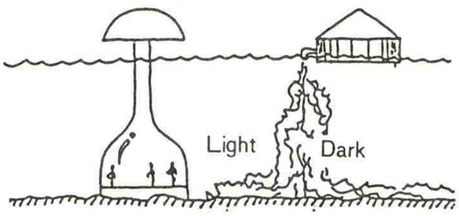
An underwater promenade could be constructed, exploiting the marvels of its submarine environement. For example, a suspension bridge could be built to cross a trench, and passages could be designed around coral beds and sea weed jungles.

Waterfall Device

Waterfalls could be generated by harnessing osmotic pressure differences between fresh and sea water.

A device could also be invented to make a colored sea waterfall by taking advantage of different concentrations of salt in the water.

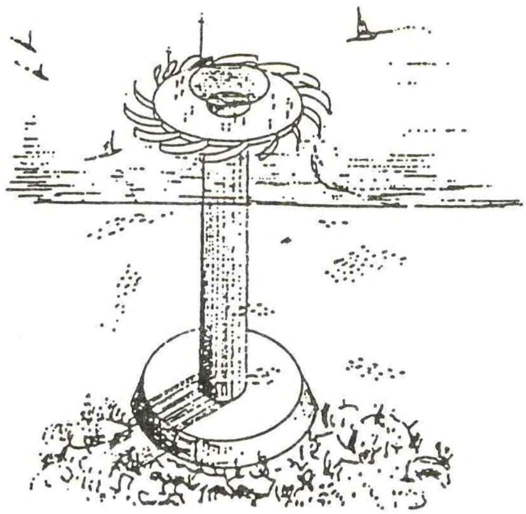




Revolving marina

Boats could depart from this marina absent of any influences from wind. Piers projecting from the marina could revolve to facilitate the departure and arrival of boats in ideal wind directions.

It would also be possible to build a club house and a boat shed on the sea rather than on land.



4. Scheme for a Large-Scale Marine Recreation Base

4.1. Fundamental Principle

The fundamental principle of this scheme is to secure a safe and comfortable sea area so that a marine recreation facility could be constructed which would permit extensive new-concept use of the sea. The unprecedented leisure site should be simultaneously relaxing and invigorating and contribute to overall well being.

(Main Points of the Scheme)

(1) The large-scale marine recreation center should be a place where people can participate in new leisure activities and, in doing so, enjoy personal development.

(2) The marine recreation base should create an environemnt that people are not afraid of, but one which is enriching enough to provide greater familiarity with the sea.

(3) The base's facilities for marine recreation activities should provide people with opportunities to refurbish their sense of humanity and vitality.
   (a) Sports: action-oriented recreation which keeps people young, lively and heathy should be encouraged.
   (b) Leisure: a place of play and relaxation should be created which encourages family communication and activities.
   (c) Resort: an environment independent of

everyday living should be created so that people may stay there to enhance their overall feeling of well being.

(4) A year-round marine recreation base can be created using new technologies.
   (a) There should be new types of recreational facilities involving use of natural phenomena of the sea—to encourage enjoyable and imaginative yearround recreation.
   (b) Various facilities to meet people's desires for knowledge and experinece should be built using the most advanced technologies.

4.2 Prerequisites for lay-out of the Scheme

A scheme for a large-scale marine recreation center for sheltered waters will be laid out according to the following prerequisites.

(1) *Availability of sheltered waters*, created by constructing a break water or an artificial island.

(2) Creation of utilizeable space to facilitate enjoyment of marine environments.

(3) Although no limitation is imposed on the selection of a site, an ordinary area of coast facing the Pacific Ocean in a temperatue zone is recommended.

(4) The range of the calm sea zone is expected to extend about 5 km offshore and about 10 km along the shoreline. About 2 million tourists are expected to visit the facility each year. It is assumed, with these figures the project is economically feasible.

(5) In consideration of an increasing elderly population, all age groups will be catered for. Most facilities are expected to be used mainly on a group basis (small groups, families).

(6) Throughout all seasons, visitors will be able to enjoy activities (from one night to one week) at the center.

(7) The early 21st century, now only a few decades away, is targeted as a completion date.

4.3 Zoning and the General Scheme

Based on fundamental principles and prerequisites described in sections 4.1 and 4.2, this section will deal with the establishment of the site and lay-out of the general scheme.

Prior to development, user demands for activities in a sheltered sea area were defined and classified as shown in Table 2.

The coordination of user demands with the distribution of special recreational zones are summarized as follows:

(1) On the assumption that tourists will stay at the facility, pattern A accomodation will be the major starting point of their activities. For this reason, Zone A should be arranged before others when developing the site. Zone A needs to be set in several locations because the land and the wave control zones are far apart.

(2) Zonce B (where activities such as swimming, sunbathing, eating and drinking will be pursued) should be located near Zone A, so that many people and all age groups may use the facilities. *The same principle should be applied to Zone F (new types of recreation).*

(3) The marinas of Zone C tend to be combined with various other functions. Therefore, this zone should be located near Zone B (accommodation, swimming areas, restaurants). It is also recommended that Zone C is located in a particularly quiet area, which is suitable for its purposes.

(4)Zonce E which would cater to Pattern E activities (using cruisers, motorboats, etc.) would require a marina. Therefore, this zone should be located hear Zone C. The same conclusion may be applied to Zone D as some Pattern D Activities, such as the use of dinghies, necessitate the use of a marina.

(5) A wide range of age groups are expected to use both Zone D (dinghies, fishing, diving, etc.) and Zone B (swimming, eating and drinking). Therefore, Zone D should be located near Zones A and B.

Based on these basic conditions for zoning, a

Table 2 Activity Patterns in the Sheltered Sea Area

Pattern	Characteristics of Zones and Their Typical Recreational Activities
A	〈Characteristics〉 · Terminal-attached accommodation: the starting point of various activities 〈Examples of Possible Activities and Facilities〉 · Hotels (on the beach or the surface of the sea, in the sea, or on the seabed), rental villas, condominiums, general information centers, etc.
B	〈Characteristics〉 · Activities in which everybody can easily participate. Direct interaction with the sea with the use of little equipment. 〈Examples of Possible Activities and Facilities〉 · Swimming, sunbathing, walking, sight-seeing, etc. · Rowboats, pleasure boats, an aquarium, an underwater observatory tower, an event plaza, etc. · Restaurants (on the ground, the surface of the sea, or in the water). a shopping center, etc.
C	〈Characteristics〉 · Marinas and other facilities as a base for boating 〈Examples of Possible Activities and Facilities〉 · Marinas and their incidental facilities (e.g. a club house, accommodation, parking lots)
D	〈Characteristics〉 · Activities different from Pattern B in reference to the use of equipment, but similar in their relative easy of participation. Some of the activities are closely related to Pattern C in their use of marine facilities. 〈Examples of Possible Activities and Facilities〉 · Dinghies, surfing, windsurfing · Diving (skin, scuba), fishing, jet skiing
E	〈Characteristics〉 · Activities are relatively equipment intensive. These activities require a marina as a base or an extensive sailing area, and are characterized by frequent sailing in the open sea. 〈Examples of Possible Activities and Facilities〉 · Motorboats, cruisers, water skiing
F	〈Characteristics〉 · All people can enjoy new types of recreation (in the beginning of the 21st century) in various facilities which harness the natural splendor of the sea. 〈Examples of Possible Activities and Facilities〉 · Shuttle boats, floating promenades, underwater scooters, transparent tubes, underwater sleighs, underwater mazes, artificial waterfalls, submarine promenades, submerged dining, gardens, etc.

fundamental zoning pattern (concept) can be formed as illustrated in Fig. 2.

Zoning was made in accordance with assumed patterns of activity. The procedure was to arrange zones A–F, taking into account the correlation between activities. In zoning the site, the complete range of activities, the assumed scale of each zone, and the scenic beauty were all taken into acount.

Fig. 3 shows a zoning plan laid out in this way. Fig. 4 shows a three-dimensional zoning plan including submerged sections.

The general scheme was formulated on the basis of such zoning with the type and scale of facilities and the transport system examined on a user demand basis. The proposed large-scale marine recreation facility can be outlined as follows, and a conceptual plan is shown in Fig. 5.

(Areas)

- The sheltered sea development consists of three large areas: land, offshore where a break water is constructed, and open sea.
- The land area is the center for managerial headquarters, various types of accommodation for large numbers of people, and recreational and cultural facilities. This area will also serve as the junction of land routes from neighboring populated areas.
- The sea facilities are the focal point of the site, encompassing area ranging from the surface to the site, encompassing area ranging from the surface to the bottom of the sea. These developments include

Fig. 2 The Concept of Zoning

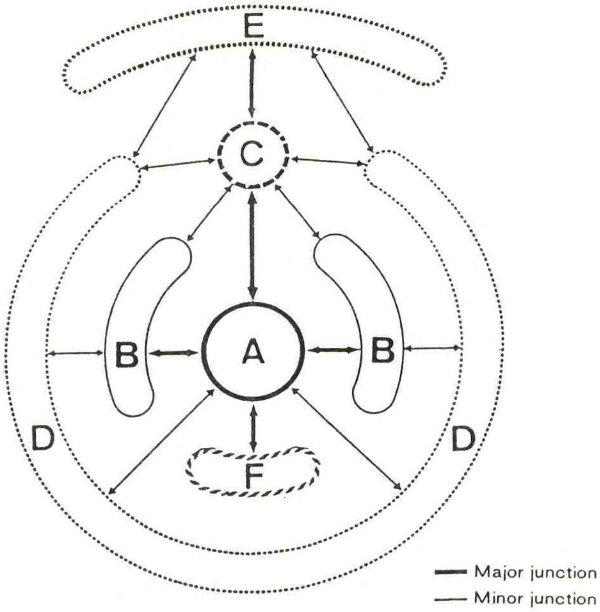


Fig. 3 Sheltered Sea Zoning

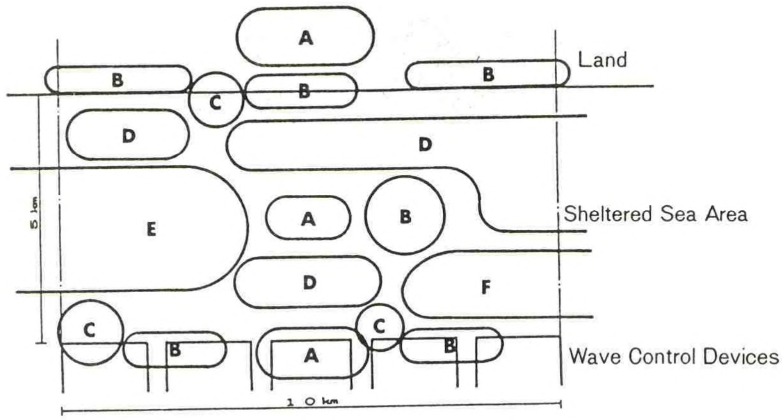


Fig. 4 A Three-Dimensional Figure of the Sheltered Sea Area

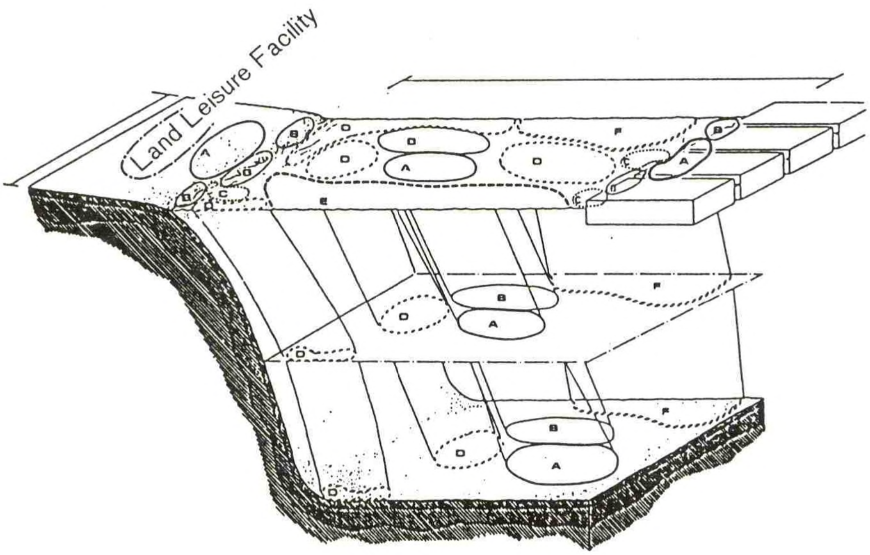
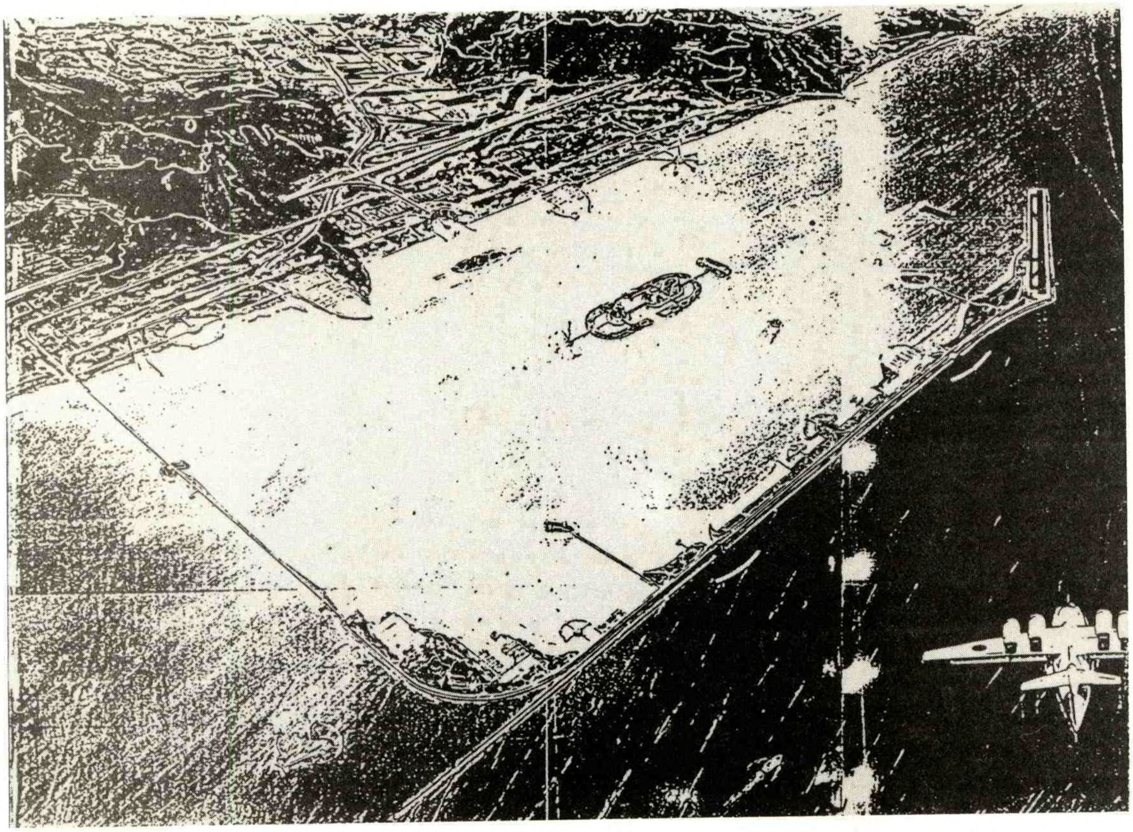


Fig. 5 A Conceptual Plan of a Large-Scale Recreation Base



a subcontrol center, accommodation, cultural facilities, creating an unusual environment to experience various novel activities.

· The offshore area around the break water structure consists of a sub-control center, marinas, condominiums, etc. Recreational facilities in this area, which are located in an enrironment contrasted with calm and rough seas, have different characteristics from the two other areas.

It is this area that will serve as the junction of air and sea routes.

(Terminal Facilities)

· Terminal facilities are located in all three areas: land, sea, and offshore, providing bases for activities in the sheltered sea area.

(Accommodation)

· Surrounding each of the terminal facilities, major accommodation such as hotels will be constructed. In addition, condominiums, villas, campgrounds, cottages, tourist homes, etc., will be arranged taking into consideration their tranquility, isolation, and convenience.

(Recreational Facilities)

· Bathing locations, where a variety of activities will occur, will be centrally situated in the land and protected wave control areas, and are expected to become major bustling areas.

· Event plazas, restaurants, and shopping centers are given accessible locations.

· A large-scale air dome including a stadium, an event plaza, and an opera house are to be constructed in an area adjoining the hotels and condominiums in the center of the open sea area.

(Marina)

· One marina in the land area and two marinas in the offshore area, will support sailing activities in the sheltered and open sea zones.

(Transport Facilities)

· The traffic network, as the infrastructure of the zone, covers all areas in the site via its terminal facilities.

· The land area is connected with the breakwater structure in two ways: one is a new transport system including electric cars running along bridges; the second, another new transport system including promenades (mobile pedestrian paths) leading through tunnels directly to three terminals.

(Breakwater Structure)

・ The breakwater, the foundation of the sheltered sea area, has two openings, maintains sea water circulation within the enclosure and can be used as an emergency exit route. The structures is 80–100 m away from the facilities around it, in order to protect them against high waves.

(Others)

・ Although it is not described in the lay-out shown, a new leisure area will extend under water in the center of the sea area (on the right side of the air dome) adjacent to the airport.

Model Test of a Huge Off-Shore Structure

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1. Introduction

Japan, whose geographical area is narrow with still narrower level space left for economical activities, seriously looks for utilization of her sea space. This aspiration is endorsed by many coastal development projests which are announced and undertaken one after another these years. However, all these projests plan an extension of the coast. Their reaches from the coastal lines are short and the depths of the sea areas to be used are shallow, and in most cases the development depends on so-called reclamation method or pier systems. However, when thoughts are given to acquisition of offshore resources, on-the-sea production activities, waste disposal, ocean freight terminals and related high efficiency utilization of our offshore space, our future undertakings may be destined to advance from the sea shores to deep offshore waters. It is a worldwide tendency that every year such projects announced involve longer distances from ashore, deeper waters and larger areas and scales. As to the floating type platform for offshore oil drilling, there is a sufficient stock of experience, and as a matter of fact actual sea area tests[1] for future realization of super-sized platforms are being executed and the eye of experts are fixed on their on-coming results.

One of the authors has conceived a future spaceport and has made public the concept of a 2,000 meter long semisubmerged floating type artificial island[2),3)]. This paper is to report the results of the basic water tank model experiments performed under such circumstances.

2. Basic Concept of the Huge Offshore Structure

2-1 Considered Sea Area and Environmental Conditions

It is believed that areas nearer to the equator are more advantageous for spaceports. However, in the present study the environmental conditions off the Bay of Sagamiwan which include comparatively severe climate and wave conditions were assumed from the viewpoint of the required general applicability of the fruits of the study in determining the behavior of a huge scale offshore structure in the sea. The history relating to the estimation of the condition and various assumptions is omitted here and their results only are shown in Table 1.

Table1 Environmental condition

ITEM	CONDITION
Wind	45 m/sec
Current	2 knots
Wave height (significant)	13.2 m
Wave period (Mean)	16.2 sec

2-2 Determination of Principal Particulars

The configurative requirements vary as the purpose of the structure varies. Here, the plan size was determined assuming an offshore airport. Other factors were based on the environmental conditions shown in Table 1. As to its buoyancy, the footing type structure proposal for the Kansai International Airport was first considered, but after all the type wherein lower hulls are arranged between the two columns was taken up to raise the ratio of the displacement to the light load. The main particulars of the structure are given in Table 2, together with the particulars of the model, which will be described later, and the outline configuration of the structure is shown in Fig. 1.

Table2 Particulars of structure

ITEMS		FULL-SCALE	MODEL (1/200)
Length	(L)	1800 m	9.000 m
Breadth	(B)	120 m	0.600 m
Depth		40 m	0.200 m
Depth of Upper Deck		12 m	0.060 m
Section of Columns		10 m X 10 m	0.050 m x 0.050 m
Depth of Columns		21 m	0.105 m
Section of Lower-hulls		10 m X 7 m	0.050 m x 0.035 m
Length of Lower-hulls		48 m	0.240 m
Number of Lower-hulls		4 rows X 25m	4 rows X 25
Draft	(d)	14 m	0.070 m
Displacement		487,900 ton	59.5 kg

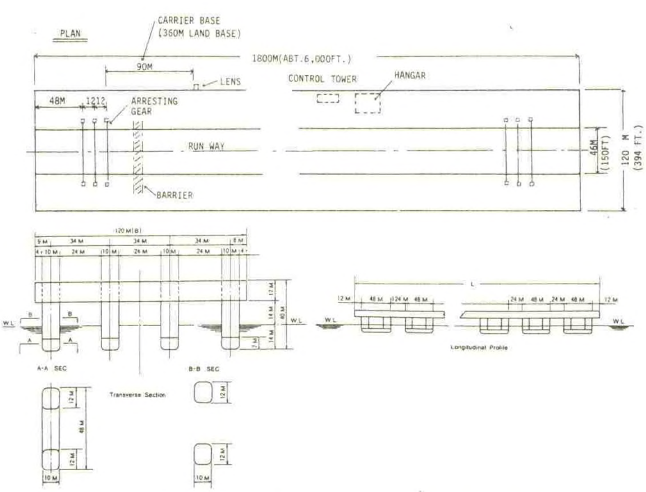

Fig.1 Outline configuration of structure

The CALM mooring system was considered with a safety coefficient of 3.0 based on the estimated steady external forces, and thus the particulars as shown in Table 3 were adopted for the mooring system.

Table3 Particulars of mooring system

	ITEMS	FULL-SCALE	MODEL (1/200)
Buoy	Diameter	20 m	0.124 m
	Depth	18.2 m	0.104 m
	Draft	12.1 m	0.074 m
	Displacement	3,896 ton	0.894 kg
Yoke	Horizontal Distance between Hinge & Center of Buoy	60 m	0.300 m
	Distance between Hinges	50 m	0.250 m
Mooring System	Chain Length	1,200 m	4.35 m
	Chain Weight in water	0.487 ton/m	12.0 g/m
	Horizontal Distance	1,090 m	3.05 m
	Vertical Distance	200 m	2.43 m
	Number of Mooring Lines	16	12
	Initial Tension (each line) Horizontal	59 ton	14.3 g
	Initial Tension (each line) Vertical	145 ton	41.0 g
	Initial Tension (each line) Total	156 ton	43.4 g
	Water Depth	200 m	2.5 m

3. Model Tests for Huge Offshore Structure in Water Basin

3-1 Purpose of the Tests

The experiments were performed for the purpose of confirming the feasibility of the concept mentioned in the foregoing section and for obtaining basic data and extracting problems measuring the hydrodynamic forces and behaviors of the structure under the effect of each and combinations of wave, wind and current as well as their loads upon the mooring system.

3-2 Test Models

The huge offshore structure, which was the subject of the experiments, consisted of a main structure and its mooring system (yokes, buoys and mooring lines). The particulars of its model are shown in Table 2, together with the particulars of full-scale structure. The sea area for locating the full-scale structure was assumed to be 200 meters deep while the tank water was 2.5 meters deep. Accordingly, the scale reduction ratio of the model had to be 1/80 if the water depth reduction ratio was considered. However, such scale reduction would result in the total model structure length of 22.5 meters making it difficult to handle it. Therefore, the scale reduction ratio of 1/200 was adopted at the sacrifice of the geometrical similarity of the water depths.

(1) Main Structure

A photograph of the main structure is given in Fig. 2. The upper deck is made of wood and the columns and lower hulls are made of foamed urethane. The model length is too long for the value of displacement, and it was inconvenient to handle as one integral structure. Therefore, it was divided into three (3) sections including two (2) 2.88 m end section and a 3.24 m central section. While in the tests, they were put together on the water using bolts. No special considerations were given to the rigidity, moment of inertia, height of the center of gravity, etc. of the model as the purpose of the experiments was not to measure the local movements of the structure or the wave loads.

Tentatively, the deflections under loading of the model as a beam supported at both ends were measured to obtain the rigidity of the model against vertical bending, and the following values were obtained:

Divided model connecting sections .... EI = 0.4321 kg-m²

Other section .... EI = 1810 kg-m²

(E: Young's modulus, I: Geometrical moment of inertia) Thus, the bending rigidity of the model joint sections was approximately 1/4200 of that of the other section meaning that under the effect of the vertical bending moment in waves, most of the bending is generated at the joint sections resulting in jackknife movements with two (2) folding points.

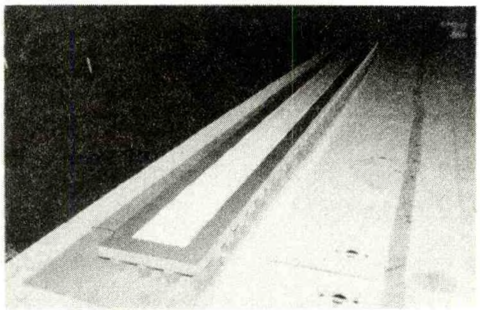

Fig.2 Model of structure

(2) York and Buoy

Fig. 3 shows a photo of a buoy-yoke model. The yoke is made of aluminum with perforations to decrease the weight. A load cell was inserted in the middle of the york to measure the axial direction force of the yoke.

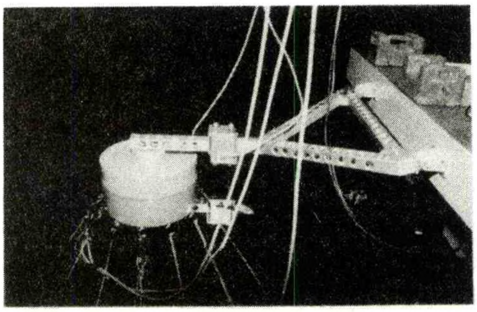

Fig.3 Model of buoy-yoke

The buoy has a cylindric shape and is connected at its upper section with its central axis to the yoke which freely rotates on the said axis. As will be described hereinafter, the water tank depth was relatively deeper than the actual sea depth where the full-scale structure was assumed to be installed. Therefore, the downward component of the mooring force in the tests was larger than that in the case of the full-scale structure. Accordingly, in order to increase the buoyancy corresponding to this downward force, the model buoy was made relatively larger than the full-scale buoy in scale. Further, two (2) types of buoy whose drafts were respectively deepened 4 times and 7 times that of the original type buoy to decrease the effect of waves were tested and the turret mooring without buoys were also tested.

Fig. 4 shows the general arrangements of both buoy mooring and turret mooring.

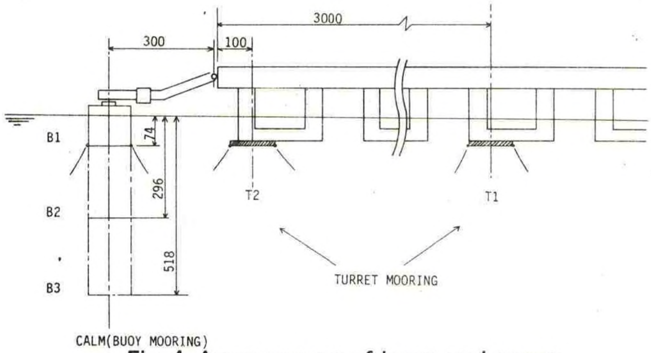

Fig.4 Arrangement of buoy and turret

In the case of the turret mooring of the present model, chains were fixed around the disk of the same diameter as the buoy and the said disk was attached to the under-su rface of the lower hull of the main structure as shown in Fig. 4. The disk does not rotate. The catenary shape of the chain in the turret mooring condition is comletely the same as in the case of the buoy mooring.

The buoy and turret adopted here can be summarized as follow:

Buoy mooring system

- Original type (draft 0.074 m) B1
- 4 time draft type B2
- 7 time draft type B3

Turret mooring system

- Turret position 3 m from the front end (1/3 of the full length) T1
- Turret position 0.1 m from the front end (1/90 of the full length) T2

(3) Mooring Line

As described in the above, the water depths were not similarly balanced in the model test and actual sea condition, therefore the mooring systems adopted in the tests were not geometrically similar either. The catenary shape of the mooring line of a mooring system similar to the full-scale system (mooring system corresponding to the full-scale system) and the catenary shape of the mooring line of the mooring system adopted in the model tests (test mooring system) are comparatively shown in Fig. 5. In the selection of the test mooring system, it was intended that the possible range of the buoy horizontal excursion and the change of the horizontal direction tensile strength against horizontal direction displacement near the initial position be almost equal in both mooring systems, however it was impossible to perfectly satisfy such conditions. The range of the possible movements of the buoy in the test system was wider compared with that of the mooring system corresponding to the full-scale system. Further, in the model tests, aluminum chains manufactured for decorative purposes and sold on the market were used as mooring chains. Therefore, the details of the shape and size of the mooring chains are not similar to those of the full-scale chains.

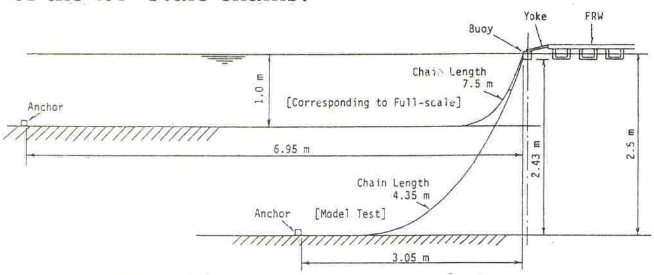

Fig.5 Catenary of each mooring line

As to the number of chains, 12 chains were used on the test model as against 16 chains on the full-scale structure, and instead the unit chain weight was increased to offset the difference.

3-3 Test Details and Method

(1) Test Conditions

The tests were performed in the seakeeping and manoeuvring basin (rectangular tank) of Hiratsuka Research Laboratory of Sumitomo Heavy Industries, Ltd.

The environmental conditions of the tests were established on the basis of the values of Table 1. However, as shown in Table 4, the actual conditions of the tests performed, as converted to those of the full-scale structure, somewhat differ from those of Table 1. The test conditions could be divided into the following two cases:

i) Under a single environmental force
 - Wave (regular wave, irregular wave)
 - Wind
 - Current

ii) Under a combination of environmental forces (composite external force)
 - Wind + current
 - Wave (irregular wave) + wind
 - Wave (irregular wave) + wind + current

The values of the environmental conditions used in the tests were more or less different from the above-mentioned environmental conditions for the full-scale structure design.

Table4 Test condition

CONDTION \ MOORING	B1	B2	B3	T1	T2
Regular wave					
ζa: 3.3 cm (6.6m)	0				
Irregular wave					
H1/3: 6.3cm (12.6m)					
Tm : 0.97sec (13.77sec)	0	0	0	0	0
1.214sec (17.17sec)	0	0	0	0	0
1.517sec (21.45sec)	0	0	0	0	0
Wind					
Vw: 1.0m/sec (14m/sec)	0				
2.0,2.2m/sec (28,31m/sec)	0	0	0	0	0
3.1m/sec (44m/sec)	0	0	0	0	0
Current					
Vc: 3.0cm/sec (0.8kts)	0				
6.9,7.2cm/sec(1.89,1.98kts)	0		0		
10.0 (2.75kts)	0				
Irregular wave + Wind	0	0	0	0	0
Irregular wave + Wind + Current	0			0	

( ): Full scale

The directions of the external forces (directions of wave, wind and current) in the tests under combinations of such external forces were all the same. Even where the direction of the external force in the initial stage of the test is different from the axial direction of the structure, the structure will finally be settled with its axis generally in parallel with the direction of such external force. Therefore, the tests were conducted in the manner that during the initial stage the structure was on the downstream side of the external force with its axial direction coinciding with the direction of such external force.

Fig. 6 shows the result of the actual measurement of the irregular wave spectrum used in the tests. The ISSC type spectrum was used.

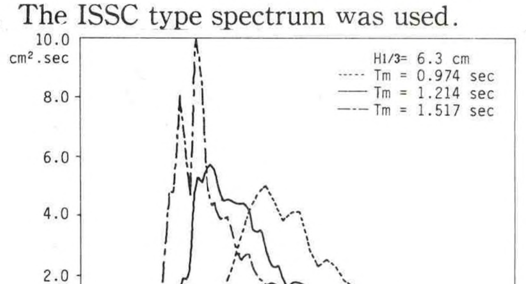

Fig.6 Wave spectrum

3-4 Measurement Method

The following subjects were measured.
 - Wave height
 - Wind velocity

- Current velocity
- Horizontal drift of the structure
- Axial force acting upon the yoke (Measured onbuoy mooring only)
- Tensile force acting upon the mooring line (changes from the initial value on mooring line No. 1, 2 and 3)

where: Mooring Line No. 1 ... Mooring line onweather side in parallel with the environmental force direction

Mooring Line No. 2 ... Mooring line next to Mooring Line No. 1

Wave height, wind velocity and current velocity were measured respectively by the servo type wave height meter, blade wheel type anemometer and blade wheel type current meter.

The horizontal displacement of the front edge of the structure was measured by means of an optical position sensor (television tracking system).

The light source was located, in the case of buoy mooring, 0.100 m backward from the fore end of the structure and, in the case of turret mooring, directly above the turret.

The axial force in the yoke was measured by inserting a load cell in the middle of the yoke, and the tension in the mooring line was measured by attaching a ring type load cell to the mooring end on the buoy side.

Fig. 7 shows the photo of the buoy mooring test.

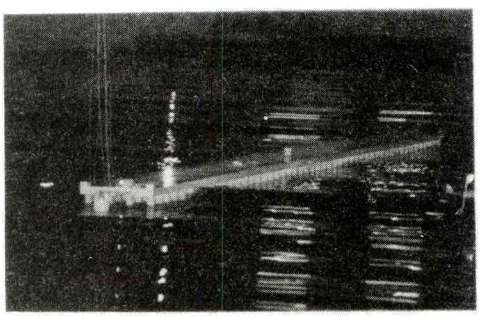

Fig.7 Model test of buoy mooring

4. Test Results

4-1 Test under Single Environmental Force

(1) Test in regular waves

The results of the test in the regular waves are shown in Fig. 8 and Fig. 9. The results shown in dimensional values were all obtained when the wave amplitudes in the test were approximately 3.3 cm (approx. 6.6 m when converted to the case of the full-size structure). The test in the regular waves was performed only on the buoy mooring system (B1).

Fig. 8 shows the axial force in the yoke. When the wave height is constant, the time averaged value of the axial force is larger as the wave length is shorter (the wave period is shorter). The mean value of the axial force in the yoke can be regarded as the wave drift force acting on the structure.

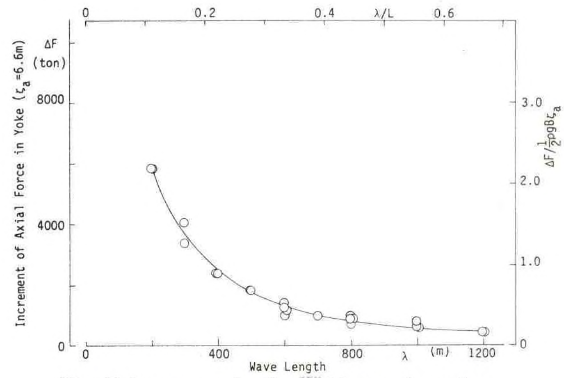

Fig.8 Increment of axial force in yoke

Fig. 9 shows the increments of tension, from the initial tension onward, acting on the mooring lines of Mooring Line Nos. 1 and 2. It is understood from this figure that when the horizontal displacement of the structure is large, the time averaged increments of tension acting on the mooring line on the weather side in parallel with the wave direction (Mooring Line No. 1) is by far larger compared with the mooring line (Mooring Line No. 2) whose direction differs from the No. 1 mooring line by 30°. This is attributable to the fact that the line of Mooring Line No. 1, from the mooring end on the buoy side through to the anchor position, is lifted up above the tank bottom or in a taut codition. Therefore, it will be necessary to optimize the number of the lines to avoid concentration of tension on a single mooring line. It may be added that the time averaged value of the tension increment of Mooring Line No. 1 and its fluctuation amplitude tend to increase as the wave length is shorter quite similarly to the case of the axial force in the yoke.

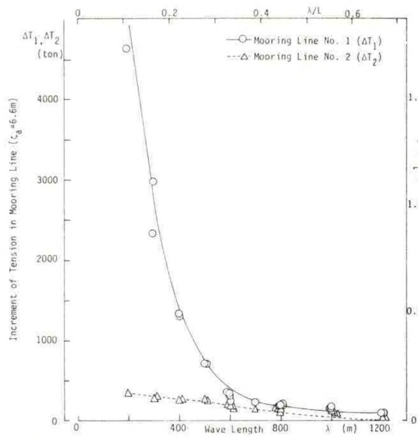

Fig.9 Increment of tension in mooring line

(2) Test in Irregular Wave

Fig. 10 shows an example of time history in irregular wave.

The comparison of the historical records of tension acting on Mooring Line No. 1, shown in Fig. 11, indicates that that component of the force which fluctuates depending on the wave period is small either in the case of the buoy mooring system

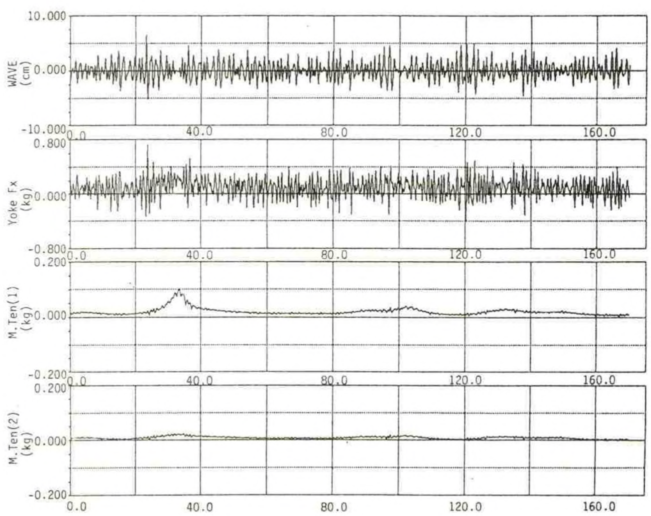

Fig.10 An example of time history in irregular wave

(B3) or the turret mooring system (T1). In the case of B1 and B2, the buoy greatly heaves in the waves, and therefore the resultant tension fluctuation is large. Further, it is understood from the results of the T2 test that large vertical motion is being generated by elastic deformation of the structure's end positions.

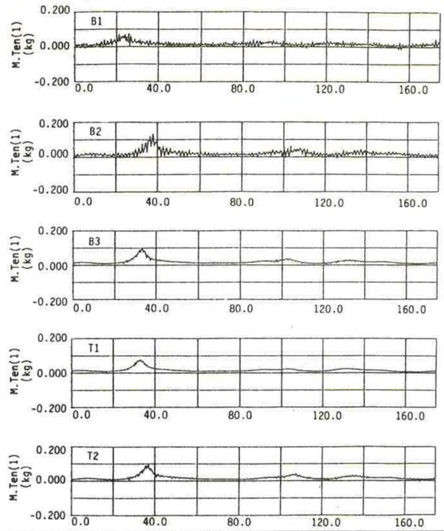

Fig.11 Comparsion of time histories of tension in mooring line in irregular wave

(3) Test in Wind

Fig. 12 shows the resultant mooring line tension increment when a steady wind singly acts thereupon. No differences are seen between the different mooring systems.

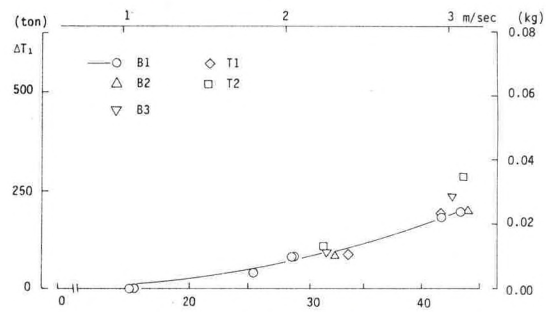

Fig.12 Increment of tension in wind

(4) Test in Current

Fig. 13 shows the mooring line tension increment, in the case of B1 and T1 mooring systems only, when the current is acting singly. A tendency is seen in this figure that T1 tension is smaller by a difference corresponding to the absence of the buoy, but generally speaking there are no significant differences.

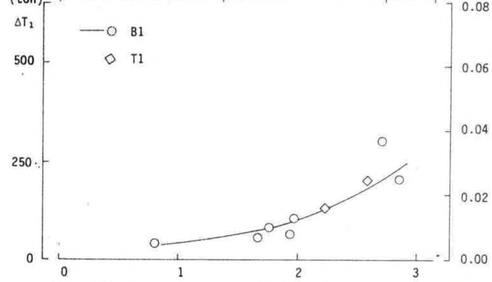

Fig.13 Increment of tension in current

4-2 Test under Combinations of Environmental Forces

(1) Irregular Wave and Wind

Fig. 14 shows the comparison of time histories of fluctuating tension acting on Mooring Line No. 1 by different mooring systems. As a steady wind force is added, the fluctuation by waves will be larger, compared with the wave-alone-case, as in Fig. 11. However, excepting the initial transitional fluctuation, the fluctuation of buoy mooring B3 and turrent mooring T1 during the latter half of the testing period is smaller, compared with the other systems.

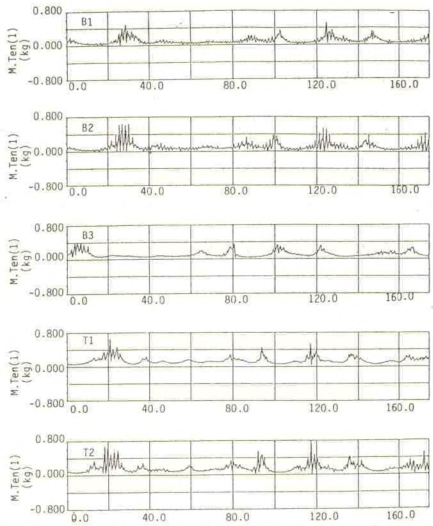

Fig.14 Comparison of time histories of tension in combined Irrcgulor wave and wind

(2) Irregular Wave, Wind and Current

Fig. 15 shows an example of time history in combined environmental forces of irregular wave, wind and current. The horizontal displacement of the structure appears on its lee side, and almost constantly a tensile force acts on the yoke axis and the mooring line on its weather side.

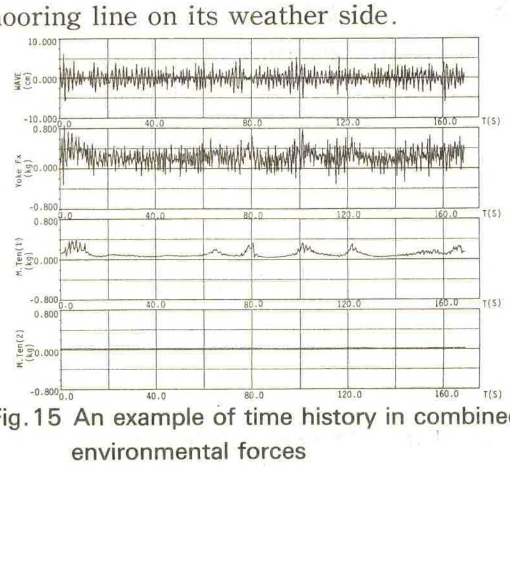

Fig.15 An example of time history in combined environmental forces

4-3 Time Averaged Values

Fig. 16 shows the time averaged values of axial force in the yoke, and Fig. 17 shows the time averaged value of the moorimg line tension increment.

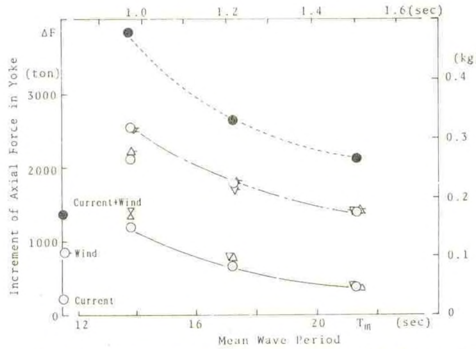

Fig.16 Time averaged drift and axial force in yoke

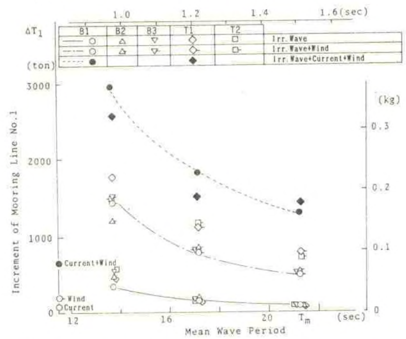

Fig.17 Time averaged tension in mooring line

In all cases of the axial force in yoke (Fig. 16) and the mooring line tension increment (Fig. 17), the time averaged value is larger as the mean wave period is shorter. This tendency is seen in all types of mooring systems, and as far as the average values are concerned, no appreciable differences are seen among different types of mooring.

By referring to the values under wind alone as plotted on the left vertical axis, it could be understood that the time averaged value of the axial force in the yoke is slightly larger than the simple total of the axial forces each under a respective single environmental force.

As to the time averaged value of the mooring line tension increment, a reference to the values under wind alone as plotted on the left vertical axis clarifies that it is also larger than the simple total of the time averaged values of the tension increments each under a respective single environmental force. In the case of the mooring line tension, an impulsive non-linear load is liable to occur in the mooring line because, beside the reason that the vertical direction force is added, when the buoy horizontally drifts under the wind pressure and the mooring line on the weather side is tensioned to a certain extent, the buoy will be moved by the waves, and if viewed in terms of time averaged values, it is presumable that such tension may be larger than the simple total of the tensions each under a respective single environmental force.

5. Conclusion

The tests performed this time was a part of the feasibility study for mooring a huge floating type offshore structure. The major results obtained from those tests are enumerated below.

(1) The motion of the buoy in the waves affects the fluctuation of the mooring line tension and the axial force in the yoke. Less the motion of the buoy will be, less will be the peak value of each.

(2) The time averaged values of the mooring line tension and the axial force in the yoke hardly vary even though the mooring system varies. It is surmised that these forces are determined by the structure itself.

(3) Since this structure is remarkably long making the wave length relatively shorter, its motion in the waves is smaller compared with common offshore structures except that its leading end part is subject to vertical vibration due to elastic deformation.

(4) In case the wave height or the significant wave height is constant, the wave drift force acting upon the buoy and the structure will be larger as the wave period is shorter. Accordingly, the axial force in the yoke (tension), the increment of tension acting on the mooring line on the weather side, and the time averaged value of the horizontal drift of the buoy (or the structure) to the lee side will also be larger as the wave period is shorter.

(5) Because of the non-linearity of the mooring line tension characteristics, the axial force in the yoke or the mooring line tension under a combination of any two (2) of or all three (3) of the environmental forces, namely irregular wave, wind and current, will, be larger than the simple total of the involved forces each acting under a respective single environmental force.

Due to the limited space of this paper, the discussions had to center around the mooring systems. However, the authors have also obtained measurement results as to motion and strengths which coincide with theoretical calculations. The author would like to conclude this paper by reporting that such finding have made it possible to perform simulations conforming to design conditions in the future based thereupon.

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OFFSHORE MAN-MADE ISLAND PLAN

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Ports and Harbours Bureau, Ministry of Transport

1. Background of Offshore Man-made Island Plan

With seas surrounding the land and mountains drawing near the ocean, our country is favored with natural environment by a lot of mountains and coastal lines, but the activity space is extremely narrow compared with other countries. So the people have created the space by reclamation and earth filling since olden times, and positively utilized the coastal areas as the place for various activities including living, industrial activities, traffic, recreation, etc., to build up its economic society now ranked as the second in the world.

While the economic society of our country is keeping on expanding through diverse developments including service, internationalization, information, etc., repletion of the economic bases have brought diversification of nation's value judgement, improvement of living standard, increase of free time, etc. Accordingly, quality rather than volume and mental satisfaction are required more strongly in the life of individuals, and development of diverse, creative and high-quality national life is required, necessitating to secure another activity space which will respond to such requirements.

As our country provides only extremely narrow usable land compared to the economic and social activities, minute land utilization has been proceeded. However, having an extensive ocean space around the land, it is inevitable to create new activity space through effective use of such ocean space in order to keep on the continuous development of our country to the future.

2. Significance of Offshore Man-made Island Plan

In order to respond to these social needs, the Ministry of Transport is promoting a plan to create Man-made Islands in the offshore areas with its experience in the development and utilization of coastal areas mainly harbors and the progress of technics as the background, that is the "Offshore Man-made Island Plan" which will meet the needs for space by securing such space having high value of use with features of coastal areas, and promote comprehensive utilization of coastal areas.

The Offshore Man-made Island Plan provides the following advantages which will allow the most diverse and advanced utilization of the benefits of coastal areas and Shorelines:

(1) As the plan affords high degree of freedom, it is possible to include various functions freely, and to create a space with high value-added meeting the new life style:

(2) The plan will secure long shoreline and create tranquil water area with high value of use behind the shoreline, to allow advanced utilization of the coastal area with the coastal are as a whole;

(3) The plan will easily allow coordination with the existing utilization of the coastal area, and

facilitate thorough correspondence to preservation of the natural environment.

In addition, since the offshore Man-made Island is constructed apart from the coast, it will also allow to locate functions which will effectively use its separability.

As described above, the Offshore Man-made Island Plan will afford an important motive power for realizing the promotion of regions by utilizing the features of water areas and shorelines to the utmost and by creating special regional characteristics distinguished from others, towards the times of the nation's increasing needs for adopting the favor of the ocean in their daily life. And, it is also important for our country which is seeking for the place of development in the ocean as a new frontier towards the future.

3. Progress of the Offshore Man-made Island Plan

For the formation of more clear concept and realization of the Offshore Man-made Island Plan, the Ministry of Transport has already carried out close surveys for 9 years while summarizing the results each time, through cooperation of Keizai Dantai Rengokai and Kozai Kurabu.

During 1980 to 1982, an energy bases, mainly coal thermal power plants, were supposed and the possibility was studied. During 1983 to 1984, a case study was performed for the consolidation of offshore Man-made Islands aimed at multiple ways of use at 7 water areas of the country. During 1985 to 1986, the Guideline for the Offshore Man-made Island Plan was prepared, and the project system feasibility, effect of regional development and support measures for promoting the project were studied.

Parallelly with the above, a feasibility study was started in 1986 by joint survey of the State and harbor controllers in order to materialize the offshore Man-made Island plans of the whole country. From 1988, the Offshore Man-made Island Project Promotion Survey has been performed about projects which are on the business stage at Yokosuka, Shimizu and Shimonoseki in order to make more concrete, detailed studies for the promotion of these projects.

On the other hand, in 1985, a system for consolidation small-scale offshore Man-made Islands was established jointly by public and private organizations, and the system is planned to be applied to the construction of Wakayama Marina City.

4. Individual Offshore Man-made Island Plans of the Country

Some of the offshore Man-made Island plans which have been studied towards the materialization under the guidance of the Ministry of Transport are described in the following.

(1) Yokosuka Offshore Man-made Island (Fig. 1-a)

Yokosuka City is a city located at the mouth of Tokyo Bay and surrounded in three directions by sea, and the Tokyo Bay coast has developed mainly with heavy chemical industries. Due to recent recession of the base industries such as ship building as a result of the change of industrial structure, however, breeding and introduction of new growing industries has become the subject. On the other hand, Kaneda Bay - Sagami Bay coastal areas form one of the centers of oceanic recreation as well as Shonan Coast, but the delay of facility improvement requires the improvement of new oceanic recreation space. For this reason, offshore Man-made Islands with introduction of comm ercial, business, oceanic recreation, distribution base and fishery functions, in addition to the local features are planned in waters of Tokyo Bay, Kaneda Bay and Sagami Bay with aims to activate and parallelly develop these areas.

(2) Shimizu Offshore Man-made Island (Fig. 1-b)

Shimizu Port is a natural good harbor, surrounded by Miho Peninsular, and has developed as commercial port since olden times. Recently, the port has been enhanced with functions as calling port for liners of foreign trade. A coastal industry area is extending behind the port, but structurally stagnant businesses are the main, raising the problem of the drop of local economic base of Shimizu City and its periphery. Therefore, in order to improve the City and its periphery as an active and attractive town area, a regional development including the coastal area and an offshore Man-made Island are planned for creating a new port space which will provide functions such as (1) advanced physical distribution and information functions, (2) international oceanic development and research functions, (3) exchange, sport and recreation functions opened for people of the country and from overseas, and (4) fishery and related research and recreation functions aimed for the utilization of fishery resources.

(3) Wakayama Marina City (Fig. 1-c)

Wakayama Bay area of Shimotsu Port, Wakayama, has Wakayama City immediately behind it, and more extensively, Osaka City and other big Municipal areas. Before the opening of Kansai International Airport, potential for tourism has been increasing more and more. Here, in order to build up a new local society matching the diversification and advancement of leisure needs due to improvement of living standard and increase of leisure time, suburban type week-and oceanic recreation center "Wakayama Marina City" is planned with internationally valuable provision of various sport facilities, condominiums, etc. centered by marina.

(4) Shimonoseki Offshore Man-made Island (Fig. 1-d)

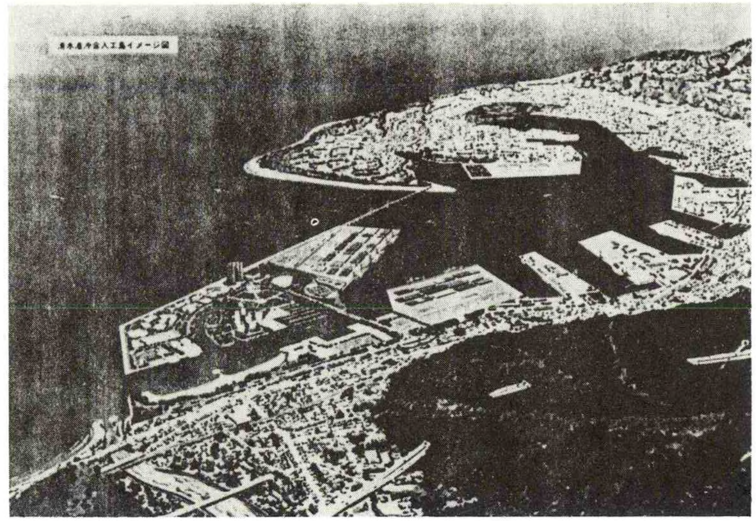
In the progress of internationalization, our country is required to play a role to promote international cooperation and mutual understanding as the core of the developing East Asia Economic Sphere. Geographically close to East Asia, Shimonoseki has a long exchange with the area, and has worked as the window of cultural and business exchanges for East Asia while acting as the departure point of "Pusan Ferry," one of the few international ferries of our country. On the other hand, Shimonoseki has enjoyed its prosperity as a fishery base, but the present situation is quite severe due to reduction of fishery resources in East Foreign trade container terminal, physical distribution, China Sea and Yellow Sea. Also, having many structurally stagnant businesses there, reactivation of the region is strongly required. For these reasons, an offshore Man-made Island is planned as the place of general exchange among East Asian countries, which will comprise oceanic industry complex and technical/cultural exchange complex for performing cooperative breeding of fishery resources among East Asian Countries, and transportation and distribution complex for forming new transactions among these countries.

Table 1 Profile of Major Offshore Artificial Island

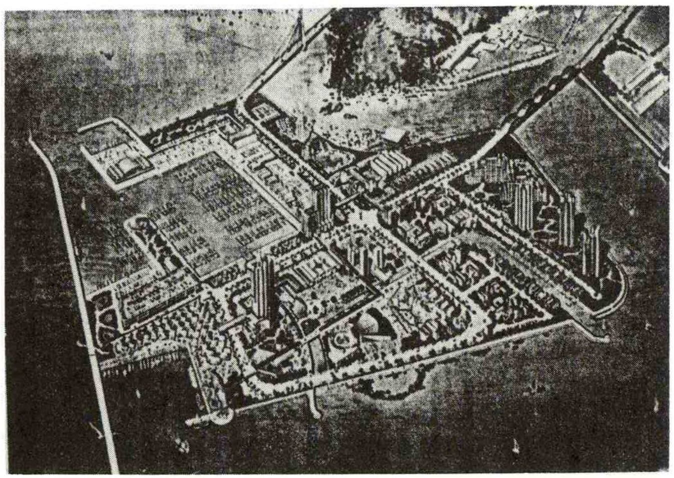
Water area		Kisarazu	Kasai•Urayasu			Yokosuka		Shimizu	Wakayama	Tamano•Kurashiki	Shimonoseki
			Urayasu	Kasai	Tokyo Bay	Kaneda Bay	Sagami Bay				
Water depth		-21 m~-23 m	-5 m~-10m	-5 m~-10 m	-5 m~-45 m	-15 m~-25 m	-10 m~-30 m	-8 m~-25 m	-3 m~-9 m	-3 m~-5 m	-9 m~-20 m
Area		240 ha (including inland water 40 ha)	54 ha (not including inland water)	200 ha (not including inland water)	160 ha	105 ha (including inland water 12 ha)	68 ha (including inland water 18 ha)	240 ha including coastal area (including inland water 26 ha)	49 ha (not including inland water)	330 ha (not including inland water)	771 ha (Maejima 48 ha, Motojima 1st term 165 ha, 2nd term 558 ha)
Type of usage		Foreign trade container terminal, physical distribution, ocean information center, convention hall, event facilities, world ...?, marina, housing with marina, sports facilities	Marina, large-size vessel berth, sports facilities, water-front green, condominiums	Marina, seaside education facilities, training center, marine sports center, training facilities, event square, man-made shore	Business, housing cultural facilities, park, advanced distribution base (fishery: future plan)	Marine land, marina, man-made shore, hotel, restaurant, fishery research base	Marina, hotel, restaurant, shipping, oceanic development and research, convention and fishery facilities	Foreign trade container terminal, marina, hotel, convention facilities, seaside town, international oceanic development and research base, fishery facilities, soccer ground, etc.	Marina, sightseeing vessel berth, sports facilities, exchange facilities, condominiums, water-front green	Marina, man-made shore fishery facilities, research and development base, convention facilities, housing facilities, local industries	International ferry complex base, foreign trade container terminal, East Asia oceanic farming (ranch) base, international oceaninc general research institute, oceanic leisure land, commutor airport
Usage of water area		Resort, oceanic recreation	Oceanic recreation	Oceanic recreation	Fishery farming	Oceanic recreation, fishery farming	Oceanic recreation, fishery farming	Oceanic recreation, oceanic survey vessel base	Oceanic recreation	Oceanic recreation, fishery farming	Resort, oceanic recreation, fishery farming
Project cost (¥1000 million)	Total cost	5,900	720	2,360	5,200	2,000	2,100	3,400	800	4,800	12,100
	Basic cost	3,400	410	1,350 (not including access bridge)	2,400	1,600	1,350	1,700 (plus 600 for bridge to Miho)	420	1,400	5,500
	Facilities cost	2,500	310	1,010	2,800	400	750	1,700	380	3,400	6,600

Note: Basic cost: Up to course lot formation, including access bridge.

