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A STUDY OF ALTERNATIVE CONCEPTS FOR PROVIDING A LAKE MICHIGAN FERRY SERVICE

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I. INTRODUCTION

The potential economic benefits of a maintained and modernized ferry service across Lake Michigan have been explored in previous work from a number of sources, including federal, regional, and state agencies (Refs. 1-3). The underlying issues involved in the survival of the existing services, using the present vessels, shore facilities, and operating methods, are complex, and not principally within the province of the ship designer.

By contrast, the economic feasibility of a modernized ferry service, taking the fullest possible advantage of relatively recent developments in vessel technology, depends quite heavily on the characteristics and performance of the vessels envisioned for the service. The purpose of this work is to assess, within the context of conceptual designs, the economic potential of various systems applicable to cross-lake ferry services, whether intended for rail or highway traffic.

In the preparation of these conceptual designs, a simple but highly significant premise has been adopted: highway and passenger traffic has been separated from rail tonnage. The rationale upon which this premise is based runs along the following lines:

1. Due to the inherent dissimilarities between these two cargoes, vessels intended primarily for one service cannot be optimally configured for the other, in terms of speed, hull form, and arrangements, Similarly, vessels designed as compromises between the requirements of the two services cannot deliver ideal performance for either. In certain cases, vessel concepts that offer extremely attractive characteristics for one service cannot be applied to the other at all.
2. Schedules and service patterns that are most suitable for one service may be wholly inappropriate for the other.

Delays arising from this divergence of scheduling requirements often render both services less attractive.

3. Loading and unloading operations associated with the two disparate cargoes are in direct competion for both time and space, further increasing turnaround times and vessel delays.
4. The operating philosophies of railroad traffic departments cannot be expected to match the requirements of highway users. Inevitably, conflicts arise, to the detriment of both services.

The principal argument against the separation of rail tonnage from highway traffic is as follows: seasonal and daily variations in highway traffic flow will not permit a vessel to earn its keep without the rail capability to take up the slack periods in the passenger demand. This contention might well be true, if the highway traffic were assumed to consist entirely of passenger vehicles. At this point, however, there is insufficient data to support any accurate prediction of how passenger-car volume would respond to a strong marketing program and a convenient, high-speed transit service. Thus, the possibility that a service dedicated exclusively to passenger automobiles could generate an economically feasible demand on a year-round basis cannot be neglected. With the addition of truck traffic at a sufficiently high level, however, it is reasonable to suggest that winter operations could be sustained at profitable load factors. Similarly, night-time operations could be sufficiently well supported by trucks to make up for the daily fluctuation in passenger-automobile traffic.

Presumably, rail operations could be scheduled on any cycle compatible with the availability of tonnage and yard operating personnel.

Briefly stated, the aims of this work are as follows:

-- develop a set of conceptual designs for vessels applicable to the cross-lake rail and highway-vehicle services;

-- provide rough estimates of building and operating costs, together with annual transport capacities; and

-- identify areas of uncertainty in these estimates as starting points for future refinements.

This work is intended to provide information on the potential economic performance of a modern generation of vessels designed for renewed cross-lake ferry services. The results of this study are expressed in terms of the economic performance of various vessel types at hypothetical levels of service demand, which will be stated explicitly. The potential demands for modernized ferry services have been estimated in previous work (Ref. 2), and these estimates were utilized for projecting the load factors in this study. More refined projections of these future demands must take into account the competitive position of the ferry services, in view of the economic performance of the conceptual designs, and will either confirm or refute the adequacy of the estimated demands used in the conceptual design process. It is in the synthesis of the design and marketing problems that the economic feasibility of modernized cross-lake ferry services will be found.

II. VESSEL TYPES

The vessel types evaluated in this study were:

- -- Conventional monohull displacement vessels;
- -- Multihull (i.e., catamaran) vessels;
- -- Integrated tug-barge combinations (ITB);
- -- Air-cushion vehicles (ACV), and surface-effect ships (SES); and
- -- Hydrofoil craft.

The following sections give brief descriptions of the conceptual designs generated within each vessel type, including special characteristics which necessitated the restriction of certain types to specialized services, whether rail, unlimited highway (automobiles and trucks), or passenger automobiles only. More detailed descriptions of the vessel designs will be found in the sections dealing with each service.

A. Conventional monohull displacement vessels

The conventional displacement vessel is applicable to all services, from the point of view of technical feasibility. A total of five conventional vessel designs were prepared:

- -- 28.5-knot auto/truck ferry, designed for a single-ship service at the assumed demand level;
- -- 26-knot auto/truck ferry, designed for a two-ship service at the assumed demand level;
- -- 21-knot auto/truck ferry, on a two-ship service;
- -- 21-knot ferry, adapted for truck service only; and
- -- 16-knot rail ferry.

B. Multihull vessels.

Concurrently with the design of the 26-knot conventional ferry, a catamaran vessel of similar size and speed was projected. A significant saving in horsepower and fuel cost was largely offset by increases in construction cost. At lower speeds, the horsepower advantage decreases. At the present level of accuracy, the net difference in economic performance between the 26-knot monohull and the competitive multihull is so slight that no reliable conclusion on economic superiority can be claimed.

However, the ice-breaking capability of catamaran forms is open to question. Since winter operations in relatively difficult localized ice formations are a major concern of Lake Michigan ferry operators, no further development of catamaran types was conducted in this study, in view of the lack of a compelling economic superiority.

C. Integrated tug-barge combinations.

The integrated tug-barge concept offers several key advantages in applications where no passengers are carried. Among these are:

- lower capital costs on the unit, due to certain relaxed standards for unmanned barges;
- further reductions in capital cost due to barge standardization;
- reduced crew size due to the differences in manning requirements between tugs and conventional ships; and
- more efficient utilization of capital and labor by employing a barge-swapping operation.

The barge-swapping scheme involves the acquisition of three barges for each tug, with the tug dropping off the incoming barge and picking up a loaded one for the return trip, resulting in a greatly reduced turnaround time for the tug and its crew.

None of the above advantages would be applicable in the case of barges carrying passengers. Accordingly, the ITB concept was restricted to the rail service, with the additional capability of transporting trailers. A 16-knot rail/trailer ITB system was designed, with an emphasis on the potential benefits to be derived from the barge-swapping option.

D. Air-cushion vehicles (ACV) and surface-effect ships (SES).

These advanced vehicle concepts offer the potential of a 60-knot automobile and passenger service, subject to certain operability restrictions due to weather and seastate conditions. Of the two concepts, the ACV offers the advantages of known ice-transitting capability, and amphibious operation that would lead to simpler and more efficient loading and unloading operations.

The extremely weight-critical nature of the ACV precludes the possibility of economically transporting either rail cars or trucks. Thus, the ACV concept is restricted to automobile and passenger service exclusively.

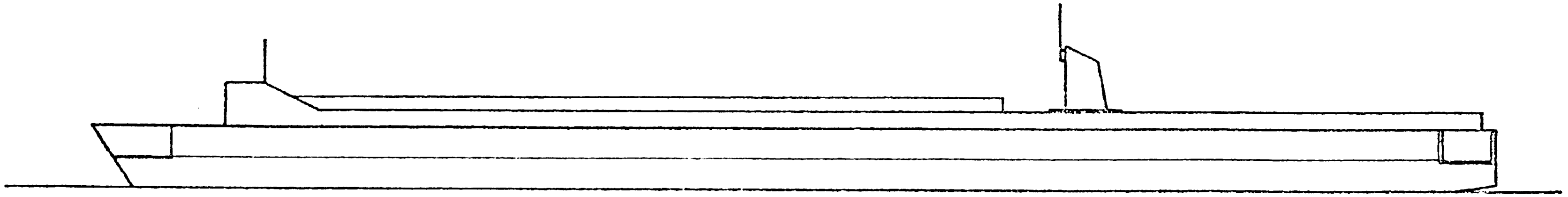
Three ACV ferry designs were considered: two alternative designs aimed at providing a single-vessel service, and a smaller vehicle designed for a two-vessel service. The latter design corresponds roughly with the SRN-4 (Modified) vehicles currently in service on the English Channel. The two larger vehicles represent significant advances in the size of operational, commercial air-cushion vehicles. All were designed for a 52-knot service.

At this stage of refinement, no significant economic difference between the ACV and SES concepts can be claimed. Thus, as a result of the advantages inherent in the ACV concept, as listed above, no further development of SES designs was conducted in this study.

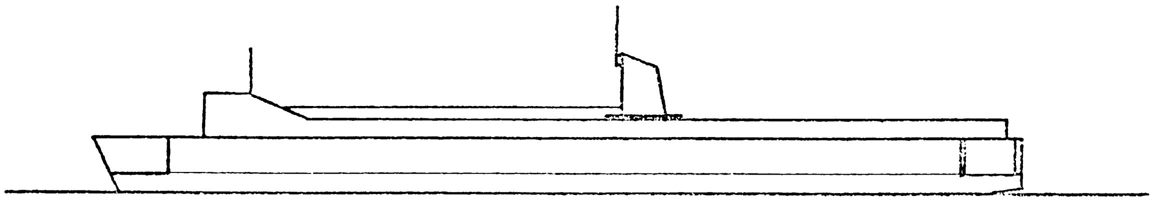
E. Hydrofoil craft.

The weight-critical nature of hydrofoil vessels is at least as severe as that of cushion-borne vehicles, and becomes even more restrictive with increasing size. In addition, the ice-transitting performance of hydrofoils is essentially nil. For these reasons, and in spite of some otherwise excellent characteristics of this type, no development of hydrofoil conceptual designs was undertaken.

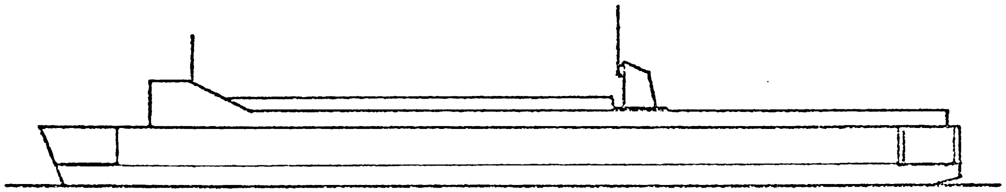
Approximate profile sketches of the vessels designed for this study are presented in Fig. 1.



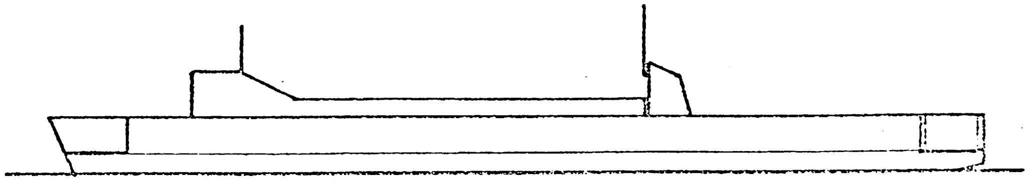
Design I: 28.5-knot highway/passenger ferry.



Design II: 26-knot highway/passenger ferry, 2-ship service.

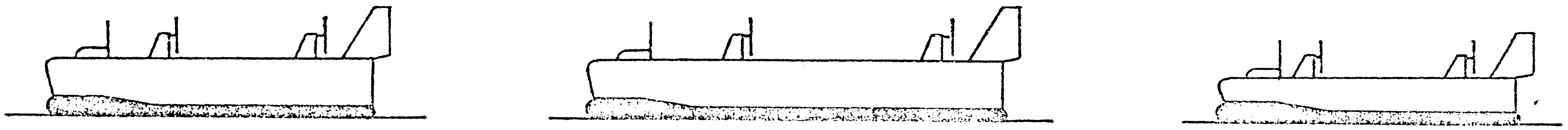


Design IIS: 21-knot highway/passenger ferry.



Design IIT: 21-knot truck ferry.

