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MIT SEA GRANT
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Quarterly Report

Engineers Trail Sewage in Boston Harbor

Figure 1. Collecting water samples in Boston Harbor.

Every year six billion gallons of raw sewage gush through 108 sewer overflow pipes into Boston Harbor and rivers feeding the harbor. Combined with the frequent malfunctioning of two giant, rusting sewage treatment plants on harbor islands, pollution in Boston Harbor is critical. Recently at the instigation of a state superior court judge, a new "superagency" was created to clean up the mess. It will take patience, hundreds of millions of dollars, and accurate information on the harbor ecosystem and how it reacts to pollution loading.

"Because of the current activity and interest in cleaning up Boston Harbor, we wanted to get involved in numerical modeling of the harbor," says MIT civil engineering researcher Eric Adams. Adams, along with civil engineering assistant professor Philip Gschwend and graduate student Richard Kossik, are applying two hydrodynamic circulation and transport models to the harbor to predict pollutant transport and concentrations as a function of winds and tides.

The models, named "TEA," for Tidal Embayment Analysis and "ELA," for Eulerian-Lagrangian Analysis, use the finite element modeling technique. They are recently-developed alternatives to the popular circulation/dispersion models CAFE and DISPER, which were created by MIT Sea Grant in the 1970s. Consulting firms have used CAFE and DISPER repeatedly to help site power plants, sewage treatment facilities, and other shoreline developments. TEA and ELA offer reduced computer cost and increased accuracy over their parent models, especially in smaller, geomorphically complex embayments such as Boston Harbor. TEA computes where, how fast, and in what direction harbor currents are moving (see *Quarterly Report*, Fall l983), while ELA follows chemical solutes as they travel with the current.

Gschwend, who specializes in halogenated organic compounds, uses these pollutants as tracers in Boston Harbor sewage. "Halocarbons make good tracers," the researcher claims, "because you can dilute them to a great extent and they will still be measurable." With Kossik, Gschwend measures the concentration of pollutants at their source and by boat at different points in the harbor. His measurements are used to verify the models' predictions. Otherwise, says Gschwend, the models would be like too many others: unverified by actual measurements and therefore of limited value.

Although the halogenated organic chemicals, which come from, among other things, household cleaners, are not present in dangerous quantities in the harbor, scientists view them with concern because they are carcinogenic and a byproduct of the chlorination that occurs in sewage treatment. While Gschwend's measurements will help validate TEA and ELA, the models will also help Gschwend determine how these substances behave in the ocean. In particular the chemist would like to know their evaporation rate.

A first step in modeling the harbor was to develop a finite-element grid for the area. At each of more than 800 intersection points (nodes) on the grid, elevation, current velocity, and particle concentration are computed. In the outer harbor, nodes are approximately 10 km apart; toward the inner harbor, where more precise data is needed, nodes are spaced at several hundred meters. The resulting pattern of triangles provides a map on which the model "moves" pollutants around the harbor, as they would be moved in reality by wind and tides.

Factors affecting the concentration of pollutants are source concentration; the rate at which the pollutants are mixed as they are discharged to the harbor; the rate at which they are dispersed by winds and tides further from the outfall; and the transformation rate. Once introduced into the water, several things can happen to a substance to "transform" it. It can sorb to suspended particles and settle, evaporate, or decompose, for example. In the context of halogenated organic compounds, evaporation is the important process. For modeling purposes, transformation is represented by a predetermined rate coefficient. A mixing rate is also calculated.

"Basically," Adams says, "you input tide and wind, then introduce a pollutant at the

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source, in this case Deer Island [the site of a sewage treatment plant in Boston Harbor]. TEA produces a circulation pattern, and ELA moves, mixes, and transforms the pollutant in the harbor." Although in its early stages, a trial run of TEA was compared with measured currents. TEA performed "reasonably well."