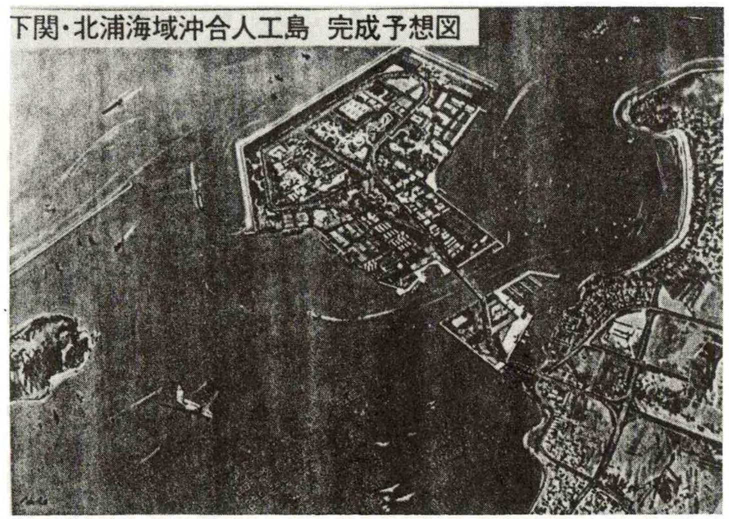
a. Yokosuka Offshore Man-made Island



b. Shimizu Offshore Man-made Island



c. Wakayama Marina City



d. Shimonoseki Offshore Man-made Island

Figure 1 Offshore Man-made Island Plan

RECENT INNOVATION AND DEVELOPMENT OF STRUCTURES IN COASTAL ZONE

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1.INTRODUCTION

Many big projects utilizing coastal and offshore zones are being executed in Japan; for example, Kansai International Airport, Extension of Tokyo International Air Port (Haneda), MM21(Yokohama), Man Made Islands (Tokyo Bay Area, Shimizu, Tamano, and Shimonoseki), New Port (Kumamoto etc.). Such projects require technological challenge because of many reasons. Locations of many projects are in offshore zones where water depths are large and structures to be constructed there are essentially very large and wave forces acting on them are huge. we need new technology to reduce the wave forces. Many projects are facing difficulties caused by soft soils which engineers meet in many places in coastal zones in Japan. We need structures of new type effective to such poor soils and procedure to improve poor soils economically and efficiently. Some projects include structures of entirely mew type, such as a floating breakwater which surely meets very large mooring forces. Beside, many newer and larger projects may come in our scope and they require further technological challenge.

Because of such circumstances, innovative technological developments have been and will be needed. Among the organizations in the Ministry of Transports (hereafter MOT), the followings are directly participating in the research and development (R&D) for those projects: the Bureau for Ports and Harbours (BPH), District Port Construction Bureaus (DPCB), and the Port and Harbour Research Institute (PHRI).

Table 1 shows the trend of the expenses for R&D concerning ports and harbours. Total amount of the expenses for R&D is about 5,290 million yen(M¥) excluding wages in the 1987 fiscal year. Among them the expenses of the PHRI is about 471M¥, but some research works are entrusted (ENTR) by the BPH, DPCBs and the Civil Aviation Bureau of which total expenses becomes 1,471M¥ including the expenses for researches concerning to facilities of air ports. Both fundamental and applied researches including laboratory experiments and computations are carried out at the PHRI, while prototype field experiments, material tests and soil investigations are carried out at the DPCBs.

On the other hand, research works on the offshore structures are so much promoted in the private sector recently. There are several fruitful works among them. The government actively adopts these fruits into the construction of port and harbour, and offshore structures. For this purpose, the promoting system comes into operation in 1988. Joint research works between the government and private sectors are also promoted actively.

Port and harbour facilities and offshore facilities are classified with respect of the function broadly as breakwaters, basin, piers and quay walls, sea walls, and others. In this paper, some topics of new type structures, execution and concerning researches are introduced.

Table 1 Trend of the Expenses for R&D concerning Ports and Harbours(M¥)

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
MOT	4,806	5,212	4,860	5,436	5,426	5,470	5,734	5,591	5,290	-
PHRI	517	524	519	489	440	405	435	424	471	473
ENTR	1,116	1,072	1,508	1,327	1,442	1,303	1,273	1,216	1,471	-

2.BREAKWATERS

1) Deep water Breakwaters

a. Breakwaters at the Port of Kamaishi

Outer breakwaters of the Port of Kamaishi is to be constructed in order to protect the port facilities and the coastal zone around the port. The port of Kamaishi locates northern part of Japan about 400km far from Tokyo. It is a part of the Sanriku district which has a typical rias coastline and is often attacked by tsunamis. The breakwater consists two parts which are so called the North Breakwater and the South Breakwater. Length are 990m and 670m, respectively. Between both breakwaters there is 300m length of harbour entrance where submerged breakwater is to be constructed. Type of the breakwaters is so called a composite breakwater which consists of a rubble mound and a reinforced concrete caisson. The water depth around the harbour entrance is about 60m, then, this may be the tallest breakwater in the world. The type of caisson is newly developed trapezoidal one as shown in **Photograph 1.** Dimensions of the largest caisson are 30m in height, 30m in height and 16m(at the top) and 30m (at the bottom) in width. The trapezoidal caisson was adopted after the laboratory experiments which had proved that wave force is much smaller on the new caissons than the ordinal ones.

In the design works, the wave height in front of the breakwaters was estimated by use of the computer prgramme for wave diffraction which was newly developed in the PHRI inconsideration of breakers on a reef. The wave forces were determined through the laboratory experiments in a wave flume at the PHRI.

The execution of rubble mound was started in 1978, and the first caisson was installed at the North Breakwater in 1982. The largest caisson of the North Breakwater is to be installed in this year.

b. Dual Cylinder Caisson

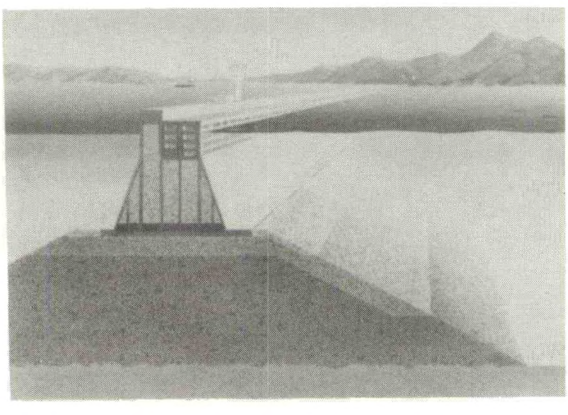
This type of breakwater is now under development and consists of dual vertical cylinders arranged concentrically and a rectangular base caisson as shown in **Figure 1.** The outer cylinder is perforated along the upper one third of the total height. Laboratory experiments on both wave dissipating capability and wave forces were carried out at the PHRI.

From the experiments, excellent performance in wave dissipation was proved and a formula for wave pressure has been derived.

Dual cylinder caisson breakwaters are going to be constructed at the Port of Shibayama, where the maximum water depth is about 30m.

2) Breakwaters with Wave Power Extracting Caisson

Photograph 2 show the sketch of breakwaters with wave power extracting caissons. The caisson has an air chamber attached to the front of a ordinary concrete caisson. The air in the chamber is leaded to an air tur-



Photograph 1 Artist's Impression of Breakwater with Trapezoidal Caisson

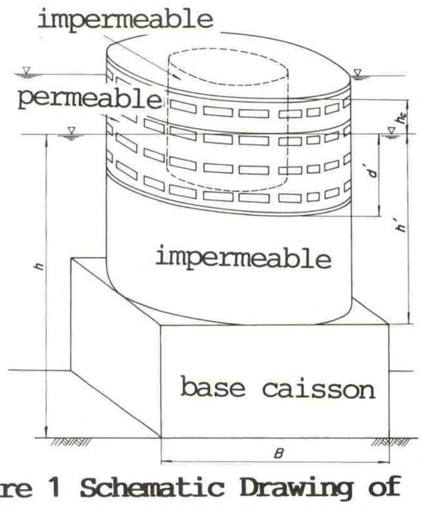


Figure 1 Schematic Drawing of a Dual Cylinder Caisson

bine and an electric generator. Waves enter into the air chamber through an opening under a curtain wall, and the vertical oscillation of the water surface occurs in the air chamber and causes air flow through the turbine.

A combination of the wave power converter and the caisson breakwater is attractive because the construction cost can be jointly borne by the accounts for power generation and harbour protection.

The study on the wave power extracting caisson breakwater was started in 1982 at the PHRI. The study shows that the conversion efficiency is relatively large when the air chamber width B_a ranges from 0.1 to $0.2L_{1/3}$, and the chamber width B_a is usually recommended to be $0.13L_{1/3}$. Where, $L_{1/3}$ is the wave length corresponding to the significant wave. The performance as the breakwater, such as wave reflection characteristics, were also studied.

The reflection coefficient varies depending on the wave height such as 0.45 and 0.55 for relatively small and large wave height respectively.

The Coastal Development Institute of Technology (hereafter CDIT) organized a committee to investigate the economical feasibility of a wave power conversion system using a wave power extracting caisson breakwater. The committee concluded that the systems with wave power extracting caisson breakwaters is feasible. The 1st DPCB is conducting a prototype test at the Port of Sakata from the 1987 to 1991 fiscal years.

3) Other Breakwater of New Type

a. Multi-Cellular Caisson

Tanimoto et al.(1981) have proposed and studied the multi-cellular caisson as shown in **Photograph 3.** The hydraulic experiments have shown that a multi-cellular caisson is more stable against wave forces than the ordinal caisson, when their width are same.

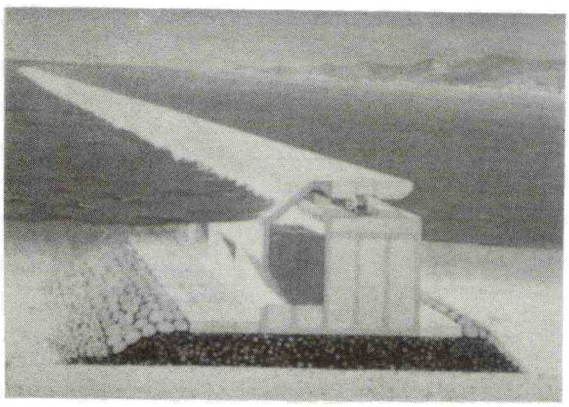
The laboratory experiments on the wave reflection and transmission were carried out at the PHRI. Though the reflection coefficient varies with the wave conditions, especially with the wave period, for the most favorable wave conditions, it becomes to 0.2.

The multi-cellular caisson is being tested as a part of the actual breakwater at the Port of Wakakyama since 1985. The caisson was designed for the wave conditions of $T_{1/3}$=12s, $H_{1/3}$=5.0m, and H_{max}=9.0m.

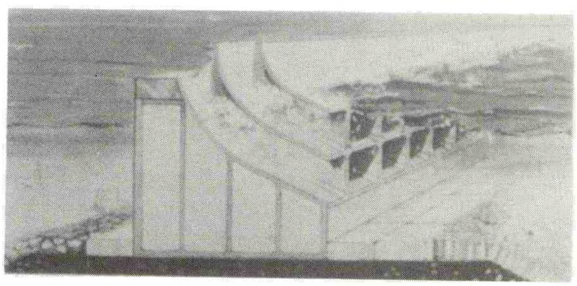
b. Curved Slit Caisson Breakwater

The curved slit caisson as shown in **Photograph 4** is one kind of wave dissipating caisson. Upper front of the caisson is made of arc-shaped members arranged in parallel each other. Behind the beam there is a hollow space which is a quarter circle in side view. From 1976 to 1983 intensive investigations had been carried out to study the hydraulic characteristics and to establish the design and execution method in the laboratory and field.

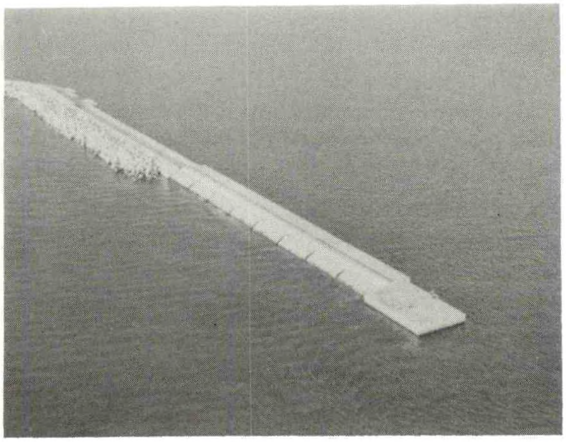
The wave absorbing capacity of a curved slit caisson breakwater is almost the same as that of the mixed-



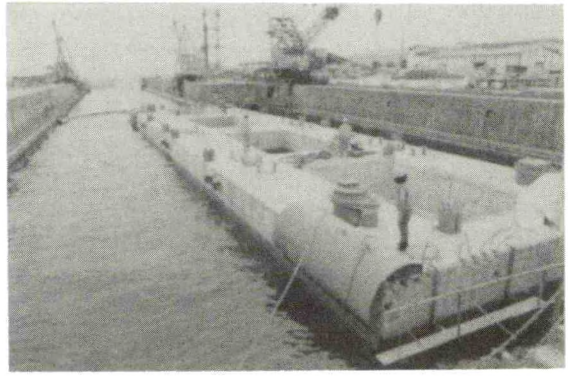
Photograph 2 Artist's Impression of Breakwater with Wave Power Extracting Caisson



Photograph 3 Artist's Impression of the Multi-Cellular Caisson



Photograph 4 Curved Slit Caisson



Photograph 5 Floating Breakwater just after joined in the dock

type breakwaters covered with wave dissipating concrete blocks. The wave transmission coefficient of a curved slit caisson is slightly less than that of an ordinal caisson without a wave chamber. The crest height of the upright section is to be determined as the same height as ordinary caisson breakwater.

The curved slit caisson breakwater of 150m in length was completed at the Port of Funakawa in 1984 by the 1st DPCB. The design wave conditions are $T_{1/3}$=8.7s, $H_{1/3}$=5.5m, and H_{max}=9.9m.

The arch-shaped of prestressed concrete members were prefabricated and fixed to the caisson by the dry joint method. Strength of a arch-shaped member was tested in the laboratory of the PHRI and the design method was established.

c. Floating Breakwater

Floating Breakwaters were constructed at several ports in Japan recently. It has been thought that a floating breakwater is not effective according to the high transmission coefficient against the relatively long period waves. But, it has been improved recently through various analyses and experiments. In the conditions that the wave period less than 5s or so, the transmission coefficient becomes under 0.5. Then floating breakwaters has become feasible in the sea where waves are of short periods and small wave heights. The sea satisfying such conditions are a inland sea, heart of a bay or a inlet, lakes and so on. Possible structural materials of floating breakwaters are steel reinforced concrete, prestressed concrete, composite of steel beams and concrete, fiber reinforced concrete, and so on.

The 4th DPCB had constructed a one unit of floating breakwater at the Port of Kumamoto in 1982 for examining the performance, stability, response and mooring forces. The unit for the examinations is 40m in length, 10m in width, 4.0m in height and 3.0m in draft. The unit was constructed in four parts on land. Then they were lifted, launched and towed into the dock where they were joined each other in one unit. The joining was executed in the wet condition with glue, then whole of the structures banded with PC bars. **photograph 5** shows the floating breakwater in the dock after joining.

3. PIERS AND QUAYS

1) Gravity type Structures

a. Steel Plate Cellular Bulkheads with Embedding

Steel sheet pile cellular bulkheads are being used as one type of gravity type port structures. For faster construction, a new type of cellular bulkhead has been developed. It uses cells made of steel plate in stead of sheetpiles. The cells are prefabricated on a yard, then carried to the construction site by a floating crane. The steel cells is driven by vibro-hammers, then the cell is filled with sand.

The stability and the earthquake resistance of the steel plate cellular bulkhead were studied jointly by the PHRI and several private companies of a steel works and contractors. And the design method was established.

The steel plate cellular bulkhead were adopted for the sea walls at the Port of Nagoya, Port of Komatsujima and Kansai International Air port. As for the Port of Nagoya, ten bulkheads were constructed of which size are 19.5m or 21.0m in height, 20.0m in diameter, 10mm in thickness and 13.0m or 16.0m in length of embedding. As for the Kansai International Air Port, 69 bulkhead has been installed in length of 1790m as a part of the sea wall of the man made island. The size of the bulkhead are 23.0m in height, 11.5m in diameter, 10mm to 13mm in thickness, and about 7m in length of embedding. **Photograph 6** show the driving of the steel plate cellular bulkhead at the Port of Nagoya.

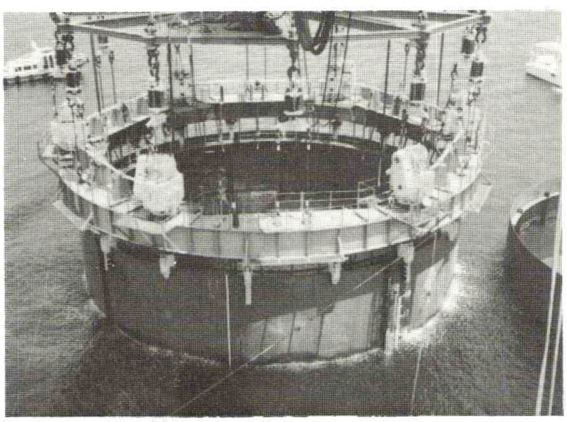
2) Floating Type Structures

The hexagonal marine structure (hereafter HMS) is a floating structure of steel reinforced concrete consisting of six trapezoidal blocks which are joined each other with PC bars to form hexagonal shape in plan. The HMS was developed by the 2nd DPCB for facilities of marine leisure and recreation. The HMS has several merits such as prefabrication of each unit at a yard, good stability because of a side-float type, durability because each concrete unit is prestressed. Since HMS has hexagonal shape many HMS can be joined together to form desired configuration. So, HMS can be used for mooring facilities, floating breakwaters, fishing piers and floating piers. Beside, basin inside the HMS is used for a swimming pool, or a space for exhibition and so on. The first HMS was constructed in the dock belonging to the 2nd DPCB, then carried to the Inawashiro Lake and installed as a boat landing. The length of a base of the each trapezoidal unit is 6m. Another HMS has been used for the Seaside Pavilion of the Yokohama Exotic Showcase '89 (YES '89) which is being held at the coastal zone of Yokohama city. The length of a base of each trapezoidal unit is 20m. The basin is used for a show stage of dolphins. **Photograph 7** shows the Seaside Pavilion at YES '89.

4.Execution

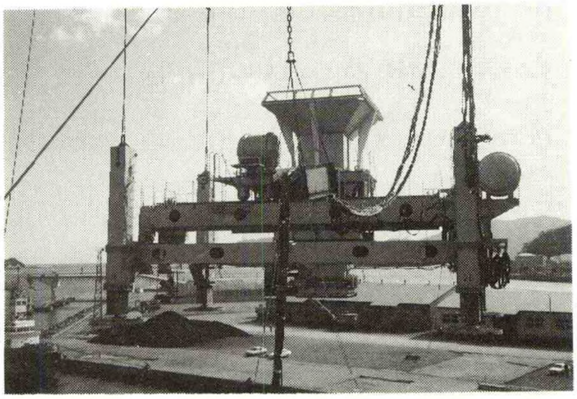
1) Leveling Machine of a Rubble Bed

In the construction of composite type breakwaters, the rubble mound on which caisson will be placed has to be made sufficiently flat. This leveling work is done by divers. As the breakwater construction goes to deep sites, the leveling of the top of rubble mound by divers becomes more difficult and dangerous. A leveling machine for a rubble bed has been developed by the 2nd DPCB. This machine can make both dumping rubble and leveling of rubble beds. The prototype test was carried out at the Port of Onahama in November 1986. **Photograph 8** shows the leveling machine hoisted by a floating crane.

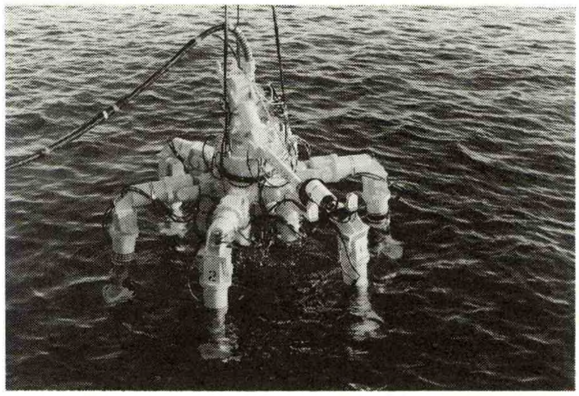


Photograph 6 Steel Plate Cellular Bulkhead with Embedding

Photograph 7 Seaside Pavilion at YES '89



Photograph 8 Leveling Machine of Rubble Mound



Photograph 9 AQUAROBOT

2) Aquarobot

An experimental model and a prototype model were made for development of underwater inspection robot. The experimental model is overland test robot which was not made watertight. The model was used for basic research and a debug tool for programme development. The prototype model which is made watertight was developed after tests of the experimental model.

The prototype model is the first walking robot on a sea bed. The robots are six-legged articulated "insect type" robot named as "AQUAROBOT". Each leg has three articulations and is driven semi-directly by a DC motor that is built in the leg and have a touch sensor on each foot. The robots can walk on uneven ground and any direction without changing its quarter.

The weight of experimental model and prototype model are 280kgf and 700kgf respectively. The control programme consists of operating and walking algorithm programmes which are independent each other but are interfaced by a robot language. A BASIC compiler and assembler are used to develop the control programme.

Walking tests of experimental model were carried out by use of both the flat and irregular terrain walking programme. As for the irregular terrain waking, the real rubble mound was constructed with rubles weighing in the range 10kgf to 200kgf. An underwater walking test was carried out in pure water in the test pool of 3m in depth. In the preliminary test, walking speed exceeds 1.8m/min. A field test was carried out in December 1987. The prototype model was operated on the underwater rubble mound in the port area of Yokosuka. **Photograph 9** shows the prototype model of "AQUAROBOT".

5.Facilities for Researches

1) Hasaki Oceanographical Research Facility(HORF)

Hasaki Oceanographical Research Facility (HORF) was constructed for field observation at the surf zone. The synthetic observation and measurement of nearshore phenomena such as waves, currents and sand drift which is very important to understand the mechanism of littoral drift in the surf zone is carrying on by the PHRI. **Photograph 10** shows the aerial view of the HORF which has been specially constructed for carrying out the field observation even in the severe wave conditions.

2) Deep water Wave Basins

The facility for experiments of deep water structures has been newly constructed. It consists of the deep water wave basin, the two-directional wave basin and the submerged shaking table. The facility is 50mx45m in size. In the deep water wave basin, there are four flap type wave generators which can make waves of the maximum height 60cm and there are four pumps which can make flow of 42cm/s in the maximum.

In the two-directional wave basin, there is a serpent type wave generator which consists of 35 units of wave generator which can be operated independently. The total system can generate short crested waves as well as a uni-directional waves in any desired direction. **Photograph 11** shows the two-directional wave basin.

3) Submerged Shaking Table

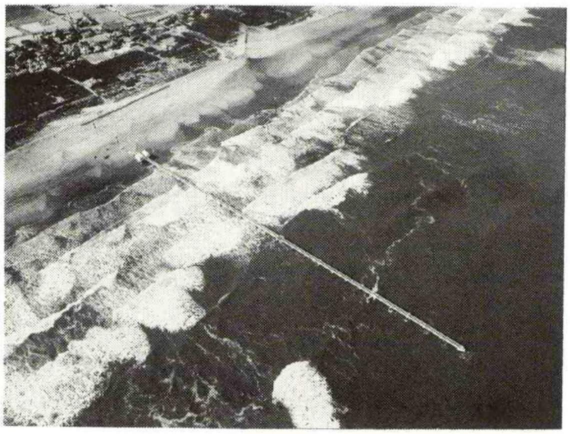
For experiments on seismic response of offshore structures, a shaking table combined with a water basin was constructed. 3.4mx3.4m portion of the floor is surface of the shaking table. The basin is 23mx13m in size, 1.8m in depth. The shaking table is driven by hydraulic actuators in horizontal and vertical directions simultaneously as well as separately.

The maximum accerelations with the maximum load of 60tf are 0.8G and 1.5G in horizontal and vertical, respectively. **Photograph 12** shows a artist's impression of the submerged shaking table.

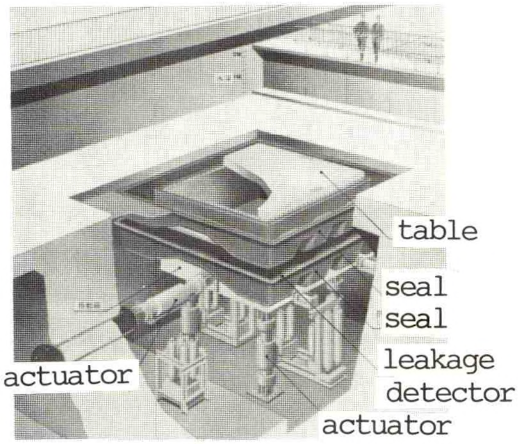
4) Geotechnical Centrifuge

A large scale centrifuge was installed in the PHRI, for geotechnical studies in March 1980 for the model tests which satisfy similarity between a model and prototype.

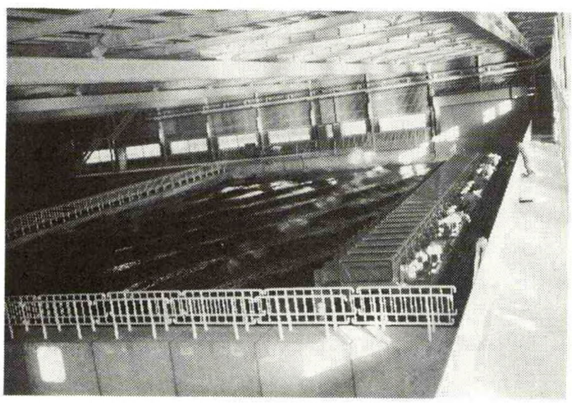
Under gravitational condition, the similarity is hardly satisfied in earth structures. This is the largest centrifuge among existing in Japan. The major specifications of the centrifuge are maximum effective radius of 3,800mm, maximum acceleration of 115G, maximum payload of 2,710kgf and maximum capacity of 276G-tf.



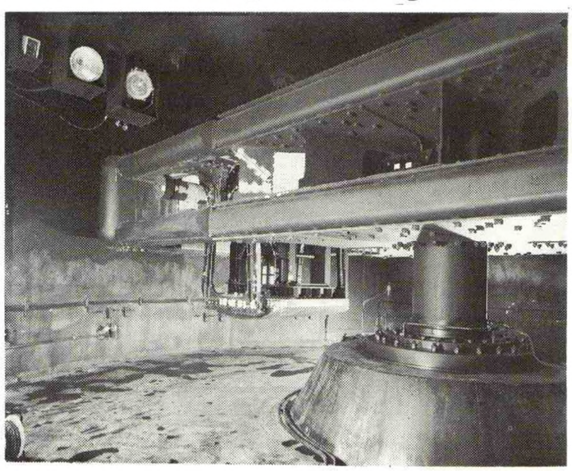
Photograph 10 Aerial View of HORF



Photograph 12 Artist's Impression of the Submerged Shaking Table



Photograph 11 Two-Directional Wave Basin



Photograph 13 Geotechnical Centrifuge

The centrifuge is used for two kind of studies. One is the simulation of soil and structure in realistic scale toreveal unknown behaviors or to verify analytical or numerical estimation. The other is the direct simulation of the prototype existing somewhere or tobe built in a future. Those studies have been carried out such as on behavior of the improved ground by the Deep Mixing Method, bearing capacity of sandy ground, behavior of normally consolidated clay ground. Furthermore, the centrifuge is employed in dynamic soil researches. **Photograph 13** shows the geotechnical centrifuge of the PHRI.

6.Observations

1) Coastal Observation

The nationwide coastal observation network consists of 40 stations as of 1986. Observed wave data are recorded on the digital magnetic tapes and sent to the PHRI by mail. At the PHRI, the characteristic wave parameters (significant wave height and period, for instance), histograms of wave height, the joint distribution of wave height and period are computed from those wave data. In addition, wave power spectra are also computed to each observation station and are published as an annual report of the PHRI. The raw wave data, the lists of the characteristic wave parameters of the observations and the statistics are stored in the data base or magnetic tapes in the PHRI.

2) Observation of Strong Earthquake Ground Motions

Strong Motion accelerographs have been installed in major ports in Japan for recording earthquake ground acceleration. As of December 1987, 80 accelerographs have been installed in 54 ports. The collected records are reported in the Annual Reports on Strong Earthquake record in Japanese Port. On ground acceleration records whose maximum accelerations exceed certain levels the analog reproduction of accelerograms, digitized records, Fourier spectra and response spectra are included. The response spectra are classified in accordance with subsoil conditions at each observation station and the average response spectra are calculated from each of them.

7.Concluding

Above mentioned topics of the newly developed structures and researches concerned are instances among all. Ministry of Transport is promoting the researches on the construction ports and harbours jointly by the Bureau for Ports and Harbours, the District Port Construction Bureaus and the Port and Harbour Research Institute. Beside any description was not made, studies on purification of sea are intensively carried on in Japan. As the results, the sea condition in a bay have been so much improved recently. Studies on civil engineering facilities of air ports are also carried on by the Civil Aviation Bureau as well as the latter two organizations above mentioned. It is expected that more advanced research works will be required according to the demand of the development and intensive utilization of coastal zone.

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FUTURE USES OF THE SEABED

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INTRODUCTION

"We know more about the back side of the moon than the bottom of the ocean," said a leader of the U.S. ocean community recently.[1] Many ocean experts believe that the seabed can be tapped for resources, recreation, security, needed land area and communications access in less time and at less cost than outer space.

The contribution of commercial (non-government) ocean business to the U.S. economy has been estimated at 1.7 percent ($76 billion) of the total U.S. gross national product of $4.527 trillion in 1987.[2] This is the same order of magnitude as other well-recognized segments of the U.S. economy, such as all farms ($76 billion), all mining excluding offshore oil and gas ($74 billion), transportation other than water ($131 billion), and communications ($121 billion). The seabed represents an area of national opportunity and long term economic growth. While current commercial uses of the seabed account for just over .25 percent of the U.S. GNP, future uses include: expanded oil and gas development, increased mineral exploration and production, innovative waste disposal solutions, corridors for cables and pipelines, harnessing ocean energy, conserving and developing biological resources, and the discovery and opening-up of cultural and recreational activities.

STATUS AND PROSPECTS FOR SEABED USE

Oil and Gas Resources. In terms of strategic importance and economic value, the exploration, development, and production of offshore oil and gas resources will remain, into the next century, the most important economic activity in the U.S. Exclusive Economic Zone (EEZ). Currently, about 12 percent of total crude oil production and 25 percent of total gas production is produced offshore and it is estimated that dependence on these resources will continue to increase each year as land reserves decline.[3]

Current technology is adequate to develop nearshore oil and gas resources. In the long term, maintaining the level of production of oil and gas from the EEZ will depend on developing technologies for deep water (over 300 m) and arctic regions. Many technical constraints face the offshore oil and gas industry as it moves farther onto the continental slope and into unexplored arctic regions. The environmental hazards of operating in deep and ice-infested waters are considerably greater and overcoming them will be far most costly than previous offshore oil and gas development operations.

Developing these areas will be affected not only by technical progress but also by nontechnical factors, such as fluctuating world oil prices, the impact of unstable political regimes in oil-producing countries, and a domestic regulatory climate subject to public pressure to protect offshore lease areas. Equally significant will be the extent to which government and industry cooperate to achieve a proper balance between meeting the nation's energy needs and environmental concerns and maintaining a competitive and technically innovative domestic oil and gas industry.

Mineral Resources. Current U.S. seabed ocean mining activity includes the dredging of placer minerals in Alaska and some dredging of construction aggregate near urban areas. Sand and gravel resources are estimated at billions of cubic meters. Placer resources and phosphorites, while not fully explored, have been discovered in abundance. Ferromanganese crusts and nodules are found in areas of 10-100 Km^2 in abundances of 10-100 Kg/m^2. Undiscovered resources of polymetallic sulfides, sulfur and other mineral lodes are also presumed to be large.

Except for construction materials, such as sand and gravel, and some placers, it is unlikely that substantial amounts of hard mineral resources will be commercially recovered from U.S. EEZ deposits within the next decade.[4] Depressed market prices, together with high costs of mining in marine environments, create an unfavorable economic environment for development of seabed mineral resources.

Future national needs for certain strategic materials could spur development of offshore mining industries for selected critical materials that are now imported by the U.S., such as cadmium, cobalt, copper, lead, magnesium and zinc. Lead times of up to 15 years are required for developing commercial seabed mining systems. It therefore seems prudent to establish the scientific and technical base necessary to assess and recover strategic or critical materials should national interests require them in the future. An integrated long-term (five to ten years) program of technology development is needed to perfect the tasks for comprehensive assessment of hard mineral resources in the EEZ seabed. Basic research is also needed in mineral recovery technology requirements for exploitation of deep-water deposits.

Waste disposal. The coastal and ocean waters surrounding the U.S. are used extensively for disposing of municipal and industrial wastes (see table), particularly dredged materials and sewage sludge.

TABLE: Ocean Disposal in the U.S. (1986)

WASTE	AMOUNT (10^6 tons)
Dredged Material	120.0
Sewage Sludge	7.0
Industrial Wastes	0.2

Public sentiment in the U.S. is currently against the use of the oceans for waste disposal. There is a growing perception that coastal ocean environments are deteriorating.[5]

Recent legislation places restrictions on ocean waste disposal and, in some cases, requires its phasing out in the next few years. However, some comparisons between land and ocean disposal options indicate that marine disposal is less expensive and less environmentally damaging than land alternatives, which leads some experts to believe that marine waste disposal is likely to increase in the next 10-20 years, despite current public sentiment against it.[6]

An estimate has been made recently of future particulate wastes, which could be disposed of in the oceans in an economically and environmentally sound manner, if the government were to authorize the activity (see table).[7]

TABLE: Future Wastes (year 2000+)[a]

WASTE	AMOUNT (10^6 tons/year)
Coal Combustion Waste	??.0
Industrial Hazardous Waste	77.0
Deep-sea Mining Wastes[b]	30.0
Municipal Incineration Ash	20.0
Oily Drill Cuttings	0.18
Ocean Incineration Waste	0.02

[a] Not included in the table is the concept of using submarine geologic formations as permanent repositories for containerized low volume, heavy, highly toxic, and radioactive wastes.
[b] Ten nodule processing plants.

Devising environmentally acceptable ocean waste disposal strategies for the future will depend on understanding of physical and chemical oceanic processes and how they affect sedimentation and mobility of contaminants. Distinguishing and isolating contaminated from uncontaminated material and specifying appropriate disposal methods for each type is another major requirement for developing sound seabed waste disposal practices.

Innovative engineered approaches to isolating and disposing of wastes in the ocean need to be tested and evaluated through pilot or demonstration projects in order to determine their effectiveness. For instance, placement of contaminated sediment in excavated pits that are then capped by clean sediment could be one of the most effective means of isolating material from the food chain.

Future use of the EEZ seabed for waste disposal will depend on socio-economic pressures, innovative technologies that won't compromise the use of other marine resources, and better understanding of the processes of dispersal and deposition of waste particulates. A comprehensive national policy for selecting long-term waste disposal strategies that includes evaluation and comparison of land- and ocean-based options and their impacts on the marine, terrestrial, and atmospheric components of the ecosystem would provide a framework for making wise choices about waste disposal.

Communications Cables. Half of all overseas communications are transmitted through ocean cables installed on the seabed. With the rapid development of fiber optic technology in the 1980s, the medium of choice shifted from satellites to cable. There are now four fiber optic communication and data transmission cables on the seabed. Five more are planned. The introduction of digital services by Intelsat International Business Service in 1986 led to a soaring demand for digital and higher quality service, as users dealt with "rain fade" and 0.25-second propagation delay inherent in satellite transmissions. One implication of the soaring demand for these facilities is an increase in the cost, in terms of lost revenue, of cable faults. The true economic cost of interruption to the user must be considered.

The greatest potential hazards to cables are bottom fishing trawlers and natural downslope processes, such as slumping and sediment flaws. Armoring and burying of cables has helped somewhat in combatting cable faulting by trawl gear, although fisherman often cut away lightly armored cables to free their gear.

Geological processes and the composition of the substrate are the most crucial physical conditions affecting emplacement and maintenance of ocean cables. Improved geophysical survey equipment and acoustical sensor systems, along with more effective procedures for interpretation of geotechnical survey data, would yield benefits in terms of improved route selection, reduced installation and maintenance, and greater reliability.

Military Uses. The U.S. military uses the seabed for the placement of sonar and transducer systems of various types to support R&D activities; to test and evaluate ship, submarine, aircraft and weapon systems; and as integral parts of tactical and strategic monitoring systems. Other military uses of the seabed include mooring systems, as a site for search and recovery of sunken objects, and (in the past) for disposal of surplus material. The military also has operational requirements for detailed information about the seabed to support mine and antisubmarine warfare, as well as submarine navigation.

There is every reason to believe that there will be an increased military presence on the seabed in the future. The same technology developments that have changed the economics of submarine cables are enhancing military capabilities and uses as well.

A major issue related to the expansion of military uses of the seabed is the conflict between military applications and commercial, recreational, and/or environmental interests. Military uses generally preclude civilian uses of an area for reasons of safety, interference, or security. An additional problem associated with military uses of the EEZ seabed is the imposition of military classification restrictions on some categories of bathymetric data, which leads to gaps in the EEZ seabed ocean data base. Recent changes in policy have reduced some of the requirements for classification. Because of the likely expansion of the military presence in the EEZ seabed, it is important that these potential conflicts with other uses be anticipated and that policies be developed for resolving them.

Ocean Energy Resources. Ocean energy resources and related technologies are in very early stages of development. The extent to which they will make significant use of the EEZ seabed is difficult to estimate. The most likely candidate for development in the near future is ocean thermal energy conversion (OTEC), which is the harnessing of temperature differences between surface waters and deeper waters as energy. Pilot, shore-based OTEC systems have been tested and are under development in Hawaii. Hawaii's Natural Energy Institute is developing and operating cold-water pipes for aquaculture-related nutrient-rich, pathogen-free cold water and an open-cycle OTEC system.

Floating and/or moored OTEC facilities will require information on the physical properties of steep slopes which border U.S. subtropical and tropical islands and have access to deep, cold water relatively close to their shorelines in order to construct safe and reliable mooring or anchoring systems. In some configurations, the electrical energy would have to be transmitted to shore by seafloor cable, creating a need for detailed seafloor information along the cable route.

Commercial feasibility of OTEC will come after a world-wide increase in the cost of energy.

Biological Resources. Living resources associated with the EEZ seabed fall into one of two categories--commercially important fishery resources and organisms of special scientific interest or of potential importance as biotechnological or genetic resources.

The U.S. is one of the world's largest consumers of seafood products. Bottom fisheries (flounders, lobsters, crabs) catch in 1988 was 811×10^3 metric tons, valued at \$1.25 Billion.[8] There is potential for expansion of the domestic fisheries industry into deeper waters to capture non-traditional resources, such as deep crabs and ocean perch.

Many bacterial species found in chemically unusual marine environments are logical candidates to study for their ability to degrade toxic chemicals; and some marine benthic invertebrates are potential sources of pharmaceutical agents in the treatment of cancer, AIDS, and other diseases.

Research in this area needs to be focused on improving our under-standing of the bases of biological productivity, its variations, and the effects of human activities on these processes. Improved methods of assessing population sizes of deep water animals and bacteria are especially necessary for increased utilization of wild stocks from the new regions of the EEZ. Newer techniques based on remotely operated vehicles, better sensors, acoustics, and improved data interpretation may alleviate present assessment problems.

Such fundamental knowledge of biological and living resource processes will contribute to expansion of American fisheries, the development of new biotechnology products, and to protecting the quality of marine environments.

Cultural and Recreational Resources. Cultural and recreational resources of the EEZ include marine archaeology, treasure seeking and commercial salvage, recreation, and marine sanctuaries. While projections are difficult, it seems likely that new and improved seafloor exploration technology will stimulate interest in both marine archaeology and underwater treasure seeking. Similarly, the recent availability of affordable submersibles, coupled with public interest in the "underwater world", is expected to cause a substantial increase in the number of tourists visiting coral-rich areas in the Caribbean, Hawaii, and other Pacific Island locations.

There are currently about 100 professional marine archaeologists in the U.S. Their efforts to locate, excavate, and restore marine cultural artifacts are supplemented by numerous commercial salvors and treasure seekers. The U.S. has two designated marine sanctuaries in the Exclusive Economic Zone. There are also two passenger submersibles carrying tourists to scenic undersea reefs in the U.S. All of these activities are expected to grow substantially in the next few years.

The identification and protection of unique underwater areas and habitats in the waters of the U.S. has to date been a limited effort. The need for designation and management of special seabed areas will grow as recreational uses and cultural interests expand. In order to designate and manage a marine sanctuary, a substantial amount of information is needed on the resources and the physical environment of the area. Federally sponsored mapping and exploration programs in the EEZ could include the identification of potential marine sanctuaries as a component in their activities. Early identification of such areas would forestall potential conflict among competing uses by allowing advance planning for the development of other resources to include sensitivity to environmental considerations.

ACHIEVING FUTURE USES

Using the seabed to its potential will involve great cost and long lead times, but the benefits to the nation will be substantial. The nation needs to plan now, if it is to realize the benefits of future uses of the seabed, which have been enumerated, in a rational way.

Policy and Coordination. The variety of uses envisioned for the EEZ seabed and the amount of data and information needed to plan and manage the rational conservation and development of this large region require planning and coordination mechanisms that involve participation by government, industry, and academia. Effective and efficient programs for the systematic mapping and surveying of the EEZ; the development of new or improved technology to gather data on the seabed; the early identification and resolution of potential conflicts among different classes of ocean users; and the development of approaches for multiple uses of certain areas depend on a successful cooperative relationship among a broad range of public and private entities with a variety of views about the best uses of this region. National leadership is needed if needed policies and coordinating mechanisms are to be developed.

Mapping, Surveying and Discovering. A national program is needed to discover the resources of the seabed and gather basic reconnaissance information as a basis for development and management. The scope of needed information is vast and includes geological framework and resources, geotechnical characterization, oceanographic conditions, biological resources, and attributes of cultural and recreational significance. Specific information products and systems need to be developed to meet user needs.

Technology Development. Marked improvements can be made in the efficiency of present activities related to mapping and surveying the EEZ through application of existing and emerging technology and optimization of their use. For example, the use of expensive acquisition platforms can be optimized through shared use and multipurpose instrument packages. More efficient bathymetric systems can also improve survey efficiency. New geoscience probes and samplers can be developed to directly indicate the presence of valuable seafloor resources and to monitor seafloor processes. Technology development for acquiring information needs to be closely related to plans for utilizing the EEZ seabed. Requirements for data and specifications for equipment to acquire, manage, and analyze such data need to be defined in terms of specific user needs.

CONCLUSION

Six years have passed since the U.S. established jurisdiction over the seabed out to 200 miles. We now understand the significant benefits to the nation that will accrue from rational seabed use. The complexities, costs and time frames of seabed development are also becoming apparent. National leadership is needed to lay a sound, rational basis for future seabed developments.

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TOWARD A DEEPEST OCEAN PRESENCE

A presentation to the UJNR Sept 16, 1989

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Common Heritage Enterprises

The Center for Ocean Management of the University of Rhode Island has taken the leadership in the development of a concept called "A Deepest Ocean Presence" It proceeds from the conclusion that enjoyment of all ocean space is technically feasible, at least as feasible as the enjoyment of the atmosphere by all citizens of the earth and more feasible than the enjoyment of space. It encourages all projects to carry out their development in a manner which accelerates that goal. For example in the design and construction of the NR-1 of the United States Navy, every external component that could be designed and tested to operate in the deep ocean was so designed and so tested. The hull of the NR-1 could not be so designed within the then existing state of the art and as a result. The depth capability of the NR-1 is limited. Future generations will not, however, have to design the exterior components to achieve much greater depths.

A new opportunity to advance this concept is inherent in the plans and programs of the Pacific Center for High Technology Research to develop a National Oceans Resource Laboratory to be located at Ke-ahole Point in Hawaii. The planning for this Laboratory was authorized by the Legislature of the State of Hawaii. The legislative intent was the result of the success of technical developments at Ke-ahole and elsewhere in Hawaii that demonstrated conclusively that a new era in the use of ocean resources is about to begin.

The PICHTR study is proceeding by reviewing the major areas of ocean resource development in the context of the need for in-situ experimentation. The concept design of the laboratory will then be prepared with an attempt to meet as many needs of ocean resource and in particular energy resource development as will be feasible and cost effective.

PART A: THE OCEAN RESOURCES

The Resource categories which are being examined are A) Deep Ocean Water, Waste Management, Ocean Minerals, Ocean Space, and a not insignificant category entitled "Unique Physical Characteristics"

DEEP OCEAN WATER

The use of deep ocean water as a resource has been under investigation by various researchers and entrepreneurs utilizing the facilities of the Natural Energy Laboratory of Hawaii. Substantial progress leading in some cases to current commercial feasibility have occurred for closed cycle OTEC, Open Cycle OTEC, the use of the deep-water cold for air conditioning, industrial cooling, atmospheric condensation, micro climate control (for the growth of spring crops), plant mariculture and animal mariculture. Many other uses of deep ocean water such as the production of fresh water from deep ocean reverse osmosis, in situ production of energy and protein through piping of photons and warm surface waters to a deep ocean site and the anchoring of location of deep ocean pumps for servicing "soft deep ocean water recovery pipes" . The development and proof of these concepts will require in situ facilities consisting of shore based complex for component development, a pipe corridor, a stable ocean platform for the ins situ tests of sea based components and a test platform located at a depth of approximatelyamtely 1000-1500 feet for the testing of components that will be located in the intake region.

Figure 1

WASTE MANAGEMENT

The use of the ocean for waste management has been a political tabu of the world society for several decades. Careful rational studies have however indicated that the most environmentally effective means of waste management can often take place in the ocean environment. Thus, and in spite of political resistance, the world will, in the not too distant future, utilize the ocean as a resource for waste management. Prominent among the proposals is one for the construction of ocean platforms for waste incineration.

Already in operation are diffusion outfalls. The use of biological wastes for nutrient enhancement is another as yet undeveloped waste management resource of the ocean. Toxic waste disposal through deep ocean dilution is equally feasible and environmentally sound but has the highest political resistance. Perhaps the most intelligent use of the ocean for waste disposal is for the deep ocean burial of high level nuclear wastes. At the same time this method of disposal is probably the most politically unacceptable. In situ test facilities employing benign materials for the demonstration of these various waste management techniques will therefore be an absolute requirement before world opinion in this area becomes rational and the resource is exploited. In situ facilities for such programs will require stable platforms for the demonstration of at sea industrial processes and deep ocean platforms for the development of techniques of seabed burial and or diffusion and disposal techniques for nutrients or benign toxin simulators. These tests sites may require depths as great as 15,000 feet or more to provide realistic environments.

WASTE MANAGEMENT

Platform Incineration

Nutrient Enhancement

Deep Ocean Dilution

Diffusion Outfalls

Deep Seabed Burial

Figure 2

OCEAN MINERALS

The potential for ocean minerals in many of their manifestations has been the subject of investigation for the past fifteen years. Although the general consensus is that practical exploitation of deep seabed minerals in the form of manganese nodules or manganese crusts will not be realized until the next century, it is equally true that mining of placer deposits may be of practical importance in the immediate future.

Much is still unknown about the nature of deep seabed mineral deposits and in particular those associated with geothermal ventsand the mineral sands which may have evolved from these geothermal vents. Therefore the development of sampling and exploration techniques for the deep seabed will be of vital importance in the next decade. Tests sites in shallow waters up to 1000 feet will be required to simulate the placer environment. Test sites at depths of about 3000 - 5000 feet will be required to simulate the manganese/cobalt crust environment and deepest ocean sites (15,000 feet or more) will be required to simulate the nodule environment.

OCEAN MINERALS

Manganese Nodules

Cobalt Crusts

Geothermal Chimneys

Geothermal Sediments

Placer Deposits

Figure 3

OCEAN SPACE

The use of ocean space, on the sea surface, in the water column and on the seabed will become one of the most ubiquitous and economically and socially relevant uses of the ocean in the next two decades. The development of a low cost stable platform module which is capable of assembly and disassembly at sea will open the way for the replacement of overseas military bases, the establishment of offshore manufacturing and processing facilities, creation of coastal zone theme parks, hotels and convention centers, etc.

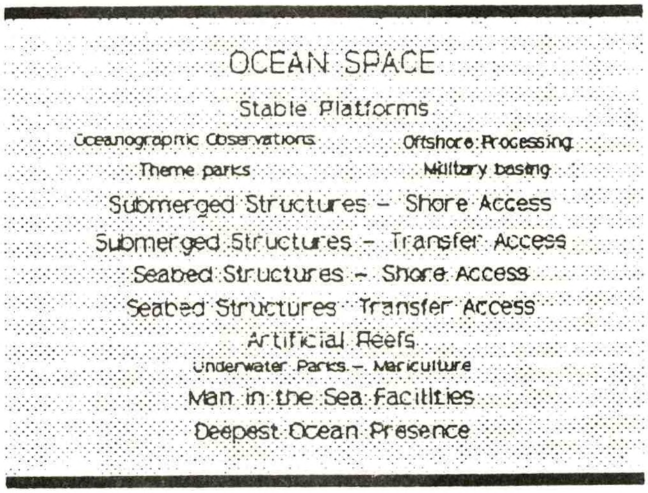


Figure 4

Tourist submersibles which are accessed from the shore or from a platform at sea are already proving popular. The submersible operator has the additional requirement of establishing entertaining underwater parks and "sea - worlds" which are visited by these submersibles. Although such facilities now exist in only few locations it is quite obvious that in the near future no oceanic recreation community can afford to not have one or more of these submersible facilities.

Submerged seabed structures which are accessed from the shore are already popular as underwater 'sea worlds' in Japan and should equally popular in the North American continent. The technical problems of the mating of a submersible to an underwater structure have already been solved in connection with the U. S. Navy Deep Submergence Systems Project. The marriage of the tourist submersible to an underwater structure will provide visitor access to underwater parks such as black coral gardens and deep seabed reefs which are not otherwise available to shallow water seabed structures.

Without particular fanfare, developments in undersea saturation have made spectacular progress. Saturation diving to a depth of 1000 meters has been demonstrated by French researchers. Although recreational saturation diving seems of limited significance, industrial and military capabilities will become of increasing importance as the use of ocean space becomes commonplace.

Test and evaluation facilities for ocean space will include the development of access tunnels through the interface, the test and evaluation of stable ocean platform modules, the development of construction techniques for the installation of structures and artificial reefs at depths of 1000 and 3000 feet. The development of saturation diving support equipments and chambers to facilitate operational techniques for divers at 1000 and 3000 feet. A diver lockout submersible will also be required for a full development, test and evaluation capability.

Finally the development of a deepest ocean capability will require a test and evaluation site having a depth greater than the triple point for most gases (i.e . in excess of 10,000 feet) and access to test areas whose depth is 20,000 feet or more. ,

UNIQUE PHYSICAL CHARACTERISTICS

There are many other unique physical characteristics of the ocean which if employed by society would constitute valuable "ocean resources". Indeed, the use of the ocean for the deployment of secure invulnerable deterrent systems. Is a prime example of one such ocean resource. In this instance it is the opacity of the ocean with respect to all but the lowest frequency electromagnetic radiation and all but the highest energy nuclear particles that provides the screen behind which submersibles can hide. This quality makes the ocean a rich scientific resource for such projects as project DUMAND. This is a volumetric array of Cerenkov radiation detectors which, deployed on the bottom of the ocean, act as a telescope to record the high energy neutrinos and muons that emanate from the farthest regions in space.

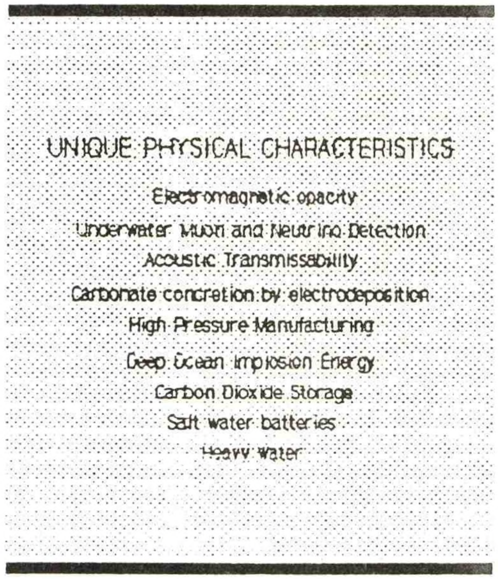


Figure 5

A corollary to the opacity of the ocean for electromagnetic phenomenon is the transmitability of acoustic signals. Acoustic imaging (acoustic tomograpahy) is thus a capability not available in the atmosphere or in the solid earth.

Other characteristics which may prove to be significant includes the ability of the ocean to store large volumes of carbon. Inherent in this capability is the storage of the excess carbon dioxide which is generated by industrial processes and which plays a major negative role in the so called "greenhouse effect".

Just as there has been a manufacturing in space program, so should there be a "manufacturing in the ocean program". Pilot programs have already demonstrated the efficacy of carbonate concretion by electro-deposition as a construction material, the use of high pressure in the curing of concrete and the possibility of utilizing implosion energy for deep ocean tools and processes.

Many other properties could be cited. The saline character of the ocean makes it an ideal electrolyte for "salt water batteries" or other electrochemical processes involving ion exchange. The large quantities of heavy water in the ocean make it the only meaningful source of this potentially valuable energy fluid. Etc, etc, etc.

The implications for a national ocean resource laboratory are obvious. The selection of a site for Project Dumand has already taken place at Ke-ahole and will be a part of the complex whether or not a NORL is officially established.

PART B: THE LABORATORY

Based upon the preceding assessment of ocean resource potentials and the existing facilities at Ke- ahole a recommended set of components and facilities is presented in a three phase development plan. The Ke-ahole complex today consists of the Natural Energy Laboratory of Hawaii and the Hawaii Ocean Science and Technology Park. These facilities are in the process of merger into an overall authority which will most probably be designated the Ke-ahole Ocean Development Authority. Conceptually the Ke-ahole Point complex is patterned after the space complex at Cape Kennedy in Florida. Government, University and Industry Clients contract to locate their facility on the point. They may at their election and subject to negotiation contract to use the facilities and/or services of NELH/HOST or they may utilize their own facilities and services or some combination thereof. In planning the NORL it is presumed that many of the services and facilities of the NELH/HOST will be incorporated into the Laboratory by contract. It is expected that the great majority of facilites and services will be devloped by NORL in accordance with such master plans and interface agreements as may be required for administration of the entire Ke-ahole point complex.

Ke-ahole is a relatively unique land sea configuration. Situated at a point of land in the tropics in an area of high solar insolation it enjoys access to deep ocean water. The slope of the underwater terrain is on the average about 2 to 1. Thus a complex located at a depth of 5,000 feet (1 miles) will be located about two miles from the shore. Figure 6 is a plan view of Ke-ahole Point showing the depth contours out to 100 fathoms. Figure 7 indicates the current location of the pipe corridors at Ke-ahole and a proposed NORL corridor. The corridor extension to a depth of 15,000 feet is not shown in these schematics. This site is, in fact, approximately 20 miles out to sea and constitutes a facility separate from the corridors.

The laboratory complex is envisioned in terms of test sites located on the sea floor and in the water column above the sea floor at locations in which the water depth is 1200 feet, 5000 feet and 15, 0000 feet. Three phases are envisioned. The first phase will require minimal capital improvements to the existing site components will be rented or contracted for whenever possible to accomplish the specific experiments that have been authorized. Phase two will involve capital expenditures for components which are required but which can no longer be obtained by lease or contract. Phase three will involve capital expenditure for components which themselves will have been developed by and for the NORL. The components themselves will provide for laboratory functions as indicated in Figure 8. No time scale is given for each phase except to note that Phase one can be implemented immediately with an operational capability in from one to three months. Phase two should be implemented in from two to three years after IOC and phase three could be in place in from five to ten years.