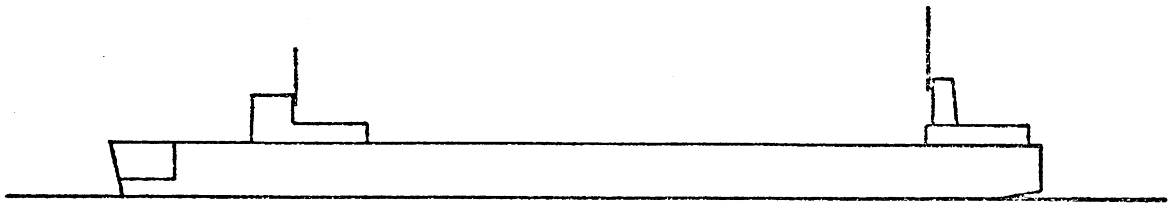
Fig. 1. Comparative profiles of conceptual vessel designs (scale: 1 in = 100 ft). (Continued)



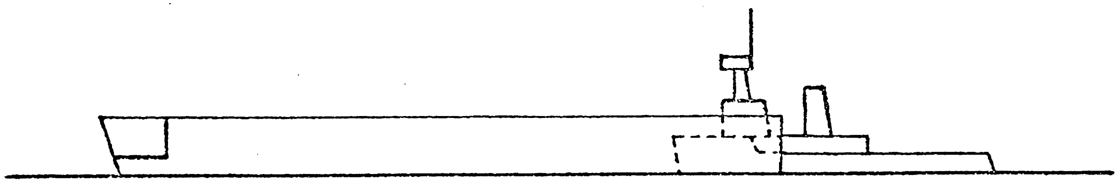
Design A: 600-ton ACV.

Design B: 700-ton ACV.

Design C: 300-ton ACV.



Rail ferry: 38-car conventional vessel, 16-knot.



Rail ferry: 30-car integrated tug/barge combination, 16-knot.

Fig. 1. (continued.)

III. HIGHWAY VEHICLE AND PASSENGER SERVICES

A. Economically significant vessel characteristics.

The potential market for any hypothetical ferry service cannot be estimated rationally without reference to the characteristics of the service itself, characteristics which depend most heavily on vessel design. To further complicate the problem, however, many of the performance and economic characteristics are directly influenced by vessel size, an artifact of the assumed service demand to which the vessel is designed. Thus, the design and market-research problems are inextricably bound together; the demand for the service is highly dependent on the competitive position afforded by vessel characteristics, while these characteristics depend on service demand, through the intervening variable of vessel size.

Among the system characteristics that must be weighed most heavily in determining the competitive position of the cross-lake ferry service with respect to its alternative, i.e., highway travel around Lake Michigan, are the following:

- vehicle transit time through the entire system, including shore facilities; this is determined by vessel speed, loading and unloading arrangements, and vessel maneuvering capabilities insofar as they affect turnaround time;
- schedule convenience, and waiting time between consecutive sailings from a given port; this is the product of vessel round-trip time, number of vessels in the service, and scheduling preferences of the owner with regard to the length of the operating day;
- reliability of service; and
- passenger comfort; these items depend most heavily on the sea-keeping qualities of the vessel, with particular emphasis on those vessel responses that are most likely to produce passenger discomfort; vessel speed, and the ability to maintain this speed under adverse conditions, must also be considered in the analysis of these service characteristics.

- attractiveness and convenience of passenger spaces; this factor, within the limitations of weight and stability, is determined by the owner's willingness to pay for more refined passenger comforts; clearly, this decision will depend on the owner's assessment of the importance of this factor in generating passenger demand; and
- price; the required fare reflects nearly every aspect of the vessel design, through capital and operating costs, as well as the financial environment, through capital availability, interest rates, taxes and possibly subsidies; furthermore, the pricing decision must also reflect the actual utilization of the system, that is, its annual transport capacity and load factor.

In addition to these factors, the intangible characteristic of novelty may play a significant role in setting passenger demand, at least initially. This intangible value, particularly in the case of air-cushion vehicles, is seen as a potential asset, with the vessel itself serving as an attraction to the service.

B. Conceptual design assumptions.

To initiate the design process, a number of assumptions were necessary. In certain cases, due to the lack of more refined data, these assumptions were based on preliminary estimates, resulting in a much simplified picture of the hypothetical service.

The types of assumptions required in the design process may be outlined as follows:

- traffic volume estimates (annual), for passenger, automobiles and trucks;
- traffic seasonality, reflecting variation in the demand over the year;

- -- traffic directionality, reflecting any inequalities between eastbound and westbound traffic flows, which may also vary with the season;
- -- vehicle dimensions and weights, including passenger space and weight requirements;
- -- routes, insofar as they affect vessel characteristics through roundtrip distance, available depth of water, port maneuvering delays, and shoreside facilities;
- -- daily operating profile and schedule;
- -- annual operating profile, including weather and ice-related delays; and
- -- financial assumptions, including interest rate (specified yield) and corporate income tax considerations.

In the following sections, each of the above assumptions will be discussed in more detail.

1. Annual traffic volume estimates.

An assumed annual traffic volume has been cited in the report of the Wisconsin-Michigan Bi-State Car Ferry Task Force (Ref. 2):

> ...New, faster and attractive vessels could serve a passenger market conservatively estimated at 1 million per year and a tourist auto market of 300,000 vehicles peryear...

These figures were used as a starting point in sizing the conceptual vessel designs. In addition, however, and primarily because of concerns regarding the seasonality of the passenger market, there was appended to this assumed traffic volume a truck service volume of 30,000 per year. (This figure is an estimate of the roughest sort, but it is believed to be well within the limits of the total available market for east-west truck movements that might be expected to benefit from a cross-lake service.) To meet the requirements of a seasonally varying demand, several of the vessel designs are envisioned as incorporating "convertible configurations" adaptable to various mixes of passenger automobiles and trucks.

Thus, the specified annual traffic volume for the "convertible" vessels may be stated as:

Passemgers	1,000,000
Automobiles	300,000
Trucks	30,000

2. Traffic seasonality.

Given a specified annual traffic volume, there remains the problem of non-uniformity in the demand over the course of the operating year. In terms of design characteristics, the principal difficulty presented by a highly seasonal traffic is simply stated: in order to carry the peak traffic load, the system must be designed at a larger capacity, per trip. The vessel, in other words, must be larger (and more expensive) while the total annual traffic volume remains essentially unchanged. During the off-season, on the other hand, the vessel must operate at a small fraction of its trip capacity. Clearly, the price of the service must be increased to cover the cost of the overdesign, unless alternative services can be provided by the vessel during the slack period.

The actual performance of the existing cross-lake passenger services indicates a highly seasonal traffic, reflecting a primary dependence on the summer tourist market (between Memorial Day and Labor Day, approximately), together with minor peaks on certain key weekends during the remainder of the year. Of course, the existing vessels provide rail-car service year-round, enabling them to generate other revenue across the slack months in the passenger/automobile traffic flow.

The seasonality of the traffic in passengers that might be experienced by new and more attractive services, with vessels specifically designed for all-year service, is open to question. For example, it might be argued that the cross-lake passenger service will remain almost entirely seasonal, regardless of changes in the attractiveness of the service offered. On the other hand, it is entirely possible that a modernized year-round service would attract more off-season passenger traffic than the existing services, thus reducing the system's dependence on summer tourism. Reliable forecasts of this potential trend are not available; for this reason it was decided not to make an estimate of the seasonality, but rather to evaluate the capabilities of the vessels for handling seasonal traffic. This vessel capability was expressed as follows:

- the average daily traffic volume was determined by dividing the assumed annual volume by the number of operating days per year;
- the maximum daily traffic volume was stated as a function of vessel capacity and scheduled trips per day; (depending on schedule assumptions, the number of trips per day may be increased during peak traffic seasons;)
- the degree of seasonal capacity increase was represented simply as the ratio of maximum daily capacity to assumed average daily volume.

For vessels incorporating "convertible configurations", a significant expansion in passenger/automobile capacity can be realized during tourist season, with a corresponding increase in truck capacity during the winter months. This feature may be of significant value in overcoming the problems of seasonal traffic.

3. Traffic directionality.

The problem of directionally imbalanced traffic is similar to that of seasonality: a larger, more expensive vessel is required to handle a largely one-way flow. Again, in the absence of reliable forecasts, it was necessary to make the simplifying assumption that flows would be equal in each direction.

By changing the number of round-trips per day, and by making use of vessels with "convertible configurations," some degree of imbalance can be accomodated without enlarging the system. Implicitly, the assumption of directional balance can be made without sacrificing the general nature of the results, provided that the directionality that actually arises can be handled by the above means.

4. Vehicle dimensions and weights.

The following weights and space requirements were assumed:

Automobiles:	Weight	3500 lb (avg)
	Lane Width Req't	10 ft (max)
	Lane Length Req't	18 ft (avg)
	Overhead Clearance	8 ft (max)
Trucks:	Weight	55000 lb (avg)
	Lane Width Req't	12 ft (max)
	Lane Length Req't	55 ft (max)
	Overhead Clearance	15 ft (max)
Passengers:	Weight (incl. luggage)	240 lb
	Enclosed Deck Area Req't	25 ft^2
	Exterior Deck Area Req't	25 ft^2
	Clear Height	7.5 ft

All of the above weight and space allowances are generous by vehicle-ferry standards. The vehicle spaces are sized and arranged to permit loading and unloading of vehicles by their owners, rather than by ship's crew or shore-facility personnel. Passenger deck spaces are sized to provide the above requirements for the maximum passenger capacity, which can be expected to occur primarily during the tourist season, when exterior spaces can be utilized to greatest advantage. During the winter months, the enclosed spaces will be at a premium, but the number of passengers will, in all probability, be far less than the maximum capacity.

5. Routes.

The principal route considered in the design and economic analysis had the following characteristics:

One-way distance (entrance to entrance)	60 stat mi
Harbor transit and maneuvering delay, per call	20 min
Maximum vessel length	450 ft
Maximum draft	18 ft

In broad terms, this route corresponds to either Ludington-Manitowoc or Frankfort-Kewaunee. A second route profile differs only in one-way distance, which is increased to 81 statute miles, corresponding to Milwaukee-Muskegon.

Apart from the factors listed above, no specific port attributes were incorporated in this study. Such further issues as the availability and price of waterfront property, highway arrangements and access to the ferry facilities, local labor and material supplies, and the precise nature of port facilities, have not been explored.

6. Daily operating profile schedule.

For normal passenger operations (other than in peak tourist periods), a nominal operating day of approximately 12 hours was envisioned. For the conventional vessel types, this corresponded to two round-trips per day on the shorter (60 stat mi) route.

During peak tourist season, it would be possible to extend this schedule to three round-trips per day, with the first departure and last arrival at reasonable hours. Typical schedules for conventional vessels serving the shorter route might be as follows:

Normal schedule: 2 RT/DAY. Single ship service.

26-kt vessel

Port A		Port B
9 a.m.	→	11 a.m.
2 p.m.	←	12 noon
3 p.m.	→	5 p.m.
8 p.m.	←	6 p.m.

21-kt vessel

Port A		Port B
8 a.m.	→	10:30 a.m.
2 p.m.	←	11:30 a.m.
3 p.m.	→	5:30 p.m.
9 p.m.	←	6:30 p.m.

Both schedules assume one hour turnaround time per call, including approximately 20 minutes for harbor transit at reduced speed, maneuvering, docking and undocking. This figure is made up of a one mile total harbor transit at five mph average restricted speed (12 minutes), three minutes to dock on a straight approach, and five minutes to undock and swing ship. (Unlike the existing ferries, the proposed vessels dock bow first, for reasons that will be detailed subsequently.)

Loading and unloading operations will also be described in connection with the vessels themselves. However, it is obvious that the requirement of a quick turnaround for a large number of vehicles (for) example, 200 automobiles unloaded, and 200 loaded, in 40 minutes), can only be met by simultaneous loading and unloading, with the passengers doing their own driving. It is believed that vessels can be designed to provide this turnaround capability, in combination with improved shore facilities.

The minimization of turnaround time becomes highly significant during peak traffic periods. For example, to realize a three round-trip per day passenger schedule, on the 60-stat route, without unduly early starts or late arrivals the following schedules could be instituted:

26-kt vessel

Port A		Port B
7 a.m.	→	9 a.m.
12 noon	←	10 a.m.
1 p.m.	→	3 p.m.
6 p.m.	←	4 p.m.
7 p.m.	→	9 p.m.
12 midnight	←	10 p.m.

21-kt vessel

Port A		Port B
6 a.m.	→	8:30 a.m.
12 noon	←	9:30 p.m.
1 p.m.	→	3:30 p.m.
7 p.m.	←	4:30 p.m.
8 p.m.	→	10:30 p.m.
2 a.m.	←	11:30 p.m.

None of the above schedules reflect time-zone differences, but the attractiveness of high speed is clearly shown, at least in terms of increasing the number of conveniently timed sailings per day. For conventional vessels, and particularly for vessels restricted in length by considerations of port maneuvering, this additional speed is dearly bought, as will be discussed later.