The principal users of the models will be consulting firms doing environmental impact statements. Already two leading firms involved in studying Boston Harbor have expressed serious interest. "The main long-term objective is to help evaluate future alternatives for cleaning up the harbor," Adams says. "At this point though, we're just trying to validate that the model does a good job. Then we can go on to future applications." The model is flexible and can be adapted for use in other harbors. ■

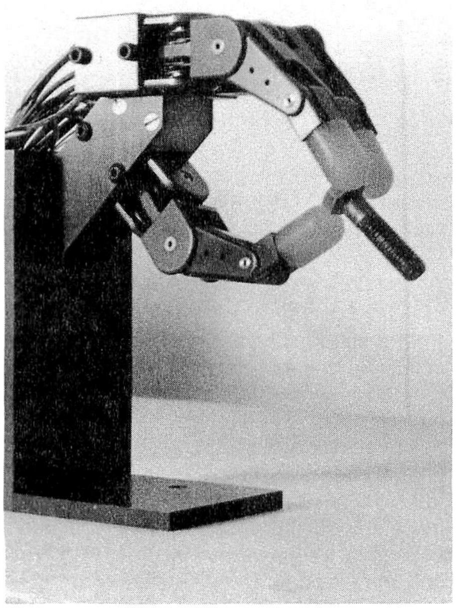

Figure 2. Robot hand can grasp objects, sense the orientation of its fingers, and control its own motion and force.

Dextrous Robot Hands

Dr. Kenneth Salisbury presented the following research to a group of industrial engineers at a meeting of the MIT Sea Grant Marine Industry Collegium in March 1985. The next Quarterly Report will focus on other MIT research in underwater telemanipulators discussed at the Collegium meeting. Contact Sea Grant for information about joining the Collegium.

Robots with physical and mental capabilities far exceeding those of their human creators are not at all strange to readers of science fiction. But in reality, robots have a long way to go before they can approach most aspects of human performance. A major obstacle to better performance—and wider application—has been poor dexterity. Robots simply don't have well-refined abilities to sense, grasp, and manipulate objects precisely.

Research at MIT's Artificial Intelligence Laboratory, however, is helping to pave the way for a new generation of more dextrous robots. Research scientist Ken Salisbury is developing a firm mathematical foundation for designing adaptive, dextrous mechanical hands that will be able to perform a wider range of useful tasks than existing robots do. To test his ideas, he has built a novel robot hand that can grasp a variety of objects, exhibit fine control of motion and force, and sense the orientation of its fingers.

Humans have no difficulty recognizing, grasping, and manipulating a wide variety of objects with different textures, shapes, sizes, and weights. However, most robots today have specialized grippers or tools designed for a single function, and they have little ability to recognize objects. Moreover, we have excellent sensors that give us information for making intelligent decisions about a grasped object. We can sense when not to squeeze too hard, as in lifting a delicate flower for example, or how to carry a cup of coffee securely without spilling its contents.

Robots do not have the complicated sensors and programs needed to make these types of decisions quickly and reliably. Accordingly, most industrial robots today are limited to such easy and repetitive tasks as spray painting, spot welding, and simple assembly. And they cannot adapt even to small changes in these tasks, such as part misalignments.

Dr. Salisbury's objective was to design a hand that could immobilize a grasped object with the finger joints locked while retaining the ability to make the object move, twist, or rotate slightly in arbitrary directions. The task was not a matter of duplicating the human hand, but a matter of how to meet a specific set of carefully chosen design requirements.

The MIT researcher has developed a method for analyzing hand designs mathematically. His analysis takes into account such variables as the number of fingers and joints, the type of contact between hand and object, and the interaction among fingers.

Starting from scratch, the geometric possibilities are enormous. For a simple hand with one to three fingers, one to three joints per finger, and up to five degrees of freedom at each contact with the grasped object, there are over 6.7 million possible configurations. Preliminary design decisions narrowed this down to a set of 600 designs for close analysis. These 600 designs were the ones with equal degrees of freedom at each contact point.

Further mathematical analysis showed that only 39 of these designs would be able to grasp and manipulate an object as desired. A detailed analysis of the force interactions of fingers and objects showed that only one of these designs would meet the full set of design requirements adequately. The design that passed has three fingers, each with three joints, and it contacts the object at the third link with three degrees of freedom.

Coming up with the geometry of the hand was only part of the problem. It was also necessary to apply the mathematical relationships between force and velocity to figure out how to control it. Implicit in Salisbury's application of these relationships is the concept of stiffness, which is crucial to controlling the interaction of the hand and the environment. When moving an unconstrained object, stiffness should be high to keep the grasped object under control as the arm goes through its motions. But as constraining forces increase, lower stiffness prevents excessive contact forces, which can lead to damage to the hand, the grasped object, or the environment. When inserting a shaft in a hole, for example, we typically hold the shaft loosely to allow it to "find" the proper orientation.