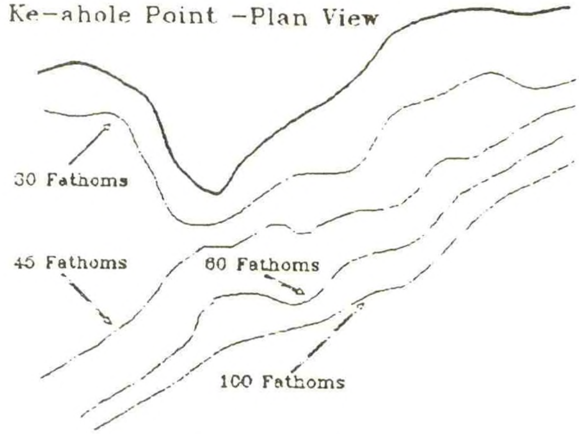


Figure 6

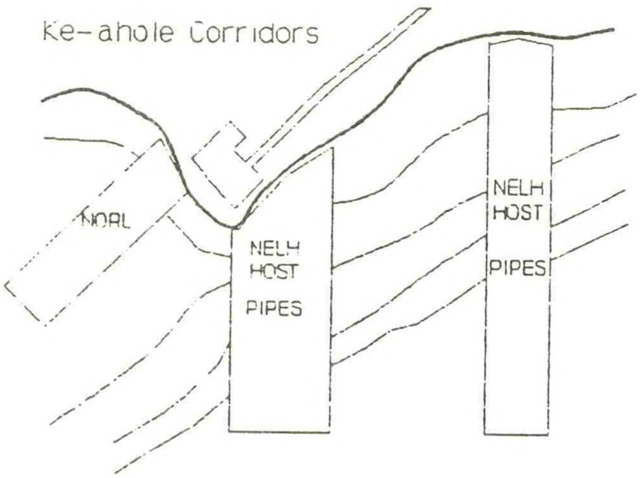


Figure 7

PART C: THE COMPONENTS

The components which are required begin with the shore based facilities. These must include shops and design spaces for the production of the incidental hardware that will be required for each project. They must include computers, data processing and computational centers for the collection and analysis of the experimental data, there must also be an archive for the collection of data which will be of relevance to multiple project users. Classroom and instructional services must also be provided for briefing of scientists who will be using the facility for the first time or who need refresher orientation. A second suite of shore facilities will be required for the land based components of systems that are to be tested and evaluated. In this category would be "hangar queen" OTEC plants, aquaculture facilities, pipe and pumping systems, desalinization components, etc.

NORL COMPONENTS

SHORE BASED COMPONENTS

Analysis Archive Conference Center

Shops – Project Test Facilities

SEA BASED COMPONENTS

Land Sea Interface Conduits – Navigation Grids

Underwater Site to Shore Umbilicals

Submerged Site Specific Facilities

Humans at the Site Facilities

Water Column Transfer, Work, Observation Facilities

Stable Sea Surface Mobile Platforms

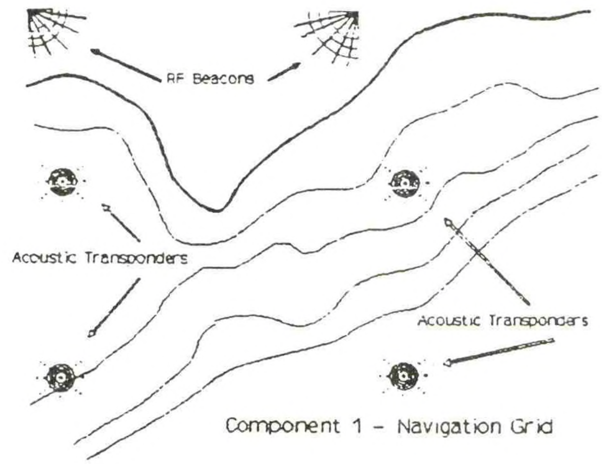
Figure 8

Seaward, the first new component that must be installed is that of an underwater navigation and positioning grid which is tied into a surface navigation and positioning net. The next component is the system of tunnels pipes conduits, marine railways, tramways for crossing the land -sea interface. The next component is the system of pipes, cables, fibre optics, hydraulic and power umbilicals that are required for the several underwater sites.

The sites themselves and the cameras, lights, space grids and other site appurtenances themselves constitute a component of the Laboratory. Submersibles and ROV's are elements of a functional component which acts as transfer and observer in the water column between the bottom site and the surface platform. An important part of this function will be carried out by swimmers, divers and saturation divers. The "Man at the Site capability will, because of its complexity and need for safety, be considered as a separate component. Finally the stable mobile platform at the surface completes the ability to work and monitor the land, the seabed, the water column and the sea surface for almost any project that can be contemplated.

THE NAVIGATION AND POSITIONING GRID

Absolutely essential to the operation of an oceanic laboratory is a precisely surveyed navigation and position grid. Due to the nature of the two environments air and sea this must consist of an above water and undersea component. Numerous shore based radio frequency surface grid systems (Shoran, Hiran) are commercially available and easily installed. The underwater system should consist of a field of transponder beacons in the range of from 15 to 20 KC. These should be installed as the very first step of phase. Phase 2 can add sub grids in the form of acoustic reflectors or simply optical markers and grids in regions of the three sites where precise location is desired. Phase two should also include a suite of doppler sonars for use on the various manned submersibles and unmanned ROV's. If not already in existence navigation satellite and inertial navigation systems should be available for the surface platforms. Phase 3 should consider the addition of an inertial navigation system for use on the submersibles and/or ROV's



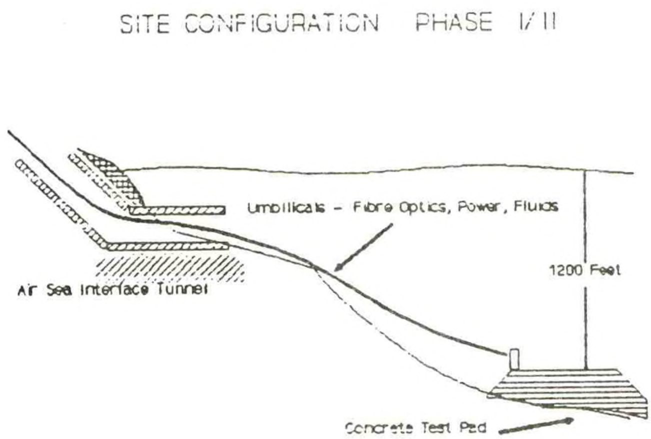
Component 1 - Navigation Grid

LAND SEA INTERFACE CONDUITS

A major component of the laboratory will be the system of access conduits and corridors from the land to the undersea. At the present time the seaward components of the Natural Energy Laboratory consists of the coldwater pipes, their pumps and the electrical cables that connect to the pump. Except for the forty inch pipe these pipe lanes are laid above the sea bed and the ground and are protected by structures with wave absorbers that are built around them. In the vicinity of the air sea interface large steel pipes are used to house the pipes and the cables that extend into the sea. The 40" pipe is below ground in a rather expensive cut and cover operation. Major installations offshore require the use of boats or ships which are deployed from the small boat harbor or from Kawaihae. Phase one of NORL will probably have to rely on similar ad hoc techniques for the umbilicals and the cables to the underwater research sites. Phase two will rely in part on authorized developments of tunneling techniques. The initial tunnels should be adequate in size for the umbilicals and perhaps for diver ingress and egress. Phase two should include a marine railway for launch and retrieval of submersibles and platforms. Phase three contemplates the construction of very large diameter tunnels capable of being employed for launch and recovery of submersibles, diver lock out vehicles etc.

SUBMERGED SITE SPECIFIC FACILITIES

It is expected that three underwater sites will be prepared for the conduct of underwater test and evaluation of resource related devices. Three depths are chosen 1200 feet, 3000 feet and 15,000 feet. The first two are chosen in part to match the depth capabilities of the submersibles Makali'i and Pisces VI and in part to match the depths required for OTEC and manganese crust mining experiments respectively.



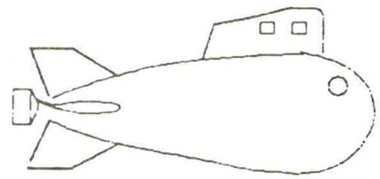
The 15,000 foot depth is chosen as the depth required for DUMAND (Deep Underwater Muon and Neutrino Detection). Phase one will require site preparation in the form of selection of reasonably flat test areas. Concrete test pads will be installed on the sea bed with fixtures appropriate for the attachment of lights, cameras, acoustic dishes and transponders etc. Fixtures for the acceptance of fibre optic cables, pipes, power cables will also be required. Phase two will include a submersible test platform patterned after the Launch and Retrieval Platforms employed by the Hawaii Undersea Research Laboratory. Each platform will be outfitted on land for the particular experiment of interest then launched submerged on the marine railway and towed to the site in the submerged condition. At the site the platform will sink to the concrete pad and be positioned by thrusters in a manner similar to the positioning of the Navy Deep Submergence Rescue Vehicle. As needed additional platforms will be built with a goal of six platforms when Phase three is implemented. Each platform will be designed to the extent possible to be located at any one of the three test sites.

HUMANS AT THE SITE FACILITIES

Diver capabilities at the platform sites (1200 and 3000) feet will materially aid in the ability to conduct experiments at these depths. Diver capability at 100 foot depths will materially aid in crossing the air sea interface and in the installation, maintenance and repair of near shore installations. Phase one should include a diver facility with a decompression chamber capable of recompression to a depth of at least 200 feet and treatment at the standard 40 foot medical protocol depth. Phase two should include a diver transfer capsule and surface deck decompression chamber to permit operations at a depth of 1200 feet. Mixed gas Heliox systems must be provided for this capability. Phase three should extend diver capability to 3000 feet on Hydrogen/Oxygen mixtures and employing protocols developed by the French. A habitat at 1200 feet should be part of the phase three complex.

WATER COLUMN TRANSFER, WORK, OBSERVATION

In the absence of divers, manned and unmanned vehicles will be required to make physical transfers, to do work and to carry out observations in the water column and in transit from the surface to the site, In phase one, the assets of the Hawaii Undersea Research Laboratory will be available on a contract basis. These consist of the Makali'i a two man submersible with a 1200 foot depth capability and its submersible launch and recovery platform, and the Pisces VI a three person submersible with a launch and recovery platform having a 3000 foot depth capability. A number of commercially available ROV's should also be included in the suite of equipments that constitute the permanent components of the laboratory. In phase two the ROV's should be supplemented by replaceable one atmospheric hulls for the housing of experimental equipments. It is also understood that the Pisces will have a replacement hull which gives it a full ocean depth capability.

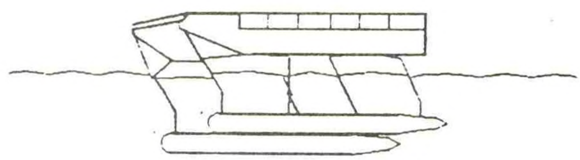


PHASE I WATER COLUMN

Makali'i 1200' Submersible

STABLE MOBILE PLATFORMS

A crucial element of the Laboratory is the stable mobile platform. Twenty years of experience with the U. S. Navy SSP Kaimalino has demonstrated an order of magnitude improvement in motion characteristics of this platform vis-a vis standard displacement hulls. The effectiveness of the ship as a research platform has also been demonstrated. Similar experience has been achieved by the Japanese Swath oceanographic ship and by the Japanese Swath ocean engineering platform. Phase I will therefore employ the Kaimalino on a contract basis with the United States Navy. It is expected that a commercial swath ship will be available for contract utilization in time for phase II. Presuming the implementation of the currently proposed national program for the development of stable ocean platforms Phase III will employ a module of that program as its permanent stable mobile ocean platform.

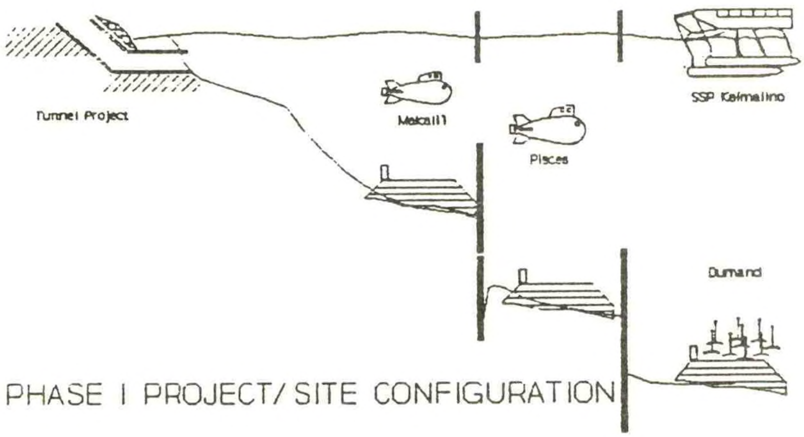


PHASE I STABLE PLATFORM

SSP Kaimalino – U. S. Navy Mobile Platform

PART D PROJECT IMPLEMENTATION

It is expected that projects for the laboratory will result from advertisement of the capabilities and availabilities of the labaoratory and its components. A number of projects are already assured for conduct at the Laboratory when it is commisioned. Most advanced of these profects is Project Dumand. This is a program under the aegis of the University of Hawaii Department of PHysics and sponsored, among others, by the Department of Energy and the National Science Foundation. An array of sensor strings of Cerenkov radiation detectors will be located at a depth of 15,000 feet and will be connected by fibre optics to the shoreside computer facility.



PHASE I PROJECT/SITE CONFIGURATION

Other projects in various stages of implementation include the construction, test and evaluation of a closed cycle OTEC demonstration facility. This project will be designed to facilitate the introduction of alternate components of closed cycle, hybrid cycle and semi-open cycle systems. The existing heat and mass transfer facility and the developing open cycle facility are candidates for inclusion in the NORL.

Already authorized with appropriated funding is a project to develop tunneling capabilities for slant drilling which will permit the low cost development of OTEC tunnels, vehicle transfer tunnels, diver access conduits, umbilical conduits etc;

Many other subsidiary projects including the development of underwater construction by electrolytic deposition of calcium carbonate on wire mesh, test and evaluation of Knapp acrylic underwater observation hulls, etc etc. Figure 9 is a schematic of Phase 1 configuration and operations at IOC (Initial Operating Capability).

FLOATING STABLE PLATFORMS: CONCEPTS AND APPLICATIONS

Howard R. Talkington

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Introduction

As specific events provide a highlight to particular requirements, the concept of applying large, stable floating structures to a variety of military missions and civilian needs is given increased emphasis about every 8 to 10 years. The recent military activity in the Persian Gulf and the frustrating negotiations for continued use of the U.S. bases overseas (particularly in the Philippine Islands) have once again provided such emphasis. In the past, conceptual and technological capabilities have indicated the viability of applying large modular floating structures to replace the past reliance on foreign sites for forward area logistic and tactical support missions; and to provide immediate fully operational capability versus repetitive, expensive, long-term construction.

This paper's objective is to describe some early work by the U.S. Navy on a mobile ocean basing system (MOBS) concept, and to relate how the Navy concepts and principles could also be applied to current needs. Mr. Dan Hightower will present a companion paper providing an update of current workshops in the United States and reviewing the status of floating structures engineering. He will also prepare a program plan to develop a full-scale demonstration and engineering development validation model.

Requirements

A recurring Navy requirement has called for a transportable (mobile) forward tactical base from which aircraft could be launched for participation in tactical missions and which would provide docking facilities for surface craft engaged in patrol activities. It would also serve as a support and deployment point for personnel involved in the tactical missions. Logistic support requirements for the base, as well as for the missions originating from it, call for runways long enough for large transport aircraft and docking facilities for large ships. A large floating stable platform of modular construction was viewed as the concept which would best meet these Navy requirements.

The project came to be known as the Mobile Ocean Basing System (MOBS). The MOBS team was under the direction of the Office of Naval Research and the Defense Advanced Research Project Agency. The makeup of the team reflected a high level of intra-Navy cooperation. In addition to scientists and engineers from the Naval Ocean Systems Center, there were personnel from the Naval Civil Engineering Laboratory (Port Hueneme, California), the David Taylor Research Center (Carderock, Maryland), and the Naval Postgraduate School (Monterey, California). The team sought to meet the Navy requirement by fully developing the floating stable platform concept.

This concept was originally proposed to provide a major support base to be placed off the coast of Vietnam. Instead, a major base was constructed at great expense at Cam Ranh Bay, and later abandoned to be used by Soviet Russia. If a modular floating stable platform had been applied, the construction would have been accomplished in the continental United States at a great cost savings, and the platform could have been withdrawn at the conclusion of operations, retained for our own re-use, and thus, denied to the Soviets. Similarly, in the Indian Ocean, we could have had an immediate mobile floating "Diego Garcia" base, one that could be used as a bargaining "chip" in negotiations for other overseas bases (Philippines, Iceland, Spain, Greece, Beirut, etc.).

Floating Stable Platform Features

The concept validation model of a modular floating stable platform as conceived by the team is shown in Figure 1. This configuration offers all of the distinctive features which make the floating stable platform concept so attractive. First, there are the stability features that are the result of a small water plane area and a large mass and buoyancy at the base of the platform. Unlike the hull of a displacement-hull vessel (tugboat, destroyer, etc.), which is constantly affected by the surface wave action, the large, buoyant base of the floating stable platform is well below the surface wave action. The deck of the platform is well above the energy of the wave action. The only part of the platform modules subject to the forces of wave or swell action is a narrow segment of the vertical column (small relative to the total mass of the module).

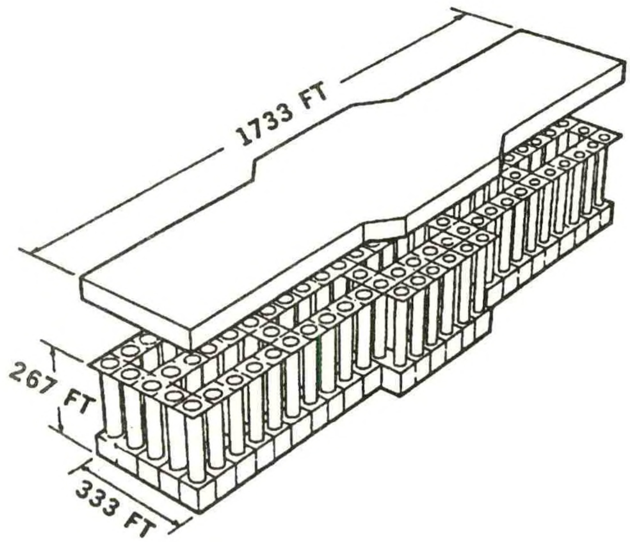

Figure 1. Modular floating stable platform concept.

Second, there are the fabrication and construction features. The modular approach provides for great versatility. The basic module can be easily formed from concrete—a low-cost, malleable material—by means of repetitive forms, such as those used for fabrication of tubes for the San Francisco Bay Area Rapid Transit (BART) or the large aqueduct pipes for the California water system. The tubes (and tube construction methods) for BART, which enabled the transit system to go under San Fransisco Bay, were of particular interest to the team working on the floating platform because the BART tubes are approximately the same length and diameter as the basic module for the floating stable platform. Each BART tube was formed in concrete in a graving dock, the dock flooded, and the tube floated to the appropriate area, ballasted, and lowered into position on the sea floor.

The same type of fabrication methods and materials (repetitive forms and concrete) will be used for the platform modules. Also the modular approach, while standardizing the basic unit, permits a wide range of possible configurations, i.e., the modules can be arranged in many different shapes. Each project could select a configuration which best meets its immediate need. Should that need change, the modular approach allows for easy modification of the configuration or for replacement of individual modules. If one or more modules are damaged due to accidents or attacks, the rest can well support the structure.

The hydrodynamic response of a floating stable platform has been demonstrated by testing a model. Figure 2 shows the model of another float configuration floating in a wave tank. Wave tests were also run on individual modules. In order to determine the model's stability (resistance to pitch, roll, and heave), many wave tank tests have been conducted. All the results indicate that the modularly constructed floating platform operates in an extremely stable condition during all expected sea states.

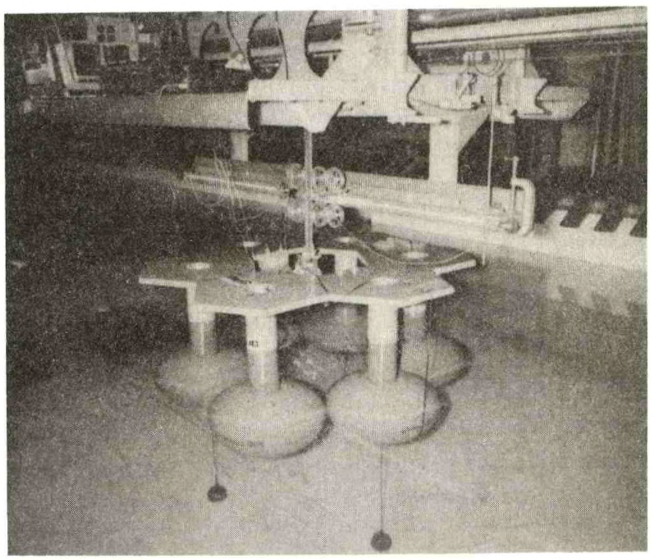

Figure 2. Floating stable platform model.

So the question is, how does the floating stable platform meet the Navy requirement for a floating, forward tactical base, the mobile ocean basing system (MOBS)? It can be shown that, by using the floating stable platform approach, the MOBS platform offers better time, material, and cost trade-offs; better security; and greater versatility than a comparable land base constructed in a forward tactical area. For example, consider a land site installation such as the Cam Ranh Bay base, approximately 180 miles northeast of Saigon, Vietnam. The base had to be designed for the particular location, carved out of the jungle, and maintained in a hostile environment (climatically and politically). When the base was vacated, the mobile equipment was salvaged, but the buildings and runways were left behind, for use by potential enemies. A multimillion dollar investment was abandoned. The MOBS platform provides an alternative which is not only less costly, but offers advantages unique to the concept.

Figure 3 shows a large MOBS-type platform that could be substituted for a base like that at Cam Ranh Bay or Diego Garcia. First, it would be available faster. The MOBS modules, having been prebuilt in the continental United States (thereby providing civilian jobs in CONUS), could be stockpiled in strategic locations throughout the world. From there the modules could quickly be assembled into the appropriate configuration (which may be changed to meet changing needs), equipped, and placed in position 10 to 50 miles from shore. Once in place and operating, the MOBS platform would not only meet the support and logistic requirements for a forward tactical base, it would be far more secure than the permanent-site base. It would be more secure against infiltration by sappers, against the plundering that can quickly denude permanent sites, and against mortar attacks (the platform is out of attack range, but close enough to support onshore ground forces). Then, when the requirement for that particular base no longer exists, the platform is either removed to a new strategic location or dismantled and stockpiled for future needs. Thus the completion of a requirement for the MOBS platform does not entail the loss of construction expenditures. Overall, the considered use of the floating stable platform concept means a more effective use of military funds. The floating stable platform concept in its military application as MOBS obviously meets the Navy's stated requirements quite successfully.

As a result of pursuing the feasibility studies on the floating stable platform, the Navy has developed a considerable amount of documentation on the technological outputs of the program. This documentation includes information on such things as material trade-off studies, detailed hydrodynamic test data, stability analyses, module construction techniques, and module attachment and configuration techniques. Aware that this technology can have useful applications in the civilian sector, the Navy has encouraged and is presently encouraging its dissemination throughout various scientific, industrial, and governmental communities. Platform data have been requested for use in connection with concepts for airports, power plants, offshore drilling and construction platforms, and industrial, and exposition sites.

Conclusion

Since the U.S. Navy's mobile ocean basing system study and experiments were completed, there have been many concept studies and designs developed for very large floating stable platforms. In a wide variety of applications, in many parts of the world, these large special-purpose platforms have been built, transported over vast distances, and successfully operated to support their basic requirements in various resources and transportation industries. Most of the MOBS-type individual components and procedures have been proven. The time has come to reassess the floating stable platform concepts and determine a plan of action to build a full-scale demonstration model.

Mr. Dan Hightower's paper will describe some current planning efforts to accomplish the goal of building a full-scale demonstration model.

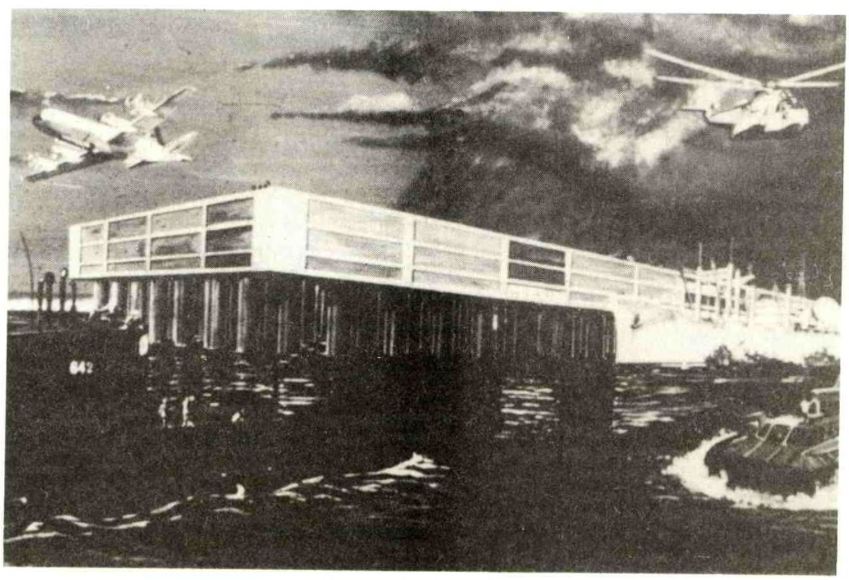

Figure 3. The 1000 × 4000 ft MOBS platform (artistic concept).

FLOATING STABLE PLATFORMS: CURRENT U.S. ACTIVITIES

J. D. Hightower
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Introduction

The concept of large modular floating structures that can be used for floating cities, airfields, or manufacturing facilities is not new. A form of the concept dates to at least 1932, when it was seriously proposed that stable landing fields be built in the mid-Atlantic as refueling stations to extend the range of commercial aircraft. In his 1960's comic strip "Our New Age" Athelstan Spilhaus envisioned that future generations would develop floating cities devoted to ocean-related industries.

In his paper for this meeting, Mr. Howard Talkington presented a historical perspective, from a Navy Laboratory point of view, on the formulation of concepts to use large stable floating platforms primarily for military logistics. The necessity of ensuring adequate military logistics basing was a major reason for this early Navy work and drove the requirements that were established in developing essential military applications.

Fortunately, top-level requirements for military applications are consistent with many, if not most, important and economically attractive commercial/industrial applications for large floating platforms. This commonality holds out the possibility of joint sponsorship by potential multiple users. Because a major floating platform development will have costs of considerable magnitude, joint utilization and sponsorship will likely be a key ingredient if such a development is initiated.

This document discusses some manifestations of the current interest in the general concept of large floating platforms and examines the symbiotic relationship between private industry, commercial and military multi-use that could make near-term development attractive as a commercial venture.

Background and Current Activity

Significant work on the concept of major floating stable structures was done in the late 1960's and early 1970's by universities and U. S. Navy Laboratories. This included work at Scripps Institution of Oceanography, the University of Hawaii, the Naval Civil Engineering Laboratory (NCEL), and the Naval Ocean Systems Center. The work at Scripps was funded by the Advanced Research Projects Agency (ARPA) and investigated column-stabilized platforms that could be used for deep ocean airfields, and a variety of ocean research and engineering support issues.

The work at the University of Hawaii concentrated on developing the concept of a floating city, an outgrowth of the Navy's Mobile Ocean Basing Study (MOBS). The significance of this work was the development of analytical tools for motion prediction and for buoyancy module designs with small waterplane area and low motion response characteristics. Subsequent sea tests verified that these tools accurately predicted the vertical acceleration of a 1:20 scale model which showed that the motions of the full size city would be below the level of human perception for the so-called 100 year storm conditions.

In 1974, based largely on this work, the Japanese built a demonstration floating city module, called Aquapolis, for the Okinawa World's Fair. In more recent years, Japan has continued efforts in this area including a design study for a 5 x 7.5 km floating "information" city. This design concept would share technical similarities with the MOBS/Hawaiian floating cities concepts by using small waterplane area buoyancy modules and dynamic ballasting techniques.

Additional recent work includes a floating airfield design by Bechtel Corporation for Kumagai Gumi of Japan and the design of a Short Take-off and Landing Floating Airport (STOLPORT) for the North Sea done by Seaforth Maritime Ltd. of Aberdeen, Scotland.

In the early 1980's the U.S. Navy initiated related work at NCEL and the David Taylor Research Center (DTRC) in the Deployable Floating Waterfront Facilities Program (DWP). In 1986, the Naval Ocean Systems Center (NOSC) suggested that it would be beneficial to consider a national effort using existing technology to develop major stable floating platforms as alternatives to overseas land bases. More recently, starting in November 1988, meetings have been held in the U.S. involving appropriate national experts, from the academic community, Navy laboratories, industry, and government to consider such an initiative.

The general consensus resulting from these meetings and preliminary studies by other various institutions, is that the employment of large floating platforms could well serve as a key element in developing a greatly strengthened national posture in ocean utilization. Further, it was generally agreed that the technology to support such an initiative is well founded. The following sections briefly present the key issues related to such a development and describe a program approach for the development of a prototype multiuse platform.

A Development Concept

While it was the experts' consensus at these recent meetings that there do not appear to be significant technology shortfalls, there are engineering issues that need to be addressed before moving ahead with a large floating platform program. These include techniques for joining modules or clusters of modules in an open seaway, verification of full scale intermodule connection loads and motions, validation of construction techniques, improved analytical tools, and costs.

The recommendation that resulted from the first meeting was that a prudent program, that would ultimately lead to the construction of a major floating platform of a size representing a city, an industrial complex, or a military base, should be done in phases. The phased development approach would center on developing and using modules that can be repetitively fabricated in conventional waterfront facilities. These modules would then be assembled into larger platform sections while floating. Finally, aggregate platform sections would be joined together in a seaway to provide the complete floating complex.

An essential step in a multi-phase validation approach would be the design, construction and deployment of a full-scale engineering prototype. An important feature of the engineering prototype would be that it would consist of at least three major sections in order to demonstrate that the three-body problem, including the joining of sections and the verification of loads and motions in a seaway, has been adequately addressed.

Figure 1 illustrates representative sizes and arrangements for the envisioned multi-phase program through the full scale engineering prototype phase. This program approach is efficient, since each of the phases not only answers engineering, operational and cost questions but also produces a useful end product. Top-level requirements have been formulated to provide a consistent set of guidelines for developing early platform concept design goals. These requirements are shown in Table I.

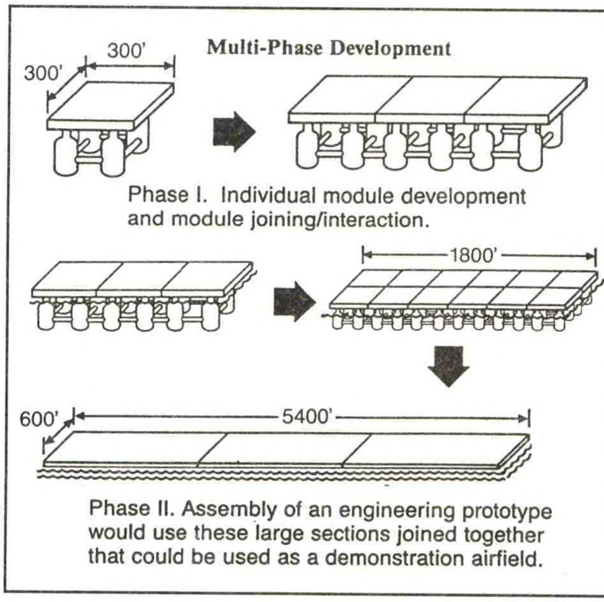

Figure 1. Multi-phase development leading to a full scale engineering prototype. Each phase would establish and validate engineering techniques and cost data while providing useful end products.

Non-Technical Issues

Based on the recent meetings and discussions noted here, the conclusions are that the overall feasibility of large free-floating (not-anchored) ocean complexes is well established from a technical standpoint. However, there are other non-technical considerations that are important to the overall practicality of this concept such as cost, law of the sea issues, and political considerations. Some thoughts at least on cost and the status of legal issues are appropriate for inclusion here.

Costs can be expected to be a critical issue and, therefore, need to be carefully studied especially when making comparisons to similar land-based functions. A common tendency is to make estimated cost comparisons based on cost per unit

TABLE I

Top-Level Requirements for Major Floating Platforms

- Size/Area. . . As large as 2 miles X 2 miles
- Construction. Reinforced concrete or steel
- Modularity. . . . . . . Built up from a few to several hundred identical modules
- Assembly/Joining. . . . . Modules and their clusters joinable in up to sea state 4 conditions
- Transport/Relocation. . Modules and their clusters towable or self-propelled at 3 - 5 knots
- Sites/Locations. . . . . . . All seas except ice covered
- Stability. . Suitable for land-based aircraft operations in sea state 4
- Station-Keeping. Maintain position within a 50-mile-radius circle.
- Infrastructure. . . . All life and operational support functions to be self contained
- Design life/Survivability. . . 50 yrs, survive all storm conditioning including the 100-yr storm, repairable in-situ
- Legal (Law of the Sea). . . . . . Operate as a ship when outside U. S. controlled water

area. In doing this, however, it must be realized that for land-based complexes it is easy to consider the cost of functions separately, (i.e. the area of the landing strip, warehouse and hanger volume, etc.), while for floating complexes it is more difficult. You cannot build a floating runway without constructing the large volume required for floatation. It is fairly obvious that it would be inefficient to construct a floating airfield without utilizing the floatation volume to satisfy other requirements.

Present estimates for building a large floating complex vary over a wide range and are dependent on specific functional requirements, as well as construction techniques and materials. Table II presents some available data and sources that have been adjusted to 1989 dollars. These figures were the best readily available and should be useful for bounding general cost estimates. A figure of $500 per square foot of top deck surface area is considered achievable and probably represents an upper cost bound including outfitting. The important point here is that these estimated cost figures are based on projected top surface area, however, they really encompass the entire complex including warehouse volume for maintenance and repair, spare parts, fuel and cargo storage, administrative office space and other infrastructure support subsystems.

It is conceivable that the per unit area cost can be lowered by a concerted effort to take advantage of the water as a building and staging site. There are proven construction techniques that are currently in use for fabrication of large floating concrete structures that if optimized and combined with economies of scale, should provide minimum basic structural costs.

In his paper Mr. Talkington briefly described one approach which was used to build the BART tubes. Another attractive approach is that used in Norway to construct concrete gravity base structures (GBS) shown in Figure 2. This technique uses a shallow temporary graving dock for initial construction of the base of the unit. The dock is then flooded and the base is floated into deeper water where slipform casting is used to complete the rest of the structure. A set up to produce

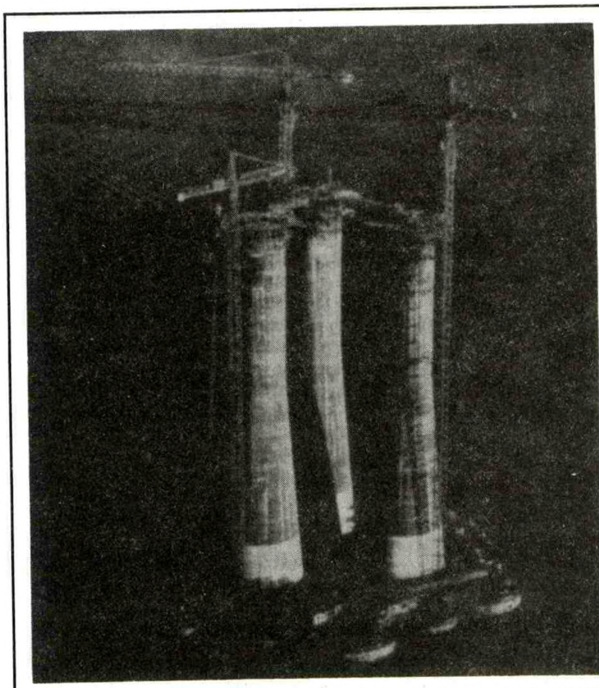

Figure 2. Large floating modules such as this concrete gravity base structure are built by constructing the base in a shallow basin then floating out to deep water for completion by slip form casting.

Table II
Large Offshore Platforms Cost Estimates
Costs Adjusted To 1989

Project Title	Size (ft^2)	Unit Cost (FY 89 $\$/ft^2$)	Total Cost (structure)
MOLI	4500 x 10,000 (19M)	400	$7.6B
Bechtel, Japan	470 x 8,000 (3.76M)	460	$1.7B
MOBS	1000 x 4,000 (4.0M)	410	$1.6B
OSP	600 x 5,400 (3.24M)	400-500	$1.3-1.6B
DWF	100 x 1200 (0.12M)	240	$29M

large numbers of identical modules using one of these methods or a variation thereof can be reasonably expected to provide real economies of scale. Designs and studies need to be done in considerably more detail than they have in the past to arrive at final costs suitable for budgeting purposes. However, considered in the above framework, it is reasonable to expect that a floating airport would be no more expensive to construct than its land-based counterpart.

The deployment of a large floating platform brings into play legal considerations that are currently being discussed and debated. In the intervening years since the initiation of the MOBS project, there has been significant change in the International Law of the Sea recognized by the United States. As noted in Table I, one of the major guideline requirements established for our concept definition is that the platform operate as a ship when outside U. S. controlled water. The principal reason for this, other than technical considerations, is that there is less likelihood of disagreement with any affected coastal state if the platform meets the technical requirements of a ship.

The present understanding is that the new law greatly constrains the nature of the floating ocean platform and the coastal state cooperation required for its deployment. Opinions center around the two obvious major options that are available for the deployment: the first that the platform installation be fixed or moored in the territorial sea or in the Exclusive Economic Zone (EEZ) of a coastal state; the second, that the platform be configured as a slow mobile ship with appropriate navigational markings. In the former case coastal state cooperation and consent will be required for both the territorial sea and the Exclusive Economic Zone. Apparently, on the other hand, if the platform meets the legal requirements of a ship, and in particular it meets the legal requirements of a warship, it has the right of free passage (including the exercise of weapons) in the Exclusive Economic Zone and the right of innocent passage (no exercise of weapons, aircraft, or submerged submersibles) in the territorial sea.

If it is not configured as a warship, then it must obtain coastal state consent if it is engaged in fishing, economic activity relating to the resources of the sea, extracting energy from the ocean, or if it is moored for scientific research, or for any reason other than survival. It is not clear whether the ship can operate as a free trade zone or engage in the conduct of manufacturing or some other non-resource related economic activity without the consent of the coastal state. The platform can operate as either a ship or a platform in any legal mode outside the 200-mile EEZ. None of these legal implications are considered negative for our purposes; they simply need to be considered in the overall context of application.

Applications

Large stable ocean-basing floating platforms offer the United States a technologically feasible opportunity to provide "real estate" for public or private use in areas otherwise restricted or undesirable because of environmental, economic, or geographic factors.

Candidate uses are many and varied, ranging from a platform sized for an offshore military support base to a platform requiring only a few modules. Ocean platforms can serve as centers to suppress narcotics trafficking and major weather stations for enhanced weather prediction and global climate studies. Other potential valuable uses include:

- Offshore power production including desalination of sea water
- Offshore mining and fishing support
- Commercial airfield/air traffic control
- Coast Guard interdiction platform
- Radar and weather observation site
- Toxic waste treatment plant
- Nuclear material production
- Major offshore recreation center
- Equatorial missile launch station
- Oceanographic research platform
- Military logistics

Figure 3 is an artist illustration of how such a multi-use platform might be configured.

In the wide variety of applications suggested here, there appear to be opportunities that may literally revolutionize the way some industrial operations are presently run. For example, the storage and treatment of some raw materials, industrial wastes or nuclear processing which is either restricted from or reluctantly allowed in the vicinity of populated areas, can be handled very effectively and efficiently on offshore floating platforms. In stressing the need for deliberate combinations of multi-purpose operations other synergetic opportunities come to mind. Energy production could certainly combine ocean thermal energy conversion (OTEC) and food production by utilizing the cold, nutrient rich discharge water. OTEC generated electrical energy could produce oxygen and hydrogen on site for non-polluting commercial space booster shots. If such a commercial rocket launch complex were located on the equator OTEC efficiencies would be optimized and the earth's angular momentum would naturally maximize payload benefits. Other optimum combinations will surely emerge with the encouragement of free enterprise incentives.

The principal advantage of the floating ocean platform as an offshore base is the strategic flexibility it affords while enabling the many troubling sovereignty issues to be avoided. The floating base would clearly be under U.S control but due to its offshore location would limit the in-country military presence. A floating base can be moved/relocated much easier and faster than a land base. This gives the military commander an

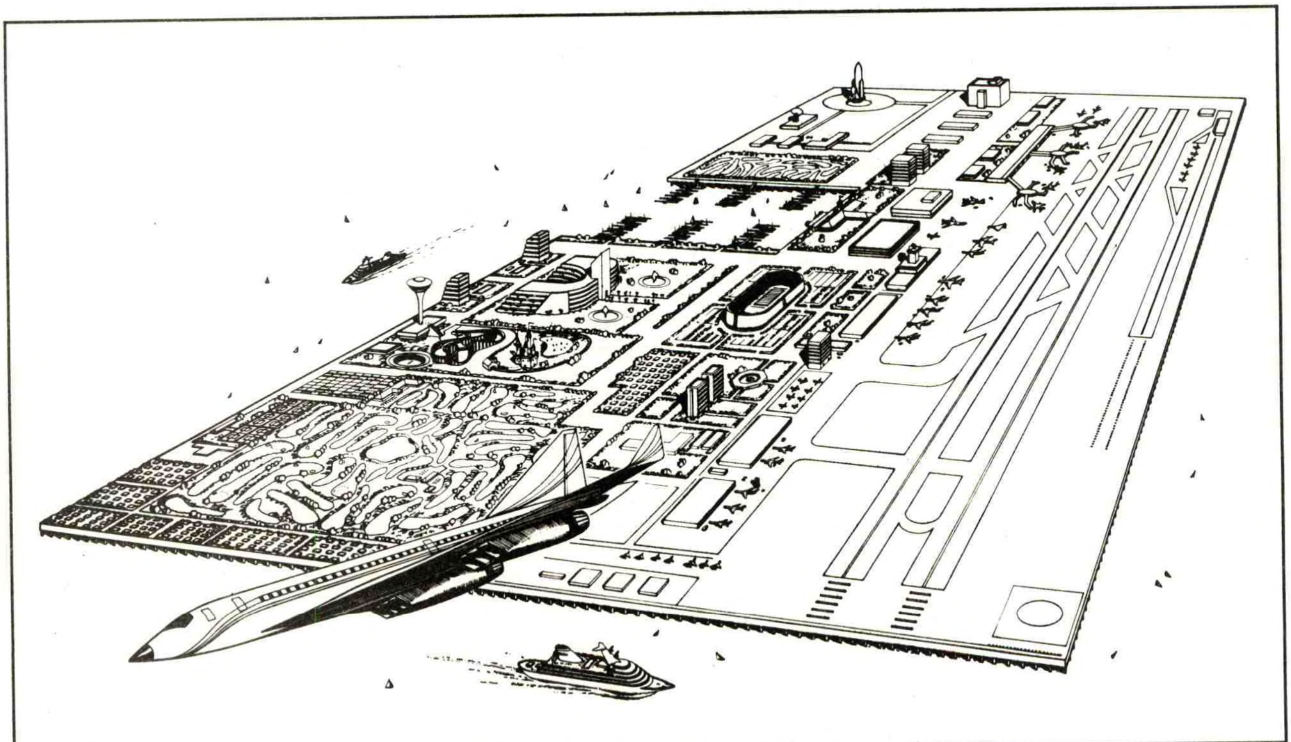

Figure 3. Artist illustration of a large multi-use floating complex. Typical dimensions might be a mile or more on each side. Design characteristics would allow either industrial or military use.

additional degree of flexibility by allowing the base location to be optimized to a specific mission. Further, the floating base has the ability to store massive amounts of equipment and supplies and would significantly augment our ability to preposition equipment in strategically critical regions. The life cycle cost of a floating base should be competitive with or possibly lower than that of a land base when the cost of land (rent and/or permits and economic assistance) is included. Costs will be more readily controllable for the floating base because they will not be directly influenced by the political, social, or financial conditions of a "host" nation.

While it is obvious that a large floating ocean platform has the potential to accommodate multiple users, it will be necessary to find uses that are compatible and manageable. An interesting concept is for the floating platform to serve one or more nondefense roles until required to support national objectives in a crisis situation. If a nondefense use that is compatible with the military need and location of the floating base can be incorporated in the design of the platform it will serve to reduce the life cycle costs chargeable to a single agency. Such distributed cost would be a favorable incentive to compensate for the large capital outlay required by initial development.

Suggested Implementation

The development of large stable floating platforms, as discussed in this paper, will require a considerable undertaking for full implementation. It is likely that a stronger and more focused government ocean utilization posture will be required to encourage private industry participation to take advantage of the opportunities afforded by large floating multi-use platforms. Some important steps that would be helpful in this direction are noted below.

1. Establish and promulgate a policy on Ocean Space Development to develop the resourcesòf the U. S. EEZ and to promote such activities or enterprises by combining the efforts of government, industry, academia, and public interest groups.

2. Initiate a multi-agency program to support large ocean platform development as a basing alternative, and as an initiator of EEZ economic development by U. S. business.

3. Formulate a plan of organization to implement this program. The Departments of Commerce, Defense and Energy would seem to occupy lead roles with other departments and agencies participating as appropriate.

4. Complete technical and cost studies in order to define the development program and provide a basis for evaluating private sector investment incentives.

5. Establish Federal guarantees for private sector financing to build demonstration platforms for selected applications on a "fast track" (2-3 year) program.

Conclusion

Although clearly beneficial to the national and security interests of the United States, such platforms would also be advantageous to the environmental and ecological studies now deemed so vital to the common interests of all the nations of the world. A concerted governmental and industrial effort funded by private capital, should be implemented to develop floating platforms under the auspices of a comprehensive national policy.

Even if none of the proposals or recommendations discussed in this paper are immediately adopted, the pressures of overpopulation, the increasingly strong feelings of national sovereignty, and the economic necessity of efficiently using and protecting our ocean resources make the idea of the large stable ocean-based platform an imperative whose time has come.

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ARTIFICIAL ISLAND PORT TECHNOLOGY DEVELOPMENTS

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Introduction

The world economy is increasingly dependent on trade and trade on efficient ocean transport, which in turn requires effective transport networks and hubs. Economies of scale and just-in-time transport are most effectively achieved by the establishment of deep draft load center ports which combine hubs for long distance ocean transport, cargo accumulation, storage and deconsolidation, as well as networks of feeder distribution and collections transport. Today this modern concept forms the basis for efficient modal and intermodal transport and is used in unitized as well as in dry and liquid bulk cargo transport. The most crucial link in this system is the deep draft hub port. Few industrial countries today have sites which are adequate to serve as deep draft hub ports and provide

1. deep water access,
2. large waterfront length,
3. large storage area,
4. good access to feeder transportation,
5. effective shelter and environmental acceptability, and
6. low cost and potential for future expansion and change in ocean and land transport technology.

Artificial island ports can provide most of the above characteristics at a low cost, with little or no interference with other economic activities in an environmentally attractive form. In fact, many offshore artificial island port facilities have been designed to serve the expanding demand of a hub port and port interface, as well as a depository and/or treatment facility for solid and liquid waste, including sometimes for toxic and even low level radioactive waste.

Artificial island ports have gained a lot of interest and their use has expanded greatly in recent years.

While most of these developments have taken place in Japan, Singapore, and other countries, which are short of land and where land with deep water access in or near population centers has very high values, other countries, such as the U.S. with lesser pressure for land, but serious problems of deep water accessibility, and of effective multimodal interchange have recently started to develop new artificial island port development and use technology, which is described in this paper.

Rationale for Artificial Island Ports

Artificial island ports have been developed in many locations to provide for efficient cargo transfer between large mainline (transocean) and short distance feeder waterborne transport vessels, such as petroleum, coal, iron ore, cement, phosphate rock, and feedgrain offshore terminals developed which combine deep draft port, feeder transfer, and cargo storage capability.

Where coal is used by electric power plants located in a coastal region, it is found attractive to establish a common deep draft coal terminal and stockpile to which coal is delivered for all plants in the region by large coal bulkers and from where coal is delivered by smaller push-towed coal barges to individual power plants where they serve as floating plant stockpiles from which coal is delivered directly to the plants' boilers. In this manner, not only are individual stockpiles (and stackin-g/reclaiming) equipments) eliminated, with a resulting savings in coastal land and great reduction in environmental pollution, but the common stockpile on the terminal island is usually significantly smaller than the sum of the individual stockpiles, while providing the same or higher levels of supply reliability.

A recent example of such an offshore terminal supplying 16 power plants with an annual consumption of over 40 million tons of coal was able to reduce stockpiled coal from over 5 million tons to about 1.3 million tons, a saving of 3.7 million tons, or a reduction of investment in inventory of over $160 million. The savings in coal inventory carrying costs alone sufficed to finance the construction and operating costs of the combined or hub offshore terminal, including those of the barge delivery system. Similarly, advantages are derived from the consolidation of oil storage tankfarms and terminals.

A plan to relocate 11 separate oil product terminals handling about 30 million tons/y-ear, with storage capacities of over 5 million tons, from the Chelsea Creek and other inner harbor waterfront sites in Boston to an artificial offshore island terminal, offers similar advantages. It would free up over 460 acres of prime waterfront land, eliminate a major source of water pollution from the Massachusetts Bay, allow deeper draft larger tankers or barges to supply the region, and reduce average required inventory from nearly 3.2 million tons to less than half that amount. Feeder or distribution transport in that case would be largely by pipeline. In future, consideration may also be given to the relocation of LNG terminals and storage.

Container transport has similarly undergone a major change. Intermodal integration and the introduction of large mainline 3000-4600 TEU vessels has generated the load center or container hub concept. Mainline vessels call at only one hub port in each region, which serves as the transfer terminal for ship to land and waterborne feeder transport. The percentage of containers transferred between mainline vessels to waterborne feeders at major container load center/hub ports has increased from just over 20% to over 50% in the last 10 years. This percentage is expected to increase further as land transport transfer is moved from load center/h-ub ports to non-port container depots or terminals. This change in the role and function of load center/hub container terminals is expected to offer opportunities for artificial offshore island container terminals with water, land, or mechanized (monorail, cableway, conveyor) transport interface to feeder terminals.

The economic and operational advantages of artificial island ports are becoming more pervasive. This trend is furthermore encouraged by the change in the historic role of the U.S. federal government which now requires that local interests assume a proportionally greater responsibility and share of the costs of channel improvements and dredger material disposal. This will obviously tend to foster relocation of deep draft terminals in naturally deeper water or offshore.

Furthermore, such a move may reduce major sources of environmental impact, permit effective development of solid waste disposal in a safe, acceptable manner, and allow the reassignment or use of traditional inner city port waterfront facilities to taxpaying and recreational activities.

Incentives for U.S. Artificial Offshore Port Development

The U.S. is the only major trading country in the world without extensive deep draft (deeper than 45') port facilities. While large U.S. container terminals are capable of handling 4th generation containerships with drafts of 12.0-12.8 m, there are no bulk facilities on the East Coast, and very limited facilities on the Gulf and West Coast capable of handling Panamax or larger bulk carriers or tankers.

U.S. ports and terminals handled an international bulk trade of over 400 million tons of liquid (mainly petroleum and petroleum products) cargo and about 380 million tons of dry bulk exports and imports. The additional cost of shipping this foreign trade in smaller ships than foreign trading ports would permit was conservatively estimated to be about $920 million in 1986 and should exceed one billion dollars in 1988. In fact, if freight and charter rates revive by 1990 as expected, the additional cost of U.S. international bulk trade resulting from the lack of really deep draft terminals (13 m plus) could readily reach $1.35 billion/year by 1990 and well over $2.00 billion/year by 1995.

This cost is enough to finance a deep draft port investment program of over $16 billion, which would be designed to provide an attractive set of new deep draft offshore or coastal artificial ports which would, in addition to savings in freight costs, reduce the cost of dredging, spoil disposal, and navigation to existing, usually for inland, terminals, many of which (particularly on the East Coast) are remote from the open sea.

It appears that the U.S. would be well advised to consider a new strategy for the development of offshore deep draft ports capable of handling bulk carriers of at least 150,000 dwt along all its major coastal regions, but particularly along the Atlantic and Gulf coasts.

The U.S. is increasingly dependent on foreign trade. The value of U.S. foreign trade has increased from barely 7.8% of GNP in 1960 to over 24% of GNP in 1988, and is expected to reach 33% of GNP well before the end of this century. The freight paid for U.S. foreign trade as a percentage of value of trade is the highest among OECD countries, particularly in liquid and dry bulk trades, and can be directly correlated with the smaller average size of tanker or bulker used and/or the additional costs of lightening.

To remain competitive in international trade and assure its economic growth, the U.S. will have to resolve its "shallow port problem". Artificial island port technology offers an attractive opportunity for the resolution of this problem.

Artificial Island Port Technology

Artificial island ports can be built in situ by filling an area with a containment barrier, by sinking prefabricated caissons by gravity, or by erecting a pile-supported platform. They can similarly be built elsewhere, towed to the site, and sunk in place, used as a semi-submerged or a floating artificial port island. Such ports can be designed to be permanently fixed in location or to be relocatable.

There are numerous design configurations, methods of construction, and choices in construction materials for use in artificial island ports. The selection depends on the purpose, environmental conditions, operational requirements, cost of material and construction, construction facilities (shipyards, etc.) and equipment available, life cycle, and value of relocability of island port.

Reclaimed or Filled Island Port

The most common type of artificial island terminal consists of a dike or containment wall designed to protect and contain the artificial fill which constitutes the island port area. Hydraulic fill or sand is preferably used and compressible material at the bottom removed or hardened by underwater cementing prior to the placement of the fill and surcharge by which the fill is burdened to assure its compacting and the consolidation of the bottom material. It is important to assure proper drainage of the fill during and after construction. the initial fill is usually placed by split barges floated in place for discharge but later, when depth becomes inadequate, fill must be placed by pumping or mechanically.

Containment of Reclamation of Artificial Islands

The traditional use of rubber mound breakwaters as a containment barrier in offshore reclaimed artificial island construction is now frequently replaced by the use of anchored reinforced concrete gravity caissons on a rubble mound base. These gravity caissons are usually armored by absorption type blocks, or inclined outer caisson cells with armor. New wave absorbing semi-circular slit caissons in which the wave force is always at right angle to the surface, recently developed and used in Japan, or multi-cellular gravity caissons in which wave energy is absorbed as the wave climbs up the slope of the breakwater [Ref. 3]. Some of these new breakwater-types have been designed for water depths of 50 meters and wave heights of 11 meters.

Various other types of breakwater have been developed recently, some of which separate the wave breaking from the containment function. Floating or penetrating caisson barriers designed to absorb the principal wave energies by converting it into caisson motion, into compression of air inside the caisson to be used to drive a turbine, or by introducing large surface and other resistance to the approaching waves. Containment is provided by a secondary barrier built of gravity caissons on rubble mound foundation at 50-100 meters from the wave breaking barrier. The containment barrier therefore need only resist small wave forces of 0.5-2.0 m. A prefabricated pervious wall-type containment and sloping caisson-type breakwater is shown in Figure 1.

A reclaimed island port requires piers and retaining bulkheads. Various approaches to the use of prefabricated gravity caissons, semi-submerged prefabricated pier construction as fill barriers, breakwaters, or for use as piers are shown in Figure 2.

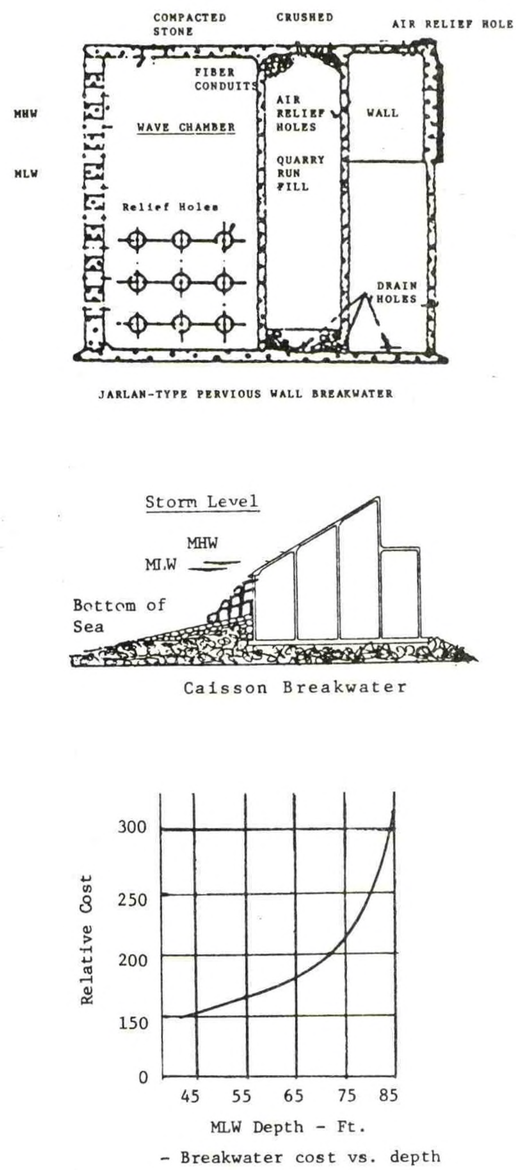
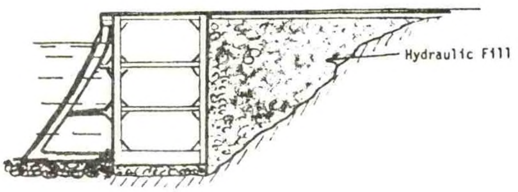


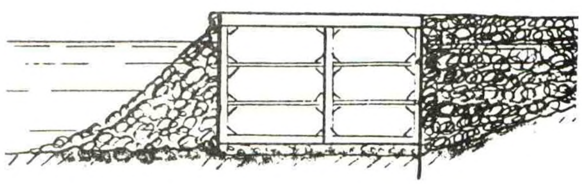
Figure 1 - Prefabricated Breakwater Caissons

These gravity caissons can be built of steel or precast, prestressed, reinforced concrete panels, floated in place and sunk by filling with water or sand and anchored with through piles and equipped with skirts driven through the bottom support layer to resist sliding and overturning.

