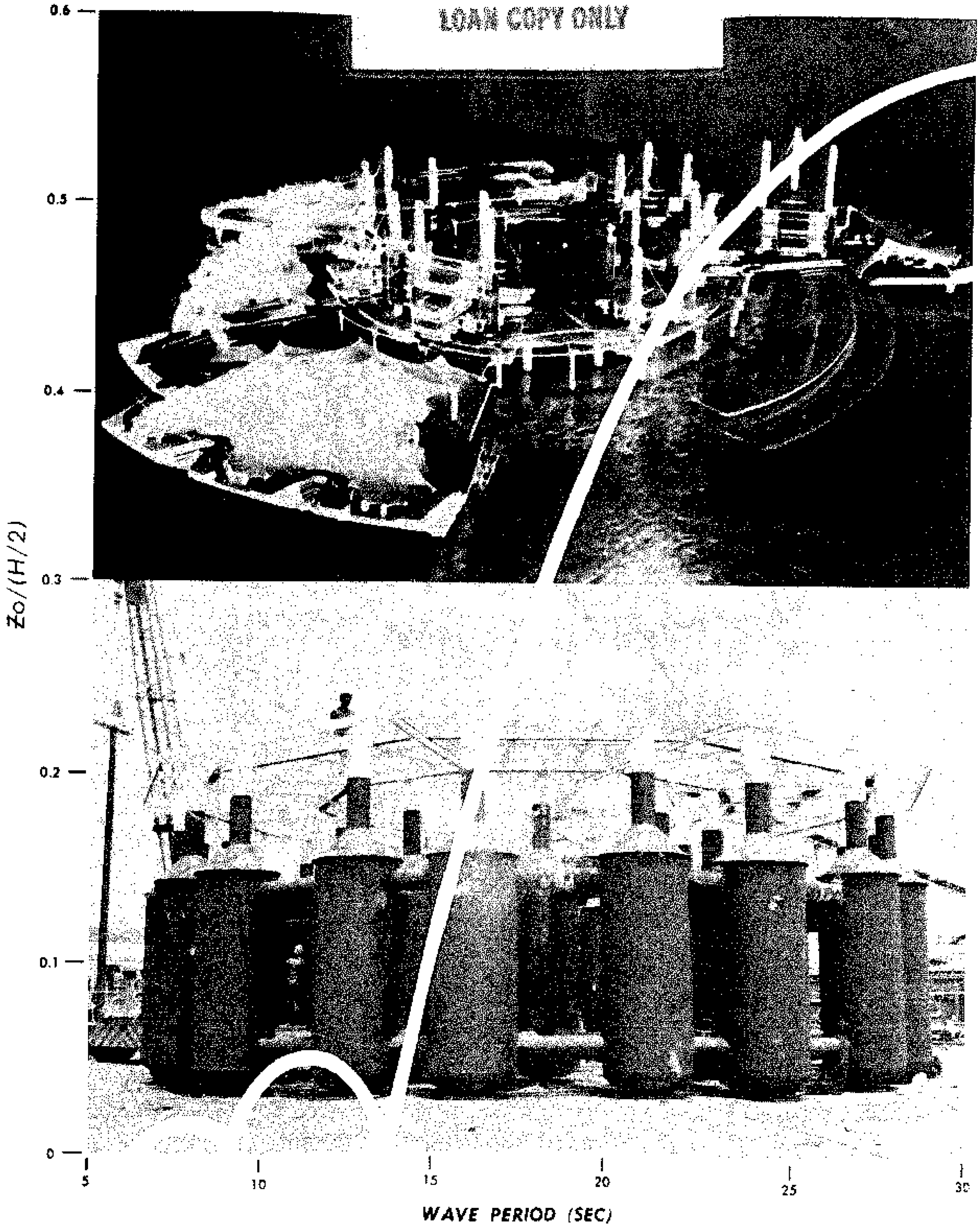
UNIHI-SEAGRANT-CR-76-01

HAWAII'S FLOATING CITY
DEVELOPMENT PROGRAM

TRANSPORTATION ASPECTS OF OFFSHORE COMPLEXES



HAWAII'S FLOATING CITY DEVELOPMENT PROGRAM

Transportation Aspects of Offshore Complexes

Technical Report No. 9

UNIHI-SEAGRANT-CR-76-01
Sea Grant College Program
University of Hawaii

September 1975

by

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PROGRAM MANAGER'S NOTE

This is the last of the "Hawaii Floating City Program" technical reports to be published. The original assumption that there could be a demonstration floating urban complex, to be employed as both an experiment and a public attraction for the National and Hawaiian bicentennial, has proven false. A revolutionary innovation such as the one we envisioned seems to be beyond the capacity of our nation's present socio-economic system--at least until needs greater than the ones perceived in 1974 become obvious. And so it was left to the industrialists of Japan to employ the fruits of our labors first in the design and construction of "Aquapolis", the miniature floating city which is to be the theme exhibit for the international ocean exposition to be held in Okinawa in 1975. For our part, we have turned our attentions to specific offshore industrial problems under the new program title "Seaward Extension of Urban Systems".

But by no means is this a sign that the concept is invalid nor that it is unrealistic to expect offshore urban industrial complexes of significant magnitude within the next decade or two. "Ekofisk City" in the North Sea already exists; while our work was pointing down the road, Phillips Petroleum took the first long step. And several recent events at the national level give encouragement that we as a nation are beginning to recognize that moving urban/industrial complexes offshore is inevitable to conserve our terrestrial environment and to expand the breadth and depth of our national resources.

This report, though it necessarily employed the exemplary Hawaii Floating City concept as its working assumptions, delves into questions of external and internal transportation systems in a way that makes its contents generally applicable to offshore platforms in unprotected waters. As such, I believe it provides the foundation on which specific transportation designs for specific offshore complexes can be erected.

Steven B. Ribakoff accomplished a large share of the early research and Jeanne M. Collier completed the research and the report. So here is the beginning; it will be interesting to look back on it in 1985.

Joe A. Hanson
Oceanic Foundation

ABSTRACT

Conceptualization of an internal and external transportation system for a "Floating City" presents many exciting opportunities for designing movement patterns and modes that can truly serve a city's inhabitants and contribute to the quality of their lives. Preplanning and purposeful modular growth offer the possibility of avoiding altogether the congestion, noise, dirt, and frustrating impaction that characterize transportation pseudo-systems which have mushroomed willy-nilly in many urban/suburban areas on land.

The outstanding opportunity in the internal component of transportation for a floating city lies in its finite limits, minimal distances across which people and goods need be transported, and its three-dimensional structure. These eliminate need for space-hungry massive vehicular traffic, with its attendant pollutions, and facilitate free, quick, and easy access to all parts of the city.

In the external component, the principal problems to be solved are: 1) the matter of safe, efficient movement of people and goods across the interface point between the platform and its environment, and 2) the capacity to provide comfortable, safe, and rapid transit for commuters that can handle peak flows. The latter problem appears to be the stickiest to solve within the cost limitations of economic feasibility; movement of goods is relatively simple.

The more complex the set of activities on a floating platform, and the larger the population, the greater the design problems for a transportation system. Here we have tackled the most complex situation--a Floating City--with the awareness that design principles developed here are equally applicable to smaller, simpler installations where they may be developed initially and proved, with greater ease and smaller investments.

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I. INTRODUCTION

This report, produced under Hawaii's Floating City Project, is one of a series setting forth the results of investigations into the various engineering, architectural, construction, and systems design aspects associated with development of an urban center aboard a very large, deep-sea floating platform. The investigations began with the formal inception of the project in 1970, under a grant by the State of Hawaii to the Department of Architecture, University of Hawaii. This following work is sponsored by NOAA, Office of Sea Grant, U.S. Department of Commerce.

The urban center itself, or "Floating City", together with the stable, buoyant platform on which it is based, are conceptualized throughout the project as a total system design. (1) The individual subsystems that function to maintain the platform, sustain the community, and support cohabiting commercial and industrial enterprises are treated as integral elements of the whole. One such element, the transportation system, is the subject of this study.

For this report, the internal and external platform design and environmental characteristics germaine to transportation design, which have been developed in preceding investigations, first are reviewed briefly to set the context. Earlier reports covering those aspects are cross-referenced for the reader's convenience. Then projected requirements for external and internal transportation of people and goods are characterized and in a very broad sense estimated.

Opportunities and problems associated with the unique environment in which the internal and external components will operate are the major concern of this study. Design objectives include optimum integration of the system elements, and achievement of maximum aesthetic and environmental enhancement.

The Floating City Project is aimed at introducing a concept in total urban system planning that will offer practical benefit and possess relevance to the solution of real urban problems. Like the investigations into other aspects of the system, this study is approached from the position of assessing the practicability and economic feasibility of potential transportation system components. In the absence of experience with a similar community, and without firm planning data as yet on population size and characteristics as well as on activities, facilities, and enterprises to be included--each with their peculiar needs that go to make up the total transportation requirements--actual cost projections and comparisons would not be realistic. It is possible, nevertheless, to project classes of cargo flow (if not actual volumes) and types of people movement, and look at what transportation modes are proving to be practical in existing situations as a base for comparison. Where current technology can be applied to the Floating City, development costs can be minimized. So the consideration of compatibility with existing transportation modes operating on land and sea is taken into account, here, as well as the desirability of utilizing these to the optimum extent to meet platform needs.

A. Study Objectives

To summarize the approach to this investigation of transportation concepts appropriate to a floating platform environment, and ultimately to the transportation system design, the objectives are defined as:

1. To determine if a very large stable platform of the type under consideration can be interfaced effectively and economically with external logistics networks.

2. To explore the opportunities for innovative system design presented by the platform configuration and environment.

3. To explore opportunities for intra and intersystem integration.

4. To emphasize simplicity and economy, as well as efficiency, in proposing development of innovative technology where this may prove to be a desirable course.

It is recognized that actual design of a transportation system, when it becomes feasible, would incorporate many more specific objectives. A few of these can be pointed out here primarily in the form of recommended design principles, to include the following aims:

1. To minimize undesirable system impact upon the platform environment and aesthetics.

2. To reduce to a minimum the space requirements for people and cargo movement, and for cargo storage.

3. To achieve maximum simplicity, speed, and flexibility in transport flow paths.

4. To minimize cargo handling and eliminate unnecessary movement.

5. To utilize existing carriers, systems, and on/off loading technology wherever these can minimize costs without sacrificing efficiency.

6. To provide system back-up for unusual or crisis conditions.

B. Report Organization

This discussion of the investigation findings begins with a statement in Section II of the basic assumptions and study limitations followed by a discussion of the problem from a systems approach. A comparative example of current cargo flow to the island of Kauai (Hawaii) is offered in this section to set the problem in perspective. Section III contains a brief review of those physical and operational characteristics unique to a large floating platform that are germane to the transportation system design. Internal and external environments are described briefly, as well as population, sustaining systems, and special considerations. Other reports produced under this project that treat the subject matter in detail are cross-referenced for the reader's convenience. In Sections IV and V, external and internal transport modes, respectively, are explored with a view toward their potential value to a platform system. In each section those modes currently in common use are surveyed first, followed by technology still under development or in the conceptual stage. A summary of the study findings, together with a short discussion of the areas where further research and/or development is required, follows in Section VI.

II. PROBLEM STATEMENT

A. Assumptions

Obviously this entire project deals with design concepts of a prototypal offshore installation of greater size and complexity than any system currently operating at sea. Therefore, in considering transportation requirements and opportunities it has been necessary to proceed on the basis of a set of assumptions extrapolated from existing on-land communities, offshore industry, real and planned, and the physical characteristics of the platform itself.

1. Mission

For the purpose of this investigation, system requirements have been predicated on the basis of a floating urban complex. There is no intent to imply that the transportation concepts developed here are restricted to serving only that purpose. It is fully recognized that large stable floating platforms may be suitable for many purposes, including manufacturing, power production, marine mining and/or mineral refining, oil refineries, waste recycling plants, and any other functions for which an offshore location may in the future prove more desirable or practical than a land base. However, the design configurations and dimensions developed under this project (2) and used as a working base here were influenced by the motion constraints inherent in assuring that the platform would provide a comfortable, attractive environment for a resident and visitor population. Platforms designed primarily to support other functions, with less emphasis on comfort and motion imperceptibility, might differ considerably in shape, draft, dimensions (including vertical distance from deck to waterline), as well as deck surface use and superstructure design. It may be expected that these differences in use and configuration would affect design requirements for the transportation components--and might in some cases even permit more options. Nevertheless, it is not anticipated that such variance will in any substantial degree invalidate the findings in this report, since basic cargo handling equipment and techniques feasible for this design would be adaptable to the requirements of other missions.

2. Population Size

As a design base for the structure (1), the resident population of the floating urban center was projected at 15,000, and that figure is assumed in this investigation. Since the Floating City is envisaged as a visitor and convention facility as well, provision was made for accommodating a minimum of 2,000 overnight guests and 7,500 diurnal visitors. These figures will not be used as an actual planning base, as yet, but they may assist in conceptualizing size. It should be noted, further, that they relate to the base size of the platform, consisting of the core ring. Addition of concentric rings of modules could increase these projections significantly.

3. Location

Since its inception, the project has envisioned the Floating City as located approximately five miles off the leeward shore of Oahu--offshore of Honolulu to be more precise. This puts it in the vicinity of a major seaport and airport and in proximity to existing urban and industrial areas. However, although Hawaii was employed as an exemplary environment for the purposes of the analysis, there was no intent to imply restriction to this area. It has been felt that the research and development done under this project would be broadly applicable to most sites which might someday move urban activities seaward on large stable floating platforms.

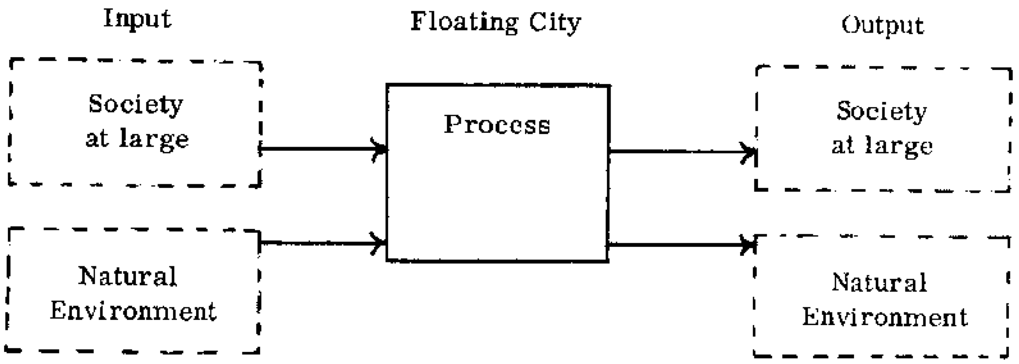
For this investigation, the assumed location has proved to be a convenience since data on cargo flow, by type and volume, has been more accessible here than at a distant port. Moreover the port of Honolulu serves as a transshipment point for cargo flowing between the neighboring islands and mainland or foreign ports. This provides a convenient analogy to the platform--or man-made island--offshore. Although the prior existence of a transshipment system on Oahu may, at first glance, appear atypical of other potential sites, it may not be. It seems illogical that the cost of constructing offshore sites would be justified where space, population, and environmental pressures do not exist. Urban/industrial complexes grow where transportation and trade routes intersect, and in coastal areas this generally means around major ports, as well as air and overland shipping arteries. And any offshore facility must, itself, be located in the vicinity of transportation and shipping routes, as well as near centers of population and economic activity, if it is to be economically viable. Therefore it is anticipated that the findings reported here will be relevant to other sites, and the discussion of external transportation modes purposely has been kept general in nature, for the most part.

B. Study Limitations

The findings in this report are largely qualitative in nature, with parametric designs and evaluations offered where information is available to support them. Without a definition as yet of specific functions for the first floating platform--with associated activities and population characteristics--type and volume of transport requirements can be estimated on only a very gross basis. So transportation modes cannot be evaluated against quantitative criteria, and any cost/benefit evaluations must be rough, at best. Similarly, multi-modal system design can be developed only to the point of exploring potentialities.

C. System Concept

In its broadest sense, a floating city may be viewed as a link, or subsystem, of a larger system--the latter being the environment in which the urban marine community exists. And in this sense, the subsystem can be viewed as an input/process/output link. Thus, in its grossest form:



The floating city as a process is a composite of the activities housed in the on-board facilities. Some of the possible facilities include:

Residential complex
Resort hotel(s)
Restaurants
Convention complex
Cluster of corporation headquarters for large companies
University of Hawaii branch for marine sciences
Medical center
Theaters and auditorium
Power production - conservative energy sources and waste conversion
Sports and recreation
Fish farming (open sea mariculture)

Manufacturing enterprises
Pharmaceutical laboratories, utilizing seaweed and marine organisms
Sea mining and mineral processing, and ocean sand recovery
Open port -- free trade zone

These examples are representative only--actually a platform may house any combination of these or other appropriate facilities. It will of necessity also house the basic facilities for support functions such as power production, water desalinization, transportation, solid and liquid waste disposal, etc. Construction and maintenance activities are included in the overall "process".

The input to the floating city process consists of incoming people--visitors, employees and residents returning from shore--and the total incoming cargo of supplies and materials. Some representative categories of goods are:

Fuel, lubricants, petroleum products
Chemicals--for waste treatment, water desalinization, manufacturing, etc.
Cleaning and maintenance supplies--solvents, equipment, etc.
Machinery and parts
Food products--fresh, frozen, canned, packaged
Household and office furnishings
Construction materials--concrete, steel pipe, fixtures
Clothing and sundries for retail commerce
Medical and drug supplies
Tourist goods, books, newspapers, films
Sports and recreation equipment
Paper goods
Paint and finishing materials
Raw materials for industry and manufacturing

In view of the residential and visitor activities it may be expected that demand for consumer goods, added to needs for construction and maintenance materials, will tip the scales rather heavily toward the in-flow volume. In this, the platform will be analogous to the state as a whole, a major source of income for both being derived from services and the visitor industry.

However the platform is not a bottomless sink by any means. There will be a balancing outflow of people, of course, including homeward bound visitors plus residents going ashore for work, shopping, recreation, visits to friends and travel. People flow may be envisioned as the pattern in Figure 1. Waste products--solid and liquid--will be among the output (where these cannot be

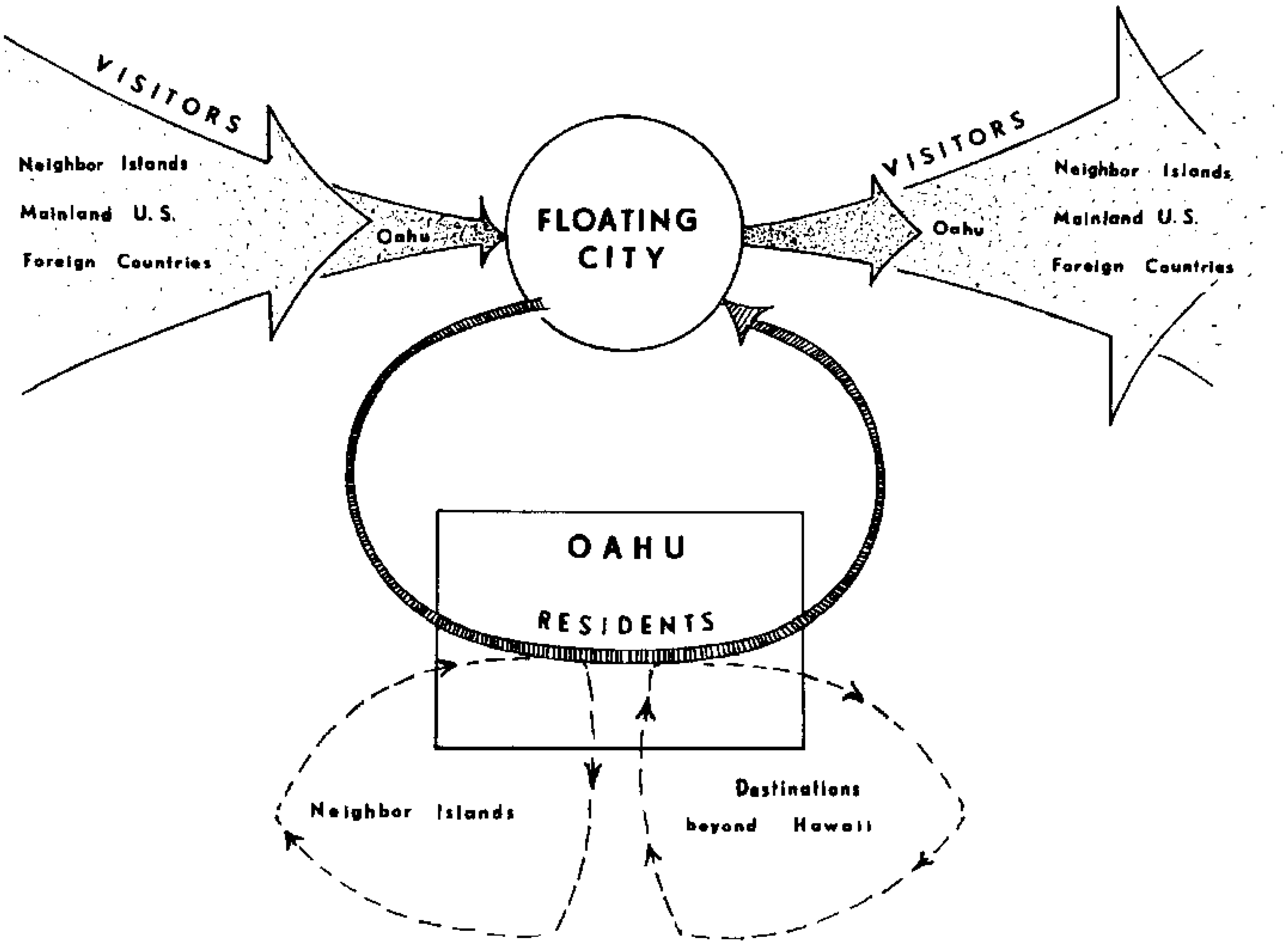


Figure 1 — External traffic flow pattern: residents and visitors.

processed and recycled, or disposed of in the ocean) as well as manufactured goods and products harvested from the ocean. Shipping containers of all types and sizes must be returned to shore for re-use. In the case of platforms employed for mariculture, hydrogen production, waste reclamation, and/or primary industry, to enumerate a few of the prospects, a wide variety of liquids and solids may be shipped out.

The transportation system of the floating city will provide for the flow of people and goods within the platform environment and between the platform and its external environment. In this sense, it is its circulation system and its life line. The marine community is relatively small, and far from self-sufficient . . . it may be more properly regarded as a suburb of the Honolulu metropolitan area, rather than an entity to itself. Located only 5 miles offshore of Honolulu, it will be actually nearer to this commercial and industrial center of Oahu than are many other suburban areas, such as Kahala and Hawaii Kai, not to mention the surrounding bedroom communities of Kailua, Kaneohe, Waimanalo, Aiea, and the others at even greater distances on the leeward and windward coasts. Although these suburbs and outlying towns possess shopping centers in abundance, much of the population makes frequent trips to downtown Honolulu to shop in the central stores, obtain special services, and conduct business. With the marine mass transit system for Oahu now in the planning stages, the platform could be incorporated into the routing pattern as a regular stop-off point for marine commuter traffic.

Bulky consumer goods such as furniture, the larger appliances, household furnishings, and other customary inventory of department stores and specialty shops need not be stocked in inventory on the platform then. Shopping in Honolulu for these categories of goods would be quite convenient, and timely deliveries could be routed from central warehousing facilities in existing commercial districts, or on Sand Island or Campbell Industrial Park, as is currently done for destinations ashore. Smaller items, e.g., drugs, sundries, perishables and staple foods, toys, reasonable selections of clothing, and so on, that normally are purchased on a carry-out basis could be inventoried by shops aboard the platform.

Overall, the bulk of cargo incoming to the floating city would be routed through Honolulu for transshipment, with or without intermediate warehousing. Exceptions would comprise principally high-volume shipments by barge of construction materials, possibly fuel, and especially bulky or heavy goods. The economics of cargo handling currently dictate this pattern of flow for the Neighbor Islands (3); the reasons for applying it to the offshore community will become clear in the discussion of external transport modes. Figure 2

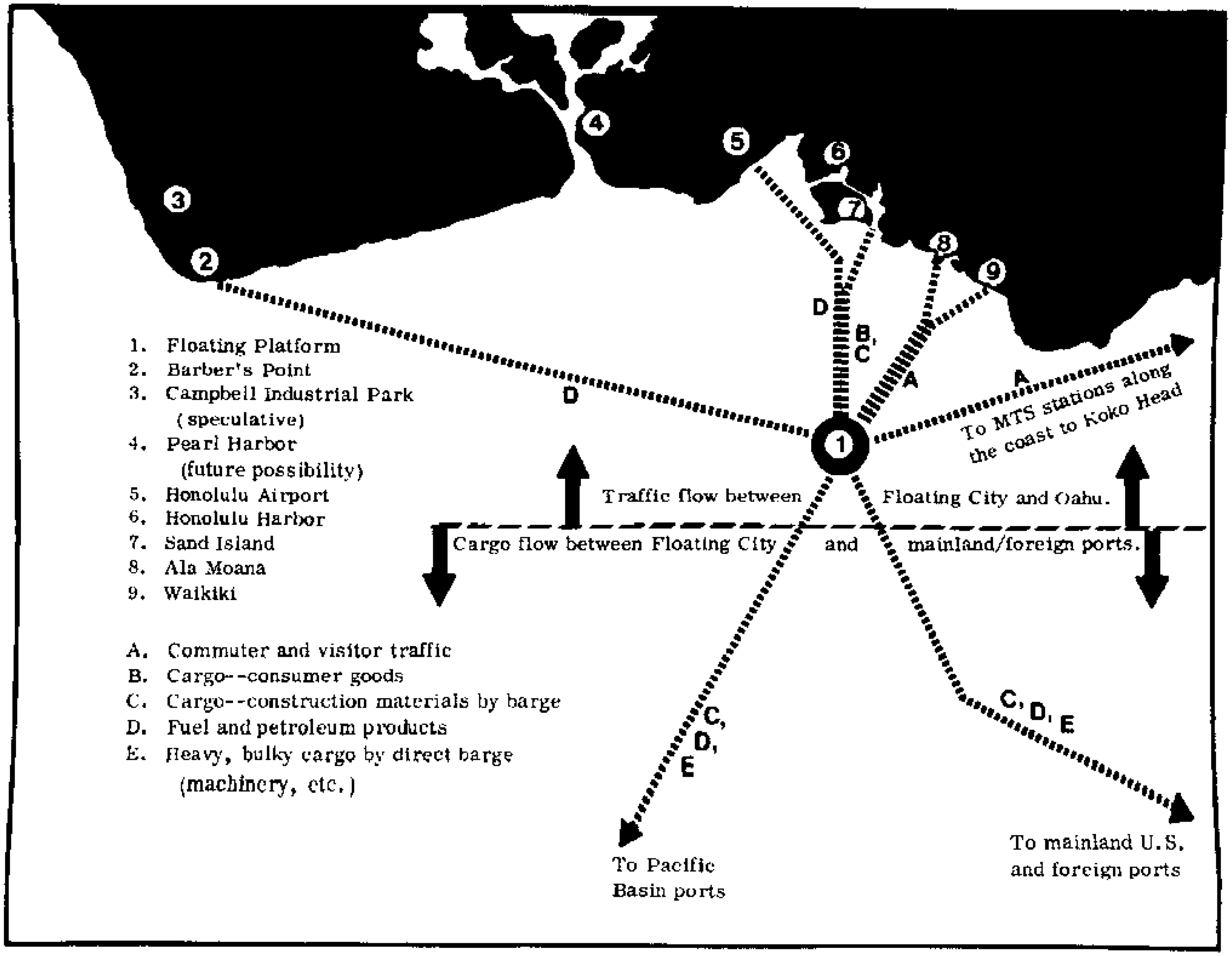


Figure 2 -- External cargo and passenger routes.

graphically illustrates the concept of the floating city as a suburb of Honolulu, and indicates, in general, the patterns of transportation flow.

D. Comparative Model

We have endeavored to put a transportation system for the floating city, and to some extent a corollary inventory management subsystem as well, into perspective by viewing the platform as a suburb of Honolulu insofar as the commuting, business, shopping and recreation patterns of its resident population are concerned. At the same time we acknowledge that in the absence of land transport links, the marine community will be analogous to Oahu's neighbor islands in its dependence upon transshipment of cargo at the port of Honolulu. On- and off-loading of large ocean-going cargo ships that cannot now be accommodated in the smaller island ports would be quite impractical at the platform, so barges and other intermediate size carriers must link the Honolulu docks and warehouses with the ultimate cargo destination.

To visualize in practical terms the potential transshipment flow, it may be useful at this point to look at the flow to one of the neighbor islands for a comparative model, as is done in Table 1. To do this we have arbitrarily selected the island of Kauai, which supports a population of around 30,000. Being roughly double the floating city population, this is a convenient comparison. Unfortunately, none of the neighbor islands resembles the platform community in economic or demographic characteristics: as in the case of Kauai, the population is predominantly rural, the economy is based on agriculture, and per capita income is low to moderate. Although tourism makes its impact on consumption, the resident population tends to generate relatively moderate and unsophisticated demand for consumer goods, and much of its fresh foodstuffs are locally produced. By contrast, the floating city will contain a high-density, sophisticated and relatively high-income urban population, with a correspondingly high demand for goods and services, and with nearly complete dependence upon imports for food and other consumer products. So it is with the caution that it be viewed only as an existing flow of goods through the current cargo transportation system, that this model is set out. To regard it as representative and be tempted to assume that a similar flow of approximately half the volume would serve the platform would be a trap. It is of value primarily as an example of the transport modes being used to move break-bulk cargo from Honolulu to the small ports.

The data developed in Table 1 was obtained from the individual carriers in the case of dry cargo, and--with one exception, as noted--from the suppliers of fluid cargo. The several carriers and shippers contacted do not

Table 1 -- Cargo flow from Honolulu to Kauai--monthly averages

Cargo	Unit	Volume	Carrier	Type of Ship	Loading Point
<u>Solid</u>		Tons (2,240 lbs.)			
General cargo: materials and consumer goods (large percentage is building materials)	24' containers	6,940	Matson	Inter-island cargo ships; 3 sizes	Honolulu
General cargo: consumer goods, appliances, construction materials, lubricants	Primarily pallets; also containers; 7 sizes (customer-supplied); some bulk	12,547	Young Brothers	Barge	Honolulu
General cargo	Mostly loose; also pallets with nets	657	Hawaiian Air Cargo	Cargo hold of passenger planes	Honolulu Airport
General cargo	Forwarded freight; primarily packaged freight	61.7	Aloha Air Cargo	Cargo hold of passenger planes	Honolulu Airport
General cargo	Forwarded freight; primarily packaged freight	9	Horizon Air Service	Small plane	Honolulu Airport
General cargo	Forwarded freight; primarily packaged freight	5.4	Island Air Transfer	Small plane	Honolulu Airport
		20,220.0			

Table 1 -- (cont.)

Cargo	Unit	Volume	Carrier	Type of Ship	Loading Point
<u>Liquid</u>		Thousands of gallons			
Diesel oil (Standard)	Bulk	840.0	Hawaiian Tug & Barge	Barge	Pier 30 - Iwilei (Honolulu port)
Diesel oil (Union)[a]	Bulk	196.2	Union Oil	Ocean-going tanker	Mainland or foreign ports
Diesel oil (Shell)[b]	Bulk	19.0	Shell Oil	Ocean-going tanker	Mainland or foreign ports (prior off-load at Honolulu)
Black (bunker C) oil (Standard Oil)	Bulk	591.5[c]	Matson	Tanker holds of cargo ships from west coast	West coast (prior off-load at Honolulu)
Gasoline - automotive and small aircraft (Standard Oil)	Bulk	504.0[d]	Hawaiian Tug & Barge	Barge	Pier 30 - Iwilei (Honolulu port)
Gasoline - automotive and domestic jet A (Shell Oil)	Bulk	21.0	Shell Oil	Ocean-going tanker	Mainland or foreign ports (prior off-load at Honolulu)

(continued on next page)

Table 1 -- (cont.)