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Netmakers	____ very interesting	____ interesting	____ not interesting
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5. (Most issues of the Quarterly Report are limited to information about MIT Sea Grant research, education and advisory service activities.) If we were to broaden the content, what additional information would be interesting or useful to you?

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The forces to move the fingers and to control stiffness are transmitted through an intricate system of cables which act like tendons. To keep the weight and volume of the hand as low as possible, Salisbury decided to locate the motors that drive the cables in the forearm of the manipulator. Each three-jointed finger has four cables to control its motions, and is independent of the other fingers. A force error analysis determined the range where the hand works with maximum accuracy and helped establish the final dimensions of the fingers and their relative placement.

Accurate force control is central to the operation of such a hand. Salisbury has placed a strain gauge tension sensor on each cable at the point where it enters one of the fingers, making it possible to sense accurately the forces exerted at the finger tips. Optical encoders on the motor shafts provide position and velocity information needed for precise overall control of the hand.

The hand meets its goal: it can grasp and manipulate an object. While it is similar to a human hand in some respects, this hand can do some tasks that would be difficult for humans. For example, its joints flex equally well in both directions, allowing it to hold a ring as easily by pressing outward from the inside as by pressing inward from the outside. The hand can also act as a slave, duplicating prescribed motions.

Future designs will include a unique force sensor embedded in the fingertip. The novel sensor system will use measurements from eight pairs of strain gauges to determine the exact magnitude and position of forces applied to the fingertip. Another major research direction will be to develop the proper languages and control schemes needed to coordinate finger movement and to plan motions for useful tasks.

A dextrous robot hand has many potential applications in space, prosthetics, manufacturing, assembly, and for work underwater or in other hostile environments. However, much more research needs to be done in sensing, actuation, and artificial intelligence in order to significantly improve the overall performance of robots. Fundamental research such as that conducted for this project prepares the way for making better robots which may not replace humans, but will instead boost our productivity and augment our abilities to perform a wider variety of complex tasks quickly, efficiently, and safely. ■

Reprinted from
Industrial Liaison Program
MIT Report, March 1985

Netmakers Experiment with New Designs

In July 1984 seven independent U.S. trawl net manufacturers participated in a major program towards improving the productivity of the U.S. fishing industry. The companies helped sponsor and conduct the first systematic experiments in this country aimed at improving trawl nets.

Organized and cosponsored by MIT Sea Grant's Center for Fisheries Engineering Research, net designers and manufacturers tested 23 scale-model trawls at the Naval Ship Research and Development Center (NSRDC) in Bethesda, Maryland. Traditionally used for studying the hydrodynamics of ships, the naval facility has been set up by MIT Sea Grant for testing fishing gear (see Summer, 1982 *Quarterly Report).*

"The sessions gave participating netmakers a better understanding of the way various net designs perform in use

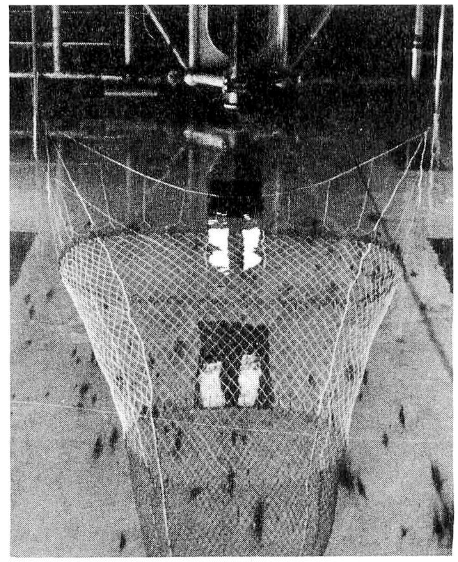

Figure 3. The circulating water channel allows this net to be observed as it would perform in actual use.

Bulbous Bow Can Improve Fuel Efficiency

Almost all large ships have a blunt bulbous projection on their bows under the waterline. This rounded shape reduces the power needed to drive the hull through water, and is more energy efficient than a knife-sharp bow.

Even though fishermen work hard to cut operating costs and boost efficiency, not many fishing boats can take advantage of this energy-saving bulbous bow. With design guidelines tailored to large merchant or naval ships, marine architects lack the technical data on which to refigure the bow of a small fishing boat.

Tests recently completed at the MIT ship model tow tank have taken an important step toward providing the missing information. Three fishing vessel models, representing a range of boat sizes and shapes trawling off New England, were retrofitted with 12 different bulbous bows each and observed over a range of towing speeds. Conducted by the Center for Fisheries Engineering Research, the experiment was sponsored by the MIT Sea Grant Program and the Canadian Department of Fisheries and Oceans. Much of the work was part of a Masters thesis by Ocean Engineering graduate student Angelos Heliotis.

