# HIGH-SPEED WATER TRANSPORTATION OF MAN

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## ABSTRACT

A variety of advanced high speed marine craft have been proposed for the transport of people. Specific vehicles have been tried on a diversity of routes both with success and failure. Claims and counterclaims have been issued. Technical debates have ensued with regard to vehicle performance, reliability, costs, control, stability, propulsion, debris, noise and air pollution, etc. The literature contains numerous reports on these subjects.

With notable exceptions, little has been said about one of the most basic of all considerations where the transportation of man is concerned, the affect of vehicle motions on the fare paying passenger. To their credit, hovercraft and hydrofoil proponents have attempted to present information on this subject, usually related to what the motions are rather than to their affect on the passenger or the resulting economic impact on the operation.

Generally, the problem is misunderstood and all too often ignored. No universally accepted method has been established to define the water conditions expected along a route, the vehicle motions likely to result, or the reaction of the passengers to those motions. This paper focuses attention on these considerations. A vehicle is discussed that will meet the critical demands of passenger acceptability even under extremely rough water conditions.



## KEY WORDS

| | |
|---|---|
| Human Comfort Boundaries | Marine Commuter System |
| Passenger Acceptance | JETFOIL |

# HIGH SPEED WATER TRANSPORTATION OF MAN

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## INTRODUCTION

Since the first man decided to climb onto a floating log and hitch a free ride downstream, waterborne travel has exerted a major influence on the progress of civilization. Most of the world's large cities were located to provide easy access to water transportation. For centuries water transport was the major mode within many countries, and the only mode of travel between continents.

Many different kinds of marine vehicles have been built. Some were better than others, but all have had their problems. There were always times when the sea conditions caused travel to be suspended. On other occasions a reduction in speed or change in course, or both, was essential for the safety of the passengers, ship and crew. Much of the time travelers were sick and the crew had difficulty in doing their jobs. Water travel was uncomfortable, undependable, and slow. It is little wonder that as other forms of transportation developed, offering greater comfort, reliable schedules and higher speeds, that people left the water to commerce and trade and went to land and air for their transport.

Current problems of population growth, traffic congestion and pollution demand that we again take a hard look at the number of potential benefits that water passenger transit has to offer, especially for our major cities. Sixty percent of the population of this country lives adjacent to water, and nine of our fifteen largest cities are coastal. These coastal cities all have main waterways that are generally under-used and underdeveloped, particularly in relation to other transit right-of-ways. These water

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freeways are available with a minimum of property condemnation or community disruption and destruction. Water right-of-ways are inexpensive to maintain and water systems are flexible.

In theory, at least, water passenger transit systems appear to have much to offer modern society and community development. The key question is can marine vehicles be made available that will meet the demands of comfort, dependability and high speed within ecological constraints and be a good neighbor to other users of the waterways, and those living on the shore? And if so, then can they be economically viable since there are already too many transit systems that are losing money at an ever increasing rate. (Reported as 1079 systems who lost a total of $332 million in 1970.)

## MAN -- THE DETERMINANT

The most critical factor in economic viability for any transportation system is passenger acceptance. No system is worth much if the people it is intended to serve won't use it. This concern is especially true for water systems, where it is contended that many past systems weren't acceptable to people and were discontinued for that very reason. Therefore, the problem starts with people, their foibles and their characteristics.

Passenger acceptance of any transportation system depends on the general acceptability of the system concept, plus specific acceptance of the individual elements. Of particular importance are: need; economic and social considerations; comfort; dependability; and convenience. Since it has been contended that other marine systems have been unacceptable to people because they were uncomfortable, undependable and slow -- this paper concentrates on what can be done to provide marine vehicles that are comfortable, dependable and fast.

Human reaction to motion environments is very subjective and for the most part seems to defy rigorous formulization and quantification. Nevertheless, engineers try to do so. Some of the recent work in the field of human reaction research, while controversial, is revealing in the sense that it offers insight into the problems of what is important in creating passenger acceptability.

It is the consensus that ship vertical or heave motions (aptly named) are the primary cause of sea-sickness and severe discomfort. (Ref. 1) Figure 1 presents a summary of the sea-sickness and comfort boundaries as a function of vertical acceleration and frequency as determined by various tests. (Ref. 2 thru 7)

## ROUGH WATER -- THE CULPRIT

Does the water ever really get rough in places like New York Harbor, San Francisco Bay, Puget Sound, Honolulu, etc.? Does it happen enough of the time to worry about? Is it going to affect the ride of any reasonable size craft in a significant manner? This is the next key problem in evaluating marine systems.

Figure 2 presents the fixed point wave amplitude spectra developed for four different sets of typical water conditions by methods established in Reference 8 and from wave data in References 9 and 10. Curve A describes the water conditions which exist ten percent of the time on Hawaii inter-island routes and five percent of the time for routes between Honolulu Airport and Waikiki, Curve B is also for Hawaii and represents conditions which occur 80 percent of the time on the Honolulu Airport-Waikiki route and 50 percent of the time for inter-island operations. Curves C and D are representative of Puget Sound with C being the five percent worst case and D being the 50 percent average situation. Provided wave data is available, similar spectra can be developed for any potential operating area.

## VEHICLE BEHAVIOR - WHAT IS IT?

If the water surface was always calm and the wind never blew, it would be a relatively easy job to evaluate marine vehicles for transit systems. Usually, calm water performance is the only information that is available. Therein lies a very key problem. Very few manufacturers tell how their vehicle behaves in rough water. In most cases they don't know how it behaves. Some-times they make such statements as, "this vehicle is capable of going in 8-foot waves". But what does that mean? How fast?, How good is the ride at that speed in those conditions?, What kind of 8-foot waves - average, significant, maximum? In the past little effort was made to define rough water performance since there wasn't much that could be done about it. If the water got rough -- the vehicle changed course, reduced speed, made people sick, or stopped operating. This might be acceptable for some operations, but if we are considering a transit system that is going to provide a sensible alternative to commuters and to the community, it has to be able to go every day -- not simply when the water is calm.

Marine vehicles come in a wide assortment of sizes, shapes and types. It is primarily the type that is of interest here. There are conventional craft, surface effect vehicles and hydrofoils. Within each type there are different kinds to further compound and confuse all but the most knowledgeable observer. Conventional craft include all normal displacement craft that depend on the bouyancy of the water for support and include catamarans and planing craft which obtain some dynamic lift as the craft increases speed. SES's include Hovercraft and sidewall craft which employ cushions of air to provide lift. Hydrofoils depend on dynamic foil lift and are either surface piercing or the fully submerged type. With only one exception these vehicles are surface followers in which vehicle heave motions will follow the waves until the synchronism encounter frequency is approached, where a motion magnification will occur. For encounter frequencies beyond synchronism, the motions will decrease as a function of the system damping characteristics.

