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THE HOVERCRAFT FERRY

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Introduction

Following a relatively short period of development, hovering craft, or air-cushion vehicles to give them their generic term, have demonstrated an ability to operate in moderate sea conditions around our coasts and have become sufficiently well engineered to carry fare-paying passengers. At present the hovercraft is by no means an all-weather vehicle; there are limitations on the height of the waves in which it can operate comfortably, and seas with regular wave shapes can present a handling problem. Experience is filling in the pattern of the behaviour of this revolutionary craft which relies upon the surface for its support but endeavours to remain detached from it.

This paper investigates the areas in which the hovercraft is likely to show a commercial return to an operator, and discusses certain of the design problems which require solution to construct a satisfactory craft. The paper is based upon studies carried out by Vickers-Armstrongs (Engineers) Limited in association with Hovercraft Development Limited.

A brief reference should be made to the development of high-speed over-water craft.

Planing hulls made their first appearance in 1870 when the Rev. C. M. Ramus built a model which, however, did not progress any further for no suitable power unit became available until after his death. The first full-size craft was manufactured in 1905.

The principle of the hydrofoil was first used towards the end of the last century. A number of patents were taken out in the early years of this century and in 1919 a craft capable of 60 knots was built and tested by Dr. Alexander Graham Bell and Frederick Walter Baldwin. It was not until after the Second World War that hydrofoils became a commercial proposition, and at present these craft have an operational cruising speed of approximately 40 knots.

By comparison, progress with the hovercraft has been characterized by a long period during which tentative ideas for air-lubricated ships (e.g. De Laval patent, 1883) and air supported land vehicles were proposed, but with little practical result.

The realization in 1953 of a practical means of containing the air-cushion has, together with the deep-cushion concept, made the operational hovercraft feasible.⁽¹⁾ The ten years which followed encompassed the development of substantial theoretical work on the subject, the building in the U.K. of at least six experimental overwater hovercraft, and others overseas, and the successful completion of passenger carrying services in coastal waters. This latter achievement is particularly satisfying in view of the stringent standards required by the controlling authorities in the U.K. where for the moment the hovercraft is officially described as an aeroplane.

The hovercraft has yet to be accepted as a practical commercial ferry vehicle. The passenger services carried out to date have been experimental and operating reliability has not been good.

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Poor serviceability of engines, damage by the sea and floating debris, coupled with the limited wave capability of the craft used, have caused services to be suspended for short periods. However, over 10,000 fare-paying passengers have been carried without injury or serious incident, and the general public has shown great enthusiasm for a journey by hovercraft wherever the opportunity occurred.

To become established the hovercraft must meet three broad requirements:—

- (1) Have acceptable economics.
- (2) Display satisfactory operating characteristics, with seaworthiness coming top of the list.
- (3) Offer a realistic engineering concept—a primary aim being a low maintenance requirement.

These three objectives become the subject headings for the first three parts of this paper; the human need for faster over-water travel is assumed to be incontestable.⁽²⁾

Part 1.—Economic Aspect

The fast hovercraft as at present conceived has a low overall efficiency, the installed power being in the range 100 to 150 shp per ton displacement for a speed of around 80 knots in still air conditions; when using gas turbine power these figures indicate a fuel consumption such as to rule out transoceanic journeys by reason of the inability of a craft to carry sufficient fuel.

The hovercraft is suited to the shorter sea routes; it shows up to particular advantage, in comparison with conventional ships, where the journey time can be cut by taking a direct route regardless of tides and shallow water; also its ability to load and unload on land enables a saving in turn round time to be made.

The short ferry routes in Northern Europe are shown in Figs. 1 and 2. Also shown is the projected rail link between France and the U.K.—the Channel Tunnel; the presence of this link completely alters the forecast traffic pattern for the years 1972 onwards, the earliest possible date for the opening of the tunnel.

A remarkable growth of passenger and car traffic over the last decade has been evident on all the short sea routes, Fig. 3, and the forecasts for future traffic have been exceeded by a small margin.⁽³⁾ Forecasts for the Scandinavian routes show similar growth up to the 1980's. It is not the purpose of this paper to discuss the traffic, or the accuracy of the published forecasts, but the great and increasing demand for travel can only encourage the introduction of new facilities.

Overall traffic figures do not give a realistic picture of daily circumstances. On all the routes investigated 75 per cent of the annual traffic occurs within the period of the five months May to September, and on many routes weekend traffic is appreciably higher than weekday traffic.