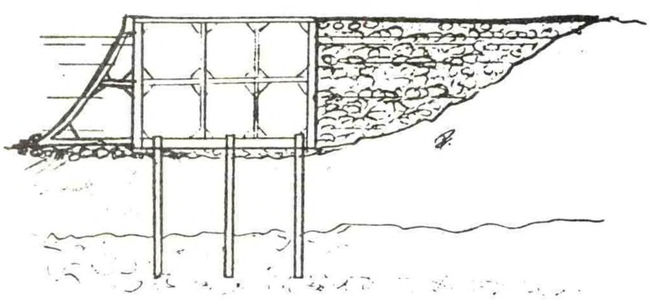
These gravity caisson containment barriers and piers can be refloated when no longer needed or relocation is required by removing the anchor piles and the ballast water or sand.



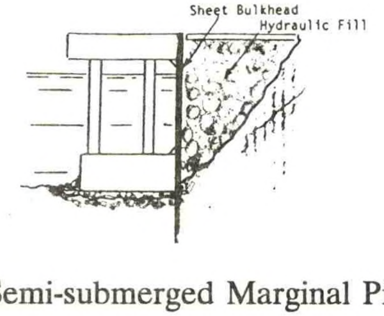
Prefabricated Sheet Pile Bulkhead Marginal Pier on Aggregate Blanket with Self Setting Skirt



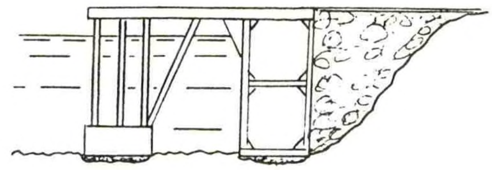
Prefabricated Island Sheet Pile Bulkhead on Aggregate or Hydraulic Fill Blanket



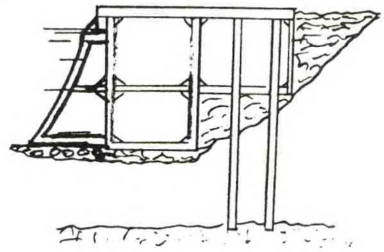
Prefabricated Island Pier on Drive Through Piles



Semi-submerged Marginal Pier



Semi-submerged/Caisson Combination Pier



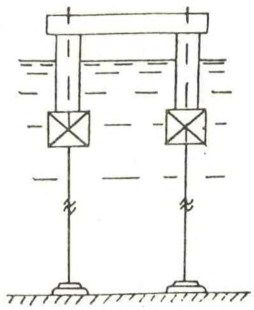
Caisson Pier With Drive Through Piled Box Extension

Figure 2 - Prefabricated Port Concepts

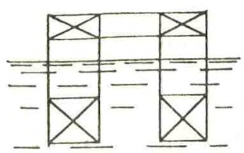
Floating and Floatable Island Ports

In many locations floating piers or terminals provide effective port capability. These are usually designed as stable platforms which use the principle of semi-submerged catamaran (Semcat) and/or tension leg platforms. A combination of these two also often provides an attractive solution as shown in Figure 3. Semi-submersible catamaran platforms can be designed to operate either under floating variable draft conditions or be ballasted down to act as submerged gravity caisson supported platforms, depending on local soil and environmental conditions.

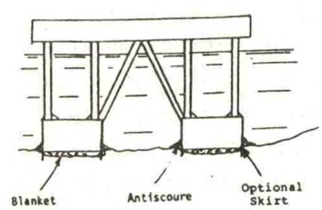
Semi-submerged catamaran terminals have been used as iron ore transfer storage and loading terminals in Murmagoa, India, and as coal loading and unloading offshore terminals in various parts of the world. Such platforms with floating displacement of 30,000 tons or larger can usually be used up to Seastate 3 with wind velocities of up to 16 knots and wave heights of 3-6 feet. They are often designed for the transfer of commodities between barges or coastal vessels and large ocean-going bulkers and provide buffers as large as the capacity of the largest bulker to be served. In some cases, such platforms are connected to shore by cableway or causeway supported cargo delivery systems.



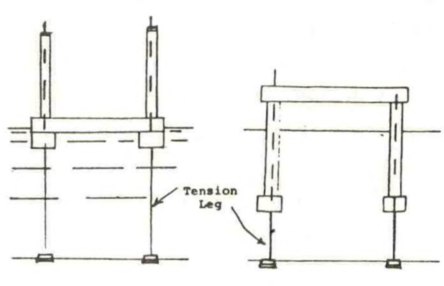
Tension-Leg Semi-submerged Platforms



Semi-submerged Platform



Semi-submerged Island Pier



Jack Down Semi-submerged   Tension Leg Platform

<u>Figure 3 - Semi-submerged and Tension-Leg Platforms</u>

Wave Effects

The wave regime in the vicinity of a floating platform terminal is probably the single most important determinant of the feasibility of a floating port terminal. While wind and current forces are, for practical purposes, constant in magnitude and direction for some period of time, in most locations, the oscillatory nature of waves gives rise to forces and motions which are time-dependent. The complexity of the problem is further increased by the interdependence of forces and motions. A rigidly-held ship will experience very large wave forces, similar to those acting on a breakwater, while a ship free to move in the wave will experience much smaller forces. The magnitude of wave forces is, therefore, related to the "give" in the moorings, anchoring, or position keeping used, both in the anchoring of the platform terminal and the ship to terminal moorings. Even small changes in the stiffness of the moorings, or a rearrangement of mooring lines, frequently have a remarkable effect on the behavior of the vessel and on the mooring stresses.

Ship motions and mooring stresses are affected principally by the following: (1) wave length, height, and direction; (2) stiffness of moorings; (3) mass of vessel; and, (4) water depth.

A given seastate may constitute a sea or a swell or a combination of the two. In the usual definition, a sea is the result of a local storm and contains waves of generally shorter period than swells which are produced in a distant storm and arrive at the operations area during otherwise good weather conditions. Vessels or floating terminals of larger mass will tend to have their maximum motions in waves of longer periods than vessels of smaller mass. This is in accord with the observation that large vessels or terminals respond more to a swell while smaller vessels respond more to a sea condition. It is important therefore to assure adequate elasticity in the mooring of a ship to a floating pier or terminal.

When semi-submerged catamaran terminals operate in their gravity caisson support mode (Figure 4), they can be connected in various ways with the shore and may also serve as container terminals as shown. Such terminals are not only cheap to built and prooutfit, and take significantly less time to complete, but are also relocatable and expandable.

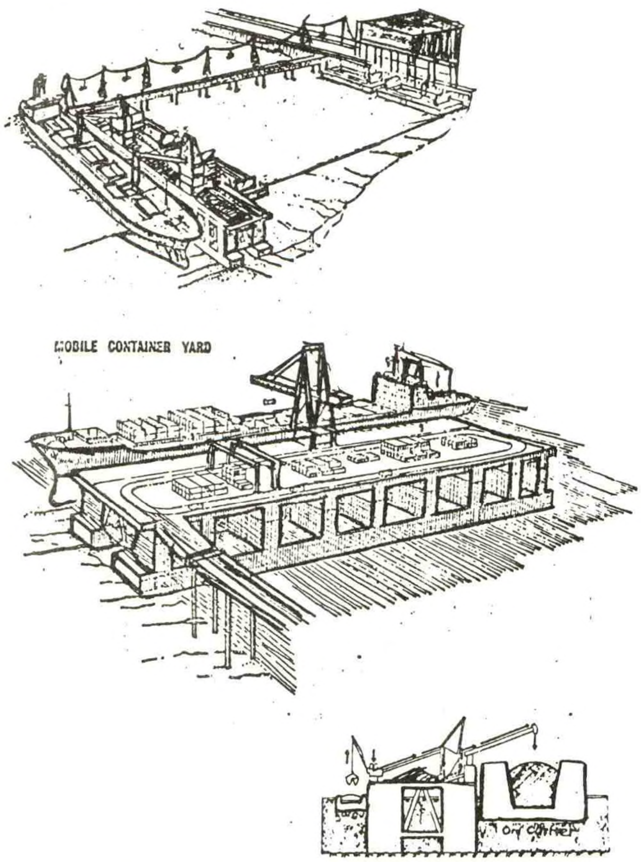


Figure 4 - Semi-Submerged Catamarans as Gravity Prefabricated Island Terminals

Economics of Artificial Island Ports

The capital costs of ports have escalated not only in terms of the cost (or value) of waterfront land but actual construction costs. Using World Bank data, the average costs per meter length of berth (with a 25 m apron) and other port facilities are shown in Table 1 (excluding waterfront or land real estate acquisition costs). The storage costs include: hardening, filling, compacting, foundations for rail or other equipment guideways, surfacing, etc.

Table 1 - Cost of Berth/M (In $000)

Water Depth (m)	Container		Dry Bulk		General Cargo	
	Berth 25m	Storage per ha	Berth 25m	Storage per ha	Berth 25m	Storage per ha
9	28	1000	20	600	10	580
10	32	1000	23	620	11.5	660
11	37	1050	27	640	13	750
12	42	1120	31	670	15	830
13	48	1200	35	710	17	-
14	54	1290	40	760	-	-
15	60	1390	45	820	-	-

In other words, a 240 m bulk terminal berth with 15 m alongside with 2 ha of storage (stockpiling) area has an average construction cost of $10.80 m plus $1.68 m or $12.48 million, excluding equipment, dredging, and related costs, which depend on local conditions, the need for breakwaters, dredged channels, etc. Such a terminal would usually take 4-5 years to build. Similarly, a 270 m long container terminal berth with 14 m alongside and 5 ha of storage and back area activity land would cost $14.58 m plus $6.45 m or $21.03 m.

Comparative costs of a semi-submerged catamaran bulk terminal (excluding equipment) 249 m x 70 m would be $15.80 m. In addition the cost of outfitting, distributed services, equipment transport and installation (all of which would be done right at the building yard) would probably be 20-40% less for the semi-submerged catamaran terminal.

Considering reclaimed island ports, the cost of barrier and containment depends mainly on water deoth, wave height, and underwater soil condition. In locations where wave heights are not expected to exceed 2 m and in sand bottoms, the cost of breakwater barriers is on average $28,0-00 m in 15 m depths. the resulting costs per bulk berth in 15 m of water with 2 ha of storage area is $29 million, if a single berth reclaimed artificial island is constructed under such conditions. These costs decline significantly when several berths and stockpile areas are constructed.

A fixed artificial island facility is therefore significantly more costly than the construction of an inshore facility, only if the value of waterfront and storage area used is ignored. If waterfront costs are in excess of $30,000/m and $1,000,000/ha, then an offshore island bulk terminal will be more economic, from a capital cost point of view alone, independent of the savings in dredging cost, ship turnaround costs, and environmental impact cost, as well as the value of tax revenues from the alternate use of the waterfront land.

Artificial Island Port Technology Developments

The increasing demand for artificial offshore island ports has fostered new technology developments in the construction and use of such facilities.

Methods have been developed for the prevention of liquefaction of sandy underwater foundations under breakwaters or gravity caissons.

Similarly, deep mixing or underwater hardening of clayey or silty underwater soils in situ by injecting and mixing cement using multiple augers arranged on a matrix eliminate the need for the removal of compressible soils and reduce the need for long-term surcharging before achieving a desired load bearing capacity of reclaimed land.

Similarly, new techniques for the modular construction of gravity caissons, extensively used in artificial island port construction, such as use of standard stiffened steel or ferro cement panels, allow large-scale modular assembly. Use of artificial buoyancy and controlled buoyancy sinking methods now allows accurate positioning of large gravity caissons and other floatable port structures without the use of massive mechanical lifting devices.

Underwater, submersible earthmoving machinery, and controlled dragline scrapers now permit inexpensive, accurate, low cost and reliable leveling of underwater foundations for artificial island port modules or construction. Similarly, hinge-joined carpets of precast and treated concrete blocks are available now to provide a hardened level support for breakwater or caisson placement.

New static and dynamic methods for wave energy absorption are now available and can be used to increase the resistance of inclined breakwater walls, transform wave energy into mechanical motion, and in general reduce the wave forces acting on a rigid breakwater or barrier.

Similarly, new methods of ship mooring and active fendering have been developed which permit the safe docking of ships alongside rigid or floating piers and the transfer of cargo in more severe weather.

Another interesting development is the hinged or flexible connection of floating pier or breakwater sections with six degrees of freedom which can impose limit and rate constraints. In material sciences, sea water impervious concrete and effective coatings for steel surfaces are other developments which make the construction and use of artificial island ports more attractive. There are many other developments but the constraints of a brief paper unfortunately do not permit a complete discussion of relevant new technology.

Conclusion

Artificial island port development technology has matured to a stage where such approaches are economic, reliable, and operationally attractive. Artificial island ports have the potential for solving many problems of modern international good transportation and logistics. They also permit the effective redevelopment of the inner parts of our major cities, may allow vast reduction in transport costs, and may even provide new solutions for the disposal of waste.

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DYNAMIC CONTROL OF BEACH EROSION BY MOVEABLE PHYSICAL BARRIERS

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With increasing development of coastal areas, particularly for recreational or second home use, there has been increasing concern in the U.S. about beach erosion. The sandy beach of the coastal vacationer is really the drawing card for the extensive leisure and recreational investment in the coastline, and the threat or risk that these beach assets may be lost, in a particular area which has seen heavy development investment <u>because</u> of the beach, has been cause for major concern in many popular areas, especially along the Atlantic and Gulf beaches. At the moment, major new programs to protect and restore Atlantic and Gulf beaches are being studies or are actually under way within the U.S. But the problem of how to protect and preserve beaches is complicated by at least two factors: first, the beach itself is by nature a dynamic and ever changing boundary between the ocean and land; second, there appears to be a continuing natural rise in world wide ocean levels which may be significant (order of feet) over the next 100 years. In addition, many traditional methods, including sea walls and groins, have been shown by empirical experience to actually be deleterious to beach lifetime and stability, and to also adversely affect adjacent beach and ocean wetland areas. This paper briefly discusses the beach erosion and protection issues, and suggests a way in which movable physical barriers and sand replenishment might be used in combination to preserve beaches with minimum cost and with minimum adverse effect on the environment.

There is a valid question as to whether the control or protection of beaches, in the sense of attempting to preserve their location and dimensions, should be attempted at all in many cases. The generally recognized rise in mean sea level predicted through the 21st century emphasizes continuing conditions of change in worldwide seacoast configurations. The importance of the coastal environment to the oceanic ecosystem is well recognized. Attempts to change the behavior of or "stabilize" the barrier island system along the eastern and southern US coasts might well result in major damage to the coastal ecosystem.

Many national environmentally concerned organizations are urging the removal of all Federal and State programs which subsidize seacoast developments (ie: insurance programs, permanent barriers, etc.). These organizations argue that a coastal policy of abandonment and retreat is both the most environmentally sound and the most economical policy in the long run. They generally accept the prediction of a 3-4 foot general rise in sea level over the next 120 years (by the year 2100) in light of which, a policy of retreat seems the only sensible one.

Despite these arguments, it seems clear that in cases of very high levels of coastal investment, and of important public beach areas serving major segments of the constituent population, there will continue to be great pressure on State and Federal governments to preserve and protect these assets. As a means of preservation, the use of beach replenishment programs appears to be more environmentally acceptable than the use of permanent physical barriers. However, experience has shown that such beach replenishment programs almost always require a greater volume of periodically emplaced replenishment sand than that which might have been predicted from the observed natural rate of sand loss prior to the initiation of the replenishment program.

Technical Problems

It is clear that the subject of beach erosion is a vitally important one to many segments of the coastal community and its socio-economic structure; and, a review of the technical data in this area quickly reveals that this subject is currently a very empirical science. The various methods which have been used for "protection" vary from the construction of hard sea walls, through the installation of permanent groins, jetties, and breakwaters intended to hold the beach sands in place, to the now current methods of beach replenishment in which new sand is brought to the beach to replace that which is carried away or redistributed by the action of wave and current. It is a well recognized general observation from experience that the use of hard permanent protective structures ultimately contributes to the more rapid loss of beach, and often produces deleterious effects on adjacent beach areas.

With regard to beach erosion modeling, no satisfactory generally applicable physical sand transport model has yet been developed. Instead, the leading researchers recommend a "rule of thumb" empirical approach based on historical data, even though such data is often incomplete[1]. The coastal sand transport mechanism is so complex, and so dependant upon the local geology, that this empirical approach will no doubt continue to be the only practicable one available to the coastal engineer.

Data organized and analyzed in a study of 90 east coast beach preservation and restoration projects shows that there is little or no correlation between "beach lifetime" (the time period for the beach to recede from a replenished or restored state to the former unreplenished or unrestored state) and the parameters which have been used in beach lifetime theory and predictions[1,2,3]. Although large sums of money have been spent on protection, restoration, and replenishment programs, the monitoring and data collection from these projects has in most cases been far from complete. However, statistical studies of this admittedly incomplete data base show essentially no correlation at all between beach lifetime and such parameters as:

- o beach length
- o beach volume
- o grain size of the sand
- o beach shelf slope
- o inlet proximity
- o average wave height

Some modest correlation is shown between beach lifetime and:

- o beach cross sectional density
- o method of emplacement of the replenished beach

There is a strong empirical correlation between beach lifetime and storm conditions[3], particularly for replenished beaches. Storm action seems to be clearly responsible for the rapid loss of beach sand, and it is after storms that the characteristic cries of the beach users and property owners arise for beach restoration.

It appears to be generally, but not universally, accepted and recognized that permanent structures to not solve the beach preservation problem and, in fact, tend to exacerbate the problem[6,7]. Sea walls in particular have been shown to contribute to the rapid removal of beach fronting the sea wall, although they undoubtedly can preserve the land behind the sea wall[4]. Other permanent barrier structures may possibly protect the immediate area behind the barrier, but have deleterious effects on adjacent beach configuration. From a cost standpoint, and considering the very empirical nature of the current level of understanding of beach formation and sand transport, there appears to be no strong technical basis for the justification of some highly particularized permanent barrier design. There is one possible exception, at least in a theoretical sense, in a recent experimental program of the Naval Civil Engineering Laboratory (NCEL)[8] to test the idea of a subsurface "Bragg reflection" grid, which would reduce wave amplitude by destructive interference from a properly spaced and oriented grid of reflecting "bars" imbedded in the sand surface of the beach. In spite of this, perceptions that some new design may in some way "imitate nature" may occasionally lead to the installation of a new highly particularized barrier design. Recent installations of new proprietary systems at Palm Beach, Florida (an "artificial reef") and at Long Island (a "breakwater") are examples[9].

The majority of beach protection programs now in progress in the U.S. appear to be those featuring beach replenishment. Sand lost during the winter storm period and over the course of the year is replaced under a periodic program, either by pumping or other transport from nearby sources, or by transport from sources which may be at considerable distance from the beach. The costs for this type of operation vary widely, from less than $1 to more than $8 per cubic yard of sand[5]. The original theory of beach replenishment assumed that the replenishment rate would just be that necessary to maintain against the historical erosion rate prior to the replenishment program. In actual experience the erosion of replenished beaches occurs at a much higher rate. With the single exception of the Miami Beach program, all other programs of the 90 beach study by Prof. Pilkey and his associates at Duke University have shown that much higher replenishment rates are required to maintain such beaches[3]. Considering the high correlation between storm occurrences and beach erosion[3], <u>it would appear that if a means could be found to provide a temporary guard against storm effects, the cost of beach replenishment programs might be significantly reduced.</u>

Socio-economic Concerns

The primary driver for efforts to preserve current shoreline and beach structure is clearly an economic one, but in the sense of the economics as they appear in the eye of the concerned "stakeholders" in the coastal or beach area. Many past and current beach and coastline preservation programs have been very costly and yet have often been justified on the basis of preserving the property of relatively few owners and users. In the case of the very large beachfront investments which have been made since the early 1960's, there are, of course, correspondingly large new segments of the coastal region economic fabric interwoven with the beach development. Thus the incentive to preserve this high value segment becomes very strong in the sense of local, regional, and State political thought and action. In the case of large public beaches, where recreational economics is a major factor in determining the socio-economic health of the coastal region, there will be additional incentive to insure the continued presence of the beach area. Such beaches are also seen as benefiting a much larger portion of the total constituent population of the State or region. These are clearly the main factors which encourage the undertaking of beach replenishment and protection activities.

At the same time, there is considerable concern among interested organizations, agencies, and coastal States and localities, regarding the observed adverse effects of permanent structures (groins, sea walls, jetties, etc.) and the sometimes damaging side effects of beach replenishment (the case of the coral reef damage from fine sediments in the Waikiki replacement sand in Hawaii, for example)[6,7,10,11]. At the State level, this has led in some cases to the development of highly restrictive development planning requirements and critical review, as a prerequisite to permission to install or initiate such systems and programs[12,13].

National environmental organizations have strongly opposed the use of permanent structures. National conferences on the shoreline have urged a policy of letting the shoreline evolve naturally through a national and state policy fostering withdrawal and retreat from eroding areas. These policy recommendations are increasingly supported by the coastal states and their Congressional delegations. The Coastal States Organization (36 coastal state members, which includes the Great Lakes States) has adopted a program of urging the repeal of all Federally supported insurance coverage for beach front property, for example, as a means of encouraging retreat[10]. The Skidway Institute of Oceanography Conferences on America's Eroding Shoreline[6,7] have consistently endorsed a National and State policy of removing any form of effective subsidy against private investor risk in the beachfront area. This strong feeling against the installation of permanent structures and the private sector development of beachfronts has been increasingly effective in dissuading governments from using such barriers as a protective measure, except in those areas of maximum economic value to the government constituencies as a whole.

Reaction within the U.S. to replenishment programs appears to be much milder, although natural processes are being altered to some extent. Aside from concerns about possible increased turbidity in adjacent water, these program appear to be seen as being of relatively low risk to the environment. They are also largely used to stabilize and preserve beaches to which large segments of the general constituency population have access, and are therefore of greater perceived general benefit to the socio-economic structure as a whole and, though often expensive, will very likely continue. At this time, a major new program to alleviate severe beach erosion in the Ocean City, Maryland areas has now been under way for two years. A major beach reconstruction over a 12 mile stretch was completed in the fall of 1988. Storms over the 1988-89 winter had removed almost all of this sand (an approximately 40 million dollar dredging job) by spring, and engendered renewed cries of the beachfront property holders for the "government to do something". The program itself is planned to continue for the indefinite future. Total funds in the area of well over $100M have already been planned for the continuation of this effort. The context is the over $2.5B invested in local real estate development and the recreational economic sector.

The use of permanent structures to preserve the bank or bar contour and the channels of entrances to harbors and for tidal navigable rivers will no doubt continue. Such uses are seen as necessary actions to protect these highways of commerce. Any new technological methods applied to these particular problems (in lieu of pilings, riprap, and dredging) will be applied almost entirely on the basis of total installation cost alone.

Environmental Concerns

Concerns about direct adverse effects on the environment are at the heart of opposition to all permanent forms of beach protection structures, and also to some elements of beach replenishment programs. A general policy of retreat before the changing shoreline and of allowing nature take its course has been urged, particularly by environmental interests. One of the most compelling arguments for such a policy may be that of the widely recognized general rise in the mean sea level. In addition, in some cases, the sea level relative to local coasts may also rise due to natural changes in the level of the land masses themselves. These inexorable processes will not yield to man's efforts which, instead, must be addressed to accommodating them. A general rise which has been predicted by some to be as much as 4 feet by the year 2100[7] would certainly cause a significant change in the natural shoreline along much of the East and Gulf coasts of the US, as well as in southern California. The Pacific Northwest and Hawaii, due to the relative steepness of the coastal area, would not be significantly affected except for port facilities, which in any case are permanent modifiable structures well accepted by all elements of our socio-economic structure.

Planning at the State and local level for the initiation of any beach preservation program and for the installation of any type of protective device will certainly be the subject of more and more rigorous examination by State and local planning and regulatory authorities. In some cases (Oregon, for example), very comprehensive coastal planning documents and programs have been and are being developed to assure the careful protection and stewardship of coastal resources for all ocean users[12,13]. Any beach protection or other application program for erosion control devices would expect to receive careful review before approval.

SYSTEMS ON THE MARKET

There are a variety of physical barrier systems which are either "on the market" in the sense of being advertised and available upon order, or which have at least been tried in principle. A brief review of those known to me is given below, and is at least representative of the field:

Beach Prism There are two types of Beach Prism designs. The first of these is an original design by Peter Payne of Annapolis, MD. This is the triangular unit form illustrated in Fig. 1. The 10-12 units are combined into sections bound with stainless steel connecting rods, and are emplaced parallel to the beach. Beach Prisms Ltd. is the exclusive licensee of the patents covering the key elements of this design: its symmetrical shape, and the specific configuration of the modular unit including the orifices, the method of attachment, and the "turbulators" or protrusions which are designed to increase the turbulence of the flow of water through the device. A second monolithic design has been recently employed in an emplacement at the Wallops Island rocket launching site. This form has again a symmetrical triangular shape in which triangular side faces and internal bulkheads are joined by massive stringers, all in a single reinforced concrete structure (Fig. 2). Use of the device at Wallops Is. has produced inconclusive results but in other Chesapeake Bay installations, a significant retardation of sand loss has been documented.

Surgebreaker "Surgebreaker" is a product of Great Lakes Environmental Marine Ltd. of Chicago, Illinois. It is superficially similar to the Beach Prism, but is not symmetrical in design. Of triangular cross section, the bottom is solid. Holes of tapering cross section lead from the seaward side to the shoreward side (Fig 3). The tapering cross section is described by the producer as a means of dissipating the wave energy while allowing water to flow through, as an artificial reef. In practice, the device has been shown to resist storm displacement, but the accelerated flow through the orifices appears to produce increased scouring behind the device. If course, it is designed to be installed in one way only and the solid bottom is intended to make removal difficult, once embedded.

Wave Buster "Wave Buster" is a product similar to "Surgebreaker" and is made by another company in the Great Lakes area. It is intended as an artificial reef. This product, and the Surgebreaker have been used in the Great Lakes region. It is also an asymmetrical design, intended to be installed in one way only, and is designed to be difficult to be moved or removed, once in place.

Beach Beams This device is built by Beach Beam Co. , a spinoff from Beach

Prisms Ltd. This device differs from the Beach Prism in not retaining triangular symmetry, having curved front and back sides, a solid bottom, and triangular openings from front to rear. Beach Beams were also installed as a protective mechanism along the Wallops Island Navy/NASA government facility, in a test of various erosion control mechanisms there. As in the case of the Beach Prism, data was inconclusive, but for both devices very little sand removal was experienced over the same period of storms in which the Ocean City beach replenishment sand was largely lost. The general design of the Beach Beam is sketched in Fig. 4.

Artificial Reef An "Artificial Reef" has been designed and installed recently at Palm Beach, Fla. by Hans Rauch of American Coastal Engineering which is again an asymmetrical design of roughly triangular cross section[9]. As noted, these permanent installations are regarded as controversial, but it is clear that the value of certain beach areas, and the cost of beach replenishment, continues to provide an incentive for more effective approaches. Again, the effect of severe storm in short term removal seems to be the main driver in interesting local and State organizations in physical barrier solutions.

Bragg Reflector This very interesting idea is now being tested by the Naval Civil Engineering Laboratory in Port Hueneme, California. It consists of s series of ridge structures, metal fences really, embedded or fixed to the offshore beach in the wave zone, such that the top of the most seaward barrier is "just submerged" at mean low tide, and all barriers or ridges are completely submerged at mean high tide (Fig. 5). The idea is that the ridges or barriers are separated such that the reflected wave from the barrier will be so phased as to cancel the incoming waves. If the barriers are spaced at 1/2 the wavelength of the incoming waves and perpendicular to the direction of travel of the waves, maximum cancellation will theoretically occur. As the reduced wave intensity and associated reduced currents would drop sand in the locality of the barrier system, the barriers would become buried and would be rendered less effective in reflecting wave energy, thus reducing the wave interference and thereby the amount of sand deposited. The idea is that the system would be more or less self regulating. So far, the tests have been reported as showing scouring to seaward of the installation and some sand deposition to shoreward. Scripps Oceanographic Institution is cooperating with the Navy on this project. Of course, this system would render any been on which it was installed unsuitable for public uses such as surfing, bathing, etc. Tests are to continue over the next two years[8].

A PROPOSED NEW APPLICATION: DYNAMIC EROSION CONTROL

In consideration of all of the foregoing, it is suggested that a specialized application of physical barriers may exist in the use of such barriers as <u>movable, dynamically positioned devices</u>. The primary near term application in which such a device might yield benefits is suggested as that of a <u>temporary barrier device to protect replenished beaches from excessive storm loss during the "storm season" to be removed at the beginning of the "beach season" on an annual basis</u>. This suggested application would be justified on the basis of cost savings realized through the reduction in the amount of replenishment sand required to maintain the beach, as compared with the amortized costs of the dynamic barrier system and its installation, removal, and storage. In this suggested application, a dynamic barrier system is explicitly designed for periodic emplacement, removal, and with a reasonable lifetime (several seasons of use) and having the following characteristics:

- Symmetrical cross section (so that if tipped over, the system will have equal effectiveness)
- An action which dissipates wave energy

and slows local water velocities so that suspended sand will be deposited more readily in the vicinity of the system (or not be carried past the system)

- A configuration which facilitates movement, emplacement, and removal with minimum cost and time.
- Rugged and corrosion resistant construction providing a long useful lifetime

The system is installed parallel to the beach as an integral part of an ongoing beach replenishment program, preferably one in which the erosion has been established as operating under some sort of "steady state" condition of erosion rate under the replenishment program. The system is employed in such a way as to mitigate the effects of winter storm activity in removing the replenished sand from the beach and installed only at the beginning of the storm season (an alternative would be to deploy only on warning of severe storms, but in most cases that might be too much to ask, in terms of the cost of maintaining a standby quick reaction capability). The system would be removed at the end of the storm season, and stored for use again during the subsequent season.

An initial experimental application is proposed which would be conducted under a cooperative program with concerned State and local governments, involving appropriate academic and other research institutional participation. Sufficiently detailed measurements would be maintained that the action of the system could be adequately monitored and, most importantly, that the overall cost savings (if any) in the replenishment program could be determined and any adverse effects identified.

This approach offers several advantages:

o Beach replenishment programs are the most prevalent current beach protection programs and will very likely continue to be so. The principal correlating factor with beach lifetime for these replenished beaches is that of storm damage.

o The temporary emplacement of the barrier system will be to alleviate storm damage during the beach "off season" and its removal over the majority of the year would minimize adverse effects on general beach evolution and would permit unfettered recreational use of the beach.

o The development of an early experimental application would provide an opportunity as a <u>part of an ongoing beach replenishment program to increase the cost effectiveness of the program</u>.

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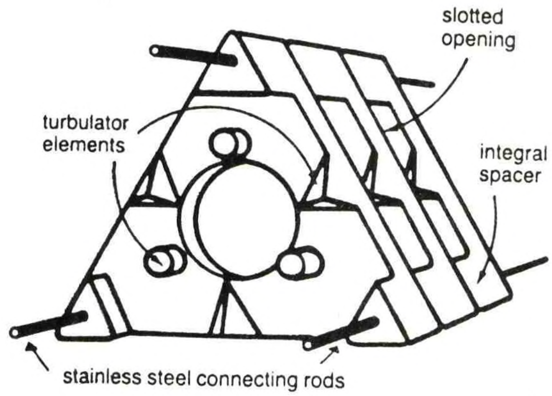

Fig. 1 First Model Beach Prism

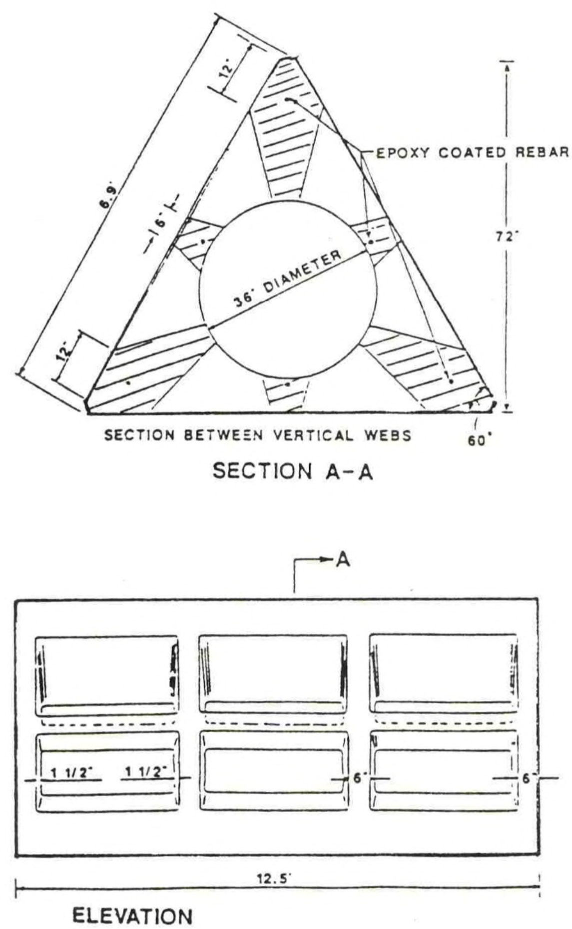

Fig. 2 Monolithic Beach Prism

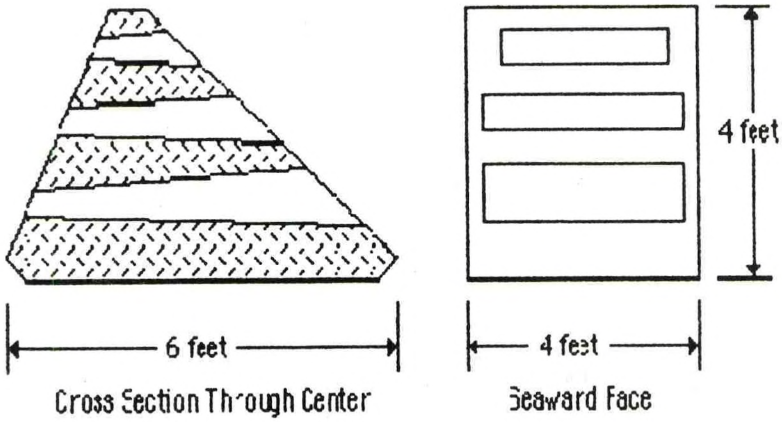

Figure 3 SurgeBreaker

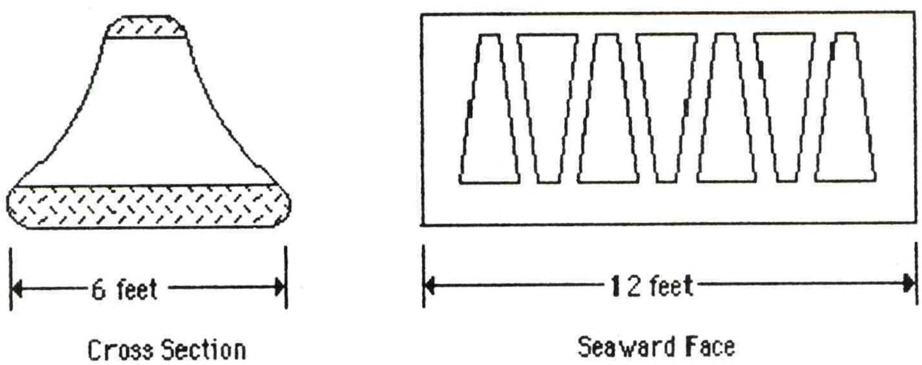

Figure 4. Beach Beam

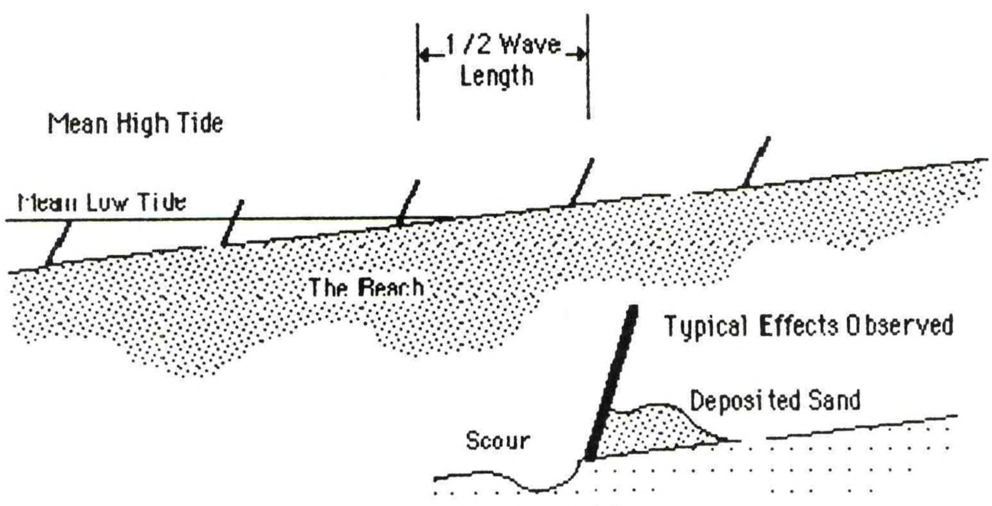

Fig. 5 NCEL Bragg Barrier (Not to Scale)

LOS ANGELES-LONG BEACH HARBORS MODEL ENHANCEMENT PROGRAM

SUMMARY

In response to the expansion of oceanborne world commerce, the Ports of Los Angeles and Long Beach, California, in coordination with the Los Angeles District of the U. S. Army Corps of Engineers, are conducting planning studies for harbor development to accommodate future needs. The Corps is charged with responsibility for providing deeper navigation channels and determining effects of the harbor expansion on the environment, while both Ports plan construction of new landfills, basins, and berthing facilities. The Los Angeles-Long Beach Harbors Model Enhancement Program has been developed to significantly upgrade the Corps' capability to determine effects of this expansion based on state-of-the-art modeling technology. This paper discussed details of the study, including objectives, tasks, schedule, and products to be provided. Major elements of the Model Enhancement Program include tidal circulation and water quality (including wind effects), harbor resonance, and ship motion. The results of the Model Enhancement Program will provide a vastly improved capability to evaluate the effect of harbor improvement plans on these parameters, thereby insuring the optimal harbor development.

HISTORIC BACKGROUND

In 1970, the U. S. Army Engineer Waterways Experiment Station (WES), was funded to conduct a comprehensive hydraulic model study of Los Angeles-Long Beach Harbors to investigate the effects of proposed harbor expansions on tidal circulation and long-period wave oscillations. The major objectives of this study were:

A. Determine incidence and severity of troublesome oscillations in the present harbor complex.
B. Investigate tidal circulation characteristics of the present and proposed harbors.
C. Determine optimum plan for future expansions to provide safe and economical berthing areas.
D. Analyze effects of proposed expansions on existing harbors.

The WES approach to achieve these objectives was:

A. Acquire prototype wave data for a one year period.
B. Obtain observations of ship motion.
C. Catalog ships using the harbors.
D. Conduct analytical investigations of moored ship response.
E. Perform extensive analyses of prototype wave data.
F. Attempt to correlate ship motion with wave height and frequency.
G. Collect prototype data for model verification of tidal circulation characteristics.

H. Design and construct a hydraulic model.
I. Conduct model tests of tidal circulation for present harbors and planned construction stages.
J. Conduct model tests of long period wave characteristics of existing harbors and planned construction stages.

In designing the hydraulic model, the effects of wave refraction, diffraction, reflection, and transmission; viscous friction attenuation; wave filters and absorbers; wave generator requirements; automated model data acquisition and control; and model data analyses were considered. The model was constructed to a vertical scale of 1:100 and a horizontal scale of 1:400 (for a distortion factor of 4) and reproduced approximately 253 square miles or prototype area. Model construction was completed in August 1973. Initial testing was aimed at evaluating various phases of harbor expansion (leading up to a master plan development) to optimize modifications from a cost and functional standpoint.

During the initial years of model testing, it became apparent that the model was evolving as a planning tool for use by both the Ports and the Corps, and that its usefulness would span decades as changing customer needs and environmental concerns surfaced. With this redefined role, came the realization that periodic upgrades in the LA-LB model technology would be necessary to maintain state-of-the-art research studies.

By the early 1980's, rapid advances in coastal engineering, particularly in numerical model development and the advent of large and powerful computers, made the 1970's technology (with which the hydraulic model of Los Angeles-Long Beach Harbors had been designed and operated) outdated. This limitation, coupled with the rapid expansion of world economy to create intense international competition in oceanborne world trade, provided the impetus for a major model upgrade to develop improved predictive capability for use in port development.

Our ports are a national resource and enhanced port capacity is vital to the nation's well being. In a feasibility study conducted by the Corp's Los Angeles District, a well defined and necessary expansion was proposed to accommodate predicted future needs. Changes in tidal circulation and harbor flushing need to be examined to determine how expansion and channel deepening will affect water quality in the harbors and local vicinity. Another factor which must be studied is the effect that new channel and basin configurations and depths will have on harbor resonance characteristics. Long period waves (15 to 400 sec) constantly invade the harbors and can create resonant oscillations which may cause ship-mooring and/or ship-loading/unloading problems. In order to provide information for the above, a long-term tidal circulation, harbor resonance, and ship motion study was initiated in FY82. The study was designed to obtain data for improving evaluations of the harbor's response to forcing functions such as the astronomical tide, wind, and long-period waves. These data then would be applied to further upgrade model capacity to predict the effect of proposed expansion plans on tidal circulation, water quality, and harbor oscillation. The program was funded at sporadic levels (partial or no funding) from FY83 to FY86. In FY87, the upgrade program finally received full support with approval of a 5-year (FY87-91), 4-million dollar program.

Due to the large scope and complexity of the work to be performed, a structured management plan was developed with well-defined roles for all parties as follows:

Los Angeles District (SPL)

-Assume lead role in overseeing the entire program
-Coordinate with Waterways Experiment Station (WES) to ensure continuation of studies and to monitor expenditures and accomplishments
-Review all outputs
-Act as window for all information from WES, SPD, and/or Ports
-Keep SPD and Ports informed of study progress and results
-Conduct at least two meetings annually for review of the Model Enhancement Program
-Prepare and justify annual budget requirements

South Pacific Division (SPD)

-Support justified annual funding requirements
-Provide funds to SPL for Enhancement Program
-Advise, monitor, and review as necessary
-Keep OCE informed of all necessary information
-Provide SPL all information pertinent to the study

Office, Chief of Engineers (OCE)

-Support justified annual funding requirements
-Provide policy guidance as required
-Provide funds to SPD
-Attend meetings as appropriate

Waterways Experiment Station, (WES)

-Execute Model Enhancement Program
-Provide Management Plan with CPM/study network
-Provide monthly status reports on actual expenditures and accomplishments
-Provide draft reports as appropriate upon completion of major tasks (includes data, analyses, conclusions, and recommendations)
-Attend meetings as required

Port of Los Angeles (POLA) and Port of Long Beach (POLB)

- Provide logistical field support
- Provide input and review as required
- Attend meetings as required
- Provide Port's acquired quality data
- Provide up-to-date maps of physical features of harbors
- Provide layouts of alternative channels, basins, and landfills to be modeled

Work for the Model Enhancement Program is being conducted by Engineers and Scientists at WES with two of WES' six laboratories involved (the Coastal Engineering Research Center (CERC) and the Environmental Laboratory (EL)).

OUTLINE OF THE MODEL ENHANCEMENT PROGRAM

The Model Enhancement Program has been separated into two major studies. The first is connected with the action of long-period waves (periods of 25 sec and above) on the harbors. Very little is known about the origin and frequency of occurrence of these waves, but their existence is evident in producing difficult loading/unloading events at various berths throughout the harbors. This portion of the Enhancement Program will provide prototype wave data, a moored-ship motion model, and an upgraded testing capability for the physical model. An introductory outline of this phase of the study is as follows:

Harbor Resonance and Ship Motion

A. Develop long-wave frequency of occurrence from wave spectra data collected at prototype wave gages in the Harbors and the Pacific Ocean.
B. Correlate moored-ship motion with incident wave spectra by monitoring prototype ship movements.
C. Verify a moored-ship model.
D. Establish frequency of occurrence for loading/unloading down time (as a function of berth location, mooring configuration, and ship characteristics).
E. Provide improved modeling methodology for evaluating the effects of SPL and Ports improvement plans and dredging on loading/unloading down time.

The second major part of the Model Enhancement Program will provide improved tidal circulation modeling with a more efficient numerical tidal circulation model system which will couple hydraulics and water quality variables. This is outlined as follows:

TIDAL CIRCULATION

A. Acquire prototype tidal data.
B. Quantify outer harbor and inner harbor circulation.
C. Evaluate and quantify water quality processes in the harbors.
D. Evaluate and quantify the effects of wind on tidal circulation and mixing processes in the harbors.
E. Provide improved modeling methodology for evaluating the effect of proposed harbor improvements on circulation and water quality.

The basic sequence involved for each of the above two major divisions is to collect prototype data to improve model predictions and define important test conditions for the existing harbors, then apply the models (physical harbor resonance model, numerical ship motion model, and numerical tidal circulation and water quality model) to determine the effect of harbor development plans on harbor resonance, ship motion, tidal circulation, and water quality.

Detailed wave data from seven harbor gages and one offshore gage are providing input for design of model tests in the physical model of LA-LB. This long-period wave data is being developed to produce wave generator control signals that will enable realistic spectral waves to be reproduced in the model. Wave gages in the model are then monitored (for the existing harbor condition) and the input signal adjusted until the appropriate harbor gage response (comparable to the prototype response) is obtained. A proposed plan then can be installed in the model and the harbor response at wave gages throughout the harbor measured and compared to the existing condition gage response. If undesirable wave conditions are found, changes in the plan can be made to seek improved harbor response.

Interactive studies are used to proceed in development of optimal harbor development plans. Tidal circulation tests may indicate specific modifications necessary for good tidal circulation. Then, harbor oscillation tests and associated ship response tests may indicate changes are necessary in the Plan which should be examined in the tidal circulation model.

DETAILED DISCUSSIONS OF MODEL ENHANCEMENT PROGRAM TASKS

Task A.1 Wave Data Acquisition

This task consists of making long-term measurements of harbor long-period wave (surge) events and the forcing functions external to the harbor that generate those events. Eight self-recording pressure gage instruments (seven in the harbor, and one on platform Edith outside the harbor) initially used were replaced by an automated surge measurement system. The automated system used upgraded versions of the eight pressure gages and telemetered data via Remote Transmitting Units (RTU's) to a central computer in the POLB headquarters. This computer was connected via a data link to data acquisition and analysis computers at WES. Final task product: automated surge measurement system.

Task A.2 Wave Data Analysis

This task consists of completing work on the software needed to reduce, analyze, and check the quality of measurements made by the automated surge measurement system, then performing these tasks and associated activities for the period of surge data collection. Final task products: periodic surge data summaries.

Task A.3 Harbors Resonance Analysis

This task involves examining and analyzing, in detail, the prototype wave data acquired in A.1. This task determines statistical parameters describing the data. Data correlation with existing ship movement reports, as collected by the Ports of Los Angeles and Long Beach, are performed. Also, data are examined to determine the correlation with wave groupiness, atmospheric pressure variation, and other phenomena. Correlation of the responses between gages is performed to gain an improved understanding of the harbor response to long-period waves.

Task A.4 Ship Motion Data Acquisition and Analysis

This task consists of the development and application of a system to measure vessel motion and mooring line forces during harbor surge events at the Ports of Los Angeles and Long Beach, and the reduction and summarization of data collected by the system. Measurements allow determination of vessel motion in each of six degrees of freedom (heave, pitch, sway, roll, yaw, and surge) and mooring loads in up to eight mooring lines simultaneously. Data collection took place over a four month period during the time of highest probability of harbor surge events. Depending upon vessel availability ship motion data acquisition and analysis were performed at berthing locations at each Port and included dry bulk and container ships. The locations and ship types were selected jointly with the Ports.

Task A.5 Ship Motion Model Development, Calibration, and Verification

A ship motion model is being developed to provide a method to evaluate the recurrence interval for adverse moored ship motion. Moored ship response may be affected by incident storm wave energy and long-period wave energy propagating into the San Pedro Bay area. Moored ship response will be influenced by navigation channel dredging, geometric configuration of the berthing area, mooring system, fendering system, and ship characteristics.

The moored ship response model includes the three motion translational components of surge, sway, and heave as well as the three rotational components of pitch, yaw and roll. The model is capable of simulating an irregular wave spectrum and the development of long-period surge modes of oscillation in harbor berthing areas. The resonant interaction between the ship, mooring system, and frequency of oscillation will be modeled incorporating both sidewall effects and shallow depth effect.

Model results will include the predicted motion of the ship and mooring line forces as a function of incident wave excitation for both short-period spectra and long-period progressive waves. Combined with wave energy recurrence interval analysis data from the wave data analysis tasks, berth downtime then can be determined.

The model was calibrated and verified initially using observed data from a container ship harbor in Iceland. This data set is quite comprehensive and includes the incident wave spectrum, ship motion observations, and mooring line forces. After initial verification with this data set, ship model calibration and verification is being completed using data for vessels typical of ship types using the Ports and obtained as a part of the Ship Motion Data Collection and Analysis Task (Task A.4).

After development is completed, the model may be used for analysis of mooring conditions at any harbor berthing facility and for commercial ship types projected to use the harbor.

Task A.6 Improved Physical Model Harbor Resonance Methodology

This task examines the transfer of long-period wave data spectra to use in physical model testing of harbor resonance. Previously monochromatic waves were used for testing. This task will aid in selecting spectra appropriate for use in model testing and can aid in reducing the number of tests required to be performed in the physical model. This task determines the appropriate programming of the wave board to properly reproduce the prototype wave spectra in the model. The improved physical model then can be used to more accurately define harbor resonance conditions and resulting ship mooring problems which may occur for proposed plans. If adverse mooring conditions develop, the physical layout of a plan can be adjusted to attenuate problem oscillations.

Task B.1 Tidal Circulation Data Acquisition/Tidal Elevations

This task consists of preparation, mobilization, data collection, and demobilization to collect tidal data inside and outside of LA-LB Harbor for a 3-month period. In addition to data from the existing 8 surge gages, 4 tide gages were installed and operated for the 3-month period. Three of the additional gages were placed outside the harbor to augment the existing platform Edith wave gages. The period of 3 months was considered long enough to extract tidal constituents for LA-LB Harbors. The measurements define boundary conditions relative to the exterior long-term gage (Edith) and interior readings. Long term measurements extending for greater than 6 months were made at the Edith platform and several interior locations. These data will assist in model application for other time periods of interest. Final task product: unprocessed tidal data.

Task B.1 Tidal Circulation Data Acquisition/Currents (In situ)

This task consists of preparation, mobilization, data collection, and demobilization to collect current data for a range of tidal conditions. Data were collected for a 30-day period using multiple current meters fixed at points in vertical profiles at eight stations covering the major tidal exchange openings inside the harbor and at the harbor complex perimeter. Final task product: unprocessed current data.

Task B.1 Tidal Circulation Data Acquisition/Currents (Profiles)

This task consists of preparation, mobilization, data collection, and demobilization to collect vertical profile current data along transects covering major tidal exchange openings or interfaces throughout the harbors. Also current profiles were taken at various locations in Cerritos Channel. Data collection took place over a 9-day period concurrent with in situ current measurements. Final task product: unprocessed current data.

Task B.1 Tidal Circulation Data Acquisition/Currents (Lagrangian)

Lagrangian current studies refer to studies where the path of the water particle is followed over a period of time. Usually this is accomplished by drogues or floats. This task consists of preparation, mobilization, data collection, and demobilization to collect current data to identify and measure a suspected tidally-induced circulation gyre in the outer harbor. The task included a low level reconnaissance survey prior to actual data collection to ascertain the gyre's general characteristics, determination of the performance potential of gyre measurement techniques in the outer harbor environment, and assessment of the feasibility of making current measurements in the interior channel areas of the harbor as part of the profile current task. Lagrangian data collection took place concurrent with in-situ current measurements. Final task product: delineation of the extent and velocity characteristics of the outer harbor gyre.

Task B.1 Tidal Circulation Data Acquisition/Data Analysis and Report

This task consists of activities needed to finalize the format and type of data products required from the tidal and current measurement tasks, developing or modifying the analysis software required to produce those products with the appropriate level of quality control, analyzing the collected data, and reporting on the results of the measurement task. Final task product: report on tidal and current data collection methods, equipment, and results.

Task B.1 Tidal Circulation Data Acquisition/Water Quality Sampling Program

The recommended water quality sampling program (WQSP) consists of a series of surveys for water quality model (WQM) boundary specification, calibration/verification, and rate of coefficient quantification. The WQSP extended through the month of August 1987, concurrent with the hydrodynamic data collection. The month of August was selected for water quality data collection because high water temperatures and low dissolved oxygen levels that historically occur during the month represent a potentially critical water quality condition. The WQSP consisted of in situ and laboratory measurements of water quality constituents and process rates. A dye release study provided data for both WQM and hydrodynamic model transport calibration. The following narrative and table describe the WQSP.

BOUNDARY SURVEY

The boundary survey consisted of sampling at two stations located outside the bay over the ocean shelf. Each station was sampled weekly. Each sampling consisted of four profiles spread over a 12 hour period. Measurements included dissolved oxygen (DO), temperature, conductivity, and pH at approximately 2-meter depth intervals and nitrate plus nitrate nitrogen (NO2+NO3), ammonia (NH4), phosphate (PO4), chlorophyll-a (Chl-a), carbonaceous biochemical oxygen demand (CBOD5), and suspended solids 1 meter below the surface, 1 meter above the bottom, and at mid-depth. Transparency was measured using a secchi disk. The purpose of the boundary survey was to collect data that can be used to specify ocean boundary conditions for profile concentrations during model simulation.

INTERIOR SURVEYS

The interior surveys consisted of sampling at 8 to 10 stations within the harbors. Each station was sampled weekly. Measurements included DO, temperature, conductivity, and pH at 2-meter depth intervals and NO2+NO3, NH4,PO4, Chl-a, CBOD5, and suspended solids

1 meter below the surface, 1 meter above the bottom, and at mid-depth. Transparency also was measured. The purpose of the interior survey was to collect a data set for model calibration/verification.

DIEL SURVEY

The diel survey consisted of sampling 4 interior stations, every 6 hours, over a 24-hour time interval. The survey was conducted once during mean tide. Measurements included DO, temperature, conductivity, and pH at 2-meter depth intervals and NO2+NO3, NH4, P04, Chl-a, CBOD5, and suspended solids 1 meter below the surface, 1 meter above the bottom, and at mid-depth. The purpose of the diel survey was to investigate the temporal variability of interior station water quality constituent concentrations over a day and over a tidal cycle. The resulting information assists in model calibration and provides a basis for extrapolating model results over time periods for which the interior surveys were not conducted.

PRODUCTIVITY SURVEY

The productivity survey consisted of light and dark bottle productivity and respiration measurements at two locations. Surface water samples were incubated at varying light intensities. The purpose of the productivity survey was to collect productivity and respiration estimates to serve as a basis for selecting reasonable rate coefficients during model calibration.

SEDIMENT OXYGEN DEMAND (SOD) SURVEY

The sediment oxygen demand survey consisted of four replications conducted at five locations to collect data to specify model SOD.

CORE SURVEY

The core sample survey consisted of organic carbon determinations of five sediment cores. Two locations corresponded to the sediment oxygen demand studies while the balance of core sediment survey stations correspond to anticipated dredging areas. The purpose of the core survey was to relate measured SOD to anticipated SOD following dredging. The basis for extrapolation would be the organic matter content of the sediments.

CBOD RATES

The CBOD rate survey consisted of a series of laboratory investigations in order to determine CBOD decay rates and the relationship between CBOD5 and ultimate CBOD.

DYE RELEASE STUDY

Several dye release studies were carried out during the study period (in Cerritos Channel and in the outer harbor). In each experiment, dye was released and traced for 48 hours. Intensive measurements were made to track the initial development of the plume and provide synoptic concentration distributions at various stages of plume development. After ambient diffusion characterized the plume movement, measurements were made at less frequent intervals. Efforts were made to measure the variance of concentration as well as the mean concentration and measurements were made throughout the vertical at fixed horizontal stations. These data greatly assisted in calibrating model lateral and vertical turbulent mixing coefficients.

TASK B.2 Circulation Transport Model

MODEL SELECTION

In order to assess circulation and water quality effects accurately in LA-LB Harbors, it is necessary that the hydrodynamic processes in the Harbors, including three-dimensional circulation, vertical turbulent mixing, and the interaction effects at the bottom and free surface, be properly represented. The hydrodynamic model selected for the study must accurately duplicate these processes for existing conditions and predict them under planned conditions. The circulation transport model selected for the study is a 3-D hydrodynamic model called CH3D.

MODEL DESCRIPTION

The model solves the time-varying, 3-D initial boundary value problem in which the governing equations are conservation equations for mass, momentum, salinity, temperature, and a conservative constituent, and the equation of state. The momentum equations in the horizontal directions include terms to account for temporal variation, convection, Coriolis effect, pressure gradient, turbulent viscosity, and density gradient. The conservation equations for salinity, temperature, and conservative constituent include terms for temporal variation, advection, and turbulent diffusivity.

The rectilinear coordinate feature of the model allows the model grid to be adjusted to conform horizontally to more accurately represent irregular shoreline and ship channel features of the bay system. In the vertical, sigma stretching is used to smoothly represent the bathymetry. It permits the same degree of resolution in shallow and deep portions of the grid. A finite difference method using an alternating direction implicit scheme in the horizontal direction and a fully implicit scheme in the vertical direction is employed for numerical solution.

APPLICATION TO LA-LB HARBORS MODEL ENHANCEMENT PROGRAM

The model mainly simulates water surface elevations and 3-D velocities due to tides and wind. A spring-neap tidal cycle is modeled. Sensitivity studies were performed on model domain and grid resolution. A conservative constituent (dye) was simulated in the model and model results furnished to the water quality model for calibrating the transport properties of the latter. Needed linkages for data transfer between the two models were developed. Temperature, salinity, and water quality variables were simulated, as needed, in the water quality model using hydrodynamic information from the circulation transport model. The latter model was calibrated and verified using field data on surface elevations and currents gathered in summer 1987 (Task B.1). To demonstrate the ability of the model to simulate plan conditions, a plan condition furnished by SPL was tested.