Cargo	Unit	Volume	Carrier	Type of Ship	Loading Point
Liquid -- cont.		Thousands of gallons			
Gasoline - automobile fuel (Union Oil)	Bulk	1,542.0	Union Oil	Ocean-going tanker	Mainland or foreign ports (prior off-load at Honolulu)
Lubricating oils (Union Oil)	Bulk	34.2	Young Brothers	Barge	Pier 21 - Iwilei (to Nawiliwili)
Solvents (Union Oil)	Bulk	4.8	Young Brothers	Barge	Pier 21 - Iwilei (to Nawiliwili)
		3,752.7			

Notes: (Source, ref. 4 through 13)

a. Deliveries every 3 months.

b. Delivered at 8-week intervals.

c. Irregular deliveries. This data from Standard Oil based on total 1973 deliveries, averaged monthly. Includes 2 atypical emergency deliveries by barge and the Hawaiian Princess. Matson provided data showing power company consumption at 546,000 gal./mo. and sugar mills at 45,000 gal./mo.

d. Includes some kerosene, solvents, weed killer, and insecticide; not itemized (insignificant).

ordinarily keep monthly records, per se, but they were exceedingly helpful in deriving average volumes, with the advantage that monthly flow is quite consistant, by and large, with relatively slight seasonal fluctuation. Any cargo movement that may not be accounted for in this model, by these or other carriers, is not of significant substance.

All of the dry cargo going to this neighbor island either originates in Hawaii or is transshipped through the port of Honolulu. Since the dead time cost of stopping a large ocean-going cargo ship is in the magnitude of $1,000-$1,500 per hour exclusive of port and crew costs the Matson Company, a major shipper, advises that it is out of the question to attempt offloading of partial cargoes at small ports. (3) They have in fact totally mechanized their containerized cargo on- and off-loading procedures at the Honolulu port (retaining human control in the person of the crane operator). This, together with the time saved by the container system in toto, holds costs to the minimum.

A simple reduction of the model data reveals that three modes of dry cargo transport are used, with volume percentages running 34 percent by inter-island container vessel, 62 percent by barge, and 4 percent by air. (There is one inter-island container vessel, the Hawaiian Princess, operated by the Matson Company, which is the company responsible for initiating containerization in Hawaii in 1958 and which now maintains a fleet of ocean-going container ships.) The remaining volume is break-bulk, originating in Hawaii or brought into Honolulu by a variety of overseas cargo lines. It might also be noted in passing that containerized cargo (34 percent) could physically be moved by barge, all other factors being equal. However, the barges now used might not be suitable for interface with the floating platform since they are not on/off loaded through deck hatches. Instead, the stern opens up and the cargo is moved by forklift. Such barges may also have roll-on/roll-off hold decking. Unless the barges can be lifted aboard the platform, other configurations may be required. (9)

Air freight is carried in the cargo holds of inter-island passenger planes by the two principal carriers, Hawaiian Airlines and Aloha Airlines, while small carriers deliver air parcel post type minor shipments using twin-engine Beechcraft. Hawaiian Airlines, the major carrier, currently uses two DC-9 aircraft that are convertible to all-cargo use. Each of these carries 8 pallets, sized 88 inches by 108 inches and palletization is employed wherever practical, although some loose cargo is also carried. The planes have roll-on/roll-off decks and the passenger seats are mounted on pallets which are rolled off for daily cargo-only flights. About 35 percent of the volume carried by Hawaiian Airlines is perishable foods and 18 percent is newspapers, both requiring timely delivery. The remainder comprises a broad spectrum from light machinery to wearing apparel to drugs, furniture, or anything that does not exceed the bulk and weight limitations. (5)

In the case of fluid cargo it may be seen that three modes of transport currently are used here too. Here the mode is determined both by category and by the supplier. Of the overall total (all types of petroleum products) 37 percent is moved by barge, and the remainder is off-loaded from ocean-going tankers and cargo ship hold tanks. (In the latter case, the tanks are then cleaned and loaded with molasses--the outgoing cargo.) The bulk of the 37 percent consists of Standard Oil gasoline and diesel oil originating at their refinery at Campbell Industrial Park, near Honolulu. These are piped to Pearl Harbor, and moved thence by barge to the storage tanks at their Pier 30 in Iwilei (a section of Honolulu Harbor). (11) It might be well to note here that the ratio of fuel shipped by tanker may be subject to change in the future. Union Oil is looking at the advantages of shipping from the West Coast by barges such as the new 1,100,000-gallon capacity barge being put into service by Sause Bros. Company between the West Coast and the Philippines. A prime reason for this prospective switchover is the high cost of the tanker discharge stop at smaller ports where a relatively low volume of fuel is off-loaded. At Nawiliwili, Kauai, for instance, their average discharge time is 6 hours--at a cost running to $15,000. Since this small port can only be used by the large vessels during daylight hours and the tankers first offload at Honolulu, it often means additional costly delay in the Oahu port before moving on to Kauai. (10) Barges offer a saving, here--a point that will be further explored in terms of the floating platform operating constraints.

E. Other At-Sea Supply Situations

The notion of delivering cargo to vessels or platforms located in the open ocean is hardly a novel one: it has been accomplished as a regular operation for quite a few years. As far as the United States is concerned, its naval forces were the first to develop the techniques for replenishing a ship's stores while underway. The advantage is two-fold: first, it enables a ship to remain on-station, eliminating non-productive time and fuel expenditures required to make trips to port; and second, a ship underway presents a more elusive target to an enemy than a vessel approaching or, especially, anchored at a port. More recently the major oil companies, in moving their drilling rigs and storage facilities to sea, have been coping with the necessity of delivering cargo to them. A shore-based service industry offering to supply food, water, and equipment to offshore rigs is growing in response to this need. Development of offshore refineries can be expected to increase requirements for supply. Without going into either of these categories of operation in any detail, it might be well to at least glance at a few of the aspects that are pertinent to the floating city.

1. Naval Supply

The United States Navy has been moving toward the elimination of in-port resupply stops for its ships to a major extent. In the past, delivery of bunker oil, aviation gas, and other petroleum products by flexible hose between oilers and ships underway has been a common and well-developed operation. Supply ships also have replenished ships' food supplies and general stores, spanning the water gap between them by suspended cables and pulleys that have coped with the problem of differential motion of the two vessels adequately enough to deal with small loads.

Currently the Navy has stepped up the practice to the degree that 80 percent of Navy material required to supply its ships is delivered to them at sea. To accomplish this the Navy generally is relying on helicopters to transfer all non-fuel supplies from ship to ship. The cargo is unitized on pallets and in nets for quick snatch and release. The supply ships carry the helicopters, with no landing pad required on the deck of the "customer" ships . . . indeed, on many of the smaller ships such as the destroyer escorts, no landing is possible. No cost figures are available at this time for the air operation; but in this application the Navy's position is that the speed and safety of the operation outweighs any other consideration. (14) Among other advantages of speed, it is possible to minimize the hazard of running two ships in close proximity to each other.

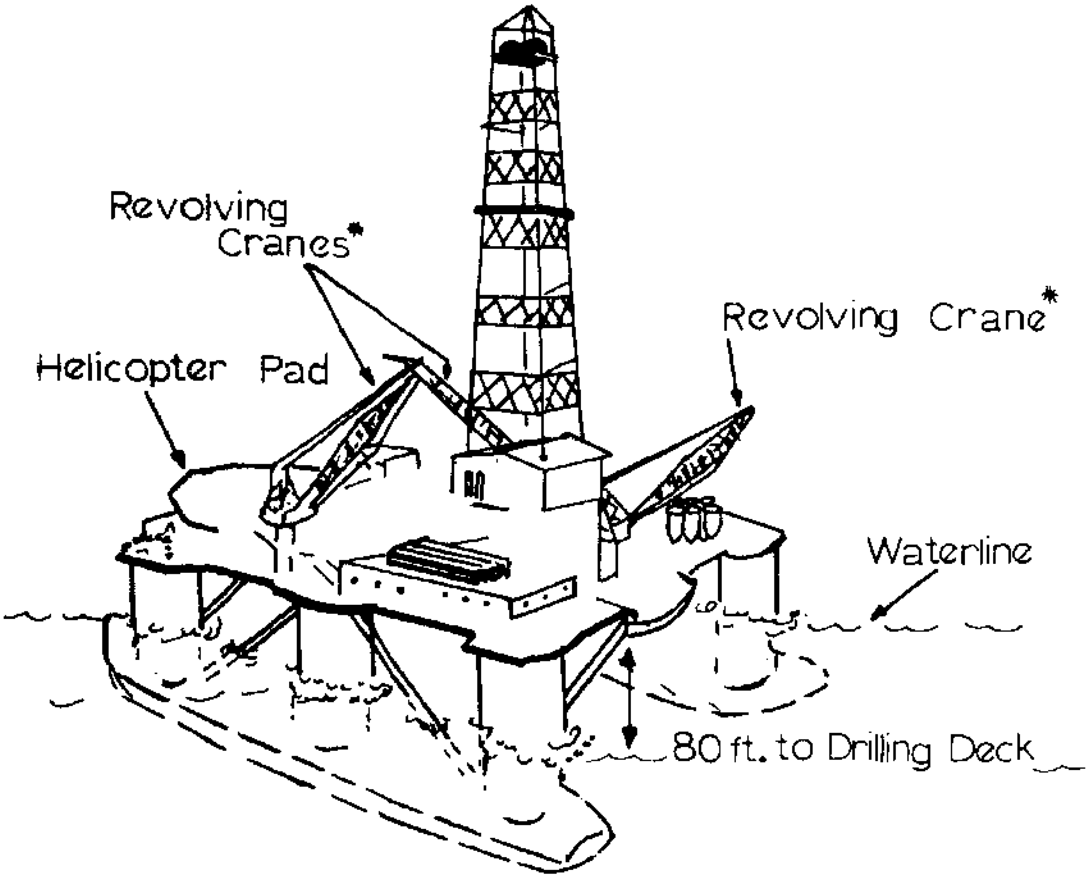
The helicopter used by the Navy for cargo transfer is the H-46 (originally a Marine aircraft) with two large horizontal rotors: placed fore and aft, these give the craft more stability than helicopter designs with a small vertical rear rotor. Rotor diameter is 60 feet, and the optimum load is 4,000 pounds. Under ideal conditions, however, with ships about 100 yards apart, the craft can carry up to 6,000 to 7,000 pounds. In traversing a distance of 5 miles, as for the floating platform, maximum load would be about 5,000 pounds. Preferred operating condition covers winds up to 25 knots, but it takes wind over 45 knots to discontinue operations entirely. The technique is worth exploring for application to the floating platform, as discussed further in Section III.

2. Offshore Oil Platforms

With their location fixed, once they are on station, offshore drilling rigs and storage facility platforms are dependent upon supply at sea. For this purpose helicopters, again, are used for cargo transfer though perhaps to a lesser extent than by the Navy. Characteristically the oil rigs--whether of the jack-up, semi-submersible, or other design--are very much smaller in deck area and overall dimensions than the floating city platform. And, if buoyant, they have a shallower draft. Yet the deck often clears the water line by a vertical distance equal to or exceeding the 50-foot clearance of the floating platform (or the 90-foot span to the top surface of the platform deck). Typically, large rigs of the Zapata semi-submersible SS-2000 class (overall dimensions 260 feet long by 200 feet wide) and the Ocean Scout (202 feet long by 182 feet wide) have two or three revolving cranes mounted on deck, as in Figure 3. (15) Equipped with motion compensators, the cranes can handle loads comparable to large dock-mounted cargo cranes. (3)

Open-ocean oil platforms, located in such diverse areas as offshore of the east and west coasts of the United States and the Gulf of Mexico as well as in the North Sea and other waters world-wide, frequently encounter marine environments harsher than the leeward Oahu site for the floating city. This factor places definite limitations on the time periods when resupply is feasible for them. For example, the Chevron Oil Company currently is engaged in research and development on offshore platforms in Alaska. Their field research office states that supply by cargo ship or barge currently is possible with waves running up to a 6-foot maximum, and the cut-off limit for helicopter operations is a wind velocity of 25 knots. (16) Potential limitations in the context of the floating city operations are discussed in Section III.

With this brief glance at typical at-sea supply systems currently in operation, we now proceed to examine the characteristics of the stable floating platform for which we would conceptualize a total transportation system.



Variable deck load capacity = 2,000 tons

*with motion compensators

Figure 3 -- General configuration of cranes and helicopter pad on Zapata SS-2000 class.

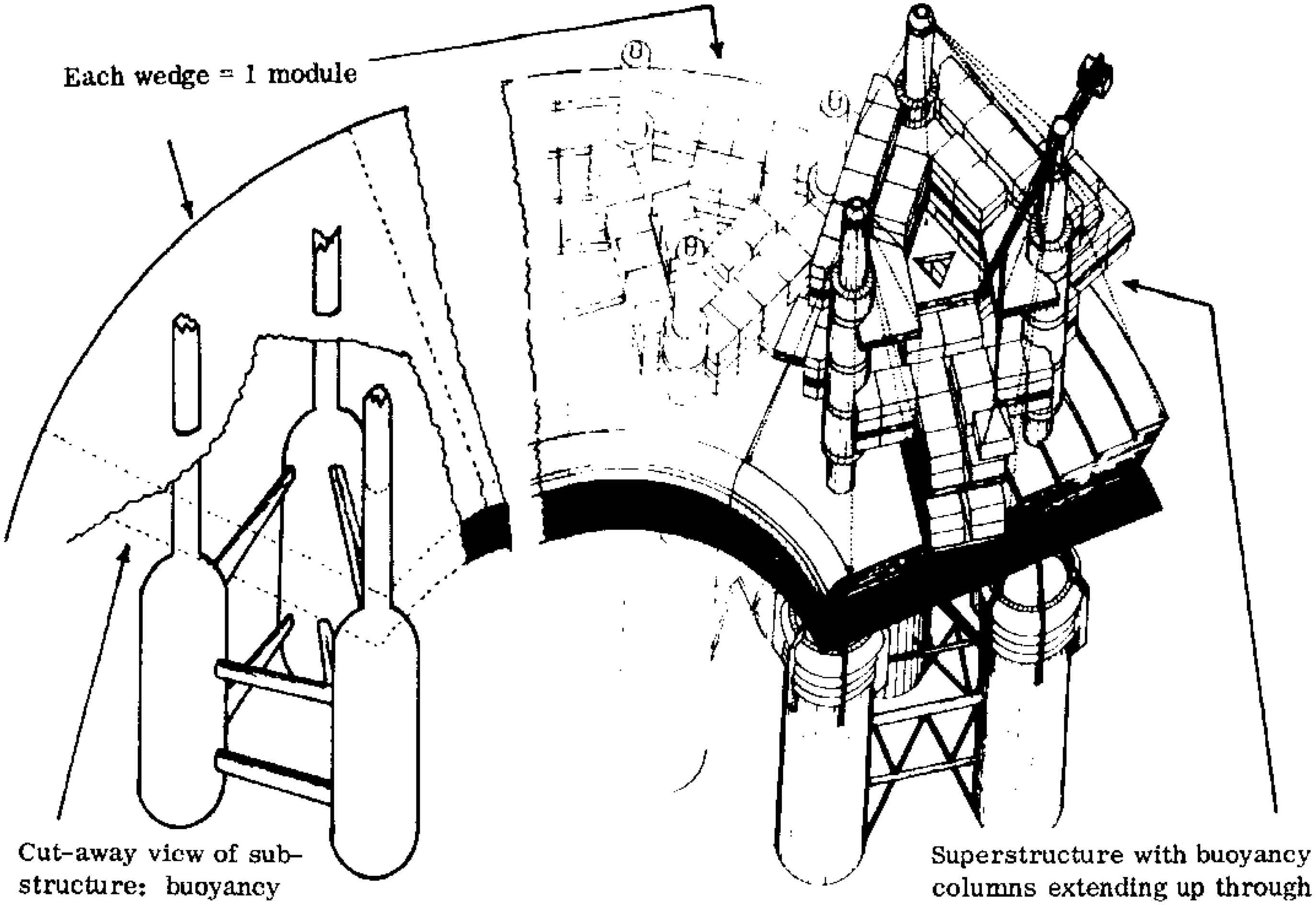
III. FLOATING PLATFORM CHARACTERISTICS GERMANE TO TRANSPORTATION SYSTEM DESIGN

A large stable semi-submersible platform provides an environment with a unique combination of characteristics analogous neither to conventional land sites nor to other types of marine structures, though with some of the features of each. Before examining and evaluating potential modes of external and internal transportation, it seems logical to review that unique combination of characteristics. Since platform design is described in detail in other reports in this series, only transportation-related features are summarized here.

A. Structure

On a submersible platform of the type considered in this study, an entire industrial and/or residential complex can be structured in three dimensions. This point may become clearer with a graphic depiction of the platform geometry. The preliminary architectural design and the configuration developed in 1972 (1) provide for a core-ring platform supported by two radially symmetrical rings of identical flotation columns, totaling 30 in all. The design concept features modularity, expressed as ten 36° modules comprising the core ring. Three flotation columns support each module--one at the narrow inner edge of the module deck and two at the broader outer edge, as shown in Figure 4. The modules are rigidly connected to form a continuous circular platform deck and the flotation columns, which extend above the deck to support the levels of superstructure, are linked below the waterline by horizontal struts. This design was retained for a later study of the preliminary structural sizing of the modules. The dimensions depicted in Figure 5 are the final results of that study, from the report published in March, 1974 (2). From Figures 4 and 5 it may be seen that the area encompassed by the floating city can be conceptualized as a vertical cylinder, with a three-dimensional internal latticework structure interconnecting multiple points, vertically and horizontally.

In a very fundamental way, this three dimensional structure offers a new kind of community environment. While modern cities may appear to be three-dimensional because of their high-rise building, they are not in fact. They are laid out flat on the ground, and a trip from the top of one building to the top of another requires a round trip to the ground level in order to traverse the horizontal distance between buildings. (A few rare exceptions to this rule are the bridges linking two commercial buildings, usually at one



Each wedge = 1 module

Cut-away view of substructure: buoyancy columns and struts.

Superstructure with buoyancy columns extending up through deck to support upper levels.

Figure 4 — Floating City module perspective.

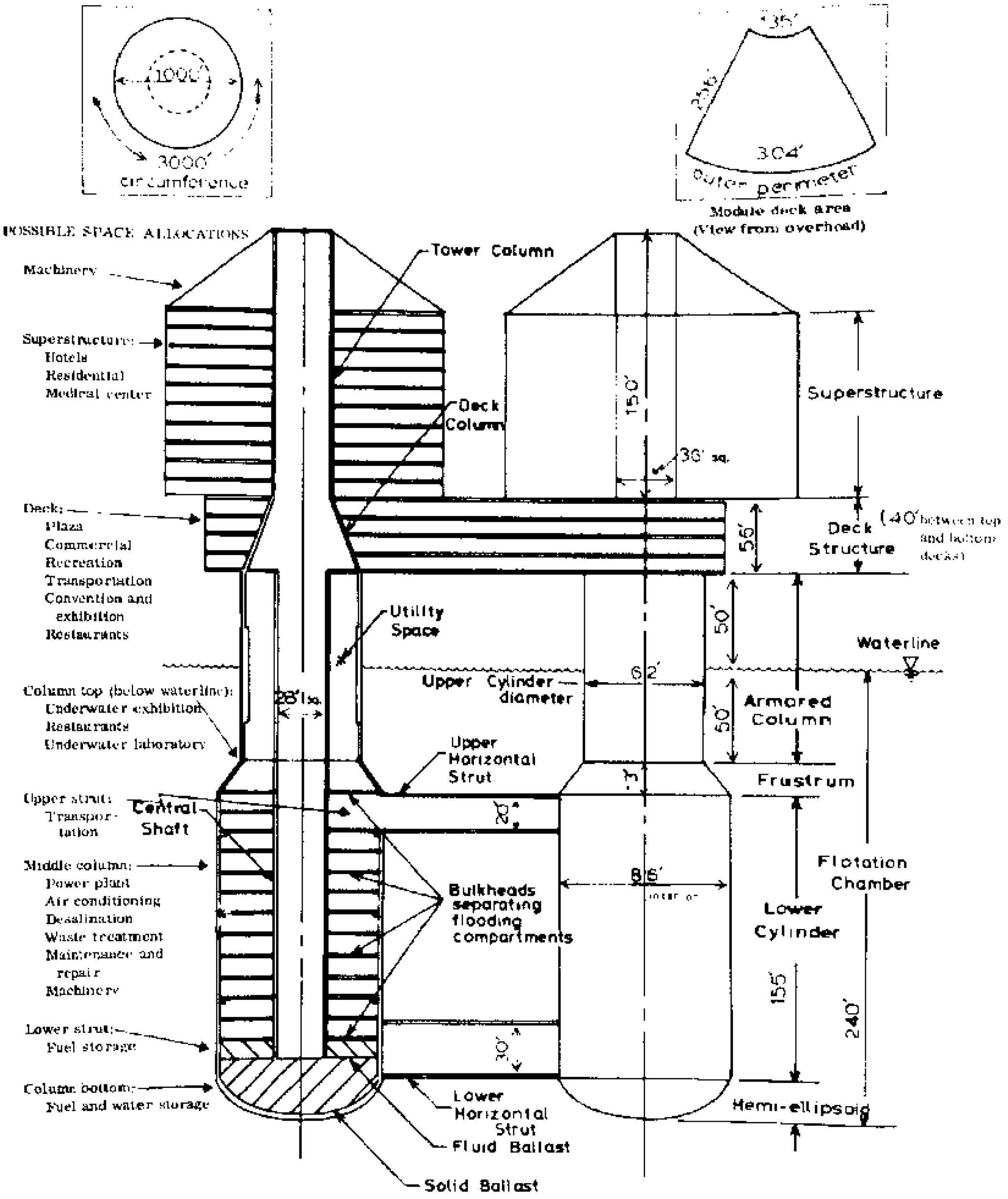


Figure 5 -- Configuration of flotation chamber, deck structure, and superstructure of a platform module (view at perimeter)

single level above the street, in some modern cities.) Moreover, urban areas contain many large structures necessary to the operation of a city but of no interest to the public. Because land areas are two dimensional, these structures are placed among the facilities the public does use, and thereby they increase the distances the public must travel in the course of daily errands. In a three-dimensional urban complex like the floating city, by contrast, functions which need not be accessible to the public, such as warehousing, fuel storage, sewage treatment, and power plants, can be placed underneath the residential, recreation, and commercial areas. Other functions that do not require sunlight, such as computer centers, libraries, some offices and medical facilities, et cetera, can also be located beneath the surface level. Not only does this free the above surface area for optimum use, but with connecting horizontal links at multiple levels it reduces the distances to be traveled by the public to a minimum. All residential and public areas can be within easy walking distance for the pedestrian, and the need for private automobiles and public mass transit is eliminated. (17)

Transportation systems for terrestrial complexes are linear (as exemplified by typical "urban sprawl"), of variable and hypothetically infinite length, and with independent vertical components (e.g., elevators in multilevel structures) at random intervals, as in Figure 6. The external transportation network of a land area may either interface with internal horizontal transportation modes, as in the case of railroads or airlines, or ocean transport in port cities, or it may be an extension of internal modes, as in the case of roadways for commercial carriers or personnel vehicles.

A: horizontal transport component
B: vertical transport component (multi-level structures with elevators)

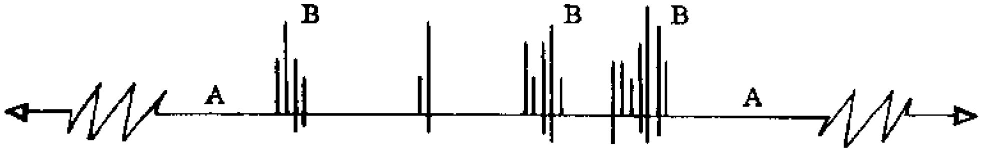


Figure 6 -- Terrestrial transportation pattern.

For a floating platform, on the other hand, internal transportation modes will be integrated with the latticed structure to provide access to all points within the defined, cylindrical space. And for external transportation the platform is entirely reliant upon intermodal interfaces.

1. Implications for the Internal Transport Net

Due to the dimensions of the floating platform, seen in Figure 5, mechanical modes of transportation will be more vital for vertical travel than for horizontal, where pedestrian traffic is concerned. But for both people and goods, an integrated vertical and horizontal network is essential to permit rapid and uninterrupted flow. System design will, of course, be subject to space limitations and noise constraints inherent in a finite and congested area. On the plus side, the lattice structure offers opportunities for multiple non-interfering flow paths to expedite movement. This aspect is explored further in Sections IV and V.

2. Implications for External Transport Net

Surrounded as it is by open water, the platform will be dependent upon marine and air transport for external transportation to link it with the shore and with distant sites. For the most part, this may mean that the external transportation system design must--for practical reasons--be concerned primarily with developing platform terminals that are compatible with existing transportation modes, since these must, in turn, interface with conventional terminals and docking facilities elsewhere through which in-and-out traffic to the platform will flow. Capital investment in cargo carriers is so substantial that adaptability, rather than innovation, may prove to be the more feasible course here. For passenger traffic, new types of craft already under development may hold an answer to both transport and terminal considerations. These aspects are explored further in Section IV. At this point it simply might be pointed out that there are basically three directions from which the platform may be approached: (1) from above, by air; (2) from beneath, by submersible craft; and (3) from the side, by surface craft. In the latter instance, there is complete freedom of approach from 360 degrees of direction--unlike a land area's dependence upon fixed roadways, the unpaved ocean is literally a total "highway". What limitations there are are imposed by winds, waves and currents, as discussed further on in Section III. C.

B. Stability

Floating (or flying) objects, unless constricted in one or more modes, have six degrees of freedom in motion, as shown in Figure 7. While the motion characteristics of a floating platform do not mean that the systems based on the platform must be capable of sustaining motion in all degrees, they do imply that the structure on which these systems will be operating

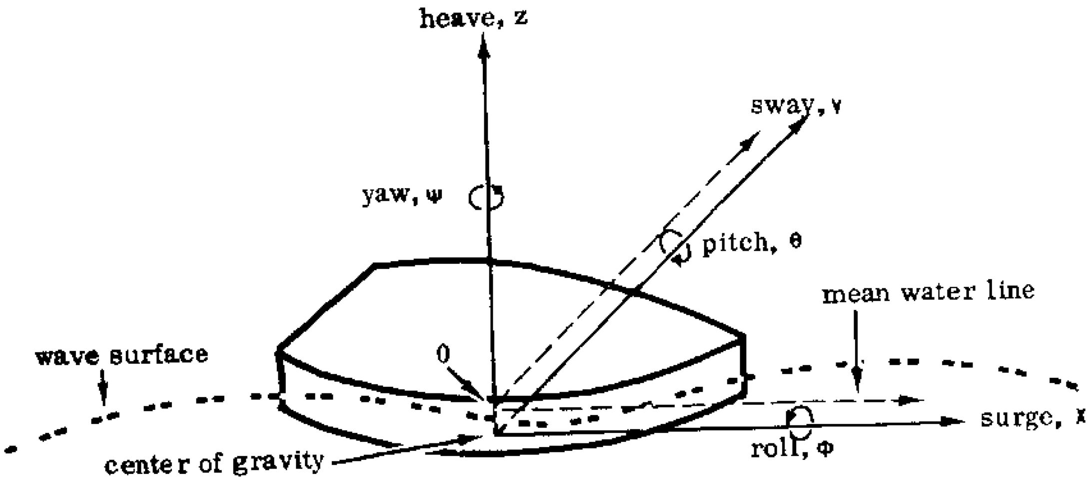


Figure 7 -- Six degrees of motion of a floating body.

will experience accelerations in all six degrees. Unless the magnitude of these accelerations lies within acceptable ranges, they may hamper the operation of certain internal and external interfacing systems. Those systems that operate from cables, such as elevators and cranes, could be affected in their operation by large deviations in magnitude of acceleration.

Since the floating city is not intended to be propelled over long distances, but rather to remain in a location five miles off the leeward Oahu shore, it is designed to provide a high degree of stability in expected seaways and to meet a buoyancy requirement to be determined by the sum of fixed and live weight of the whole city. "Intact stability requirements are defined by criteria limiting the maximum static angle of heel due to wind and current loads, as well as off-center weights and forces. Furthermore, vertical, lateral, and rotational displacements and accelerations must remain within limits which will ensure human comfort at any location in the city and, of course, must not exceed the limits for structural integrity of buildings above the main deck. Maximum allowable acceleration, then, is set at 0.015 g in any direction at any point in the structure." (18)

The principal forces acting upon platform stability are winds, waves, and currents. In the first technical report (1), the wind question was divided into trade and "Kona" (southerly) winds on the one hand and cyclonic storm winds on the other. It pointed out that for trade and Kona winds the highest mean wind intensity is 22-27 knots--occurring a total of only

1.3 per cent of the year. Short term peak intensities (defined as the maximum one-minute averages recorded over a one-month reference period) showed a highest recorded value of 53 knots, with a peak gust intensity (recorded at the Honolulu Airport in 1959) of 58 knots. The long-term (100-year) trend of mean wind intensity was set at 39 knots and the long-term peak at 62 knots. For Kona storms and tropical cyclones the peak instantaneous value is approximately 125 knots, with a peak sustained value of 80 knots, approximately. Wind, tide and global circulation components of the highly complex current patterns in nearby areas combined to yield a maximum expected surface current velocity around 175 cm/sec. The tidal component appears to be nearly 60 per cent of the total, causing directions as well as velocities to vary with time and depth.

The data derived in that same technical report predicted that the floating city will be exposed to waves with a significant height of 4-12 feet and a period of 5-8 seconds for 90-95 per cent of the time during summer months. During winter months, waves of the same sort will prevail slightly more than half the time, interspersed with some dominance of 1-4 foot southerly swells having periods ranging from 14-22 seconds, and with Kona storm waves of 10-15 feet with periods of 8-10 seconds about 10 per cent of the time. During infrequent instances of intense cyclonic activity, wave height maxima could rise to 50 feet, with periods around 16 seconds.

In a theoretical investigation of the platform's seakeeping characteristics, Dr. Seidl undertook to investigate all six possible motions of the core-ring. (18) Since the platform is essentially a spar buoy cluster, pitch and roll motions are generated mainly by heaving forces of the columns, and these are the dominant factor in platform motion. The investigation was subject to certain limitations: (1) time and resources did not permit analysis of the theoretical behaviour of the platform under various damaged conditions, so that was postponed for later study, (2) environmental data was not sufficiently complete to allow more than approximate calculations, and (3) theoretical tools currently available are imprecise in their ability to define real platform motions in real complex wave trains, requiring subsequent calibration by tests with scale or full-size models. Given these reservations, the projections of platform stability can be summarized.

Note that at the time of Dr. Seidl's study, a model size equivalent to a full-scale upper cylinder diameter of 48 feet was chosen for analysis because it appeared at that time to be the optimum configuration to yield minimum motion response in both pitch and heave. Recognition was given to the fact that a 54-foot configuration would yield even less response up to a wave period of 25 seconds, but resonance conditions coming into play at longer wave periods were uncertain. In the subsequent engineering study on structural sizing of the flotation modules, an upper column diameter of 62 feet was selected to give greater stability and lower heave response in the 15- to 20-second range. (2) This might possibly indicate that actual motion might eventually prove to be less than Dr. Seidl's calculations have predicted.

It already has been pointed out that the principal direction of motion for the platform appears to be vertical. The calculations determined that under the worst conditions--sea state 7--total maximum vertical motion on the periphery of the platform (surge + pitch + heave) could reach 11 feet. This extreme sea state 7 was reached in Hawaiian waters during hurricane stage ("Nina" in 1957 and "Dot" in 1959)--a time when interface with surface ships would not likely be attempted, except possibly in dire emergency. In the longest period swells of any height on record, with a period of 24 seconds and a height of 8.5 feet, Seidl calculated a heave of 2.9 feet with extremely gentle acceleration. For the most part, a vertical movement of 8 feet at the periphery is likely to be the maximum encountered and much of the time it will be less.