Current fares charged for air and ship ferries show an interesting pattern. Fig. 4 shows single fares where passengers

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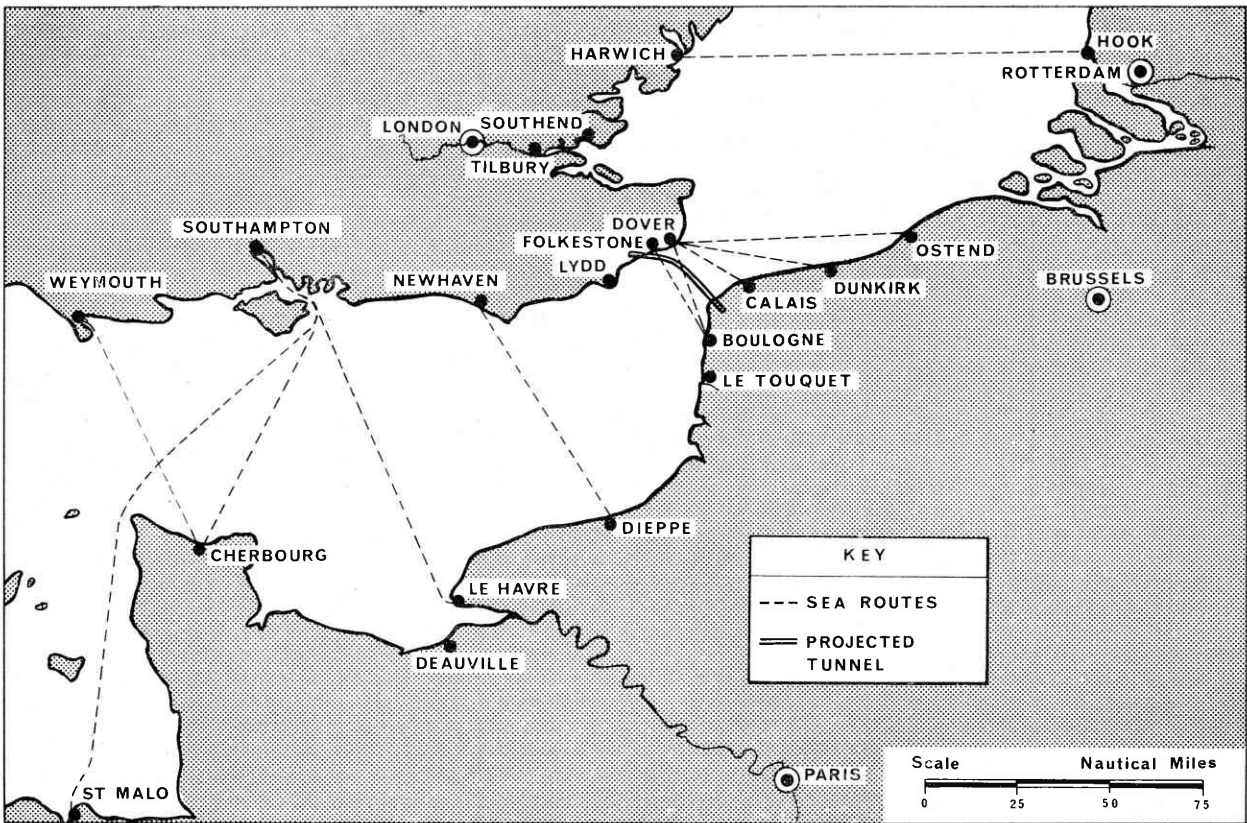