Figure 3 presents vertical motion transfer functions which were developed from data in References 11 through 16. The upper two curves are for a 200-ton, 140 foot long conventional ship operating in a head sea at 22 and 35 knots. The middle curves are for a typical 60-ton surface piercing hydrofoil operating in a head sea at 35 knots and a 175 ton surface effect ship in the same sea at 33 knots. The lower curve is for a Boeing Jetfoil operating in a head sea at 45 knots.

Figure 4 presents the acceleration characteristics determined by combining the conventional ship transfer functions with the four different wave spectra from Figure 2. As can be seen, a reduction in speed from 35 to 22 knots does reduce the acceleration levels.

Figure 5 presents the vertical acceleration responses obtained from the 175 ton surface effect ship transfer function of Figure 3 with the wave spectra of Figure 2. One paper on Hovercraft operation in the English Channel (Ref. 17) reports that over ten percent of the passengers carried were seasick when operating in observed wave heights of five feet and higher at speeds less than 33 knots. The associated vertical accelerations in these waves was from 0.13 to 0.15 RMS g's. No frequency response data was presented and therefore this data is shown as a band on Figure 5.

Figure 6 presents the acceleration characteristics for the hydrofoil vehicles. The surface piercing hydrofoil at 35 knots provides a ride comfort approximately comparable to the 200 ton conventional ship at 22 knots. The addition of control systems to surface piercing hydrofoils (as is currently being undertaken by some manufacturers) shows promise of as much as 50 percent reduction in vertical accelerations. The Boeing Jetfoil data is based on computer simulations correlated with four years of operating experience with a similar hydrofoil vehicle, the U.S.N. TUCUMCARI. The Jetfoil is further described in Appendix I.

## CONCLUSIONS

If as previously contended, the development of new marine passenger transit systems will offer much of modern society and community development, the key requirement is passenger acceptance. Passenger acceptance of the vehicle is primarily dependent on comfort, dependability and speed.

If an acceptable ride is defined as being comfortable to 90 percent of the passengers (represented by the line marked "Annoying to ten percent of the people" on Figures 1, 4, 5 and 6) and dependability is defined as meeting this comfort requirement 95 percent of the time (represented by points A and C on Figures 4, 5 and 6), the following conclusions can be made for service in the four typical seas shown:

1. Reasonable-sized conventional ships at high speed (35 knots) would have a ride objectionable to over 50 percent of the people, all of the time. Slowing down to 22 knots would be little better and in fact it would require a speed of less than eight knots to be acceptable.

2. The Hovercraft cannot meet the acceptable ride definition in any of the conditions considered and in five foot and over seas has over ten (10) percent of its passengers seasick at 33 knots.

3. The surface piercing hydrofoil at 35 knots has a ride objectionable to well over 50 percent of the people. This could be improved by reducing speed or adding a control system. However, the resulting ride would still be marginal.

4. The Boeing Jetfoil is the only vehicle capable of achieving passenger acceptance. It will provide a ride at 45 knots that is acceptable to 90 percent of the people almost 95 percent of the time.

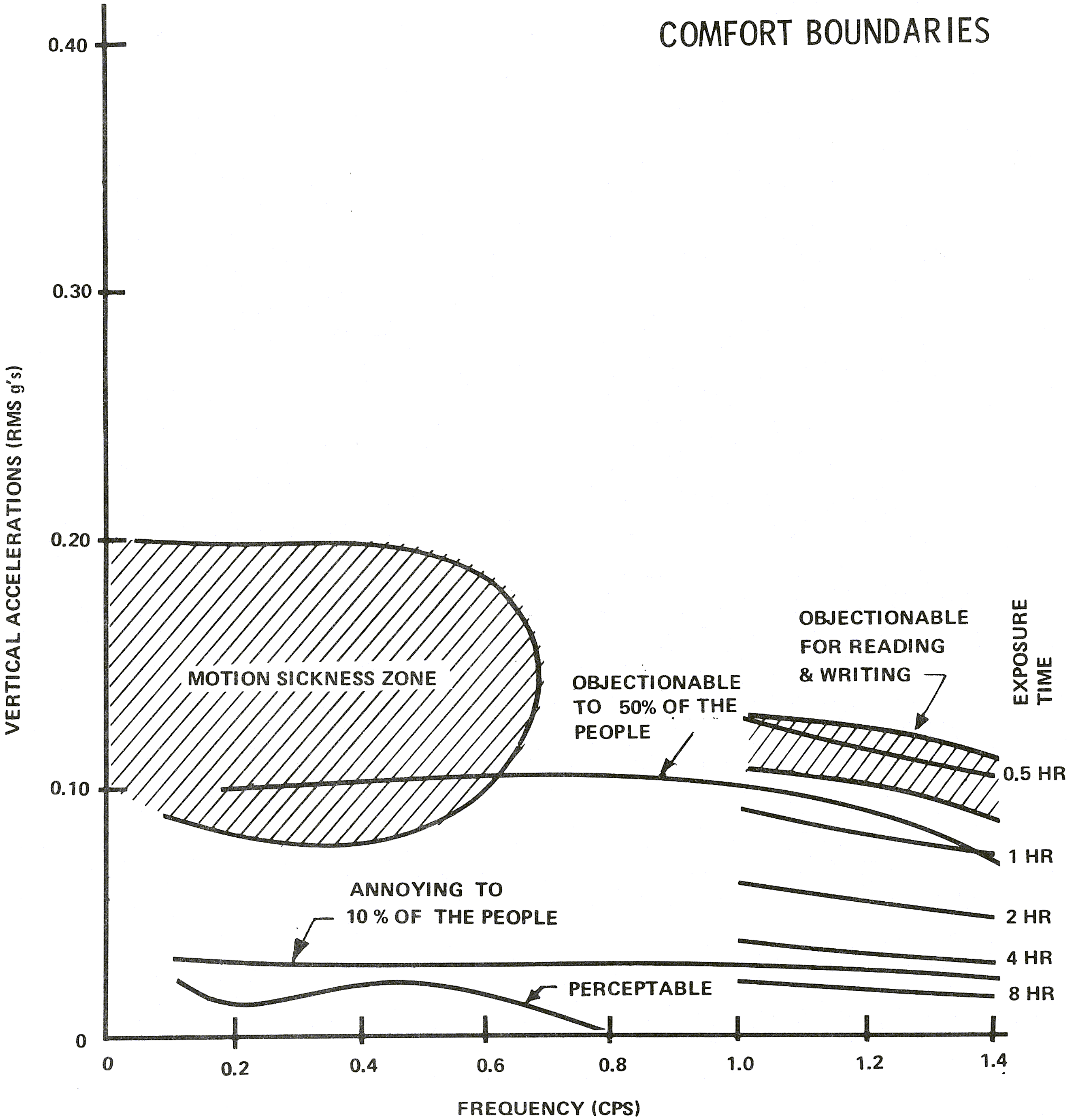

COMFORT BOUNDARIES
VERTICAL ACCELERATIONS (RMS g's)
0.40
0.30
0.20
0.10
0
MOTION SICKNESS ZONE
OBJECTIONABLE TO 50% OF THE PEOPLE
OBJECTIONABLE FOR READING & WRITING
EXPOSURE TIME
0.5 HR
1 HR
2 HR
4 HR
8 HR
ANNOYING TO 10 % OF THE PEOPLE
PERCEPTABLE
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
FREQUENCY (CPS)