It was further determined that the motion of the platform would be imperceptible to persons on board at any wave period. Of course, here we are dealing with the question of human tolerance to motion and the primary factor is the rate of acceleration. But experience gained from the operating oil platforms indicates that when the magnitude of motion is small enough to be tolerable--much less, imperceptible--to human beings, it is unlikely to interfere with the operation of systems. As a matter of fact, oil production platforms are not designed for minimum motion in heavy seas; sheer human tolerance has been a greater factor in maintaining operations than has engineering design. Most of their equipment functions even under the most adverse environmental conditions, and has not been a limiting factor in drilling operations. The inference may be drawn that stability of the floating city would virtually assure satisfactory operation of internal modes of transportation.

The magnitude of motion, particularly at the periphery (where it is also the greatest) is of more concern in terms of interface with external transportation modes. In the absence of a sheltered harbor, the principal factor in differential motion of the two bodies--the platform and the cargo carrier--in the open sea will be the motion of the carrier vessel. Means of dealing with this are explored in Section IV.A. In the case of passengers, stepping aboard even a fixed dock from a floating ship or small boat may involve some concern. Possibilities for solving this problem also are explored, in Section IV.B.

C. Environment

In exploring the constraints upon transportation system design for the floating city, system interaction with its environment must be given due consideration. On the one hand there is the environment's effect upon system components, and on the other there is the system impact on its surroundings and users. In the first instance, the platform's internal climate will for the most part be compatible with system operation. The factors of temperature and humidity control have been investigated in terms of design aspects to regulate these for human comfort. (19) But that study did not deal with the effects of the external elements and certain internal conditions upon rust and corrosion of machinery. The marine environment is generally inhospitable to man-made structures as the combination of water and corrosive salts takes its toll in deterioration of materials. Components of a large floating platform will encounter both the problems common to surface ships and some of the additional difficulties typical of submerged vessels or deep sea chambers. This does not imply that the problems cannot be dealt with successfully, but it does require recognition of the environment to be encountered by the platform-based transportation systems, as well as by its life-support and other operating systems.

For a platform with an underbody configuration extending 240 feet below the sea surface, large temperature as well as pressure variations can be expected along the buoyancy column walls. The temperature difference between the warmer inner walls and colder outer surfaces of the columns will cause condensation to form on the inside surface. Unless prevented or removed, this condensation will cause corrosion or oxidation of the metallic components used in any machinery or equipment placed within a column. Moreover, trends in construction techniques for offshore platforms in general, and the conclusions reached in an investigation of construction techniques for this project specifically, make it clear that concrete probably will be the principal construction material used. (20) Since this is a non-homogeneous substance with a relatively high permeability rate in comparison to steel, the interior of the submerged columns may be subject to water seepage through the walls. Unless controlled by external protective coating or through concrete mixture controls, this seepage can lead to the entry of large quantities of water into the columns. Actual amounts of water seepage would be determined by the hydrostatic pressure and the permeability of the concrete. In either case, whether from condensation or seepage, excess moisture will have to be controlled.

An even greater hazard can be anticipated from salt buildup. Some of this will come from the ambient sea air as well as from seepage. Seawater contains a variety of salts that interact with metallic substances. Obviously the problem is not confined to the column interiors: cargo handling equipment, surface vehicles and any helicopters on board, all will be exposed to salt air and spray, though not actually coming into contact with the sea. It seems clear that emphasis must be placed on maximum feasible use of corrosion-resistant materials and on direct protection of interior and exterior metallic surfaces.

In the area of system impact upon its environment, both on the open deck and especially in enclosed areas, there are the factors of possible pollution from the solid and gaseous by-products of fossil fuel consumption and from the noise associated with internal combustion engines. Combustion by-products are a pollution source too familiar to require elaboration. Less familiar but of growing concern is the hazard to both physical and emotional health created by ambient noise associated with industrialization, mechanization, and various human activities in congested spaces. Employment of electrical power as the energy source for most, and preferably all, of the transportation system components on a floating platform can be a major factor in reducing system impact on the environment to a manageable minimum. This approach is integrated into system concepts explored in Sections IV and V. It will not, of course, eliminate all sources of noise: final design of the platform should include sound control in the transportation system as well as accoustical insulation in living spaces and in industrial and operational areas. Given the state-of-the-art in accoustical engineering, floating city inhabitants need not be exposed to hazardous or disagreeable noise levels.

D. Energy Efficiency

Open ocean deployment of a stable floating platform requires that power generation facilities be located on the platform itself. System capacity, and in some cases the type of system, will be determined by the power requirements of the various subsystems operating either on or from the platform. The open ocean location and research facilities will offer prime opportunities to explore potential development of solar energy sources, including wind, waves, ocean thermal gradients, etc.

Another, somewhat less direct, exploitation of solar energy resources lies in the rapidly developing technology for converting organic wastes into fuels. Traditional methods of obtaining energy from combustible wastes have been based on simple incineration. Examples of this include the Union

Electric Company process in St. Louis and regional plants being planned for Connecticut for generation of electricity. More sophisticated are the newer techniques for converting solid wastes to gas and oil through pyrolysis, or destructive distillation. Many processes are involved here, under development by utilities such as Pacific Gas and Electric Co. (San Francisco), Union Carbide, Monsanto, and others across the nation. With plants already in operation, estimates of output go as high as 15 per cent of the fuel needed by electric utilities, with a national average of 10 per cent. Methane production by anaerobic digestion of sewage and organic waste is another avenue of energy production that has proven practicality. (21) Still under development, the Bureau of Mines is successfully converting cellulose, the chief constituent of organic solid waste, to a low-sulfur oil potentially suitable for use by power plants or for conversion to gasoline and diesel fuels. They estimate that total utilization of urban refuse, waste paper, sewage sludge, wood and animal wastes, in this manner could supply about 50 per cent of the U.S. demand for oil. (22) More esoteric and long range is current research at the Army Laboratory, Natick, Massachusetts, on the employment of a tropical fungus to reduce solid organic wastes to glucose, whether for use in the food chain or as an intermediate step in producing ethyl alcohol. It is apparent that destruction of waste materials without recovering energy will soon be an obsolete concept. Implications of this for a self-contained community like the floating city are apparent.

Nevertheless, the power generation system of a floating platform will for some time to come be totally dependent for fuel upon stocking by supply ships, and even in the long run major systems such as propulsion and station-keeping can be expected to continue this dependency. Obviously then, the total power output of the platform would be a limited quantity, and normally would be kept to a minimum. Indiscriminate power utilization, uncoordinated requirements, and wide variations in demand--characteristic of terrestrial urban areas and increasingly troublesome even where supply is relatively unlimited--are luxuries that cannot be tolerated aboard a floating platform. Available information on power usage by semi-submersible platforms (23, 24, 25, 26) shows that the propulsion and position-keeping system makes the heaviest demand on power, and that the service load to the remainder of the platform systems is a very small percentage of the total power consumption. Should this be the case on the floating city, power distribution throughout the entire platform will be crucial in regulating the various loads for the many subsystems. In any case, propulsion, positioning, and life-support systems must take precedence over non-essential activities in times of emergency.

It is clear that the internal platform transportation system must be designed for maximum economy in power usage, as well as minimum pollution. Consideration must also be given to providing forms of system backup for emergencies when power must be severely cut back.

E. System Integrity

Like land-based structures, a floating platform is subject to the hazards of fire and high winds but perhaps of greater concern it is, like other floating marine structures, vulnerable to damage from collision and/or flooding of the buoyancy columns. The hazard has been minimized by the design specifications for the flotation chambers, calling for armored sections extending 20 feet above and 30 feet below the waterline. Here the column walls are constructed of concrete 3 feet thick and steel-jacketed inside and out. A further safety measure consists of 4 watertight horizontal bulkheads in each column, as indicated in Figure 5. Nevertheless, for the transportation designer the possibility of damage imposes three important design criteria, over and above the usual safety precautions. First, the platform must be capable of maintaining stability in the location of the damaged section (unless the section is completely severed). Second, all internal transportation networks must operate without interference with the watertight bulkheads in the buoyancy columns. Third, in the unlikely event of catastrophic failure, the vertical transportation systems must provide a means of quickly moving those occupants to the main, or surface, deck who cannot get there under their own power. (The platform's separate emergency evacuation plan could take over from that point.)

A vertical transportation system is required to provide access to all working levels within a buoyancy column. The second and third design criteria just stated depend to a large extent on the integrity of the vertical system.

In structural design, crisis prevention itself must be at least as important as measures to cope with any situation that might arise through a failure of preventive precautions. Here too, transportation system design has a role. One critical area where the probability of damage would be relatively high comprises the transportation terminals and the navigable channels leading to them. These areas will bear the brunt of incoming and outgoing traffic, including both surface and subsurface craft.

IV. EXTERNAL TRANSPORTATION

The single most important problem to be dealt with in considering design aspects of an external transportation system to support a floating city is the requirement for practical forms of interface between cargo and passenger carriers and a free-floating platform subject to the forces of wind and the sea.

Structural and hydrodynamic characteristics of the platform preclude availability of the calm water harbor that has historically been a necessity for conventional port operations. A very large platform moving slowly but freely (and sometimes with large excursions) through six degrees of freedom presents a further hazard that makes interface with another surface vessel, also subject to the forces of the open sea, appear precarious at best. Under those conditions both vessels exhibit complex and unpredictable combinations of motion. Consequently it is necessary to evaluate the relative cost and feasibility of integrating a large floating platform with transportation networks existing in the rest of the world at the time it is constructed versus designing specialized forms of transport selected for ease of interface. To the extent that specialized transport craft and on/off loading devices are required, the cost of an external transportation subsystem may be increased. On the other hand, the flow of people and goods between the platform and external systems will be of a relatively low volume as compared to the flow through a conventional port, and could possibly be handled most feasibly (perhaps even economically) by special equipment.

Surface transport over water has been the easiest and most economical way to move bulky and/or heavy loads ever since early man discovered the use of the raft. However, a disadvantage to water surface transport is its vulnerability to weather conditions. This would be particularly true in a situation where a vessel would have to come to a stop in the open sea. Here mooring and transfer of cargo and/or passengers would be limited to a comparatively narrow range of wave and wind states and impossible in times of extreme weather. Since it would be impracticable for a floating city to be dependent upon external transport that would be inoperable some percentage of the time, it will be necessary to design for system flexibility. Alternate modes that are virtually independent of weather conditions must be available, while the bulk of traffic certainly should move by the least costly mode whenever possible. These two criteria may not prove to be mutually exclusive. Some of these potential modes, now current or under development, are discussed in this section.

Among the design parameters for the external transportation subsystem are the volume and timing of passenger flow; the costs involved in queuing and on/off loading times for both passengers and goods, and acceptable standards of safety; and determination of optimum storage capacity, internal routing, loading rates and number of interfaces, for cargo.

The techniques of cargo transfer across the external interface may employ any of three types of connecting link: (1) flexible coupling maintainable within the range of relative motions to be encountered; (2) rigid coupling strong enough to withstand complex and substantial dynamic loadings; and/or (3) a method of bridging the gap between vessels without a direct contact. In the first instance, fluids--and non-fluids that can be made to behave like fluids--can be transferred between vessels via flexible hose connections. Solid cargo may be transferred via flexible couplings if such couplings actively compensate for the differences in relative motions between the two vessels. In the second type of link, rigid couplings that would eliminate motion differential would permit on/off loading procedures similar to current dockside operations. One example of the third type would be use of helicopters for the transfer. Each of these categories is discussed in more detail in the following sections, as are the additional requirements for safety and comfort in the case of passenger transfer across the interface.

A. Characteristics of Flow--Personnel and Material

A discussion of techniques to transport and handle cargo may be more profitable if we first take a look at what precisely is likely to be moved.

1. Inflow of Goods

A projection of a warehousing system for the offshore community was derived in some preliminary work, basing the calculations of the daily volume of goods for the residents upon the Navy's figures for full-time resident workers on a Naval base plus, for the visitor population, a supply of goods comparable to the offerings of a post exchange facility for single enlisted men. (27) Given the permanent and visitor populations stated in Section II, the daily volume was roughly approximated at the equivalent of 21 container (8' x 8' x 20') loads, or 625 per month. On a per capita basis, this is a little less than the volume to Kauai in our model, but the lack of precision of this figure cannot be overemphasized. According to those early calculations, it was projected that about 1/3 of the total supply of solid cargo would require refrigeration, 1/3 would be stackable, unitized or bulk, freight, and the remainder would be miscellaneous types.

To obtain a rough calculation of total fuel supply load on transportation and storage, power requirements for all contained systems were summed and treated as a single demand, although this was not expected to be the actual configuration. It was determined that the load was insufficient to warrant use of nuclear power, so fossil fuel--namely residual, or Bunker C, oil--would be the power source. Based on the fuel characteristics (28), the rate of consumption was estimated at 5,000 gal/hr, average load, and 20,000 gal/hr at peak load. At this rate, 7.5 million gallons would constitute a 15-day supply at peak power demand, or 60 days' supply at average rate of use. Resupply would be scheduled so as to maintain a minimum stock of about 1 million gallons at all times. Volatile fuel requirements for transportation vehicles of all kinds including helicopters and recreation craft are too uncertain to estimate at this point but no problem in meeting the demand is anticipated.

2. Outflow of Goods

The volume of goods, foods and raw materials flowing to and from a platform cannot be estimated without a determination of selected industries the platform would house. It is most probable that there certainly would be some outflow, in addition to the return to shore of containers, pallets, etc., used for incoming goods. One category of goods that could be expected to move in both directions would be the household furnishings and personal possessions of residents moving to and from the community. In our transient society the volume of this flow within and between communities is heavy; until the magnitude of the resident population for the floating community is finally determined and a behavior pattern of their movement is developed, the volume of household shipment to and from the platform remains a matter of conjecture. But the fact of it must be taken into account.

Earlier consideration of a waste management system for the offshore community, predicated on the principal that the community must be essentially nonpolluting to its environment(17), determined that the system must be capable of handling three types of waste: (1) domestic sewage, (2) solid wastes, and (3) industrial wastes. Anticipated volume of domestic sewage was estimated at 150 gal/day/person. Generation of solid wastes was estimated at 5,000 cu. ft./day. With the number and character of industrial enterprises still highly speculative, volume of industrial wastes was not defined. Based on traditional methods of waste disposal, the following assumptions were made.

a. Given its biodegradable character, and assuming a collection system that would keep it separate, domestic sewage could be discharged into the ocean with proper attention to depth and current.

b. Solid wastes could be removed by transport to shore or disposal into the deep ocean water, or they could be burned. Simple incineration on board, at a reduction rate of 10-20 to 1 (29), would produce ashes to be disposed of in either of the two above methods. If transport to shore of solid wastes were the chosen method, storage of at least 10 days' output would be required, which would undoubtedly require a compaction process, at a reduction rate of 5 to 1. Hence the load of solid waste or residue to be transported from the platform could run anywhere from 250-500 to 1,000 cu.ft./day.

c. Non-biodegradable industrial wastes would require either prior treatment before release into the deep ocean, or transport for disposal ashore.

It now seems apparent, from the trend discussed in Section III-D, that waste output would more likely be burned, pyrolized, or otherwise utilized as a source of energy to the maximum extent possible, and this would reduce the cargo outflow of this category. Whether or not this actually occurs would depend on the economics of a reduction plant aboard the platform, versus the cost of transport and reduction elsewhere.

3. Personnel Traffic

At a theoretical daily rate of 7,500 diurnal visitors plus the flow of 2,000 overnight visitors (if the floating city is a visitor center), transient traffic could be estimated at close to 10,000 round trips per day. Peak loads can be anticipated during the morning and evening hours for this traffic. For the (presently nebulous) volume of resident commuter travel, peak loads in the reverse direction would occur in the morning and late afternoon hours. Magnitude of the latter will be affected greatly by the opportunities for employment in commerce, industry, research, etc., aboard the platform. Certainly some components of current highway traffic would be reduced or eliminated, such as travel to school, some social and recreational commuting, and minor shopping trips. Figure 8 shows a State of Hawaii Department of Highways estimate of traffic rate and distribution for a typical Oahu highway with an unsaturated flow on a weekday. If the daily commuter volume, for business, shopping, etc., for the platform is assumed to be 1/2 of the resident population, for an example, and peak rate is extrapolated (from Figure 8) at 12 percent, it can be expected

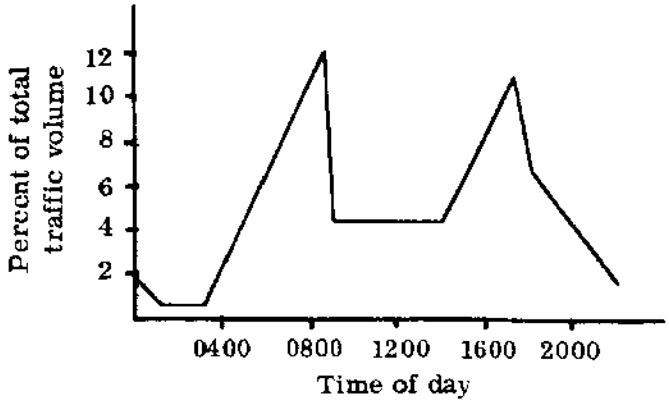


Figure 8 -- Commuter traffic flow pattern on Oahu.

that peak load would approximate 1,800 passengers/hr. Even though the peak load for visitors would be flowing generally in the opposite direction from commuter traffic, thereby providing payload in both directions, it is apparent that there may be a heavy demand on the personnel transportation system. Again, this is only a theoretical example, using arbitrary figures; an actual projection is premature at this point.

4. Evolution

The flow of goods and people described in subsections 1 to 3, above, is characteristic of what may be expected when the platform is fully operational as a base for the projected offshore community described in Section II-A. Initially, once basic construction is completed and the floating platform is located on site, there will be a period of at least a year during which light construction of the interior and superstructures continues, as well as the finishing work and installation of equipment, fixtures and decorative details. The magnitude of the work is indicated by the estimate of a $100 to $200 million cost for this phase. During this time the major cargo traffic will consist of construction materials--steel, concrete, pipes, machinery, etc.--with very little flow of consumer goods, if any. Much of this cargo can be expected to move from the west coast of the mainland by ocean-going barges, unloading directly at the platform. (Obviously the installation of cargo-handling equipment, at least in a temporary form, on the platform will have to be one of the first steps.) (30)

As the platform becomes habitable, residential and commercial use will gradually phase in. At this point the proportion of cargo transshipped from Honolulu will begin to grow and gradually assume a major role, although some materials and machinery, and possibly fuel, will undoubtedly continue to be barged direct from the mainland or other overseas ports. Figure 9 indicates the general pattern likely to occur during this evolution, while not attempting to quantify it. It might be noted that lines A and B in the figure represent chiefly one-way flow, while two-way traffic gets underway with line C.

5. Cargo Unitization

Containerization, and unitization in general with a broad spectrum of intermediate gradations, provide a convenient means of enlarging cargo drafts, saving on labor costs and time, and offering protection from weather and pilferage.

For large-volume shipments, the favorable cost/effectiveness of containers in standard sizes running from 8 x 8 x 10 feet to 8 x 8 x 40 feet has been well demonstrated and there is a strong trend in this direction. Figure 10 shows some representative container configurations and standard dimensions. (31)

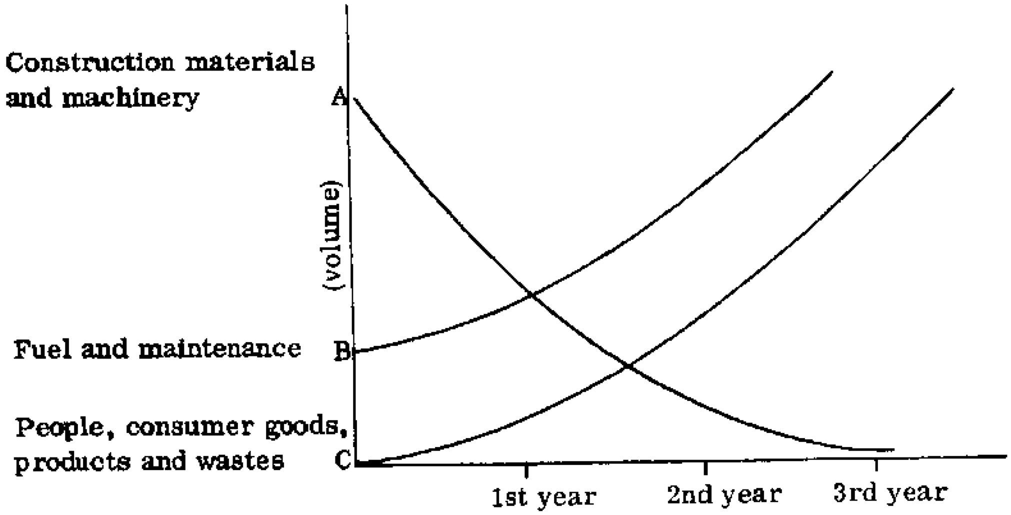


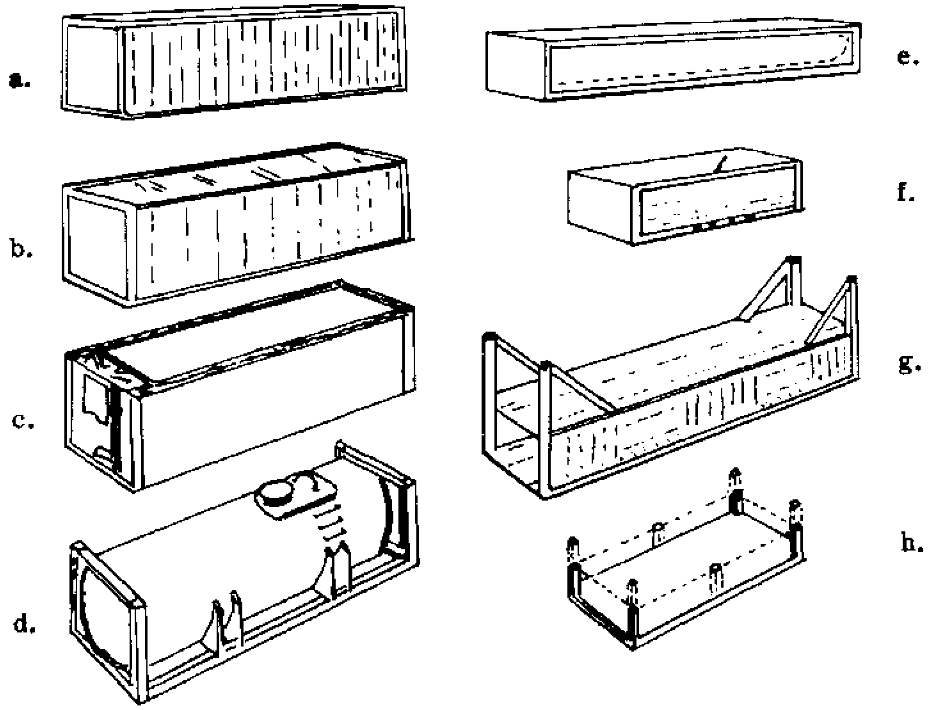
Figure 9 -- Evolution of cargo flow for floating platform.

Standard net load for an 8 x 8 x 20 foot container is figured at 15 tons, or about 1,200 cu. ft. Maritime Administration data indicate that cargo density averages 21 lbs./cu. ft. Consequently, many operators report that 90 percent of their 20-foot container loads are cube limited, contributing to an increased use of 40-foot containers, which have a more favorable ratio of cube to maximum weight.

A major advantage to containers lies in the fact that they are designed to be handled and hauled by rail, truck, air, or ship; hence their suitability for loading at the point of cargo origin for through shipment by intermodal carrier to their destination without intermediate handling of the contents. This advantage is contingent upon several factors, however.

a. The goods must be shipped in full container lots. Partial shipments that must be consolidated somewhere enroute defeat the purpose of reducing handling, as well as reducing pilferage.

b. The consignee must either be able to use the entire volume of goods packed in the container, or must be able to act as a distribution point, unloading the contents and shipping portions (break bulk) to the ultimate users. At the present time, a large proportion of all cargo arriving in Hawaii is shipped via container vessels and the latter role of the consignee is performed at the port of Honolulu for partial container loads destined for the neighbor islands.



a. Dry General Type
b. Open Top
c. Refrigerated
d. Tank Type
e. Shallow Tank Type
f. Open Tray Bulk Type
g. Automobile Carrier
h. Master Pallet with Adjustable Corner Posts and Removable Side Rails

STANDARD DEMOUNTABLE VAN CONTAINER DIMENSIONS AND TOLERANCES

Nominal Sizes	Actual outside dimensions & tolerances						End doorway dimensions	
	Length		Width		Height		Width	Height
40' x 8' x 8'	40' 0"	+ 0 - 3/8	8' 0"	+ 0 - 3/16	8' 0"	+ 0 - 3/16	90" min.	55" min.
30' x 8' x 8'	29' 11$\frac{1}{4}$"	+ 0 - 3/8	8' 0"	± 0 - 3/16	8' 0"	± 0 - 3/16	90" min.	55" min.
20' x 8' x 8'	19' 10$\frac{1}{2}$"	+ 0 - 1/4	8' 0"	+ 0 - 3/16	8' 0"	+ 0 - 3/16	90" min.	55" min.
10' x 8' x 8'	9' 9$\frac{3}{4}$"	+ 0 - 3/16	8' 0"	+ 0 - 3/16	8' 0"	+ 0 - 3/16	90" min.	55" min.

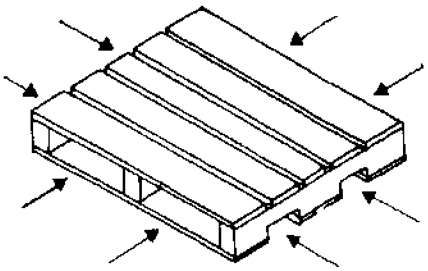
Diagonal Tolerances ± 1/4" in all planes.

Figure 10 -- Typical container configurations and dimensions.

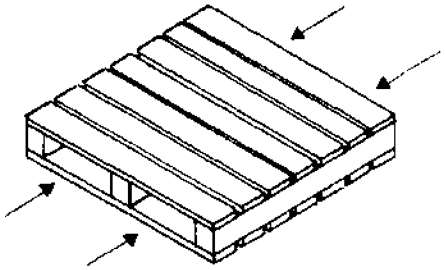
It is obvious that the economic advantage of containerization is lost if goods in lots less than container size, coming from two or more suppliers, arrive by various modes at the port of overseas shipment and must be assembled into containers there for shipboard transport. For many goods--food items and other--full container loads of a single product, or of several products from a single source, may be a volume too great for the small platform population to absorb. In the case of non-perishables, they may place an unnecessary load upon the platform warehouse area. Several other disadvantages of containerization include container cost (approximately $2,000/unit), less efficient use of cargo space per cubic volume than well-stowed break-bulk, and--in cases of uneven cargo flow, as for the platform--the cost in space and money of storing non-collapsible empties and of returning non-revenue-producing empties to their source. It will also be necessary to evaluate the likelihood of shipping whatever goods the platform industries may produce, in container size lots, to single consignees.

There are several other forms of unitization that may serve the cargo flow to and from the platform better than containers in many instances. Palletization is the first simple step in cargo consolidation. There is a wide variation here in construction and dimensions. Rectangular pallets may range in size from 24" x 32" to 48" x 72", while the square models may vary from 36" x 36" to 48" x 48". These figures are for standard versions; custom designs may be any size suitable to a given transport system. Capacities vary accordingly with, for example, a 40" x 48" pallet taking a load of 1,000 to 2,000 lb., depending on the bulk of the goods. Several types of pallets can be nested for storage or transfer when empty. Figure 11 illustrates several typical pallet designs and lists the ASA Standard dimensions. A recent development, in the form of a plastic skid pallet in sheet form with one or more up-curved edges to facilitate fork lift, reduces stowage space for unit loads by around 15 percent and yields even greater economy when transporting empties. Flexible fabric webbing used to strap packages and parcels to the pallet base offers flexibility in size and shape of load, and rapid assembly/disassembly. A rigid cover may also be used. Possible disadvantages include a greater variation in size than encountered in containers (which could, at times, be an advantage) and a lack of uniformity in dimensions of the overall "envelope" of the unitized load. (31)

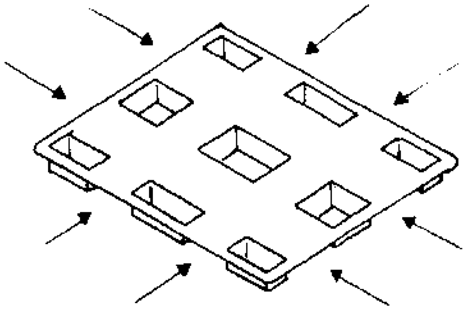
A third group of cargo unitizers is intermediate in both physical form and cargo load, having some of the features of both the containers and the pallets. These are known as "cargotainers", a term copyrighted by the Tri-State Engineering Company of Washington, Pennsylvania, and used generically here in a general descriptive sense. This is a knockdown type of open container with a pallet type base, having a configuration similar to that in Figure 12. In this illustration, the basic design is modified slightly--to include beveled skids, lifting eyes for crane or helicopter pickup, side pins and heavy top rungs to



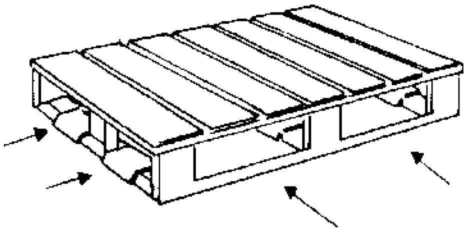
Notched Stringer Non-Reversible (Four-Way)



Double Decked Reversible (Two-Way)



Nestable, Metal Non-Reversible (Four-Way)

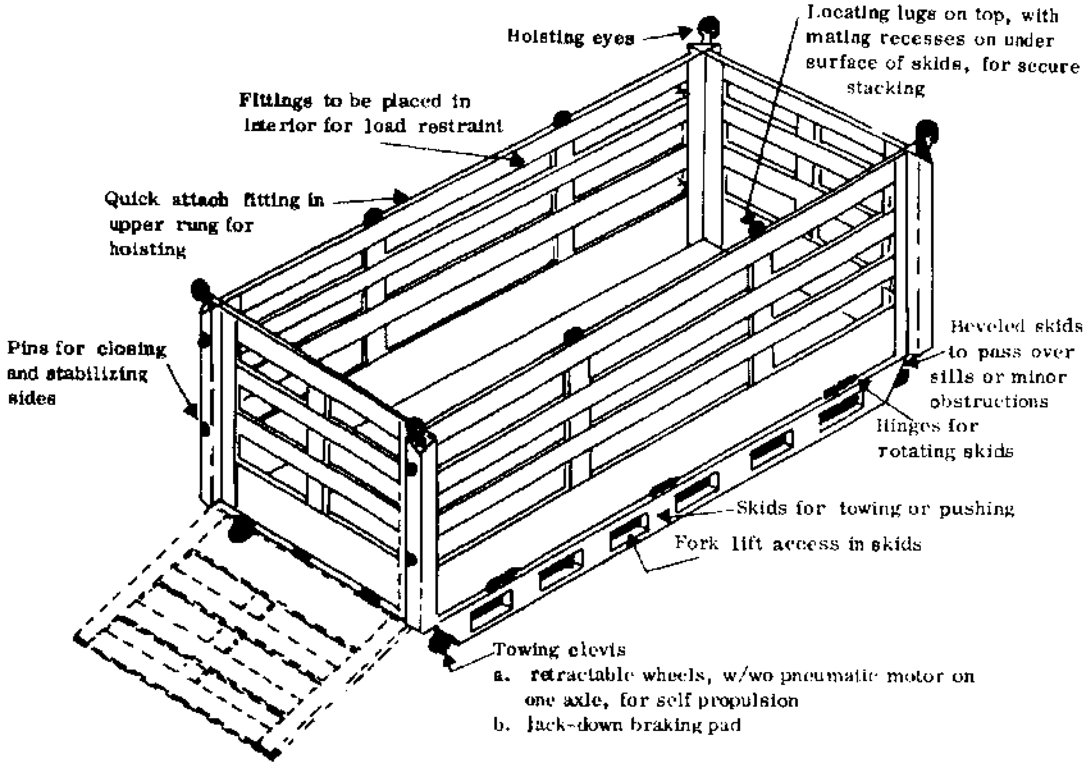


Steel Non-Reversible (Four-Way)

Dimensions in Inches

Rectangular		Square	
R-1	24 x 32	S-1	36 x 36
R-2	32 x 40	S-2	42 x 42
R-3	36 x 42	S-3	48 x 48
R-4	32 x 48		
R-5	36 x 48		
R-6	40 x 48		
R-7	48 x 60		
R-8	48 x 72		

Figure 11 -- Representative pallet types and sizes.