The air-cushion vehicle is not limited by the relationship of speed and length. With the potential for speeds of 50-60 knots, under favorable weather and sea conditions, schedules can be made very attractive indeed. Assuming a turnaround time of 40 minutes per call, (20 minutes port transit and maneuvering, and 20 minutes loading and unloading), the following normal schedule could be achieved on the 60 statute mile route.

Normal schedule: 4 RT/DAY. Single ACV service.

52-kt Air Cushion Vehicle

Port A		Port B
8:30 a.m.	→	9:30 a.m.
11:10 a.m.	←	10:10 a.m.
11:50 a.m.	→	12:50 p.m.
2:30 p.m.	←	1:30 p.m.
3:10 p.m.	→	4:10 p.m.
6:50 p.m.	←	4:50 p.m.
7:30 p.m.	→	8:30 p.m.
10:10 p.m.	←	9:10 p.m.

As a rule, frequency of service is the most important single factor in service attractiveness for passenger automobiles. The advantage of high-speed craft is apparent, provided that the service is reliable, and that the price is reasonable.

A further analysis of scheduling might reveal the desirability of altering these basically clock-like operations to correspond with actual diurnal variations in potential traffic volume. The effect of this kind of schedule rearrangement on the design requirements of the vessels themselves is negligible.

7. Annual operating profile.

For purposes of this preliminary economic overview, the vessels are assumed to operate on their normal schedules year-round, except as specifically noted. The effects of a given seasonality on operating costs can be estimated by straightforward methods, although, as mentioned earlier, there is no specific estimate of the actual degree of seasonality that will be experienced by the service.

For all vessels, a preliminary estimate of 345 working days per year has been made. Of the remainder, 10 days are set aside for layup, and 10 for weather and ice. It is felt that with the vessel's relatively light daily duty cycle, a 10-day layup is conservative. Similarly, based on experience with the existing ferry services, 10 weather days, including ice, is probably conservative. No explicit consideration of actual weather or ice delays was made, other than to include a margin on fuel consumption to account for the principal costs of these delays. Apart from the lost weather and ice days mentioned above, no loss of round-trips was attributed to adverse conditions.

8. Financial assumptions.

a. Capital recovery costs.

The annual cost of capital recovery was based on the following set of conditions:

- all capital investments were assumed to be 100% equity, no loan;
- a corporate income tax of 48% was assumed with tax deferral;
- no tax credit was applied:
- an after-tax yield on investment of 10% was specified; and
- the economic life was assumed to be 35 years for conventional vessels, 15 years for air-cushion vehicles.

It is felt that these assumptions represent very nearly a "worst case" portrayal of the financial situation.

The capital recovery factors (CRF) resulting from these assumptions are as follows:

Conventional vessels	0.134
Air-cushion vehicles	0.165

(Capital Recovery Factor is the fraction of the investment that must be paid annually in order to yield the specified 10% return after tax.)

No subsidy of any kind was incorporated in the economic analysis, recognizing the conservatism of this assumption.

b. Operating costs.

Only the usual items of vessel operating cost were included in the analysis. Specifically excluded were the direct operating costs (as well as annual capital costs) associated purely with shore facilities. While this is recognized as a weakness in the approach, it was felt that a full study of shore-facility costs was strictly in qualitative terms, remembering that some addition to the resulting fares will have to be made in the final analysis to cover the costs of these facilities.

c. Passenger catering costs.

As presently envisioned, all vessels will provide catering services, such as a snack bar, coffee shop, restaurant, lounges, and other public spaces. Sufficient space and weight has been allowed for these catering services, together with sufficient life-raft capacity for their personnel. However, these personnel are not considered members of the ship's complement for the purposes of crew cost assessment, nor are the passenger-catering provisions (stores and supplies) included in the ship's budget. Specialized catering equipment, similarly, was excluded from the cost of the ship. (In effect, catering services are treated as a concession, and it is assumed that the concessionaire will absorb these costs in his pricing.)

Maintenace of public spaces, apart from the concessionaire's domains, was included as a separate maintenance and repair item, assessed to the ship. This item will consist mainly of the costs, for labor, supplies, and overhead, of daily cleaning and routine maintenance of public spaces, assumed to be performed by a subcontractor rather than by the ship's crew.

C. Measure of merit.

The simplest measure of merit has been selected for this analysis, bearing in mind that the ultimate price to the consumer, and hence the revenues, are unknown. This measure of merit is the required fare (RF), which can be written as follows:

$$RF = (AOC + P \cdot CRF)/ATV,$$

where AOC is the annual operating cost, P is the capital investment, CRF is the capital recovery factor given previously, and ATV is the assumed annual traffic volume. Thus the required fare is the fare that must be charged, at a given level of traffic volume, to cover all operating costs and return a 10% yield on the investment, after tax.

For the vehicle ferry service, annual traffic volume represents a nonhomogeneous quantity, including passengers, automobiles, and trucks. Obviously, each of these units must be assigned a different fare, and there are an infinite number of ways in which the pricing may be structured.

To simplify the pricing scheme, the pricing was confined to passengers, automobiles, and trucks (tractor-trailer combinations) only. Similarly, no consideration was given to seasonal variations in pricing, nor special pricing for night trips, nor discounts for round trip tickets. These are details which should be considered at a more advanced stage of the analysis.

To arrive at a definition of the quantity ATV, the following relationships between the various rates were arbitrarily set:

-- The automobile fare, exclusive of passengers, was set at 3 times the passenger fare. (Current services use a factor of approximately 1.8 for this relationship, but it was considered desirable to encourage better utilization of automobiles by decreasing the passenger fare.)

-- The fare for a standard tractor-trailer combination, not exceeding 55 ft in the overall length, by 8 ft width, was set at 4.5 times the automobile rate, based on a compromise between single-deck lane occupancy and two-deck lane occupancy. Thus, the truck fare is 13.5 times the passenger fare. (As presently envisioned, this truck rate would include the driver.)

In accordance with these relationships, the value of ATV is given by:

$$\text{ATV} = \text{Annual Passengers} + 3 \text{ Annual Cars} + 13.5 \text{ Annual Trucks.}$$

This value can be inserted in the expression for required fare, obtaining the passenger rate, which can then be multiplied by the above factors to yield the required fares for automobiles and trucks.

Apart from the required fare (a measure of merit related to the ultimate price of the service to the consumer) consideration was given to those variables in the vessel designs that contribute to the other economically significant factors in the service: transit time, total system time, frequency and schedules of service, etc.

IV. HIGHWAY VEHICLE AND PASSENGER VESSELS

A. Design Philosophy.

Several design features are common to all the vessels described below. Broadly, these common aspects are as follows:

1. Day-boat arrangement of passenger accommodations.

None of these vessels is fitted with stateroom accomodations. On the shorter (60-mile) route, the transit time is two hours for the 26-knot vessel, two and a half hours at twenty-one knots. The shortness of this trip will probably preclude a significant use for staterooms, and the added weight and cost was not considered justified. On a longer route, perhaps, this design philosophy might have to be reevaluated.

2. Drive-through arrangement of vehicle spaces.

All vessels are arranged for simultaneous loading and unloading, with the vehicles handled by their owners. In the case of conventional vessel types, vehicles would drive aboard through a quarter port, and exit through the bow. For ACV's, the amphibious capability would permit loading and unloading in any flat area, straight through the vessel.

3. Sophisticated automation systems for engine-room operations.

All engine rooms would normally operate unattended, with an engineer on watch in the control room. Bridge control of the power plant is assumed in all cases.

4. Active fin stabilization.

All conventional vessels are assumed to be fin stabilized, with the stabilizing units retractable for docking and ice transit. It is felt that stabilization will do much to improve passenger comfort during the rougher fall and winter months. Air-cushion vehicles, whose motion characteristics are completely different from those of conventional ships, cannot be stabilized in this manner. Recent innovations in ride-control systems for ACV's are more difficult to assess, and their incorporation in our designs is not explicitly assumed.

All conventional vessels, by virtue of their relatively high power, narrow waterline beam, raked bow forms, and flared sides, will possess superior ice-transitting capabilities. Hulls are assumed to be ice strengthened to ABS ice-class B. Air-cushion vehicles, when operated carefully in areas of rough ice, have a proven ice-transitting capability. (Ice coverage on Lake Michigan, in normal winters, is usually confined to a few miles of relatively thick but unconsolidated ice in the vicinity of the shore. [Ref. 4])

6. Vessel maneuverability.

All conventional vessels are equipped with bow thrusters. In addition, single-screw vessels are fitted with stern thrusters. It is felt that these investments will pay for themselves in expediting port maneuvering and docking operations, essential to rapid turnaround of the vessels. An intangible saving in hull and port facility repairs should also be realized. Maneuvering of the much smaller air-cushion vehicles was not considered to represent a problem area.

B. Conventional displacement vessels.

Four conventional vehicle-ferries were considered in the conceptual design. They are identified as follows:

Design I: To explore the possibility of meeting the entire specified traffic volume with a single conventional ship, a 28.5-knot automobile/passenger/truck ferry was considered. The required dimensions exceeded the 450-ft limitation on length; however, its characteristics are included for the sake of comparison. No further development of this vessel was pursued.

Design II: A 26-knot alternative, designed for a two-ship service, fell within the prescribed dimensional restrictions. Although the total annual costs of the two-ship service are significantly higher than those of Design I, corresponding advantages are gained in frequency and flexibility of service.

Design IIS: A derivative of Design II, with service speed reduced from 26 to 21 knots. Significant building cost and fuel cost reductions were obtained by incorporating a more modest speed, at the expense of some reduction in service frequency, and a possible sacrifice of the three round-trip per day capability.

Design IIT: A simplified version of Design IIS, abandoning the "convertible configuration" in favor of a straight single-deck arrangement. This design was envisioned as a truck ferry, with limited accommodations for other classes of vehicles. Passenger accommodations were scaled down to reflect the greater emphasis on commercial traffic. In spite of these attempts to reduce costs, the results of the analysis were not favorable to the "all-truck" alternative, and no further development of Design IIT was undertaken.

The principal particulars of these designs are summarized in Table I. Estimated building cost breakdowns are given in Table II. Annual operating costs and average annual costs (including capital recovery) are given in Table III. Finally, required fares, based on the extensive assumptions given previously, are listed in Table IV, along with other measures of merit.

A typical layout sketch of one of these vessels (Design II) is shown in Fig. 2, and a midship section of the same vessel is shown in Fig. 3. The general layout of all designs is broadly similar to Design II, apart from dimensions and some details. Most notably, the single-deck vessel, Design IIT, is characterized by the omission of the movable platform decks, and the machinery casing is placed on the vessel's centerline, supplanting the twin machinery uptakes of the other designs.

1. Service Speeds

As the estimated horsepowers reveal, the penalty for increased speed is remarkably severe for vessels limited to 450-ft length. In particular, at this length, a speed increase from 21 to 26 knots requires a tripling of the installed horsepower, (Refs. 5,6), with concomitant increases in weight, first cost, maintenance, and in fuel cost. The parameter most

Table 1. Design particulars of conventional displacement vessels for cross-lake highway vehicle ferry services.

Design	I	II	IIS	IIT
Dimensions (ft):				
Overall length	725.0	450.0	450.0	450.0
Waterline length	685.0	425.0	425.0	425.0
Maximum beam	83.0	83.0	83.0	80.0
Waterline beam	62.0	58.0	58.0	58.0
Full-load draft	16.5	16.5	16.5	16.5
Depth to main deck	34.0	28.0	28.0	28.0
Depth to upper deck	51.0	45.0	45.0	44.0
Depth to weather deck	59.0	53.0	53.0	52.0
Capacities:				
Normal Configuration:				
Automobiles	248	128	128	0
Trucks	22	12	12	36
Passengers	1036	536	536	72
Tourist Configuration:				
Automobiles	384	204	204	--
Trucks	0	0	0	--
Passengers	1536	816	816	--
Winter Configuration:				
Automobiles	--	--	--	--
Trucks	62	32	32	36
Passengers	124	64	64	72
Deadweights and Displacement (Lton):				
Normal cargo deadweight	1039	552	552	892
Maximum cargo deadweight	1536	793	793	892
Operating deadweight	198	144	88	73
Light ship	8003	4371	3853	3598
Normal displacement	9240	5067	4493	4563
Full-load displacement	9737	5308	4734	4563
Speed and Powerings:				
Service speed (knots)	28.5	26.0	21.0	21.0
Service speed (mph)	32.8	29.9	24.2	24.2
Machinery type	St Tbn	St Tbn	MS-D	MS-D
Arrangement	Tw Scr	Tw Scr	S Scr	S Scr
Total shaft horsepower	30 000	28 000	8500	8500
All purpose specific fuel consumption (lb/hp.hr)	0.48	0.48	0.45	0.45
Fuel type	Bunker	Bunker	Diesel	Diesel
Fuel price ($/Lton)	95	95	115	115

(continued)

Table I. (continued).