FIG. 1.—CONTINENTAL FERRY ROUTES

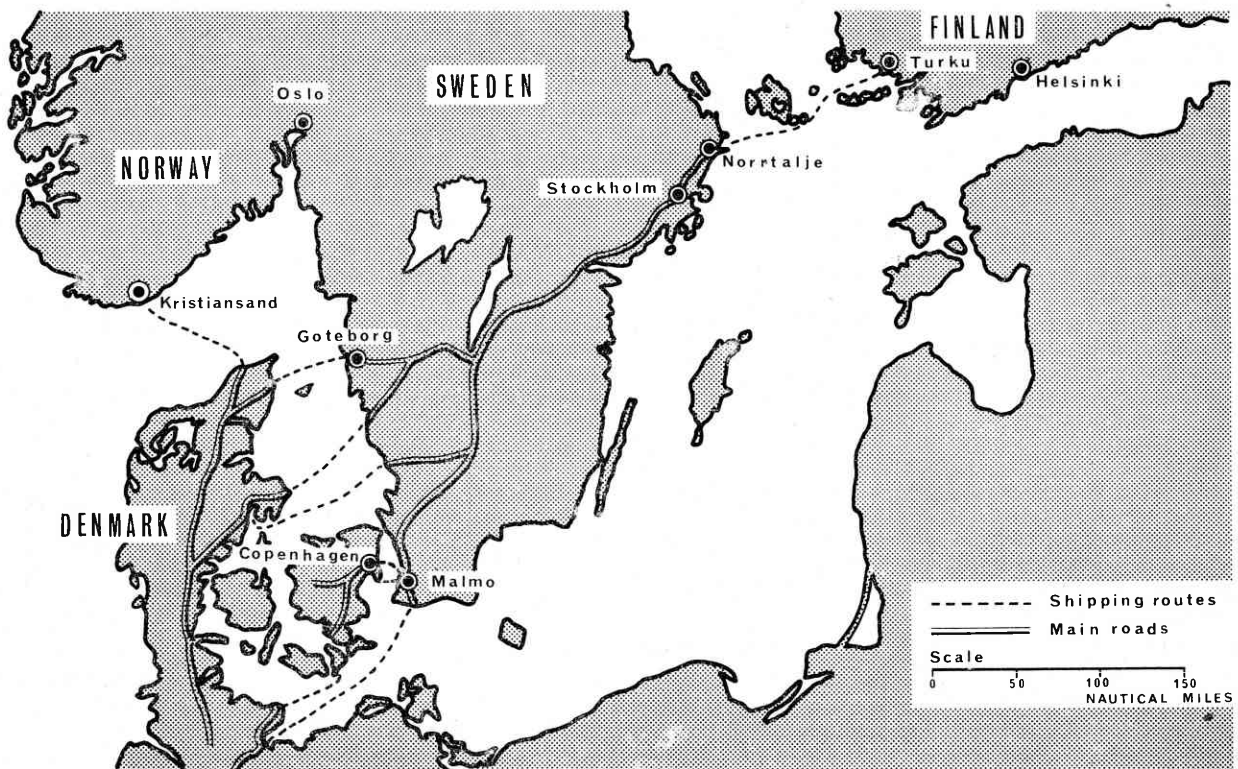
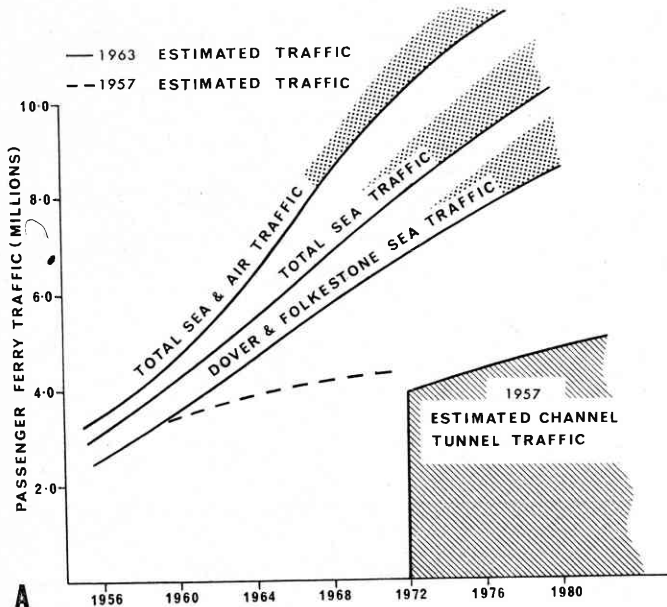
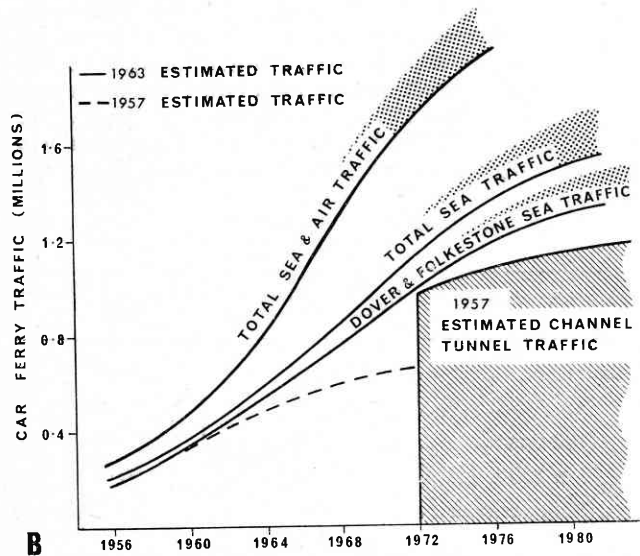


FIG. 2.—SCANDINAVIAN FERRY ROUTES

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A



B

FIG. 3.—TRAFFIC FROM U.K. TO CONTINENT

are either second class or one class (berths are extra on the night ferries), and the car fare is that charged for a length of 14½ ft. A constant fare irrespective of distance is indicative of the working of a particular fares policy and due account of this must be taken when making comparisons with the calculated operating cost of a competitive vehicle.

By reason of the heavy and increasing traffic and the current fare levels, domestic and U.K. to Continent routes offer the most attractive area for introducing a new, and as will be shown, a fairly expensive craft.