Task B.3 Water Quality Model

The water quality model (WQM) is a 3-D integrated compartment (box) model linked to the 3-D hydrodynamic model (HM). With the harbor deepening that has been proposed, a fully 3-D model is required to assess impacts on dissolved oxygen (DO) in the deep areas.

The box model is a modified version of the Environmental Protection Agency WASP code. The box model grid is a slightly coarser overlay of the hydrodynamic grid. Hydrodynamic model output is spatially and temporally averaged before being used to drive the box water quality model.

WES has linked the box model to output from several hydrodynamic codes, and the use of the box model provides the flexibility for linkage to any hydrodynamic model while allowing relatively long-term water quality simulations with reasonable computational expense. However, when taking this approach, the modeler must be careful to assure that the transport properties of the HM are preserved in the WQM.

The WQM simulates the following variables: temperature, DO, carbonaceous biochemical oxygen demand (CBOD), ammonia nitrogen, nitrite plus nitrate nitrogen, algal biomass, inorganic suspended solids, orthophosphate, and an arbitrary conservative constituent (with a nonconservative decay option). In addition to advection and diffusion, the processes that are included in the model are: surface heat exchange and radiation; gas exchanges between the air/water interface; CBOD decay; sediment oxygen demand (SOD); algal photosynthesis, respiration, mortality, and excretion; nitrification; light transmission; absorption/desorption; and settling. This level of detail is sufficient to address the immediate issues, yet provides enough flexibility to address future issues. Additionally, with the WASP code, other kinetic formulations for conventional pollutants and toxic substances exist and can be added later if needed.

The model was calibrated with the water quality data set collected during August 1987, which was concurrent with hydrodynamic data collection. This data collection effort was structured to provide information for model variables, fluxes, and rates, as well as provide data for model calibration/verification.

Task B.4 Wind-Driven Circulation Analysis

The response for the LA-LB harbors to wind is being investigated in this task. Since tidal currents are relatively slow, wind-induced current circulation could be important in these harbors. With the aid of a calibrated numerical model, parameterized testing can be performed. The circulation model is being verified for wind driven currents as a part of Task B.2. Observed wind data are being used to predict the effect of seasonal winds on the circulation patterns and associated water quality. The influence of the wind driven currents on formation of the outer harbor gyre and currents in the inner channel are being quantified for seasonal effects. The effect of winds on the three-dimensional circulation of the harbors also is being determined. The effect of seasonal winds on the demonstration plan is being evaluated to determine if wind circulation effects provide supplemental circulation.

Task C.1 Project Management

This task provides management of the study and coordination between SPL, SPD, and the Ports. Included in this task is responsibility for submitting monthly progress reports, quarterly project management reports, and coordination of project meetings. These meetings take place at least semi-annually. Also, at the conclusion of the Model Enhancement Program a summary report for the study will be prepared. This report will contain significant conclusions of both the harbor resonance and ship motion portion of the study and the tidal circulation portion.

SUMMARY OF PRODUCTS

Listed below are the publications and upgraded models resulting from the Model Enhancement Program.

PUBLICATION

Long Period Wave Data Reports

Long Period Wave Data Summary Report

Harbor Resonance Analysis Report

Ship Motion Data Report

Ship Motion Model Development Report

Improved Physical Model Harbor Resonance Methodology Report

Tidal Circulation Prototype Data Report

Tidal Circulation Transport Model Report

Water Quality Model Report

Wind Driven Circulation Analysis Report

Overall Summary Report

UPGRADED MODELS

Ship Motion Model

Tidal Circulation and Water Quality Model

Physical Model With Spectral Wave Capability

CONCLUSION

The Corps of Engineers has developed an extensive Model Enhancement Program to provide state-of-the-art tools for use in optimizing future expansion of the Harbors to the year 2020. These research products will benefit the Corps, the Ports of Los Angeles and Long Beach, and the Nation.

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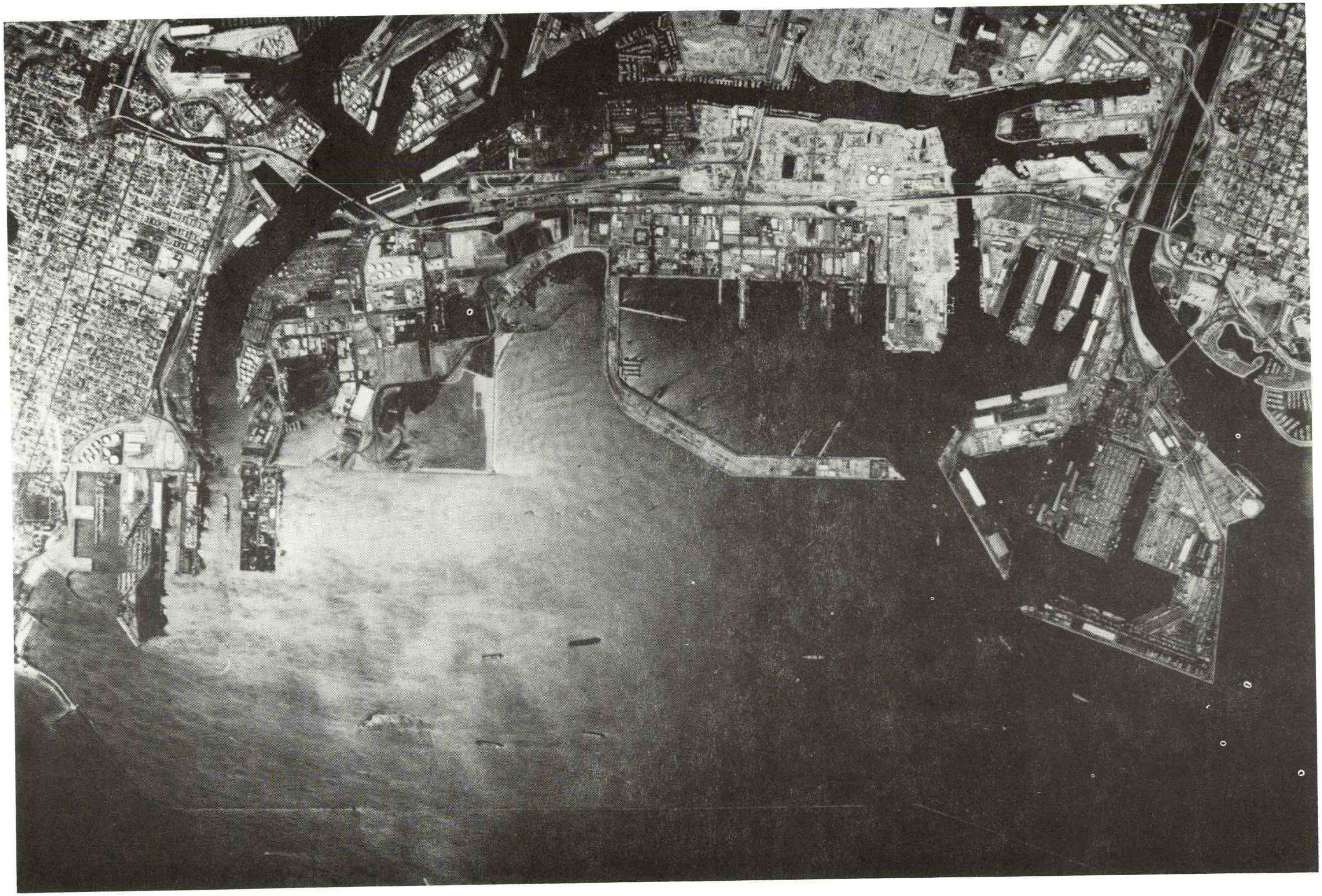

Figure 1. *Aerial View of Los Angeles - Long Beach Harbors.*

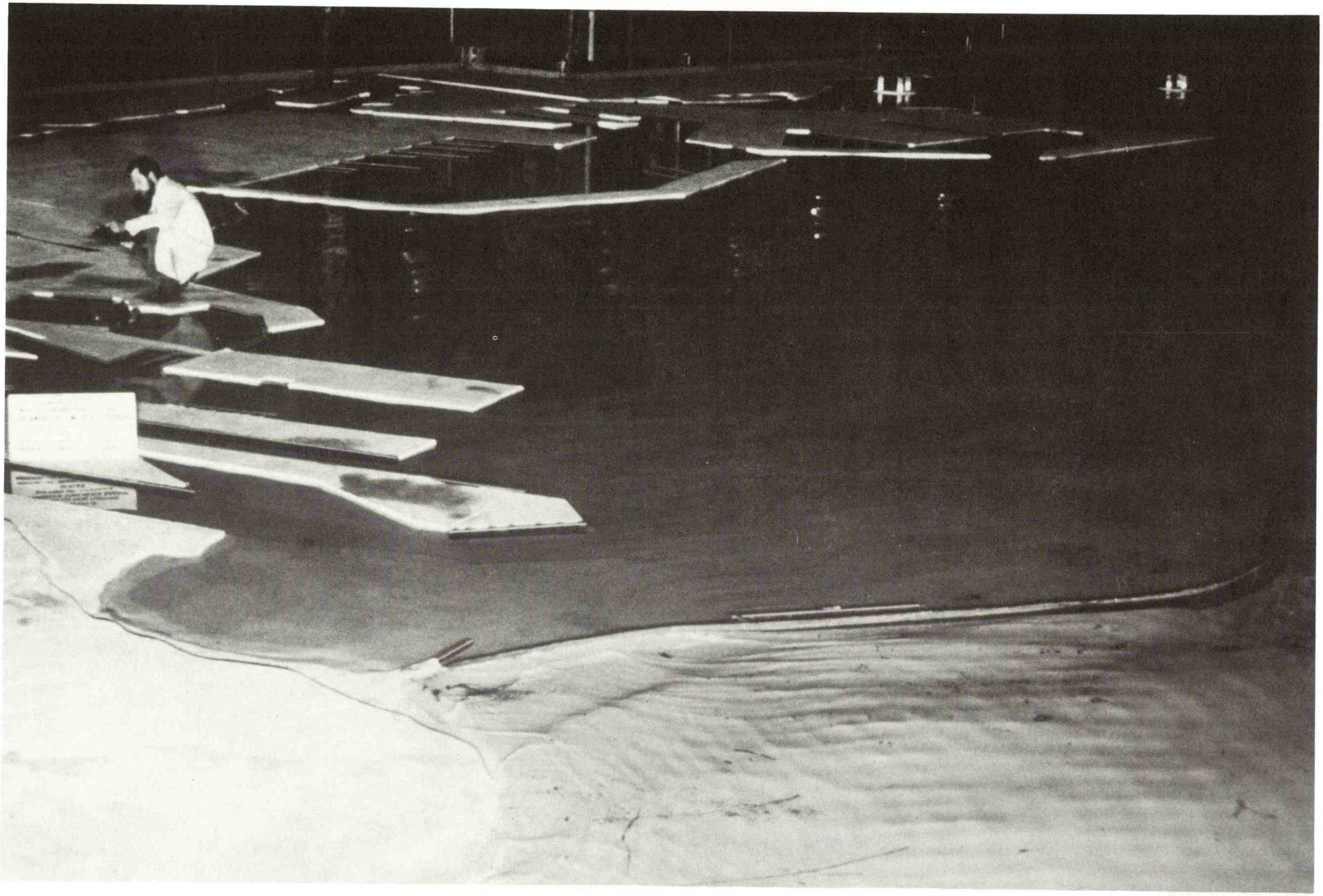

Figure 2. General view of hydraulic model.

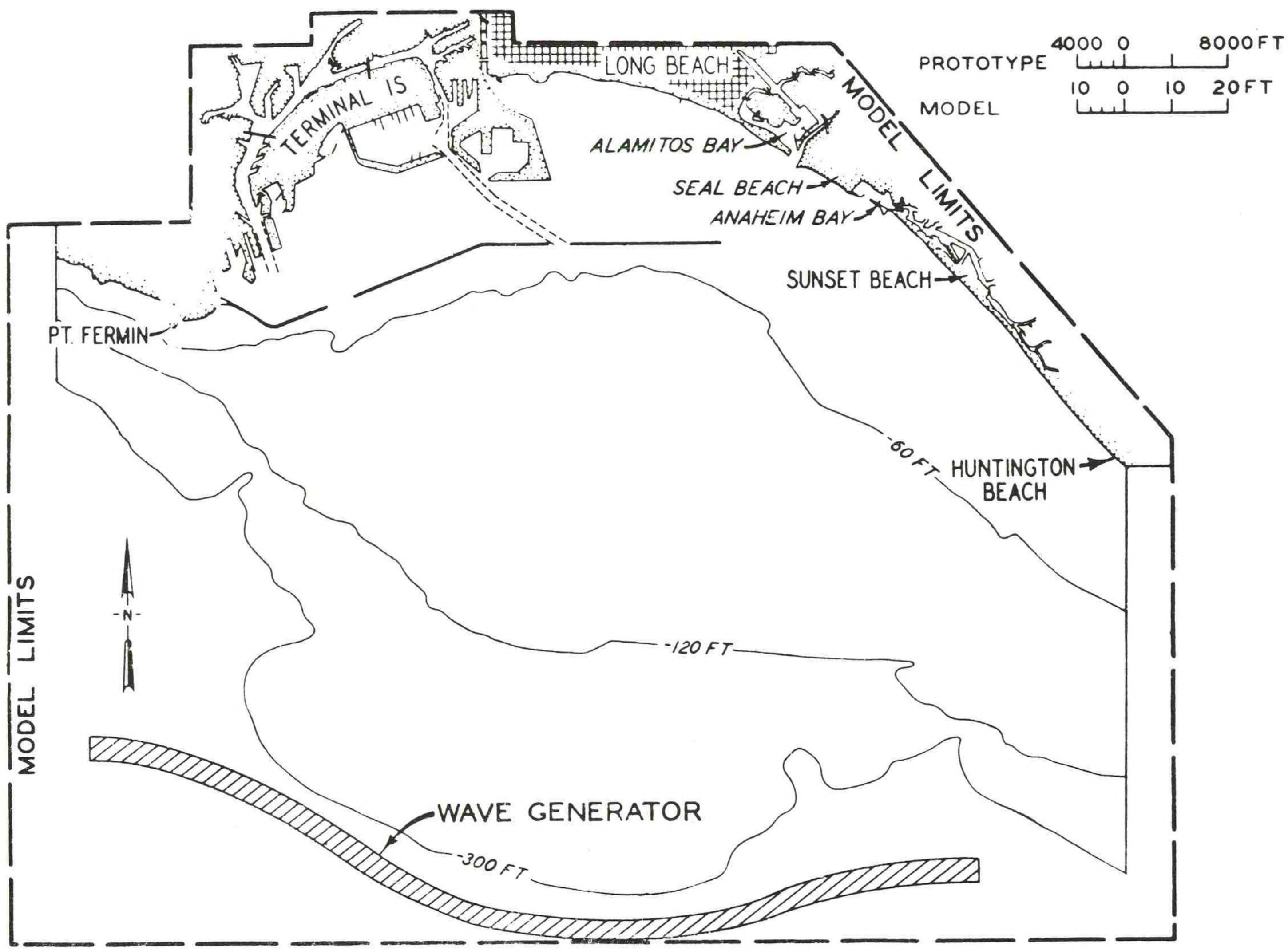

Figure 3. *Los Angeles - Long Beach Harbors model layout.*

Figure 4. *Artist's concept of 2020 plan.*

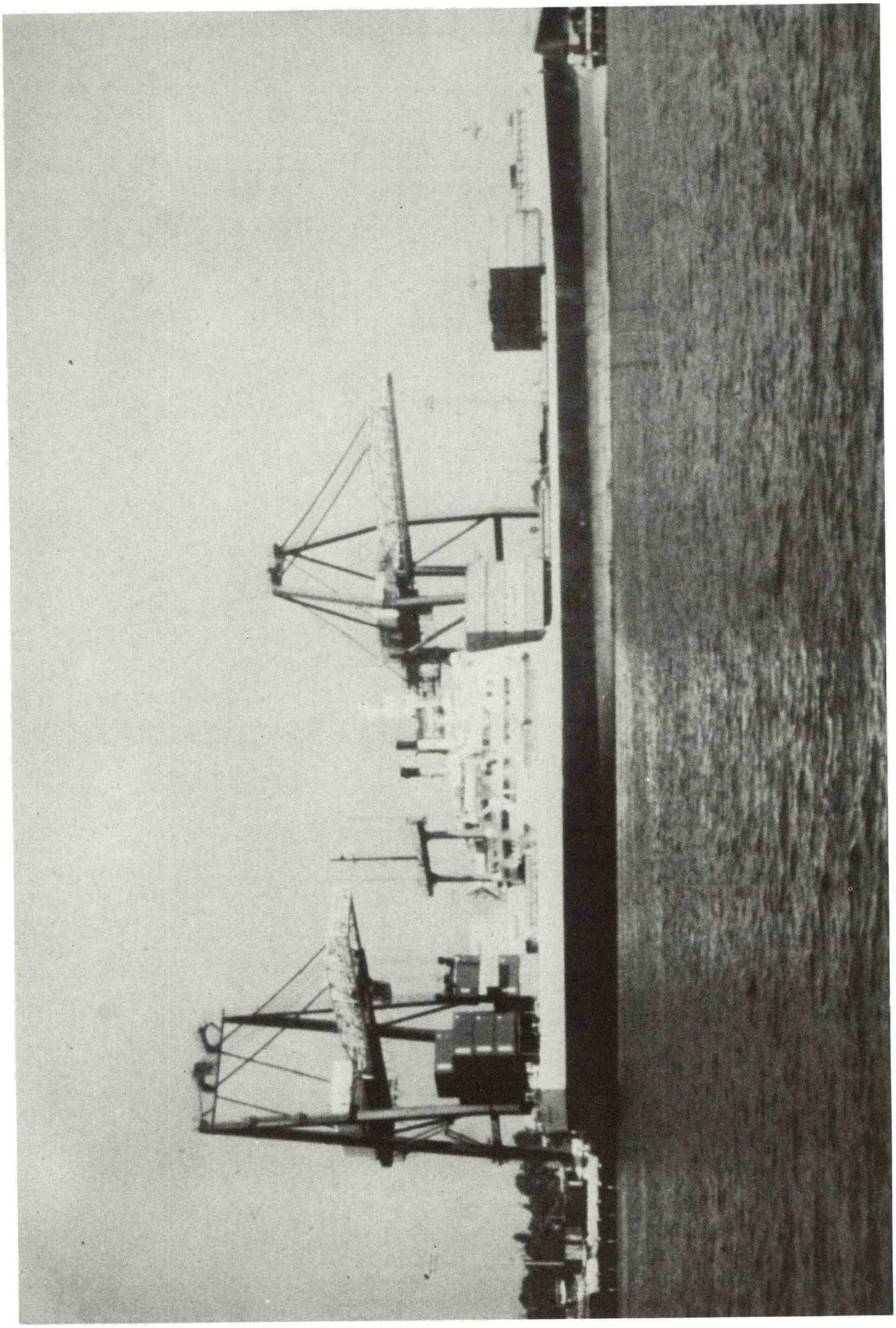

Figure 5. Typical containerized ship berth.

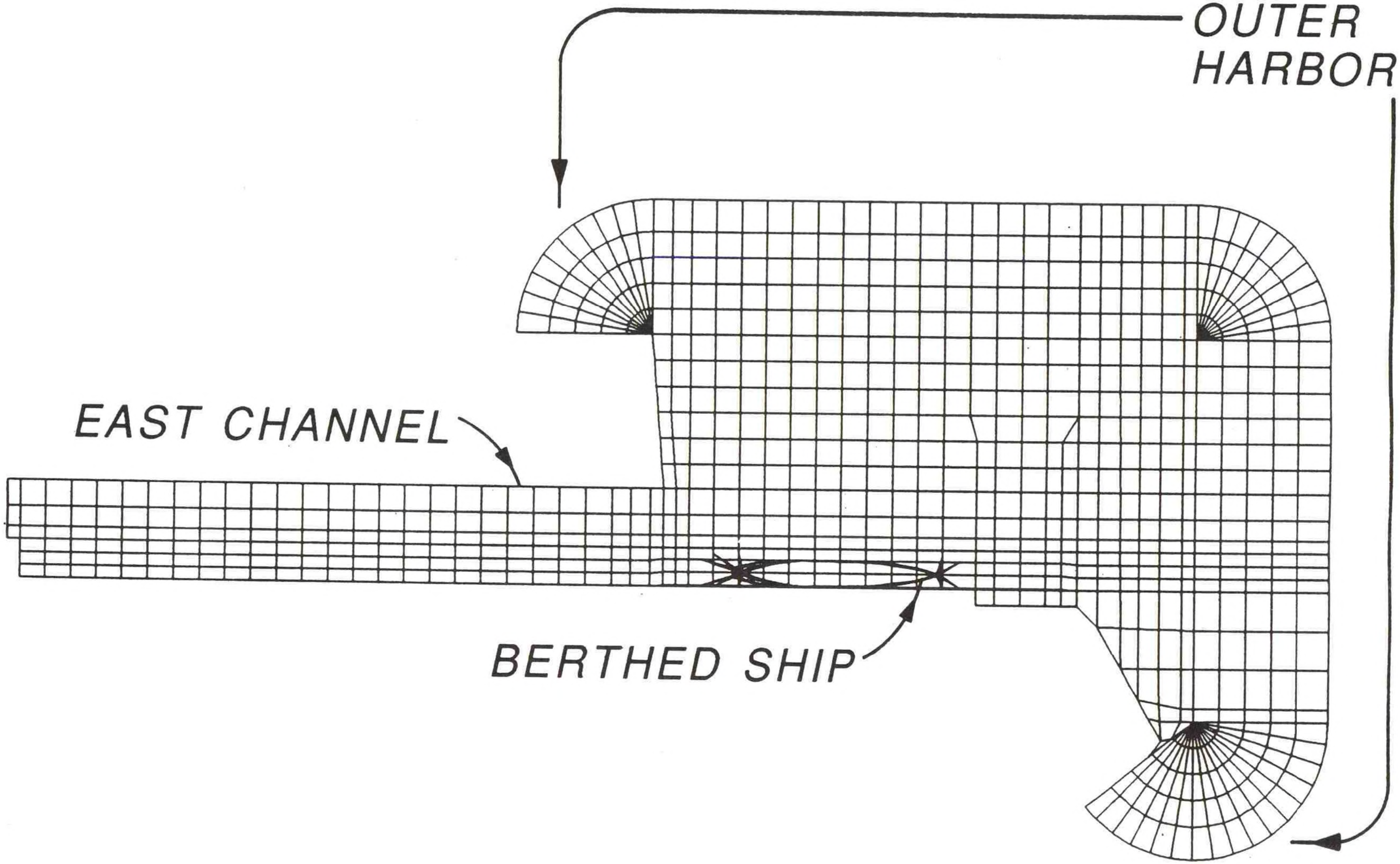

Figure 6. Finite element numerical ship motion model — east channel area of Los Angeles Harbor.

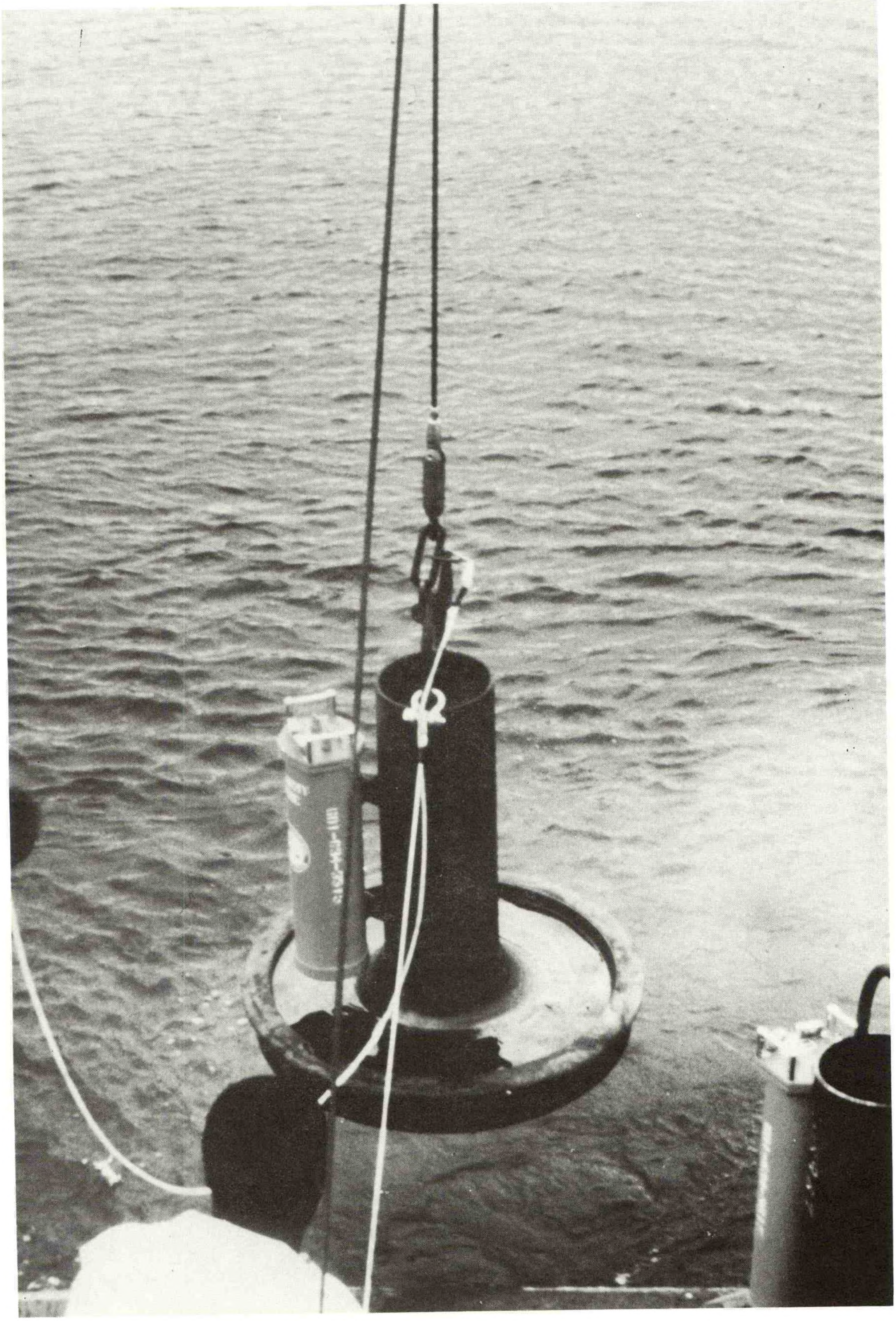

Figure 7. Installation of prototype tide gage.

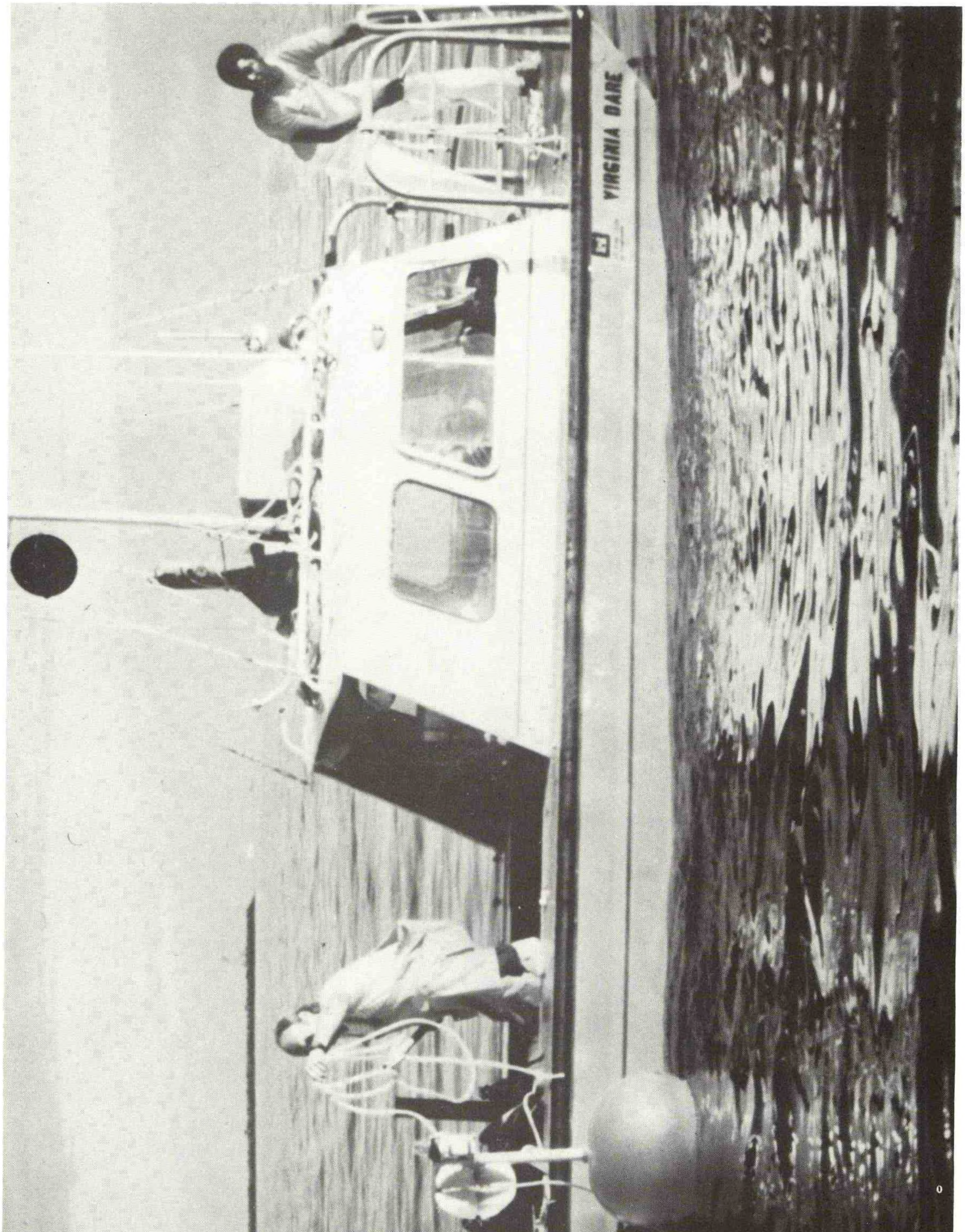

Figure 8. *Installation of current velocity range in outer harbor.*

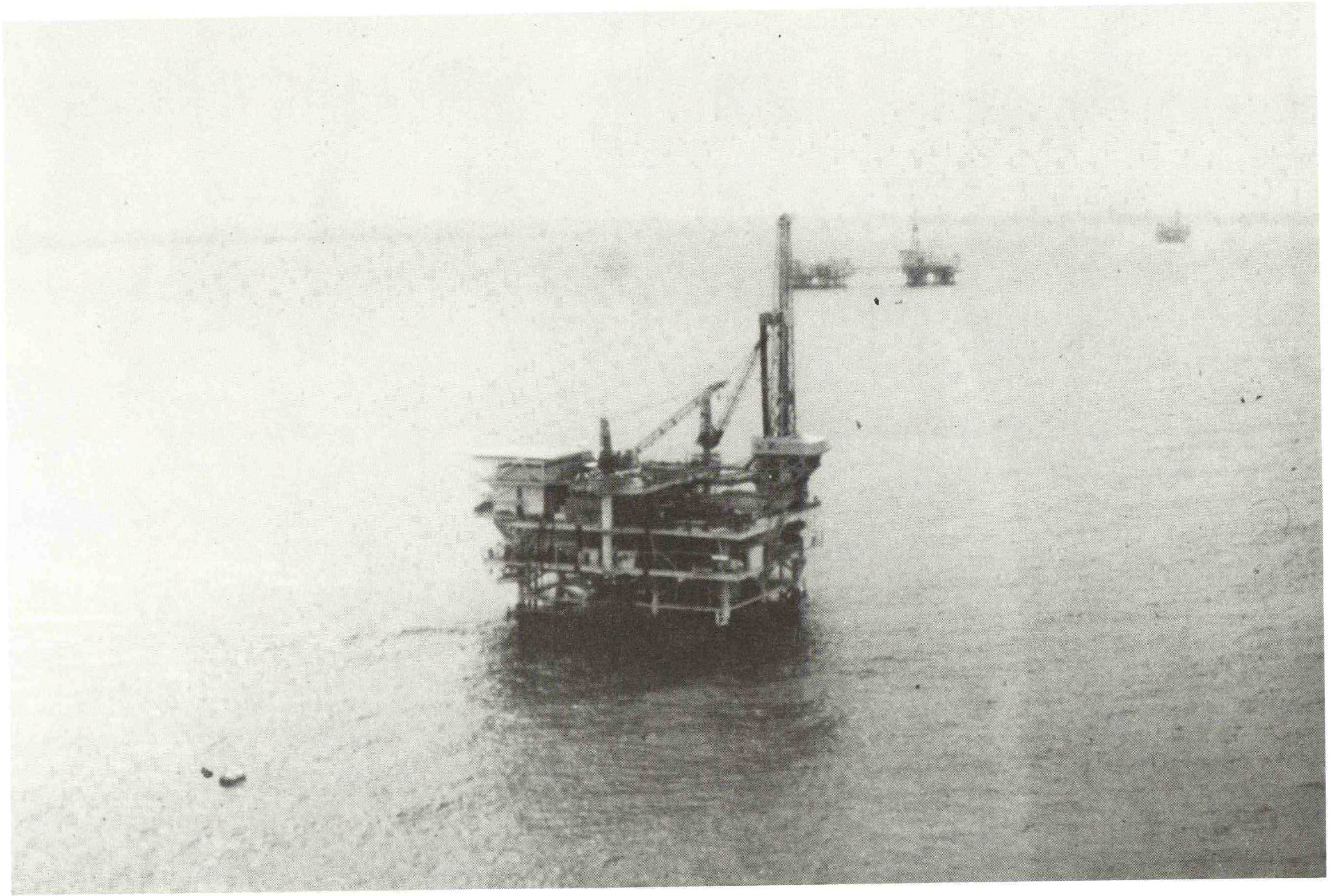

Figure 9. *Platform Edith — incident wave measurement location.*

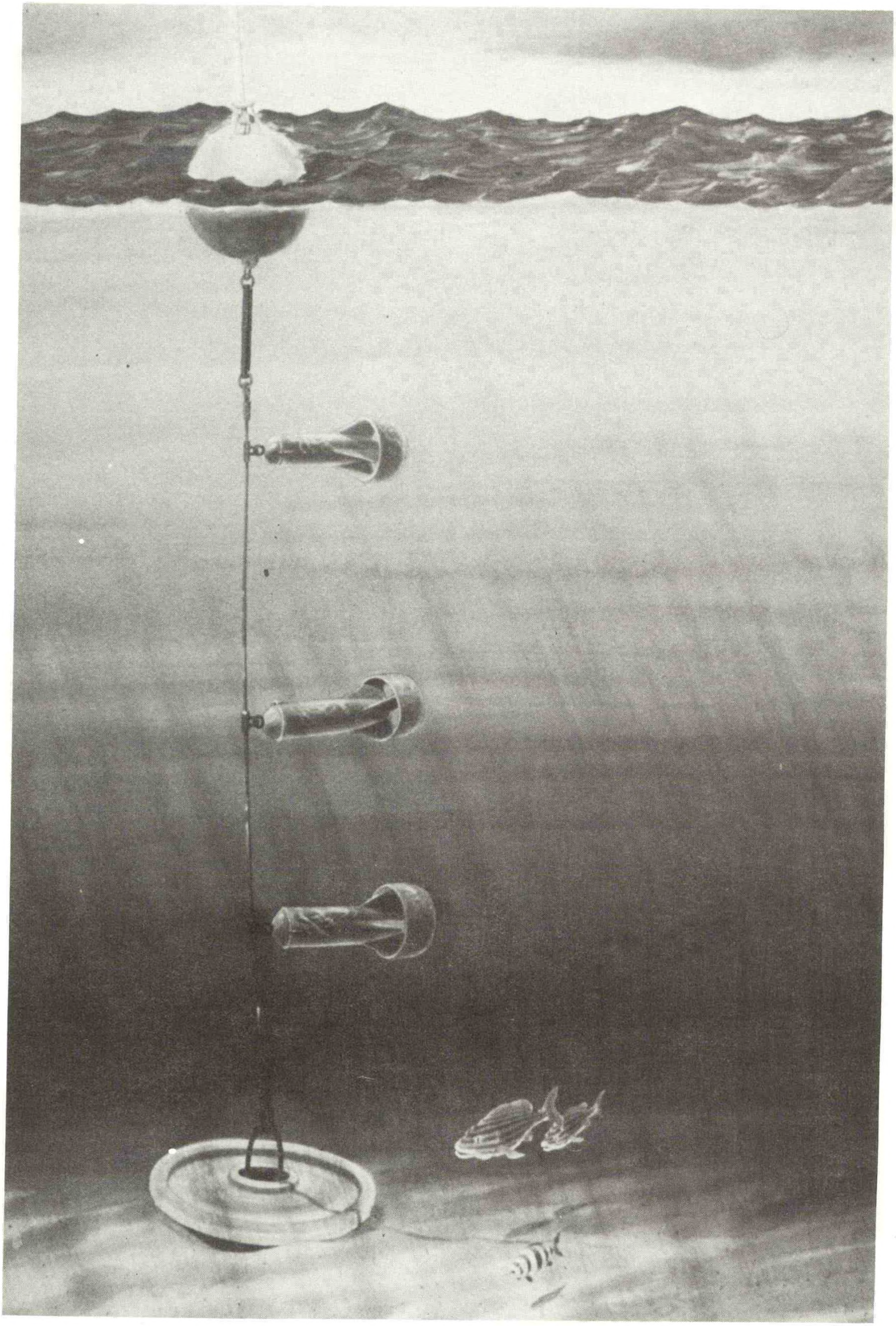

Figure 10. *Typical current meter string.*

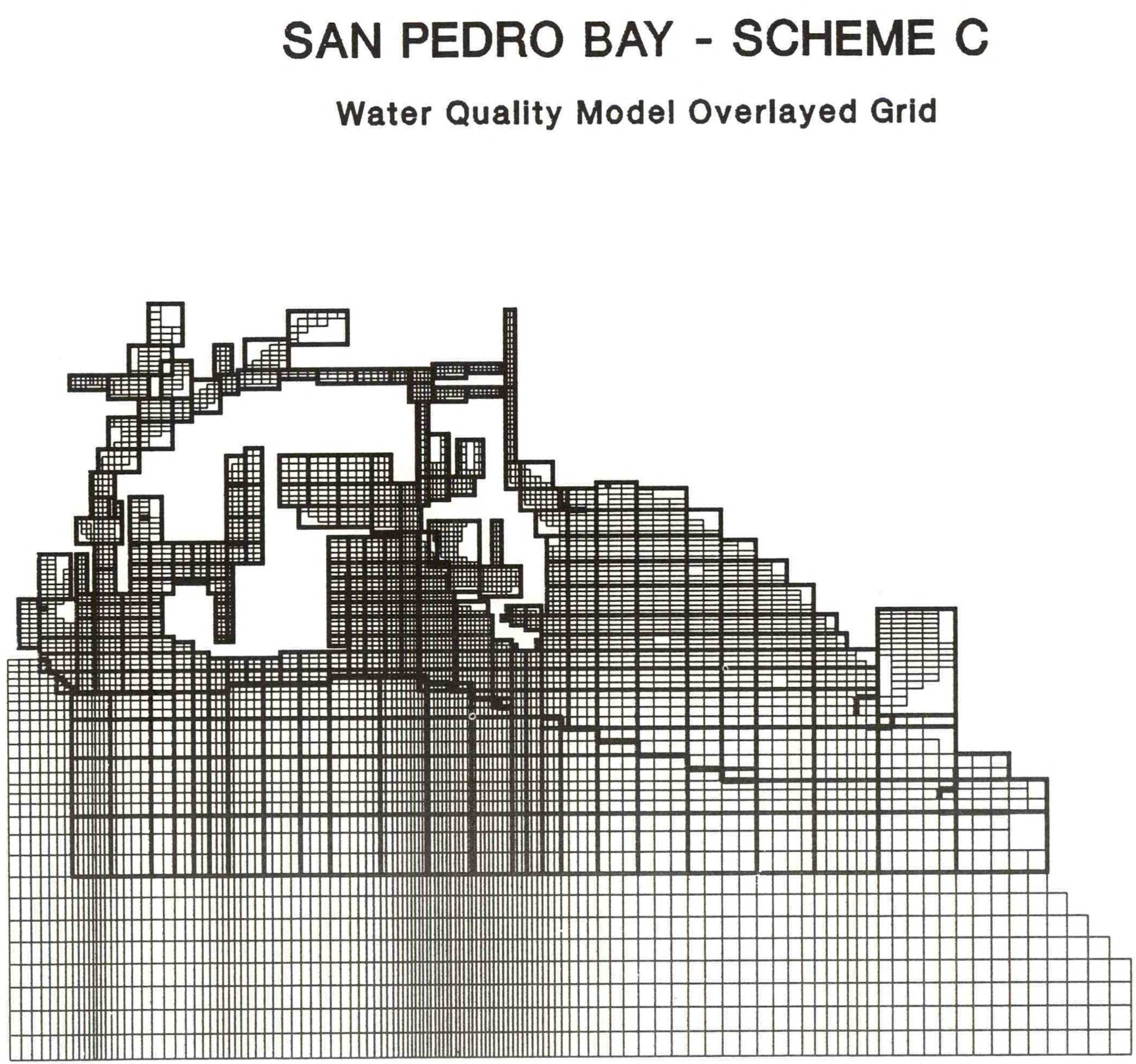

Figure 11. Water quality model grid overlayed on hydrodynamic grid.

Triportopolis: A Concept for an Ocean-Based Multimode Transportation and Communication Complex

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Introduction

In the 20th Century, society has advanced from a monolithic industrial base through continuous technological advancements into a complex, high-technology, computerized telecommunication and information-utilization society.

At the same time, the population continues to grow, from five billion now to perhaps more than nine billion by 2030. Population growth continues to favor the coastal regions, centered mainly on the major coastal ports. It is estimated that by the year 2000, 75 percent of the population in Japan and the U.S.A. will live within 50 miles of the coast.

Commensurate with the increased population and population densities favoring major coastal cities, the flow of people and goods is concentrated there. As a result of this burgeoning concentration of people and goods, present transportation means are becoming overburdened and less effective. Traditional, decentralized methods of expanding and adding more of the same transportation systems will eventually reach a limit in the 21st Century. Therefore, it is wise to explore new ideas and provide options which may accommodate the needs of the future.

One approach, described herein, proposes a centralized, integrated multimode transportation system located on an artificial island constructed offshore adjacent or apart from a major coastal city. The artificial island would integrate futuristic air, sea and land transportation systems into a unified port. Hence, the name Triportopolis. Centralization and integration of transportation systems will facilitate handling a large volume of people and goods and increase their flow rate. Such centralization also provides a focal point for person-to-person communications and information transfer.

In the Northern Hemisphere, the proposed Triportopolis approach can be applied to major world-port cities such as Tokyo, New York, Los Angeles, and London-Amsterdam-Rotterdam, based on demographic data pertaining to the highest flow rates for distribution of people and goods. These cities could provide the foundation for a global distribution network in the Northern Hemisphere, which could be expanded to include other strategic areas, e.g., Sidney, Australia and Rio de Janeiro, Brazil in the Southern Hemisphere.

The Triportopolis concept involves the co-location and integration of airports, seaports and land ports utilizing advanced transportation systems, now in various stages of development and planning in the highly developed nations. Seaports would consist of conventional cargo ports for existing surface ships and new high-speed ships, and for advanced submarine tankers with consideration of new sea routes under the Arctic ice cap.

Airports would be developed to accommodate: supersonic airliners, including the futuristic National Aerospace Planes with cruising speeds of Mach 8 to 24 being considered by several nations for rapid global transport; as well as conventional aircraft for domestic distribution of people and goods.

The Land Port System would consider various rail system configurations, including linear motor cars such as the Magnetic Levitation (MAGLEV) system; and for domestic local and intercity transportation networks, a busing and container trucking port would also be included for distribution via conventional networks.

A major objective of Triportopolis is to provide a smooth interface and integration of the port to ensure high efficiency and timely distribution of people and goods. The objective of this paper is to propose a new concept for the 21st Century that addresses:

- growing needs for international and domestic transport of people and goods.
- facilitating international communications for information exchange.
- Utilization of coastal ocean space for expansion of major world-port cities.

This concept is intended to stimulate new ideas and system approaches to help focus long-range developments to meet the needs of the 21st Century.

It is important to note that the concept and ideas presented are solely the views of the authors and do not represent the organizations with which they are affiliated.

Socioeconomic Centers in the Northern Hemisphere

Since the dawn of civilization some 6,000 years ago in Mesopotamia and the Nile Valley, the major thrust of development has advanced westward toward Europe, Great Britain, North America, Japan, Korea, China and Asia as a whole. This westward advancement occurred between the 20-degree and 60-degree northern parallels.

It is now apparent that major new development is accelerating in the Pacific Rim Countries, led by Japan. The highest rate of development in the 21st Century will be in the Pacific Rim, centered on Asia.

During the last decade, new economic alliances have been forming in the Northern Hemisphere. The European Economic Community (EEC) of 12 nations has formed a major economic alliance that reaches official status in 1992. The U.S.A. and Canada have already shed trade barriers for economic benefit, and with the addition of Mexico, one could postulate a North American Economic Community (NAEC).

In order to illustrate the function of a new global transportation-communication network in the Northern Hemisphere, one could envision three international nuclear blocks, with each representing a cooperative regional economic community of nations. The three blocks envisoned are:

- European Economic Community (EEC) (12 countries)
- North American Economic Community (NAEC) (3 countries)
- Asian Economic Community (AEC) (8 countries)

Additional economic blocks in the Southern Hemisphere, e.g., Sydney, Australia and Rio de Janeiro, Brazil, can also be considered but are not necessary to illustrate the concept at this time.

Depending on how strong the winds of change blow and how efficiently the Soviet Union tills the sail in the wind, it is also possible that the Soviet Union and Eastern Block nations could become an effective economic nuclear block.

For the purpose of this paper, the basic global network will consider the three nuclear blocks.

The GNP and population comparisions (1985 data) illustrate the strength of the three postulated blocks in the Northern Hemisphere. Population comparisions show the EEC Block with 248 million people, the NAEC block with 343 million and the AEC block at 204 million (not including China). The GNP per capita (normalized) shows the NAEC assuming 47 percent, the EEC 29 percent and the AEC 24 percent, with the latter having the greatest growth potential.

The world share of air passenger transport is 54 percent for the three blocks; for air cargo, it is 66 percent.

In the past, air cargo transportation has been handicapped by limitations in payload and high freight rates. However, there is now substantial growth in air cargo. This is because of the change in industrial structure from a raw-material type of industry to a high-value type--such as processing and assembly of semiconductors and computers--which has resulted in smaller, lighter air cargos.

Based on total world population, the three blocks combined represent only 20 percent. However, this 20 percent is responsible for 90 percent of the world GNP per capita.

Regarding distribution of goods, the three blocks combined have an inflow of 30 percent of the world's goods, while having a 65 percent outflow.

Regarding air transportation of passengers and cargoes, the NAEC leads with 584 billion passenger-KM versus 182 for the EEC and 104 for the AEC. In cargo, the NAEC leads with 10.5 billion tons-KM, compared to 8.7 for the EEC and 7.8 for the AEC. Particularly, the new industrial countries have shown a high growth rate, averaging 50 percent over the past decade. As the AEC Block continues to grow, air transportation can be expected to show rapid growth.

Having provided some rationale for a tripolarized Northern Hemisphere merely to establish a global network, one can select a location representing the socioeconomic center of each nuclear block, to be referred to as a Nuclear Megapolis.

Nuclear Megapolis: Selections

AEC Block

In the AEC, Japan has the highest GNP, the largest volume of sea and air cargo, and the greatest number of intellectual property items. In Japan, Tokyo is the focal point of the highest concentration of people, the highest volume of passenger and cargo transportation, and is the leading financial and information center. Hence, Tokyo is selected as the nuclear megapolis and site for a Triportopolis. The Kansai region of Japan, with Osaka as its center, is an alternate.

NAEC Block

In North America, the U.S.A. has the highest GNP and the highest volume of air and ocean transport of passengers and goods. On the East Coast, New York City is the center of the highest concentration of population and the leading financial and information center in the U.S.A. On the West Coast, the Los Angeles-Long Beach Region is another choice. It handles the greatest amount of air and ocean cargo and is in the midst of major development through its 2020 Project. This region will provide a major U.S. interface with Asia.

EEC Block

In the group of 12 countries comprising the EEC, the nuclear megapolis would be located somewhere within the three-city triangle of London-Amsterdam-Rotterdam. London is the financial center and leads in registered patents (intellectual property rights). London's Heathrow Airport and Schiphol Airport in Amsterdam are major passenger and air-cargo distribution centers. Rotterdam is the world's most active seaport.

Triportopolis

Each nuclear megapolis, viz., Tokyo, New York, Los Angeles, London-Amsterdam-Rotterdam, can be used as a site for a Triportopolis. The Triportopolis would be constructed as a giant, offshore artifical island either adjacent to or apart from a nuclear megapolis. The artificial island would be designed to integrate air, sea and land ports into a major multimode transportation complex. A communication complex would be co-located to provide facilities for person-to-person communications and information exchange by providing for multiple convention-exhibit-trade centers. The complex would include hotel-restaurant, entertainment and recreation facilities to accommodate convention participants and visitors. The complex would include on-site satellite telecommunications facilities for real-time international communications as part of the conference and information-exchange facilities. The Triportopolis would also have a number of office facilities associated with operations and use of the complex, as well as office facilities of major international corporations doing business on a global scale.

Triportopolis Construction

The giant artificial island associated with each nuclear megapolis would be constructed based upon requirements peculiar to the selected site. These requirements would be influenced by numerous factors, including the area's multiple users, the site's geological characteristics, environmental conditions and characteristics such as wave, wind and current loading on the planned structures. Depending on the requirements, various construction means can be selected. Construction that makes use of reclamation/containment has the added benefit of utilizing municipal-waste products that are mounting out of control in major cities. Also, dredged materials or excess soils from the land can be used as fill for the artificial island. The reclamation process requires a long lead time to effectively use these materials to provide a geologically stable base and an environmentally suitable containment.

Pile foundations can be used to stabilize the seafloor and sea wall used to contain the waste products and other fill material. Pile foundations can also be used to support offshore structures and platforms above the water level.

Caisson soft landing structures can also be used, especially for regions prone to earthquakes such as Japan. Giant floating platforms linked together can be used as an extension of a fixed artificial island, or as movable modules to accommodate special functions such as waste processing and utilities services.

The artificial island would require between 300 and 400 hectares depending on specific needs. For planning purposes, a resident population of 30,000 and a daytime population of 200,000 are assumed for design purposes. The artificial island would require all of the basic utilities and normal facilities for year-round habitation.

Triportopolis Interface

The Triportopolis, which serves as a depot and physical distribution center for air, sea and land cargoes, can be provided with a fully automatic transponder system which will ensure rapid identification and accurate transfer of cargoes between various types of transportation means. With this system, an optimum combination of transportation systems can be arranged to meet transportation requirements at the lowest cost. Thus, cargoes both at home and abroad can be collected from and distributed to the world's three major bases and their outlying cities by making efficient use of sea, air and land transportation systems. For international passenger transportation, airliners are naturally expected to remain the principal transportation means. However, there are also people who want to enjoy cruising aboard a luxury liner. For such demand, passenger liners and air terminals must be provided with a means of easy access to each other. Similarly, air and sea passengers need to transfer to domestic transportation upon arrival at the Triportopolis terminal. For this change, a safe and comfortable interface transfer system will be required. Both physical distribution of goods and passenger flows will be monitored and controlled at a centralized interface control center to ensure rapid and efficient transfers.

Terminal Functions

Air Terminal

The airport is a cargo-passenger airfield which will consist of one 5,000-meter runway for horizontal takeoff and landing of supersonic airliners (with a speed of Mach 8) and two 3,000-meter runways for conventional jet planes. The passenger terminals will be directly connected with the Triportopolis. The airport will be safely linked with cities via a high-speed Automated Guideway Transit or Personal Rapid Transit. The cargo terminal will consist of three basic line systems, including: an international transit line (which will perform functions to promptly relay and transfer emergency international cargoes from air to air, or from air to land); a domestic distribution line (domestic transfer functions for international cargoes, using air, sea and land transportation systems); and a bonding and stockyard line to temporarily stock goods intended for later distribution. All these functions will be controlled by computer, and goods will be automatically sorted by destination or by the object they will serve.

Sea Terminal

The seaport is a port with berths for submarine-type container cargo and conventional container cargo ships. The sea terminal will also use systems basically similar to those for the air terminal. However, the berths for passenger liners and pleasure boats will be constructed at the city waterfront as facilities attached to the Triportopolis, because these ships and boats serve purposes different from those of cargo ships.

Land Terminal

The land terminal will serve the two functions of cargo transportation and passenger transportation. For principal high-speed transportation systems linking cities on land, passenger-cargo-type linear motor cars will be used to transport cargoes and passengers at a speed of 400 to 500 kilometers per hour. Conventional container trucks and large trucks will be used for less urgently required goods. For this purpose, a truck terminal will also be constructed. A backup system will be provided to effectively link this truck terminal with the air and sea terminals. Since the Triportopolis is an artificial island located offshore, the land transportation system will be linked with the coast through an underground tunnel so that this system will not interfere with any conventional sea transportation system.

New Traffic Systems for the 21st Century

The feasibility of this Triportopolis concept is based on three hypotheses. The first hypothesis is the formation of a North American Economic Community (NAEC) similar to the existing European Economic Community (EEC), and further formation of an East Asia Economic Community (AEC), thereby establishing a tripolar international economy. The second hypothesis is the formation of international distribution bases within each regional economic community. And the third hypothesis is the development of economic and revolutionary rapid-transportation means. The first and second hypotheses will be strongly governed by the delicate balance of international economy and politics. However, the third hypothesis depends greatly upon research efforts by scientists and engineers. Technology has already been developed in various countries, so that the possibility of realizing this hypothesis is very high. Therefore, traffic systems of the 21st Century that will meet this concept will be reviewed.

Submarine Cargo Ship and Superconducting Electromagnetic Thrust Ship

A Superconducting electromagnetic thrust ship (SES) was originally proposed in the U.S.A., and research on its practical application is being made in Japan. This ship will operate based on Fleming's rule. When one end of a magnet is installed on the bottom of a ship and an electric current is run through a field which the magnet generates in water, a force vertical to their orthogonal plane is generated and moves the ship in water. To realize this concept, there are still many problems to solve, including the development of stable raw materials for a superconducting system and its economy. However, in theory, a cruising speed of 100 to 200 kilometers per hour is said to be possible. Considering wave-making resistance which will present problems in high-speed surface ships, it is already clear that submarines can economically cruise at a high speed. Thus, a submarine SES would be the most optimum form of applying this principle in order to fully and effectively exploit performance characteristics of an SES. Submarines are indispensable to Arctic Ocean routes. In the case of a submarine SES utilizing Arctic Ocean routes, the distance between Japan and Europe may be covered in about three days, compared with the approximately 30 days presently required. The economic advantages of reduced transit time are very great and can result in major improvements in ocean transportation. There may be some concern about the large costs involved in constructing a submarine SES. However, this cost would come down if the demand for ocean transportation using Arctic Ocean routes is established and if construction of submarine SES in large numbers is economically desirable. The construction cost for submarines is higher than that of conventional ships, however, submarines may be operated at a lower cost.

Hypersonic Horizontal Takeoff and Landing Aerospace Plane

The Hypersonic Horizontal Takeoff and Landing Aerospace Plane (HOTLAP) proposed under this concept was referred to in former U.S. President Ronald Reagan's annual State of the Union message delivered in February 1986. The message declared that HOTLAP will be developed by the 21st Century as a U.S. National Aerospace Plane (NASP) to fly between Tokyo and Washington, D.C. in about two hours (one-seventh of the present flight time). To attain adaptability and flexibility of manned and unmanned missions to lower orbits and high-speed transportation on the ground surface, this plane will use conventional runways for takeoff and landing, while using a super-high-speed ramjet in the atmosphere with the target maximum speed of Mach 25. At present, this plane is in research and prototype stages with experimental plane X-30, and the research project for NASP will be partly formulated based on the results of flight tests on the X-30. NASP is also known as the Oriental Express. Similar research is being conducted in the U.K. (HOTOL Project), Japan (HOPE), West Germany (Sanger II), France (Hermes), and the Soviet Union. Although the concept varies depending on the country, the projects can basically be divided into two types: the reusable orbiter type in which the orbiter is launched by rocket and lands on its own, as in the case of the Space Shuttle, and the complete horizontal landing and takeoff reusable type. These planes are relatively heavy and the cost is high for payload because they carry complex and sophisticated flight-control systems. However, they have the advantage of a short transit time. HOTLAP could link the Triportopolis in each of four international distribution bases in a short time. However, there are several major problems. The first problem is the overall economy of such an operation. Aside from passengers, there is the question of what cargo should have to be transported at such a super-high speed. Secondly, there is the problem of whether every passenger could physically withstand such supersonic flight. And thirdly, because research and development costs would be too great simply for cargo and passenger transportation, this project needs to be part of national space development programs, and thus, pursued on a national basis.