Heliotis's tow tank results showed that the bulbs have a slightly detrimental effect on resistance at low speeds. But at the higher speeds that a boat would typically steam to and from a fishing grounds, the bulb designs showed clear advantages over the bare hull. Depending on the size of the boat, the reduction in resistance provided by the bulbous bow ranged from 10% to more than 25%.

In addition, Heliotis found that the best bulbs reduced the vessel motion at trawling speeds, suggesting that a bulb may allow boats to go fishing in worse sea conditions without the crew suffering as much seasickness.

At cruising speed the bulb reduces the wave-making resistance, which for some boats is the most important part of the total drag. The normal wave pattern produced by a hull shows a pronounced wave crest just behind the bow, formed by water pushed aside by the hull. This high bow wave, a veritable mountain of water, imposes water pressures on the hull which the propeller thrust must overcome. Although a bulbous shape also produces a wave pattern, proper selection of bulb size, depth and location can make the hull wave and the bow wave partially cancel each other.

For the fishing boat owner, the bulbous bow appears to offer real potential in reducing the hull resistance. However, the efficiency of a trawler depends on many factors including the propeller performance. Vessels with a fixed pitch propeller may not reap the full fuel savings benefit of a bulb retrofit. A trawler with a controllable pitch propeller will allow pitch adjustments to take advantage of the fuel savings or increased steaming speed.

The Center for Fisheries Engineering Research plans to continue this research by retrofitting and evaluating a bulbous bow on a full scale commercial vessel. Costs of such installations and the effects of the bulbs on maneuverability will be studied. Anyone interested in obtaining a detailed report on the model test results should contact the Center for Fisheries Engineering Research, MIT Sea Grant Program, Bldg. E38-376, Cambridge, MA 02139 and ask for publication 85-7. ■

and a better appreciation for the way design changes affect the performance of a trawl net," said Clifford Goudey, Sea Grant fisheries engineer and coordinator of the NSRDC experiments.

Throughout their long history of use among fishermen, trawl nets have evolved very slowly in this country. Partly due to the lack of a testing facility where underwater net performance can be evaluated, it has been difficult to suggest improvements. On the other hand, foreign countries such as the USSR, Japan, England, and Denmark have large and sophisticated testing facilities exclusively for fishing gear research. As a result, these countries have become the leading innovators of gear designs.

Access to the NSRDC facility, perhaps the most sophisticated of its kind in the world, is therefore a significant step forward for the U.S. fishing industry. Tests in NSRDC's circulating water channel, where trawl models are positioned in a uniform stream of water in the 22-foot-wide test section, are a vast improvement over at-sea tests, which are costly, time-consuming, and often unreliable due to environmental effects. Researchers at the circulating water channel can observe the net at close range through observation windows and make adjustments to the nets and rigging until the desired performance is achieved. They can compare varied designs easily, as the July test session demonstrated.

Comparing nine two-seam bottom trawls, eleven four-seam bottom trawls, and three midwater rope models in the circulating water channel, important design features were systematically altered. Such parameters as taper rate, relative size of top and bottom panels, and the height and length of the side panels were varied. Other parameters, however, were held constant on each model to allow proper comparison between the studied features. For example, the net circumference was always 388 meshes, and wing length and corner details remained the same.

Netmakers attending the tests watched for bottom-tending, or how closely the nets hugged the bottom as they were streamed in the water channel. Consistent bottom contact is important depending upon the species of fish targeted. The manufacturers also monitored the vertical opening of the net at the center and at the wing ends, and the way strain was distributed in different parts of the trawl.

They found that in all but one case, the net tended bottom more closely at higher speeds. "A lot of fishermen think they need more weight on the footrope at high speeds to ensure bottom contact," Goudey said, "but our tests indicated that heavier trawl doors are all that is necessary."

Also contrary to popular belief, under certain conditions the two-seam models produced more headrope height (the net's vertical opening) than four-seam designs.

Experimenting with the placement of floats, designers found a possible way to reduce wear and tear on the nets. By clustering floats at the center of the headrope, the floats provided nearly as much vertical opening as when they were distributed around the net, as is commonly the practice. However, clustering the floats would cause less damage to the netting when wrapped around the net reel during handling.