Hovercraft economics favour a low density high value cargo. Passengers and motor cars come into this category with mean values as follows:—

	Weight	Area allocated	Acceptable fare
Passenger	lb.	ft. ²	d/mile
Motor car	170	7	20
	2,100	110	60

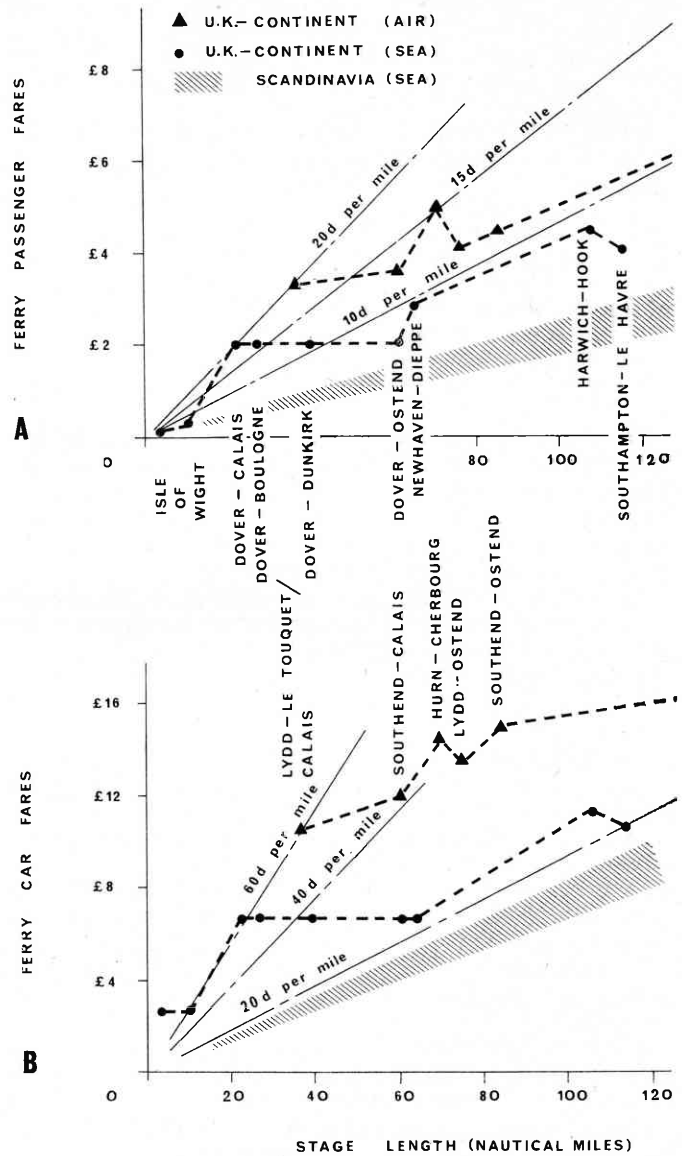


FIG. 4.—FERRY FARE RATES

Clearly then in terms of revenue per lb. weight carried or per sq. ft. deck area occupied, the passenger gives the greater return. However, conditions may exist where a car-carrying capacity is required and the optimum hovercraft to accommodate the same load would be larger than the passenger equivalent and could lead to radical changes in design as will be discussed later.

Part 2.—Operational Characteristics

Part 1 arrived at the conclusion that the English Channel routes were likely to be an attractive commercial proposition for hovercraft. In this Part the performance required of the hovercraft is described against the background conditions of wind and sea encountered in the area. A similar analytical procedure to that to be described would be carried out for any other routes; the Scandinavian routes, for example, would certainly prove less arduous.

The construction of present-day hovercraft has provoked some expression of doubt from conventional shipbuilders. The one sidewall type operating is constructed principally of glass-

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fibre reinforced polyester resin with a marine plywood passenger deck. The other amphibious high-speed types are built up from 18 s.w.g. or thinner high strength aluminium alloy.

The light weight, low inertia and flexible make-up, of the craft results in low impact loadings and permits the use of thin plating.

Structural loading conditions arise in the main from high-speed impact with the sea; the impact load I increases according to the relationship

$$I \propto \frac{V \cdot W^{\frac{2}{3}} h_w}{\sqrt{l_w}}$$

where W = displacement weight;
 h_w = wave height;
 V = craft speed relative to the water;
 l_w = wavelength.

Waves may contact the craft at any point over the bottom, inducing vertical and often rotational accelerations to the craft. Far more severe to the local structure and to the detriment of passenger comfort are impacts on the bow and beam area. Loads incurred when floating on the water with no air cushion are less than impact loads on high-speed craft.

A background of manufacturing experience on flying boats and sea planes enables the constructors to contemplate using aircraft type structures and materials for hovercraft, but the high-stress levels permitted in these structures make it necessary to expend considerable design effort to check each component of the structure.

Common sense reasoning was used to produce loading cases on the first generation of craft which operated with generally satisfactory results.