Non-Wheel System and Linear Motor Cars

Although conventional means of land transportation use wheels to support the body, the method for propelling transportation means by supporting the body with other than wheels has been attracting attention since the latter half of the 20th Century. With conventional transportation systems, the wheels would lose the force of friction with rails and the system could no longer be controlled if the speed reaches 400 to 500 kilometers per hour. In addition, the problems of noise and vibration would also develop. Non-wheel Systems attract attention for these reasons, as well as for their low running cost because the rails are virtually free from wear. This has led to the development of the Linear Motor Car. The Linear Motor Car supports the body about 10 cm above the rails with the repelling power of magnets. In Japan, an experiment conducted in 1979 recorded a speed exceeding 500 kilometers per hour for the first time in the world. Research conducted in the past had focused on a system that supports the body with compressed air discharged from under the floor of the body. Aero Tran of France and TACV of the U.S.A. were of this type and were being developed with the target of 300 kilometers per hour. At present, the Linear Motor Car is drawing attention as a super-high-speed transportation system. It comes in two types. The one employed by Japanese Railways, Ltd. (formerly Japanese National Railways) is a superconduction magnetic levitation system known as "MAGLEV" (magnetic levitation). The other type is a system called High Speed Surface Transport (HSST), which is being developed by a company of the Japan Air Lines group and which uses normal conducting magnets. The HSST offers a higher practical application possibility than MAGLEV and is already scheduled for operation in the U.S. city of Las Vegas, Nevada. Using such super-high-speed linear cars, cargoes and passengers transported by submarine cargo ships or HOTLAP will be transported to various places from the Triportopolis as the originating international distribution base.

Conclusions

The Triportopolis conceptual project presented in this paper proposes a new type of offshore artificial island and an idea for an international cooperative distribution network based on the emergence of tripolar international economic blocks. To realize this project, there are still many problems to solve and many research subjects to cover. Particularly, if this project is to be taken from the viewpoint of ocean development, development of the Arctic Ocean routes, as well as research and development on submarine cargo ships for exploitation of these routes, are urgent tasks. At the same time, the early introduction of the SES as a thrust engine will be indispensable. It is proposed that the Triportopolis concept be investigated as a new Japan-U.S. cooperative project for the 21st Century.

In conclusion, we wish to express our grateful appreciation to the late Dr. Kenji Okamura, who was a distinguished engineer and one of the co-authors of this paper, for his guidance and valuable contributions to the advancement of this concept. May Dr. Okamura rest in peace.

Aside from proposing this new concept, the authors wish to stimulate the engineering community to think about the needs of the 21st Century and to help solve many of the major problems and issues described herein. Tomorrow is in your hands. What will it be?

Ocean Measurement, Assessment and Environmental Protection

WIND AND WAVE STATISTICS ON THE NORTH PACIFIC OCEAN

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INTRODUCTION

Ship Research Institute has a long history in assembling and publishing wind and wave statistics on the Pacific Ocean for use of the naval architecture and marine safety. The first attempt was finished in 1970 with a publication of the statistical tables and charts on the wave climate on the North Pacific Ocean. (It was also known as name of SR80 since the work was done as a joint collaboration with SR80 committee of JSRA.) About one and a half million data on wave climate reported to Japan Meteorological Agency(JMA) by voluntary ships during 1954 to 1963 were made use of in completing the analyses. It can be said that the publication had made clear for the first time of the long-term wave statistics on wave height, period and direction and wind speed and direction and their correlation in the North Pacific.

Following that publication, the second project had been completed in 1980. The purpose of that work was to supplement the former result with data accumulated since 1964. (The work is sometimes called SR163 statistics because of the same reason as SR80.) In this analyses, the data provided not only by JMA but also by NOAA were included. That enabled us to handle more than three and a half million data from 1964 to 1973 for processing and thereby to have wider and denser coverage over the North Pacific.

Almost ten years have passed since the last publication in 1980 and there are growing demands for new kinds of wave information which can meet requirement for designing marine vehicles under a new concept, as well as refined wave statistics based on recent achievement of dynamics on ocean waves. Thus a new R & D project has just started in order to answer the demand under the joint collaboration with the Japan Foundation for Shipbuilding Advancement. The project will take three years to get to the goal. This paper describes briefly plan of the project for improved long-term wave statistics of the North Pacific Ocean.

OVERVIEW OF THE PROJECT

The objective of the project is to build a data base system on wave climate on the North Pacific Ocean, as is shown in Fig.1. Elementary information comprised of ship reports and hindcasted results, after having been verified by appropriate reliable data, forms base of the further processing for various kinds of wave statistics. The wave statistics form another data base of practical interests and main part of the data base system. They are computed from the elementary information.

The procedure will take steps as are shown in Fig.2. The first will be data collection step. Then hindcasting, verification and fabrication of the data base system will follow. Details will be discussed in the following.

DATA SOURCE

There are two kinds of data at hand for the long-term wave climate in the upper ocean. One is the weather report from ocean going vessels and the other is, known as wave hindcasting, data through numerical simulation on wave generation, evolution and propagation in the ocean caused by wind data in the past.

Ship reports are the largest source of the wave climate and it has vast historical accumulation of comparable data. One of the problem with the ship reports is that they are concentrated along the particular ocean routes and their vicinity. The hindcasting is free from such regional restrictions. However, it has a problem that its results may depend on a wave model selected for the computation and its reliability has not been fully confirmed.

These two kinds of data sources are made use of to form the basic data for wave statistics.

Ship Reports

Thousands of voluntary ships report their locations and climate at their point every 4 hours for meteorological agencies that have responsibility for data collection assigned by WMO. JMA is the responsible body for the data collection in the North West Pacific Ocean and NOAA is responsible for the North East Pacific, as is shown Fig.3. The accumulated data have been analyzed for regular publication by the organizations. It has been felt, however, further analyses are desirable for the engineering purposes like long-term wave climate for use of the ship design.

In this project, those items essential to present purpose will be selected out of reported information with respect to wind, wave and atmospheric climate to form elementary information. They will be passed for screening, verification and data base processing before stored in the data base.

First phase will be to take up JMA data from 1974 to the latest as material data. Furthermore if it is available, NOAA data during the same period will be included in the same manner in order to extend its coverage and reliability of the wave statistics. Also planned is adoption of the former data from 1964 to 1973, which had been used in the late work in 1980. That will enable us to process vast volumes of data.

Hindcasting

Hindcasting will be done to create wave data in the areas otherwise unavailable. Wind data which comprises essential parts of the numerical simulation will be introduced through a reliable wind model calculation. The hindcasting will be made for the whole North Pacific Ocean for past ten years or so. With use of recently revised wave model, the simulation will be made at approximately 300 km by 300 km square mesh points covering whole North Pacific at every 6 hour interval. Fig.4 shows grid plan for the hindcasting. Ten years of hindcasting are planned from 1980 till 1989.

There is a demand for data telling detailed temporal and regional variation of the ocean wave. Since the above mentioned global hindcasting might miss a mid-range disturbance like a typhoon and a large storm, fine mesh and short time interval hindcastings are planned for prominent storm conditions in the past. (See Fig.5) The temporal sequence at the extreme wave inception can be traced with this simulation. This will also serve as a measure when verifying with the buoy data.

VERIFICATION

Verification is a crucial step for wave statistics with accuracy and reliability.

There have been arguments on its accuracy and reliability arising from possible human factors contained in the ship reports. The ship reports are said to be biased for the smoother sea state and shorter wave components possibly due to the practice for safer routing and human factors. The data therefore has to be compared and verified with information from reliable measurement, in addition to cross-examination among their own climatic information derived simultaneously.

There is similar kind of problems in hindcasted data since they may be dependent on the wave modelling. They have to be verified by so-called "sea truth".

It is known that offshore buoys give most reliable wave climate data so far and are possibly only sources of such kind of information. At present, it is planned that data from meteorological buoys deployed off the coast of Japan by JMA will be made use of for that purpose.

There are several stages for the verification. The first and most fundamental one would be to correlate temporal variations of wave climate given by different sources. But this will not be possible for every data and will be limited for data of particular area and dates. The next would be to verify if their statistical nature checks well among those from the different sources.

DATA BASE

All the data derived in a manner described in preceeding sections will be fed into a data base system. The reason why the data base is introduced is twofold. One is as a mean to help data verification and the other is as a mean to let users have an ease access to their desired information. The statistical analyses will be made by using a function of the data base.

A part of the data base will be comprised of data from ship reports and hindcasting results. There will be examination from all conceivable points of view and will be run in trial bases for verification of its usability. Through that process, it will be decided whether both kinds of data may be combined into a unified data source or should be treated separately.

The data can be retrieved in one or grouped zonal categories on monthly, seasonally ,annually and all time period. For zoning of the Pacific in this data base, refer to Fig.6.

Some examples. of the statistics to be derived are joint probability distribution among wave height, period and direction and wind speed and direction. It will also be interesting to know the persistence of wave height or recurrence interval of particular wave height based on the hindcasted results.

There are demands for spectrum shapes of the ocean waves in connection with the sea state. There is hardly measured spectrum with accuracy in the middle of ocean. An alternative way is to present spectrum shape derived through hindcasting. It has a room for examination on its reality but nevertheless gives a certain figure of the wave spectrum.

Although primary information of the data base will be statistically analyzed distribution or histogram of wave, wind and other climatic information, the data base will give us on demand an access to elementary information if it is desired. There will be capability for statistical information of newly devised combination of elementary data on user's choice.

Final product of this project will be a publication of summary wave statistics on the North Pacific as is exemplified in Fig.7 and 8. At the same time the data base itself will be available in the form of magnetic media.

ACKNOWLEDGEMENT

We acknowledge great help extended from meteorological agencies of both countries. Also our thanks are due for support extended by Mr.Nicholson, the former chairman of this Panel, and Mr.Quayle of NOAA who had enabled us to have an access to NOAA data in the last work.

In this occasion, we would like to ask again supports and helps of members of the Marine Facility Panel of UJNR in including NOAA data into this new project.

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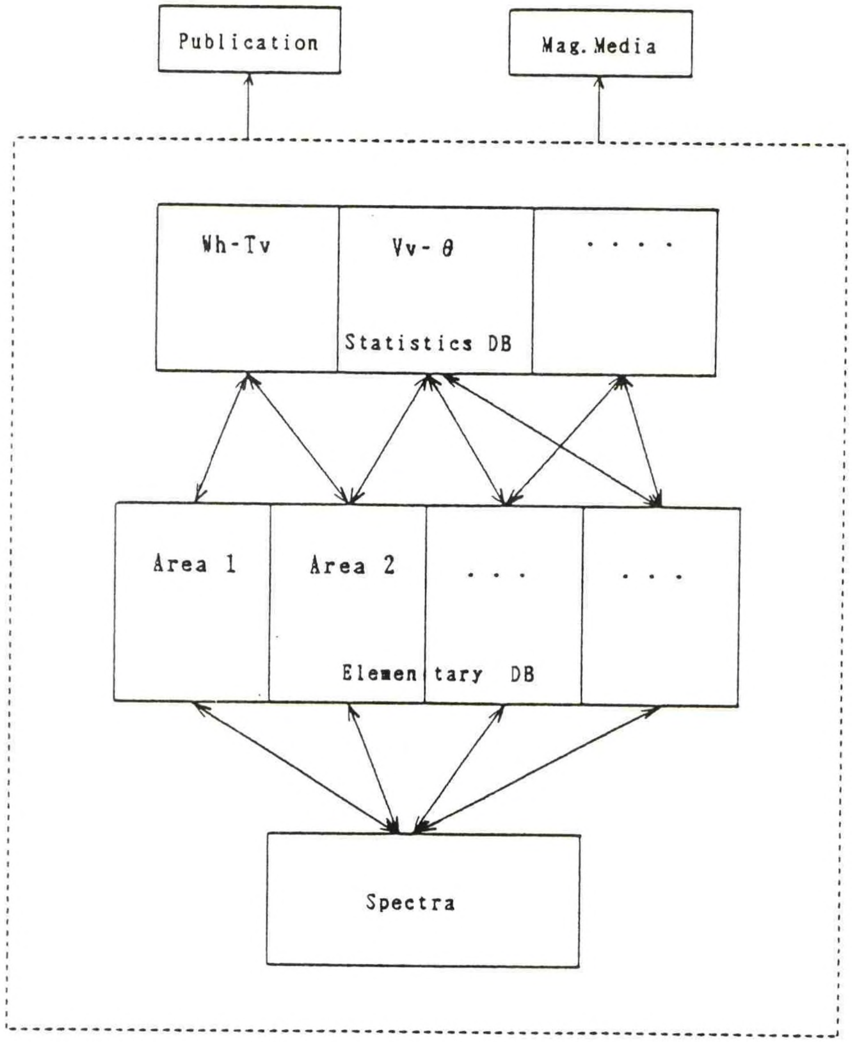

Fig.1 Outline of Data Base on Wave Climate

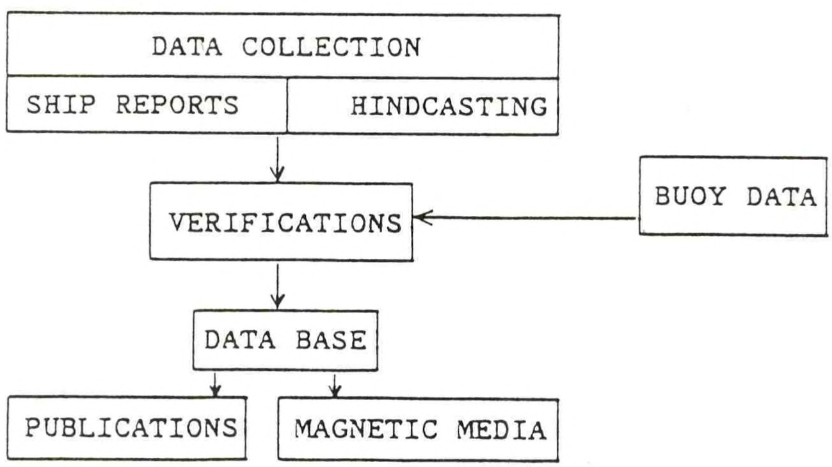

Fig.2 Schematic Flow of Works

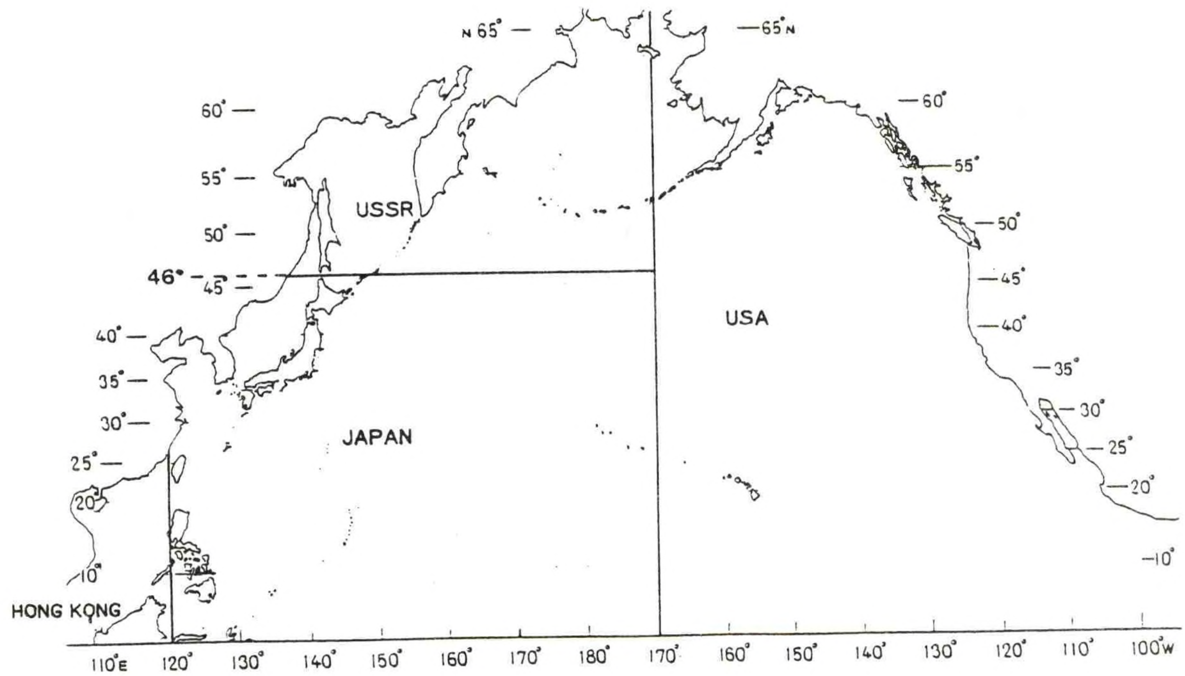

Fig.3 Countries Responsible for Ship Reports
Collection and Their Covering Areas

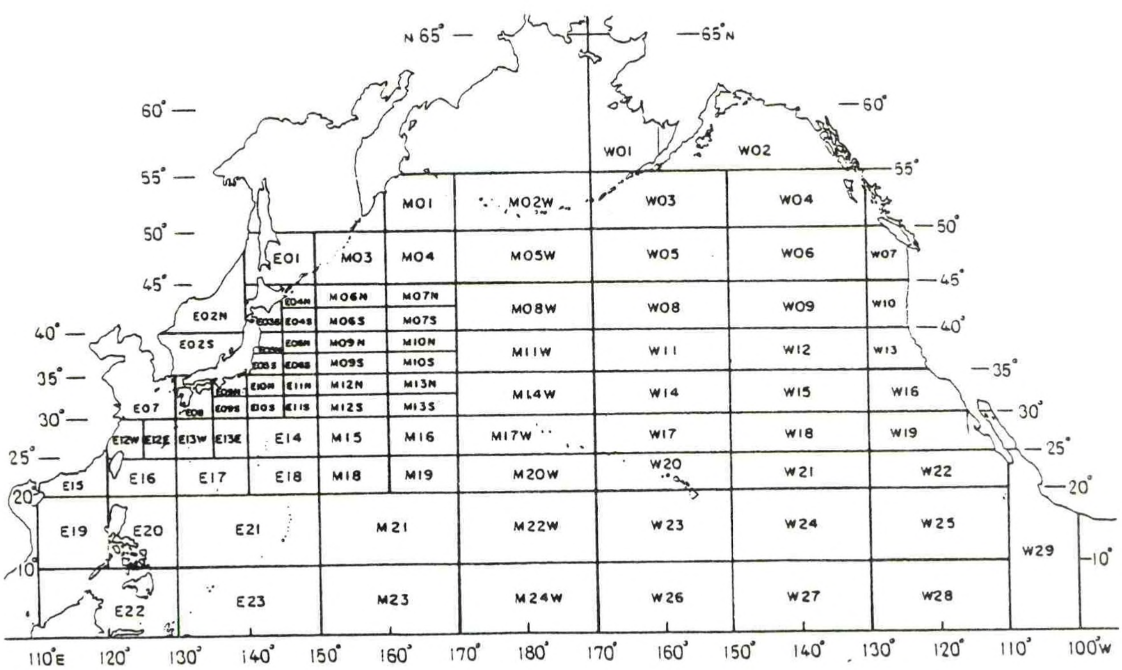

Fig.6 Zoning for Wave Statistics

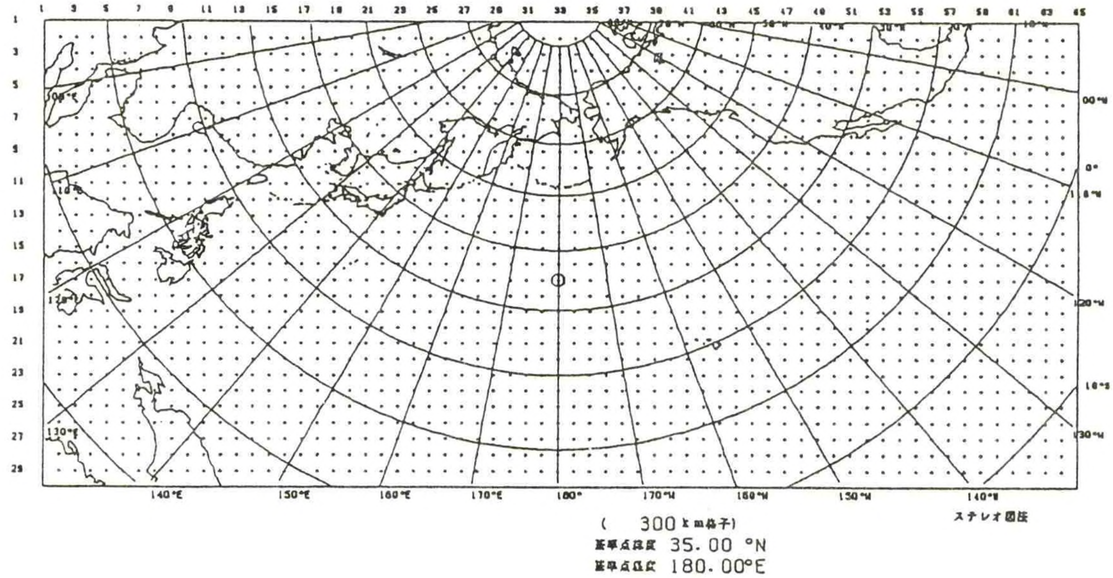

Fig.4 Grid Points for Wide Range Hindcasting

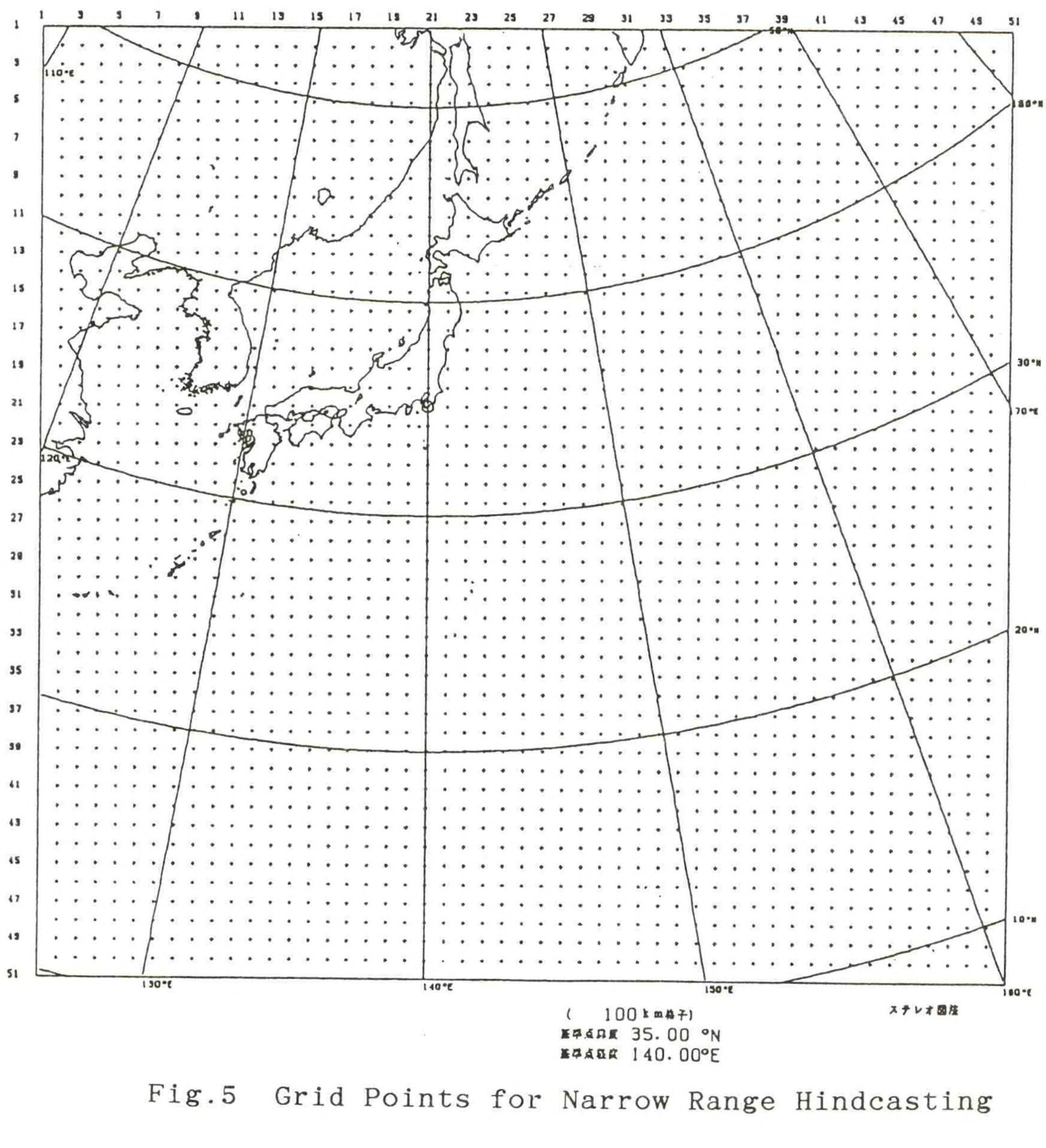

Fig.5 Grid Points for Narrow Range Hindcasting

AREA M17W (25N-30N, 170E-170W)

DATA NUMBER 12240
MEAN OF DATA 1.35 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	1795	112	66	18	4	6	147	2148
0.75 -	4678	1374	716	104	82	60		7014
1.75 -	693	834	552	120	80	48		2327
2.75 -	112	176	164	32	20	3		507
3.75 -	6	45	44	4	4	3		106
4.75 -			3	7	1	2		13
5.75 -		1	1					2
6.75 -								
7.75 -								
8.75 -								
9.75 -								
10.75 -			1					1
11.75 -								
12.75 -								
13.75 -								
14.75 -								
CALM							122	122
TOTAL	7284	2542	1547	285	191	122	269	12240
MAX	4.00	6.00	11.00	5.50	5.00	5.00	.00	11.00

AREA M21 (10N-20N, 150E-170E)

DATA NUMBER 8004
MEAN OF DATA 1.32 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	1354	49	49	15	4	13	108	1592
0.75 -	3044	914	492	72	52	47		4621
1.75 -	401	543	305	61	23	37		1379
2.75 -	49	120	96	21	19	3		308
3.75 -	5	22	21	11	1	1		61
4.75 -	1	1	2	2		1		7
5.75 -		2	4	1		2		9
6.75 -		1						1
7.75 -								
8.75 -						1		1
9.75 -								
10.75 -								
11.75 -				2				2
12.75 -								
13.75 -								
14.75 -								
CALM							27	27
TOTAL	4854	1652	969	185	104	105	135	8004
MAX	5.00	7.00	6.00	12.00	4.50	9.00	.00	12.00

AREA M18 (20N-25N, 150E-160E)

DATA NUMBER 3213
MEAN OF DATA 1.36 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	517	16	12	8	5	1	76	637
0.75 -	1121	373	208	43	40	22		1807
1.75 -	170	189	115	40	20	5		539
2.75 -	29	51	37	22	20	3		162
3.75 -	3	7	11	1	1	2		25
4.75 -	1	3	7	2		2		15
5.75 -	1	2				3		6
6.75 -			1					1
7.75 -								
8.75 -						1		1
9.75 -		2						2
10.75 -								
11.75 -								
12.75 -								
13.75 -								
14.75 -								
CALM							10	10
TOTAL	1842	645	391	116	86	39	86	3213
MAX	6.00	10.00	7.50	5.00	4.00	9.00	.00	10.00

AREA M22W (10N-20N, 170E-170W)

DATA NUMBER 5483
MEAN OF DATA 1.48 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	643	16	18	3	4	2	38	724
0.75 -	2150	521	345	45	47	20		3128
1.75 -	399	475	284	32	42	28		1260
2.75 -	70	111	86	15	22	20		324
3.75 -	1	14	16	1	2	5		39
4.75 -	1		5		1			7
5.75 -								
6.75 -								
7.75 -								
8.75 -								
9.75 -								
10.75 -								
11.75 -								
12.75 -								
13.75 -								
14.75 -								
CALM							1	1
TOTAL	3264	1137	754	96	118	75	39	5483
MAX	5.00	4.00	5.50	4.50	5.50	4.00	.00	5.50

AREA M19 (20N-25N, 160E-170E)

DATA NUMBER 2561
MEAN OF DATA 1.32 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	411	16	22	11			36	496
0.75 -	1060	270	138	16	17	14		1515
1.75 -	139	141	95	18	17	11		421
2.75 -	18	29	38	5	3	3		96
3.75 -	6	5	5	3		2		21
4.75 -								
5.75 -		2						2
6.75 -		1				2		3
7.75 -								
8.75 -								
9.75 -								
10.75 -								
11.75 -								
12.75 -								
13.75 -								
14.75 -								
CALM							7	7
TOTAL	1634	464	298	53	37	32	43	2561
MAX	4.50	7.00	4.50	4.50	3.50	7.50	.00	7.50

AREA M23 (00N-10N, 150E-170E)

DATA NUMBER 6248
MEAN OF DATA 1.11 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	1324	120	106	8	17	16	83	1674
0.75 -	2000	1127	481	61	57	36		3762
1.75 -	201	242	164	8	10	23		648
2.75 -	14	52	30	1	2			99
3.75 -		5	5					10
4.75 -								
5.75 -		1						1
6.75 -								
7.75 -								
8.75 -								
9.75 -								
10.75 -								
11.75 -								
12.75 -								
13.75 -								
14.75 -		1						1
CALM							53	53
TOTAL	3539	1548	786	70	86	75	136	6248
MAX	3.00	15.00	4.00	3.50	3.00	2.50	.00	15.00

AREA M20W (20N-25N, 170E-170W)

DATA NUMBER 9428
MEAN OF DATA 1.40 M

PERIOD (SEC)

HEIGHT (M)	-5	6-7	8-9	10-11	12-13	14-	CALM	TOTAL
0.00 -	1146	65	22	11	1	2	34	1281
0.75 -	4048	1146	504	83	52	31		5864
1.75 -	583	625	463	101	44	20		1836
2.75 -	66	156	112	10	13	4		361
3.75 -	7	28	12	5	5	3		60
4.75 -			1	3		3		7
5.75 -	1							1
6.75 -								
7.75 -								
8.75 -						1		1
9.75 -								
10.75 -								
11.75 -								
12.75 -								
13.75 -								
14.75 -								
CALM							17	17
TOTAL	5851	2020	1114	213	115	64	51	9428
MAX	6.00	4.50	5.00	5.00	4.50	9.00	.00	9.00

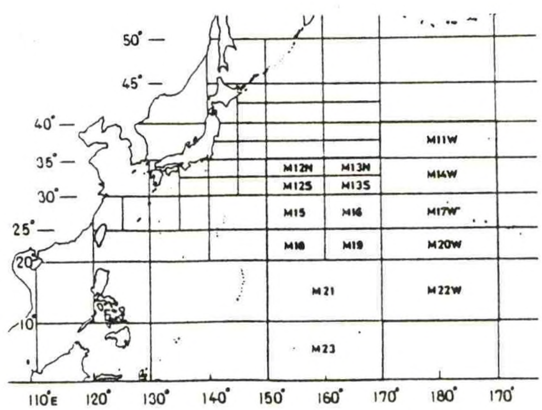

Fig.7 Example of Wave Statistics Tables
(From Ref.2)

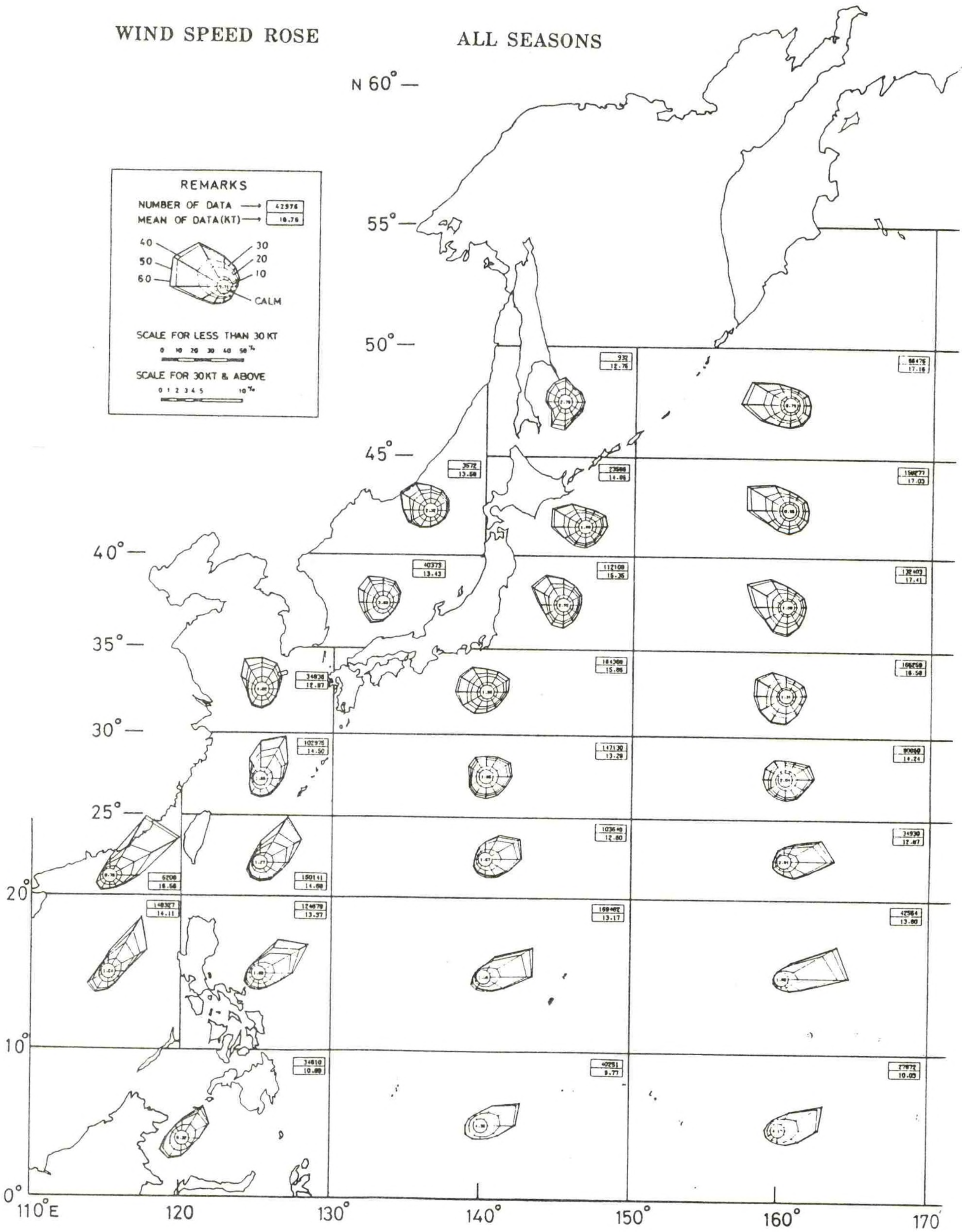

Fig.8 Example of Graphic Presentaion of Statistics (From Ref.2)

A Radio-controlled Buoy for Survey on Submarine Volcanoes

1989. July. 24.

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1. Introduction

The Hydrographic Department of Japan has developed a radio-controlled and navigable buoy for ocean surveys by the end of 1987. The Radio-controlled buoy, named "MANBOU", is engaging in surveys of waters surrounding active submarine volcanoes, which are usually very difficult to survey with existing manned survey vessels. The HD of Japan has carried out Bathymetric survey some active submarine volcanoes in 1988 and 1989. The outline of this remotely-controlled unmanned buoy and results of its surveys will be given in the followings.

*"MANBOU" means a sunfish.

2. Systems

The development of a radio-controlled buoy required a five-years plan which coverd the period from fiscal 1983 to 1985 for desinging of a buoy and its production, and second phase for the two-year period from fiscal 1986 to 1987 for verification of its capabilities and possible improvement.

The radio-controlled buoy is conceived as consisting of four major systems, the navigation system, self-guard (collision avoiding) system, the body of buoy and the data acquisition and data transmission system. On the first phase of development, works to design and produce these four systems were being carried out separately, and concurrently. The following are the outlines of the four major sytems.

(1) Navigation System

The navigation system of the radio-controlled buoy includes, a LORAN C receiver, a GPS receiver, a gyro compass (a magnetic compass for spare), and a water current speed indicator.

Using these apparatus, the system is capable of automatically navigating the buoy to its planned waypoints and destination. To do this, the system first detects the position, the direction and the speed of the buoy, and then calculates the position of the buoy´s helm by comparing the obtained data with those put in before-hands. We can also maneuver the buoy by transmitting directions through radio from the mother ship.

(2) Self-guard System
(Avoiding Collision System)

The system is designed to safeguard the buoy in operation. It consists of several apparatus which will be explained in the following.

- Two TV cameras and a radar are installed to monitor ahead of the buoy and its surroundings in order to prevent the buoy from running into a ship or other obstacles on the sea. Pictures taken by the TV cameras and reflections on the radar screen are sent to the mother ship as static images to be renewed in every 23 seconds.
- Signal light and a sound-warning device are equiped to make the buoy conspicuous to passing ships.

(3) Body of Buoy

The radio-controlled buoy is shaped like a ship, because it was planned to be replace the 10-meter survey boat now being mounded to the Myranda David aboard the large-class survey vessel, the "Shoyo", belonging to the Maritime Safety Agency.

The body was designed to be resistent to submergence, having a 180-degree restoring moment. This is to make it fit to surveys under rough weathers as well.

Table 1. Main Items of the Body

Material:	FRP
Total Length:	10.00 meters
Maximum Width:	2.78 meters
Total Height	2.60 meters
*Excluding the antennas and radar.	
Speed:	6 knots
Distance for Continuous Navigation:	more than 120 nM
Displacement:	6.6 tons
Output of Generator:	40 kVA
Voltage of Generator:	225 V
Cycles of Generator	60 Hz
Output of Electric Propulsion Device:	15 kW
Electric Propulsion Device:	1800rpm
* Continuous rating. Three propulsion wings fixed pitch	

(4) Data Acquisition and Data Transmission System

The radio-contorlled buoy is carried out four functions of survey: sounding, measuring sea surface tempartures, water sampling and XBT. The items are shown on Table 2.

Obtained data are recorded on the IC-memory, and at the same time, it is transmitted to the mother ship. Water samplers and XBT launchers can be operated at any time, responding to the directions from the mother ship or pre-established programs.

Table 2. Items for Measurement

Echo Soundings:	30kHz; up to 999 meters
Sea Water Temparature:	10 to 50 degrees Centigrade
Water Samplling:	Four water bottle 10 litters for one time
XBT:	Mounted with three
Data Recording:	IC-memory

There are also devices to see if the engine and related machines are in good operation. These devices constantly monitor temparatures and humidities of the engine room, voltages of the batteries, operating conditions of motors, fuel level etc. Data from these devices as well as those from ocean surveying are to be transmitted to the mother ship in every ten seconds.

Communication between the mother ship and the buoy are transmitted through the VHF (60 MHz) for static images, and through the HF (20 MHz) for survey data and control data. Urgent control data such as emergency stop can be transmitted through the VHF as well

Among the data transmitted to the mother ship, data sent as static images are to be displayed on the CRT on the mother ship. Data indicating the position of submarine volcano and other survey data are drawn on the plotter. Reading these data the operator of the radio-controlled buoy conducts surveys by choosing adequate mode from automatic and manual modes. We estimate that the distances for data transmission will more than 20 kilometers for VHF, and 80 kilometers for HF.

3. Survey by the Radio-controlled Buoy

We are now in the operating the radio-controlled buoy for surveys around actie submarine volcanoes.

As for and Hukutoku-Okanoba Myozin-Syo which are not very active in recent years, detailed surveys by the radio-controlled buoy were carried out in 1988 and 1989 to help identify sea-bottom topography, making possible drawings of precise maps.

Recently we carried out survey around an active submarine volcano, "Teisi Knoll" erupted on 13 July 1989 offing 3km of Ito City one of famous resorts near Tokyo.

4. Conclusion

There are a lot of submarine volcanoes in the seas around Japan, which include Myouzin-Syo, Kaitoku Seamount, Hukutoku-Okanoba and Hukuzin Seamount. Many of them are active. In order to grasp their activities, various surveys are necessary including identifying sea-bottom topography, and measuring water temparature, and sampling sea waters. So far, surveys on cenral part of an active submarine volcanoe could not conducted using existing manned ships becourse of its dangerous activities. A radio-controlled buoy, "MANBOU", is being expected to make such surveys for preventing disaster of submarine volcanoes.

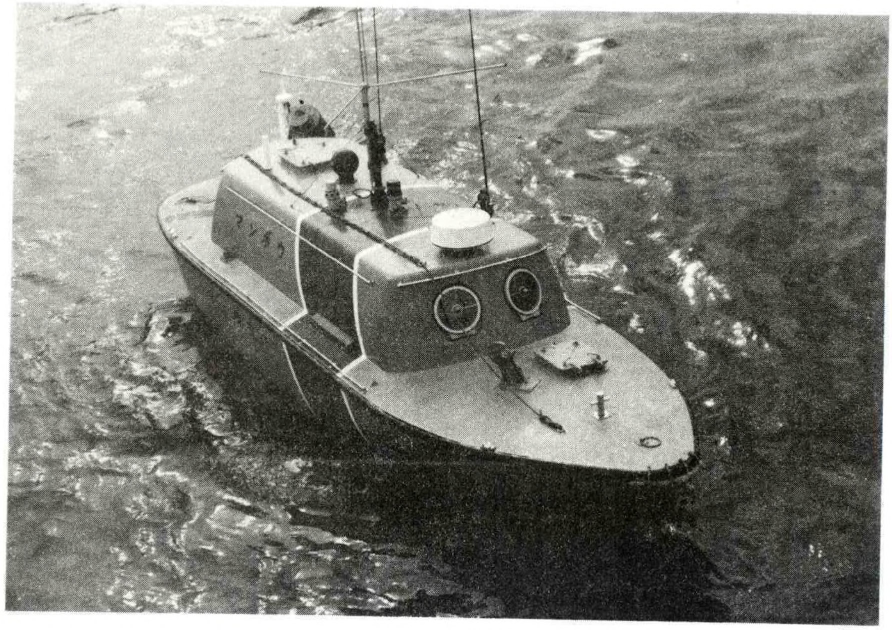


fig.1

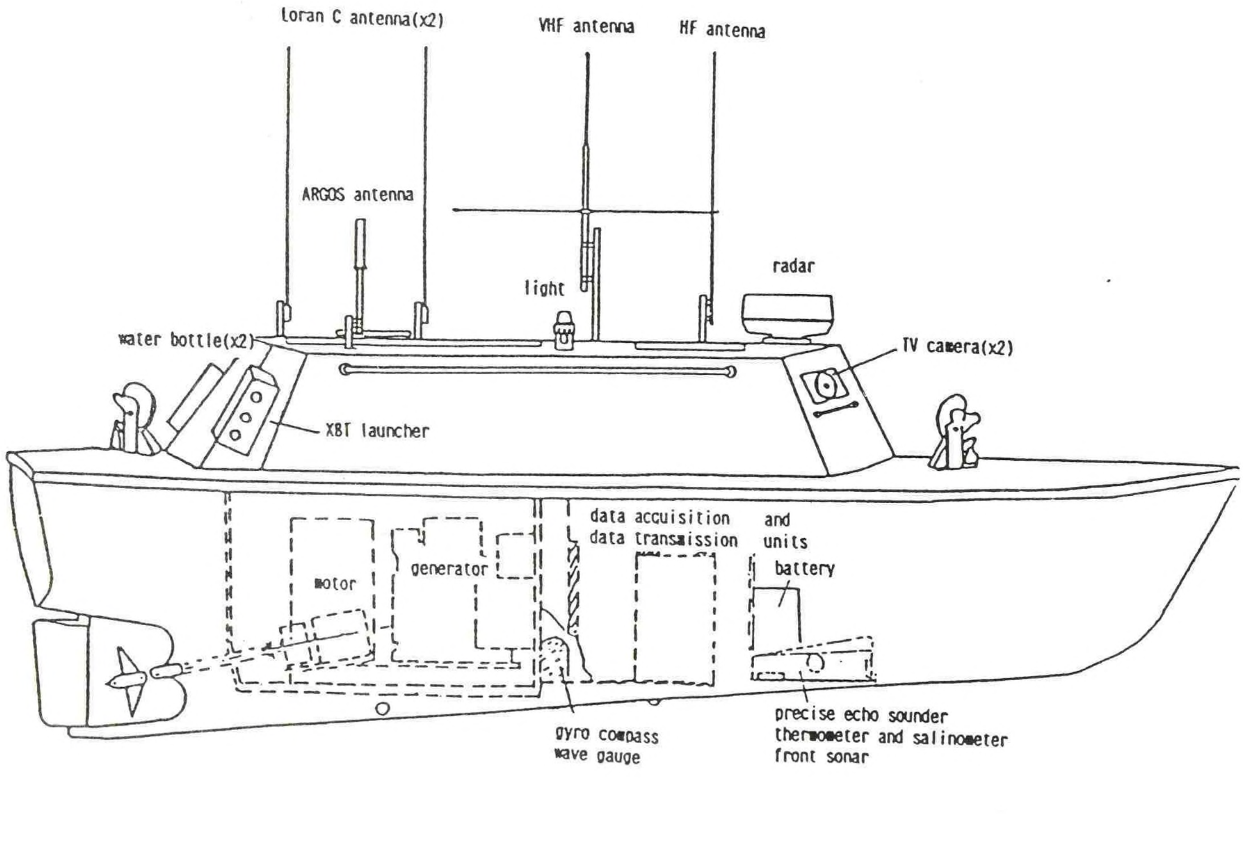
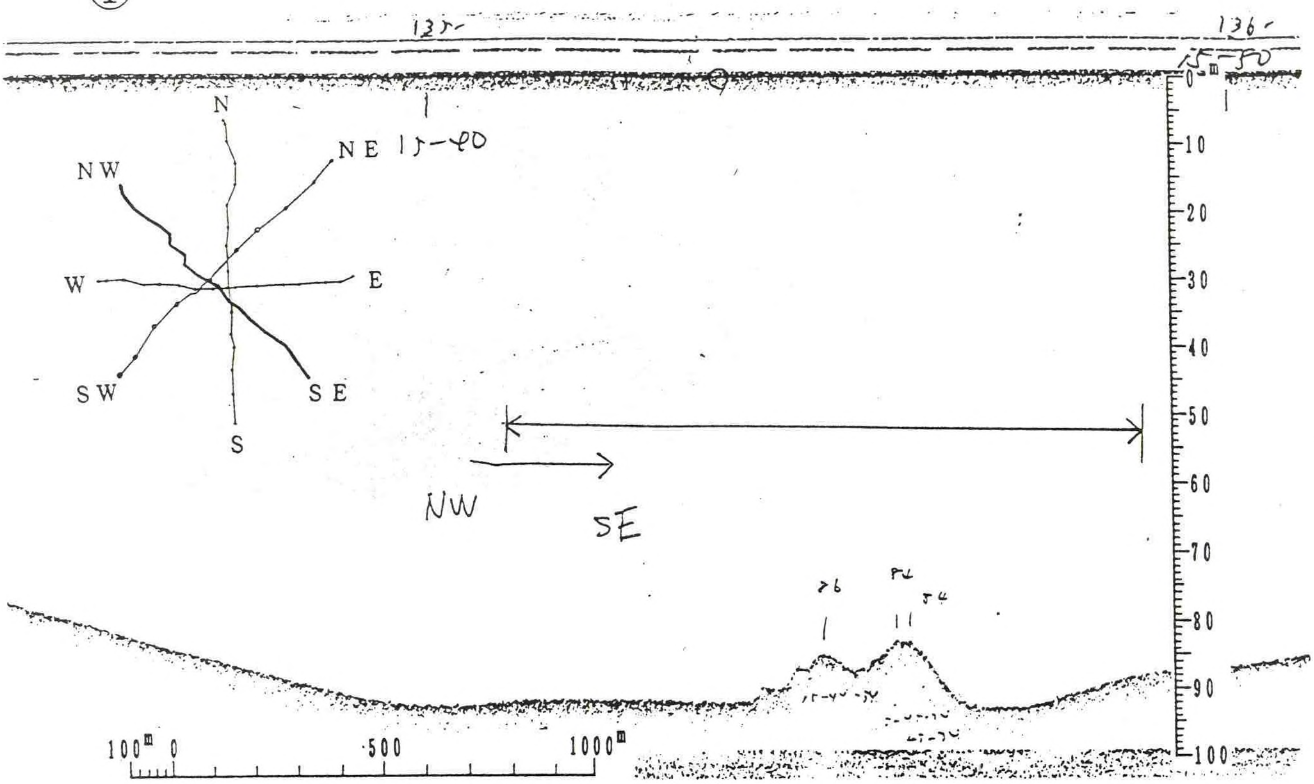


fig.2 schematic plan

火口付近の音響測深記録

「マンボウ」　(平成元年７月15日)

①



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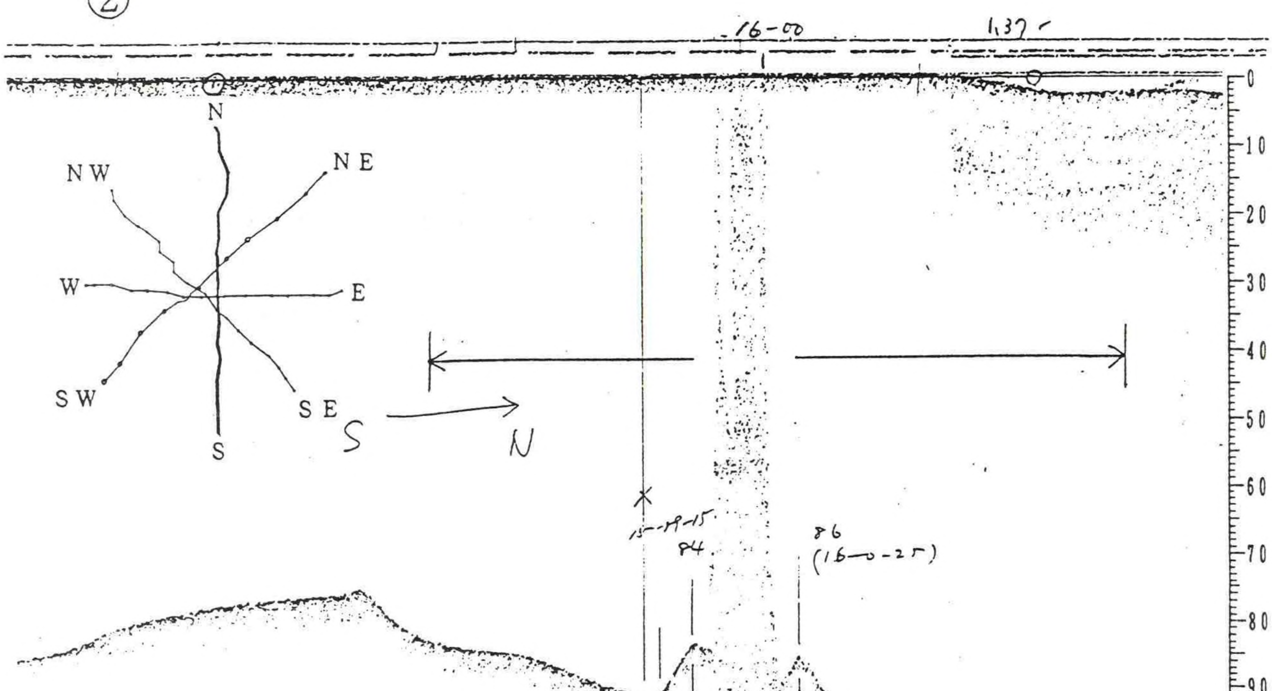

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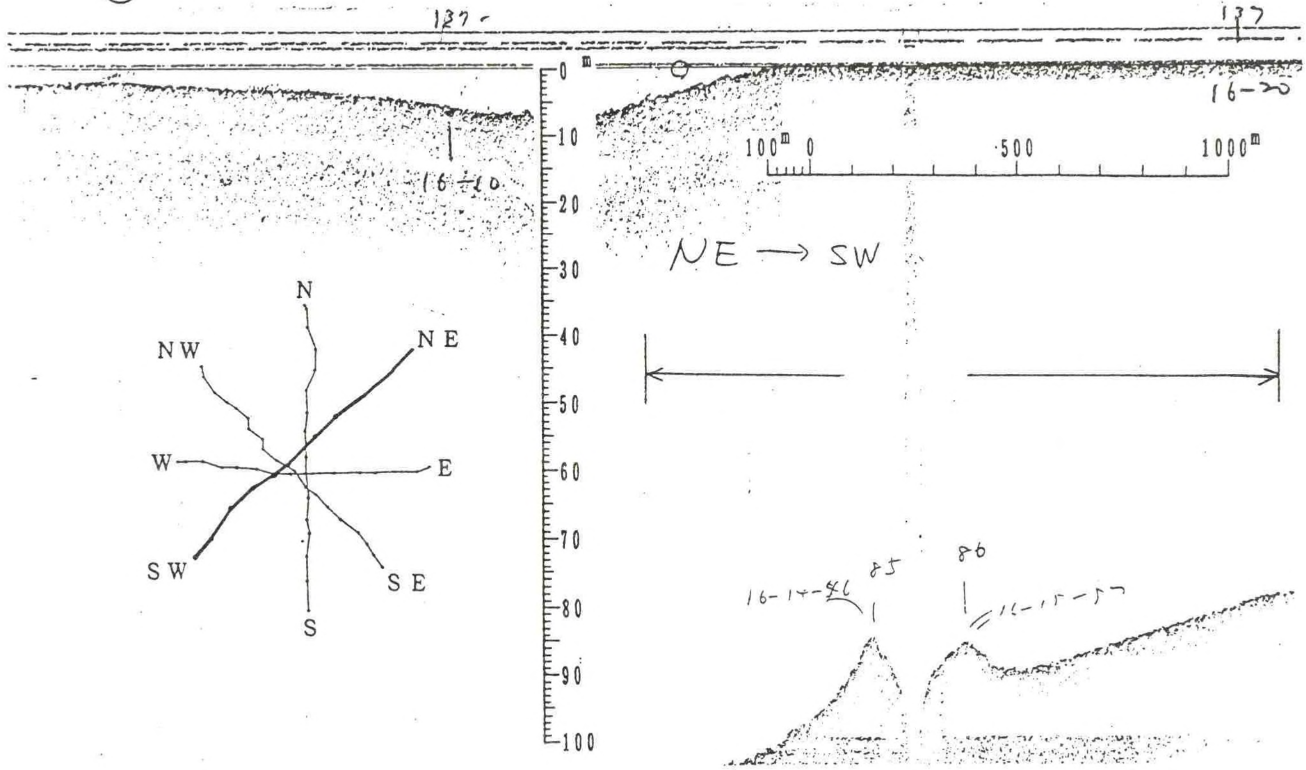
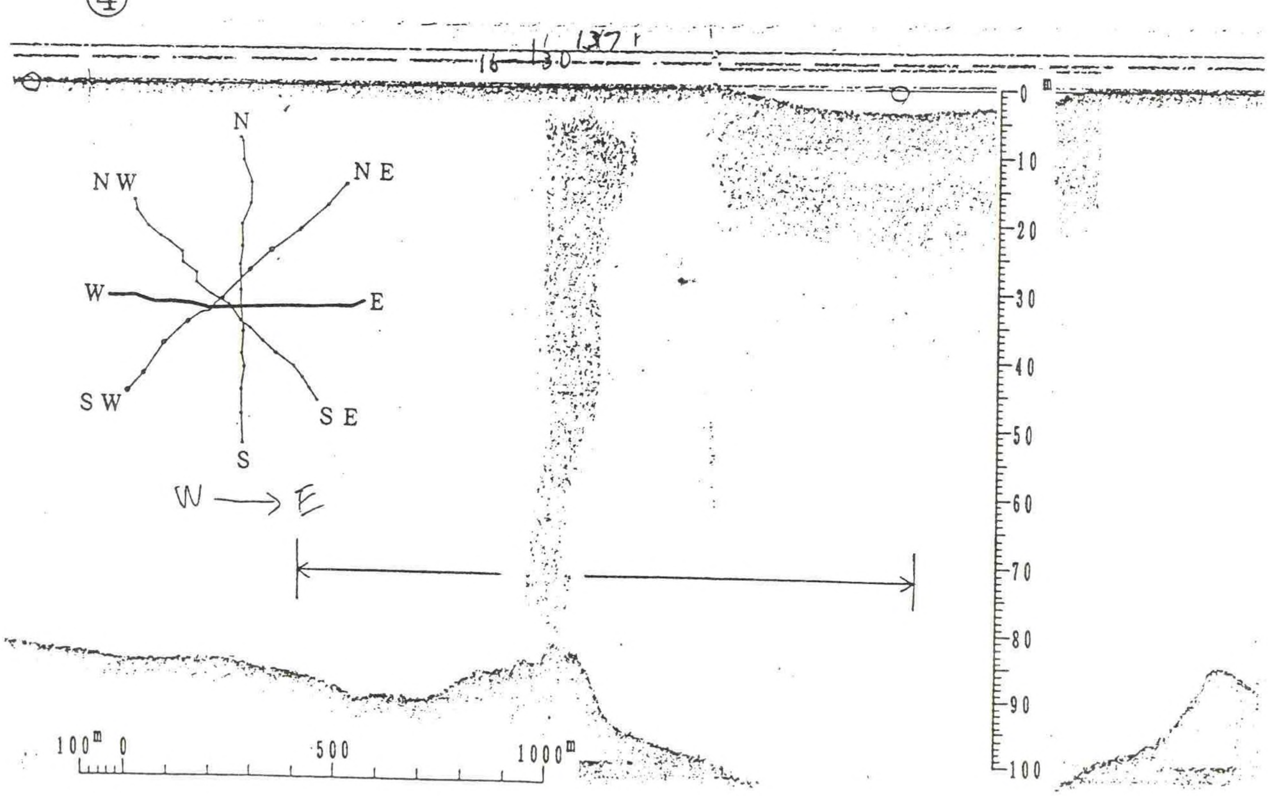


137
16-20
0 m
10
20
30
40
50
60
70
80
90
100
100 m 0
500
1000 m
NE → SW
N
NW
NE
W
E
SW
SE
S
85
86

④



137
16-13-0
0 m
10
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100
N
NW
NE
W
E
SW
SE
S
W → E
100 m 0
500
1000 m

EARTH OBSERVATION PROGRAMS IN JAPAN

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1. Introduction

In 1972 the first earth observation satellite ERTS (LANDSAT-1) was launched by NASA. A number of investigators from Japan participated in this ERTS program for the satellite data analysis. This was an initial step of space remote sensing activities of Japan. NASDA established the Earth Observation Center(EOC) at Hatoyama near Tokyo in 1978 and started direct reception of LANDSAT data in 1979. Since then, various organizations and universities in Japan have been involved in a wide range of remote sensing activities.