Design	I	II	IIS	IIT
Complement:				
Master	1	1	1	1
Mates	2	2	2	2
Wheelsmen	2	2	2	2
Chief Engineer	1	1	1	1
Cert. E.R. Crew	5	5	3	3
Patrolman	2	1	1	1
Vehicle Deck Crew	3	3	3	3
Crew Stewards	3	2	2	2
Passenger's Stewards	8	4	4	2
Purser	2	1	1	0
Total	29	22	20	17
Replacement Crew:	15	11	10	9
Additional Technical Data:				
Speed-length ratio	1.089	1.261	1.019	1.019
Block coefficient (full load)	0.500	0.470	0.419	0.404
Prismatic coefficient	0.550	0.570	0.520	0.520
Midship coefficient	0.909	0.825	0.806	0.777
Volumetric coefficient $\times 10^3$	1.091	2.489	2.220	2.140

Table II. Capital cost breakdown for conventional vessel designs. (1977 $/1000)

Design	I	II	IIS	IIT
Hull steel material @ $314/Lton	1742	742	742	718
Hull steel labor	7508	3638	3638	3537
Outfit material @ $2500/Lton	3161	1851	1851	1195
Outfit labor	3373	2083	2083	1406
Hull engineering material @ $4900/Lton	2708	1556	1556	1510
Hull engineering labor	3244	2141	2141	2093
Machinery (installed)	7873	7600	3955	3955
Vehicle-handling equipment	1566	1236	1236	480
Bow thruster installed	250	250	250	250
Stern thruster installed	--	--	250	250
Stabilizers	750	750	750	750
Electronics & automation	350	350	300	300
Total	32525	22197	18752	16444
Profit (5%)	1626	1110	938	822
First ship price	34151	23307	19690	17266
Second ship price	--	22470	18922	--

Table III. Annual cost breakdown for conventional vessel designs. (1977 $/10

Design	I	II	IIS	I.
Annual fuel cost:				
2 R/Tday, 60-mile transit	1959	1829	728	7
2 RT/day, 81-mile transit	2576	2405	980	9
3 RT/day, 60-mile transit	2802	2615	1078	10
3 RT/day, 81-mile transit	3734	3485	--	--
Lubricating oil	0	0	37	3
Hull maintenance and repair	253	160	160	16
Machinery maintenance and repairs				
2 RT/day	104	99	60	6
3 RT/day	127	121	90	9
Passenger space M & R	104	69	69	35
Layup costs	45	30	30	30
Crew wages and benefits	929	738	684	610
Crew subsistence	44	33	30	26
Crew indemnity	52	40	36	31
Stores and supplies	11	4	2	1
Hull & Machinery insurance	478	320	270	242
Passenger liability	250	125	125	50
Cargo insurance	80	40	40	50
Overhead and miscellaneous costs	80	40	40	20
Total annual operating cost:				
2 RT/day, 60-mile transit	4389	3517	2311	2049
2 RT/day, 81-mile transit	5006	4093	2563	2301
3 RT/day, 60-mile transit	5255	4325	2691	2429
3 RT/day, 81-mile transit	6187	5195	--	--
Annual capital recovery	4576	3067	2587	2314
Average annual cost:				
2 RT/day, 60-mile transit	8695	6584	4898	4363
2 RT/day, 81-mile transit	9582	7160	5150	4615
3 RT/day, 60-mile transit	9831	7392	5278	4743
3 RT/day, 81-mile transit	10763	8262	--	--

Table IV. Measures of merit for conventional vessel designs.

Design	I	II[a]	IIS[a]	IIT
2 RT/day, 60-mile transit				
Average annual cost ($/1000)	8965	13168	9796	4363
Required fares:				
Passenger	$ 3.89	$ 5.71	$ 4.25	--
Automobile	11.67	17.14	12.75	--
Truck	40.84	59.98	44.62	87.82
Service frequency:				
Sailings per day (each way)	2	4	4	2
Time between sailings (hr)	6.0	3.0	3.5	7.0
First daily departure	9 am	9 am	8 am	8 am
Last daily arrival	8 pm	8 pm	9 pm	9 pm
Vehicle transit time[b] (hr)	3.67	3.67	4.14	4.14
Seasonal overload capability[c]	2.32	2.39	2.39	1.50
Seasonal price increase[d] (%)	9.66	12.27	7.76	8.71

(continued)

Table IV. (continued).

Design	I	II[a]	IIS[a]	IIT
2 RT/day, 81-mile transit				
Average annual cost ($/1000)	9582	14320	10300	4615
Required fares:				
Passenger	$ 4.16	$ 6.21	$ 4.47	--
Automobile	12.47	18.64	13.40	--
Truck	43.65	5.23	46.92	92.89
Service frequency:				
Sailings per day (each way)	2	4	4	2
Time between sailings (hr)	7.5	4.0	4.5	9.0
First daily departure	8 am	8 am	7 am	6 am
Last daily arrival	9 pm	10:45 pm	Midnite	11 pm
Vehicle transit time[b] (hr)	4.43	4.43	5.09	5.09
Seasonal overload capacity[c]	2.32	2.39	1.59	1.00
Seasonal price increase[d] (%)	12.32	15.39	0.00	--

Notes:

[a] Prices and service frequencies for two-ship service.

[b] Vehicle transit time is ship transit time (dock to dock), plus 40 minute vehicle handling delay at each end.

[c] Seasonal overload factor reflects increased passenger vehicle capacity due to convertible configuration, and potential extra round-trip per day.

[d] Seasonal price increase reflects average daily cost increase due to expanded schedule.

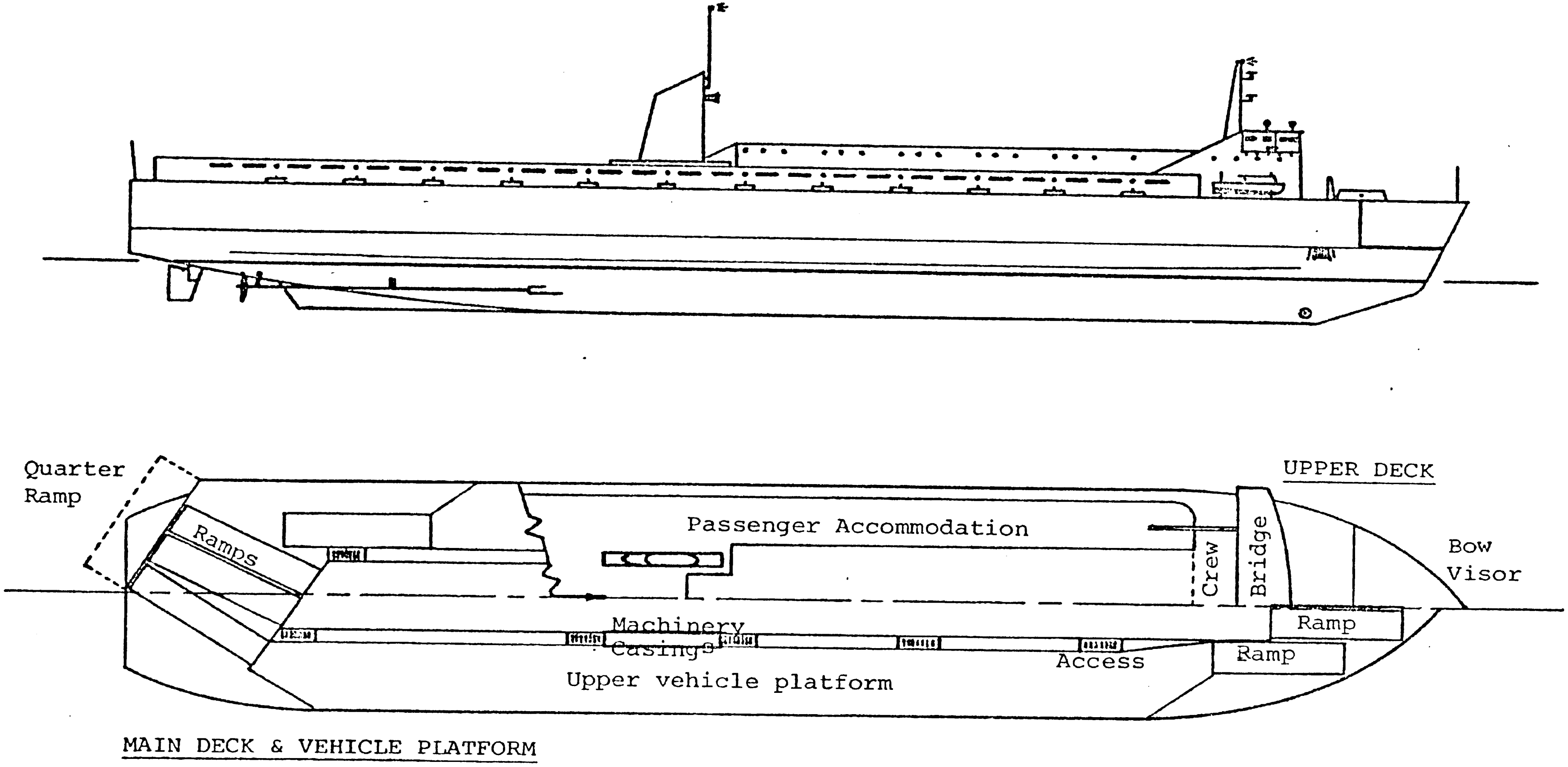


Fig. 2. Outboard profile and general arrangement, Design II. (scale: 1 in = 60 ft).

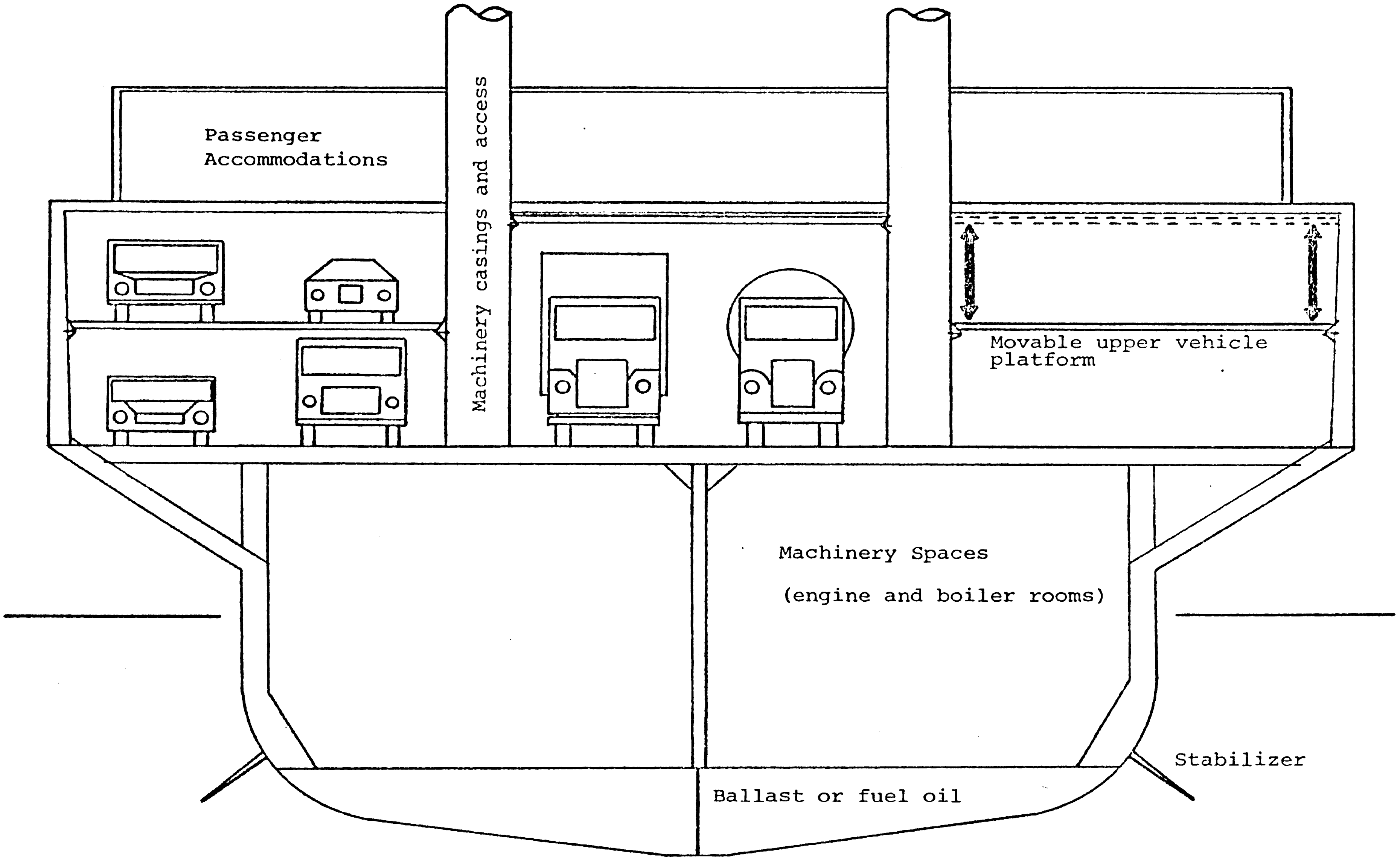


Fig. 3. Midship section (through machinery space), Design II. (scale 1 in = 10 ft).

relevant to this phenomenon is the "speed-length ratio," defined as $V/\sqrt{L}$, the speed (in knots) divided by the square root of waterline length (in feet), At high values of speed-length ratio (typically greater than 1.0-1.1), the required horsepower increases drastically with relatively small increases in speed. The values of speed-length ratio for these conceptual designs are included in Table I. For purposes of comparison, a typical cross-channel ferry (of similar function and form) operates at a speed-length ratio of 1.1-1.2, although ratios as high as 1.4 have been attained in exceptionally fast examples.