Note: Approximate dimensions: 11'-8" lg. x 5'-0" wd. x 5'-1" high

Cargotainer in knockdown condition for return trip, empty

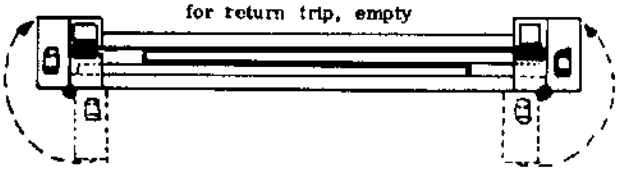


Figure 12 -- Knockdown cargo unitizer showing some potential modifications for ship-to-ship handling.

enable use of quick-acting grabs, stacking lugs and recesses, etc.--for use in amphibious operations by the Navy. (31) The structure is similar to a metal pallet but with collapsible side structures, of wire mesh for light loads, and of grids or truss-patterned steel tubing for loads upwards of a ton. Units can be handled by forklift, crane, hoist or burtoning gear (see Section III-C-1-b) and could have a demountable undercarriage to add mobility. In the latter case they could be semi-self-propelled, using compressed air, for traversing short distances and loading elevators. The cargotainer can consolidate palletized loads; with 3 pallets averaging 1,200 lbs., plus tare weight (about 300 lbs.), total load would be about 4,000 lbs. This unit can accommodate large drafts, while offering some advantage over containers, such as utilizing stowage and transport space more effectively (when empty and folded they require little more space than pallets) and offering more flexible load size for outgoing cargo, thereby eliminating some queuing involved in accumulating container loads.

From these three examples alone it may be seen that considerable flexibility exists in the size and type of loads that may be unitized for economical handling. There are many other variations on the theme, as may be seen in the mobile storage bins, transporters, etc., used in airline terminals as well as the usual ship cargo units (31). Without attempting to evaluate any of these units for platform transport at this stage, the point can be emphasized that flexibility currently exists, and further, it can be designed into the system. Of course, not all cargo can be unitized, including bulky materials such as pipes and some construction materials, for example, as well as fluids. This is taken into account in the following survey of transport modes.

B. Cargo Ships

In the face of the trend to containerization for large-scale cargo movement, there is a natural tendency to think "container ships" when the subject of cargo vessels comes up. In relation to a port the size of the floating platform, however, this translation is not really appropriate. For one thing, the capacity of modern container ships, running typically to over a thousand containers (whether 20- or 40-ft. models) scarcely compares to the rough estimate of platform requirements of around 600 20-ft. container loads per month, even if the disadvantages of load size, cited in subsection A-5, above, could be overcome.

Secondly, there are the economic factors. It has already been pointed out that dead time cost alone of stopping an oceangoing cargo ship is in excess of $1,000/hr. A pre-containerization study by Matson, in 1958, showed that ship loading and discharging costs constituted 43 percent of the total ocean freight costs. Under similar handling conditions, this percentage would be greater today. Containerization has brought about approximately a 10 percent reduction in cargo unit delivery cost (at 100 percent conversion). This is in the face of a capital investment cost that has doubled; for example, a cargo liner with a capacity of 800 containers requires at least 2,000 containers (a ratio of 2.5 to 1) to service it, at an approximate cost of $2,000 per unit. This investment in containers must be doubled during the life of the ship, very nearly approaching the cost of the ship itself. The overall reduction in cargo unit delivery cost is achieved by decreased turn-around time in port and reduced application of manpower. Both result from a high degree of mechanization. Short turn-around time also depends upon quick movement of off-loaded cargoes, frequently on individual chassis, and immediately available outbound cargoes; the need for marshalling space, in turn, leads to port facilities with large open space requirements close to the ships' berths. (32)

A third argument against the prospect of offloading containerships--or any type of large oceangoing cargo ships--at the platform is the question of safety. In relation to this aspect, as well as the economic factor, it was emphatically stated by the Matson Company (3) that it would be "out of the question" for a large ship to stop in proximity to a floating community. We would not rule out the possibility that future developments in technology for offshore ports handling cargo other than petrochemicals might modify this statement, but for the present it seems appropriate to let it stand.

Given the impracticability of attempting a direct interface between the offshore platform and oceangoing cargo ships, it would be pointless to conceptualize cargo-handling equipment or techniques. Containers, as well as other cargo units, are currently carried by barge between the island ports, and the applicability of this mode to the floating community is explored in the next section. It applies equally to direct shipments by oceangoing barge.

C. Barges and Lighters

It has become apparent that a major share of interisland solid cargo flow in Hawaii is moved by barge. Quite a small amount goes by air; Matson, a major containerized shipping line, transports the rest in containers by small interisland cargo ship. It is also apparent that barges possess the flexibility to carry solid cargo in any form (loose or unitized, including containers) as well as liquid cargo such as fuel oil. It is further apparent that economic and technical constraints point unmistakably in the direction of transshipment of most cargo through the port of Honolulu to the floating platform, treating it as one of the neighbor islands--or more likely, in view of its population, demand, and proximity, as a suburb of the major urban area ashore. Moreover, the characteristics of demand generated by this offshore community suggest that a considerable volume of the solid cargo flow would be in break-bulk form including the smaller units of consolidation like pallets and cargotainers. Heavy and/or bulky cargo (e.g., construction materials and machinery) that may be shipped directly from the mainland or overseas ports to the platform can be expected to move by oceangoing barge.

So it can be anticipated that a major area of interface with an external transportation system will occur between the platform and barges of various types. Since these may vary from open flat decks to hatch-loaded to roll-on-roll-off (Ro-Ro), etc., the matter of conceptualizing this mating involves a look at several alternative interface techniques.

1. Flexible Interface

Transfer of a load from one moving surface to another moving surface can be an extremely hazardous operation, even in calm seas. Actually, since the lifting mechanism is affixed to one of the surfaces itself, and therefore it and its load are "stationary" with respect to that surface, the hazard is involved primarily with picking up or setting down the load on the second surface without damaging stress or impact as that surface drops, heaves, rolls, or sways unpredictably.

a. Transloader

To solve this problem the Navy has been researching methods of handling cargo between vessels in the open sea. Several systems have been explored to regulate lowering of loads to lighters by sensing the motions of the smaller craft. One promising approach to container handling has been developed by the Rucker Co., in the form of an electromechanical, hydraulically operated servo-system, termed a Transloader (31). The main components of this system, the arrangement of which is shown in Figure 13, are designed for integration with existing equipment. The input to the Transloader unit governing retraction or extension of the load line is generated by a sensor line attached to the lighter deck. This sensor line is under tension as the lighter heaves with respect to the transport; increasing tension in the sensor line causes the load cable to lengthen, while decreasing tension produces the opposite reaction. There appears to be no obvious reason why this system could not be adapted to handling other forms of unitized cargo.

b. Burtoning

Another approach to motion compensation by flexible interface has long been in use, particularly by the Navy--where it is termed "burtoning". It requires the use of two cranes, one mounted on each vessel. This principle is illustrated in Figure 14.

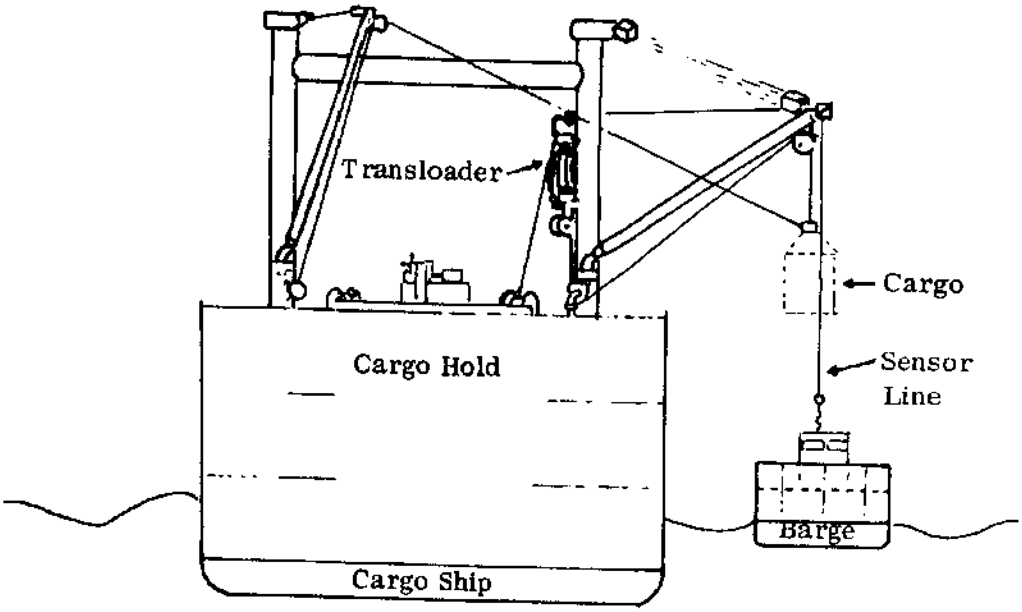


Figure 13 -- Transloader.

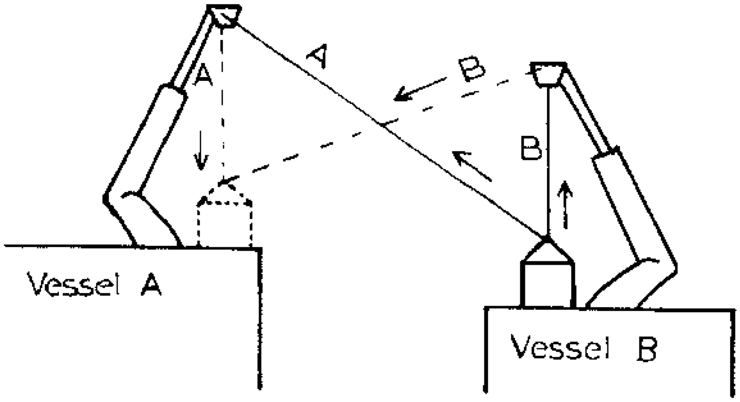


Figure 14 -- Burtoning with two cranes.

Line B raises the cargo unit from the deck of its own vessel B. Then tension is increased on line A and slackened on line B, so that while both lines bear the weight, the unit is swung over the deck of vessel A. When line A becomes vertical, it then bears the whole weight and lowers the unit to the deck of the vessel A.

The principal disadvantage to this system lies in the fact that it requires a crane on the deck of each vessel, which may or may not be practical. An alternative concept would be to use a floating crane that could temporarily affix itself by magnetic attraction to each barge during the transfer process. This would be an adaptation of the Navy's Ship-Indexing Approach for container off-loading from non-self-sustaining containerships at advanced bases without port facilities. (33)

A variety of crane types (rotating, derrick, telescoping, rail-mounted, etc.) might be used in the cargo operations but the technical details of equipment design to meet platform requirements must properly follow the choice of interface modes. The same is true of potential employment of wing decks, hatch arrangements, hoist fittings, etc.

c. Flexible Coupling

It already has been mentioned that fluids and solids that can be made to behave like fluids (slurrys, etc.) can be transferred between vessels easily. For the floating platform, bulk liquid cargo will typically include any of the following: water, sewage and/or sewage treatment chemicals, petroleum products and lubricants, coolants, cleaning fluids, and cryogenic gases, to name a few. Small volume shipments would probably be shipped in some form of tank container, such as is shown in Figure 10. The technology for the transfer of high-volume shipments by tanker or barge already is well developed by the oil industry in its movement to offshore oil storage depots. This type of interface, explored further in Section IV-D on tankers, would be equally appropriate for liquid-cargo barges, which appear to be the probable transport mode for the platform's external system.

2. Rigid Interface

The hazards associated with cargo transfer between two vessels moving freely and independently could be avoided by temporarily joining the two into a single unit. One method of accomplishing this might be to connect a cargo barge to the platform at the waterline, either by rigid moorings or by magnetic attraction. This is not likely to prove practical in the open sea environment. For one thing, the barge, being a surface craft,would undergo stresses from the waves to which the platform would be impervious and these stresses would be transferred to the coupling. Secondly, in all but the calmest of seas the rim of the platform would be rising and falling as the result of heave response. While the acceleration would be so slow as to be imperceptible on the platform itself, the vertical movement could affect a rigidly attached barge by alternately forcing it under, and lifting it clear of the water surface. A more feasible concept might incorporate bringing the barge aboard the platform, where it could be unloaded by forklift, Ro-Ro decking, conveyor, crane, etc. This approach is a relatively new development, but the concept is employed in two currently operational systems.

a. Lighter Aboard SHip (LASH) System

A recent innovation in large-scale cargo systems comprises the development of deep-draft container vessels capable of carrying 49 shallow-draft barges preloaded with containers. In essence the barges are a form of unitizing cargo loads equivalent to approximately 7 containers/load. The mechanics of on/offloading the huge cargo vessels themselves are minimized since the entire loaded barges are picked up out of the water by the ship's crane and lifted aboard, or conversely, lifted from the ship deck and set into the water. This serves two purposes: (1) it permits access by deep-draft ship to shallow-water ports, and (2) it minimizes the expensive ship deadtime during turnaround. The LASH system is not expected to service the Hawaii area, since it is designed for use where the barges can negotiate inland waterways, consolidating cargo and bringing it out into deep water. It is of interest here primarily in terms of its capability for transferring the barges between shipboard and the water surface. The heavy cranes needed to lift the barges are located on the LASH vessel; some adaptation of these might be mounted on the platform deck. Two considerations immediately become obvious here. One is the open space on the top platform deck that might be required to accommodate a barge loading area. LASH barges, for instance, with a capacity of 415 tons, are 61 ft. long, 31 ft. wide and 13 ft. high. It would be possible, of course, to use smaller barges, but space might still be a consideration, as well as aesthetics. Another solution might be to run the barges under the platform (where there is a 50-ft. clearance) when wave conditions permit, and lift them up into the lower deck of the platform. The second obvious consideration is the hazard involved, given the differential motion of the two vessels while the barge is still in contact with the water. Here some version of the Transloader might be employed. Also apparent, and indeed always present, is the question of cost. Although special handling equipment is not required, the lift demands a heavy traveling crane capable of taking the vertical stress and the torque loads.

b. Lykes Seabee Ships

The Seabee class of ships, built for Lykes Bros. Steamship Co., Inc., of New Orleans is one of the most unique and revolutionary new kinds of commercial cargo vessels in the world.(34) The first of these ships was placed in service in 1972. The system features a completely new self-contained hydraulic stern elevator for fast loading and unloading of cargo away from congested terminals, as shown in Figure 15. Specially designed barges can be floated over the submerged elevator, which can lift up to 2,000 tons of cargo at any time to any one of three decks. On each deck there are self-propelled transporters to move the cargo to stowage. Cargo types include liquids in tanks, unitized, and break-bulk.

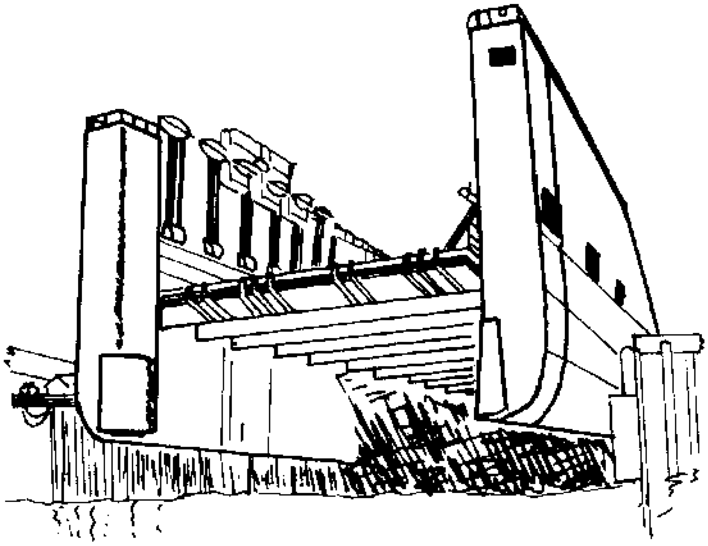


Figure 15 -- Stern elevator for loading and unloading barges on Seabee class ships.

The barges used by the Seabee system are 97.5 ft. long, 35 ft. wide and 17 ft. deep, and load maximum is 850 long tons. They will carry 10 30-foot or 24 20-foot containers, or can easily be converted to special use. Designed for easy integration with regular tows in the United States and abroad, they also are large enough to permit short coastwise voyages in rough water.

Some version of this system, scaled to fit the platform, might be employed as an effective interface with barge transport in Hawaii. The hydraulic elevator might be located at the platform perimeter if it could be designed to clear the buoyancy columns, or it might be placed somewhere nearer the center, to lift barges up from underneath the bottom decking. In either case it might be feasible to service the interior deck area without requiring space on the top surface.

3. Non-coupled Bridge

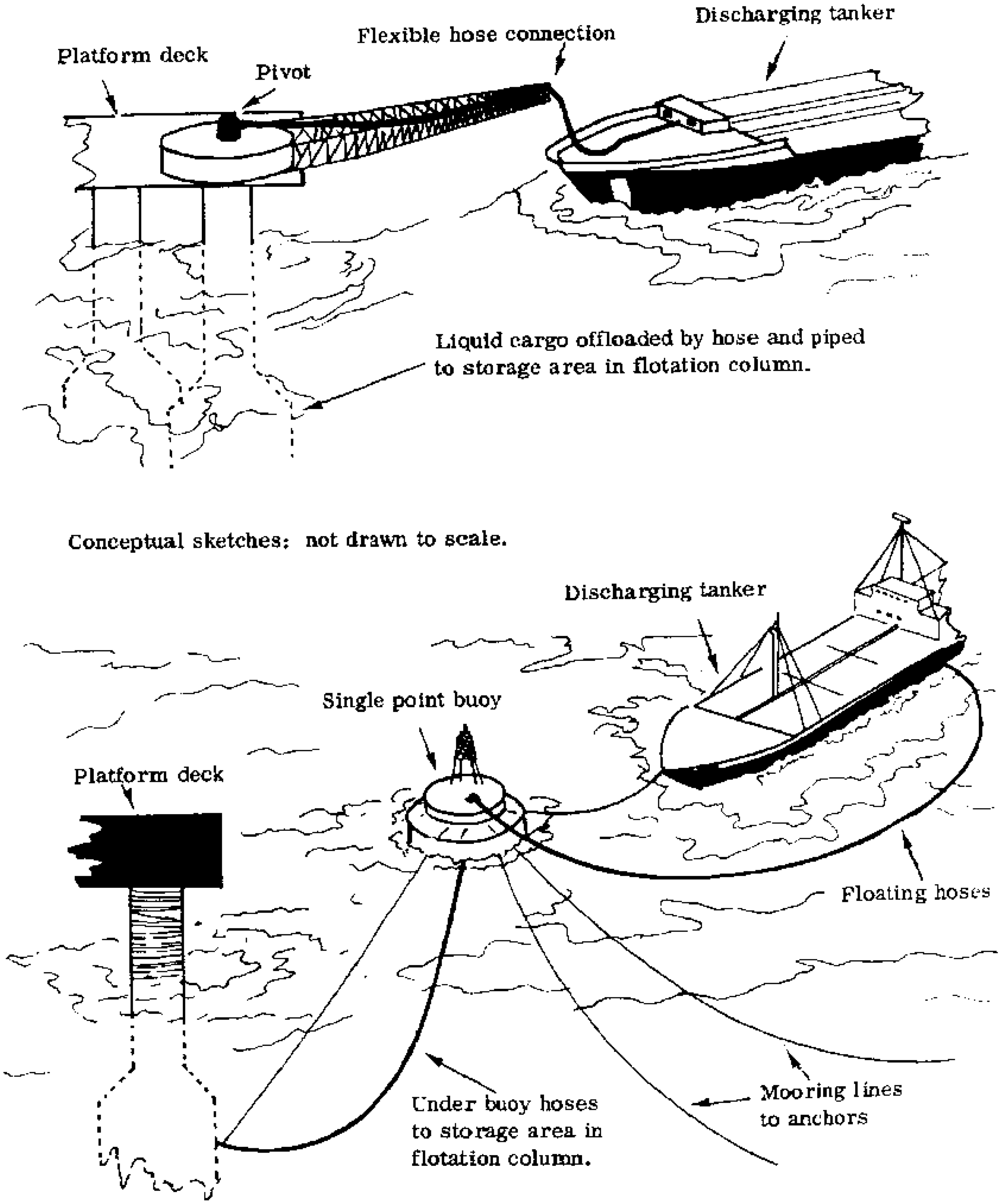
The third interface technique mentioned at the beginning of Section III involves bridging the gap between two vessels without depending upon a direct connection. Currently this approach is confined to the use of helicopters for cargo transfer (Section II-E-1) and as such it is explored later in Section IV-I dealing with air transportation systems. It is appropriate, however, to mention here that it appears to be a technique suitable for on-offloading barges as well as ships. As such it could provide still another practical aspect to the use of barges in the external transportation system.

D. Tankers

Fluid cargo for a platform could be transported by any combination of three methods, all of which are well developed and in current use by the oil industry. Two of the methods--tank containers and barges--have already been discussed.

The third system for shipping bulk liquid cargo is by tanker vessel. Bulk crude oil carriers in current use range from tens of thousands to over 500,000 deadweight tonnage (DWT) capacity. The deep draft of current and future "supertankers"--up to and exceeding 100-foot depth clearances for navigation--exceeds the capacity of most ports, leading to the development of offshore terminals for loading and unloading cargo. On/off-loading employs flexible hose connections ... a method long in use by the Navy for at-sea refueling of ships from tankers while both are underway. Two examples of possible interfaces with a floating platform are illustrated in Figure 16.

The flexible hose type of connection between tanker ship and floating terminal is far less vulnerable to differential motion of the two vessels than are any of the methods for transferring solid cargo--where impact between deck and cargo cannot be avoided. Conceivably a tanker ship could moor to a floating terminal buoy and unload a month's supply of fuel via hose to the platform, by way of the buoy. However, it has already become clear that even if safety considerations were not a constraint in stopping a large vessel close to the platform, the costs involved would not favor this approach and the oil companies themselves are unlikely to agree to it.



Conceptual sketches: not drawn to scale.

Figure 16 -- Two examples of potential linkage systems for on/off-loading bulk liquid cargo between a tanker vessel and a large floating platform.

E. Hydrofoil Craft

Hydrofoil vessels incorporating the first generation technology have been in use for many years. However the early design, employing surface-piercing foils, was impractical for high-speed mass transport. More recently, in the second generation stage of evolution, the vessels have been designed with submerged foils to obtain lift. Unlike its surface-piercing counterpart, the submerged foil is located well below the sea surface where the wave effect on lifting surfaces is reduced. Figure 17 illustrates the several designs. For operation in shallow water the foils are retractable; while in this configuration, maneuverability is maintained by using the main engines and a ducted bow thruster for turning. This system enables the vessel to pivot about its center.

Two technological breakthroughs have improved the performance of hydrofoil craft to the point where they could be considered for incorporation into composite commuter transit systems in Hong Kong, New York, San Francisco, and Honolulu. The first significant breakthrough in hydrofoil design was the use of jet turbine engines to drive the water pumps. The second was an automatic control system for the foils similar to the autopilot systems used on aircraft. Sensors on the leading foil supply data about the oncoming waves for automatic adjustment of the foil attitude to compensate for wave height and frequency. This constant adjustment gives the passengers on the deck a near-level ride.

Since these are passenger vehicles, comfort is an important factor. The interior layout of the cabin is similar to aircraft design. Insulated walls provide an interior noise level under 68 dbA when underway at cruise speed. And even at top speed of 50 knots, exterior noise level is still under 90 dbA. Some facilities for simple food and beverage service are among the amenities.

The hydrofoil has an operating range through sea state 6. Tests on full-scale prototypes have shown a maximum vertical acceleration of 0.05 within this range. During emergency situations, when a fast landing is necessary, hull contact with the water produces an impact of less than 0.5g, which is comparable to landing in a jet aircraft. Under normal conditions landings are programmed by the control system and impact is barely perceptible.

In the first attempt at a waterborne inter-island passenger transportation system for the State of Hawaii since before World War II, three Boeing Jetfoil 929's have been placed on order and are expected to go into service sometime in 1975. Due to their shallow draft (5 feet of water with retracted foils), the craft can operate out of a small boat harbor, using conventional docks or piers, and will operate on a regularly scheduled basis between Oahu and the outer islands. Contracted for at a cost of $4.5 million each, the vessels are 90 feet

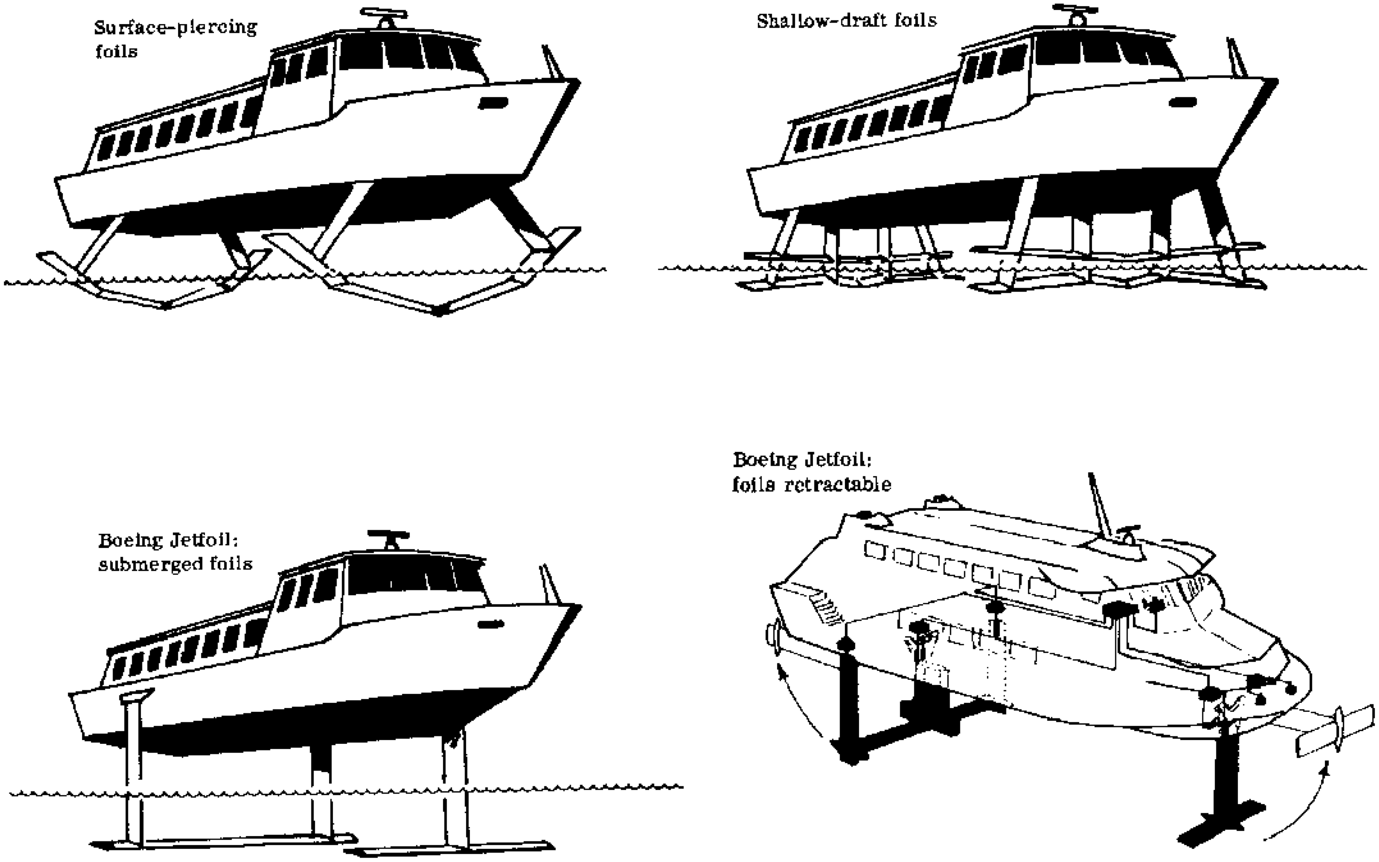


Figure 17 -- Foil configurations for hydrofoil craft.

long by 30 feet wide and carry a capacity load of 190 passengers with baggage, but no freight. Cruising speed is 45 knots.

With the merits of the hydrofoil as a commuter vehicle well established, and with a regular schedule of operation expected by the time a floating platform can be completed and placed offshore of Oahu, the potential attractiveness of incorporating these craft into the external transportation network of the platform is apparent. The main concern, then, is the interface problem involved in the transfer of passengers between the vessel and the platform.

According to analysis of the site environment performed by Dr. Manley St. Denis (1), "the floating city will be exposed to waves having a significant height of 4-12 feet and a period of 5-8 seconds from 90-95 percent of the time during the summer months. Waves of the same sort will prevail slightly more than half the time during the winter months and will be interspersed with some dominance of 1- to 4-foot southern swells with periods ranging from 14-22 seconds about 10 percent of the time." Wave motion of this magnitude prohibits sole reliance on a simple step on/step off procedure for transfer of passengers; some type of wave damper may be necessary to ensure their safety.

In discussing passenger traffic, it would be well to first take note of the fact that the platform deck clears the waterline by 50 feet. Therefore, it will be necessary to place some sort of dock surface beneath the main structure, near the waterline. This area would most likely be partially or entirely enclosed to afford passengers protection from sea spray and wind, and it would necessarily be linked to the main deck by elevators. There might be multiple dock areas, some for arrivals and some for departures, or they might each serve two-way traffic.

One safe interface method would be to lift the entire vessel out of the water and swing it onto the dock platform. This might employ some form of the mechanism used for lifting barges out of the water. It would allow transfer of passengers in all sea states in which the commuter vehicle is capable of operating.

Still another approach, which would be less drastic and which, on the face of it, appears to be more practical, would be to install a form of submerged cradle in each berthing space. As a vehicle approached the dock and came to a halt, it would float into place over the cradle, which would then be raised to either hold the vehicle stationary with respect to the dock, or to raise it slightly out of the water. This principle is conceptualized in Figure 18. At departure time, the cradle would submerge and float the vessel free again. It may be seen that this concept possesses some elements in common both with the design of a drydock and with the stern elevator of the Seabee cargo ships.

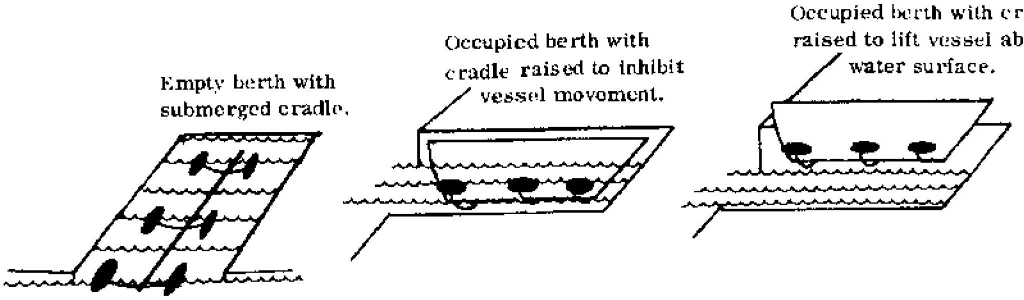


Figure 18 -- Submerged cradle system for docking passenger craft.

F. Surface Effect Vessels

While surface effect craft are operational in some instances, such as the English Channel ferry and for specialized military missions, for the most part they must be considered still in the developmental stage. As amphibious vehicles operating over solid or liquid substrates alike, they ride on a cushion, or bubble, of air. Commonly termed hovercraft, these vehicles are in contact with their substrate only when at rest.