Figure 1:

FIXED POINT WAVE AMPLITUDE SPECTRA

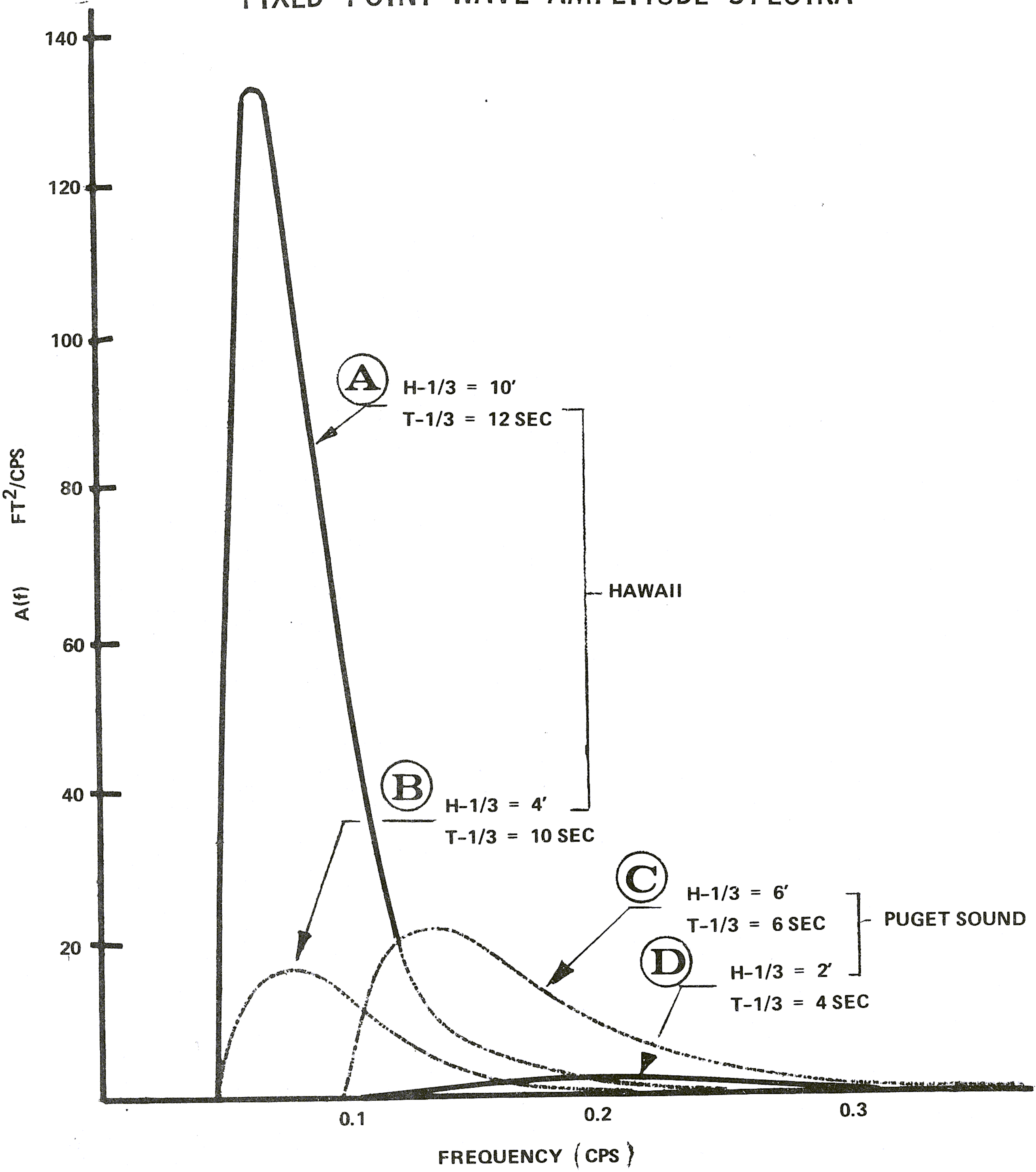



Figure 2:

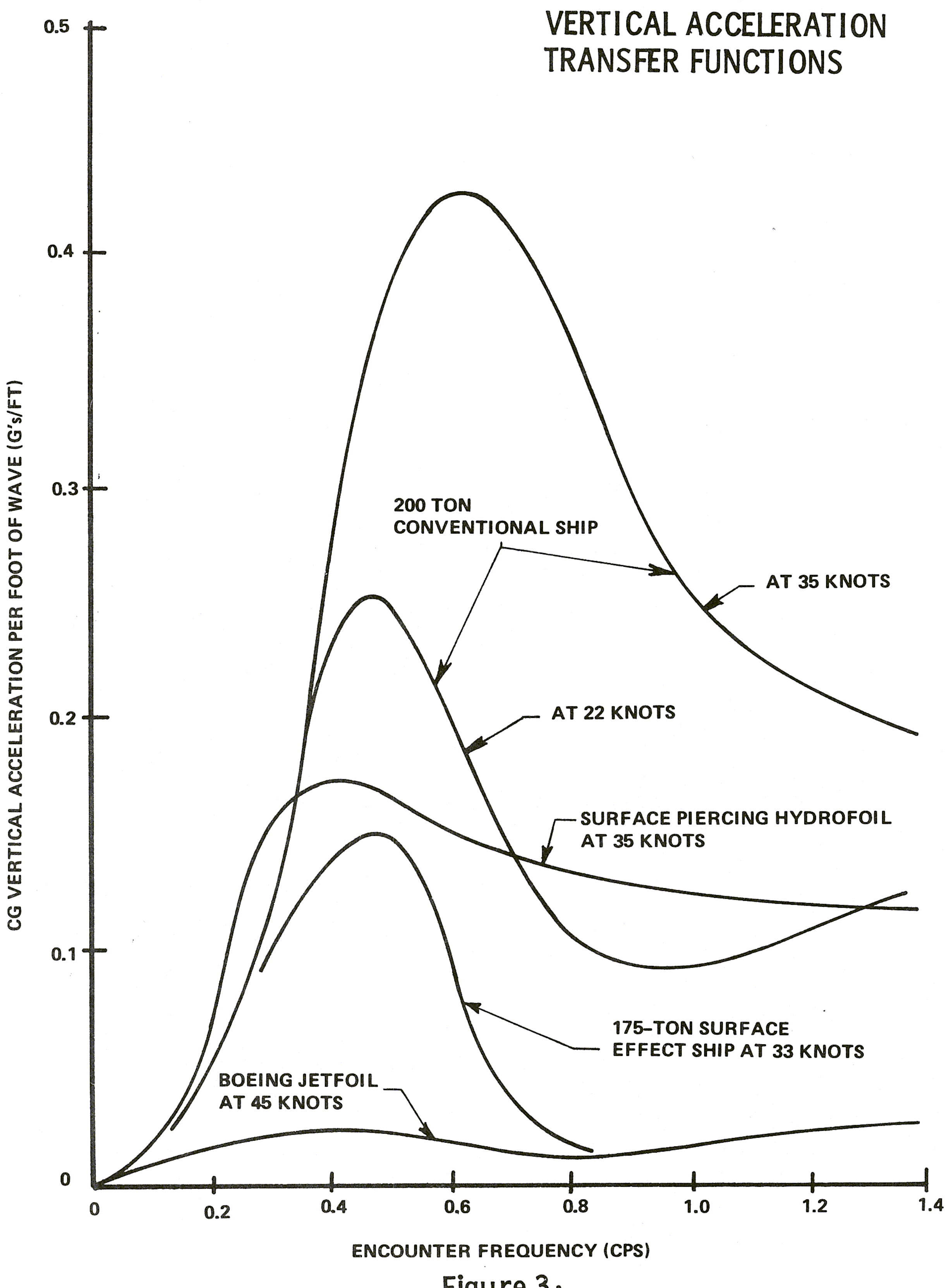

VERTICAL ACCELERATION
TRANSFER FUNCTIONS
0.5
0.4
0.3
0.2
0.1
0
CG VERTICAL ACCELERATION PER FOOT OF WAVE (G's/FT)
200 TON
CONVENTIONAL SHIP
AT 35 KNOTS
AT 22 KNOTS
SURFACE PIERCING HYDROFOIL
AT 35 KNOTS
175-TON SURFACE
EFFECT SHIP AT 33 KNOTS
BOEING JETFOIL
AT 45 KNOTS
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
ENCOUNTER FREQUENCY (CPS)

Figure 3:

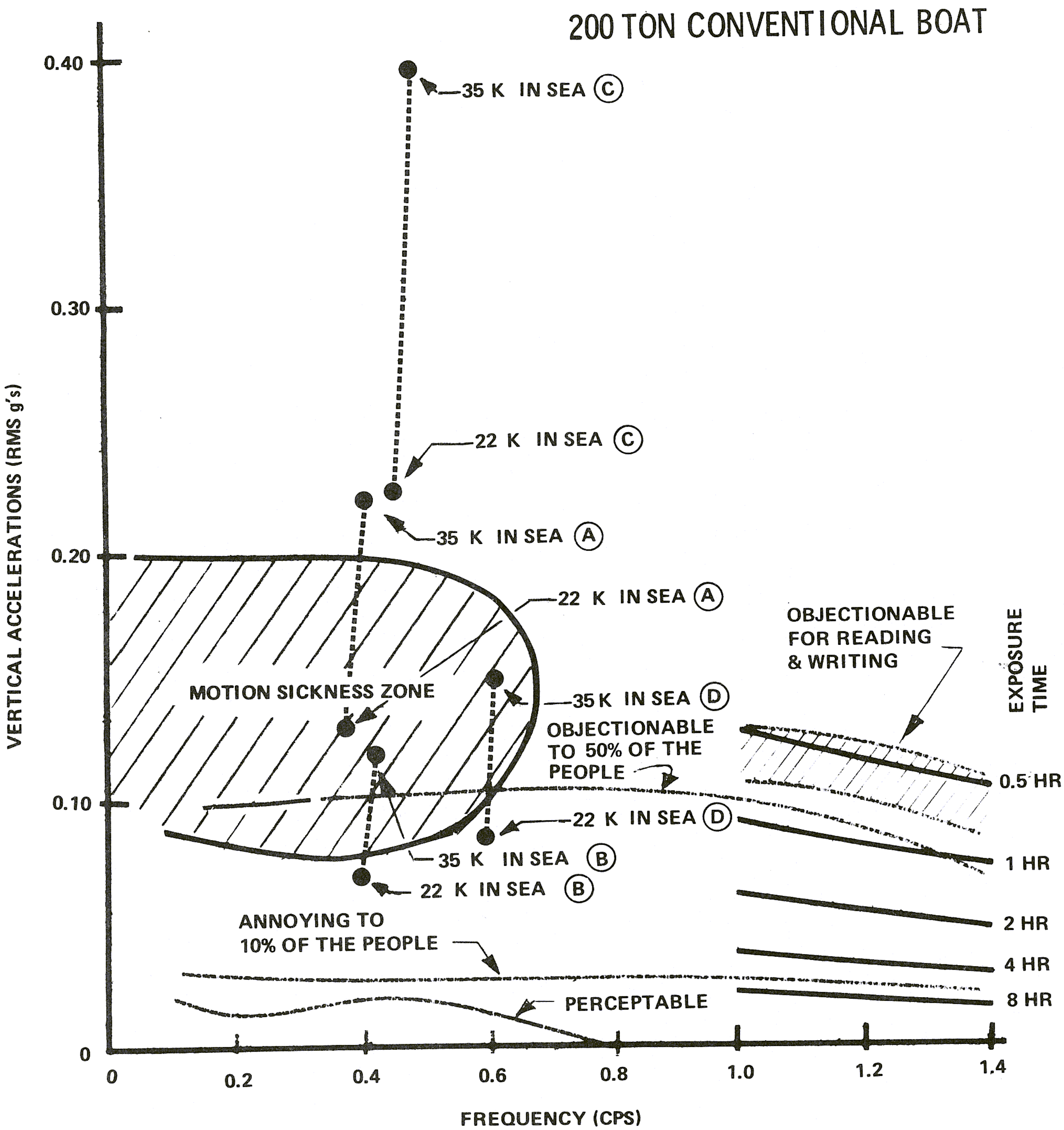
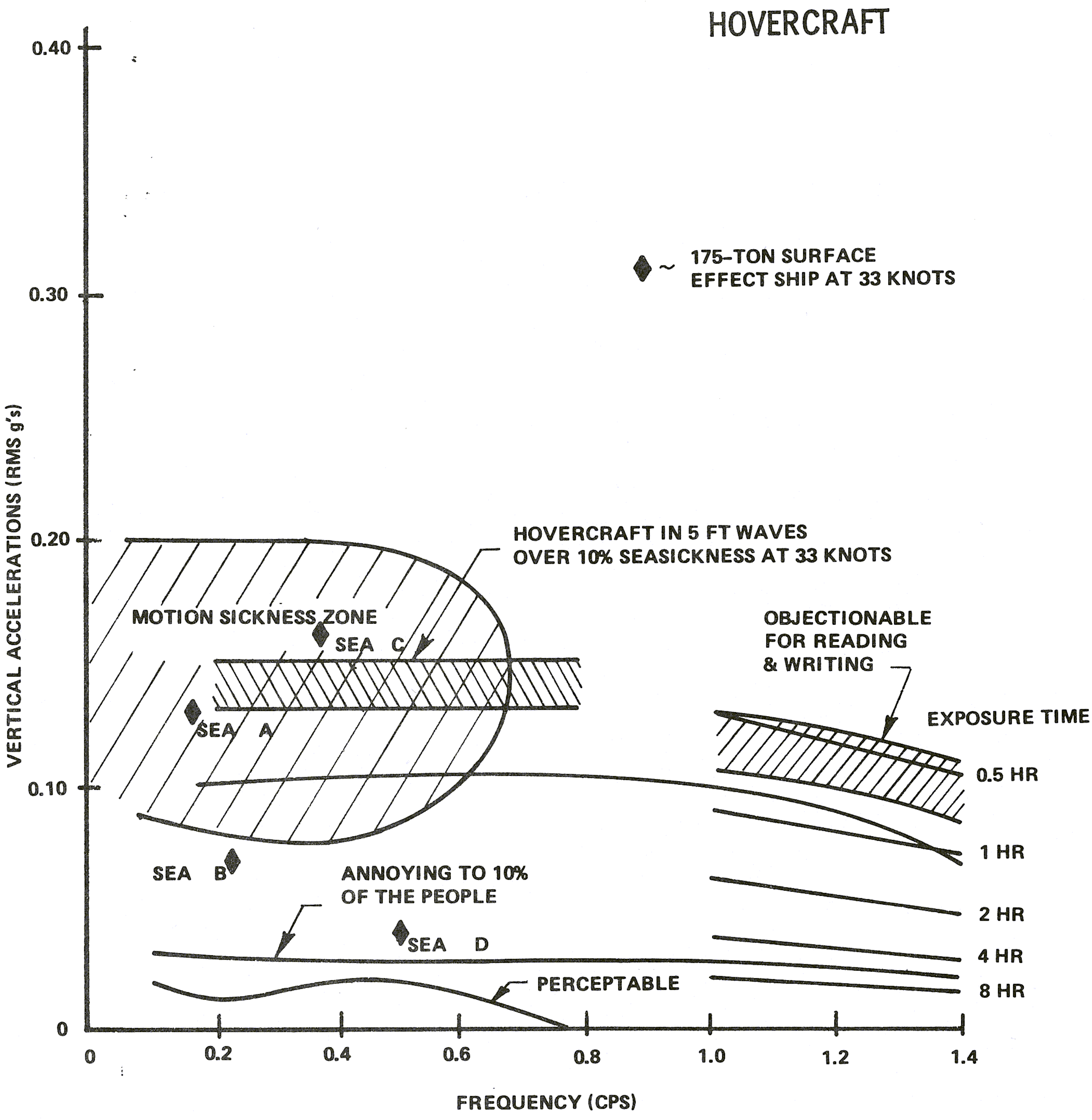