The conceptual designs have been based on a relatively high speed requirement, being quite long for their displacements, and with extremely fine hull forms. Nevertheless, it does not seem reasonable to expect material improvement in vessel merit by increasing the speed above 26 knots, at the required length of 450 ft. Similarly, speed reductions below 21 knots do not yield sufficient cost advantages to outweigh losses in service frequency and attractiveness.

2. Power plants: Steam versus diesel, and single versus twin-screw.

At the higher powers required by the fast vessels (Designs I and II), steam turbine and medium-speed diesel plants are roughly cost competitive, with the diesel delivering somewhat better fuel consumption at the price of slightly higher total weight and initial cost. It is possible that the diesel plant would be more amenable to automated systems, and should require a smaller engineering staff. In addition, the diesel propulsion engines can be completely shut down when the vessel ties up for the night, while the steam plant might require some firing all night to avoid the problems of raising steam from cold boilers every morning. Some saving of fuel would result from this factor, in addition to the lower fuel consumption while underway. Geared diesels would provide better maneuverability.

However, in the higher horsepowers, the weight and cost advantages of the steam plant cannot be neglected. Several residual advantages also accrue to the steam turbine plant. These include the ready availability of steam for accomodation heating, and for de-icing of critical portions of the vessel's exterior, especially loading ports and bow visors. The overload characteristics of turbines might be of some advantage in heavy ice, although reverse power would be less available than for geared diesels, unless controllable pitch propellers were fitted to the turbine vessel (as they would be to the diesel). Finally, and perhaps most importantly for energy considerations, the steamer could be designed to burn coal or, at some increase in cost and complexity, a mixture of coal and oil.

With horsepowers in the neighborhood of 30,000 shp, single-screw arrangements were not considered at the draft limitation of 18 ft.

On the other hand, for the lower-powered 21-knot vessels, the superiority of the geared medium-speed diesel, in terms of fuel rate, weight, and price, was manifest.

Similarly, 8500 shp was well within the limits of single-screw capability, with significant improvements in propulsive efficiency as well as weight and cost reductions. The loss in maneuverability due to a single-screw installation is easily countered by the incorporation of a stern thruster in addition to the bow thruster fitted to all vessels.

Thus, the high-speed vessels are conceived as twin-screw, steam-turbine powered, while the lower-powered ships are envisioned as single-screwgeared medium-speed diesels. None of these powering assumptions can be held sacred, however, and all would be subject to further scrutiny if the design process were continued to a more detailed level. Specifically, consideration of gas-turbine power plants should not be neglected.

3. Maneuvering, docking, and undocking.

As presently envisioned, the vessels would dock with the bow to a more-or-less conventional ferry stage, with a quarter ramp extending to the quay at the vessel's stern. Thus, access would have to be provided to both ends of the ship, and this would require modification of the existing shore facilities. In addition, the wider beam of the vessels would require modification of the present ferry stages, apart from those geometric changes resulting from bow-first docking. The docking layout is shown in Fig. 4.

The principal advantage of this docking arrangement, apart from permitting simultaneous loading and unloading without turning of vehicles

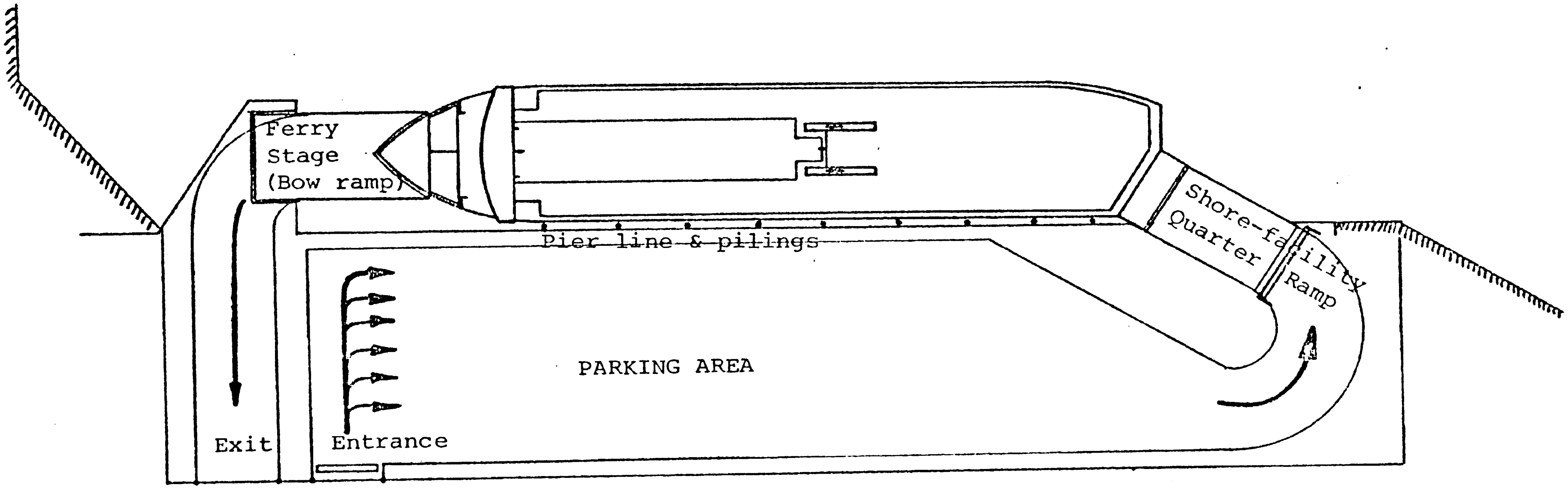


Fig. 4. Typical dock and shore terminal arrangement, Design II. (scale 1 in = 100 ft).

on board, is a matter of vessel maneuvering. Docking bow-first, the vessel can make a straight approach to the stage, decelerating in an approximately straight line. Since maneuvering of the vessel during deceleration is made more difficult by lack of propeller wash over the rudder, a straight approach to the dock is quite desirable from the operational standpoint. After backing away from the stage, the swinging maneuver can be made under acceleration, when propeller thrust adds to rudder effectiveness. The net effect of this alteration in operating procedure should be several minutes saved in total maneuvering delay.

4. Loading and unloading operations.

Clearly, the loading and unloading of the vessel holds the key to a quick turnaround. As mentioned previously, all driving is performed by the vehicle owners, and simultaneous loading and unloading are made possible by a "drive-through" arrangement of the vehicle spaces, involving a minimum of turning.

As an illustration of the vehicle handling process, consider the midship section illustrated in Fig. 3, together with the general arrangement of Fig. 2. In its normal configuration, the vessel might enter port with the two center lanes in a single-deck arrangement, occupied by trucks. The outboard spaces might be in their two-deck arrangement, thus giving a total of eight lanes of automobiles. The ramps accessing the upper platform would be lowered, both forward and aft, and the vehicles on the platform would drive off through the outboard lanes of the bow visor ramp, while their replacements drive on through the outboard lanes of the quarter ramp. Meanwhile, the truck lanes would be loaded/unloaded through the inboard lanes of the bow and quarter ramps. When the upper platforms are refilled, the ramps would be raised, giving access to the outboard lower lanes. These would then load/unload using all four lanes of the bow and stern ramps. Finally, as the vessel undocks, the quarter ramp would be raised into its sailing position, the bow visor would be lowered, and all internal ramps would be returned to their lower position, ready for the next sequence.

Variations on this procedure would be required for the alternative "convertible configurations," but the principle remains unchanged: each lane is a traffic flow through the ship. The assignment of each vessel lane to a given shore lane, and vice versa, is a relatively simple traffic control problem. As presently envisioned, this function would be controlled from forward and after stations, using remote controlled traffic signals mounted along the vehicle lanes.

During peak tourist season, with about 200 vehicles ready for loading, the process amounts to moving four lanes of traffic through about three ship lengths, or approximately one-quarter mile. At an average speed of 1 mph, certainly conservative, the process would require 15 minutes, plus a minimum amount of time for ramp raising operations.

However, the vehicle-handling operation is only a part of loading/unloading. Since passengers are, in effect, part of the loading system, passenger access to and from the vehicle decks must be well planned and efficient. This will require a multiplicity of access points, so that a minimum of walking about will occur on the vehicle decks. Even with the assumption that all passengers will be required by law to remain on the passenger decks while the vessel is underway, this movement of passengers should be achievable within twenty minutes, ten minutes to allow disembarking passengers to reach their cars, and another ten to clear the vehicle decks of embarking passengers. Passengers will be required to leave their cars unlocked, keys in the ignition, so that any laggard passengers can have their vehicles moved by a crew member. (Perhaps a small penalty will have to be placed on this service, to prevent its abuse.) In any event, the configuration of the vehicle decks is such that a stalled car need not stop the loading operation, although some delay will result. (In this regard, the passenger loading system is no worse than the presently used system of handling cars with ship's crew, and is probably significantly better, due to the more spacious vehicle decks and partial redundancy of traffic lanes.)

In short, the entire loading and unloading operation should occupy less than forty minutes, perhaps much less. It is felt that this design feature is well worth the price of the extra space requirement and sophisticated access ramps involved.

5. Passenger spaces.

Currently, passenger spaces are envisioned on two decks, extending nearly over the entire vessel's beam, and occupying as much of the vessel's length as can be arranged.

The lower of these two passenger decks will be completely enclosed, with only narrow side decks for line handling and life-raft stowage. Access to these side decks will be closed except for emergencies, but there will be many openings to permit rapid access to the rafts, and for crew movement. Numerous stairways, perhaps four or five on each side, will give access to the vehicle spaces below. These stairways will be in line with the machinery uptakes, and thus will require no additional sacrifice of vehicle lane space. Each stairway will have a landing at the level of the movable platform deck, in addition to its foot on the main vehicle deck. The landings will have exits to port and starboard, and when the platform deck on a particular side is stowed (in the single-deck lane configuration), the corresponding exit will be permanently secured, to prevent passengers from leaving the stairway in the direction of a deck that isn't there.

The upper passenger deck will be almost entirely open, perhaps with a partial canopy and a small enclosed lounge, or concession area. This open deck will be protected from direct headwinds by the bridge structure at its forward end, and will be broken only by the two machinery casings, port and starboard, well aft.

All passenger spaces will be brightly lit, conveniently arranged, and unconfusing. On the enclosed lower deck, a central promenade could extend for the entire length of the passenger space, opening on either side into the various lounges, restaurants, and other shops or facilities. Extensive use of bright colors, translucent plastic panels, and indirect lighting would contribute to an open feeling in the passenger spaces. The central promenade could be 20-ft wide without unduly cutting into the available width for the other spaces on either side, and skylighting of this central area would be an attractive possibility.

On the truck-ferry alternative, the passenger accomodation would follow the same general scheme, although its area would be less extensive.