Fans create a flow of air from the bottom of the vehicle, directed toward the underlying water or ground surface. An inflated rigid or flexible skirt suspended from the perimeter of the craft confines the air flow beneath the hull, forming in effect an air bubble on which the craft "rides". The bubble (or confined forced-air flow) provides enough lift to support the entire vessel approximately 2 to 6 inches above the water surface, as illustrated in Figure 19.

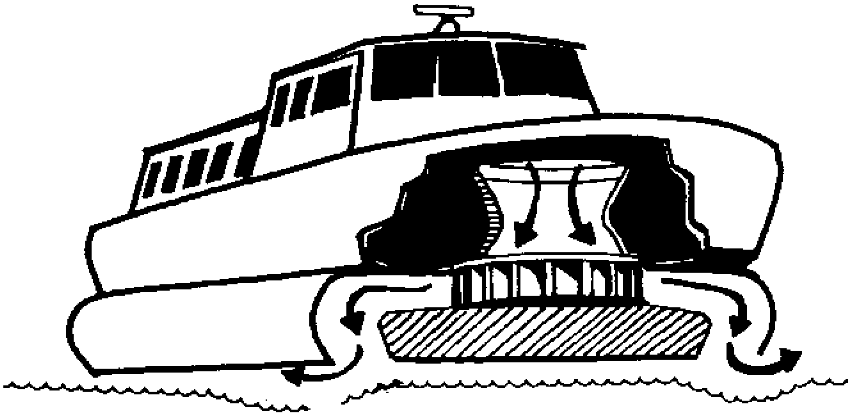


Figure 19 -- Simplified design of surface effect craft.

Horizontal propulsion is provided by fans mounted on pivoting pylons at the stern. These fans steer the craft by rotating about the pylon, in much the same manner as steering by rudder, while propelling it at speeds in excess of 80 mph.

Hovercraft attain high speed through minimal drag or friction by riding on air free of contact with the sea surface; yet they operate so close to that surface as to be extremely susceptible to sea state limitations.

The load-carrying ability of surface effect vessels is related directly to their power output which, in turn, is tied directly to fuel consumption. Since the volume--and therefore the loaded weight--of any vessel is roughly a third-power function of its length, and since power required of a surface effect craft is roughly a linear function of its weight, these vehicles would appear to have inherent size limitations. Consequently it is probably not appropriate to consider this class of vessel for any service other than passenger and light freight transport.

With respect to passenger traffic the size limitation is related to the sea state limitations, since the ability of hovercraft to traverse seas comfortably is at least partially dependent on the ratio of wave height and length to vessel length. Actually, although this type of vehicle can operate in seas up to 10 feet, passenger comfort requirements would limit its operation to 2-foot seas. Figure 20 gives a comparison of vertical acceleration versus wave height for the hovercraft, the hydrofoil, and a conventional surface-displacement vessel of comparable size.

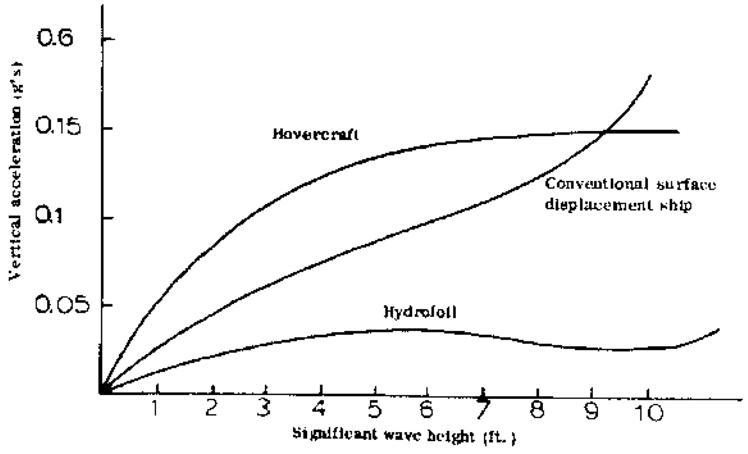


Figure 20 -- Comparison of vertical acceleration patterns for hydrofoil, surface effect, and conventional craft.

The Hawaiian wave climate would render surface effect craft unacceptable for open sea passenger transport as a component of the external transportation network of a floating platform in this locale. Future consideration of this vehicle type in connection with platforms in other sites would depend on sea state patterns at those sites.

G. Semisubmersible Ships

The semisubmersible ship (or S^3) is also known as a Small Waterplane Area Twin Hull (or SWATH) craft. The concept is, in fact, a moderate-speed, self-propelled expression of the same semisubmerged platform concept upon which the Hawaii Floating City platform and semisubmersible marine drilling rigs are based. This vessel's stability is affected somewhat by its speed and its heading relative to surface waves, but the basic stability characteristics inherent in semisubmersibles remain, even when it is at rest. For this reason, the S^3 appears potentially attractive as a component of an external transportation system and a mode of interface with the floating platform.

The original concept of a semisubmerged ship, introduced by C. G. Lundborg in 1880, consisted of a single submerged hull. In 1929, W. R. Blair filed a patent for the first multihull semisubmerged ship, which was designed as a floating air terminal. (35) Recently the Naval Undersea Center (NUC) has been investigating the S^3 concept in the development of a high-speed material and personnel carrier. (36, 37, 38) The NUC prototype design consists of two hulls, 6.5 feet in diameter, submerged 15 feet below the water surface. Each hull is joined by two surface-piercing columns to the 45 x 62 foot deck, which rides above the water surface, as may be seen in Figure 21. With a displacement of 190 tons, the design payload is 35 tons, maximum speed is 45 knots, and the cruising range is 450-675 nm. (36)

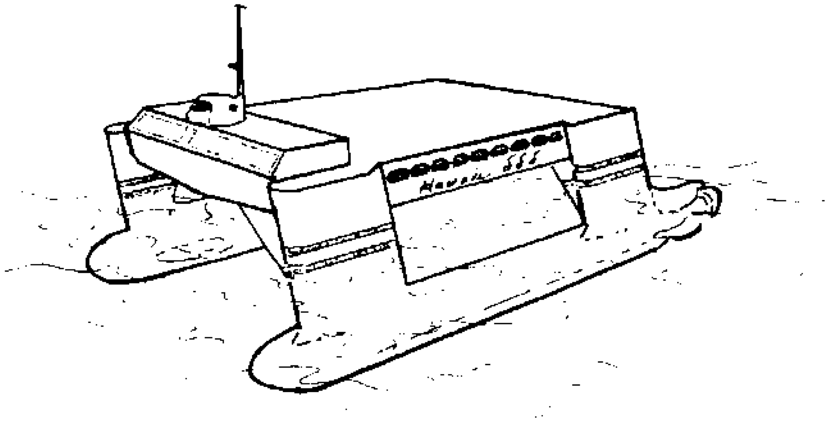


Figure 21 -- Hull configuration of the semisubmersible ship (S^3).

The 190-ton prototype S^3 launched by the NUC serves as a model for testing the concept for a 3,000-ton version. At this time only preliminary test results from the 190-ton model are available, but based on earlier work with a much smaller scale model, the S^3 looks very promising. Test results indicate that wave drag is negligible at cruise and top speeds; this allows the ship to have good burst speed capability. Model basin studies predict that the 3,000-ton vessel would operate nearly level through sea state 6 and well into sea state 7.(39) This means that, given the prevailing weather, the S^3 would be operational in Hawaiian waters and could safely interface with the platform approximately 90 percent of the year.

Lacking the size limitation of the jet hydrofoils and the hovercraft, the semisubmersible design concept potentially has the versatility to fill several roles in an external transportation system. Whether future development realizes this potential remains to be seen.

1. Passenger Traffic

Outside of the test models there have never been any plans to produce the S^3 in any versions smaller than 3,000 tons. However a smaller craft, such as the 190-ton model, could have definite merit as a high-speed passenger vessel operating between the mainland and the platform, as well as the neighbor islands. Its 15-foot draft would permit access to all the deep-water ports in the island chain and the ballast can be varied to permit a minimum 6.5-foot draft in shallower, calm-water harbors. Its small overall dimensions, plus its twin offset propulsion system, would give the craft the high degree of maneuverability desirable for operation within the platform's perimeter.

2. Cargo Traffic

For cargo transport the 3,000-ton version of the S^3 could be an ideal vehicle. If the payload is assumed to be no less than 20 percent of its displacement, it should have a carrying capacity of at least 600 tons, or roughly 30 standard 8 x 8 x 20-foot containers. (The payload might be somewhat less; the exact figure is unknown at this time.) Although the dimensions of the vessel have not been determined, preliminary engineering calculations show that a deck size of 315 x 137 feet is attainable with an operating draft of 28 feet.

The deck size affects the vessel's maneuverability, and it could create hazards for operation inside of the platform's perimeter. This potential danger could be alleviated by placing the terminal facilities at the perimeter and by protecting the buoyancy columns with a fender system. Cranes mounted on the platform or a helicopter could be used for cargo transfer.

At this stage in the design and development of the semisubmersible ship, several limitations are apparent in considering its potential role as a component of the offshore community's external transportation system. Until further development proves out their validity, they are factors to be recognized and given further consideration:

a. The ratio of structural weight to total weight is greater for the S^3 than for conventional ships of the same displacement.

b. Its broad beam may present problems in docking or dry-docking.

c. A more precise and responsive static trim is needed.

d. The draft of a large cargo version may be too great to be accommodated in the local Hawaiian deep water ports.

H. Submersible Carriers

The transportation modes discussed so far have ranged from conventional craft in common use to some that are still in developmental stages. The latter have progressed beyond the purely conceptual phase, but have yet to be proven practical for large-scale commercial application. All have this in common, however: they require a vehicle-platform interface at the sea surface. Several possibilities have been considered for eliminating the surface forces on at least one of the two vessels by removing it from the surface environment altogether.

Another possibility might lie in the use of sub-surface craft to move passengers and/or cargo between the platform and the shore ports. The concept of fully submersible craft as an external transportation subsystem for the floating platform is entirely speculative at this juncture, and this fact must be kept in mind throughout this discussion.

1. Design Concept

In hypothesizing the design of a cargo submersible system the first assumption is that each ship should be capable of transporting a minimum of several 8 x 8 x 20-foot shipping containers, or the equivalent load in break-bulk or pallets, between the shore and the platform. For a passenger submersible, capacity most likely would need to be at least comparable to surface craft, but the break-even point would have to be a function of the capital investment amortization and operation cost versus the income from fares, all of which have yet to be determined.

Maneuverability requirements when operating in proximity to the platform would place constraints on hull length; diameter would be a function of the minimum load capability for economical operation versus the maximum load for safe operation. Figure 22 shows a typical configuration of a submersible cargo hold, incorporating a Ro-Ro deck for loading and unloading. It bears considerable resemblance to the interior of a cargo jet. The cabin of a passenger submarine could also be expected to resemble an airliner.

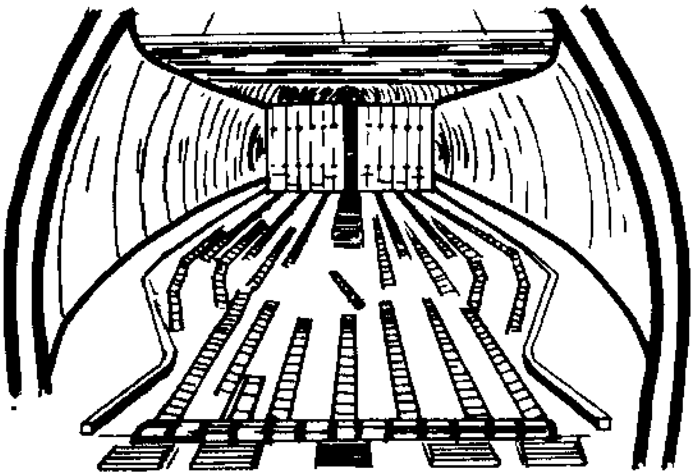


Figure 22 -- Hold configuration for a cargo submersible.

Although a submersible carrier could surface beneath the platform for on-offloading, this would negate the objective of avoiding surface stresses during interface. Therefore the interface would be located at some depth on one or more of the buoyancy columns. It might be noted here that for exterior maintenance and cleaning (defouling) of the platform substructure, diver-supported operations may require pressure locks at various depths on the columns. The maintenance operations, as well as other undersea activities connected with platform-based enterprises, may even employ working submersibles which might be housed in the column interiors. Pressure locks for access by divers and/or work vehicles might be multi-purpose, serving also as docks for cargo or passenger craft; or the technology for these might be modified to provide docking ports. Another possibility is the employment of a mating ring to provide a watertight seal against ambient sea pressure. Here spacecraft technology developed to enable link-up with orbiting satellites might be applied to the undersea environment.

To maintain neutral buoyancy while on/offloading, the submarine must be equipped with large ballast tanks and large-volume water pumps whose flow rates are controlled by sensors capable of measuring instantaneous static loading.

Propulsion system design for the submersible would depend upon the distance between terminals. For the 5-mile stretch between the floating city and Honolulu harbor, an efficient propulsion system might combine two methods. During transit between harbor and platform, the sub could operate at snorkel depth on diesel engines that also would charge lead-acid batteries. Upon reaching the platform the sub would switch to the batteries before descending to mating depth, and would remain on battery power until it returned to snorkel depth for the return trip to the harbor by diesel. Deeper running depth would, of course, be necessary during extreme weather or wave conditions.

2. Operating Concept

The docking and loading procedures for the submersible carrier are likely to be quite different at the shore and platform terminals. Platform docking procedure is implied in the preceding discussion of system design. Once it is accomplished, a clamshell-type door in the bow of the submarine would allow access to the passenger or cargo compartment. At this point on/offloading of containers, pallets, mobile cargo bins, etc., could be handled in much the same manner as the cargo-handling systems of the large cargo jets, with mechanically assisted Ro-Ro tracks. Figure 23 depicts this concept.

Loading of the submersible at its shore port might be accomplished in any of several ways. It conceivably could be boarded by passengers in much the same manner as a Navy submarine now is boarded by its crew, but this would require a safer and more comfortable route to the cabin than the ladders now used for descending into the ship's hull. Two more sophisticated procedures are conceptualized below; the first would be suitable for either passenbers or cargo, while the second would serve only cargo.

a. In a specially designed drydock facility, the submarine could enter its berth, either at the surface or submerged, and come to a stop poised over a submerged cradle. The hydraulically activated cradle would then raise the sub above the water level for access to the bow door, as in Figure 24. This scheme requires specialized terminal facilities, and although it probably would maximize passenger comfort, it well might not be practical for the volume of passenger and cargo traffic generated by a single platform.

b. A second method, and one that is perhaps more economically feasible for handling cargo, would be to equip the submarine with a double-door hatch situated on the top of the hull. The hatch opening would be large enough to

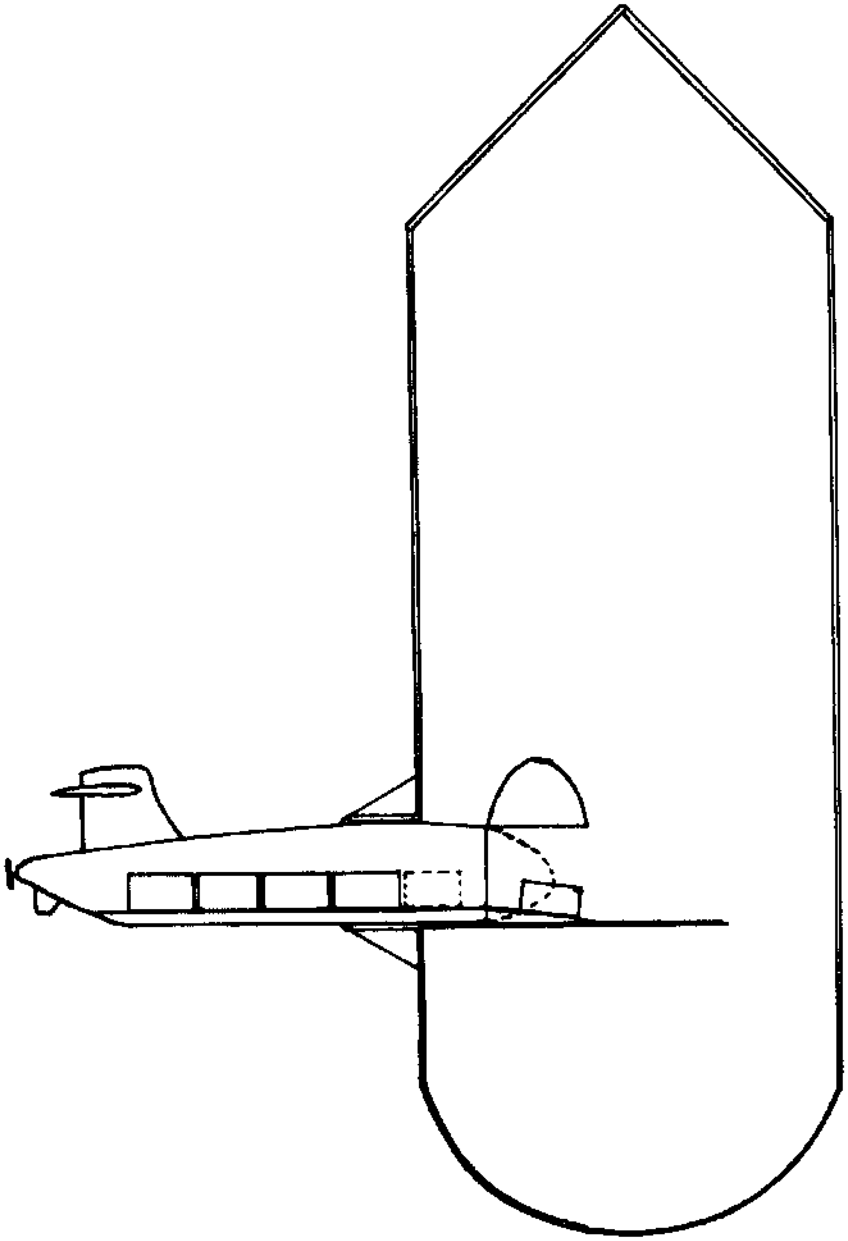


Figure 23 -- Docking and loading system concept for a submersible carrier/floating platform interface.

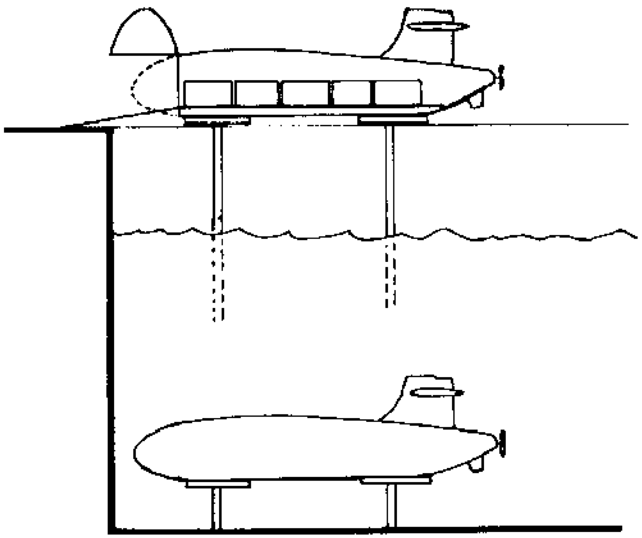


Figure 24 -- Shore terminal docking design concept for a multi-purpose submersible carrier.

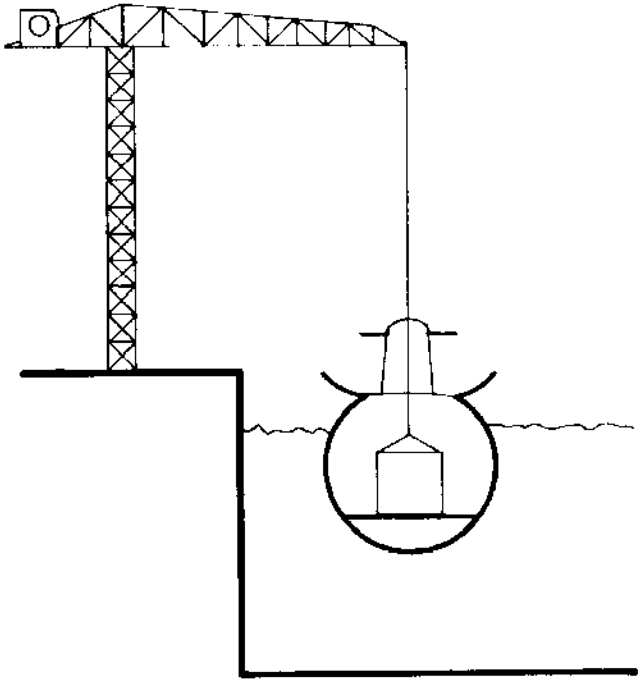


Figure 25 -- On-off loading system concept for a cargo submersible at shore terminals.

accommodate a 20-foot container with adequate clearance. With the submarine positioned on the surface, as in Figure 25, the hatch covers would be opened and the cargo would be transferred by overhead crane in much the same manner as for a conventional cargo ship or barge. This second concept provides maximum system flexibility since it does not depend upon special port facilities, but it would not take advantage of the speed and efficiency inherent in the craft's Ro-Ro capability.

3. Applicability to the Floating Platform Transportation System

The most obvious merit of a submersible passenger or cargo ship is that its operation would not be hampered by sea state conditions. Due to its load limitations, it could not be expected to eliminate the use of barges for outsized containers (over 8 x 8 x 20 feet) and for other bulky cargo.

The use of fully submersible craft for interface in the open sea is appropriate only for large semisubmerged platforms that are deep enough in draft for the substructure to extend below the realm of significant orbital motion. And the portion of the buoyancy columns extending to this calm depth must be sufficient to provide an adequate on/offloading area to interface with a submersible lying below the zone of surface turbulence. A shallower operating depth might provide for economies in operation and in docking facility construction, but it would place stress on the linkage and lose the advantage of deep-water calm, thereby canceling out the purpose in using submersibles.

Since the floating city platform meets the requirement for buoyancy columns extending to sufficient depth for advantageous docking, development of cargo submarines as a component of the external transportation system may be an approach worth investigating. As a passenger vehicle, a submersible would be somewhat slower than a surface craft; however, it could offer safe, comfortable transportation during periods of rough weather when surface craft are inoperable. This could be a valuable backup system when a crisis condition makes immediate evacuation of the platform mandatory. Of course cargo subs could also be pressed into service for this purpose in an emergency.

It must, however, be kept in mind that (as pointed out elsewhere in this study) even if the submersible is nearly motionless the large platform may not be if input wave forces are of low frequency. Further study is required here on the potential stresses involved. Too, the costs involved in developing and constructing the docking system, and in capital investment in the submersibles, may make this concept impracticable in comparison with other modes of transport.

I. Airborne Transportation Systems

A second approach to avoiding the stresses of surface interface entirely lies with the possibility of incorporating aircraft into the external transportation system for the floating city. (This is not to be confused with the potential functional application of a floating platform as an airport terminal.) Due to the limited deck area and the multi-purpose use of that space, a lengthy runway for fixed-wing aircraft obviously cannot be provided; so the only type of aircraft suitable for platform support would be the vertical takeoff and landing (VTOL) craft, i.e., helicopters, which can take off and land in spaces only slightly larger than the craft itself.

Helicopters have proved to be practical and economical transportation vehicles in support of offshore oil production, where they have played a prominent role in the transport of men and materials to the hard-to-reach open sea rigs since the early 1950's.(40) These same craft have been called upon for ambulance service, rescue, and for emergency evacuation in the face of impending storms. The heliport, or landing pad, has become an integral part of an oil platform's design. Figure 26 shows one such rig. In Section II-E-1 the Navy's extensive use of helicopters for cargo transfer between ships has already been pointed out. In both cases, cargo is handled in units less than container size.

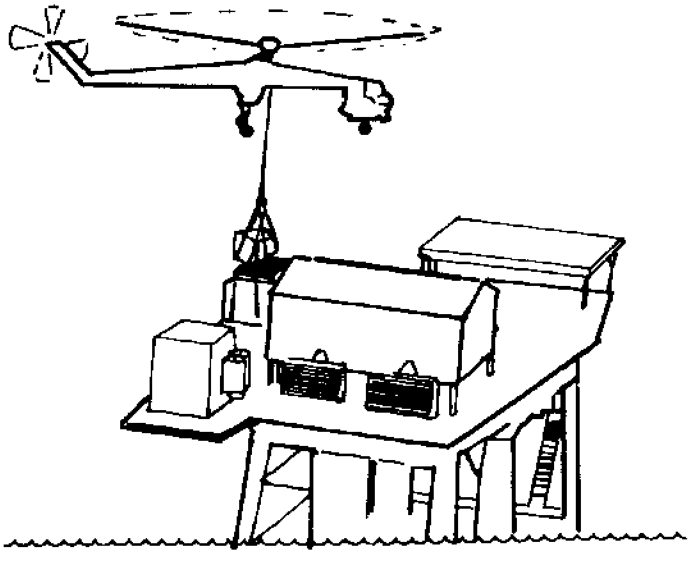


Figure 26 -- Cargo transport to offshore oil platform by helicopter.

Bell, Boeing, and Sikorsky are the three principal companies currently designing and constructing commercial helicopters. Going beyond the helicopter's role in supporting offshore installations, these three manufacturers have given remarkably successful demonstrations of its potential for off-loading container ships at sea. It appears that the ship-to-shore delivery concept was first tested in 1967 when American Export Isbrandtsen Lines and Sikorsky Aircraft conducted a trial in Long Island Sound to prove its feasibility. The project objective was to deliver containerized cargo weighing up to 10 tons from the deck of a ship to a destination five miles distant. During the trials, storm warnings were posted and the wind gusted up to 50 knots. Despite the adverse conditions, the offloading project continued on schedule and within the projected performance times. At the conclusion of the 5 1/2-hour test (including refueling stops), 31 containers had been transported at the average elapsed time of 9 minutes, 36 seconds per round trip.(41)

1. Operating Characteristics

Free as they are from contact with the water surface, helicopters are not affected by sea conditions; the one environmental factor acting as a constraint on operations is the wind velocity and gustiness. The H-46 helicopter used by the Navy, with a payload of 5,000-7,000 lbs., can operate in winds up to at least 45 knots. And in the test conducted by Sikorsky, the S-64F, with a 10-ton payload, maintained operation on schedule in winds up to 50 knots. The environmental analysis of the Floating City site concluded that "A velocity of 22-27 knots appears to be the highest mean wind intensity, occurring a total of only 1.3 percent of the year." For short-term peak intensities (1-minute average over a 1-month period), highest recorded value was 53 knots. Peak gust intensity recorded at Honolulu Airport (1959) was 58 knots. Long-term mean wind intensity (100-year return period) was estimated at 39 knots. (1) It can be concluded, then, that in its operational area, a helicopter supporting the platform offshore of Hawaii would remain operational in excess of 95 percent of the time.

In economic terms, the cost of helicopter operation drops off sharply in inverse ratio to the flight hours per unit time. The graph in Figure 27 plots base hourly cost data for annual utilization rate of the Sikorsky S-64F. Base cost here includes depreciation, insurance, interest, fuel and oil, personnel, and maintenance. (42) A second graph, Figure 28, shows the number of off (or on) loading cycles/hour versus radius that the S-64F can maintain with a 1-container payload. A quick calculation of the hourly cost per utilization rate,

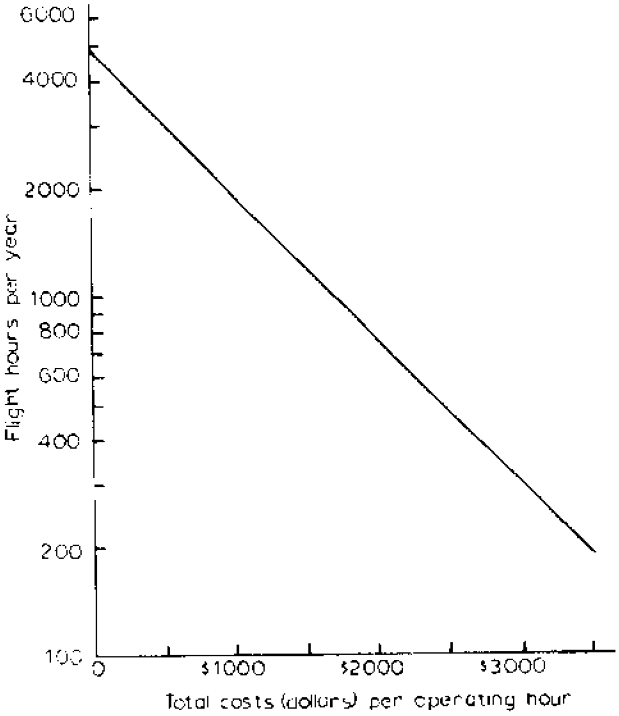


Figure 27 -- Base hourly cost versus annual utilization rate for the Sikorsky S-64F. (42)

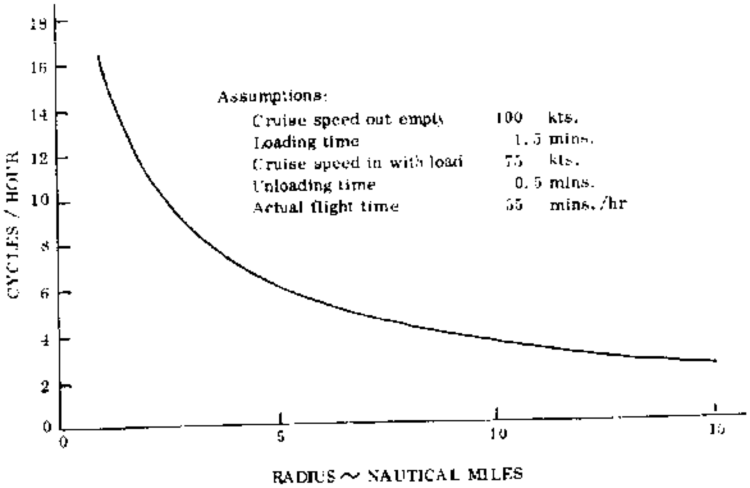


Figure 28 -- S-64F containership offloading cycles/hour versus radius (helicopter with 1-container payload). (42)

from Figure 27, versus the number of offload cycles per hour over distances of 5nm and <1nm, yields the following comparison.

Table 2 -- Helicopter offload cost per container

Trip distance / Utilization rate	5nm	1nm
500 FH/yr.	$419	$152
1,500 FH/yr.	224	81

(FH = flying hours)

From this comparison it is apparent that helicopter transport is most suitable, economically, where it is characterized by heavy utilization over short distances.

2. Application to Floating Platform Transportation System

Based on its proven capabilities, the helicopter seems to be a transportation mode particularly well suited to support multipurpose offshore platforms. The principal consideration appears to be whether it could be kept busy enough; not only the cost ratios but the harsh effects of the open sea environment on machinery dictate constant use.

Only two models of helicopter have been discussed so far, both of which possess a fusilage that functions primarily as a skycrane. These would be highly efficient craft for transferring cargo between the platform and a barge or a small cargo ship. For traffic between the platform and the shore, other types designed to carry cargo in their interiors--such as the Chinook CH-46, with a 4,000-lb. payload, and the CH-53, with a 12,000-lb. payload--could be more practical. These now are commonly loaded with palletized cargo. Helicopters with the flexibility to handle cargo and passengers interchangeably would maximize craft usage. This would involve a helicopter fusilage frame to which a standard-size container-like unit could be attached. One version of the unit would be a cargo carrier and another version could be outfitted inside as a passenger cabin. The helicopter would carry the passenger unit during commuter shuttle hours; then it would deposit it at the shore terminal (where it might be based) during off hours and shuttle the cargo unit between shore and platform. Since the number of cargo trips per hour that could be achieved over the 5-mile hop would be limited, this would probably be most practical for high-value or perishable goods, while the bulk of cargo could be barged and handled by a skycrane helicopter at the platform. Other potential employment during otherwise idle hours could be as a relatively high-fare tourist attraction and airport shuttle.