"The midwater rope trawl models were not based on any specific commercially available design," Goudey said, "since we were specifically studying netting resistance." The models were designed to have varied mouth openings while maintaining constant twine surface area. This is accomplished by varying the width, or hanging ratio, of the meshes. "We found minimum drag with a hanging ratio of approximately .4," Goudey reported, "compared with the commonly used ratio of .5."

Besides changes in the design for which net manufacturers are responsible, some changes that fishermen can make with rigging were tested. The spread of the net was varied, as well as the towing speed, which ranged from the equivalent of 2½ to 4 knots.

"The trends we found in the effect of design features should have a reasonably broad application for other designs of similar style," Goudey claims. "We've only begun the process of developing an understanding of trawl design from an engineering standpoint. There's a lot to do to catch up with foreign technology in this area." Another test series is planned for Summer, 1985 to study the effects of other design features. ■

Net manufacturers participating in the July, 1984 tests:

Coastal Net Company
Warren, Maine

Flagg's Trawler Supply
Portland, Maine

Jamestown Trawl Company
Jamestown, Rhode Island

Nor'Eastern Trawl Systems
Bainbridge Island, Washington

Shuman Trawl
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Madeleine Hall-Arber
MITSG 83-26 34pp No charge

In an effort to better fulfill the needs of the commercial fishing industry, MIT Sea Grant and the Massachusetts Maritime Academy (MMA) began a commercial fisheries training program in 1976. This survey documents the financial benefits of the program as estimated by the participants. The value of the training courses is summarized in the areas of employment, equipment (construction, use, and repair), and safety. Comments, criticisms, and suggestions from participants have been included, and there are also lists of workshops and courses offered to the fishermen. A note on the methodology of the survey is given by the author.

☐ **Biotechnology of Marine Polysaccharides**

E.R. Pariser
Anthony J. Sinskey
MITSG 84-15 59pp $40.00

Among the chemicals that have recently shown great promise in biotechnological processes are the polysaccharides. These are biopolymers that include cellulose, chitin, and a host of other compounds which represent the most abundant naturally renewable resource of organic chemicals. This book contains a collection of papers dealing with the occurrence, nature, function, production and use of marine polysaccharides. The papers were originally developed for presentation at the April 1984 MIT Sea Grant Lecture/Seminar on the Biotechnology of Marine Polysaccharides. Essays include the significance of polysaccharides in biofouling, drag reduction, enhanced oil recovery and pharmaceuticals.

☐ **Potential for Advanced Brayton-Cycle Engines for Commercial Vessels**

David Gordon Wilson
Theodosios P. Korakianitis
Center for Fisheries Engineering Research, Report 7
MITSG 84-15 14pp No charge

The authors propose an engine that is predicted to improve fuel consumption by 10 to 30 percent over the advanced Diesel engine at full and part power, while retaining its advantages of small size, reliability, and potentially lower cost. The engine uses highly effective ceramic heat exchangers, which enable the compressor pressure ratio to be reduced from the common 5-15 range to about 3. The result is an engine in which stresses and speeds can be so reduced as to allow the compressor to be made from a commercial reinforced plastic, while giving outstanding efficiency and range of operation.

☐ **Sewage Disposal and the Ocean: The Sea Grant Role**

Richard C. Kolf
MITSG 85-6 30pp $2.50

Disposing of sewage sludge in the ocean is emerging as a viable option among the scientific community. Rather than advocating or excluding any particular disposal alternative, however, this report recommends a flexible policy combining case-by-case decisionmaking with subsequent monitoring, research, and reevaluation. Although this approach is gaining popularity among scientists, policy change in that direction will be slow because general public opinion still condemns ocean disposal. Since public opposition to disposal projects causes serious delays during the permit process, social scientists should concentrate on conflict-avoidance and conflict resolution methods to help resolve sociopolitical opposition.

Journal Reprints

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K.T. Shum W.K. Melville
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An integral transform method is used to obtain continuous time series of wave amplitude and period from ocean wave measurements. The joint statistics of these two variables are determined and directly compared with the theoretical probability densities predicted by Longuet-Higgins (1975, 1983). Good agreement is found for data from both calm and hurricane sea states. This method avoids the ambiguities in the definitions of wave amplitude and period found in earlier comparisons of field data with theory.

☐ Deepwater Breaking Wave Forces on Surface Piercing Structures

E.S. Chan W.K. Melville
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