6. Design problem areas for future research.

Apart from more detailed analysis of weights and costs, optimization of service speed, and rational selection of power alternatives, the following specific areas deserve more attention.

a. Seakeeping. The behavior of these vessels in waves must be ascertained, with particular regard to under-flare slamming due to pitch and roll. The heavily flared hull form is not novel, but care is required in its application. Similarly, the high-speed, fine-formed hull may be susceptable to uncomfortable pitching motions in certain seastates. These responses are of some importance in determining the operability of the vessels at full or nearly full speed in waves.

b. Loading arrangements. Special vehicle access systems, such as movable decks, and ramps, will have to be designed in greater detail, and a possible revision of vessel capacity may have to be made, consistent with these details.

c. Icing of bow visor and quarter ramp. The degree to which these components will collect frozen spray is unknown, although it will certainly be non-negligible. For this reason, systems to free these components of ice, at least to the point of maintaining their operability, will have to be designed if winter operations are to proceed with acceptable efficiency.

B. Multihull (catamaran) concepts.

Concurrently with the design of conventional monohull types, a catamaran vessel of approximately the same size as Design II was conceived. The principal characteristics of this vessel are given in Table V.

At a speed of 26 knots, the catamaran yielded a fuel saving of 14 percent. neglecting concerns regarding ice-transitting capability, (Ref. 7). However, the multihull vessel was found to cost 17 percent more than the comparable Design II, and this estimate is felt to be optimistic. As a result,

Table V. Design particulars of multihull vehicle ferry.

Dimensions (ft):	
Overall length	450.0
Waterline length	410.0
Maximum beam	90.0
Waterline beam	2 x 26.0
Full-load draft	16.5
Depth to main deck	30.0
Depth to upper deck	47.0
Depth to weather deck	55.0
Capacities:	
Normal configuration:	
Automobiles	144
Trucks	12
Passengers	600
Tourist configuration	
Automobiles	216
Trucks	0
Passengers	864
Winter configuration:	
Automobiles	--
Trucks	36
Passengers	72
Deadweights and Displacement (Lton):	
Normal cargo deadweight	584
Maximum cargo deadweight	892
Operating deadweight	128
Light ship	4908
Normal displacement	5620
Full-load displacement	5928
Speed and Powering:	
Service speed (knots)	26.0
Service speed (mph)	29.9
Machinery type	St Tbn
Arrangement	Tw Scr
Total shaft horsepower	24 000

Complement: See Design II, Table I.

Estimated first ship price (1977 $/1000)	26 034

the overall economic performance of the multihull concept was found to be slightly less attractive than its monohulled competitor, although the difference in average annual cost (including operating and capital items) amounted to only about one percent. This cannot be called a significant difference at this stage of the analysis. With increasing fuel price, or on a longer route (with fuel representing a higher fraction of average annual cost), the catamaran might acquire a slight edge, although its actual capital cost might be a few percent higher than estimated here.

At this point, however, the principal operational concern attached to the multihull concept is its unknown ability to transit ice. Ice accretion and blockage between hulls is not a certainty, but is more than a slight possibility. Technical evasions of this problem are possible, for example, by turning the flat surfaces of the bows inboard, and by a slight toe-in of the hulls to provide ice relief. However, both of these methods are counterproductive in terms of resistance and powering, and their effectiveness in mitigating the ice-transit problem would still be questionable. Rather than wrestle with this design problem at such an early stage, we decided to let the matter rest, until more data become available.

At lower speeds, in the neighborhood of 21 knots, the resistance benefits of the multihull concept vanish. For these reasons, no further development of the catamaran concept was undertaken for this study.

In overall appearance, the catamaran would present a similar profile to that of Design II, as represented in Fig. 2. Other design and operational features of the catamaran ferry would be closely similar to those of the monohulled Design II. A practical advantage of the multihull configuration, namely, increased deck space on given overall dimensions, is attractive for vehicle ferries. It was with some reluctance that this concept was abandoned, temporarily yielding to misgivings in the area of ice performance.

C. Air-Cushion Vehicles

Three conceptual air-cushion vehicles were considered for this analysis. Two of these conceptual designs represent significant advances in the practical present size of commercial ACV's, and were designed with single-vehicle service in mind. The third design is based on the proposed SRN-4 Mk. 4, the leading particulars of which are available in the literature (Ref. 8). This vessel was aimed at providing a two-vehicle service. The particulars of these three conceptual designs are listed in Table VI.

At a relatively early stage, it was decided to confine further analysis to two of these vehicles: identified as Designs B and C in Table VI. (Design A was found to have an annual traffic capaciy slightly below the assumed volume.) Annual cost breakdowns for Designs B and C are given in Table VII, (Ref. 9).

As mentioned previously, the weight limitations on ACV's precluded the transport of trucks at an economical rate. Roughly estimated, the required fare per truck was placed at $335, one way. For this reason, further study of the air-cushion vehicle concept was restricted to passengers and automobiles only. Measures of merit for the two ACV designs are listed in Table VIII.

1. Operability and speed.

A service speed of 52 knots was based on SRN-4 Mk. 3 data, assuming an average sea state of 3-5 ft significant wave height, corresponding to approximately a 20-knot wind. Under calm conditions (5-knot wind, with significant wave height under 2 ft), the vehicles would be capable of cruising at speed in excess of 60 knots. With significant wave height in the neighborhood of 8 ft, however, operating speeds would be reduced to about 40 knots. Generally, English Channel operations, based on the smaller SRN-4 Mk. 1, are subject to cancellation under a mean wind speed of 30-35 knots, with an associated significant wave height of 8-10 ft, (Ref. 8). It is believed that the SRN-4 Mk. 4, not to mention the still larger conceptual Design B, would possess superior operability.

For the purposes of this preliminary work, a 345-day operating season for ACV's was assumed. It is felt that any additional weather days would be compensated by supposed reductions in ice delay days. Speed reductions

Table VI. Design particulars of air-cushion vehicles

Design	A	B	C
Dimensions (ft):			
Length	202.5	255.0	185.0
Breadth	90.0	95.0	82.0
Cushion height	14.0	14.0	14.0
Hull depth	24.5	24.5	16.0
Overall height on landing pads	48.5	50.0	40.0
Capacities:			
Automobiles	108	124	54
Passengers	432	496	216
Estimated weights (Lton):			
Payload	215	247	108
Fuel (1 RT) plus reserve	21	24	12
Remainder of operating deadweight	2	2	1
Estimated light weight	369	424	168
Maximum gross weight	607	697	289
Speed and Powering:			
Service speed (knots) 3-5 ft waves	52	52	52
Service speed (mph)	59.9	59.9	59.9
Machinery type	Aircraft-derived gas turbine		
Arrangement	Shaft-driven airscrews		
Shaft horsepower:			
Lift	5800	6700	3800
Propulsion	20500	23500	11400
Total rated shp	26300	30200	15200
All purpose specific fuel consumption (lb/hp·hr)	0.50	0.50	0.52
Fuel type	#2 Gas Turbine Distillate		
Fuel price ($/Lton)	168	168	168
Complement:			
Master	1	1	1
Mate	1	1	1
Wheelsman	1	1	1
Chief engineer	1	1	1
Asst. engineer	1	1	-
Stewards	4	4	2
Vehicle deck crew	2	2	1
Total	11	11	7
Replacement crew:	11	11	7

Table VII. Estimated initial and operating costs of air-cushion vehicles

(1977 $/1000)

Design	B	C
Estimated vehicle price	35000	20000
Annual cost items:		
Fuel cost:		
4 RT/day, 60-mile transit	3384	1771
4 RT/day, 81-mile transit	4586	2400
6 RT/day, 60-mile transit	5076	2657
6 RT/day, 81-mile transit	6879	3600
Maintenance and repair:		
Hull and skirts	310	177
Machinery	191	120
Passenger spaces	50	25
Crew wages and benefits	534	372
Crew indemnity	20	13
Hull and Machinery insurance	490	280
Passenger liability	250	125
Cargo insurance	50	25
Overhead and miscellaneous costs	80	40
Total annual operating costs:		
4 RT/day, 60-mile	5359	2948
4 Rt/day, 81-mile	6561	3577
6 RT/day, 60-mile	7051	3834
6 RT/day, 81-mile	8854	4777
Annual capital recovery	5775	3300
Average annual cost		
4 RT/day, 60-mile	11134	6248
4 Rt/day, 81-mile	12336	6877
6 Rt/day, 60-mile	12826	7134
6 Rt/day, 81-mile	14629	8077

Table VIII. Measures of merit for air-cushion vehicle designs.

Design	B	C[a]
4 RT/day, 60 mile transit		
Average annual cost ($/1000)	11134	12496
Required fares:		
Passenger	$ 5.86	$ 6.60
Automobile	17.58	19.79
Service frequency:		
Sailings per day (each way)	4	8
Time between sailings (hr)	3.33	1.67
First daily departure	8:30 am	8:30 am
Last daily arrival	10:10 pm	10:10 pm
Vehicle transit time[b] (hr)	2.0	2.0
Seasonal overload capability[c]	1.71	1.50
Seasonal price increase[d] (%)	15.20	14.18

(continued)

Table VIII. (continued).

Design	B	C[a]
4 RT/day, 81-mile transit		
Average annual cost ($/1000)	12336	13754
Required fares:		
Passenger	$ 6.49	$ 7.26
Automobile	19.48	21.78
Service frequency:		
Sailings per day (each way)	4	8
Time between sailings (hr)	4.10	2.05
First daily departure	8:00 am	8:00 am
Last daily arrival	11:45 pm	11:45 pm
Vehicle transit time[b] (hr)	2.37	2.37
Seasonal overoad capacity[c]	--	--
Seasonal price increase	--	--

Notes:

[a] Prices and service frequencies for two-ACV service.

[b] Vehicle transit time is ACV transit time (dock to dock), plus 20 minute car handling delay at each end.

[c] Seasonal overload factor reflects increased passenger vehicle capacity due to slight capacity overdesign, and potential extra round trips per day.

[d] Seasonal price increase reflects average daily cost increase due to expanded schedule.

in ice would result, not from increased resistance, but rather from operational considerations: First, the necessity to avoid skirt damage due to impact with rough or broken ice; second, the requirement for increased margins for slowing and maneuvering.

2. General arrangements and passenger accommodations.

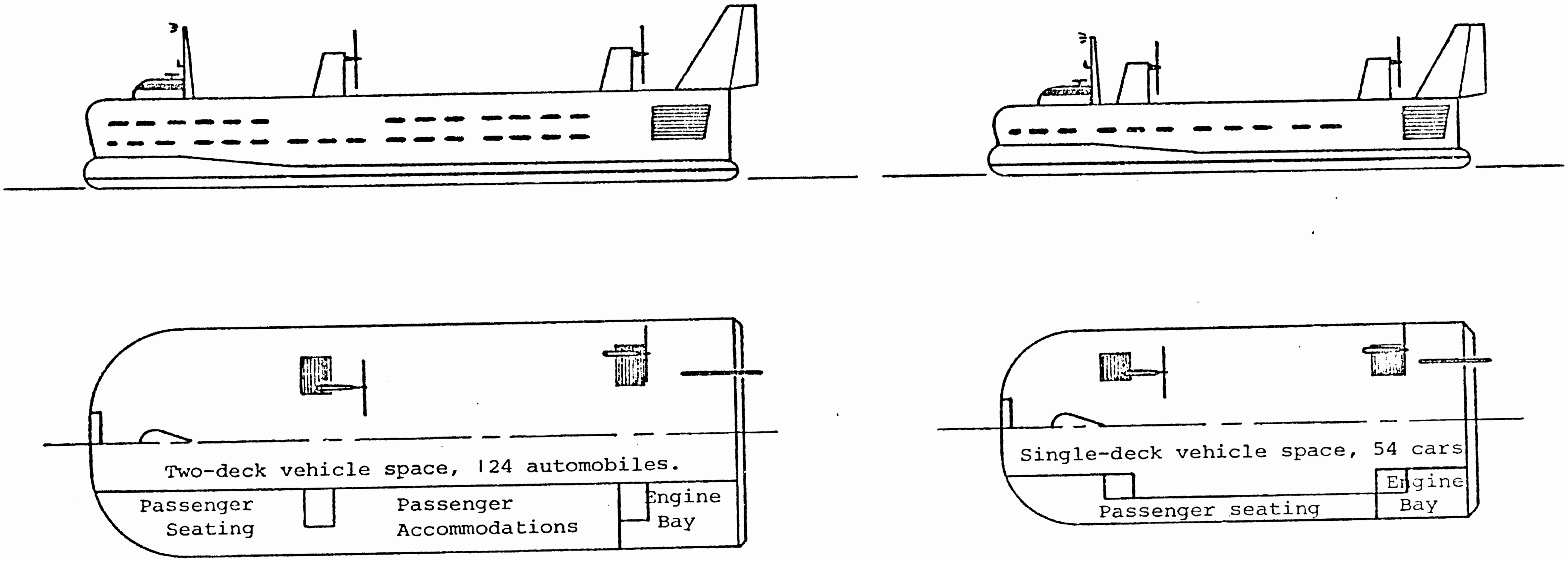
With regard to vehicle spaces, the smaller ACV was able to carry its full capacity of automobiles on a single deck. The larger craft, Design B, in order to obtain slightly more than double this capacity while remaining within credible overall dimensions and weights, was conceived as a two-deck configuration. In both cases, the major components interrupting the vehicle spaces were the engine compartments and lift-fan ducts. The placement of these components tends to divide the arrangement into an inboard space for vehicles, with passenger spaces outboard. Nevertheless, it should be possible to maintain straight-through vehicle lanes.