Impact pressure measurements have not so far been entirely satisfactory, and the development of this technique is essential. At present, much useful data is obtained from measurement of craft accelerations when impacting waves, and from an examination of the dents in the craft.

In the interests of passenger comfort, and of minimum resistance, it is desirable to prevent the hull making any contact with the water.

The early concept of hovering craft and the first working models relied upon the hover gap, or daylight beneath the craft, to avoid impact. If craft rolling and pitching, etc., is ignored the mean hovergap requires to be approximately half the wave height, crest to trough, to just avoid contact. In keeping power requirements to a manageable level, project designs for craft to operate over waves in excess of four feet became larger than the square/cube law of structure size/weight would permit in practical terms. This state of affairs was changed completely by the demonstration that proofed fabric extensions fitted to the air curtain nozzles in the metal hull could be made sufficiently flexible to deflect readily when encountering waves and yet have a sufficient "life" to be an engineering proposition. The important contribution made by the flexible nozzle extension, or "skirts," to improving hovercraft wave riding capability cannot be over-emphasized. On the debit side, skirt contact with the water when negotiating waves creates additional drag and the permanent increase in craft frontal area increases air resistance.

Irrespective of whether flexible skirts are fitted, a hovercraft aligns itself with the mean water surface slope. It follows that the hovercraft designer requires some knowledge of wave shape, height, length, and velocity and the contribution of wind speed, fetch, and topographical factors.

Fig. 5 shows the wave shape envelope of height and length derived using expressions developed by Darbyshire⁽⁵⁾ for wind generated waves.

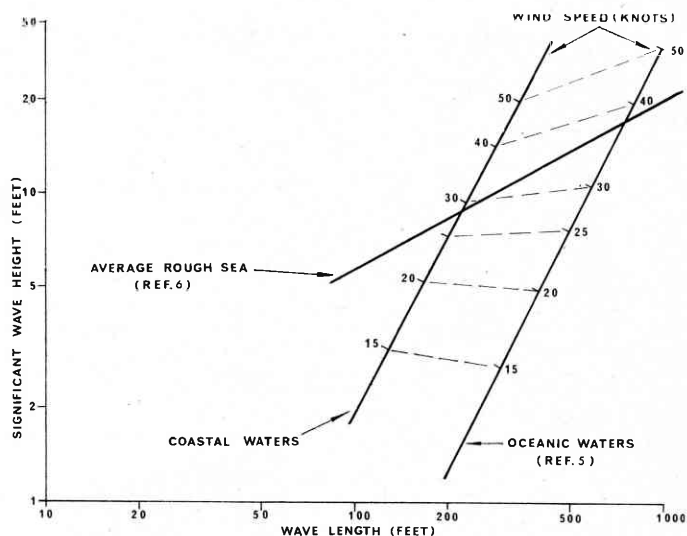


FIG. 5.—WAVE CHARACTERISTICS

From personal observation it is clear that succeeding waves in a sea have varying heights and that occasionally waves considerably higher than the average do arise. The ordinate scale displays units of significant wave height; for a given sample of recordings the highest one-third are taken and the average of this batch is referred to as the significant wave height. The numerical value so derived is a good indication of a wave height frequently encountered but certainly higher waves must be anticipated.

The following table will be of interest.

Wave height parameter	Relationship with significant wave height	Percentage occurrence of smaller waves
$H_{\frac{1}{3}}$ or H_{sig}	1.0	87
$H_{\frac{1}{10}}$ (1 in 10 average) ..	1.27	96
H_{max} (100 waves) ..	1.6	99
$H_{\frac{1}{100}}$ (1 in 100 average)	1.67	99.5
H_{max} (long periods) ..	2.4	99.999

It is important to realize the limitations of the data derived from the method referred to above. No account has been taken of waves arising from distant storms, increased height of waves due to wind against tide or from refraction of waves from estuarial banks or from steepening in shallow water, nor of waves generated by passing ships. Nevertheless it is considered that the techniques now available can be very useful in the initial assessment of wave characteristics.

Perhaps more than on any other seagoing craft, the hovercraft is likely to be affected by topographical influences; the amphibious hovercraft inevitably passes through regions of very shallow water and possibly surf. Both these circumstances produce steeper and often higher waves than winds generate. Therefore it soon becomes most desirable that the actual conditions on a proposed route are sampled over a reasonable period of years.

A wave shape envelope based upon visual observations at sea⁽⁶⁾ differs considerably in form from the envelope now proposed, Fig. 5, and confirms suspicions regarding the tendency for the human observer to exaggerate wave heights in the seas normally encountered.

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The weather ships and some light vessels now regularly measure sea conditions. Information on the short sea routes, Fig. 1, is available from the British, Dutch, and German stations.⁽⁴⁾ In terms of wave height and length some data is shown in Figs. 6 and 7.