Terminal facilities for a helicopter would include a landing pad, probably 80 to 100 feet square, with free air space above it, and with adjacent refueling and maintenance facilities. Refueling capability might not be required for a shore shuttle, and this would eliminate a hazard, but it would be needed for a skycrane if this were in constant use, at times. The principal hazard to the platform environment would be presented by noise and downwash produced by the rotor. Countermeasures in the form of cantilevering the heliport from the platform perimeter and surrounding the pad with wind deflectors could alleviate the problem. Certainly it would be a consideration in overall system design. The heliport would also have to connect with the internal cargo movement system, and would need a certain amount of cargo staging area. This latter could be minimized by efficient and rapid cargo flow, and the use of folding or retractable wing decks at the platform perimeter. Such wing decks might possibly serve also as auxiliary landing pads for any occasion when emergency evacuation might require assistance from other helicopter operations ashore. Obviously, normal system backup would be required at all times to maintain service during craft maintenance and downtime periods. Given the limited space aboard the platform, the backup craft could be stationed ashore, possibly at the airport.

J. System Design Considerations

Assuming all the external transportation modes mentioned above to be technically feasible, how is one to make a choice among them? What useful criteria can be established on which to base the selection of one approach to moving people and goods over another?

The most critical variables will be cost and reliability. (Surprisingly, safety is not a criterion of choice, for all systems under consideration will have been *a priori* qualified as acceptably safe.) Other variables will include, for passengers--comfort, convenience, and user acceptance; and for cargo--adaptability and flexibility. Ultimately all of the variables are related to the basic considerations of optimum fit and economy of investment and operation.

The open sea location of the floating platform renders it uniquely vulnerable to its environment in the matter of transportation links. For a population of the size projected for the floating city, the dependability of those transportation links is critical. Its dependence upon outside sources for food, fuel, and all other supplies has already been pointed out. As a visitor center it must be accessible, and a resident population must have reliable commuter transportation for business and other activities ashore. Figure 29 shows graphically the degree of weather limitations upon the potential transportation modes. It is apparent that the most dependable mode is also the least conventional, and for passenger traffic the question of user acceptance would have to be dealt with here. It also is apparent that no single mode offers 100 percent reliability. The variety of modes available, and the requirements for system backup and flexibility will have to be balanced against economies of scale to be realized by reliance upon fewer and larger subsystems in order to determine the optimum fit in terms of economy and dependability.

The problem of handling commuter traffic is similar to the quandry facing urban metropolitan areas on shore. With a few exceptions, they have long postponed their day of reckoning by the relatively simple device of laying down strips of concrete on the land, allowing their commuters to exercise their inclination to furnish their own private transportation, until eventually the resulting impaction of the city's arteries forces them to consider capital investment in public mass transportation (or the urban core dies and the city sprawls out over the land). The floating city would not have that option at the outset, and the cost of providing mass transit, unrelieved by private transportation, might pose an economic barrier that would cause the size of the resident and visitor population to be transportation-limited.

When developing realistic cost estimates, several questions should be asked, some of which may not be readily apparent, at least in the beginning.

1. The question of fit involves a careful matching of the gross capabilities of the selected mode to the problem at hand. An example is the selection of a size and shape of cargo container that meets the demands of Floating City residents and matches the cargo bays of short-haul city-oriented equipment, but does not fit any of the standard long-haul specifications. The result may be a cheaper, more efficient short-haul from the city to shore, but a greater cost to the shipper because of the extra handling involved in repacking the goods into standard containers.

A somewhat different kind of question of fit arises, for example, with consideration of helicopters. Strong economies may be possible in terminal facilities, maintenance costs, all-weather operation, and relative freedom from built-in limitations of the size of cargo containers, as well as through the existence of a well-developed, fully tested technology. But whereas all the cargo traffic generated by the city might be handled easily by one large cargo

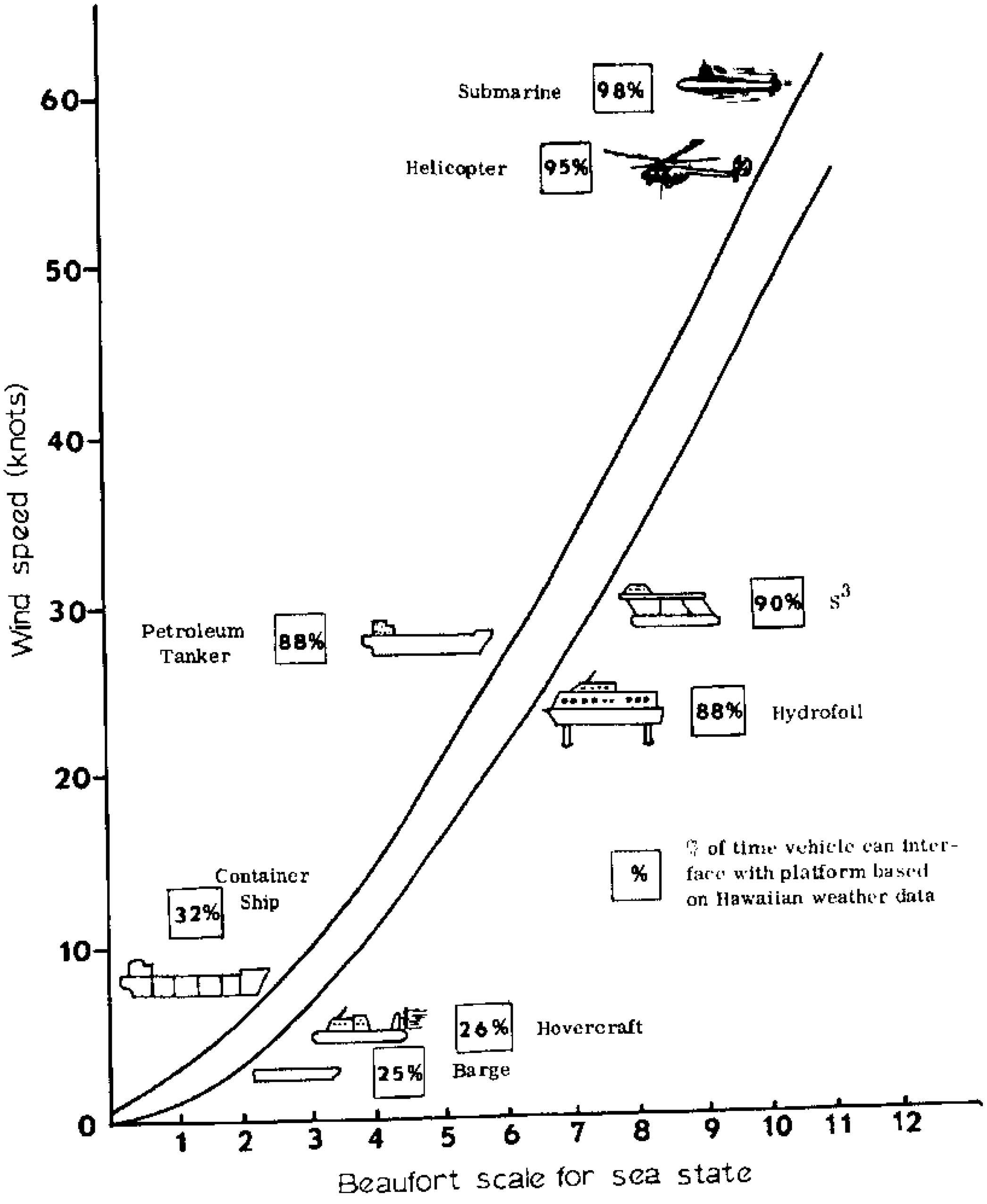


Figure 29 --Wind and sea state limitations on interface between a floating platform and potential transportation modes.

helicopter, the problem of several thousand residents commuting to shore each day might be economically insurmountable with helicopters.

The hydrofoil is another example of the fit problem. In subsection IV-A-3 we derived some estimates on commuter travel volume. Given that these figures are strictly theoretical, for modeling purposes, it developed that for a floating city of 15,000 residents in which half the population commuted to shore daily for work or other purposes, the peak traffic volume (morning rush hour) might be about 1,800 passengers per hour. An overnight visitor population of 2,000 might add another, say, 500 passengers returning to shore to make travel connections, etc. We will ignore, for the moment, the diurnal visitors who would be travelling in a counterdirection to the commuters. Over a two-hour morning peak period, then, there might be 4,100 passengers to transport to shore. The Boeing Jetfoil 929 in service in Hawaii has a capacity of 190 passengers. Allowing a 10-minute period for loading and unloading at the terminals and a minimal 10 minutes travel time, each craft--at optimum efficiency--could make three round trips per two-hour period, for a total of 570 passengers from platform to shore. Assuming the absence of other transport modes, it would take seven hydrofoils to cope with the 4,100-passenger load, and as we can see from the simple illustration in Figure 30, they would require two terminals at each end of the run. The Boeing Jetfoils in Hawaii cost approximately $5 million each, so this would represent a capital investment of $35 million, exclusive of the cost for four terminals. Adding to the scheduled amortization on this investment the factors of labor, operation, maintenance costs and depreciation, it appears that the fares might be too high for user acceptance. There is also the question of how to economically utilize the seven hydrofoils during non-peak hours and on weekends. Incorporating the shore/platform link as one leg of an overall marine mass transit system might be a possibility for off hours traffic, but the peak commuter load appears likely to overtax such a system during periods when the system as a whole also is carrying peak volumes, unless alternate modes ease the pressure.

2. The question of uniqueness, or the degree to which the planned transportation system requires new hardware designs, also poses some unsuspected problems. First of these is the development cost for the hardware. While it is evident there will be extra costs for development of a cargo submersible, for example, which can be shown to be cheaper to operate than a surface craft of equivalent capacity, and to have as well a greater degree of freedom from weather limitations, what may not be so evident are the costs of specially designed airlocks, elevators, and cargo handling equipment at the Floating City, as well as specialized docking facilities ashore.

	Round trip #1				Round trip #2				Round trip #3					
Time in minutes:	5	15	25	35	45	55	65	75	85	95	105	115	120	
Hydrofoil #1	T #1 L	in 〰	ST #1 U L	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	PT U	(1)
Hydrofoil #2	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	
Hydrofoil #3	T #1 L	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	PT #1 U L	in 〰	ST #1 U L	out 〰	PT #1 U L	in 〰	ST U	(1)
Hydrofoil #4	in 〰	ST* U L	out 〰	PT* U L	in 〰	ST* U L	out 〰	PT* U L	in 〰	ST* U L	out 〰	PT* U L	in 〰	
Hydrofoil #5	T #2	in 〰	ST #2 U L	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	PT U	(2)
Hydrofoil #6	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	
Hydrofoil #7	T #2	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	PT #2 U L	in 〰	ST #2 U L	out 〰	PT #2 U L	in 〰	ST U	(2)

PT #1 = platform terminal #1
PT #2 = platform terminal #2
ST #1 = shore terminal #1
ST #2 = shore terminal #2

PT* and ST* = platform and shore terminals of choice
U = unload (5 min.)
L = load (5 min.)
〰 = travel time (10 min.)

Figure 30 -- Hypothetical schedule to move 4,190 commuters in 2 hours, using hydrofoils with capacity of 190 passengers.

In addition to the predictable development costs associated with a unique solution to the transportation problem (or some aspect of it) there is the added question of risk. For a system under design, for which by definition cost experience is lacking, risk involves the following:

a. Can design performance be made to match demand?

b. Will this design performance be achieved?

c. Can all significant physical factors be controlled?

d. In the case of passenger service, will the system achieve adequate user acceptance?

e. Will capital and operating costs be acceptable?

f. Will the weather-related use factor be tolerable?

To a greater or lesser degree, all these questions will be answered only after the unique system has been in service for some time. At the beginning, the designer must be prepared to face this fact and to assess the risk, and hence the cost, of guessing wrong.

In short, it appears prudent for the designer of transportation for the Floating City to consider just those existing modes and systems which show a high degree of "fit" to the problem at hand and whose implementation requires the least new hardware, and to understand the economics of these systems thoroughly. So armed, he may then attempt to achieve higher or more economic performance with new solutions.

V. INTERNAL TRANSPORTATION MODES

As pointed out in the review of the floating platform structure in Section III-A, its cylindrical, three-dimensional lattice-type configuration presents some interesting problems and opportunities for an internal logistics system. The three flotation columns that support each module can house three vertical transport segments roughly 65 ft. apart at the perimeter and 85 ft. apart from rim to center. When modules are joined into a ring, as in the core-ring configuration, the maximum distance between any two inner vertical segments (i.e., through the diameter) will be less than 500 ft. This maximum distance will increase slightly as concentric rings or partial rings of modules are added, but since it is unlikely that any module assemblage would exceed four rings in size, the probability that any point-to-point horizontal distance will exceed, say, a half-mile is quite low.

Given the area limitations, the principal transportation requirement for personnel will be vertical movement. Horizontal transportation probably will be secondary, and might be largely limited to persons carrying bulky and/or heavy loads and to persons with limited mobility, such as invalids and semi-invalids.

For transport of goods and materials of all types, vertical movement retains its importance, and the geometric configuration of the floating station offers some intriguing opportunities to design a logistics net characterized by minimum expenditure of energy.

It might be useful at this point to review the probable space allocation within the platform structure, to conceptualize the areas that will be served by internal transportation and their relative location. Referring back to Figure 5 on page 23, it is apparent that the superstructure may be occupied primarily by living space and public areas. The prime space on the main deck surface will probably be in demand for public facilities, commercial enterprises such as restaurants and shopping esplanades, recreation and open space, and possibly a mass transit system. The 40-foot-high main deck can accommodate four interior levels, although these are not required to maintain structural integrity. Some of these levels can provide space for theatres, classrooms, lecture and exhibition halls, and enterprises similar to those on the deck surface. In other areas, interior space up to 40 feet high can be utilized as required for warehousing, cargo handling, and hangar and maintenance facilities for helicopters and other craft, etc. Exterior port openings at the rim of the deck could provide access to barges for cargo on/offloading by retractable cranes, keeping this activity off the surface. Such multiple access could improve block stowage and selective discharge, while reducing horizontal internal flow paths.

Folding wing decks could provide additional staging areas here. Or port openings beneath the deck could provide for lifting surface craft into the bottom deck level.

The buoyancy column interiors would probably be designed as minimum traffic areas since each column will have 4 watertight bulkheads which would inhibit vertical movement. Here the support machinery would be located, including power plant, desalinization, waste treatment, propulsion, air conditioning, etc. These spaces normally would be closed to the public and require minimum access by the service crew. The upper level of the column substructure might be utilized for underwater labs and exhibition, and other purposes, provided watertight integrity could be maintained for the top bulkhead.

The preceding description of platform layout is about as far as it is practical to go in level of detail until the platform mission is outlined.

Internal transportation system design should be required to satisfy the following criteria.

1. There should be multiple non-interfering flow paths.

2. Flow paths should be simplified to the maximum degree possible.

3. Equipment capacity should be balanced along the entire flow path.

4. Flow paths should not consume space needed for other purposes.

5. Speed and scheduling of carriers should be sufficient to minimize queuing.

6. Alternate flow paths must be available to bypass malfunctioning equipment.

7. System backup in the form of extra equipment and/or alternate carriers should be designed in to handle maintenance and unscheduled breakdowns.

In addition to these general criteria, two more related specifically to cargo and one related to passengers should be added.

8. For cargo, flow paths should eliminate needless double handling. This requires coordination of on/offload terminals, storage areas, and internal user and/or producer areas.

9. Cargo prestage areas should be designed into the system to enable high peak flow rates as needed.

10. The total system should be programmed to operate in an emergency mode, specifically to handle evacuation of all personnel within a specified time limit in the event of a catastrophic crisis.

Before the question of system design is explored further, it might be useful to survey some transportation modes that potentially might constitute system components.

A. Elevators

An elevator is the single effective vehicle for providing rapid access and movement of people and materials to all levels of a multi-level structure such as a tower-type residential or commercial building on land, or a large semi-submerged platform at sea. Elevator technology now provides high-speed vehicles capable of traveling at speeds in excess of 1,800 feet/minute, with semi- or fully automated controls for variable patterns of service and access to the various structural levels along their vertical tracks.

The design of an adequate elevator system--whether it consists of a single vehicle or a complex of a bank (or multiple banks) of vehicles--must respond to traffic volumes and distribution patterns generated by the function of the structure it serves. At sea, as on shore, a structure may function as an industrial plant, a commercial or business facility, or a residence, or it may comprise any combination of these categorical functions. A floating platform will almost certainly combine at least two, to a degree determined by the extent of its self-sufficiency, and a multi-purpose platform will by definition include all three.

Although they may vary widely in terms of speed, size and capacity, all elevators belong to one of two categories as determined by their propulsion and suspension systems, namely traction or hydraulic. Figure 31 illustrates a typical traction elevator mechanism for a passenger car. Versions of this design principle are used for elevator applications in high-rise office and residential buildings requiring high speed and where the vertical transport distance is great.

Other versions include industrial freight elevators with capacities of 2,500 to 20,000 pounds or more. Some special-purpose vehicles are designed to facilitate on/off loading by means of small industrial trucks and forklifts. To provide maximum entrance space, vehicle doors open vertically--the top half rising and the bottom half dropping--so that the opening is the full height and width of the cab interior. The lower door section, when open, forms a sill, or bridge, between the car and the platform, as in Figure 32.

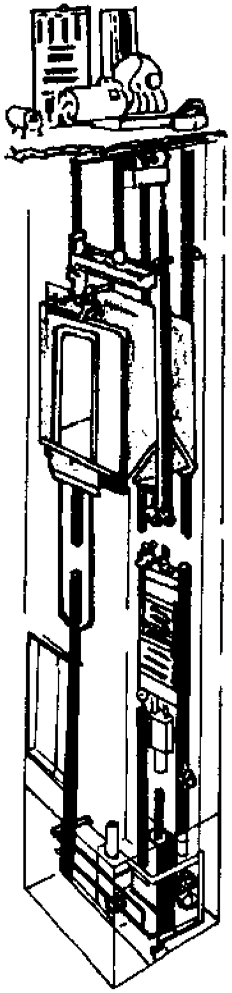


Figure 31 -- Passenger elevator, traction type.

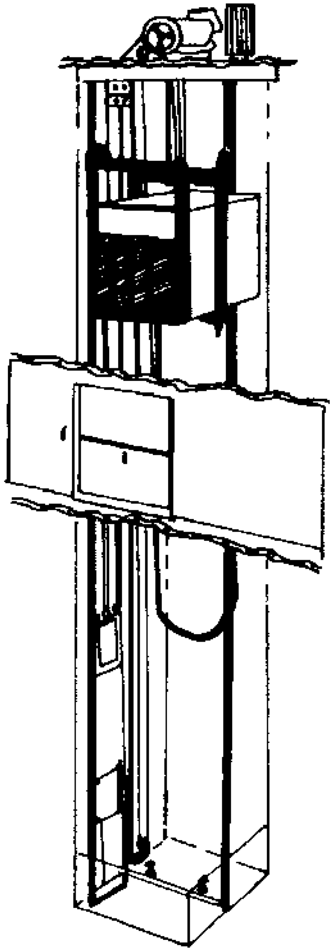


Figure 32 -- Freight elevator, traction type.

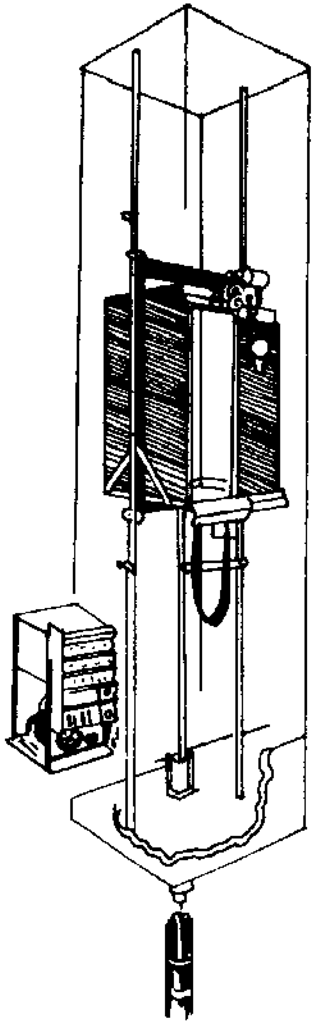


Figure 33 -- Hydraulic elevator.

For applications where service can be limited to six levels and to a speed of less than 200 feet/minute, the hydraulic elevator generally is the preferred vehicle. This is especially true where heavy loads must be lifted, and elevators of this type shown in Figure 33 have been specified for heavy-duty freight movement with rated capacities in excess of 100,000 pounds. In this design concept the vehicle is supported from beneath by a hydraulically actuated piston; there is no overhead machinery with the hydraulic mechanism, but this design does require a deep pit to house the piston.

1. Capacities and Limitations

a. Residential Elevators

A large floating platform can support many multi-level complexes of dwelling units. These may be entirely above the sea surface plane or may extend down into the buoyancy columns. It is anticipated that Hawaii's Floating City will include 10-level complexes in the superstructure. Structures in excess of 4 levels require elevators for resident traffic. Irrespective of function, structural design of a building and design of its vertical transportation system must be dealt with simultaneously, but since system capacity must be determined by traffic volume during peak loading, the function will shape the usage patterns. During the morning and evening peak flows (Figure 34), the system may have to accommodate 5 to 7 percent of the total building population within time spans as short as 5 minutes...a designed capacity generally employed by system designers. Passenger elevators usually operate within the speed range for gearless traction systems shown in the following table.

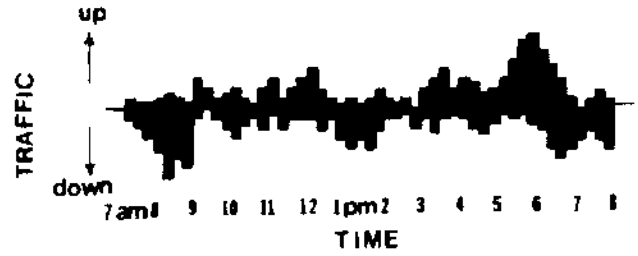


Figure 34 -- Typical pattern of elevator traffic in apartment house. (43)

Table 3 -- Typical passenger elevator speeds for high-rise residential buildings. (43)

Stories	Speeds (fpm)
10 - 20	200 - 350
20 - 30	350 - 500
30 - 40	500 - 700
40 - 50	700 - 1,000
50 - 60	1,000 - 1,200
60 or more	1,200 or greater

Traffic volume, vertical distance to be traversed, and number of loading stops are factors in determining size, speed and number of vehicles required to meet service criteria. For example, passenger elevators for buildings in excess of 10 levels should have cars with 2,000 pounds capacity and interiors at least 6 feet wide by 3 feet 8 inches deep. This size can comfortably accommodate 8 to 10 passengers.

In and out movement of household furnishings and personal possessions occasioned by tenant population turnover and other activities in large dwelling complexes places demands on elevator service that may tie up the system for prolonged periods. Service elevators are essential to avoid this disruption in passenger flow. Vehicles designed for such freight service should have a load capacity of at least 2,500 pounds and minimum interior dimensions 6 feet 8 inches wide by 4 feet 3 inches deep. A car of this size can easily handle furniture items up to 8 feet long. Recommended speeds depend more upon building height than tenant demands; for a 10-20 level structure, appropriate speed is 200 fpm. (43)

b. Commercial Elevators

A multi-level commercial facility can accommodate many tenants in diverse types of business, each of which may place a somewhat different load and/or loading pattern on the vertical transportation system. In customary usage, overall passenger service demand reaches a peak twice a day, when the business employees arrive and leave, as in Figure 35.

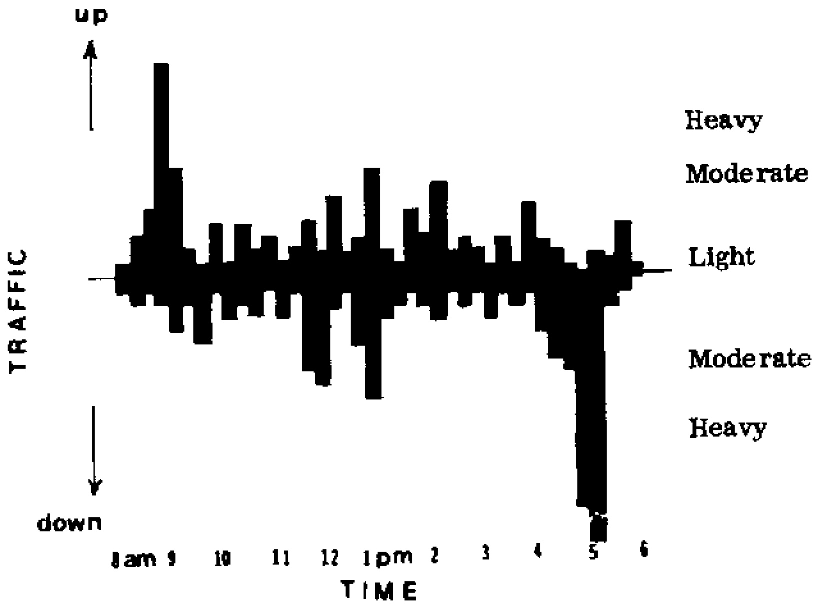


Figure 35 -- Typical pattern of elevator traffic in an office building. (43)

Designed capacity is based on the peak demand period, during which time anywhere from 10 to 30 percent of the entire building population may seek to enter or leave within a 5-minute time span. Designed capacity for peak load is further influenced by the queuing factor: passengers tend to grow impatient when waiting more than 30 seconds for an elevator. This queuing problem may vary under the influence of psychological, environmental, and geographic factors. It appears obvious, also, that some degree of control based on overall system planning would enable reduction in peak passenger load through staggered business hours to flatten the arrival and departure traffic curves. Economies to be realized thereby in system requirements for hardware, maintenance, and energy consumption would seem logically to require such control, given the platform environment and its limited capacity to produce power. This same assumption applies to all forms of usage.

Service elevators are even more essential to commercial structures than to residential complexes. Incoming and outgoing materials in office buildings are estimated, for architectural design and planning purposes, at 150 to 200 pounds/week/employee. In addition to this load, internal traffic includes mail delivery and movement of supplies, cleaning equipment and office furnishings and machines, etc. Elevators with 3,500 to 4,000 pounds capacity and dimensions similar to passenger elevators have proved adequate to meet the requirements of most small to medium-sized buildings.

c. Industrial Elevators

Freight elevators for industrial facilities are classified according to their lifting capacity into categories usually termed light duty, general purpose, and industrial truck loading.

Light-duty freight elevators have capacities up to a maximum of 2,500 pounds and rises to a maximum of 35 feet. This category includes both traction and hydraulic systems, the choice for any given installation being determined by economy and convenience.

General-purpose freight elevators, covering a rated capacity range from 2,500 to 10,000 pounds, can meet a wide variety of transportation requirements. Usually they are of the traction type, but for low-rise applications, hydraulic systems may be used.

Industrial truck elevators, designed for loads over 10,000 pounds, are specially designed to withstand the impact and stresses of on/off loading by the small industrial trucks and forklifts commonly used to handle very heavy or bulky materials. These systems, too, may be either traction or hydraulic, with the latter type restricted to low-rise structures.(43)

2. Application to the Floating City Transportation System

The elevator systems in most land-based structures are positioned to channel traffic vertically through one or more centralized cores, from which location the traffic fans out horizontally to the peripheral areas at each level. By contrast, the positions of vertical columns on a floating platform will be dictated by structural and hydrodynamic requirements rather than architectural considerations. Consequently the location and design of the major elevator systems for a platform will be largely predetermined by the position, number, and functions of the supporting columns.

Another constraint points up the importance of designing the elevator facilities as a subsystem of the total internal transportation network. According to the configuration shown in Figure 5, page 23, the central shaft of each buoyancy column will measure 28 feet square. This space for elevators is extremely limited as compared to land-based structures that may provide as many as 30 or more elevators massed in banks of multiple shafts. For some locations in the platform, then, below deck the number of elevators that can be installed may be inadequate to meet user demand unless careful system design ensures maximum utilization of the limited facilities. Consequently, the vertical transportation component must be thoroughly integrated with the horizontal subsystem in order to achieve efficient movement of both people and goods throughout the structure. A platform module may house a variety of industrial plants on its multiple levels, as well as operational facilities to sustain the platform. Some of the possibilities were listed in Section III-C. For each there will be an elevator system usage pattern shaped by:

- Materials to be transported; weight, size, and shape of the largest item.
- Rate of vertical flow in units of tons/hour.
- Distribution of vertical flow between levels over a given period of time.
- Methods by which materials are transported in the horizontal direction.

It is apparent that the vertical transportation system for each module must be planned to handle the composite traffic flow and it must have a capacity equal to the heaviest load that any of the units in its complex may impose. Clearly, either the total complex that will be housed in any given module--including support operations and every specific industrial, residential, or commercial activity--must be determined before the transportation system is designed, so that it can meet the composite requirements, or the maximum system capability for a column must be determined and then the mix of operations and activities to be housed in that module must be selected within the constraint of the total load it will place on the system.

It appears at this point that the question of extensive elevator service to the substructure of the buoyancy columns is a moot subject. A significant problem exists potentially in maintaining the integrity of the watertight bulkheads; even if the elevator shaft itself were a watertight column, the openings for the doors at each level might require some form of special pressure lock. This is, of course, a factor to be considered in any form of crew and material/equipment access to those lower levels.

One important design aspect is noise control. Noise from elevator equipment is centered about the machine room and resonates down the shaft to all levels. Acoustically designed machine rooms have been successful in reducing reflected noise from the room walls, but have not controlled the sound transmitted directly down the shaft. Some possible solutions to this problem are to isolate the machine room from the shaft and place all machinery on rubber pads, or to line the walls of the shaft with acoustical dampening material.

Safety is another important design aspect, and modern elevator technology has racked up an impressive record in this area. The motion of the platform itself does not appear to present any significant hazard to the movement of elevator cars within the shafts. Design modifications for platform applications would comprise a constant tension cable system that could compensate for the minor vertical accelerations, and automatic leveling devices such as are commonly used, at present, on freight elevators of the industrial truck variety.

The question also arises as to the effectiveness of the elevator system in evacuation of the platform population in time of emergency. We have seen that design capacity for residential elevators may be as low as 5 to 7 percent of the total building population in a 5-minute span. And commercial elevators have a higher design capacity of up to 30 percent of the population within 5 minutes. It might prove practical to require the latter design capacity as a minimum. This would place total evacuation time at between 15 and 20 minutes--which could be inadequate in case of fire, explosion, or sinking. On the other hand, this time estimate assumes none of the platform population at the deck level at the moment an emergency strikes, which is scarcely likely at most hours. Further, it assumes none of the population moving by the routes of escalators or stairs. If elevators were operative during an emergency, the evacuation time would be cut considerably by pressing the freight and service elevators into passenger service. Since the superstructure is only 10 floors high, and the deck is 4 floors, the use of stairs would be a practical alternate route for the able-bodied population. The greatest problem would probably be presented by evacuation of the buoyancy columns, where stairs would be essential.

There is also a strong possibility that the elevators would not provide an evacuation route at all. This is certainly true in the event of fire, where modern-day experience with high-rise buildings has proven elevators to be a death trap. Here the only safe route out is by stair, regardless of fire height. Whether or not explosion would cause fire and create the same hazard is not necessarily predictable. In the case of leakage due to damage below the waterline, as well as in the event of sinking, the degree of list developed by the platform could well determine whether the elevators would remain operable.

B. Conveyors

Reduced to its simplest terms, a conveyor is a mechanical device for moving objects from one place to another. The nature of the object is immaterial to the principle. It may be an entity ranging in size from a very small machine part (for example) on an assembly line, through packages of various bulk and weight, up to very large objects such as shipping containers. Or it may be, broadly speaking, an unpackaged collection of objects, such as bulk grain or ores. Or it may be a human being. The concept is embodied in a virtually limitless variety of applications in commercial and industrial situations, including, for instance, manufacturing plants, shipping terminals, airports and railroad terminals, and even within other transport vehicles such as ships and aircraft, to name just a few. Theoretically there is virtually no limit to the distance that can be traversed by some version of the device; in practical use the widest range of distance spanned by conveyors is in industrial situations, where they vary in length from several feet to several miles, as determined by such factors as size and weight of commodity transported, purpose of transport, plant layout, etc.