Passenger accommodations are restricted to fully enclosed spaces, port and starboard, with a single deck on the smaller vessel, and two decks on the larger. These spaces are envisioned as full-length passenger lounges, fitted with aircraft-type reclining seats. A limited amount of clear deck space is available, but in general, passengers would probably spend the majority of the transit time in their seats.

Profile and general arrangement sketches of the two ACV's, designs B and C, are shown in Figure 5.

3. Docking and port arrangements.

Due to its amphibious capability, the air-cushion vehicle requires nothing more than a smooth, probably paved, ramp and a suitably sized level area for loading and unloading. Maneuvering of the vessel ashore might be materially aided by the provision of wind breaks around the unloading site. In this aspect, the ACV concept offers some potential economies in shore facility costs, by comparison with conventional craft. As a side-effect, the ACV might be more flexibly routed, due to the smaller costs of shore facilities.



ACV DESIGN B: 1-ship service.

ACV DESIGN C: 2-ship service.

Fig. 5. Profiles and general arrangements, air-cushion vehicles Designs B and C. (scale: 1 in = 60 ft.)

4. Surface-effect ships (SES) versus air-cushion vehicles.

The rigid-side-walled SES cannot, at this point, be economically differentiated from the fully skirted ACV, in terms of capital or operating costs, (Ref. 10). However, the SES is subject to the same misgivings as the catamaran in terms of its ice-transitting capabilities. Moreover, the SES relinquishes the amphibious capability of the ACV. For these reasons, no explicit treatment of the SES concept was undertaken in this study.

Further analysis of the ACV concept should center on refinement of the cost estimates, and on seakeeping and ride control systems.

D. Comparison of Highway Vehicle and Passenger Vessels.

An overall comparison of measures of merit for the vehicle/passenger ferry designs described in the foregoing sections is given in Table IX. The tangible advantages and disadvantages of conventional vessels and ACV's may be listed as follows:

Characteristic	Superiority
Vehicle transit time	ACV
Schedule convenience and frequency of service	ACV
Reliability of service	Probably conventional
Passenger comfort	Probably conventional
Attractiveness and convenience of passenger spaces	Conventional
Price of service (Required fare)	Conventional
Flexibility of cargoes	Conventional
Flexibility of routing	ACV
Costs of shore facilities	ACV
Fuel economies	Low-speed conventional
Novelty and intangible appeal	ACV

Clearly, the above list of characteristics should not be interpreted as a basis for selecting the superior concept, nor can the results shown

Table IX. Comparative economic performance of highway-vehicle and passenger ferry concepts. Transit distance:60 statute miles. Nominal operating day limitations: 12 hours. All services: two-ships.

Vessel type	High Speed Conv.	Low Speed Conv.	Air Cushion Vehicle
Design	II	IIS	C
Service speed (knots)	26.0	21.0	52.0
Service speed (mph)	29.9	24.2	59.9
Operating days per year	345	345	345
Annual transport volume:			
Automobiles	300000	300000	298080
Trucks	30000	30000	0
Passengers	1000000	1000000	1000000
Required fares:			
Passenger	5.71	4.25	6.60
Automobile	17.14	12.75	19.79
Truck	59.98	44.62	--
Service frequency:			
Sailings per day (each way)	4	4	8
Time between sailings (hr)	3.00	3.50	1.67
First daily departure	9:00 am	8:00 am	8:30 am
Last daily arrival	8:00 pm	9:00 pm	10:10 pm
Vehicle transit time (hr)	3.67	4.14	2.00

in Table IX be so construed. The fact is that air-cushion vehicles and conventional types can be applied with advantages depending on the nature of the market. Any attempt to discriminate between the two concepts, in the hopes of determining the overall superior type, would be premature at this stage.

It is felt that further market analysis is essential. In the interim, it can be concluded that various technologies exist, each of which offers some promising solutions to the problem of establishing and maintaining an attractive and competitive cross-lake passenger and vehicle ferry service.

V. RAIL SERVICE

A. Economically significant vessel characteristics.

Important system characteristics for a hypothetical rail ferry service are somewhat simpler than those attached to a passenger service. Briefly, these characteristics are as follows:

1. Rail-car transit time, including yard delays at each end of the ferry.
2. Reliability of service.
3. System capacity.
4. Price.

B. Conceptual design assumptions.

The assumptions required in the design process are outlined below.

1. Traffic volume: 60,000 car movements per year, including loads and empties, both directions.
2. Traffic seasonality: Flat:
3. Traffic directionality: Balanced.
4. Rail-car dimensions and weights:

Coupled length	60 ft (avg)
Req'd width	12 ft (max)
Overhead	20 ft (max)
Gross weight	224,000 lb (max)

5. Route: 60 statute miles one-way distance. Draft limit: 18 ft. Over-all length limit: 450 ft.
6. Daily operating profile: 24-hour operation, maximum round-trips/day.
7. Annual operating profile: 330 operating days per year.
8. Financial assumptions:

Yield on equity	10%
Corporate tax rate	48%, deferred
Subsidies and tax credit	0
Economic life	35 years

Several of these assumptions require some explanation. Most important, perhaps, the assumed traffic volume is contingent on a number of factors lying outside the scope of this report. Substantial increases in utilization of the ferry link will only occur if improved service is available to and from the ferry terminals. Similarly, consolidation of the existing freight pattern into a smaller number of essential routes would improve the utilization of the vessel system, although at the expense of additional rail mileage.

In turn, these trends will only be realized if institutional factors are restructured. The primary barriers to new and more efficient rail ferries are institutional, rather than technological, and are manifested in an insufficiency of capital to undertake new system construction, and an insufficiency of interest in maintaining and improving the existing system.

It is not the purpose of this report to explore the problems peculiar to the railroad industry, but rather to depict the economic potential of vessels designed to serve as a link in an efficient regional rail network. Primarily as a result of energy considerations, we see an expanding role for rail transportation in the intermediate and long-term future, rather than the reverse. Given this trend, and the institutional environment that will make the trend realistic, an annual rail-car traffic of 60,000 cars per year is well within the available potential demand.

The assumptions of flat seasonality and directional balance of the total traffic are probably accurate enough for preliminary results.

Car dimensions represent an increase in car weights and lengths, a trend which we feel will continue into the future, given an expanding role for the rail mode.

The assumption of a 60-mile transit is not critical. As a rough estimate, marine costs-per-car-mile would remain virtually constant for the longer route of 81-miles.

The daily operating profile, however, assumes a 24-hour availability of car-handling personnel and equipment. Clearly, this favorable situation does not now exist, nor will it, unless institutional barriers are lowered. The present availability of yard and switch-engine crew is on a shift basis, while economical unloading and loading of a conventional vessel involves perhaps two hours out of each shift. Indeed, one of the primary advantages of an integrated tug/barge combination would lie in the ability to make more efficient use of yard labor since the vessel would not be tied up by delays in car-handling, given the ability to swap an incoming loaded barge for an outgoing loaded barge, regardless of time of day.

The 330-day operating season was applied uniformly to the conventional vessel and the integrated tug/barge concepts. With some advances in barge-linkage technology, this assumption should not prove overly optimistic.

VI. RAIL VESSELS

Two operating systems were designed to serve the cross-lake rail link: one based on a single conventional vessel, the other based on a barge-swapping arrangement including three barges and a single tug. Principal particulars of these systems are listed in Table X, estimated capital costs in Table XI, and annual costs in Table XII.

Note that the faster turnaround of the tug-barge system permits a significant increase in transits per day, therefore allowing a smaller vessel to serve the same specified traffic volume. In addition, the swap-barge capability permits a single yard-crew shift to unload and load a waiting barge. The tug, on its next return, could then couple up this loaded barge, and leave a loaded barge to await the next morning's yard shift. By comparison, the conventional ship must have a yard crew in attendance if it is to turn around at all, at least under the present labor setup.

General arrangements and profiles of the conventional rail ferries are shown in Figure 6. As presently conceived, the vessel would be fully covered, 6-rail arrangement, and would unload and load through the bows. (The ITB, obviously, must unload through the bow, if the tug is to uncouple easily.)

The conventional vessel is barge-like in form, with engines aft and bridge forward. Single-screw diesel power was selected without a detailed comparison with steam. Bow and stern thrusters were fitted, in an effort to reduce port and maneuvering delays to a minimum.

The ITB system was based on a quick-release coupling system, which could take any of a number of patented forms, (Ref. 11). Rather than speculate on the relative merits of these systems, we have simply made the following assumptions:

1. The system installed will permit push towing on 95% of all transits. Delay time due to forced hawser operations was estimated on the basis of a 16-knot speed push-towing, and a 10-knot speed wire-towing.

2. The linkage system initial costs and maintenance costs were not compared in detail, but were assumed to be as shown in Tables XI and XII.

Table X. Design particulars of rail ferries

Design type	Conventional Vessel	Integrated Tug/Barge
Dimensions (ft):		
Overall length	450.0	430.0
Waterline length	425.0	420.0
Barge length	--	330.0
Tug length	--	155.0
Barge beam or vessel beam	78.0	78.0
Tug beam	--	46.0
Full-load draft	16.5	--
Barge draft	--	10.0
Tug draft	--	15.0
Depth to car deck	24.5	18.0
Depth to cover deck	45.0	38.5
Capacities:		
Rail cars	38	30
Deadweights and displacement (Lton):		
Cargo deadweight	3800	3000
Operating deadweight (barge operating dwt)	60	20
Light ship (barge light weight)	3750	2160
Displacement (barge displacement)	7610	5180
Tug displacement	--	1485
Speed and powering:		
Service speed (knots)	16	16
Service speed (mph)	18.4	18.4
Machinery type	MS-D	MS-D
Arrangement	S Scr	Tw Scr
Total shaft horsepower	6500	7000
All purpose specific fuel consumption (lb/hp·hr)	0.42	0.42
Fuel type	Diesel	Diesel
Fuel price ($/Lton)	115	115
Complement:		
Master	1	1
Mates	2	2
Wheelsmen	2	2
Chief Engineer	1	1
Cert. E.R. Crew	3	3
Car Deck Crew	6	0
Stewards Dept.	3	2
Total	18	11
Replacement Crew:	9	6

Table XI. Capital cost breakdown for rail ferry designs. (1977 $/1000)

Design type	Conventional Vessel	Integrated Tug/Barge
Hull steel material	1030	685
Hull steel labor	4808	2045
Outfit material	955	100
Outfit labor	896	118
Hull engineering material	1323	75
Hull engineering labor	1896	150
Machinery installed	3376	0
Rail and RR equipment installed	483	370
Bow thruster installed	250	250
Stern thruster installed	250	--
Electronics and automation	300	--
Total	15567	3793
Profit (5%)	778	190
First unit price	16345	3983
	--	3813
	--	3655
Total barge acquisition cost	--	11451
Tug acquisition cost (7000shp)	--	6500
Linkaqe acquisition, installation	--	1000
Total ITB system price		18951

Table XII. Annual cost breakdown for rail ferry designs. (1977 $/1000)

Design type	Conventional Vessel	Integrated Tug/Barge
Annual fuel cost	770	1092
Lubricating oil	28	30
Hull maintenance and repair	74	153
Machinery maintenance and repair	51	54
Layup costs	30	60
Crew wages and benefits	628	434
Crew subsistence	27	17
Crew indemnity	32	20
Stores and supplies	2	1
Hull and machinery insurance	229	265
Overhead and miscellaneous costs	20	20
Total annual operating costs	1891	2146
Annual capital recovery	2190	2539
Average annual cost	4081	4685