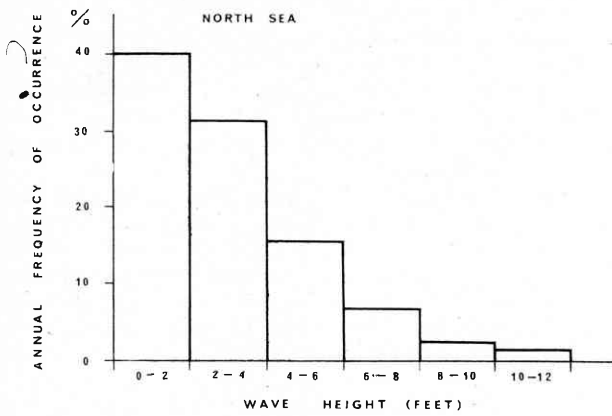


FIG. 6.—WAVE HEIGHT PROBABILITY

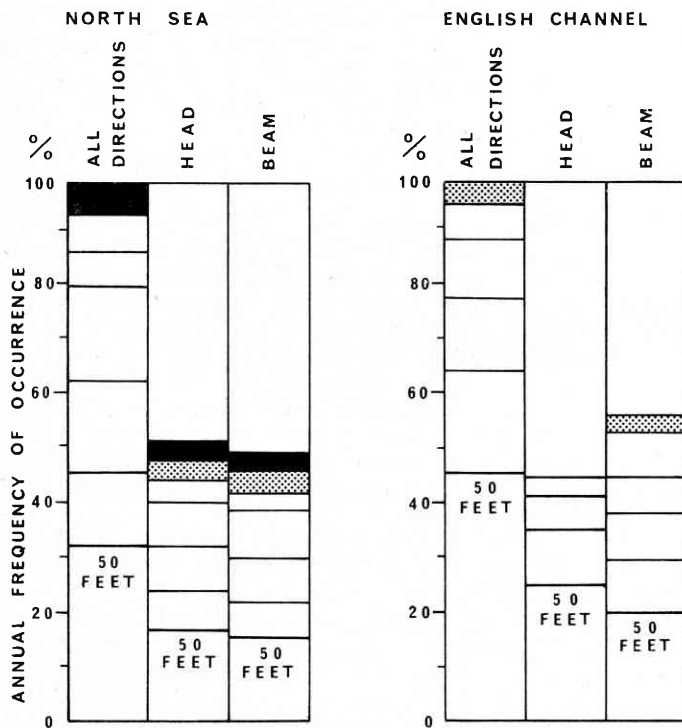


FIG. 7.—WAVE LENGTH PROBABILITY

Before decisions can be taken about the necessary height of the "hard" structure above the calm water to avoid impact in the wave heights assessed or measured, the response of the craft to waves requires some attention in much the same way that the freeboard of a displacement ship may be related to wave height and pitch and roll amplitude. Resonance and build-up of amplitude occurs in a certain band width about an encountered

wave period, where the encountered wave period is derived from the wavelength in the direction of motion divided by craft speed.