Mechanical devices employing the conveyor principle take many forms, all of which can be classified generally into five categories: (1) screw (or auger) conveyors; (2) flight conveyors; (3) endless chain conveyors; (4) rollers; and (5) belt conveyors. Within each of these classes there are subcategories representing physical variations of the operating principle. Strictly speaking there is a sixth category, known as a pneumatic conveyor, in which material is moved through a hose or pipe by means of differential air pressure. For purposes of this analysis, that category is classified as a form of pipeline.

1. Description

It would be impractical to attempt a review of the endless variations and subcategories of the five classes named. A brief description of each major conveyor category will serve to suggest its basic design and potential use.

a. Screw Conveyors

The screw conveyor is an enclosed single-plate or double-plate helix formed about a turning shaft that moves material along a trough or tube. As the shaft rotates, the material fed to it moves forward by the thrust of the lower part of the helix and is discharged through openings in the trough bottom or at the end. Screw conveyors can be operated along an inclined path but the capacity decreases rapidly as the angle of inclination increases. This design is practical only for handling non-abrasive pulverized or granular materials.

b. Flight Conveyors

This mechanism consists of wooden or metal plates attached to an endless chain that pulls them through an open conduit or trough. The plates are at right antles to the direction of travel, like partitions in the conduit. The trough contains the bulk material to be moved, which is pushed along as the plates travel through the trough on the moving chain. Like the screw, this device is suitable only for handling nonabrasive granular materials.

c. Endless Chain Conveyors

While recognizing that the principle of an endless chain moving over terminal pulleys or rollers is the driving mechanism for the flight conveyor, and that the endless chain itself may--in some assembly plant applications--serve as a "belt" conveyor, it is treated here as a separate category. This category encompasses those devices or uses that have more in common with each other than they have with the two already described. Their feature is that they all rely on some form of container to hold the material being transported...the containers being attached to or supported by the moving chain.

In one of these versions, the cargo travels in buckets attached to the chain (which, for purists, may in fact be a belt or cable, although in principle it is referred to as a "chain"). This application is probably in the widest usage, to the extent that it is commonly referred to simply as a "bucket conveyor". It can handle most types of bulk cargo and is principally used for transport in a vertical or near vertical direction.

In other versions, a set of arms or trays is used, where the nature of the cargo or the direction of travel does not create the hazard of spillage. And, finally, the conveyor may take the form of hooks or containers (such as baskets or carriages) attached to a moving chain or cable suspended by rollers from overhead supports. In the first instance, of course, the cargo would have to consist of self-contained items or materials prepackaged in their own containers.

d. Rollers

This form of conveyor consists simply of a series of horizontal, cylindrical rollers spaced close together. Movement of the cargo is accomplished either by powering selected rollers along the route or by gravitational forces acting upon the cargo itself. Although it is not suitable for bulk cargo, the roller conveyor design offers great versatility in sizes and weights of materials it can transport. It is the most suitable for handling very heavy units such as containers or pallets, and is used extensively in the sorting, loading and unloading processes for packaged freight and baggage as well. Not only the transporters that carry cargo to a plane, for instance, may have a roller surface, but also the cargo decks of planes and barges may have what is referred to as a Ro-Ro (roll-on-roll-off) deck.

e. Belt Conveyors

Probably the most versatile type of conveyor, this is an endless moving belt that operates over terminal rollers or pulleys. Propulsion is achieved by friction between the belt and one or more drive pulleys. Essentially this provides a flat moving surface suitable for transporting virtually anything except loose bulk materials that would fall off the belt surface, and it is used to move both cargo and personnel. The first use needs little further explanation, since the principal constraint has already been mentioned. The second use merits some further examination.

- Moving Sidewalks

A moving sidewalk is one of the applications of the belt conveyor to human transportation. In this form it has, until recently, been practical only when long distances must be traversed since its principal function is to eliminate pedestrian effort rather than to save transfer time. Conventional systems operate at a maximum speed of 132 feet per minute, or 1.5 miles per hour, since speeds in excess of that limit have created difficulties during embarking and disembarking. Recently several European countries have produced solutions to that problem.(44) A British version, the Dunlop Speedway system, was publicized in 1972. Another, a rotary accelerator designed in Germany by Krauss-Maffei, relies on a rotary elevator at each end of the conveyor belt to bring its passengers up to the 12 mph speed of the belt for boarding and dismounting. It has two drawbacks for platform application: one is the considerable space required by the elevator, and the other is the queuing involved in boarding the stationary elevator. It also requires an elevated belt. None of these disadvantages characterize two French accelerators. One is the Paris Subway Authority's Trax system, based on overlapping plates that slide over each other longitudinally. In low-speed zones the plates are close together. Increasing their spacing, as in Figure 36, raises their speed between boarding zones. The other French version, by Engins Matra, uses the lazy-tongs principle of interlocking parallelograms. Where this diamond-patterned belt is compressed sideways, it stretches out rapidly, and vice versa, as in Figure 37. The array of metal blades is covered with overlapping plates that slide over each other like fish scales. All of these devices require fixed loading zones, or terminals; they sacrifice the flexibility of boarding at any point, as with the slow 1.5 mph type belt, for speeds of 10 mph and higher.

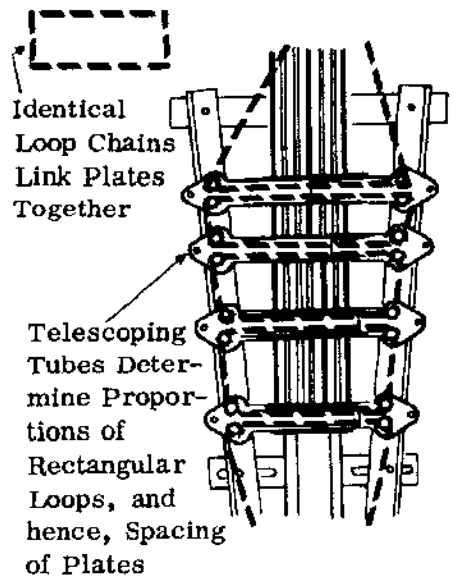


Figure 36 - Schematic of Trax system used in the Paris Subway.

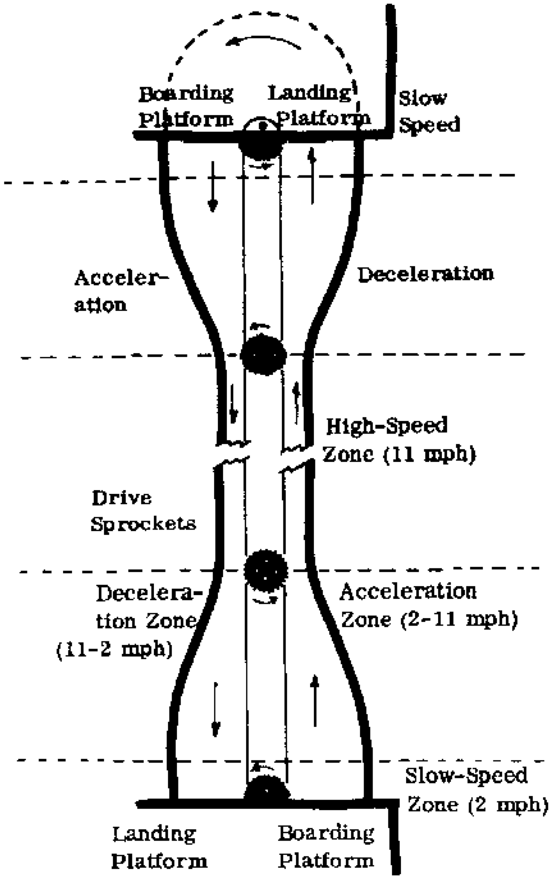


Figure 37 -- Schematic of "lazy-tongs" conveyer, by Engins Matra.

- Escalators

A conveyor belt consisting of a series of discrete, though continuous, plates is also the basis of the moving stairway, or escalator. Functionally this system differs little from the moving sidewalk conveyor used over level surfaces, but here the conveyor traverses an inclined plane in either direction, up or down. As it moves, the individual plates, attached by risers to the common base belt or chain, remain level and move independently of each other as they adjust to the angle of incline. The complete system consists of three major components: moving stairs, synchronized moving handrails, and the power and drive unit, as shown in Figure 38. (45)

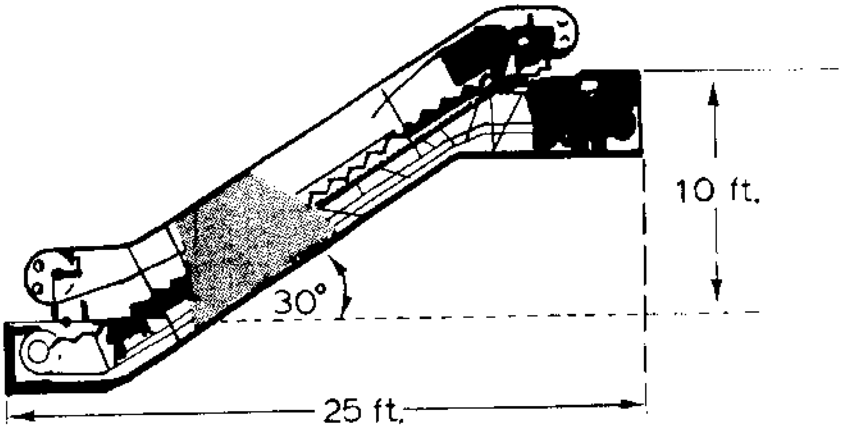


Figure 38 -- Typical escalator, cut away to show steps and driving machine.

Escalators are in common use for vertical transportation between levels in low-rise structures, where they serve as an alternative or supplement to elevators. However, they do move people at slow speeds--about 90 to 120 feet per minute--so architectural designers have suggested that system applications be limited to a maximum of three levels, except for special purposes. A second disadvantage of an escalator is the extent of the floor area that must be sacrificed on both of the levels it serves--to accommodate the stairwell, or shaft, as well as the entrance and exit sills and the machinery situated beneath them. Vertical inclines are limited to an angle of 30 degrees or less (the angle defined by the intersection of the truss and a horizontal plane). Using this criterion, a 10-foot rise would require, for system installation, a minimum floor area, on each level, of 25 feet by about 3 to 4 feet--depending upon the stair width (Figure 38).

2. Capacities and Limitations

The capacity of conveyor systems, overall, for transporting materials is subject to so many variables as to rule out any attempt to generalize. Within each category there may be subcategories and a virtually infinite variety of versions of the basic designs, particularly of the endless chain and belt types. Add to this, variability in size, length, and speed, and then add the variables in cargo types and sizes (again, especially for the versatile chain and belt types) and the nature of the problem begins to appear. So apart from the limitations already pointed out--in terms of bulk versus self-contained materials--it appears that a conveyor system can be designed to move almost any material from point to point within a defined area, at least on the horizontal plane. The requirements will dictate the capacity.

On the other hand, capacities of conveyor systems for moving human beings can be determined, or at least estimated, since the variables are greatly reduced. And they are limited as to speed by the tolerance level of their human cargo...which consists of selfcontained units of standard shape and size. Table 4 lists the theoretical capacities of the slow, 1.5 mph, belt conveyors employed as moving sidewalks. Actually, any capacity rating in terms of ability to transport "x" units to a given destination or over a specified distance in "x" amount of time, which would be meaningful in terms of moving materials, would be approximated at best in this instance since, acting on individual determination, the passengers may vary their distance traveled, and enter and leave the system at will. Moreover, while the system design allows approximately 2 square feet of space per person, users will almost invariably position themselves at greater distances from each other, for subjective reasons, and

Table 4 -- Rated capacity of moving sidewalks (46)

Lanes	Beltwidth (inches)	Rated Capacity (persons per hour)
1	25	3,600
2	42	7,200
3	66	10,800
4	81	14,400
5	108	18,000

so reduce the actual system capacity. The higher speed systems described earlier obviously would have a much higher capacity rating, but no figures are available at this time.

Table 5 compares the carrying capacity of moving stairs with speed and width of the conveyor. Here again the tremendous differences between the theoretical and actual carrying capacities can be attributed to the peculiar factors governing human behavior. More specifically, a pedestrian boarding an escalator almost always will pause and allow several steps to pass before stepping onto the moving belt. The number of skipped steps will depend upon the individual's self-confidence and skill in safely timing his entry. It has also been observed, in a study in transportation terminals, that gaps in traffic increase when people either are carrying packages or are distracted by other coincidental activities such as reading newspapers, both of which interfere with vision and/or coordination. (47)

Table 5 -- Carrying capacity of moving stairs (46)

Width	Speed	Theoretical 5-min capacity	Actual 5-min capacity
32"	90 fpm	335	241
32"	120 fpm	450	292
48"	90 fpm	670	516
48"	120 fpm	900	630

3. Applications for Floating Platforms

As internal transportation system components for a floating platform, conveyor systems can be expected to play an important role in the horizontal movement of materials between loading terminals, storage zones, and distribution centers. Initially at least, emphasis will be on the roller and belt types. Most incoming cargo (other than bulk fluids) will be containerized and best suited to the rollers; while the belts probably are versatile enough to meet any other requirements. In particular, the potential of the belt conveyors for personnel transportation may prove especially valuable. Versions of the other conveyor types may be designed as needed to meet the needs of particular industries or special-purpose usages.

No significant limitations on type or size of conveyor are anticipated as a result of the platform environment. For the purposes of establishing a reference point, it has been assumed that maximum linear accelerations of the floating platform will be less than 0.05 g's over the full frequency of the wave climate predicted at the selected site. This figure of 0.05 g was chosen because it lies well within the comfort levels established for human tolerances to linear accelerations, as pointed out in the review of the platform characteristics, Section III-B. However, there may be industrial applications for a floating platform where the magnitudes of the accelerations may exceed the prescribed 0.05 g level, requiring design modifications for the safety of both personnel and equipment. Any conveyor system will experience the same accelerations and displacements as the platform it is on, of course, i.e., hydrodynamic motions characterized as long-period harmonic oscillations.

Stability of objects transported by any conveyor system is subject to the rate of change in acceleration, a factor that can also be stated as the degree of jerk. On a free-floating platform, change in acceleration rate can be caused by any of three sources: (1) high-frequency accelerations (in excess of 10 hz) produced by machinery and heavy equipment operating on the structure; (2) external forces acting upon the structure, produced by wave impact or wind push; and (3) free-bar vibration of the platform. Since the stability of the transported materials will be affected by the magnitude and frequency of the impulsing function, conveyor systems will have to be designed to operate safely within the parameters of all possible acceleration changes.

The potential of the belt conveyors for human transportation is of special relevance in the floating city environment. Given the relatively short walking distances and times (as set forth in the next section, V-C), moving sidewalks may not be greatly used, but there will be many applications for moving stairs in the residential and commercial areas. As presently designed, the structure of the platform is multi-decked, with four levels and a ten-foot rise between them. Below the level of the main deck, escalators probably would not be suitable for vertical transport since the large floor area required for their installation would conflict with the space limitations within the buoyancy columns. But above the deck they would be an entirely appropriate vehicle operating between the levels of the superstructure, within the hotel and residential facilities, and in the terminals for the external transportation system. In this capacity, moving stairs can relieve the elevators of a substantial portion of the human traffic load...a significant consideration in view of the necessarily limited number of elevators that can be installed in the shaft space available, and in view of the heavy requirements for vertical transport of goods, materials and incoming cargo. With proper attention to safety precautions, handrails and balustrades, no passenger hazards with regard to motion stability are foreseeable in installing escalators on an offshore floating platform.

As in the case of all other conventional systems operating in the open sea environment, corrosion is a problem for the conveyor systems, and materials used in exposed areas must be selected carefully. Plastics and stainless will be the materials of choice wherever practical, and these certainly would increase costs.

C. Pedestrian Traffic

In highly populated industrial or commercial areas in land-based urban centers, walking is the most rapid and direct method by which most people can move from one place to another. Mechanized transportation, however sophisticated, cannot match self-locomotion for convenience over short distances in congested spaces. In fact, on the average, people walk at least 2/3 of the total distance that they travel within such areas on any given day. (This does not include mileage covered by commuting between urban areas and outlying residential communities, of course.) However, this highly efficient mode of travel (in terms of energy/distance/unit mass) is usually employed without conscious selection, and under pressure of time; actually, our cultural climate has produced technological and psychological conditioning which causes us to avoid walking whenever feasible. And for distances in excess of half a mile (or less in inclement weather), some form of mechanical vehicle normally will be used if at all available.

Many attempts have been made to discern an overall pattern associated with the human activity of walking. To date all study reports are inconclusive in their findings. There is common agreement, however, that patterns vary from subject to subject, from the patron of a highly populated shopping center to the solitary stroller. In all cases they are greatly influenced by factors such as time of day, destination, weather, and length of trip. Most urban designers have agreed on a value of 4 feet per second as the average rate of walking speed, for design purposes, as in Table 6. (48) This rate will vary a little by

Table 6 -- Mid-block pedestrian travel rates.

	Number of Observations	Mean Travel Rate (ft/sec)
Men	649	4.93
Women	544	4.63
TOTAL	1,193	4.80

time of day, as Figure 39 shows, and considerably more according to ambient temperature. Although we have no data on it, it is observable that other factors affecting speed include whether or not the pedestrian is carrying anything, and the bulk and weight of his load, as well as the angle of incline of the surface on which he is walking, and his direction along that incline. This latter factor is not particularly significant in the case of a floating platform, where surfaces are likely to be level, for all practical purposes.

Whatever the mission of a given platform, pedestrian traffic will be an integral component of the internal transportation system. Where the functions include residential and commercial activities, as in the floating city, walkways should be isolated from systems moving cargo or industrial materials.

In comparison to the boundaries of an average city, the area encompassed by the floating city will be quite small...on the order of 2 to 3 city blocks. So it is unlikely that any passenger vehicle form of horizontal transportation will be needed. Under the proposed city plan, based on a circular platform 3,200 feet in circumference, the maximum horizontal distance to be traveled would be half the circumference, i.e., 1,600 feet, for which the average walking time would be a little over 5.5 minutes.

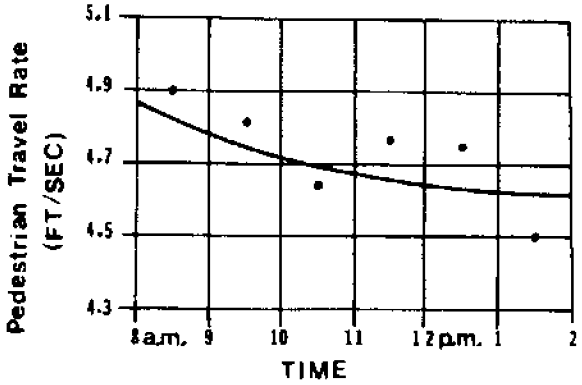
Single-purpose platforms for industrial use--power plants, waste management, petroleum refineries, etc.--will require optimum utilization of all deck space to maximize productivity. This might possibly eliminate any mode for horizontal movement of people other than walking, with mechanical transportation reserved for cargo and materials.

D. Self-Powered Vehicles

Most movement within the enclosed area of the floating platform will comprise trips shorter than the one-third to one-half mile maximum horizontal vector. Distances, then, are too short to warrant consideration of "door-to-door" transport for the platform population. Moreover, in the limited area encompassed by the floating city, free-moving and self-powered vehicles (i.e., automobiles, buses, motorcycles, etc.) would constitute an untenable hazard and an environmental nuisance. If personal transport is to be provided at all, it would be on the order of the moving sidewalks to reduce pedestrian effort, already described, or a fixed-rail system to speed up movement. This latter type of transit will be discussed in the next section, V-E.

Use of self-powered vehicles will be confined, then, to the movement of materials and goods, where their use is necessitated by the bulk and weight of the load. For this purpose, two types of equipment--service carts and

HOURLY VARIATION.



VARIATION WITH AMBIENT TEMPERATURE.

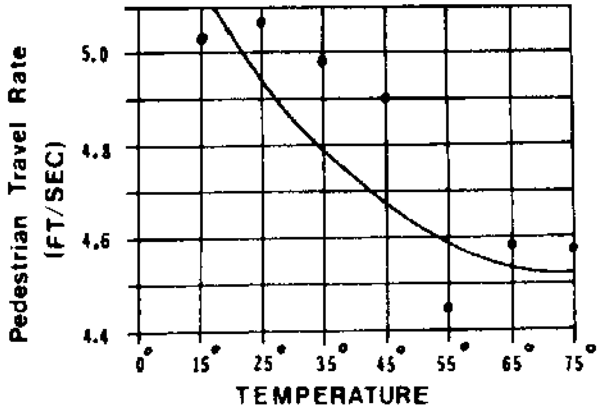


Figure 39 -- Variations in pedestrian travel rate. (48)

forklifts--are considered especially appropriate as freight carriers for the internal transportation system. Both are designed for use in manufacturing plants and warehouse facilities and so are suitable for operation within the confines of the platform deck and substructure. The following subsections give an individual description of each of these vehicle types, followed by a look at the opportunities and limitations of self-powered vehicles in general, in the platform environment.

1. Service Carts

Within modern industrial and commercial plants, single-operator gasoline, LPG, or battery-powered carts are widely used for handling materials. This type of vehicle has proved effective for a variety of other functions and specialized tasks, too, such as: distribution of small heavy parcels in mail and freight terminals; baggage distribution in passenger terminals; personnel transport; and trash removal, to name a few.

As a class, service carts are characterized by a low profile (Figure 40), large carrying capacity (up to 5,000 pounds), small turning radius, ease of operation, and low operating costs (approximately $0.40/hour). Their low profile ensures a high degree of stability while operating under heavy loads. The small turning radius provides for mobility in small spaces--as between aisles and in storage areas within a warehouse. Initial success in operating within warehousing facilities has led to development of a wide range of models and accessories for specific plant applications.

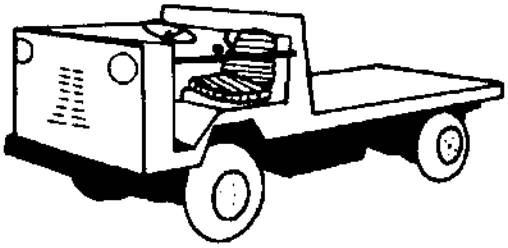


Figure 40 -- Electric powered service cart.

2. Driver-Operated Forklifts

Storage space, for most industrial/commercial enterprises, is expensive and often limited not only by cost but also by physical availability of space in congested areas. It was pressure for optimum use of this limited space, as well as convenience in shipping, that led to the development of palletization; i.e., unit load storage on portable platforms that can be moved and stacked by a compact, specially designed machine. The machine, known as a forklift, is a vehicle with a hoisting mechanism mounted on the front, consisting of two horizontal blades that are inserted under a load and hydraulically elevated along a vertical guide to the required height for transport or stacking. Figure 41 shows a typical model.

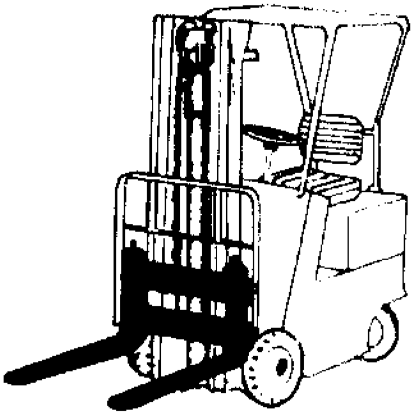


Figure 41 - Forklift.

Forklifts are manufactured in a wide range of sizes and lifting capacities--from 2,000 to 30,000 pounds--and can be powered either by electric motors, diesel, or gasoline engines. The design principle has proved sufficiently economical and practical in operation to be adapted, by means of accessory attachments, to the handling of many large or heavy items other than pallets. Among these are rolls of wire, newspaper rolls, gasoline drums, etc.

Once its cargo is hoisted to the desired height, the forklift is operated like any other conventional, power-driven vehicle and the load can be easily transported directly to its destination or transferred to another carrier where it may become a component of a larger cargo. Table 7 lists the dimensions and load capacities of several electric forklift models in commercial production.(49) This list is by no means complete, but should provide the system designer with some feel for what is available.

Table 7 -- Electric forklift dimensions and capacities

Capacity at 24" load center (pounds)	Overall Width (inches)	Overall Length (inches)
1,500	38	64
2,000	35 7/8	70
2,500	34 1/2	66
3,000	34 1/2	71 1/4
4,000	41	74 5/8
4,000	38 1/2	92 7/8
5,000	40 1/2	77 3/8
6,000	44	81 1/4
7,000	46	85 3/4
8,000	46	91 1/2
10,000	51	96 1/2

3. Floating Platform Applications

Self-powered service carts would be a very practical transport mode within residential areas of a floating city for moving furniture and large appliances, removing solid wastes, and providing other hauling and maintenance services for tenants. In commercial facilities they could perform these same services and also transport goods and units of freight between business establishments, shipping terminals, and storage areas. As a component of the internal transportation system, the vehicles could be owned and maintained by the platform management and leased to tenants. For industrial enterprises the practicality and value of these small trucks has been demonstrated in the many plants where they currently are providing numerous services, varying according to type of facility.

The electric powered models of this vehicle class are recommended for platform use to avoid the engine and exhaust noise and atmospheric pollutants of fueled engines. The batteries can be recharged easily, using standard electric current and a converter to the proper output voltage... usually 36V/48V. (Development of power production from conservative energy sources, by a platform-based facility, could possibly reduce their operating costs and they, in turn, could contribute to the platform's self sufficiency.) It may prove feasible to stack the carts when they are not in use, to conserve storage space, but in any case a centralized service and storage facility should be provided within a column or a deck area for maintenance and battery recharging.

Forklift trucks would be used principally in industrial facilities and in shipping and storage areas. Cargo shipped by surface or semi-submersible craft will be on and off loaded at the main deck of the platform and at this handling point the larger, heavy-duty forklift models would be employed. These would be equipped with accessory attachments for hoisting and moving special cargo such as paper rolls, steel beams, machinery, and lumber as well as the fully loaded 20-foot shipping containers. The latter would more likely be handled by conveyors--either roller type or overhead suspension mechanisms--or cranes, but the possibility exists that forklifts would also be employed. The main platform deck would provide the necessary space for mobility of these oversize vehicles, and they could be powered by fueled engines in the relatively open environment, if these were more efficient than battery power. It is not likely that shipping containers would be handled at all below the deck level... with the exception of shipments arriving by cargo submersibles (should these be developed) and unloaded directly into the buoyancy columns. Instead, the containers would be unloaded at on-deck receiving areas, at which point incoming cargo would be split up into units for direct delivery to consignees or to storage.

Cargo moving into and out of the receiving areas would be palletized wherever practical and in any case it would be transported by forklift models of smaller size, with mobility and maneuverability in the limited spaces of the super- and sub-structure passages, elevator cars, and storage areas. Since storage space limitations require compact, orderly stacking and inventory methods, fully utilizing vertical as well as horizontal space, the forklift appears to be a requisite vehicle for internal transport and handling of freight between and within storage and receiving areas. (This is not to imply that the overall system for internal movement of goods would not also utilize conveyors in areas where these are more efficient. Nor would it obviate the use of service carts to make individual and direct deliveries of materials between the receiving or storage areas and the platform tenants.)

Operations within the enclosed spaces of the platform structure should employ electric-powered forklifts to avoid noise and pollution problems. This can be done without sacrifice of mobility or load capacity. Maintenance services and battery recharging should be coordinated with similar facilities for the service carts.

The key to successful use of small, motorized vehicles of any type for moving goods on the platform lies in their integration with the vertical transportation system. The geometry of movement within and through the latticed structure of the floating city makes it completely impractical to plan on transferring loads from one vehicle type to another at points of intersection between vertical and horizontal transport. So vehicle sizes and service and freight elevator clearances must be coordinated to permit elevators to carry at least one fully loaded vehicle at a time--either cart or forklift. Installation of ramps between levels might possibly be feasible in some areas of the superstructure, for use by carts but not forklifts, but these would probably require too much space for the subsurface columns. Anticipated traffic loads will determine whether some elevators need be designed with space and lift capacity to accommodate more than one loaded vehicle at a time.

E. Mass Transit, Fixed-Guideway Systems

The fixed-guideway concept developed in response to a need for rapid and safe transportation systems that could move large numbers of passengers and large volumes of goods at minimum cost. It employs the principle of vehicles moving on wheels along one or more permanently installed rails that perform the following functions:

(1) Support the vehicle's weight and withstand the dynamic forces created by its motion.

(2) Supply traction for acceleration and deceleration.

(3) Guide the vehicle along its predetermined route.

(4) Provide switching mechanisms to shift the vehicle onto intersecting tracks, in order to divert its course:

- from one route to another
- from express to local routes
- to loading and unloading terminals
- from storage and maintenance areas to operating track.

(5) Stabilize the vehicle against sway and yaw from inertial forces, wind, unbalanced load, etc.

Systems are broadly classified as either monorail (employing a single rail to perform all five functions) or multi-rail. Multi-rail systems using two rails and self-powered vehicles--namely the cross-country railroads--have been in use for over a century and a half. Some other versions of the multi-rail concept (of which there are many) employ vehicles deriving their driving energy from an outside power source. This may, for example, be an underground or overhead electric cable with which the vehicle maintains contact, or it may be an electrified third rail running parallel to the guide tracks. The first is typified by the familiar streetcar, serving metropolitan areas usually bounded approximately by the city limits and sometimes encompassing a hundred square miles, or more. Examples of the latter are the elevated (overhead) and subway railroads, or combination systems, that serve congested urban areas and often extend for miles to outlying suburbs. Both types have been in operation for many years.

The term "monorail" is commonly used in referring to single-rail passenger trains consisting of a series of linked vehicles, the whole being able to accommodate hundreds of passengers. These trains are designed to travel at very high speeds and this, together with their size, makes them practical for use only where distances between loading stops are fairly great and space is available for long loading platforms. They are still in the developmental phase.

With the obvious exception of the cross-country railroads, which were developed as dual-purpose freight and passenger carriers, all of the fixed-guideway versions mentioned above are devoted solely to high-volume passenger traffic, hence their common designation as high-speed mass-transit systems. All are on too large a scale to be compatible with the short distances and limited space of the stable platform deck.

Of greater potential relevance to floating city design, one of the newest and most promising concepts for providing transportation in a congested urban area is the Personal Rapid Transit (PRT) system, using sophisticated, medium-capacity vehicles designed to carry from 6 to 25 passengers. This one is of sufficient interest to warrant a fuller description here.(50)

1. Description of the PRT System

Two types of Personal Rapid Transit systems are in operation or under development at the present time. Both are automatically controlled, by computer, and share common performance characteristics. The principal difference between them lies in their physical configuration.

One type of PRT system uses bottom-supported vehicles, riding either on wheels or on an air cushion. Both models operate on a guideway that consumes space for the required easement. For example, a single route (or track) system occupies approximately a 6-foot-wide right-of-way along its entire length.

The other system type employs vehicles suspended from an overhead guideway, as in Figure 42. The supporting columns each occupy only about the same amount of ground area as a telephone pole. An additional space-saving advantage of the overhead route lies in the possibility for stacking several tracks on a single set of supporting columns.

The heart of the PRT system design lies in its central computer facility. It operates the drive mechanism of each car and adjusts speed and queuing patterns to suit traffic loads. Other control functions of the central computer include vehicle distribution, service scheduling, emergency planning, performance monitoring, and maintenance management.

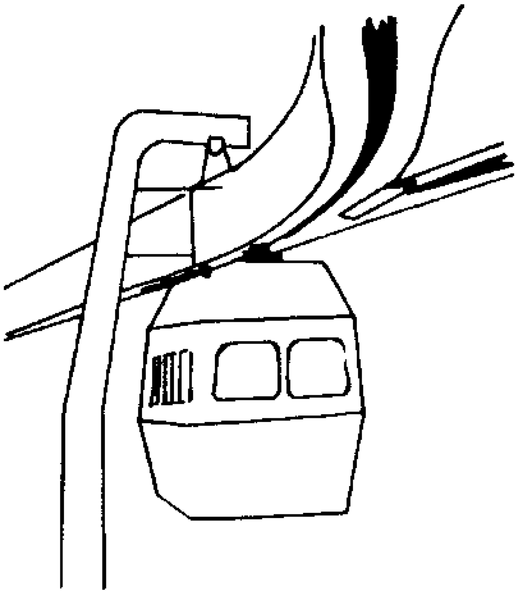


Figure 42 -- Overhead Personal Rapid Transit system.