200 TON CONVENTIONAL BOAT
VERTICAL ACCELERATIONS (RMS g's)
0.40
0.30
0.20
0.10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
FREQUENCY (CPS)
35 K IN SEA C
22 K IN SEA C
35 K IN SEA A
22 K IN SEA A
35 K IN SEA D
22 K IN SEA D
35 K IN SEA B
22 K IN SEA B
MOTION SICKNESS ZONE
OBJECTIONABLE TO 50% OF THE PEOPLE
ANNOYING TO 10% OF THE PEOPLE
PERCEPTABLE
OBJECTIONABLE FOR READING & WRITING
EXPOSURE TIME
0.5 HR
1 HR
2 HR
4 HR
8 HR

Figure 4:



HOVERCRAFT
VERTICAL ACCELERATIONS (RMS g's)
0.40
0.30
0.20
0.10
0
175-TON SURFACE
EFFECT SHIP AT 33 KNOTS
HOVERCRAFT IN 5 FT WAVES
OVER 10% SEASICKNESS AT 33 KNOTS
MOTION SICKNESS ZONE
SEA C
SEA A
SEA B
SEA D
OBJECTIONABLE
FOR READING
& WRITING
EXPOSURE TIME
0.5 HR
1 HR
2 HR
4 HR
8 HR
ANNOYING TO 10%
OF THE PEOPLE
PERCEPTABLE
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
FREQUENCY (CPS)


Figure 5:

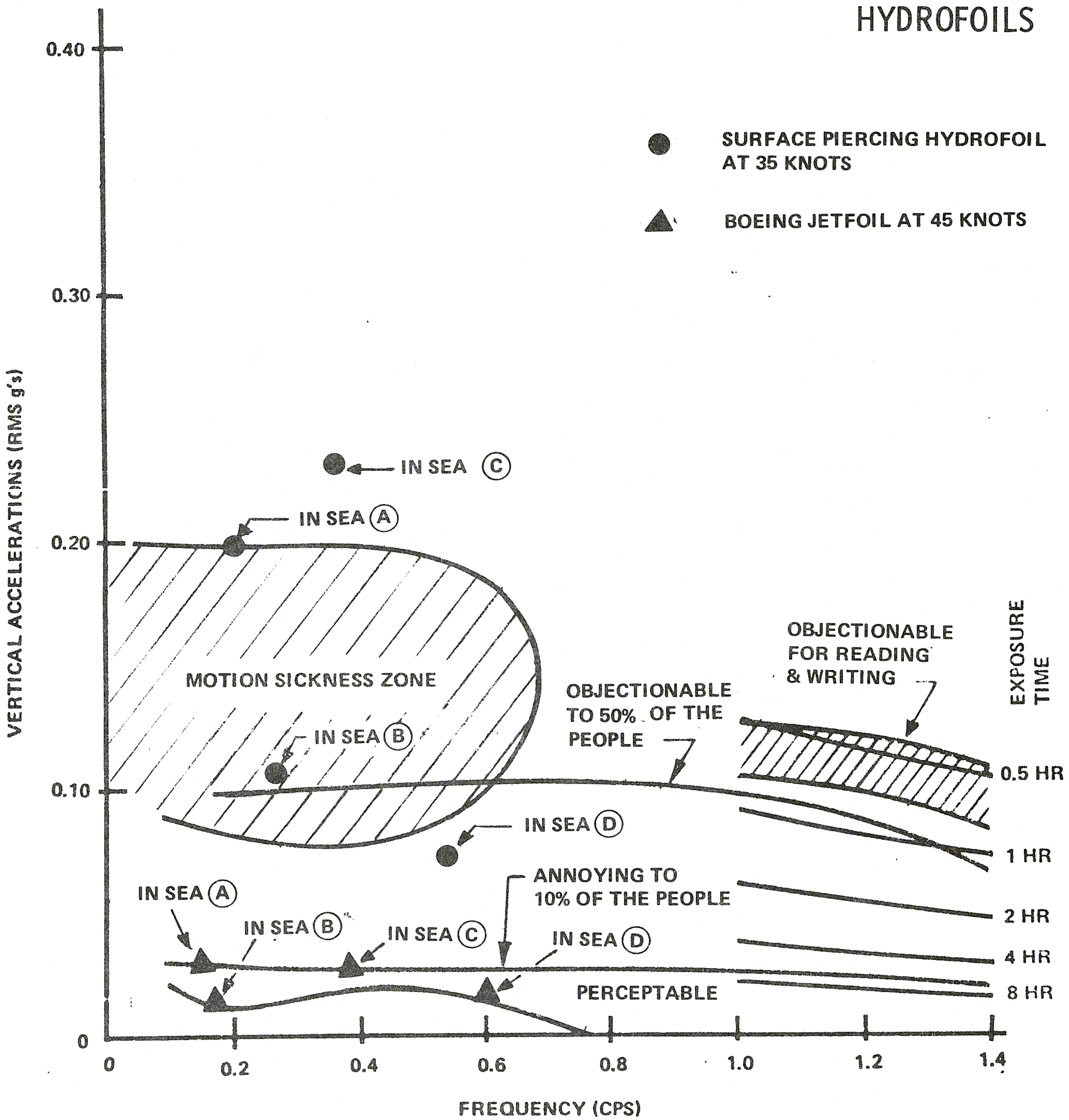

HYDROFOILS
SURFACE PIERCING HYDROFOIL AT 35 KNOTS
BOEING JETFOIL AT 45 KNOTS
VERTICAL ACCELERATIONS (RMS g's)
0.40
0.30
0.20
0.10
0
IN SEA (C)
IN SEA (A)
MOTION SICKNESS ZONE
IN SEA (B)
IN SEA (D)
OBJECTIONABLE TO 50% OF THE PEOPLE
OBJECTIONABLE FOR READING & WRITING
EXPOSURE TIME
0.5 HR
1 HR
2 HR
4 HR
8 HR
ANNOYING TO 10% OF THE PEOPLE
IN SEA (A)
IN SEA (B)
IN SEA (C)
IN SEA (D)
PERCEPTABLE
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
FREQUENCY (CPS)

Figure 6:

# APPENDIX I - THE BOEING 929 JETFOIL

## A. ARRANGEMENT

The Boeing Model 929 Jetfoil, Figure 7, is a submerged-foil, automatically-controlled, waterjet-propelled passenger-hydrofoil. Table I presents a set of particulars.

The foil system is fully retractable, permitting operation out of shallow harbors and the foil tips do not extend beyond the hull edge, thereby permitting existing docks to be utilized.

## B. ACCOMMODATIONS

The passenger accommodations are arranged in three cabins to provide a comfortable, pleasant, air-conditioned interior. (See Figures 8 and 9) All aisles are 30 inches wide. The tourist configuration provides 66 cubic feet of cabin per passenger which is classed by Reference 18 as "superb" for trips up to 4 hours duration and "excellent" for trips up to 7½ hours.

The commuter configuration provides 56 cubic feet of cabin per passenger which is classed "superb" for trips up to 2½ hours and "excellent" for trips up to 5½ hours.

The baggage area in the aft lower deck of the tourist version is arranged for roll-on/roll-off containerized baggage handling. Space is provided for food and drink service if desired. Cabin interior maximum noise level will be less than 68 db SIL, which is comparable to current jet aircraft levels.

## C. PROPULSION

The propulsion system consists of two Lycoming TF35 gas turbines each coupled to a waterjet pump. Water enters a ram inlet at the aft foil, travels up the strut duct to the pumps, and is discharged through nozzles in the hull bottom. A hull inlet provides for water entry when the foil system is retracted. Thrust vectoring and reversing buckets are provided on each nozzle for hullborne maneuvering. A