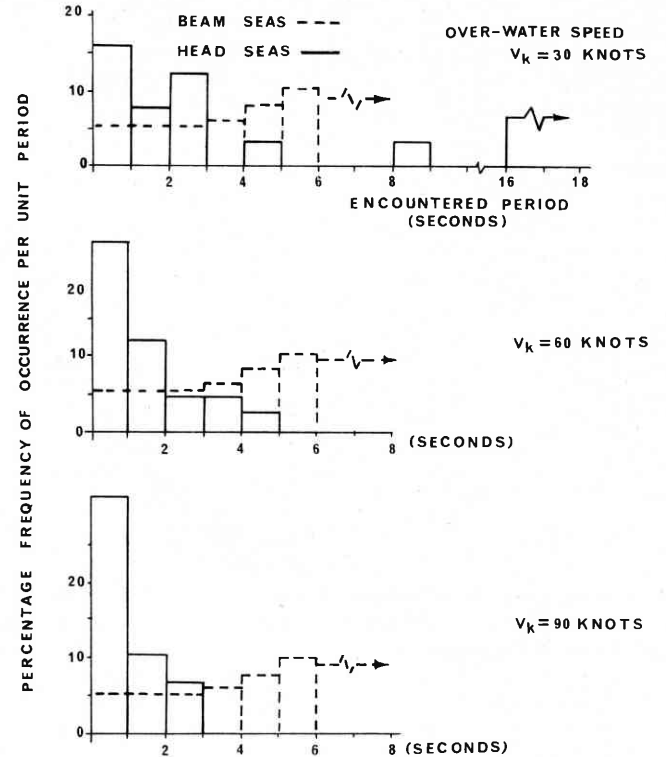


FIG. 8(a)—FREQUENCY OF ENCOUNTER—NORTH SEA

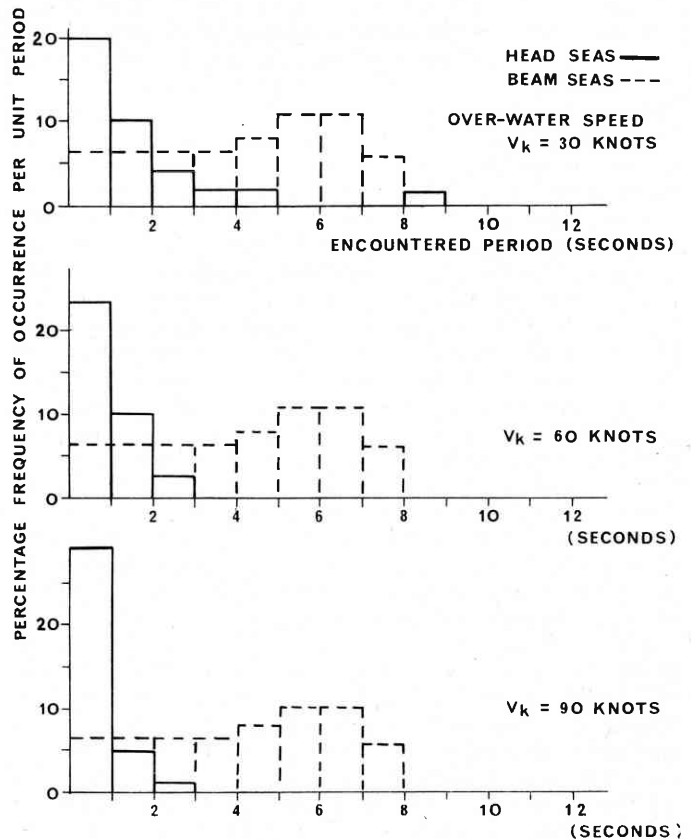


FIG. 8(b)—FREQUENCY OF ENCOUNTER—ENGLISH CHANNEL

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For the short sea routes Figs. 8(a) and 8(b) show the frequency of occurrence of waves of given encountered period; by the nature of the definition the faster the craft the shorter the time between wave crests in head seas but beam seas show no apparent shortening.

Natural oscillation data for the present-day family of hovercraft with cushion pressures (or base loading, a measure of structural density) of up to 60lb./sq.ft. are illustrated by Fig. 9.

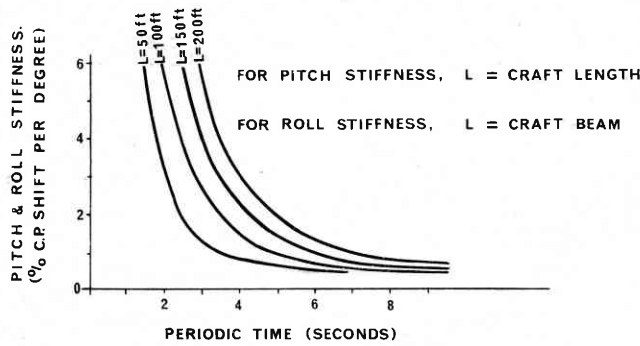


FIG. 9.—PITCH AND ROLL RESPONSE

The ordinate scale of stiffness has units “percentage centre of (lift) pressure shift per degree.” Stiffness is calculated from the applied moment required to roll or pitch the craft, i.e.

$$\text{per cent C.P. shift/degree} = \frac{M}{WL} \times 100$$

where M is moment to tilt craft through 1 degree in roll or pitch;
 W is craft displacement weight;

L is cushion dimensions either beam or lengthwise.

Unless special arrangements are made a stiffness of $2\frac{1}{2}$ per cent in pitch and $1\frac{1}{2}$ per cent in roll may be expected. A period of 3 to 4 seconds about both axes will be exhibited by a craft of 150 tons displacement weight.

Assuming a band width of excessive response to waves $\pm \frac{1}{2}$ second about the critical region, a craft maintaining 60 knots cruise speed should meet beam seas which for 6 per cent of the time introduce roll amplitudes greater than the wave amplitude; in head sea conditions there is less likelihood of meeting resonant conditions, about 3 per cent of occasions in the North Sea area and 1 per cent on the Dover-Calais route.

Naturally the well-known ship techniques of changing course or speed to avoid excessive pitch or roll oscillations are available to the hovercraft captain. Quite marked changes of course are required and speed reduction is likely to make matters worse for these routes, the driver may be reluctant or unable to increase speed to move away from this uncomfortable condition.

The alternative course of action to changing the encountered frequency is to modulate the craft characteristics artificially so that in effect the natural period of oscillation is remote from the wave period encountered. Most cross-channel ferry ships are stabilized in roll and it may be essential to fit at least roll stabilization in a cross-channel hovercraft.