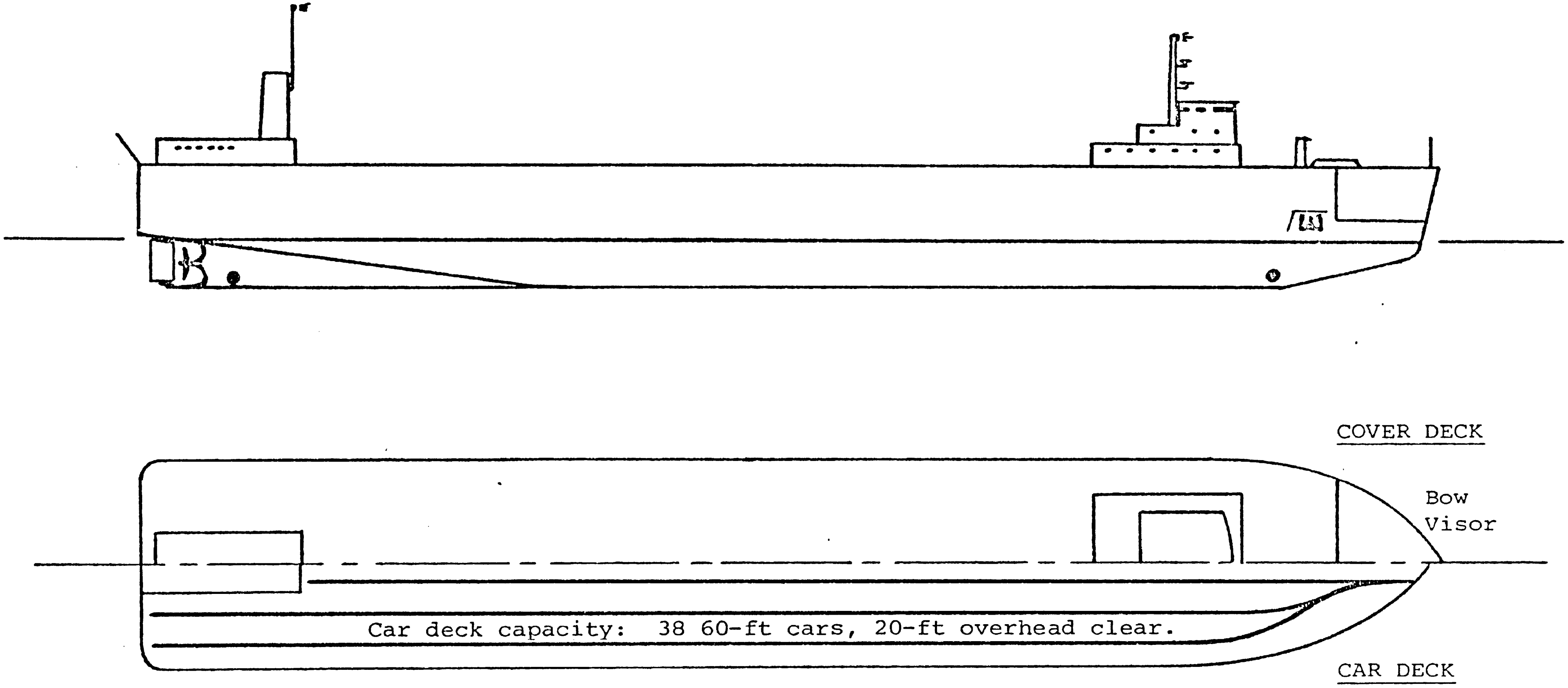


Fig. 6. Profile and general arrangement, rail ferry conventional vessel (scale: 1 in = 60 ft.)

3. The linkage system was assumed to permit barge-swapping in a total time of 10 minutes, including shifting the tug.

Port maneuvering and docking times were considered to be equal for both alternatives, estimated as 20 minutes per call. (Each barge was fitted with a bow thruster, and in combination with a twin-screw tug, it was felt that the ITB combination could match the maneuverability of the conventional vessel. An additional 60 minutes of port delay per call was exacted for wire operations only.)

Car-securing operations were assumed to be performed by ship's crew, in the case of the conventional vessel, and by yard crew in the case of the ITB system. Loading and unloading delays were estimated at 90 minutes for the conventional vessel, perhaps unjustly long, but assuming a single switching locomotive assigned. (The delay might be cut in half by assigning twice the locomotive and man-power, but the ecomonics of this decision will not be considered without further data.) The ITB combination was not delayed by cargo-handling operations, apart from the barge-swapping time mentioned previously.

The economic comparison of the two systems is shown in Table XIII. The virtue of the tug-barge system is dependent on achieving an identical transport capacity with a smaller capital outlay, or smaller operating cost, or both. The integrated tug/barge system has obvious advantages in this regard, combined with a more flexible and efficient use of shore facility personnel. In addition, should the traffic volume require it, system capacity can be doubled by adding one additional barge and one additional tug. The ability to double capacity at such a low relative cost is unique to the ITB concept, once a system is in operation.

The major problems associated with the ITB concept involve operational acceptance, and linkage operability and reliability. These areas deserve further study. The issues of barge handling in port, in the absence of the tug, have not been approached in detail. With duplicated ferry stages, the barge need not be shifted at all. An alternative, however, is to provide quay space for the idle barge, shifting it from the stage to the quay either by simply warping it along the wall, or with a pony tug. Neither of these operations has been included in the costs of the ITB system.

Table XIII. Economic Performance of rail ferry systems.

Design type	Conventional Vessel		Integrated Barge	
Operation	Contin.	2 RT/d	Swap	1-barge
Transits per day	4.72	4.00	6.00	4.58
Annual car movements (330 days)	59189	50160	59400	45342
Initial cost ($/1000)	16345	16345	18951	11483
Annual capital cost ($/1000)	2190	2190	2539	1539
Annual fuel cost ($/1000)	770	671	1092	829
Remainder of operating cost ($/1000)	1121	1121	1054	820
Average annual cost ($/1000)	4081	3982	4685	3188
Required freight per car	$ 68.94	$73.39	$78.87	$70.31

In conclusion, the technology exists to expand the role of the cross-lake rail service in an economically attractive way. The remaining problems are primarily institutional.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions.

1. General

Subject to the specified projections of passenger and highway-vehicle traffic volumes, early analysis indicated that a separation of rail and highway ferry services could be justified on an economic basis. With this separation of services, several alternative vessel types would become attractive options, whereas under the present combined service their use is not technically feasible.

The economic performance of these alternative vessel designs is sufficiently promising that the separation of rail tonnage from highway traffic, which was initially stated as a premise, can be presented as a conclusion, subject to the verification of the potential traffic volumes used in the design process. It is felt that the separation of rail and highway services offers the best opportunity to increase the attractiveness and convenience of the passenger-oriented highway service, while decreasing the unit costs of the rail service by employing less costly specialized rail vessels.

2. Highway Vehicle and Passenger Services.

For a ferry service designed to transport passengers and passenger vehicles only, the air-cushion vehicle offers unusual potential benefits. The ACV is a high-speed system, capable of making a Lake Michigan transit in less than one hour. Additionally, it needs only a simple concrete ramp and loading area at its port terminals, greatly reducing the cost of shoreside facilities. This attribute enables an ACV system to serve a variety of cross-lake passenger-transit needs, with the possibility of seasonal variation in routes to follow seasonal traffic patterns. The estimated fare requirements for the ACV system are competitive with those presently charged on the existing ferry services. Finally, the value of the ACV as a trip attractor has been demonstrated by the English Channel operational experience.

A high-speed (26-knot) conventional ferry could provide rapid cross-lake service for passenger vehicles and trucks, with a "convertible" internal configuration allowing for seasonal variations in traffic mix. Estimated fares for passengers, automobiles, and trucks are in the same range as the present service, under the more stringent financial conditions of ten percent required return after a forty-eight percent corporate profits tax. A two-ship service would provide for departures every three hours, and the higher speed would permit a convenient summer schedule incorporating three round trips per day, for each vessel.

A moderate-speed (21-knot) conventional ferry service would offer substantially the same service as the high-speed alternative, with some increase in vehicle transit time and time between departures. However, the estimated required fares would be significantly below present levels.

A single-deck version of the 21-knot conventional ferry, intended primarily for trucks, showed unsatisfactory economic performance. Based on an all-truck demand of 50,000 units per year, the required fare per truck was higher than that for any of the other concepts.

3. Rail Service.

At the present low levels of rail service demand, no conceptual design was found to offer a significant improvement in economic performance over the existing fully depreciated vessels, when the cost of capital was considered in addition to operating costs.

For a moderately expanded rail service, the most attractive alternative vessel type is the single-barge integrated tug barge (ITB). With initial costs significantly less than those of a conventional vessel, the ITB system appears to offer economic advantage over the present service if a service level of about 45,000 car movements per year can be maintained. The break-even point against the existing service would occur at a level of about 37,000 car movements per year.

For a greatly expanded rail service, in the neighborhood of 60,000 car movements per year, a specialized rail ship of bargelike design appears to offer the most economical alternative, provided that yard personnel can be made available for turnaround on the vessel's schedule without imposing undue increases in shoreside labor costs. A swap-barge ITB system offers the possibility of avoiding the problem of yard personnel availability, while maintaining a level of service of about 60,000 car movements per year. However, the cost of the three-barge ITB system is somewhat higher, and a trade-off of shipboard versus shoreside costs would be involved in any final decision.

In any evaluation of rail-car ferry economics, it should be remembered that institutional factors are the major determinants of profitability. The volume of car movements, for example, is more directly related to internal railroad management and operating practices than to the actual costs of ferry operation.

D. Recommendations.

The study recommendations are divided into three categories: (1) development of more definitive ship design concepts and costs, (2) market demand analysis, and (3) analysis of organizational concepts appropriate to expanded ferry services.

1. Development of ship design concepts and costs.

Four conceptual designs, especially, merit more detailed analysis for further refinement of costs and performance. They are:

- 26-knot conventional vessel (Design II)
- 21-knot conventional vessel (Design IIS)
- 60-knot air-cushion vehicle (Design C)
- single-barge and swap-barge ITB systems for rail and trailer services.

Further analysis of these systems should include detailed evaluations of port facility costs, construction, modification, and operating.

2. Market demand analysis.

A market analysis should be undertaken to confirm the potential demand for ferry services across Lake Michigan. This analysis should indicate market needs for each of the services, passenger, truck, and rail, and the demand/cost elasticities for each. In this analysis, it would be beneficial to differentiate between truck service (i.e., tractor-trailer combination) and trailer service only, if possible.

3. Analysis of organizational concepts.

A study should be undertaken to evaluate the costs and benefits to the State resulting from various organizational forms of an expanded ferry service. This analysis should include questions of ownership, sources of capital, financial arrangements and incentives, and management structures. The analysis should be sufficiently detailed to provide guidance for the selection of an organizational concept for the expanded ferry service.

REFERENCES

1. Interstate Commerce Commission Docket No. AB 18 (Sub-No. 21), and Docket No. AB 31 (Sub-No. 5), "Abandonment of Cross Lake Michigan Car Ferry Service," October, 1976.

2. Wisconsin - Michigan Bi-State Car Ferry Task Force, "Report on Lake Michigan Car Ferries," February, 1977.

3. Michigan Department of State Highways and Transportation, "Economic Benefits of Lake Michigan Car Ferry Service," December, 1976.

4. Department of the Army, Lake Survey District, Corps of Engineers, "Great Lakes Ice Atlas," April, 1969.

5. All resistance predictions for conventional vessel types were based on M. Gertler, "Reanalysis of the Original Test Data for the Taylot Standard Series," D.T.M.B., March, 1954.

6. Preliminary propeller selection for conventional vessels was based on the Wageningen Series B propeller, and the Netherlands Ship MOdel Basin cavitation criterion, as cited in Principles of Naval Architecture, 1967.

7. E.C.B. Corlett, "Twin Hull Ships," Trans. Royal Institute of Naval Architects, Vol. 111, 1969.

8. R.L. Wheeler, "An Appraisal of Present and Future Large Commercial Hovercraft," Trans. Royal Institute of Naval Architects, Vol. 118, 1976.

9. J. Trillo, Marine Hovercraft Technology, Leonard Hill, London, 1971.

10. W.J. Eggington and N. Kobitz, "The Domain of the Surface-Effect Ship," Trans. Society of Naval Architects and Marine Engineers, Vol 83, 1975.

11. D. B. Waller and J.J. Filson, "Advanced Ocean Tug-Barge Systems," report to U.S. Maritime Administration, May, 1972.