In 1976, NASDA, supported by various groups of Japanese experts, started the investigation study of the Japanese needs and eventual contributions in earth observation program. Following these activities, in 1978, the Space Activities Commission of Japan(SAC), which supervises all space activities in Japan, recommended in the "Fundamental Guidelines of Japan's Space Policy" that "marine and land observation satellite series" should be developed in order to establish the earth observation technology and to step forward to operational satellites. This recommendation resulted in developing two remote sensing satellites, namely Marine Observation Satellite-1 (MOS-1) and Japanese Earth Resources Satellite-1(ERS-1). In 1979 NASDA started the development of MOS-1 which was launched in Feb. 19, 1987. NASDA also started the R&D of ERS-1 in 1980 and conducted critical design review in July 1989. Development task of ERS-1 is shared by MITI and NASDA. MITI is developing the mission equipment(sensors) while NASDA the satellite system. ERS-1 is currently planned to be launched in early 1992.

Following the fulfillment of these programs, Japan is to pursue its next step earth observation programs. As a next generation earth observation satellite, NASDA plans to launch Advanced Earth Observing Satellite(ADEOS) in early 1995. Moreover, a new earth observation program with Polar Orbiting Platform(POP) is now planned and coordinated among the Space Station Partners, namely, NASA, NOAA, ESA, Canada and Japan. Currently, NASA and ESA have their own platform launch plans in late 1990's. The overall schedule of Japanese earth observation satellite programs is shown in Table 1.

2 MOS-1 Program

The Marine Observation Satellite-1 (MOS-1), the Japanese first experimental earth observation satellite, was launched on Feb. 19, 1987 successfully by NASDA. The aims of MOS-1 is to establish the basic technology for earth observation system, to carry out practical observation of the earth (primary the ocean) using on-board sensors and to verify the performance of the sensors.

(1) Satellite System and Mission Instrument

The profile and description of MOS-1 are shown in Fig.1 and Table 2. MOS-1 has three sensors and a Data Collection System Transponder(DCST). These sensors are the Multispectral Electronic Self Scanning Radiometer(MESSR), the Visible Thermal Infrared Radiometer(VTIR), and the Microwave Scanning Radiometer(MSR). The characteristics of the sensors are shown on Table 3.

(2) MOS-1 Operation

Although the two-year design life expired on Feb. 18, 1989, mission equipments on the satellite has good prospect to work on. NASDA, monitoring and checking its performance, has been continuing the data transmission.

The ground support system for MOS-1 is shown in Fig.2. Earth Observation Center(EOC) is the main ground station responsible for mission management, scheduling, data acquisition and processing. In Addition to EOC, MOS-1 data are also received at nine other receiving stations in the world. The world coverage of MOS-1 is shown in Fig.3.

(3) MOS-1 Verification Program (MVP)

MOS-1 Verification Program(MVP) was conducted to evaluate the system parameters of mission instrument, function and characteristics of sensors and satellite systems, and its data usefulness. In order to obtain fruitful result, NASDA publicly announced the opportunity to participate in the MVP, and 92 proposals were selected. Many fruitful results were presented in three MVP symposiums, and MVP was successfully concluded after two years of its verification period.

(4) MOS-1 Data Distribution

In Aug. 10, 1987, NASDA started to distribute MOS-1 data through Remote Sensing Technology Center of Japan(RESTEC). All the MOS-1 data acquired and archived by any ground station is made available on public and non-discriminatory basis. MOS-1 data distribution flow is shown in Fig.4.

3. ERS-1 Program

Japanese Earth Resources Satellite-1(ERS-1), with its launching scheduled in early 1992, is under development as a joint program of Ministry of International Trade and Industry(MITI) and NASDA. The main objectives of the ERS-1 are to establish the technology of the active microwave sensor, namely the Synthetic Aperture Radar(SAR), and the high resolution Optical Sensor(OPS), and to examine the terrestrial resources and environment, primarily focusing on the geological and topographical survey.

The profile and description of ERS-1 is shown in Fig. 5 and Table 4. ERS-1 is planned to carry two sensors which are the SAR and OPS. The characteristics of these sensors are shown in Table 5. Their primary design and critical design was completed in 1987 and in July 1989, respectively.

4. ADEOS Program

Following the fulfillment of MOS-1 and ERS-1 programs, NASDA plans to launch Advanced Earth Observing Satellite(ADEOS) in early 1995 as a next generation earth observation satellite. The main objectives of ADEOS are as follows.

(1)Monitoring the global change of the earth.
(2)The development of advanced earth observation sensors.
(3)The development of the modular satellite that is the prototype of the future platform.
(4)The experiments on earth observation data relay using data relay satellites to form a global observation network.
(5)The contribution to domestic and international cooperation by installing sensors developed by domestic and/or foreign organizations.

The profile and description of ADEOS are shown in Fig. 6 and Table 6. ADEOS will carry two core sensors which are Ocean Color and Temperature Scanner(OCTS) and Advanced Visible and Near Infrared Radiometer (AVNIR). In addition to the core sensors, NASDA issued an Announcement of Opportunity(AO) to install the AO sensors as mentioned above. The characteristics of these sensors are shown in Table 7.

5. Polar Orbiting Platform Program

Earth observation program by means of Polar Orbiting Platform (hereinafter referred to as POP Program) is being established among NASA, ESA, STA/NASDA and Canada who are the partners of the Space Station Program. The main objectives of POP Program are to guarantee the continuity of operational meteorological observation which is currently operated by NOAA satellite and to make effective observation of the area of earth science. According to the current schedule, NASA plans to launch one platform in 1996 and ESA plans to launch one in 1997. The countries who participate in POP Program within the frame work of the Space Station Program will provide on-board sensor instruments. In Japan, NASDA's AMSR(Advanced Micro-wave Scanning Radiometer) and MITI's ITIR(Intermediate Thermal Infrared Radiometer) are planed to be provided to NASA POP as Core sensors. The characteristics of AMSR and ITIR are shown in Table 8.

To make this POP program more effective and fruitful, announcement of opportunity (AO) for the participation in this program was issued from NASA, ESA and STA respectively to the organizations and/or individual researchers concerned.

Table 1 Schedule of Japanese Earth Observation Satellite Programs

Calendar Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000~
Satellite Launch Schedule	▲ MOS-1			△ MOS-1b		△ JERS-1			△ ADEOS	△ NPOP-1	△ EPOP-1/A1	△ JPOP △ NPOP-2		△ EPOP-2/B1
Satellite Allocation Concept		Japanese Sensors Japanese Expendable Satellite Bus							Japanese Sensors / Non-Japanese Sensors Japanese Expendable Satellite Bus	Japanese Sensors / Non-Japanese Sensors Non-Japanese Platform		Japanese Sensors / Non-Japanese Sensors Japanese Platform		

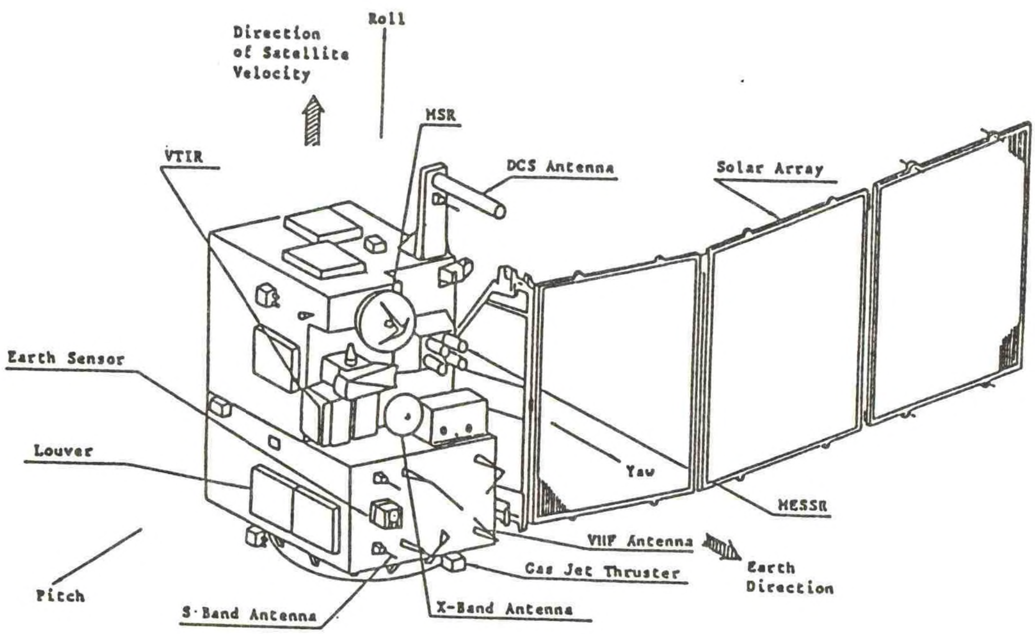

Fig. 1 Profile of MOS-1

Table 2 Description of MOS-1

Item	Parameter
Orbit	Near-Polar (909km) Sun-Synchronous (Local Mean Time 10:05AM) 17 days Coverage Cycle Duration
Weight	740kg
Power	Solar Arrey 640(BOL)
Stabilization	3-Axis, Earth-Pointing
Launch Vehicle	N-II from TNSC
Design Life	2 Years
Instruments	MESSR (Multispectral Electronic Self Scanning Radiometer) VTIR (Visible and Thermal Infrared Radiometer) MSR (Microwave Scanning Radiometer) DCS (Data Collection System)
Launch date	Feb. 19, 1987
Status	Flight segment PM Completed FM Completed and in flight

Table 3 Characteristics of MOS-1 Sensors

Item \ Sensor	MESSR	VTIR		MSR	
Wavelength (μm)	0.51 - 0.59 0.61 - 0.69 0.72 - 0.80 0.80 - 1.1	0.5 - 0.7	6.0 - 7.0 10.5 - 11.5 11.5 - 12.5	——	
Frequency (GHz)	——	——	——	23.8	31.4
Geometric Resolution (IFOV in km)	0.05	0.9	2.7	32	23
Radiometric Resolution	(39dB)	55dB* (Alb.=80%)	0.5K	1K	1K
Swath width (km)	100 (one optical element) x 2	1500		320	
Scanning Method	electric	mechanical		mechanical	
Remarks	* Signal to noise ratio excluding quantization noise.				

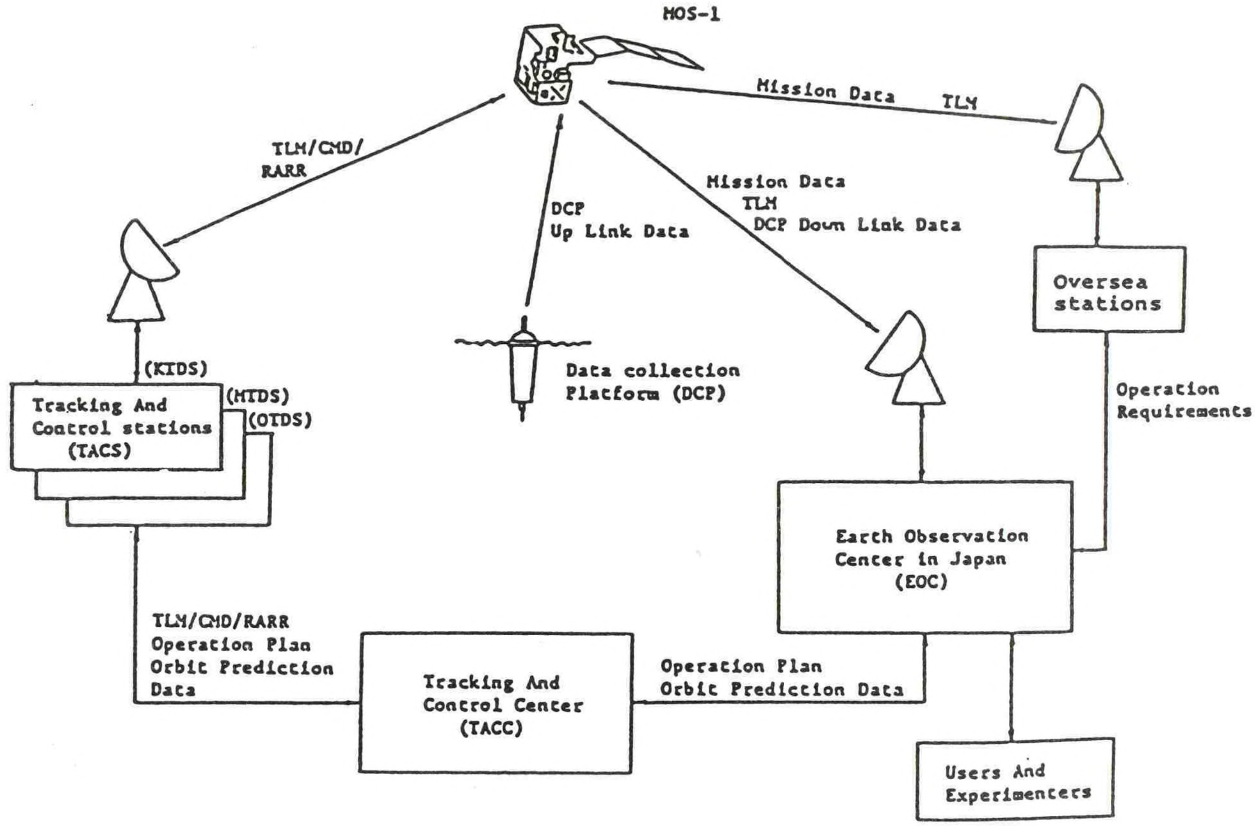

Fig.2 Ground Support System for MOS-1

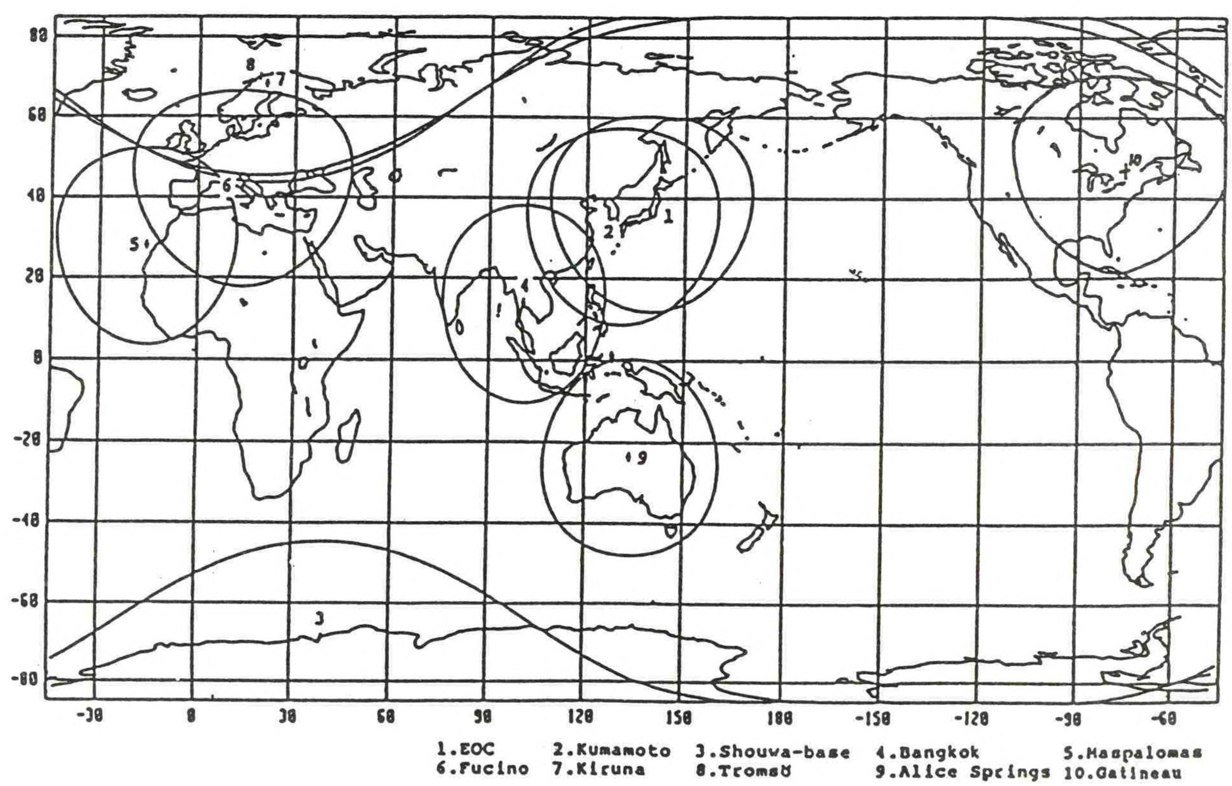

Fig.3 World Coverage Map of MOS-1

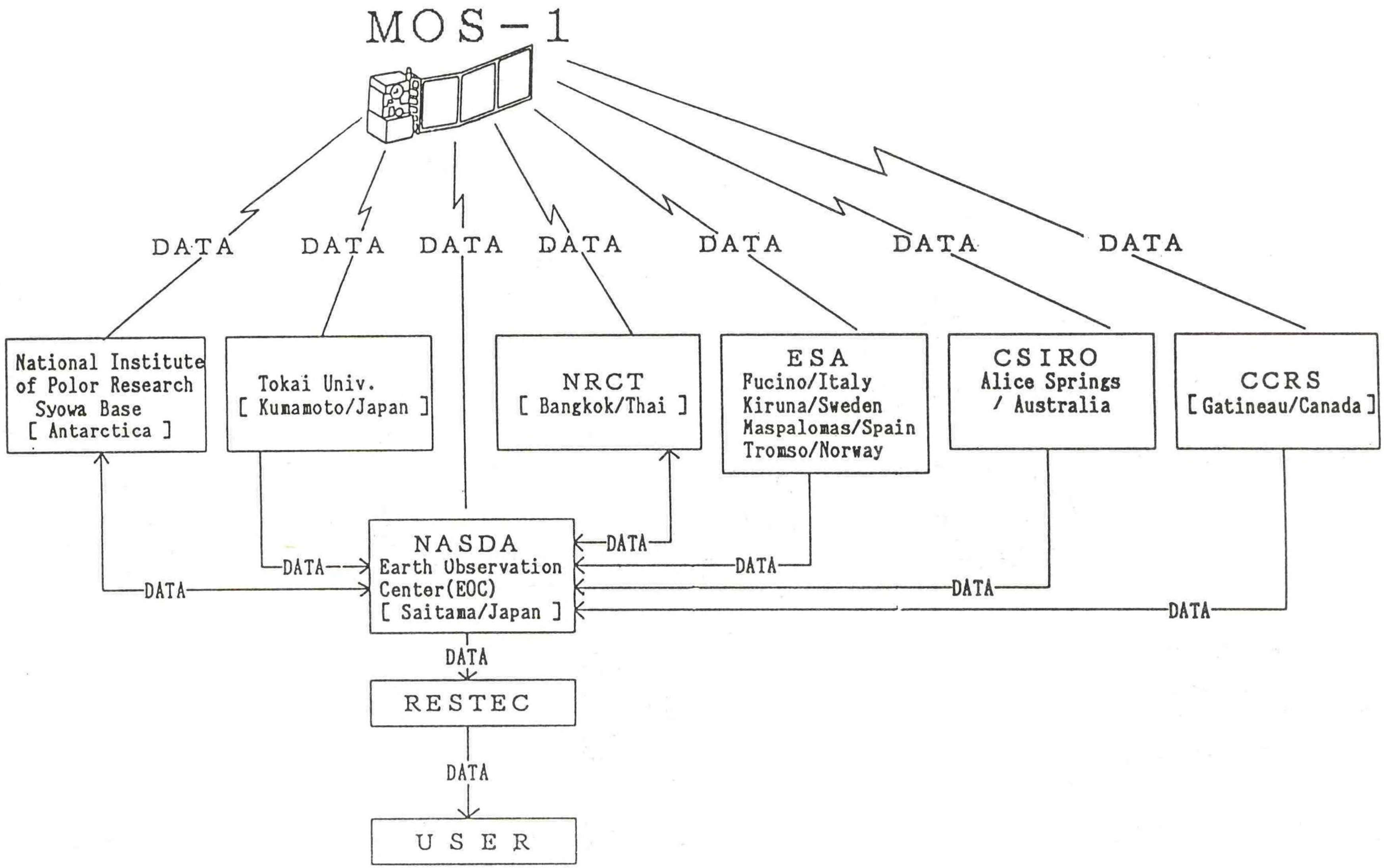

Fig.4 MOS-1 Data Distribution Flow

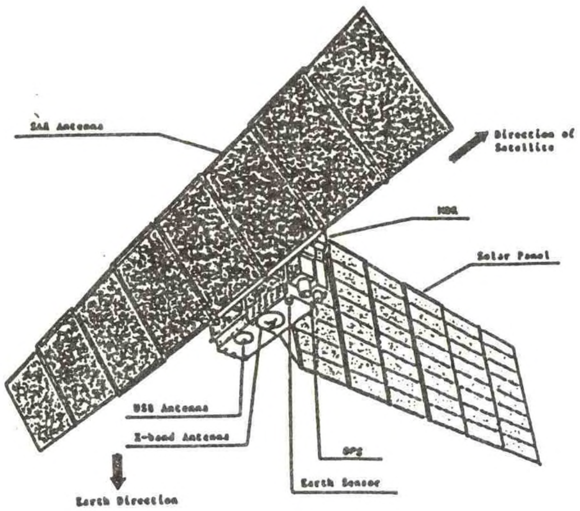

Fig. 5 Profile of ERS-1

Table 4 Description of ERS-1

Item	Parameter
Orbit	Sun-synchronous
Altitude	Approx. 568 km
Inclination	Approx. 97.7°
Recurrent period	44days(Westward)
Local mean time (descending)	10:30-11:00AM
Number of orbit per day	Approx. 15
Weight	Approx. 1400 kg
Launch Vehicle	H-I Rocket
Design Life	2 Years
Launch Schedule	Early 1992

Table 5 Specification of ERS-1 Sensors

Item \ Sensor	SAR	OPS			
		Band	Center Wavelength	Band width	Note
Wavelength (μm)	L-band	1 2 3 4 5 6 7 8	0.56 0.66 0.81 0.81 1.655 2.065 2.19 2.335	0.08 0.06 0.10 0.10 0.11 0.11 0.12 0.13	Band4 is for off nadia viewing. Band3 and 4 makes a stereo-pair.
Polarization	H-H	——			
Band number	1	8			
Spatial resolution (meter, squares)	18 (approximately) (3 look)	18 × 24 (approximately)			
Off Nadia Angle (degrees)	35	15.33 (Band4 only)			
Swath Width(Km)	75 (approximately)	75 (approximately)			
Stereoscopic Imaging Capability	——	Yes			

Table 6 Description of ADEOS

Item	Parameter
Orbit	Sun-synchronous (Approx. 800km)
Weight	Approx. 3.2 ton
Power	Approx. 3.5 kw
Launch Vehicle	H-Ⅱ Rocket
Design Life	3 Years
Launch Schedule	Early 1995

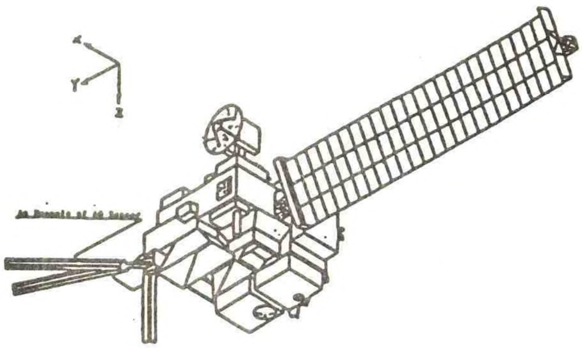

Fig. 6 Profile of ADEOS

Table 7 Characteristics of ADEOS Sensors

OCTS(Ocean Color and Temperature Scanner)		
Spectral Channels	Visible	6 Channels
	Near-Infrared	2 Channels
	Middle-Infrared	1 Channel
	Thermal-Infrared	3 Channels
FOV	±40 Degree(1400 km at the altitude of 800 km)	
IFOV	0.85 mRAD(0.7 km at the altitude of 800 km)	
Data Rate	2.6 MBPS	
Weight	290 kg	
Power	300 W	
AVNIR(Advanced Visible and Near Infrared Radiometer)		
Spectral Channels	Visible	3 Channels
	Near-Infrared	1 Channel
	Panchromatic	1 Channel
FOV	4.6 Degree(80 km at the altitude of 800 km)	
IFOV	20 μRAD(16 m) for multi-spectral bands	
	10 μRAD(8 m) for Panchromatic band	
Pointing Angle	±40 Degree(1500 km at the altitude of 800 km)	
Data Rate	60 MBPS x 2ch	
Weight	250 kg	
Power	250 W	
AO Sensors (AO:Announcement of Opportunity)		
Total Weight	Approx. 520 kg	
Total Power	Approx. 400 W	
Volume	TBD	
Thermal	Self Control	
Data Rate	< 100 MBPS	
FOV	TBD	
Schedule	Selection	Middle of 1989

Table 8 Characteristics of AMSR and ITIR

CANDIDATE SENSOR	AMSR ADVANCED MICROWAVE SCANNING RADIOMETER	ITIR INTERMEDIATE THERMAL INFRARED RADIOMETER
BASIC SPECIFICATION (TENTATIVE)	• FREQUENCY 6.6, 10.65, 18.7, 23.8, 31.55 GHz • SPACIAL RESOLUTION 9.2 - 28 km • SWATH WIDTH 1,200 km	• WAVELENGTH 0.85 - 11.7 μm (NUMBER OF BANDS:11) • SPACIAL RESOLUTION 15m (NIR/SWIR) 60m (TIR) • SWATH WIDTH 30km
OBSERVATION FIELD AND FEATURES OF UTILIZATION	• OCEAN AND ATMOSPHERE OBSERVATION • DATA CONTINUITY OF MOS-1 MSR	• MINERAL RESOURCES OBSERVATION • GEO-THERMAL OBSERVATION
TECHNOLOGICAL FEATURES AND EXPECTED TECHNOLOGICAL RESULTS	• MULTI-FREQUENCY • ESTABLISHMENT OF TECHNOLOGIES REQUIRED FOR LOW NOISE RECIEVER AND LARGE ANTENNA • ELECTRICALLY SCANNING	• PUSHBROOM TYPE SENSOR SYSTEM • ESTABLISHMENT OF TECHNOLOGIES REQUIRED FOR HIGH RESOLUTION OBSERVATION • MULTI-BAND SENSOR COVERING NEAR INFRARED THROUGH THERMAL INFRARED WAVELENGTH

INNOVATIVE OCEANOGRAPHY – PACIFIC MARINE ENVIRONMENTAL LABORATORY'S CONTRIBUTIONS TO OBSERVING THE OCEANS

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Oceanography is a dynamic science that requires innovative technology to improve the accuracy and timeliness of information. Over the past decade the Pacific Marine Environmental Laboratory (PMEL) has been a leader in developing or improving oceanographic equipment so that data collected is precise, accurate, and delivered in a minimum amount of time. This report highlights some of the achievements PMEL has made over the years while advancing the state of operational oceanography. Instruments and instrument systems are described in terms of design and scientific value. For each instrument/system a reference is given for additional information. The order of presentation is:

1. Moored Current Meter Arrays
2. Transport Measured by Electromagnetic Methods
3. Free-fall Velocity/CTD Profiler
4. Satellite-Linked Temperature/Wind Moorings
5. Freon Tracers
6. Trace Gas Equilibrator
7. Bottom Pressure Recorder
8. Deep tow CTD/Transmissometer/Sampler
9. Submersible-Coupled Sampling System
10. Deep Tow Camera System
11. Sequentially Sampling Sediment Traps
12. CTD Mounted on a Remotely Operated Vehicle
13. Satellite Linked Hazard Alerting System

1. Moored Current Meter Arrays

PMEL pioneered the use of taut-wire surface moorings for long-term current measurements in the equatorial ocean. Since the mid-1970's, approximately 80 surface current meter moorings have been deployed for ocean circulation and climate studies. Over 8 years of data in the upper 250 meters now exist near the equator at 110°W with a data return in excess of 90%. Mooring techniques developed at PMEL have been exported to other groups in the U.S. and abroad for deep ocean mooring work in the tropics.

Each mooring consists of a surface buoy and tower, steel cable with fairings (to reduce drag), nylon rope, subsurface flotation, an acoustic release and anchor. The upper 500 meters are instrumented with Vector Averaging Current Meters (VACM), Vector Measuring Current Meters (VMCM), temperature recorders, occasionally pressure recorders, and recently conductivity (*i.e.* salinity) cells. The surface buoy also contains instrumentation to record winds, air temperature, and sea surface temperature.

All equatorial Pacific current meter moorings transmit air temperature (from 3 meters height) and sea surface temperature in real-time. The EPOCS moorings also transmit winds (from 4 meters height) and two of the moorings transmit currents (from 8 meters depth). All data are transmitted 4 to 6 times per day via satellite and the ARGOS system plus being recorded internally on cassette tape.

The arrays are used to focus on the study of climate variations on time scales of months to years, with emphasis on the El Niño-Southern Oscillation (ENSO) phenomenon. This requires the collection of a multi-year time series of environmental parameters, such as winds, Sea Surface Temperature (SST), upper ocean temperature, and currents that are critical for the evolution of ENSO events. Time series measurements of currents near the equator are essential because of the breakdown of geostrophy and because the equatorial ocean can adjust much more rapidly than higher latitudes to transient wind forcing.

Moored current measurements collected in the past 10 years as part of NORPAX (North Pacific Shuttle Experiment), EPOCS (Equatorial Pacific Ocean Climate Studies), TROPIC HEAT, and the U.S/P.R.C. (Peoples Republic of China) bilateral have fundamentally shaped our understanding of equatorial dynamics and air-sea interaction on climate time scales. The data have been used to

describe seasonal, intraseasonal (*e.g.* instability waves, 60–90 day waves), and interannual (ENSO) variations in the upper equatorial Pacific ocean; to **diagnose** processes affecting SST and current dynamics; and to **evaluate** the quality of operational satellite data and *in situ* data products. Mooring data has also been used in **model validation** studies of the Geophyical Fluid Dynamics Laboratory (GFDL) and National Meteorological Center's (NMC) general ocean circulation models.

Reference: McPhaden, M.J. and B.A. Taft, 1988: On the dynamics of seasonal and intraseasonal variability in the eastern equatorial Pacific. *J. Phys. Oceanogr.*, *18*:1713–1732.

2. Transport Measured by Electromagnetic Methods

The transport of the Florida Current has been monitored on a daily basis since 1982 using cross stream voltages derived from an abandoned submarine cable that spans the Florida Straits from 10 miles offshore of Jupiter, Florida (90 miles north of Miami) to the coast at Settlement Point, Grand Bahama Island (70 miles east of Jupiter). The voltages are observed as hourly mean values and reduced to daily mean values after removing the geomagnetic variations (predicted from the San Juan and Fredericksburg magnetic observatories), tides, and outliers. Voltages are then converted to transport units of Sverdrups (1 Sv = 10^6 m^3/s) using a calibration factor derived from comparisons with the transport based on velocity profiling data. The misfit of the transports derived from cable voltages with the transports computed from 120 days of velocity profiling data and 2 years of current meter mooring data is less that 1 Sv, amounting to 3 percent of the mean (32 Sv).

This observation effort is continuing and six years of daily mean transports are presently available for a unique opportunity to study the origins of the fluctuations of one of the major ocean currents and to compare them with atmospheric forcing fields. The fluctuations are highly variable. For example: the transport has been observed to change as much as 10 Sv within six days, the month to month changes are as large as 15 Sv (50 percent of mean), and the summer high and winter low can be displaced by several months for some years compared to the usual times of highs and lows. On a yearly basis the transport for any particular day lies within a band of 10 Sv about the long term seasonal variation.

Reference: Larsen, J.C., and J.B. Sanford. Florida Current volume transports from voltage measurements. *Science, 227*:302–304 (1984).

3. Free-fall Velocity/CTD Profiler

TOPS (Total Ocean Profiling System) is a free-fall profiler which measures vertical profiles of horizontal ocean velocity, conductivity, and temperature throughout the water column (6000 dbar pressure limitation). Larger vertical wavelength velocity fluctuations are resolved by acoustically tracking TOPS relative to an array of bottom moored transponders. Shorter vertical wavelength velocity fluctuations are resolved by an onboard acoustic velocimeter which measures ocean velocity relative to the profiler. Motions of the profiler are monitored with a two-axis accelerometer and flux-gate compass. In order to interpret the onboard velocimeter measurements a planar, irrotational flow model was developed which describes the response of TOPS to an arbitrary oceanic shear profile.

TOPS has been used primarily in the EPOCS program to provide spatial resolution of the eastern tropical Pacific current systems. The TOPS data, which provides a snapshot across the equatorial system, has been analyzed in conjunction with moored current meter measurements which provide the temporal variability at a given location. These data enabled an examination of the large surface and upper ocean changes in volume and heat transports which accompanied the 1982/83 ENSO event.

Reference: Hayes, S.P., H.B. Milburn, and E.F. Ford. TOPS: A free-fall velocity and CTD profiler. *Journal of Atmospheric and Oceanic Technology 1*(3):220–236 (1984).

4. Satellite-Linked Temperature/Wind Moorings

ATLAS (Automated Temperature Line Acquisition System) is a moored wind and temperature measuring array. Vector averaged wind speed and direction are computed using a vaned propeller and compass wind sensing system mounted on the tower of the surface buoy. Air temperature, sea surface temperature, and subsurface temperature to a maximum depth of 500 meters are measured and the data is multiplexed to the surface acquisition system through a 3-conductor double armored cable. All data are telemetered via polar orbiting NOAA satellites to the ARGOS system. The addition of other sensors, such as humidity, conductivity, and barometric pressure have been installed on some buoys.

ATLAS moorings provide valuable surface and sub-surface temperature data for monitoring the equatorial Pacific thermal structure. The ATLAS wind data also helps to fill the continued need for improved tropical wind fields throughout the Pacific in order to quantitatively model and understand the ocean's response.

Reference: Milburn, H.B., and P.D. McLain. ATLAS—A low cost satellite data telementry mooring developed for NOAA's Climate Research mission. Proceedings, MDS '86, Marine Data Systems International Symposium, April 30–May 2, New Orleans, LA, 393–396 (1986).

5. Freon Tracers

PMEL pioneered the development of chlorofluoromethanes (CFM) as tracers of thermocline ventilation in 1980/81. The method involves ultraclean hydrocast water sampling and analysis of trace levels (10^{-12}–10^{-15} moles/liter) of dissolved freons by electron capture gas chromatography.

First demonstrated to the oceanographic community during TTO (Transient Tracers in the Ocean) experiment in October 1981, the freon tracer method has now been widely adopted by marine tracer groups in the U.S. and aboard. Freons have been endorsed as the primary transient tracer to be sampled intensively during the global ocean survey of the World Ocean Circulation Experiment (WOCE) scheduled for 1990–1995. The primary utility of measuring the evolving freon distributions in the worlds ocean is to understand the critical pathways and quantitative rates of ventilation and mixing in the upper ocean on decadal timescales. This will be accomplished by validating the ability of general circulation models to simulate the freon transient.

Reference: Gammon, R.H., J. Cline, and D. Wisegarver. Chlorofluoromethanes in the Northeast Pacific Ocean: measured vertical distributions and application as transient tracers of upper ocean mixing. *Journal of Geophysical Research, 87*:9441–9454 (1982).

6. Trace Gas Equilibrator

The Gortex Equilibrator is used in conjunction with a gas chromatograph to determine the amount of trace gases dissolved in sea water. A Gortex tube acts as an interface between air and sea water. The trace gases dissolved in sea water come to chemical equilibrium with the air inside the tube. Sea water is continuously flowing from the sea surface past the outside of the Gortex tube while air flows through the inside of the tube into a gas chromatograph.

A major advantage of the Gortex equilibrator is that the volumetric flow rate of sea water required to extract a trace gas sample is much less than traditional equilibrators. Also the system can be operated continuously and automatically by pumping sea water from the sea surface to the equilibrator and by pumping air from the equilabrator (inside of the Gortex tube) to a gas chromatograph.

References: Johnson, J.E., J.E. Lovelock, and T.S. Bates. The ECD-Sulfur Detector: Oceanographic Sulfur Species Measurements at the Femtomole Level. In American Chemical Society Division of Environmental Chemistry, 194th National Meeting, Extended Abstracts. 27:256–257.

7. Bottom Pressure Recorder

PMEL maintains a network of approximately 5 bottom pressure recorders (BPRs) in the northeast Pacific Ocean. Continuous, multi-year time series are being acquired for the study of oceanic long wave phenomena characterized by periods of several minutes to several months. In addition to tsunamis, these phenomena include very long ocean swell, seismic surface waves, tides, and planetary waves.

The program is presently focused on the Shumagin Seismic Gap, a subduction zone in the Aleutian Trench which possesses high tsunamigenic earthquake potential. Four BPRs are currently in place near the gap, one on the inner slope of the trench and three in a directional array about 400 km to the southwest; the fifth recorder is located 500 km off the U.S. West Coast.

Reference: Bernard, E.N., and H.B. Milburn. Long-wave observations near the Galápagos Islands. *Journal of Geophysical Research, 90*(C2):3361–3366 (1985).

8. Deep Tow CTD/Transmissometer/Sampler

SLEUTH (System for Locating Eruptive Underwater Turbidity and Hydrography) is a compact, hydrodynamically-faired, deep-towed CTD and water sampler designed for mapping and sampling seafloor hydrothermal emissions. Hydrothermal plumes are relatively small features with steep horizontal and vertical hydrographic gradients that cannot be mapped by traditional vertical CTD casts.

SLEUTH is towed along a vertical sawtooth pattern near the seafloor at speeds of 2–3 knots, providing detailed and quasi-synoptic hydrographic information from which the distribution and concentration of hydrothermal plumes can be determined.

Reference: Baker, E.T., and G.J. Massoth. Characteristics of hydrothermal plumes from two vent fields on the Juan de Fuca Ridge, northeast Pacific Ocean. *Earth and Planetary Science Letters, 85*:59–73 (1987).

9. Submersible-Coupled Sampling System

The manifold sampler (SIS-cube: Submersible-coupled Sensing and Sampling System) was designed to be used with research submersibles to collect temperature-documented and non-diluted vent fluid samples from a range of vent types (i.e., the organized flow of high-temperature vents and the diffuse flow of warm springs).

The instrument is of unique scientific value because it provides, in a single system, the previously unattainable collection of coincident vent fluid chemistry and temperature data. Further, the SIS^3, by virtue of its pumping system, allows for the sampling of the diffuse flow vents without the entrainment of ambient seawater. Paired temperature and chemistry data from this range of vent types is fundamental to the resolution of the effects of venting on the chemistry of seawater, an overall goal of the VENTS program.

References: Massoth, G.J., H.B. Milburn, S.R. Hammond, D.A. Butterfield, R.E. McDuff, and J.E. Lupton (in press). The geochemistry of submarine venting fluids at Axial Volcano, Juan de Fuca Ridge: new sampling methods and VENTS Program rationale. In NURP Research Report 88–4, 1989.

10. Deep Tow Camera System

The Deep Tow Camera system was developed to meet the special needs of the VENTS project. It incorporates five data collection systems: transmissometer, Benthos 35 mm camera, remote color video, real time black and white video, and a Seabird CTD system, into one large (2800 lbs) towable package.

The camera system is towed on a conducting cable 5 to 10 meters above the ocean floor at speeds of 1 to 2 knots. CTD information, the black and white video display, and transmissometer data are telemetered to the ship through the conducting cable on a real time bases to enable the investigator to interpret the data while the camera system is near the bottom.

A unique feature of this system is that the Benthos 35 mm camera has been modified with a light sensor that measures the light which actually reaches the films surface and adjusts the output of the flash unit accordingly. This greatly enhances the quality of photographs from the camera, which can take 4000 frames per tow. Also, the towed unit is equipped with a downward and forward looking obstacle avoidance sonar which enables the camera system to be maneuvered through rugged terrain 5 to 10 meters above the bottom.

This system was used successfully in 1987 and 1988, in conjunction with the long baseline acoustic navigation system, to photographically and chemically map new vent fields on the southern Juan de Fuca Ridge.

Reference: Embley, R.W., K.M. Murphy, and C.G. Fox. High resolution studies of the summit of Axial Volcano. *Journal of Geophysical Research* (accepted).

11. Sequentially Sampling Sediment Traps

The Sequentially Sampling Sediment Trap (SSST) developed by PMEL in 1980 is a self-contained, moored instrument that collects 10 sequential samples of vertically settling marine particulate matter. Each sample is collected over a predetermined and variable time period and then stored in isolation until the trap is recovered.

Sequentially Sampling Sediment Traps have been routinely used in estuarine, coastal, and deep ocean programs of PMEL since 1980. Sediment trap measurements are crucial to many oceanographic investigations because they are the only way of determining the magnitude and composition of the sinking rain of particles from the ocean surface to the seafloor. Design blueprints for the PMEL traps have been supplied to many US and foreign investigators who have built traps for their own use. The multi-sample design allows traps to be deployed for long time periods and still sample at a high enough frequency to resolve the temporal variability of the vertical particle flux in the ocean. This important feature enables sediment trap studies to be easily integrated with other mooring programs.

Reference: Baker, E.T., and H.B. Milburn. An instrument system for the investigation of particle fluxes. *Continental Shelf Research, 1*:425–435 (1983).

12. CTD Mounted on a Remotely Operated Vehicle (ROV)

In support of project FREEZE in Nome, Alaska a Seabird CTD was mounted onto a Phantom 300 ROV, reballasted, and fitted with a special steering and orientation device. The ROV was used as a platform for the CTD because the ROV could move through the water with a minimal amount of disturbance to the water column. The ROV was operated from the bridge of a 65' tug boat capable of maneuvering through the thin ice to reach desired ice conditions.

The ROV was operated at several different depths under ice thicknesses ranging from zero to 10 cm. The CTD data was displayed and stored on a small portable computer. This data was collected to better understand how sea ice is formed to improve in NOAA's ice prediction model.

References: Pease, C.H. and R.D. Muench, 1989. The Freeze Experiment: Oceanographic conditions during Autumm Freeze-up in the western Arctic, W.F. Weeks Sea Ice Symposium Volume, Cold Regions Research and Engineering Laboratory, Hanover, NH, in press. (Abstract at same title, 1988, *Eos, Transactions American Geophysical Union, 69*(44):1269–1270).

13. Satellite Linked Hazard Alerting System

THRUST (Tsunami Hazards Reduction Utilizing Systems Technology), a prototype local (=100 km) tsunami warning system, was developed to deliver tsunami warning information within 2 minutes of an earthquake's origin time. The system was installed in Valparasio, Chile to evaluate its value in mitigating tsunami hazards in a country without a regional warning system. The satellite linked network consists of a pre-tsunami preparedness program and real-time data collection and information dissemination instruments.

The preparedness program was developed after an examination of past tsunami wave heights supplemented by numerical simulations of potential tsunamis. This program provided the basis for determining evacuation areas in Valparasio's emergency operations plan. Instruments used to collect geophysical data include an accelerometer, to measure earthquake intensity, and a water pressure gage, to measure tsunami activity. Once the acceleration threshold has been exceeded, a warning signal is transmitted that prompts the GOES satellite to automatically broadcast an alert message. Receivers in Valparasio and other warning locations under the GOES communications umbrella (Honolulu, Hawaii; Seattle, Washington; and Boulder, Colorado) continuously monitor the satellite for this alert message and take predetermined action once alerted.

THRUST is an example of a systems approach to natural hazards mitigation management which blends satellite technologies with existing operations for the benefit of affected populations. An additional scientific application includes two-way communications with remote platforms. Any sensor can be set to send an alert message once a threshold condition has been met. Upon receipt of this alert, a message can be transmitted to that same sensor or any sensor in the GOES communication umbrella to take predetermined action; such as change sample rate, turn on/off additional sensors, or modify reporting procedures.

References: Bernard, E.N., R.R. Behn, G.T. Hebenstreit, F.I. Gonzalez, P. Krumpe, J.F. Lander, E. Lorca, P.M. McManamon, and H.B. Milburn. On mitigating rapid onset natural disasters: Project THRUST. *Eos, Transactions of the American Geophysical Union, 69*(24):649–661 (1988).

Glossary of Acronyms

ATLAS	Automated Temperature Line Acquisition System
BPR	Bottom Pressure Recorder
CFM	Chlorofluoromethanes
CTD	Conductivity, Temperature, Depth

ENSO	El Niño-Southern Oscillation
EPOCS	Equatorial Pacific Ocean Climate Studies
GFDL	Geophysical Fluid Dynamics Laboratory
GOES	Geostationary Operational Environmental Satellite
NOAA	National Oceanic and Atmospheric Administration
NORPAX	North Pacific Shuttle Experiment
PMEL	Pacific Marine Environmental Laboratory
P.R.C	Peoples Republic of China
ROV	Remote Operating Vehicle
SIS	Submersible-coupled Sensing and Sampling System
SLEUTH	System for Locating Eruptive Underwater Turbidity and Hydrography
SST	Sea Surface Temperature
SSST	Sequentially Sampling Sediment Trap
THRUST	Tsunami Hazards Reduction Utilizing Systems Technology
TOPS	Total Ocean Profiling System
TTO	Transient Tracers in the Ocean
VACM	Vector Averaging Current Meter
VMCM	Vector Measuring Current Meter
WOCE	World Ocean Circulation Experiment

NEW PROGRAMS AT THE NATIONAL DATA BUOY CENTER

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Introduction

For nearly two decades, the National Data Buoy Center (NDBC) has undertaken the mission of implementing and operating a network of automated data acquisition stations for the purpose of environmental monitoring in ocean and coastal areas. During that time, the network has grown from just a handful of buoys to over 50 moored buoys and a comparable quantity of coastal stations on land and offshore platforms. Technology to support this network has been refined and expanded to provide greater capabilities at lower cost and with higher reliability.

In addition to moored buoy and coastal (fixed) stations, NDBC has designed, developed, and operated expendable drifting buoy systems since the mid-1970's. The technology produced as a consequence of the evolution of NDBC's moored buoy network has been aggressively applied to the drifting buoy arena.

In the 1980's, NDBC has also played important roles in major environmental monitoring demonstration projects outside the marine field as a result of its expertise in automated data acquisition systems. These include Automated Surface Observing Systems (ASOS) at airports and Doppler radar upper air, wind profiling systems in the midwestern United States.

In the future, the overall need for environmental monitoring, particularly in coastal and ocean regions, can be expected to become increasingly important. At the same time, it is not likely that budgetary constraints will ease. The Center is beginning to see the consequences of these two factors in expansion of its networks, both in terms of geography and number of stations, and in terms of required measurement capabilities. The accompanying complex engineering, data management, and logistics issues, augmented by the general climate of fiscal austerity, pose the challenges NDBC is now encountering.

This paper describes several program initiatives the Center has undertaken in the last 2 years. These initiatives are significant in terms of both geographical and technical network expansion. They are examples of NDBC's commitment to systems reliability, flexibility, and cost-effectiveness.

Western Pacific Island Station Network

In January 1987, the U.S. Air Force announced that aircraft weather reconnaissance operations in the Western Pacific (WESTPAC) would be discontinued after September 30, 1987. The last typhoon surveillance mission was flown on August 15, 1987, into Typhoon Cary in the Philippine Sea, ending 25 years of weather surveillance by WC-130 aircraft in WESTPAC. As a result, the Joint Typhoon Warning Center (JTWC), staffed by the U.S. Navy and Air Force at Guam, was tasked to investigate alternative data collection capabilities and tropical cyclone forecast and warning techniques. Drifting buoys were supplied by NDBC in both 1987 and 1988 to help compensate for the loss of weather reconnaissance.

Under the auspices of the Pacific Region of the National Weather Service (NWS), the JTWC, and the Naval Oceanography Command, NDBC's initial involvement regarding fixed stations was to make recommendations in the planning and implementation of a network of island-based Automated Meteorological Observing Stations (AMOS) for use in WESTPAC. Due to the extremely remote locations of the AMOS sites, NDBC proposed the use of a dual system that would operate with both the NOAA Geostationary Operational Environmental Satellite (GOES) and the NOAA polar-orbiting satellite (TIROS/ARGOS). The GOES system is similar to the one developed by NDBC for the Coastal-Marine Automated Network (C-MAN) and reports data at 1-hour intervals. The TIROS/ARGOS system is similar to the type used on drifting buoys, has an enhanced sensor suite, and reports data an average of seven times daily at the WESTPAC latitudes (i.e., one report derived from each satellite pass).

During early discussions, concern was expressed about the reliability of the GOES data from areas in the Western Pacific because of low station-to-satellite elevation angles with the GOES West Satellite. NDBC proposed installing a GOES system on Faraulep Island for a demonstration. This proposal was accepted, and, in October 1988, NDBC installed a C-MAN type system on Faraulep. It has been providing quality data and has resolved any previous concerns relating to system performance degradation due to low satellite elevation angles.

The NWS Pacific Region and JTWC have identified a total of 20 islands in the South Pacific Ocean as candidates for AMOS installations (Figure 1). The four stations west of 144°E will be TIROS systems since they are out of range of the GOES West Satellite. All of the stations east of 144°E will utilize GOES systems, and will be complemented with a TIROS system as a back-up.

Implementation of the WESTPAC-AMOS network will take place over the next 5 years. It is expected that NDBC will install three additional stations in fiscal year 1989 and four stations each year thereafter through 1993.

The JTWC in Guam is extremely pleased with the quality of the data being received from the demonstration system on Faraulep Island. The performance of this first station has demonstrated that an operational WESTPAC-AMOS network would provide a significant enhancement to tropical analyses in the Western Pacific.

Drifting Buoys For Alaskan Oil Spill

On the night of March 24, 1989, the *Exxon Valdez* ran aground on a reef in Prince William Sound. Some 267,000 barrels of crude oil proceeded to flow out of the tanker's cargo tanks, fouling one of the world's most biologically productive and pristine environments.

On Friday afternoon, April 7, 1989, NDBC received a request from the NWS Office in Anchorage, Alaska, for drifting buoys to be deployed in the oil slick. At that time the oil slick had moved out of Prince William Sound and into the Gulf of Alaska, heading in the direction of Kodiak, with the threat of entering Kamishak Bay and Cook Inlet. It also had become a threat to the shores of the Kenai National Wildlife Refuge.

On Monday, April 10, 1989, NDBC air-shipped to Anchorage some drifting buoys from its rapid response inventory. The buoys arrived in Anchorage the next day and were shipped by truck from the airport in Anchorage to the U.S. Coast Guard (USCG) Command Post in Seward. On Wednesday, the buoys were assembled, tested, and prepared for deployment.

Late Wednesday afternoon, the buoys were loaded on board a local fishing vessel for deployment at strategic locations in the Gulf of Alaska. These locations were determined by scientists from the NOAA Hazardous Materials Response Team at the NOAA Command Post in Valdez. On Thursday and Friday, April 13-14, 1989, three buoys were deployed in the Gulf of Alaska at the locations indicated in Figure 2.

Each buoy was equipped with air pressure, air temperature, and water temperature sensors. Additionally, the third buoy was also equipped to measure wind speed and direction.

The buoys proved to be extremely valuable in supporting the efforts of the National Weather Service in Anchorage, the NOAA Hazardous Materials Response Team in Valdez, and the USCG in Seward. Buoy position data accurately tracked the movement of the oil. This tracking was especially effective once the slick had dissipated and the oil congealed into tarry lumps.

One buoy in particular (46507), circulated within an eddy for a few days (see Figure 2). Knowledge of this eddy and its characteristics was of critical importance to the clean-up operations. An eddy tends to accumulate vast amounts of oil, which remain within the eddy until the eddy dissipates. The position data from buoy 46507 identified this eddy, and when the eddy dissipated, the data indicated that the buoy and the large accumulated mass of oil had broken loose and started to head in a southwesterly direction.

In addition to the effectiveness of the buoy position data, the meteorological data provided by the three buoys allowed the NOAA Hazardous Materials Response Team to make major improvements to their oil-spill computer models. Even though buoys 46505 and 46506 ran aground a short time after deployment, the data they reported prior to running aground were very valuable.

Ocean currents and water circulation patterns continually change and are difficult to predict in ocean areas adjacent to the coastal shoreline, especially around points and peninsulas. The buoy tracks identified currents and circulation patterns, and the meteorological data allowed realistic conclusions to be made in determining the causal relationship between changes in meteorological parameters and nearshore ocean currents and water circulation, and in turn, oil-slick movement.

As of this writing, the Coast Guard plans to retrieve the two buoys that ran aground. NWS Anchorage plans to refurbish the two buoys and have them redeployed. The buoy that is currently south of Kodiak Island will also be recovered and redeployed in a more critical area.

Tropical Ocean and Global Atmosphere (TOGA) Program

The TOGA Program continues to be one of the highly successful programs at NDBC. Since the official start of TOGA in January 1985, NDBC has provided a continuous network of 50 operational drifting buoys throughout the oceans of the Southern Hemisphere. The buoys have provided reliable meteorological and oceanographic data (barometric pressure, air temperature, sea surface temperature, and ocean current/drift track) while experiencing a mean time to failure of over 400 days. This degree of success is attributed partly to the conservatism employed in defining requirements specifications for the electronics.

In order to deploy the drifters in the desired locations, NDBC has developed an extensive logistics program that involves the cooperative participation of several countries and other U.S. agencies. Figure 3 shows the current locations of the TOGA network in the Southern Hemisphere.

A second part of the TOGA Program has been the deployment and continued maintenance of a moored 3-meter buoy in the South Pacific at 18°00'00"S, 85°06'00"W. The first buoy was deployed in January 1986 by the Chilean Navy with assistance from NDBC personnel. The buoy provided nearly 100 percent reliable data for 13 months and was retrieved only because the reported battery voltage was considered too marginal to undergo another winter in the Southern Hemisphere. In February 1987, the Chilean Navy, again with assistance from NDBC, replaced the first buoy with a new one. The new 3-meter buoy also provided extremely reliable data. In March 1987, NDBC conducted an extensive 3-meter buoy refurbishment training program with the Chilean Navy at the Instituto Hydrographico De La Armada (IHA) in Valparaiso, Chile.

In March 1988, the final training phase was completed, and the IHA is now maintaining and operating the 3-meter TOGA buoy. IHA, with NDBC logistical assistance, performed a successful complete replacement/ refurbishment of the TOGA buoy in March 1989.

Gulf of Mexico Joint Industry Meteorological/ Oceanographic Measurement Systems (MOMS)

In the Gulf of Mexico, NDBC has undertaken a groundbreaking environmental monitoring program in cooperation with industry. This successful endeavor is an example of the exceptional productivity and benefits that can accrue from the appropriate synergism of industry and government resources and capabilities.

On December 4, 1987, a Memorandum of Agreement was signed by Chevron USA, Eastern Division, and NDBC by which Chevron funded NDBC to install and operate an automated meteorological station on Chevron's Main Pass 133C oil production platform. The platform is situated in the Gulf of Mexico near the mouth of the Mississippi River.

Chevron's objectives in instrumenting the Main Pass platform were threefold: (1) obtain severe weather data to support cost-effective engineering design of future offshore platforms; (2) improve the accuracy and timeliness of emergency evacuation decisions associated with severe weather; and (3) provide real-time data for platform operations, such as equipment and personnel transfer.

Chevron initially contacted NDBC to obtain information on technology and procedures associated with design, maintenance, and data quality control of automated meteorological systems. It was their conclusion that NDBC offered a unique and cost-effective source for a "turnkey" measurement system, including quality control and data archival. At the same time, the data would be available via routine NOAA circuits for NWS use in its warning and forecast programs. This improves the baseline used by Chevron to support its operations and fills some data-void areas in the northern Gulf of Mexico.

NDBC installed the meteorological station on February 11, 1988, employing hardware that is standard to C-MAN. The data acquisition payload includes core sensors for measurement of wind speed and direction, barometric pressure, and air and sea surface temperatures. Also, data from Chevron's wavestaff are accessed by the system.

Hourly data are acquired and reported in real time via GOES, disseminated by NWS, and archived at the National Climatic Data Center. As with many C-MAN stations, data are also available to NWS via phone modem, in this instance Chevron's microwave telecommunications link to the platform.

On May 11, 1989, a further agreement was entered into by Chevron and NDBC providing for C-MAN system installations on up to three additional industry platforms and the NDBC monitoring of data quality on up to five more platforms equipped with industry-supplied systems. As a result, the Chevron Garden Banks platform has been identified for a C-MAN installation.

Buoys for NASA Space Shuttle Weather Forecasts

On August 9, 1988, NDBC deployed a 3-meter aluminum discus buoy at station 41009 approximately 32 kilometers east of Cape Canaveral, Florida, on behalf of the NASA Kennedy Space Center. The purpose of the buoy is to acquire surface observations in the heretofore data-void, offshore region adjacent to Cape Canaveral in support of weather forecasts for space shuttle launching and landing operations. Data from this buoy, which are comprised of the standard NDBC measurements of wind speed, gust, and direction; barometric pressure; air temperature; sea surface temperature; and nondirectional waves (significant wave height, peak period, and wave energy spectrum), are being acquired and relayed via GOES at half-hour intervals. This reporting frequency, which is double NDBC's standard hourly observation rate, was implemented specifically to meet NASA requirements.