With the boarding stations located on spur tracks, system routing is continuous over the entire course. Speeds along the main route can be as high as 60 miles per hour, with a limit of 30 miles per hour on the spur tracks. Boarding stops are short, contributing to overall system efficiency. Small vehicle size places the seats within a few steps of the entrance, facilitating quick passenger on/off loading; peak load periods are accommodated by entraining two or more cars to function as a single unit. Here again, it is the combination of automatic monitoring of demand and computerized scheduling of vehicle use and distribution that ensures an adequate supply of vehicles ready to move whenever and wherever they are needed. Supported by properly placed terminals, this system concept is one reliable, fast, and safe solution to urban mass transit needs.

2. Application to Floating Platforms

Generally speaking, unless a floating city is extremely large--i.e., with maximum horizontal distance (circumference) greater than 3,000 feet--it will not require a mass transit, fixed-rail system as a utilitarian facility. It is possible, however, that some other applications of the fixed-guideway principle might prove of value within the total design of the city.

A certain similarity between the PRT system and the endless chain conveyor discussed in Section V-B-1 may be noticed--for instance that model of the conveyor that employs containers (baskets or carriages) attached to a chain or cable suspended by rollers from overhead supports. This suggests that large industrial complexes on a platform might possibly find a practical application for a modified version of the fixed-rail system in distribution and storage of materials or merchandise. Routes could be laid out using the subsurface horizontal connecting members to link adjacent vertical columns. This would provide a transportation network between any two locations on the same horizontal level. With proper cargo-handling equipment at the route terminals, the fixed-rail vehicles could service a highly efficient and fast distribution net. This is completely out of the field of mass transit, of course, but it need not be; if a need for personnel mobility warranted it, the system might be designed to carry passengers as well as cargo.

In another functional category entirely, small-scale versions of the PRT system might provide scenic transport around the platform at the surface or subsurface level or at some level of the superstructure. This would be a non-utilitarian use, in the strict sense, designed rather as a recreational facility and visitor attraction. System characteristics for this type of application might be significantly different from those described in the preceding subsection. For instance, small-capacity vehicles (for 5 to 10 passengers), having large viewing windows and traveling at a relatively slow speed of about 5 miles per hour, could be routed along a course--both horizontal and vertical--that would offer a complete tour of the platform. Indeed, a scenic tour of the surface and subsurface structure might prove to be a popular tourist activity, as has been the experience with similar leisure facilities in complexes such as Disney World and the Seattle World's Fair. Due to the limited deck space on the floating city, it probably would be advantageous to use the overhead guideway and cantilever the supporting columns for any system operating at the surface level. This would also give passengers an unobstructed view of the platform and the outlying coastal landscape. Several such cantilevered systems are in operation at airport terminals, such as Tampa and Dulles Airports, throughout the mainland.

3. System Constraints on a Floating Platform

Any overhead fixed-guideway system operating on a floating platform will be subject to lateral stresses on the hinged connection between the vehicle and the track, due to the rolling motion of the platform and to wind forces acting on the car. These stresses might be counteracted by employing a gimbaled joint between the car and the rail, as in Figure 43, to allow for offsets in the operating plane. It would also be necessary to restrain the vehicle from free swinging due to dynamic wind forces and to torsional effects generated by tractive motors operating on the guideway.

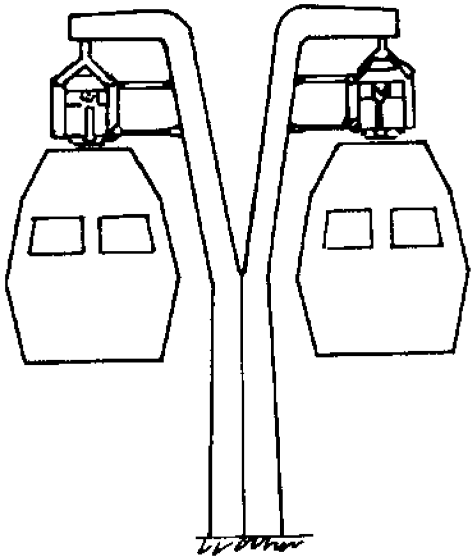


Figure 43 -- Cantilevered overhead PRT with gimbaled critical joint. (50)

In contemplating the use of a bottom-supported guideway in the platform environment, due consideration must be given to the potential hazard embodied in the high-voltage bus line that runs the length of the track. This line supplies the electric power to the drive motors and serves as the communication link between the vehicle and the control computer. The line would have to be laid in a subsurface groove and/or otherwise protected both against damage to itself and against accidental contact by passengers or surface traffic, to which it represents a hazard.

No special measures would be necessary to protect the general environment within which an electric-powered fixed-guideway transport system would be used, since both the overhead and bottom-supported types are atmospherically nonpolluting and operate at noise levels well within acceptable limits.

VI. SUMMARY

The concept of a marine city based on a large stable platform floating offshore of a metropolitan area offers opportunities for many innovations in meeting the needs of an urban population in ways that can contribute significantly to esthetic values, comfort, convenience, a healthful environment--in short, those factors that define the term "quality of life". A comprehensive transportation system, internal and external, is not the least of these opportunities. The liabilities of noise, dirt, and congestion so commonly encountered in land-based metropolitan communities where transportation "systems" have largely "just growed" like Topsy, with piecemeal planning and for the most part without system, can be avoided. Once the mission of such a marine community has been defined, with its mix of commercial, industrial, social, and recreational activities, and the projected population size has been determined, an optimum transportation system can be designed at the outset to serve it. This is not to imply that flexibility to accommodate growth would be ignored, but since such growth would be incremental, by preplanned stages, incremental growth of the transportation system also can be planned in advance to fit defined needs.

This survey has not identified any insurmountable problems of cost or technology related to transportation modes, per se, that are potentially appropriate to the internal component of a floating city system. There is a significant technical challenge to be met, however, in the matter of vertical transport through the watertight bulkheads of the buoyancy columns. Elevators can move people and materials through the more than 200-foot vertical shafts of the columns, and stairways or ladders can be installed for emergency exit. Whether or not this can be done while still maintaining the watertight integrity of the columns--and at an acceptable cost--is a question yet to be answered.

The external component, subject to environment constraints and dependent upon achieving a fit with external terminals and systems, poses an interesting challenge to the system designers also. The considerations of fit and cost to be dealt with here have been outlined already in Section IV-J. Actually these considerations, while potentially more difficult to deal with in the external component, are apropos to all aspects of the system.

Assuming then that planning factors discussed here and in Sections II and V are appropriately handled, what might a transportation system for a floating city look like? Here we gaze into our crystal ball, put together a mix of the modes we have surveyed, and come up with a theoretical system. Technical feasibility is our principal guide here, in the absence of data on which to base an evaluation of the economic limitations. For our theoretical system concept we are assuming the platform mission to be the floating city described in the beginning of this report.

Since it is not possible to go into any detail on so speculative an exercise, we have chosen to represent the transportation network graphically. Various components are identified in the simplest terms, chiefly to indicate how and where they might fit in. An actual network might utilize some or all of these, or some of these and others not yet identified. In the previous discussions of transport modes, we looked at them in terms of the external and internal subsystems. In a practical context that is an artificial division, since people and goods must flow smoothly across the interface between the two in moving to their various destinations. The exterior boundary of the platform is not likely to be a destination for either one. In fact, one design criterion is to minimize queuing at the point of interface for both people and goods moving into or out of the platform environment. Consequently, Figure 44 portrays components of a network intended to move people from point to point within the floating city and to and from the shore. Figure 45 concerns itself with modes of transport for goods which will: a) arrive as incoming cargo and pass (usually) through a warehousing station enroute to a user; and b) originate at some point on the platform, pass (usually) through some form of staging area, and leave as outgoing cargo.

The survey of individual transportation modes in Sections IV and V, and design considerations outlined in Sections II and IV are more likely to be of value, ultimately, to some future system designer than this sketchy layout for a given platform configuration. It seems appropriate here to redirect attention back to the latter two sections, particularly Section IV-J, for emphasis and to iterate the following basic points.

1. In designing a transportation system for an offshore facility, whatever its configuration and mission, the problem must first be totally and specifically defined. This is, of course, elementary in any design project--and so obvious as to sometimes be overlooked: we feel it bears repeating here.

2. The designer should be thoroughly conversant with existing modes and systems; consider the potential application of those that show a high degree of "fit" to the problem at hand and whose implementation requires the minimum of new hardware; and understand the economics of those systems in depth.

3. If the situation requires an attempt to achieve higher or more economic performance with new solutions, the designer should then analyze the predictable

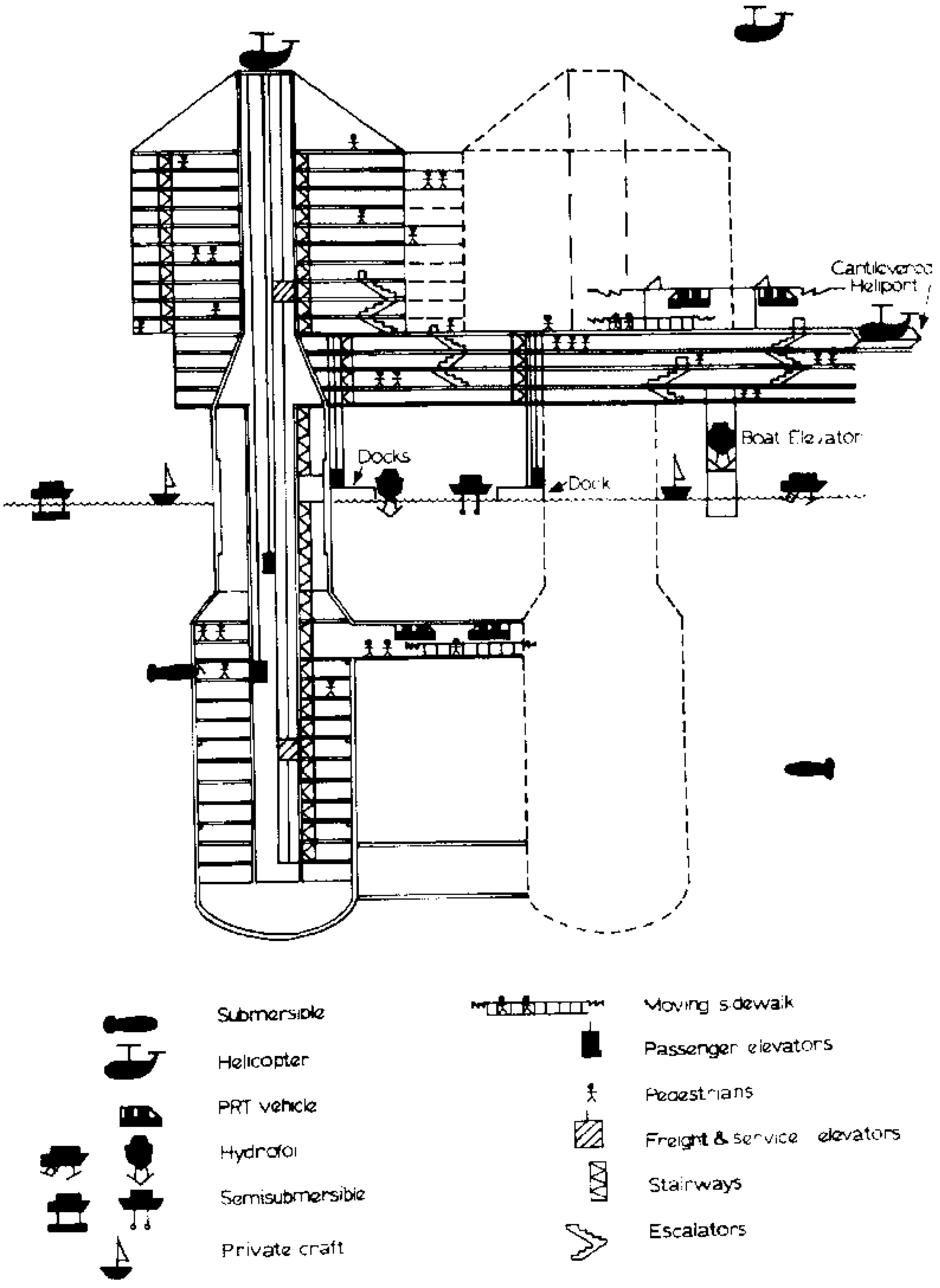


Figure 44 -- Personnel transportation modes for a floating city.

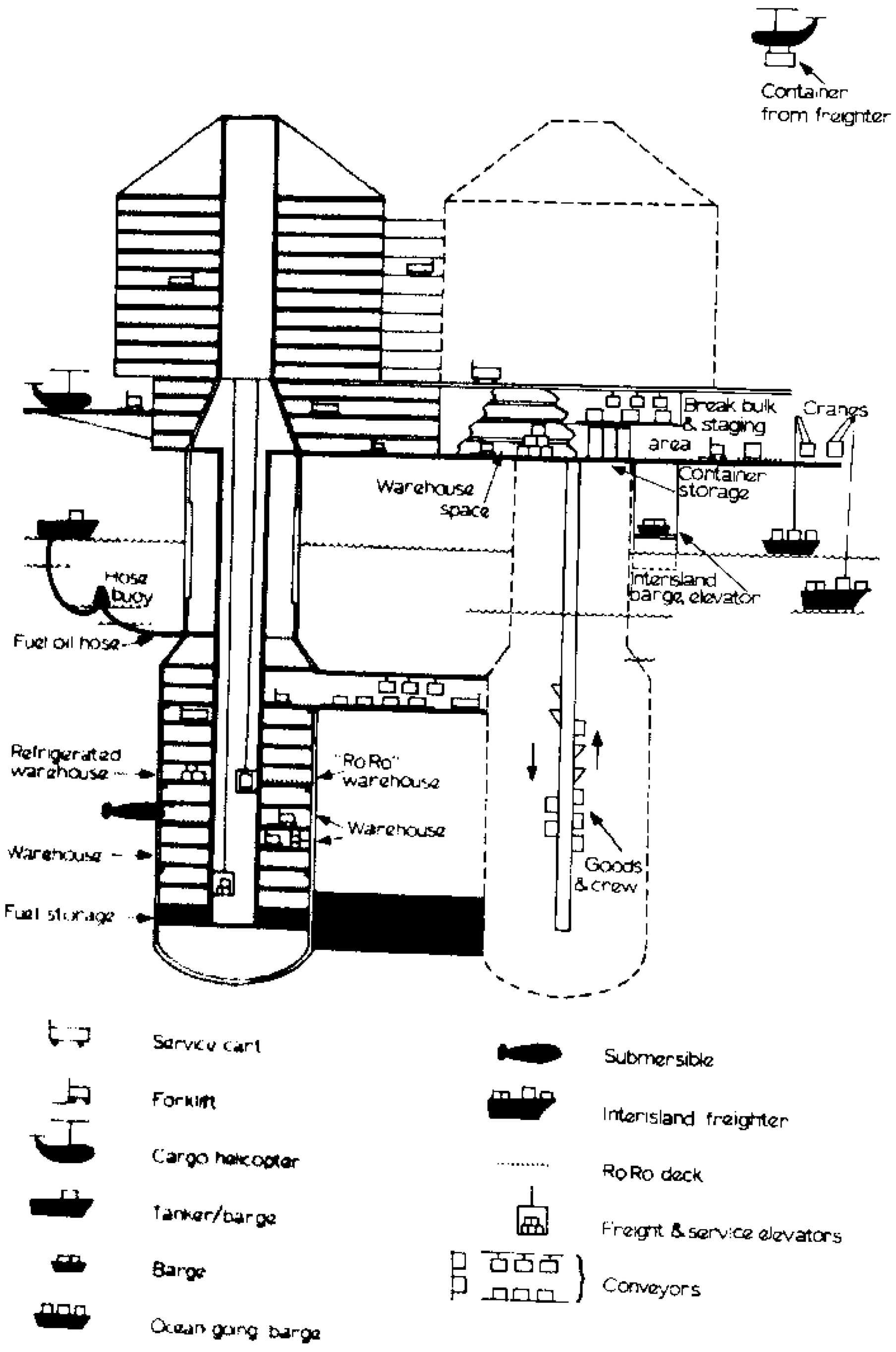


Figure 45 -- Network for transporting and warehousing materials for a floating city.

development costs and realistically assess the risk factor and the potential penalty should the solutions not prove viable.

Finally, we would bear in mind that while this survey may be valid for this point in time, it should in no way be taken as definitive. The development of offshore platforms for purposes other than fossil fuel mining and power production appears to lie somewhere beyond the immediate future, and technology is developing at a rate that forecasts obsolescence for some uncertain proportion of the material covered here. For the present, we can state that it appears to be technologically possible to serve the transportation requirements of an offshore community such as proposed by the Hawaii Floating City project. Whether or not it would be economically feasible remains an open question.

REFERENCES CITED IN TEXT

1. Craven, J. P., and J. A. Hanson. 1972. Hawaii's floating city development program: first annual report - fiscal year 1972. University of Hawaii and the Oceanic Institute. (Aug.)

2. Yumori, I.R. 1974. Structural sizing of flotation modules and construction barges. Hawaii's Floating City Development Program, Technical Report No. 5. UNIH-SEAGRANT-CR-74-03.

3. Suverdrup, G. Matson Navigation Co. 1974. Personal communication. (May)

4. Panui, P. Young Bros Ltd. 1974. Personal communication. (May)

5. Sakamoto. Hawaiian Airlines, Air Cargo Division. 1974. Personal communication. (May)

6. Wong, G. Aloha Airlines. 1974. Personal communication. (May)

7. Horizon Air Service. 1974. Personal communication. (May)

8. Island Air Transfer, Ltd. 1974. Personal communication. (May)

9. Heddenberg, R. Hawaiian Tug and Barge Co. 1974. Personal communication. (May)

10. Chaffin, D., and Chung. Union Oil Co. 1974. Personal communication. (June)

11. Smith, R. Standard Oil Co. of California Western Operations, Inc. 1974. Personal communication. (June)

12. Tome. Shell Oil Co. 1974. Personal communication. (June)

13. Arciero, R. Matson Navigation Co. 1974. Personal communication. (June)

14. Weaver, E.R., Lt. Cdr. Fleet Supply, PacFlt Hq. 1974. Personal communication. (May)

15. *Maritime Reporter and Engineering News.* 1973-1974

16. Hudson, T.A. Standard Oil Company, La Habra, California. 1974. Via personal communication with Campbell, Standard Oil Co. of California Western Operations, Inc. (June)

17. Craven, J.P., et al. 1972. Floating marine community. Research Report, Department of Architecture, University of Hawaii. (Dec.)

18. Seidl, L.H. 1973. Theoretical investigations and optimization of the platform's seakeeping characteristics. *Hawaii's Floating City Development Program, Technical Report No. 2.* (May)

19. Yamashita, Y. 1973. Internal thermal and humidity control. *Hawaii's Floating City Development Program,* Technical Report No. 3. *UNIHI-SEAGRANT-CR-74-01.*

20. Wilson, D. 1974. Concrete for large floating structures. *Hawaii's Floating City Development Program,* Technical Report No. 4. *UNIHI-SEAGRANT-CR-74-02.*

21. Anonymous. 1974. Converting garbage into energy. *Business Week.* 3:20:74

22. Appell, H.R., et al. 1971. Converting organic wastes to oil: a replenishable energy source. *U.S. Department of Interior, Bureau of Mines. RI 7560.*

23. Foster, K.W. 1966. Dynamic anchoring of floating vessels. *Transcript: 2nd Annual Meeting, MTS Conference and Exhibition.*

24. Howe, R.V. 1968. Offshore oil mobile units. *Ocean Industry 3*(7):38 (July)

25. Pounds, A.L., and H.B. Stover. 1967. Design and operating features of the SEDCO 135-F floating drilling vessel. *J. Canad. Petrol. Tech.* 6 (March)

26. Kenz and Hall. 1969. Design of a dynamically positioned support platform for a tethered unmanned submersible vehicle. *SNAME Spring Mtg.*

27. Anonymous. 1967. Facilities planning factors for naval shore activities. Naval Facilities Engineering Command NAVFAC P-80. Department of Navy, Washington, D.C.

28. Brane, J.S.S., and J.G. King. 1967. Fuel: solid, liquid, and gaseous. 6th ed. Edward Arnold, London.

29. Corey, R.C. ed. 1969. Principles and practices of incineration. Wiley Interscience, N.Y.

30. Rothwell, G.N. Hawaii Floating City Development Program, Chief Engineer. 1974. Personal communication.

31. Anonymous. 1968. Systems studies in amphibious materials handling: advanced approaches and proposed applications. Control Systems Research, Inc. CSR-120-3. Arlington, Virginia.

32. Berger, S., et al. 1970. A critical analysis of the state of the art in containerization. Control Systems Research, Inc. AD-877259. Arlington, Virginia.

33. Anonymous. 1971. Ship-indexing approach to container offloading at a naval advanced base. Control Systems Research, Inc. CR 72.004. Arlington, Virginia.

34. Covey, C.W. 1971. Dr. Lykes -- the world's most versatile cargo ship. Undersea Technology. Dec. pp. 14-15

35. Boericke, H., Jr. 1959. Unusual displacement hull forms for high speed. International Shipbuilding Progress 6.

36. Anonymous. 1972. Stable semi-submerged platform (SSP) description. Naval Undersea R&D Center, Hawaii Lab. (May)

37. Lang, T.G. 1970. Naval feasibility study of the NUC semi-submerged ship concept, Part I. Introduction, general characteristics, and summary. NUC TN-414. Naval Undersea R&D Center, San Diego, California (Sept.)

38. Lang, T.G. 1972. S^3 -- new type of high performance semisubmerged ship. J. Engin. for Industry. (Nov.)

39. McClure, A.C. 1972. Design for a semi-submersible support ship. *Ocean Industry*. (Aug.)

40. Anonymous. Helicopter transportation to offshore location. Sikorsky Aircraft Co., Stratford, Conn.

41. Anonymous. 1970. Skycrane/containership delivery system -- operations report. Sikorsky Aircraft Co. Stratford, Conn. (July)

42. Watson, J.G. Commercial Marketing Report, Sikorsky Aircraft Co., Stratford, Conn. Correspondence dated 4-19-73.

43. Adler, R. 1970. *Vertical transportation for buildings*. American Elsevier Pub. Co., Inc. N.Y.

44. Scott, D. 1974. Three new ideas accelerate the pace of people. *Popular Science*, (May) p. 80.

45. Strakosch, G. 1967. Vertical transportation, elevators and escalators. Otis Elevator Co., Wiley, N.Y.

46. U.S. Department of Transportation, Urban Mass Trans. Admin. 1968. Modes of transportation. *J. of Urban Transportation.* (Aug.)

47. Sacks, D.R. 1967. An engineering study of pedestrial traffic in transportation terminals. Unpub. Polytechnic Inst. of Brooklyn. (May)

48. Hoel, L.A. 1968. Pedestrian travel rates in central business districts. *Traffic Engineering 38*:10-13

49. Company product brochures. Toyota Motor Sales Ltd. and Clark Equipment, Industrial Truck Div., Battle Creek, Michigan

50. Wahl, P. 1971. Personal Rapid Transit. *Popular Science*. (Nov.)

SUPPLEMENTARY REFERENCES

Annett, F.A. 1960. Elevators. McGraw Hill, New York. 3rd. ed. pp. 351-376.

Anonymous. Alden StaRRcar. Alden Self-Transit Systems Corp., Bedford, Mass.

Anonymous. 1971. Conco tankers bring four important innovations. Ocean Industry. June.

Anonymous. 1971. Semi-submersible ship -- vessel with a future! Ocean Industry. Nov.

Anonymous. 1968. Transfer of oil cargo at sea. Shipbuilding International. July.

Anonymous. 1971. Current production models. Sikorsky Aircraft Co., Stratford, Conn. March.

Anonymous. S-64E Skycrane -- test proven for commercial use. Sikorsky Aircraft Co., Stratford, Conn.

Anonymous. 1964. Heliport design guide. Federal Aviation Agency AC 150/5390-1. Nov.

Anonymous. 1970. Varo Strato Line. Transportation System Div., Varo, Inc.

Anonymous. Seattle Monorail. University of Washington Press.

Anonymous. 1960. Report on monorail systems. Transit Research Foundation.

Anonymous. 1960. Planning manual for CENTURY 21 exposition, Seattle, Washington. Economics Research Associates, Los Angeles, California.

Anonymous. 1967. Pedestrian characteristics and space requirements. J. Urban Transportation. Institute of Traffic Engineers. March.

Anonymous. 1972. Hawaii tourism impact plan, vol. 1: statewide. State Dept. of Planning and Economic Development, Hawaii.

Anonymous. 1966. Town and traffic: yesterday, today, tomorrow. International Exhibition of Transport and Communications. J. Eberl K.G., Munich.

Anonymous. 1970. Unitization of cargo. Report by the Secretariat, United Nations Conference on Trade and Development, New York.

Anonymous. 1966. Lifts for large buildings. Symposium, Ministry of Technology, Building Research Station, Garston, England. June 15.

Baerwald, J.E. 1965. Traffic engineering handbook. Institute of Traffic Engineers, Washington, D.C. 3rd. ed.

Baumeister, T. and L.S. Marks (eds.) 1967. Standard handbook for mechanical engineers. McGraw Hill, New York. 7th ed.

Bender, E. and A. Collins. 1969. Effects of vibration on human performance: a literature review. Bolt, Beranck and Newan, Inc., Report No. 1767. Feb.

Benepe, B. 1965. Pedestrian in the city. Traffic Quarterly 19 (1): 28-42.

Botsford, J.H. 1970. Damage risk. Transportation noise, a symposium on acceptability criteria. Chalupnik, J.D., ed. University of Washington Press, Seattle, Washington.

Botzow, H. 1962. Monorails. Simmons Boardman, New York.

Bragg, D. and J. Bradley. 1971. Work plan for a study of the feasibility of an offshore terminal in the Texas Gulf Coast region. Sea Grant Report TAMU-SG-71-212. Texas A&M University. June.

Bush, L.S. and J. McLaughlin. 1970. Introduction to fire science. Glencoe Press, Beverly Hills, California.

Corey, R.C. (ed.) 1969. Principles and practices of incineration. Wiley Interscience, New York.

Cox, C.R. 1968. The sound of helicopter operations. Bell Helicopter Co. Sept.

Craven, J.P. 1971. Ocean engineering systems. M.I.T. Press, Cambridge, Mass.

Cross, I. Introduction to hovercraft and hoverports. Hovering Craft and Hydrofoils 9 (11): 10-16.

Dymsza, W.A., F.C. Hung, and C.A. Theodore. 1965. The proposed inter-island sea ferry system: feasibility and its probable impact on the Hawaiian economy. Economic Research Center, University of Hawaii.

Fair, G.M. and J.C. Geyer. 1954. Water supply and waste-water disposal. Wiley, New York.

Farrington, J. 1972. Lifeline for North Sea oilmen. *Geographical Magazine XLIV* (12). Sept.

Grava, S. 1969. *Urban planning aspects of water pollution control*. Columbia University Press, New York.

Gusrae, G. 1956. Moving sidewalks. *Architectural Records 119*: June. pp. 220-223.

Henke, H., A. Cooperstein, and J. Rockey. 1962. Final report of CENTURY 21 Exposition, Inc. Washington State World's Fair Commission, Seattle.

Hoel, L.A. 1969. Transportation requirements of dependent users. *Transportation Engineering Conference: Defining Transportation Requirements*. American Society of Mechanical Engineers, New York.

Horonjeff, R. and H. Lapin. 1954. Planning for urban heliports. *Institute of Transportation and Traffic Engineering, Research Report No. 19*. University of California, Berkeley, California.

Hudson, W.G. 1954. *Conveyors and related equipment*. Wiley, New York. 3rd ed.

Jennings, B.H. 1970. *Environmental engineering: analysis and practice*. International Textbook Co., Scranton, Penn.

King, G.A.B. 1956. *Tanker practice*. The Maritime Press Unlimited. Chap. 1.

Kocivar, B. 1973. Jumbo jetfoil will be super-fast, super-smooth. *Popular Science*. April. pp. 76-78.

Kryter, K.D. 1970. Annoyance. *Transportation noise, a symposium on acceptability criteria*. Chalupnik, J.D., ed. University of Washington Press, Seattle, Wash.

Lang, A.S. and R.M. Soberman. 1964. *Urban rail transit*. M.I.T. Press, Cambridge, Mass.

Le Gross, P.G., et al. 1968. A study of the disposal of the effluent from a large desalination plant for the Office of Saline Water. *U.S. Dept. of Interior*. U.S. Government Printing Office, Washington, D.C.

Levine, S.N. (ed.) 1968. *Selected papers on desalinization and ocean technology*. Dover Publications, Inc., New York.

Little, J.W. 1970. Criteria for design. Transportation noise, a symposium on acceptability criteria. Cahlupnik, J.D., ed. University of Washington Press, Seattle, Wash.

McGuinness, W.J. and B. Stein. 1971. Mechanical and electrical equipment for buildings. Wiley, New York.

Mose, R. 1970. Public works: a dangerous trade. McGraw Hill, New York.

Muller, J. 1971. People transportation sub-system for the Floating City Marine Expo. Report for Ocean Engineering 691, University of Hawaii. Dec. (unpub.).

Murin, W.J. 1971. Mass transit policy planning. Heath Lexington Books, Lexington, Mass.

Newbrough, E.T., et al. 1967. Effective maintenance management. McGraw Hill, New York.

Nishioka, R. 1971. Final report: Hawaii Floating Exposition communication system. Report for Ocean Engineering 691, University of Hawaii. Dec. (unpub.)

Oram, R.B. and C.C.R. Baker. 1971. The efficient port. Pergamon Press, Ltd., New York.

Peterson, R. 1972. HEART Study. Sea Grant Pub., University of Hawaii.

Phillips, R.S. 1966. Electric lifts. Pitman, London, England. 5th ed.

Post, R.H. and R.L. Seale (eds.). 1966. Water production using nuclear energy. University of Arizona Press, Tucson, Arizona.

Ranken, M.B.F. 1971. Can we delay the next major tanker disaster? Ocean Industry. June.

Ribakoff, S. 1971. A conceptual approach to the internal transportation of people and logistics for the proposed Floating City. Report for Ocean Engineering 691, University of Hawaii. Dec. (unpub.)

Rogers, A.C. 1965. Downtown pedestrian system: integral part of traffic plan. Traffic Engineering 35 (4): 20-22. Jan.

Shaw, C.C. 1954. On the dynamics of motion sickness in a seaway. Science Monthly 78: 110-116.

Shultz, W.M., C.S. Coffey, and R.J. Gornstein. 1971. High speed water transportation of man. Naval Systems Div., Boeing Co. ASCE-ASME National Transportation Engineering Meeting, Seattle, Wash. July 26-30.

Small, W.E. 1971. Third pollution. Praeger Pub., Inc. New York.

Smith, W. & Assoc. 1966. Transportation and parking for tomorrow's cities. The Automobile Manufacturers Association, New Haven, Conn.

Smulders, L. 1972. New concept in offshore oil storage. Ocean Industry. Feb. pp. 42-43.

Tucker, A.J. 1970. Boom in tankers ahead. Ocean Industry. Jan.

van den Burg, G. 1969. Containerisation, a modern transport system. Hutchinson, London, England.

Wilkins, G. 1971. Design of a complete marine science facility (campus?) as part of the Floating City. Naval Undersea Center, Hawaii. (unpub.)

Wilkins, G. Submersible towing/pulsing technology. U.S. Naval Ordnance Test Station, Technological Forest #24, China Lake, California.

Wohl, M. 1964. Urban transportation system concepts. Traffic Engineering 34 (6): 11-13. March.