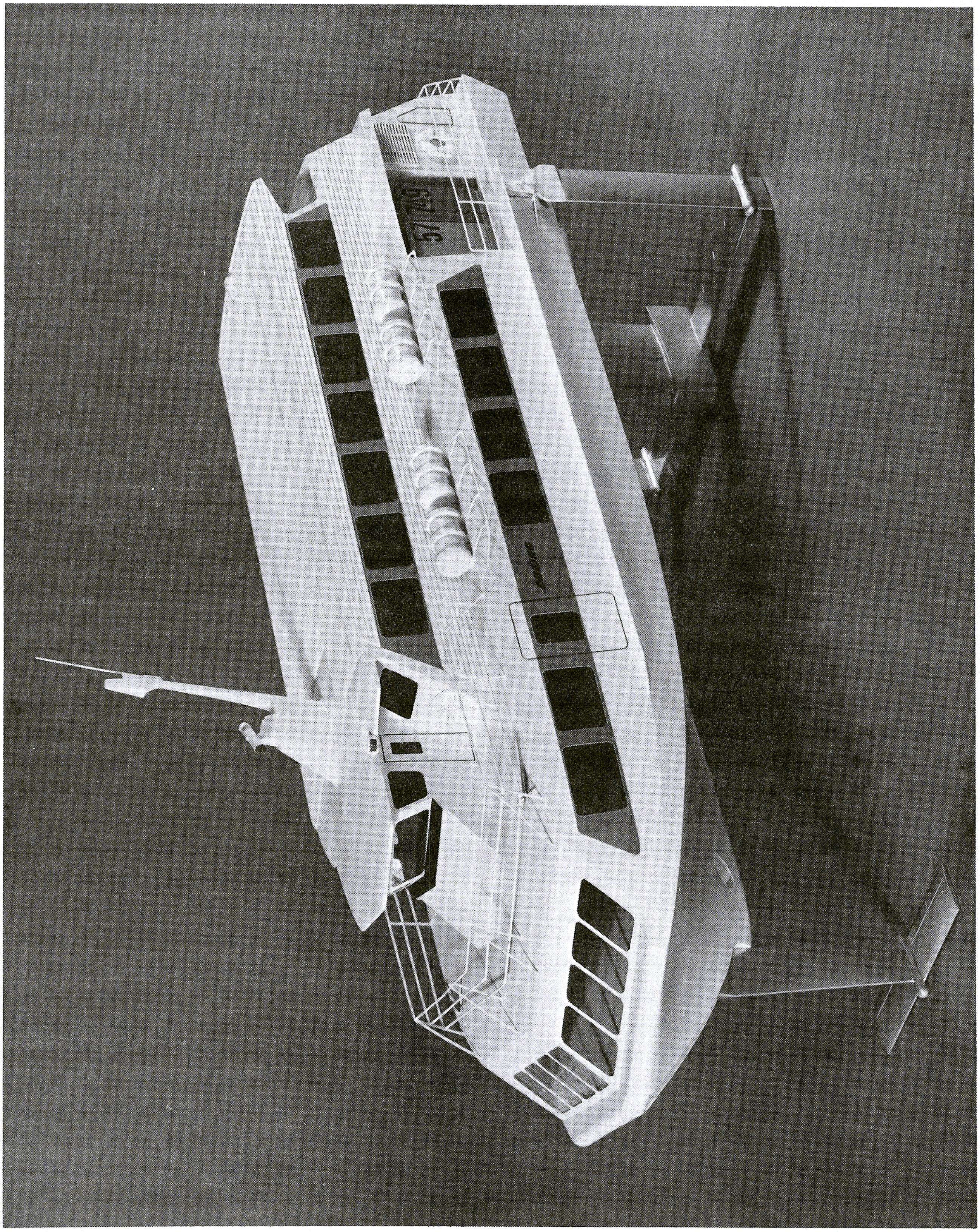


Figure 7

## TABLE I

## BOEING MODEL 929 JETFOIL PARTICULARS:

| | |
|---|---|
| Displacement | 100 tons |
| Length, overall | 87 feet |
| Beam, maximum | 30 feet |
| Draft, hullborne, foils retracted | 5 feet |
| Draft, hullborne, foils extended | 16 feet |
| Propulsion power | 5200 hp |
| Design cruise speed | 45 knots |
| Design seastate | 12 foot waves |
| Design fuel load | 1700 gals. |
| Fuel consumption at cruise | 7 gpm |

Payload:

192 tourist passengers with baggage

or

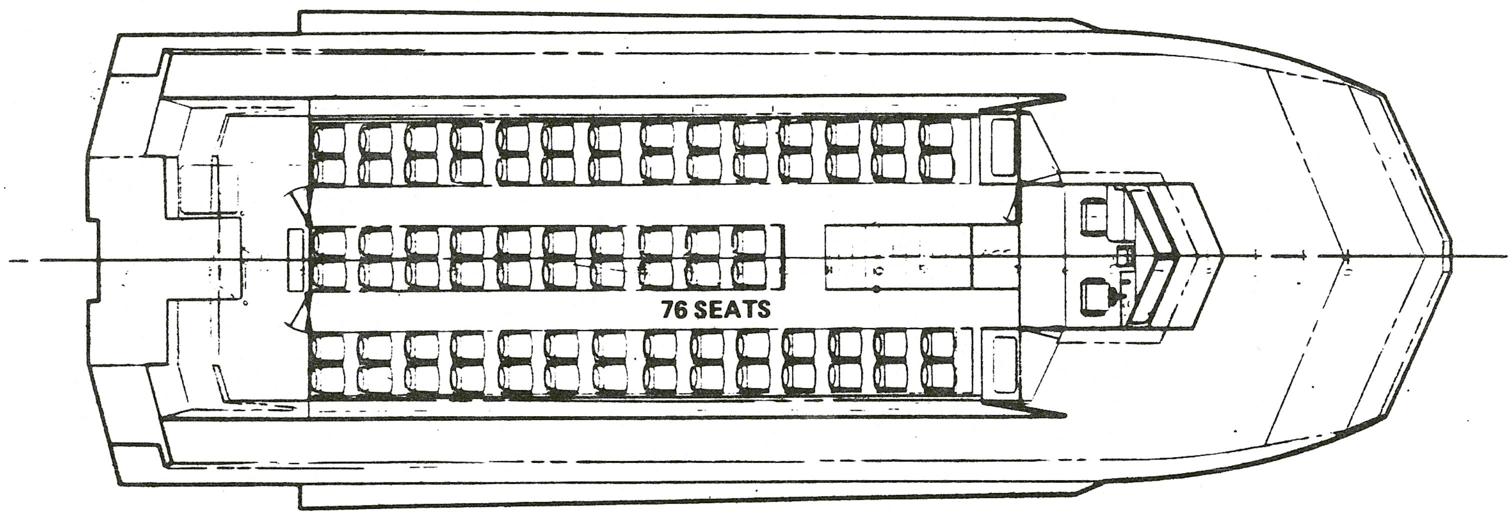
254 commuter passengers

or

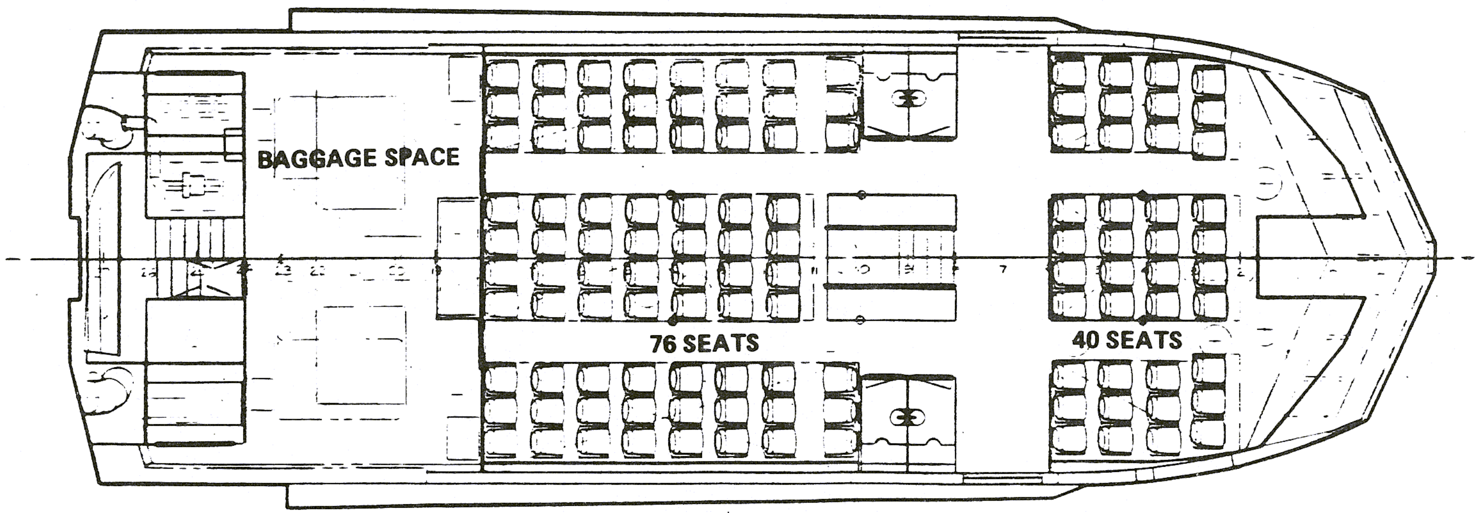
25 tons cargo

Crew: 2 operators plus passenger attendants

# 929 JETFOIL TOURIST CONFIGURATION (192 PASSENGERS)



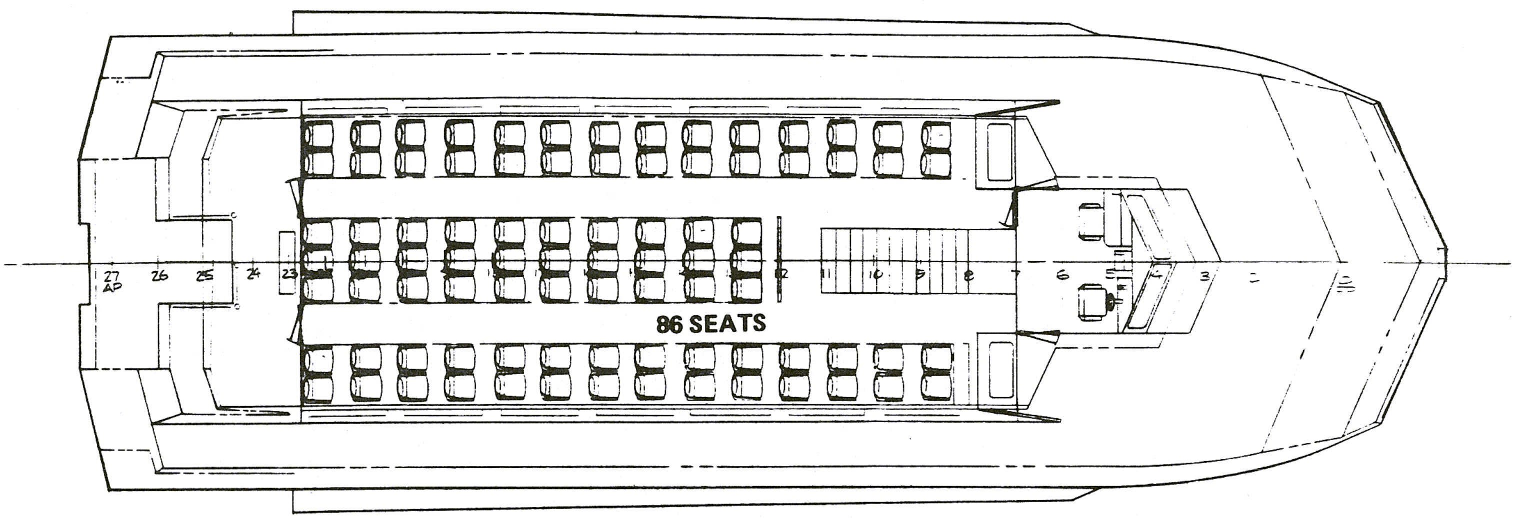

UPPER DECK ARRANGEMENT



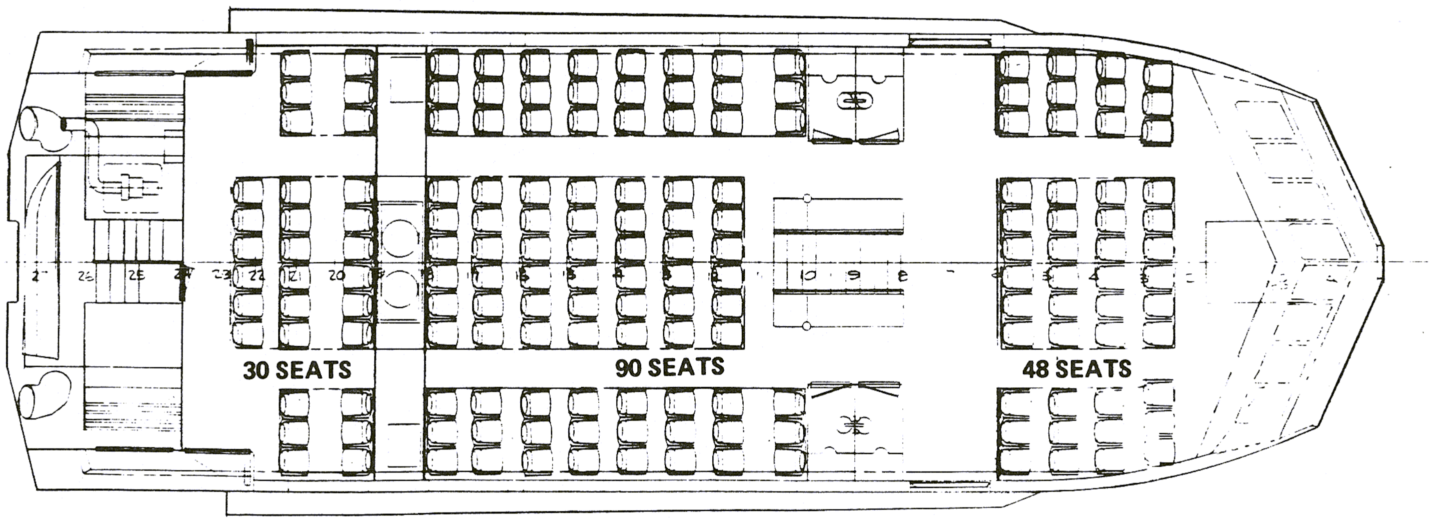

MAIN DECK ARRANGEMENT

Figure 8:

## 929 JETFOIL COMMUTER CONFIGURATION (254 PASSENGERS)




UPPER DECK ARRANGEMENT




MAIN DECK ARRANGEMENT

Figure 9:

bow thruster is provided for difficult docking maneuvers. Electrical generation and hydraulic power is provided by each propulsion turbine.

E. PERFORMANCE

The 929 Jetfoil is designed to maintain a foilborne cruise speed of 45 knots in all sea conditions up to waves 12 feet high. For extreme operating areas, longer struts can be installed to increase this sea-state capability.

Normal endurance is 4 hours at cruise speed, however, tankage is provided for up to 8 hours operation.

Precise maneuvers can be made at all speeds and in all seas. The 45 knot turning radius is less than 1,000 feet. All turns are automatically banked for passenger comfort. Stops from 45 knot foilborne can be accomplished in less than 500 feet with no passenger discomfort. In emergency conditions, tighter turns and shorter stops are possible.

F. SAFETY

The 929 Jetfoil meets or exceeds all the applicable regulations of the U. S. Coast Guard and SOLAS. The hull provides two-compartment subdivisions and a high degree of stability. Life rafts and life jackets are provided for ocean service. The foilborne control system is completely fail-safe. The foil system is designed for floating debris impact without damage or passenger discomfort and impact with solid objects such as reefs with safety.

G. ENVIRONMENTAL CONSIDERATIONS

The external noise level of the 929 Jetfoil at full power will be less than 90 db A. (Proposed 1975 State of California legislation will limit highway trucks to 92 db A)

The 929 Jetfoil's air emissions are extremely low. There will be no visible smoke (as defined by Ringleman 0); hydrocarbons and oxides of nitrogen emissions will be less than 5 grams per brake horsepower hour;

and carbon monoxide emission will be less than 25 grams per brake horsepower hour. This air polution is less than the 1975 State of California proposed standards for highway vehicles of over 6,000 pounds gross weight.

No contaminated fluids or wastes of any kind will be discharged in the waters while underway or dockside.

H. ECONOMICS

Because of its ability to maintain a high schedule speed with good passenger acceptance in all sea conditions, the 929 Jetfoil will provide better operating economics than any other advanced marine vehicle. For a more detailed analysis of these economics see Reference 19.

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