As the second element in the program, NDBC deployed another buoy at station 41010 on November 9, 1988. This location is about 177 kilometers offshore, on the far side of the Gulf Stream from 41009. Due to its distance from land and its proximity to the Gulf Stream, a 10-meter discus hull was utilized. This large, steel hull, along with its inverse-catenary mooring, is specifically designed to withstand severe currents, such as could occur during a meandering of the Gulf Stream. In addition, the 10-meter buoy can be boarded and serviced at sea with relative ease, which, in view of the remote location of 41010, is critical.

NDBC is continuing to work with NASA to pursue new opportunities in other relevant meteorological areas. One project now under way is the concept engineering of one or more platforms to support C-MAN systems and electric field mill sensors. NASA operates a network of some 30 electric field mills in the Cape Canaveral/Kennedy Space Center area to measure surface electric fields as an indicator of lightning. All of these sensors are on land. Electric field mill systems on platforms would enable this important data acquisition network to be extended offshore.

Wave Measurement Programs

NDBC, on behalf of the Naval Civil Engineering Laboratory and the U.S. Army Corps of Engineers (COE), has deployed a number of directional wave measurement buoys at locations off the East and West Coasts of the United States, in the Gulf of Mexico, and in the Great Lakes. This capability is fully demonstrated for 10- and 12-meter discus buoys and for the 3-meter discus, which has become the directional wave "workhorse" due to its size, convenience of transport and deployment, and cost. NDBC 3-meter buoys with directional wave measurement systems will be deployed in the Atlantic over the 1990-1991 time frame for the Surface Wave Dynamics Experiment (SWADE) sponsored by the Office of Naval Research.

SWADE will involve two NDBC directional waves measurement buoys equipped with additional special sensor systems to be supplied by the Canadian Center for Inland Waters. A prototype SWADE buoy with a direction-keeping fin mounted to the buoy mast was deployed April 24, 1989, adjacent to the Shell Oil Company's Bullwinkle offshore oil platform in the Gulf of Mexico. Following the Bullwinkle deployment, the buoy was remoored next to NDBC's Offshore Test Platform (OTP), a 12-meter buoy off the Mississippi Gulf Coast. This will enable comparisons to be made between the OTP directional wave data and the data from the smaller 3-meter SWADE prototype. Completion of this field evaluation will occur in late 1989. In early 1990, the prototype buoy with modifications and a second directional 3-meter discus buoy will be prepared for the actual SWADE deployments, which are scheduled for October 1990 through March 1991. Both buoys will be moored in the Atlantic east of the entrance to Chesapeake Bay.

The U.S. Army Corps of Engineers has supported numerous directional wave measurement deployments since 1987. Most of these have been at nearshore coastal locations for the COE's Coastal Engineering Research Center (CERC). CERC buoys have been deployed off Duck, North Carolina; (two) off Mobile Bay, Alabama; off Monterey Bay, California; off St. Marys Inlet, Georgia; and in Lake Erie. Further directional wave measurement buoy installations are anticipated to meet the requirements of CERC's national wave gaging program.

NDBC has made continual improvements in its shoreside directional wave data processing system. These improvements, such as the calculation of heave spectra from slope spectra and the graphical representation of wind and wave directions in the frequency domain, are important data quality control techniques. Other data analyses have led to significant insights into the nature of buoy response, wind-wave generation, and directional wave spreading. These findings have both validated theory and spawned concepts for additional efforts in directional wave measurements.

Demonstration and Development Activities

Wind Profiler Program

In 1980, NOAA established a Wind Profiler Program at the Environmental Research Laboratories (ERL) in Boulder, Colorado, to further explore the feasibility of an upper-air monitoring system. ERL-developed research profilers demonstrated the ability of pulsed Doppler radar signals, electronically steered to the east and north of a vertical beam, to accurately measure the wind speed and direction at high-resolution, discrete altitudes up through the troposphere. The research systems also revealed the most probable mix of system engineering and operational parameters for a larger scale demonstration program.

The demonstration program calls for NOAA to deploy a network of approximately 30 wind profilers in the Midwest beginning in 1989, and to operate this network until 1993. The central aim of this demonstration is to determine operational and engineering requirements for a nationwide, four-dimensional, synoptic and mesoscale, wind-observing system.

Successfully integrating the existing wind profiler technology into a large network of continuously operating, unattended sites required the development of a Statement of Work and an associated procurement to ensure the transfer of that technology to commercial industry. The expertise of NDBC in the development of highly reliable, maintainable, and operationally successful remote meteorological data systems made it the logical choice to assist ERL in the solicitation of industry participation. This process culminated in June 1986 with the award of a contract to the Sperry Corporation (now UNISYS).

A Preliminary Design Review was held at UNISYS in September 1986, and the Final Design Review was conducted at UNISYS in February 1987. Assembly of the prototype system was completed in December 1987. Prototype No. 1 was shipped to Platteville, Colorado, and installed in August 1988. Prototype No. 2 was installed at the UNISYS facility in Bloomfield, Connecticut, in September 1988. Acceptance testing is proceeding and production authorization is anticipated by fall of 1989.

Additionally, ERL has requested that NDBC implement and operate surface observing systems at some 20 of the 30 profiler network sites. A prototype surface observing system, based on NDBC's C-MAN equipment, has been installed and connected to the Platteville prototype profiler. Standard measurements for the profiler surface observing systems are wind speed and direction and rainfall amount, which are needed for meteorological assessment of the profiler network performance.

Great Lakes "Ice" Buoys

During 1976, a data buoy program was begun on the Great Lakes, prompted by the loss of the Great Lakes ore carrier *Edmund Fitzgerald* in November 1975. An initial requirement for twelve buoy stations was defined, but the network was funded for only eight buoys to be operated during ice-free periods.

Weather and other requirements necessitate that the eight buoys be retrieved each fall prior to the end of the shipping season before the Lakes ice over. In an experiment to assess the feasibility of year-round buoy operation on the Lakes, a 12-meter discus hull was deployed in central Lake Superior in November 1985. The hull survived the 1985/86 winter season, but the mooring system failed, as was anticipated. The buoy was redeployed during the 1986/87 mild winter season and operated without failure. Prior to the 1987/88 winter season, the buoy system was retrieved, repowered, integrated, tested, and redeployed. In February 1988, the buoy was surrounded in winter ice and dragged its anchor (as designed) and eventually came to rest about 37 miles away from its original position. The ice buoy evaluation continued during the 1988/89 winter season with the Lake Superior buoy and with a second 12-meter buoy in northern Lake Michigan. Both of these buoys have been replaced with seasonal, 3-meter discus buoys for the 1989 summer; however, assessment of the cost-effectiveness of the "ice" buoys is under way, and the decision to redeploy them is under consideration.

Technology Development

In support of its operational activities and on behalf of evolving user requirements, NDBC conducts a continuous technology development activity. The objective of this effort is to both improve the reliability and cost-effectiveness of NDBC systems and to develop and qualify new sensor systems to meet expanding measurement needs. Several new technology development projects are listed below:

- LINE-OF-SIGHT DATA RELAY - NDBC has been developing a line-of-sight digital radio link system to provide data relay from offshore sensors to shoreside data acquisition stations. Particular emphasis is being placed on the requirement for "local waves" information at NDBC's C-MAN sites. This technology will also find application in the Cape Canaveral offshore electric field mill installations described previously.

- COASTAL BUOY - A small, foam-based buoy hull is being developed to meet C-MAN "local waves" and other nearshore needs.

- LOW-DRAG, 3-METER BUOY MAST - A low-drag, streamlined mast is being designed for the 3-meter buoy. This mast, which will align the buoy with the prevailing wind and result in much less wind-induced buoy tilt, is expected to result in both improved directional wave data and better wind measurements.

- INFRARED DOPPLER LASER WAVE SENSOR - This is a down-looking laser system for measuring wave displacement from offshore platforms. NDBC has systems-engineered and procured a number of these devices, which are now undergoing field testing.

- SOLAR POWER - NDBC is moving towards all solar power in its moored buoy and coastal station programs. Two- and three-year hybrid primary battery/solar power systems are presently in use. Five-year "all solar" power systems are now being developed and tested.

- DATA ACQUISITION SYSTEMS - As new technology becomes available, NDBC continually works to improve performance and reliability and to reduce the costs of its buoy and fixed station systems. Multiyear, unattended operation is the design goal for all NDBC systems. A small increase in system reliability translates into significant savings in maintenance and repair costs, especially for stations in remote locations.

- OTHER SENSOR SYSTEM ENHANCEMENTS - On behalf of NOAA, NASA, and other agencies, NDBC is working to enhance its existing sensor capability and to integrate new and novel sensors. Implementing continuous wind measurements on selected coastal stations and buoys for satellite remote sensing verification is an example of enhancements to existing NDBC systems. Novel sensor requirements, pursued in support of NASA, the Navy, and other agencies, include optical rain gauges on buoys, a very low frequency (VLF) radio receiver on buoys, and other special projects in subsurface temperature and acoustic measurements.

Conclusion

The diversity and scope of the Nation's environmental monitoring needs is radically expanding as the decade of the 1990's approaches. At NDBC, we are looking forward to the challenges this entails, and we are confident in our ability to meet those challenges fully. This paper describes a number of programs in which NDBC continues to deal successfully with a variety of technical intricacies and operational complexities in doing the job at hand. Our objective is to continually improve the reliability, cost-effectiveness, and scope of our networks and systems as we progress toward the twenty-first century.

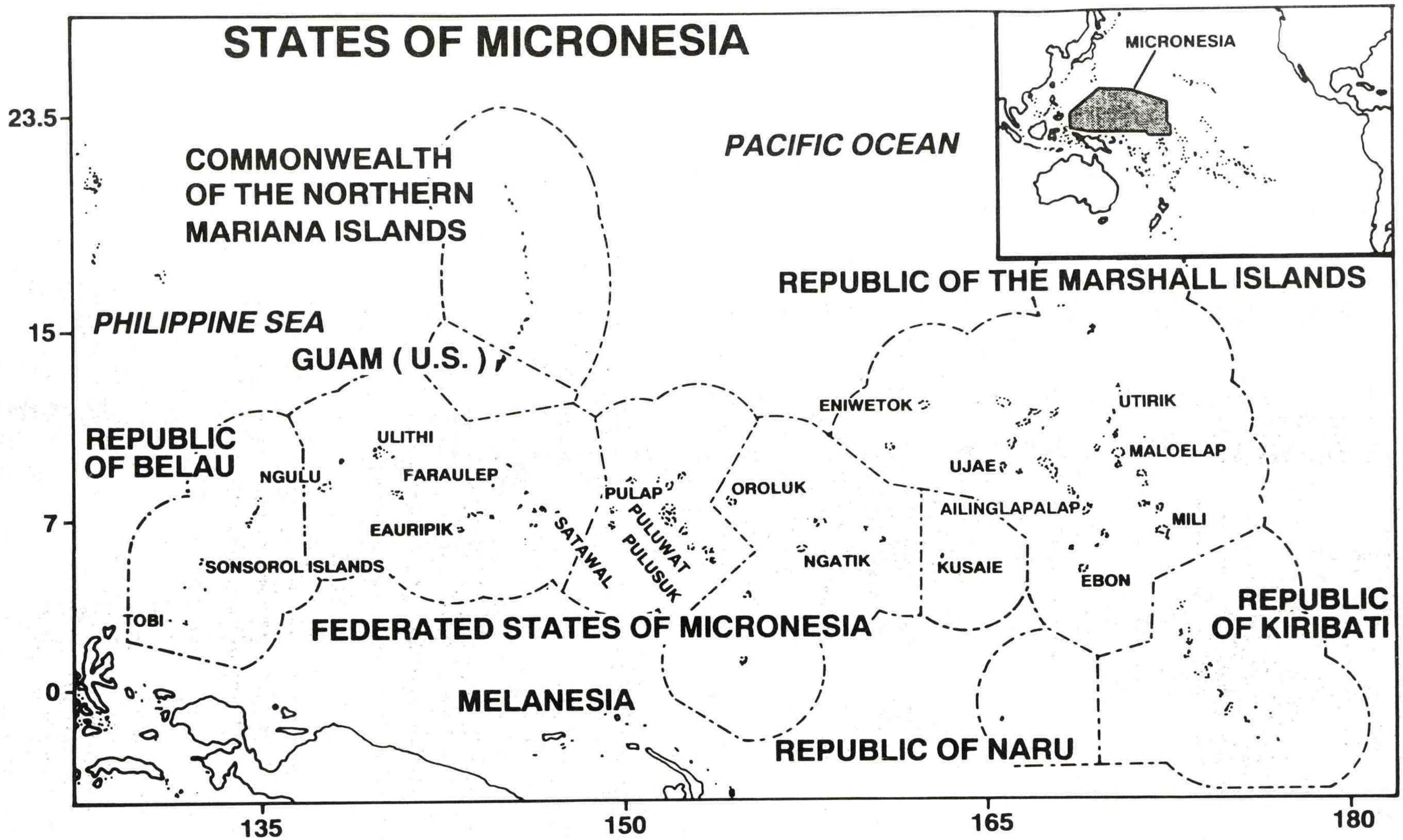

Figure 1. Western Pacific - Automated Meteorolgical Observing Stations (WEST PAC - AMOS)

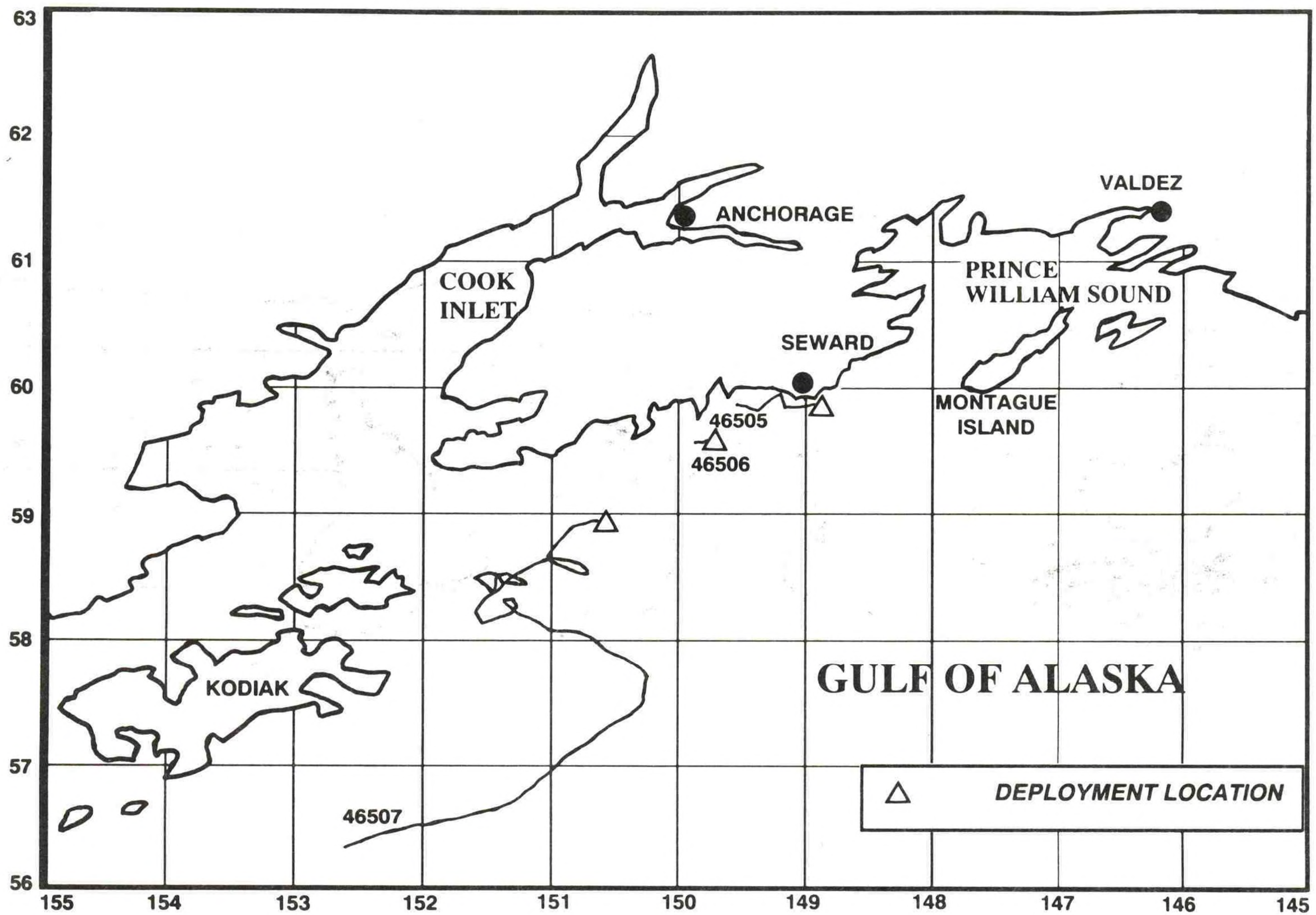

Figure 2. Drifting Buoy Tracks Valdez Oil Spill April 13, 1989 to May 31, 1989

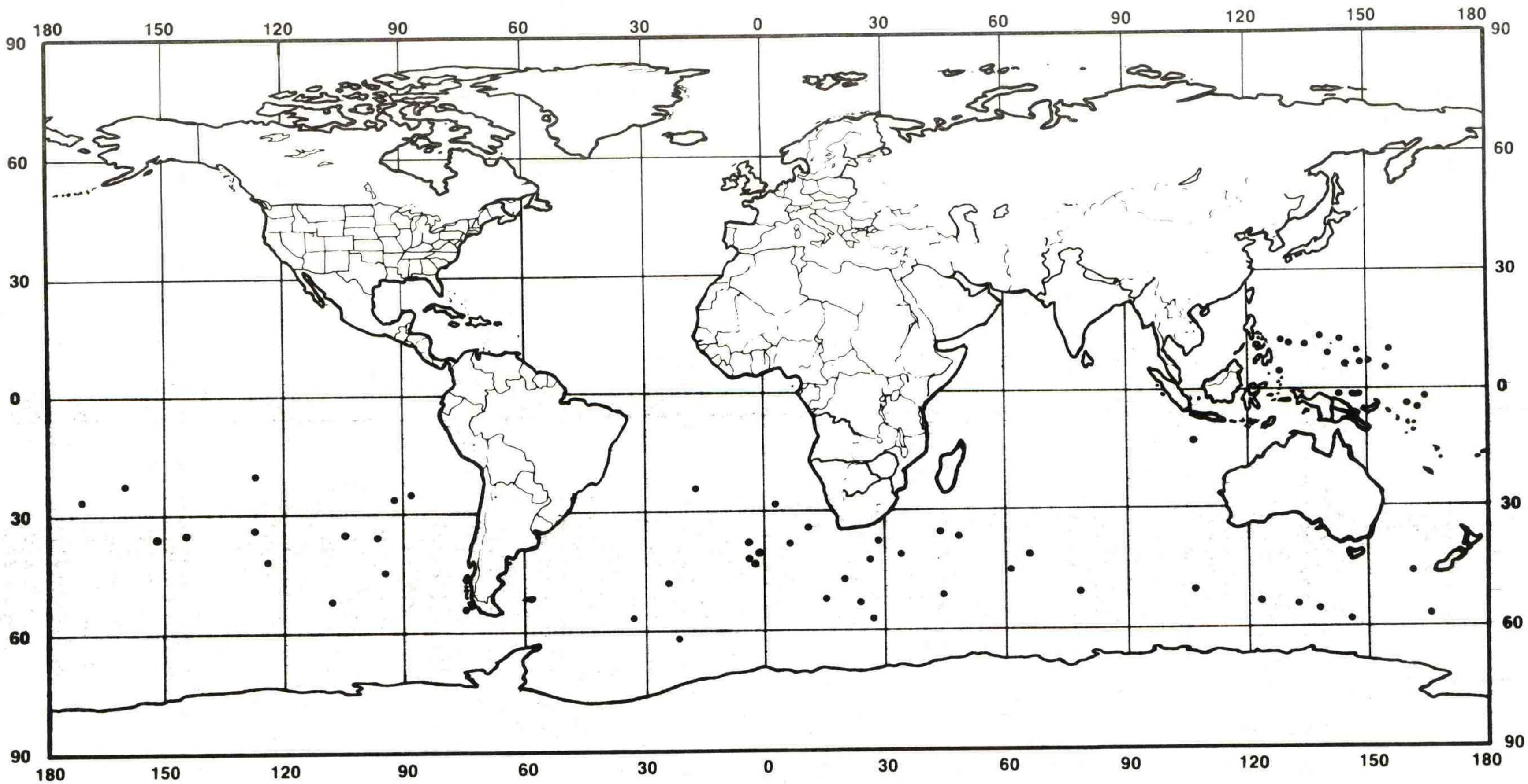

Figure 3. Toga Drifting Buoy Network January 25, 1989

New Ocean Technology for Satellite Oceanography

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Japan is to launch Advanced Earth Observing System (ADEOS) in early 1995. It will carry Ocean Color and Temperature Scanner (OCTS) with three objectives: (1) global observation of ocean color and sea surface temperature in visible and infrared region; (2) enhancement of the application of remote sensing to the field of fisheries; and (3) establishment of technologies required for multi-channel, wide swath width and moderate resolution optical sensor. Plans are also made for ADEOS to carry a U.S. NASA Scatterometer (NSCAT), a microwave system for the measurement of wind stress over the ocean (Figure 1).

ADEOS Satellite in Orbit

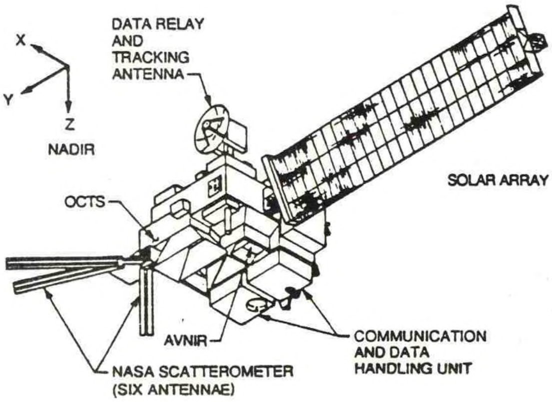

FIGURE 1. ADEOS SATELLITE

In the United States, plans are made by NASA to initiate, starting October 1990, a comprehensive program called Earth Observing System (EOS) to observe the earth from space using unmanned platforms to be launched starting in October 1996 into polar orbit so that all parts of the globe can be viewed. The ocean components of the EOS program are as follows:

1. **Sea Ice** extent, characteristics, and motion by:
Moderate-resolution Imaging Spectrometers-Nadir (MODIS-N)
Advanced Microwave Scanning Radiometer (AMSR)
Advanced Medium Resolution Imaging Radiometer (AMRIR)
Synthetic Aperture Radar (SAR)

2. **Sea Surface Wind** by:
AMRIR
Scatterometer (SCAT)
Altimeter (ALT)

3. **Ocean Waves** by:
SAR
ALT

4. **Ocean Circulation** by:
Atmospheric Infrared Sounder (AIRS)
Moderate-resolution Imaging Scatterometer-Tilt (MODIS-T/MERIS)
MODIS-N
ALT

5. **Ocean Biological Activity** by:
MODIS-T/MERIS
MODIS-N
High-Resolution Imaging Spectrometer (HIRIS)

In addition, wetlands extent in estuarine and coastal areas are to be determined by Electronically Scanned Thinned Array Radiometer (ESTAR) and SAR.

Brief descriptions of the EOS instruments that will be used to study the ocean are given below:

ATMOSPHERIC INFRARED SOUNDER (AIRS)

An infrared sounder of atmospheric temperature and trace species. Temperature retrievals obtained with AIRS will be accurate to $1^{\circ}C$ and will achieve a vertical resolution of 1 km through the vertical extent of the troposhere. AIRS is a prototype for the next generation operational IR sounder.

ALTIMETER (ALT)

Radar system for the study of ocean topography and topographical measurements over ice. Dual frequency radar configuration with altitude precision less than 3 cm. Precision orbit determination will also be provided.

ADVANCED MEDIUM-RESOLUTION IMAGING RADIOMETER (AMRIR)

Visible and infrared radiometer for global measurement of cloud cover, sea surface temperature, measurement of snow and ice extent, plus measurement of vegetation cover and characteristics. Sensor will also provide atmospheric temperature and water vapor measurements and will be a follow-on instrument replacing the combined capability of the current Advanced Very High-Resolution Radiometry (AVHRR) and HIRIS instrumentation. Sensor will have a spatial resolution of 500 m at nadir and a ground swath of approximately 2940 km.

ADVANCED MICROWAVE SCANNING RADIOMETER (AMSR)

Radiometer providing measurements of atmospheric water vapor, precipitation, and snow and ice extent. Multifrequency (5 to 40 GHz region) electronically scanned cylindrical parabolic antenna approximately 3 m x 6 m with a 3 m phased array. Field-of-view of 40° with spatial resolution of 5 to 20 km. Anticipated radiometric performance of less than $1^{\circ}K$. Swath width of 1000 to 1500 km with an incidence angle of 45°.

ELECTRONICALLY SCANNED THINNED ARRAY RADIOMETER (ESTAR)

Microwave radiometer providing high-resolution soil moisture measurements using an aperture synthesis technique. Single frequency instrument at 1.4 GHz. Antenna size 18 m x 18 m covering a swath of 1400 km; approximate temperature resolution of $1^{\circ}K$.

HIGH-RESOLUTION IMAGING SPECTROMETER (HIRIS)

Spectrometer providing highly

programmable localized measurements of biological and geological processes at a spatial resolution of 30 m. Pointable instrument with a 30 km swath coverage, viewing accessible areas 25° off track and +60°, -30° in track. Spectral coverage of 0.4 to 2.5 µm at 10 nm resolution. Spectral bands total 196.

MODERATE-RESOLUTION IMAGING SPECTROMETER-NADIR (MODIS-N)

Imaging spectrometer for the measurement of biological and physical processes and atmospheric temperature sounding on a 1 km x 1 km and a 0.5 km x 0.5 km scale. Scanning instrument covering 1500 km swath centered at nadir. Spectral ranges of 0.4 to 2.3 µm, 3.0 to 5.0 µm, and 6.7 to 14.2 µm. Total of 40 bands, 27 at 1 km and 13 at 0.5 km resolution available for readout.

MODERATE-RESOLUTION IMAGING SPECTROMETER-TILT (MODIS-T/MERIS)

Imaging spectrometer for the measurement of biological and physical processes on a 1 km x 1 km scale. Scanning instrument covering a 1500 km swath centered at nadir, with scan mirror tilt for sun glint avoidance. Spectral range of 0.40 to 1.04 µm, in 64 bands.

SYNTHETIC APERATURE RADAR (SAR)

Imaging radar for all-weather studies of small- and large-scale structural characteristics of the surface for application in geology, glaciology, plant physiology, hydrology, and oceanography. Resolution of 30 to 500 m over a selectable swath from 50 to 1000 km located on either side of the subsatellite track. System variables include frequency (L-, C-, and X-band), polarization (quad for L- and C-, HH and VV for X-band), and imaging geometry (incidence angles of 15° to 55° and azimuth angles of 0° up to approximately 60°).

SCATTEROMETER (SCAT)

Microwave systems for the measurement of wind stress over the ocean. System provides measurements along two parallel swaths from 120 to 700 km on either side of the subsatellite track, with a six-stick antenna configuration. Wind speed to 2 m s^{-1} and 10° angular resolution are measurement goals.

All of these instruments require the establishment and maintenance of a parallel <u>in situ</u> (at-sea) measurement capability in order to maintain the integrity of the satellite data sets, since the detection and verification of intra- and inter-annual environmental fluctuations for the EOS global change program place most stringent long-term accuracy and precision requirements. Proper and effective algorithms, too, must be developed.

The field measurements have two purposes. The first is <u>in situ</u> (at-sea) verification of satellite-generated data. The second is to extend this two-dimensional sea-surface satellite data vertically downward. Thus, three dimensional data can be obtained real-time. There is, therefore, a challenge in front of us to develop intelligent, sophisticated ocean technology to further our quest to understand the ocean. To illustrate the importance of in situ (at-sea) verification of satellite-generated data, a marine optical buoy system being developed at NOAA Satellite Research Laboratory (attention Dennis K. Clark) to support the ocean color study from space is given below.

Ocean Color from Space

The NASA Nimbus-7 satellite carried Coastal Zone Color Scanner (CZCS), a radiometer, from 1978 to 1986. The CZCS global data sets, scheduled for publication from 1989 onward, are a monumental scientific cornerstone to understanding the ocean's productive capability as well as the ocean's role in the global carbon cycle. In sum, for the first time, ocean scientists can view the global distribution of photosynthetic organisms, phytoplankton, in the world's ocean from space. Since phytoplankton pigments, mainly chlorophyll a and phaeopigment a, absorb energy primarily in the red and blue regions of the spectrum and reflect green light, the spectrum of sunlight backscattered by upper ocean layers and the distribution of phytoplankton pigments are related. Satellite measurements of ocean radiance at selected wavelengths can thus be used to estimate phytoplankton concentrations and primary productivity (Figure 2).

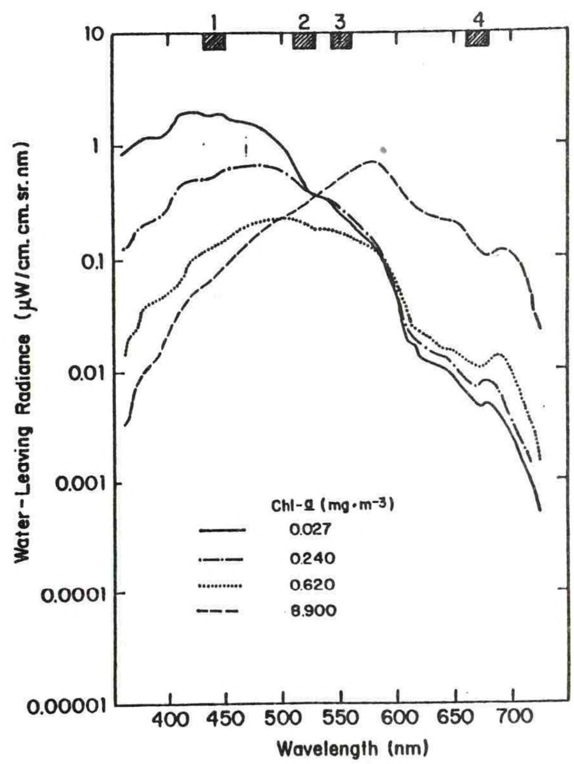

FIGURE 2. WATER-LEAVING RADIANCE AS A FUNCTION OF CHLOROPHYLL A CONCENTRATION. FOUR SPECTRAL BANDS USED FOR CZCS ARE GIVEN IN NUMERALS.

To obtain the needed *in situ* spectral radiance information, features of a marine optical buoy system were developed as shown in Table 1.

TABLE 1. MARINE OPTICAL BUOY SYSTEM FEATURES

Optical System	
	Optical
	Dual spectrographs
	Dichroic beam splitter
	Concave holographic gratings
	Linear array detectors
	Thermoelectric coolers
	Collectors
	Pressure
	Temperature
	Magnetic heading
	Inclination
Data Acquisition	
	Direct
	Telemetry
Deployment	
	Ship
	Drifting and moored buoys
Satellite Positioning	
	Global positioning system
	Data collection and location system
Data Archive	
	Near-real time & historical
	Phone access

The actual buoy measurements and derived parameters are shown in Table 2.

TABLE 2. OPTICAL BUOY MEASUREMENTS AND DERIVED PARAMETERS

Direct	Downwelled spectral irradiance Upwelled spectral radiance Temperature
Computed	Water-leaving spectral radiances Diffuse attenuation coefficients for downwelled irradiance and upwelled radiance Photosynthetic active radiation Fluorescence line Height @ 685 nm Spectral reflectance (or radiance) factor
Derived	Phytoplankton pigments (Chlorophyll *a* plus Phaeopigment *a*) concentration ($mg\ m^{-3}$) Total suspended matter (TSM) concentration ($mg\ liter^{-1}$) FLH-Chlorophyll *a* concentration Fluorescence quantum efficiency
Potential	Phaeopigment *a* concentrations ($mg\ m^{-3}$) Primary production ($mg\ C\ m^{-3}\ h^{-1}$)

The design of a marine optical buoy system is shown in Figure 3. It can be tethered to a ship, moored to the sea-floor or let adrift. Spectral radiance can be collected at any desired depth with fiber optics relays.

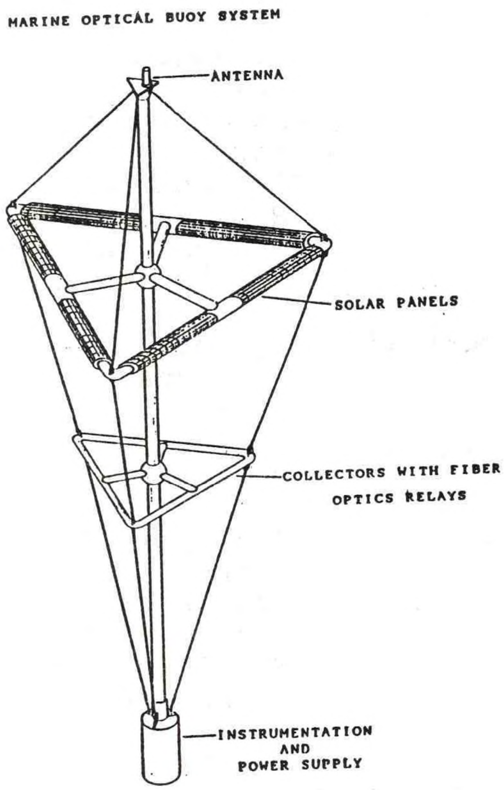

FIGURE 3. A MARINE OPTICAL BUOY SYSTEM

A detail of the instrumentation package at the bottom of the optical buoy is shown in Figure 4.

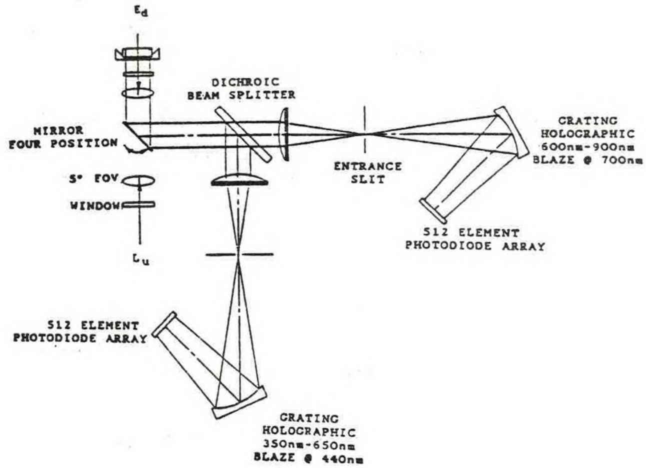

FIGURE 4. INSTRUMENTATION PACKAGE OF THE OPTICAL BUOY

The real-time data collection and relay system is shown in Figure 5.

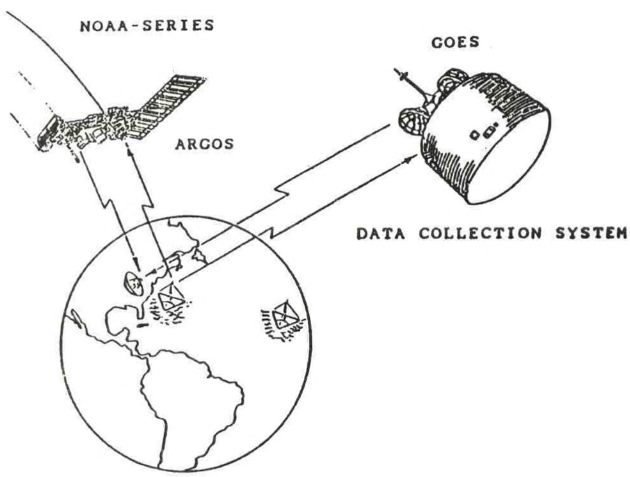

FIGURE 5. SATELLITE DATA RELAY. ARGOS IS THE FRENCH DATA COLLECTION AND LOCATION SYSTEM, AND GOES DENOTES GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE THAT IS THE NOAA OPERATIONAL GEOSYNCHRONOUS SATELLITE.

In summary, great care and highest quality control are needed to obtain in situ (at-sea) information. Instrumentation needed to achieve it must be developed concurrently with the design and construction of satellite systems. I personally thank Dennis K. Clark of Satellite Research Laboratory of the National Oceanic and Atmospheric Administration for his unselfish cooperation in preparing this report for UJNR Marine Facilities Panel.

TECHNIQUES FOR REAL-TIME ENVIRONMENTAL MAPPING AND MONITORING

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ABSTRACT - *The characteristics of a real-time, multi-parameter measurement system for monitoring pollutants in the marine environment are described. The system couples measurements from a suite of physical, chemical and biological sensors to a positioning/navigation system through a microprocessor-based data acquisition and processing system. Environmental data can be displayed on map overlays, as it is collected, in order to track the dispersal of contaminant plumes and other dynamic features. The system can be used at a fixed location in order to document temporal variability. Recent efforts in which the system has been used in conjunction with a specially developed automated organotin analyzer are discussed.*

Traditional methods of environmental sampling in which discrete samples are collected and taken back to the laboratory for later analysis are not sufficient to adequately describe highly dynamic situations in aquatic environments. In contrast to land-based sites, where it is possible to describe where a sample came from by simply documenting geographic position, in the marine environment it is also necessary to understand the local hydrography of the water in which the sample was collected. This is because in aquatic systems totally different water masses can occupy the same location at different times. Hence, to determine the source and/or fate of contaminants in marine systems it is necessary to know what the water is doing. A mechanistic understanding of complex distributions can only be achieved using a multi-parameter approach which simultaneously measures related physical, chemical and biological parameters in addition to the toxicant of interest.

To this end scientists at the Naval Ocean Systems Center have developed a real-time mapping/monitoring capability. The system integrates a suite of chemical, physical and biological sensors with a microwave positioning/navigation system [1] and a data acquisition and processing system [2]. The main components of the Marine Environmental Survey Capability (MESC) system are shown schematically in Figure 1. The system can accommodate both *in situ* and flow-thru sensors for measuring water properties and chemical constituents. *In situ* sensors (ie., temperature, conductivity, dissolved oxygen, pH, light transmission, chlorophyll *a* fluorescence) are housed in an instrument cage (Fig. 2) that can be towed from a survey craft with the aide of a 1 m hydrodynamic depressor wing

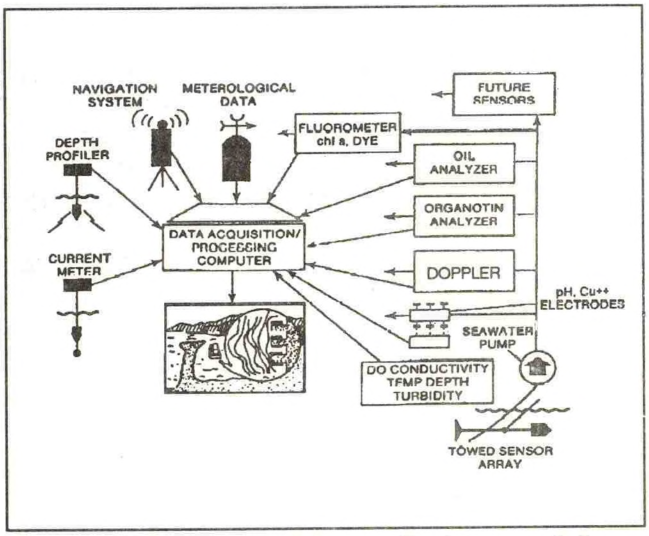

Figure 1. *Schematic of Marine Environmental Survey Capability (MESC) System showing major sensor systems.*

or lowered over the side to make continuous vertical measurements. For parameters for which *in situ* sensors are not presently available a high-capacity pump is used to pump water on-board the survey craft through a fared Teflon-lined hose. A manifold system distributes the flowing sample to a series of on-line instruments which include: flow-thru fluorometers for measuring petroleum hydrocarbons, fluorescent tracer dyes, etc.; a flow injection system for measuring nitrate, phosphate, silicate and ammonia; and an automated organometal analyzer. A sampling port is provided to allow on-board collection of discrete samples

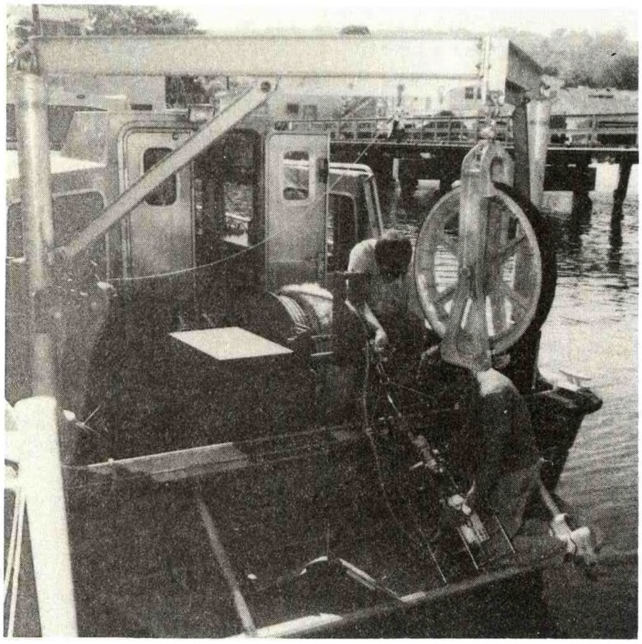

Figure 2. *Photograph of the MESC In Situ instrument package and oceanographic winch for deploying fared teflon sampling hose/telemetry cable.*

for later analysis in the laboratory. In addition to the above sensor systems a acoustic doppler current meter, standard electro-magnetic current meters, and a meteorological data station (wind velocity and direction, relative humidity, and rainfall) are also available.

Signals from both the *in situ* and flow-thru instrumentation systems are fed into a data acquisition computer which performs analog to digital signal conversions and samples incoming digital data. Sensors can be sampled at rates up to 30 times a minute. For horizontal mapping operations conducted at a typical craft survey velocity of 5 knots this translates to a spatial resolution of approximately 5 m. For vertical profiles spatial resolution on the order of 10 cm is easily obtainable. Data from the sensors is stored as a function of time and position in IBM-compatible files. Data is also distributed in real-time to other PCs running programs for both "strip-chart" display of data and for display of selected parameters on map overlays of the study area.

In addition to the standard sensor systems that are interfaced with the MESC system, several efforts are in progress that are aimed at developing automated instrumentation for measuring selected chemical compounds that are of particular concern to the Navy. An example of such an instrument is the Automated Organometal Analyzer (AOA) (Fig. 3) developed for the determination of tributyltin and related compounds[3]. Methods for determination of organotin compounds are of interest because they are used in antifoulant coatings that the Navy is evaluating. This instrument automatically performs a complex chemical analysis which previously required a highly trained technician to complete manually. When configured for organotin analyses the instrument can perform a complete analysis of a water sample from the flowing seawater system for tributyl-, dibutly-,and monobutytin at parts-per-trillion concentration levels in approximately 5 minutes. Used in conjunction with the MESC system the AOA analyzer provides near real-time information about the distribution of organotin compounds and thus helps guide monitoring efforts and ensure sampling effectiveness.

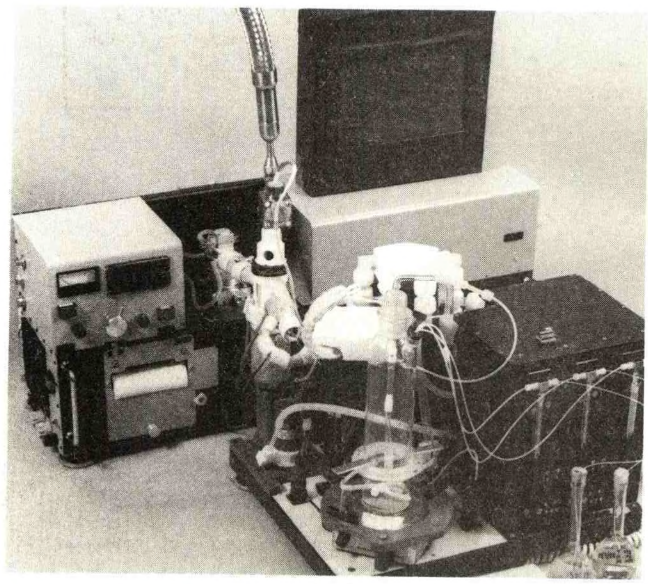

Figure 3. *Photograph of the Automated Organometal Analyzer.*

The MESC system has a modular design which provides a high degree of flexibility and permits the system to be easily transported and deployed from a variety of platforms. Because the objectives of each study determine the individual parameters that must be measured, the option is provided to select the appropriate sensors and instruments that will satisfy the unique requirements of each survey. Also, MESC can accommodate new sensors and/or instruments for specialized studies.

TABLE 1. RV/ ECOS SPECIFICATIONS	
GENERAL SPECIFICATIONS	
Length / Beam / Draft	40 ft / 12 ft / 2 ft
Freeboard	3 ft
Transport Height	11 ft-6 in
Laboratory Space	140 sq ft (10 x 14 ft)
Wheelhouse Space	50 sq ft
Deck Space	160 sq ft
Weight	20,000 lbs
OPERATING CHARACTERISTICS	
Max Speed	20 kt
Data Taking Speed	2 to 9 kts
Range	200 miles
Positioning System Range	18 miles
AUXILLARY SYSTEMS CHARACTERISTICS	
Diesel Generator	12 KW
Hydraulic Capstan	1000 lb capacity
Davit/Hydraulic Winch	1500 lb capacity
Thru-Hull Transducer Well	12 in diameter
Oceanographic Winch	200 ft Teflon sampling hose/data telemetry cable
Radar	24 mile range
Loran C	

To insure quick response the system can be shipped by air and installed on craft of opportunity. The system is primarily intended for use aboard small vessels (suitable craft generally range from approximately 10 to 20 m in length). For environmental emergencies where a response time of 24 hours or less is required a minimum system can be transported as baggage on commercial airlines. For detailed surveys at sites where there is no suitable survey platform a custom 40 ft twin diesel support craft (R/V ECOS) is available (Fig 4). Physical and operational characteristics of the R/V ECOS are given in Table 1. This craft can be can be transported by truck anywhere in the continental U.S. A special cradle is also available that will permit the craft and entire MESC system to be shipped via air (C5A) when time is critical.

One of the key features of the MESC system is the automated positioning/navigation system that is interfaced with the data acquisition and processing system. The microwave positioning system uses a receiver-transmitter with an internal range processor mounted on the survey vessel to interrogate two or more shore-based reference stations to determine vessel location. A typical set up used

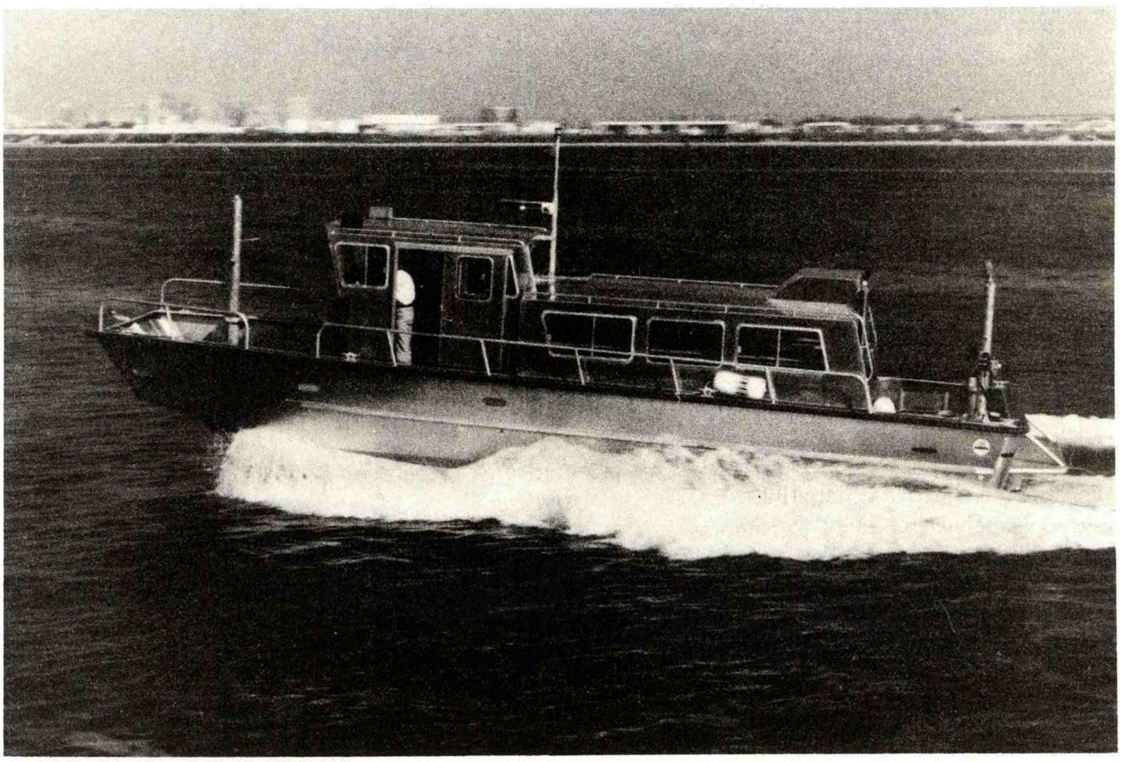

Figure 4. *Photograph of MESC survey vessel R/V ECOS.*

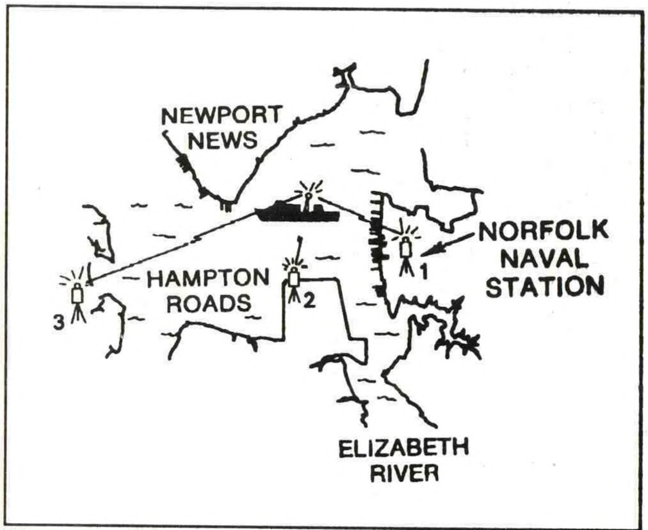

Figure 5. *Schematic of the microwave positioning system setup used for a monitoring survey in the Hampton Roads area off Norfolk Naval Station.*

in tests in the Norfolk area is shown schematically in Figure 5. The system provides updates of the survey craft position at rates as high as 30 times a minute with an accuracy of ±2 m. Position information is recorded with each data record and displayed in real-time on a video monitor. For mapping surveys, track-lines can be displayed on map overlays and the progress of the survey craft along the defined pathway can be monitored by the boat operator as the survey progresses. Figure 6 shows pre-established track-lines with an overlay of the actual position of the survey craft for a survey conducted off Norfolk Naval Station.

Data collected during a survey operation can be displayed in several ways to facilitate interpretation of the observed distributions. Figure 7 is an example of a stacked three-dimensional representation showing two of the twelve parameters that were measured at a depth of approximately 1 meter during the survey shown previously in Figure 6. The flow of water from the Elizabeth River in the vicinity of the Naval Station is determined primarily by the local bathymetry. The data in Figure 7 suggests that the highest concentrations of hydrocarbons (as determined by a fluorescence method) were found mainly in the dredged channel and the immediately adjacent shallows of the Hampton Roads area. Other data showed that the source of these hydrocarbons was the Elizabeth River.

The utility of instrumentation such as the automated organotin analyzer for monitoring chemical variability as a function of time at a single sampling site is shown in Figure 8. This data shows vertical temperature structure and or-

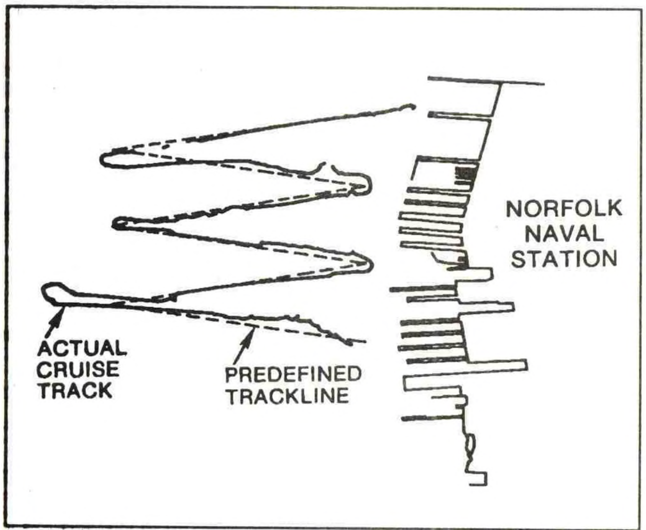

Figure 6. *Map showing predefined track-lines and overlay of actual cruise track of survey craft for mapping operation conducted off Norfolk Naval Station.*

ganotin concentrations measured at a distance of 1 meter off the bottom as a function of tidal height at a location in San Diego Bay. The data shows that tributyltin concentrations in near bottom waters vary by as much as a factor of seven between low tide and high tide. Comparison of the tributyltin data with the temperature and tidal data (Fig. 7) illustrates the dramatic covariability between chemical and physical properties. This type of data allows formulation of mechanistic models for the distribution of chemical toxicants.

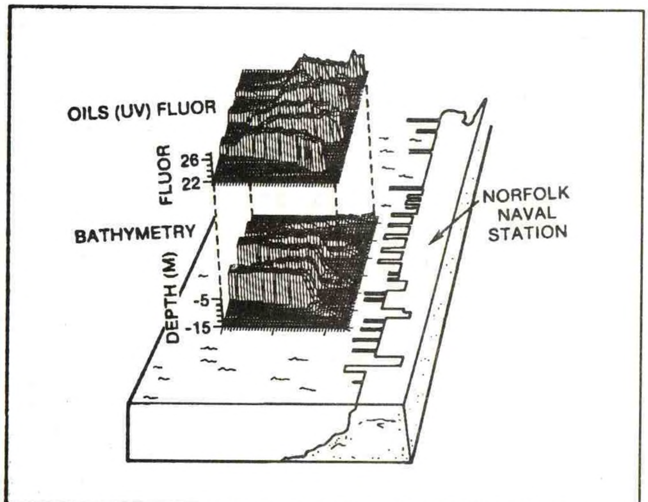

Figure 7. *Map showing stacked 3-dimensional representation of hydrocarbon concentrations (as indicated by oils fluorescence) and bathymetry (bottom depth) for data collected along transit shown in Fig. 6.*

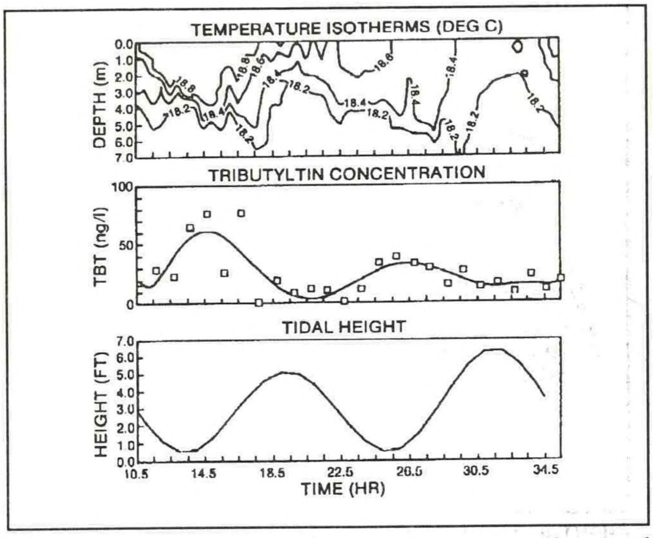

Figure 8. *Time history of organotin concentrations and vertical temperature structure at a site in San Diego Bay as a function of tidal height.*

With traditional methods and equipment it would not be practical, or in many cases even possible, to document this type of variability. Furthermore, there is evidence to suggest that this type of variability in the distribution of a chemical toxicant may have important biological consequences. Because an organism living on the bottom may experience significant changes in concentrations of a toxicant over time scales as short as a few hours it may not respond to the environmental insult in the same manner as it would with constant exposure. This is an important point because most toxicity tests conducted in laboratories use static levels of toxicant.

The MESC system and automated instrumentation such as the AOA are two tools that appear to have great potential for establishing a mechanistic framework for interpreting the distribution, fate and consequences of inputs of toxic chemical compounds to the aquatic environment. One of the most promising uses of these tools is for validation of computer-based models that are used to assess environmental effects from inputs to aquatic systems. At present most models lack adequate "sea- truth" data (especially in terms of chemical data) for rigorous testing of the predictions they generate. The ability of the MESC system to collect synoptic "snap shots" of contaminant distributions and related hydrographic data should provide a sound data base for validating and improving computer-based models. Use of the system for point monitoring can also provide very useful information for evaluating short term temporal variability (hours to days).

In order to function as a responsible member of the community in which it has facilities, the Navy must not only satisfy existing environmental regulations and requirements but also anticipate and attempt to predict the environmental consequences of changes in the way it operates. The development of the MESC system for real-time environmental mapping and monitoring represents an attempt to take the lead in establishing a technology base for evaluating environmental impact of its operations, in particular those resulting from activities that are largely unique to the Navy. This provides the Navy with the means to work with regulatory agencies for establishing safe and realistic regulations and criteria. Regulations based on sound scientific data, rather than political expediency or emotional perceptions, would better insure the health and safety of military and civilian personnel and at the same time promote efficient and cost effective operations.

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