Hovercraft operating at the time of writing do not have artificial stabilization although Hovercraft Development Limited (H.D.L.) have conducted some trials at sea of an experimental nature. Resonant oscillations have been encountered, but the non-regular make-up of succeeding waves has usually prevented this effect becoming objectionable. An exceptional case occurs when meeting on calm waters the lateral wave train of a passing ship in which case a build up of pitch amplitude is frequently experienced.

A further operational feature possibly unique to hovercraft, although planing craft might exhibit it to some extent, is evident when operating in beam seas. The free-of-the-surface hovercraft is constrained only by gravity to accelerate down any incline over which it might be hovering, this is true whether the incline is a sloping beach or the side of a wave. Consequently a hovercraft operating in a beam sea will quite readily operate along the crest or trough of a wave, but should it find itself on the sloping side it will pick up speed sideways remarkably quickly and slide towards the trough and, if circumstances are favourable, up the side of the next wave. However, this is an uncontrolled manoeuvre and technique must be sought to avoid it or to render it innocuous.

Wind conditions in themselves, apart from the wind-induced waves, considerably affect hovercraft performance. A 20-knot headwind reduces by a similar amount the speed of a craft capable of cruising at a maximum speed of 80 knots; this represents a considerable increase in journey time or alternatively a reduction in range for a given fuel load. Annual distribution of winds in the Channel area is:—

Wind speed	Frequency of occurrence (from all directions)
knots	per cent
0-10	50
10-20	36
20-30	10
Over 30	4

Summarizing the position, the craft must be expected to operate regularly in 5-ft. waves and headwinds of 20 knots; a statement of the performance in these conditions represents actual circumstances better than still air, calm sea data.

The wave and wind conditions have been discussed for a desirable route area and have shown the order of problems they present. In addition to making the crossing safely, despite wind and waves, the hovercraft must give a reasonable passenger comfort level. Vehicle noise is now a matter of much debate and the government committee report on the subject⁽⁷⁾ recommends that hovercraft noise levels be controlled by legislation at this early stage in development.

Noise, defined as unwanted sound, is inevitable on a high-powered machine such as the hovercraft. External noise emanates principally from the air propellers and noise levels are reduced if the tip speed and blade loading is not allowed to exceed well-understood levels; however, such measures are accompanied by some thrust loss. To the passengers, gearbox and transmission noise is generally the most noticeable; the science of gear design does encompass vibration and noise and although good gear design practice is well established the behaviour of an assembly comprising gearbox, transmission shafting, and a thin plate structure cannot be predicted at all accurately.

At the lower frequencies, 0.1 to 50 cycles per second, vibration gives rise to body discomfort through the human frame itself. Fig. 10 shows a criterion for bodily comfort.⁽⁸⁾ Analysis of comments in reply to a questionnaire during the Rhyl-Wallasey experimental hovercraft service in 1962, coupled with vibration measurements on the craft itself, fits well on the diagram.

In addition to vibration generated by machinery on board, an oscillating longitudinal acceleration can occur when operating through head seas. Fig. 11 indicates this condition which differs from calm water in that the normal to the water surface upon which the cushion pressure reacts has a rearward component; a half-wave later this has become a forward component.

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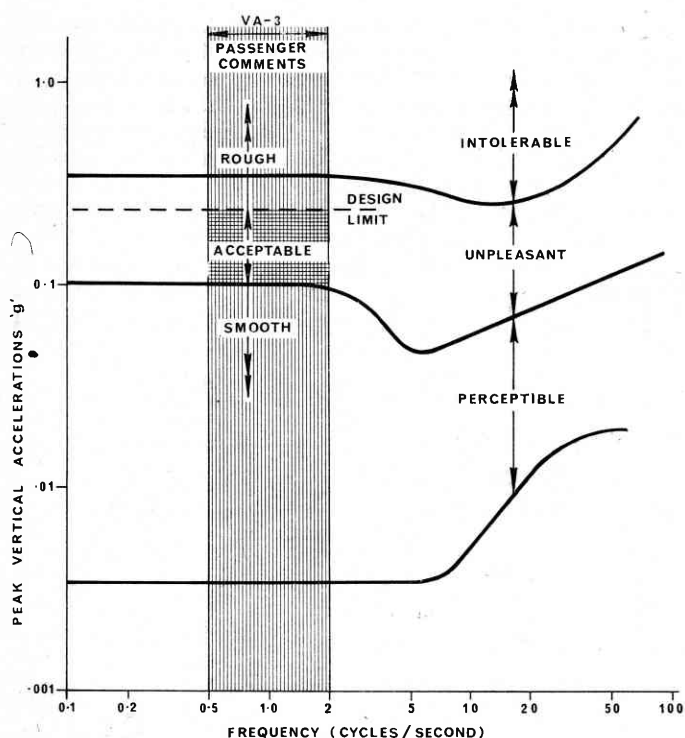


FIG. 10.—COMFORT BOUNDARY

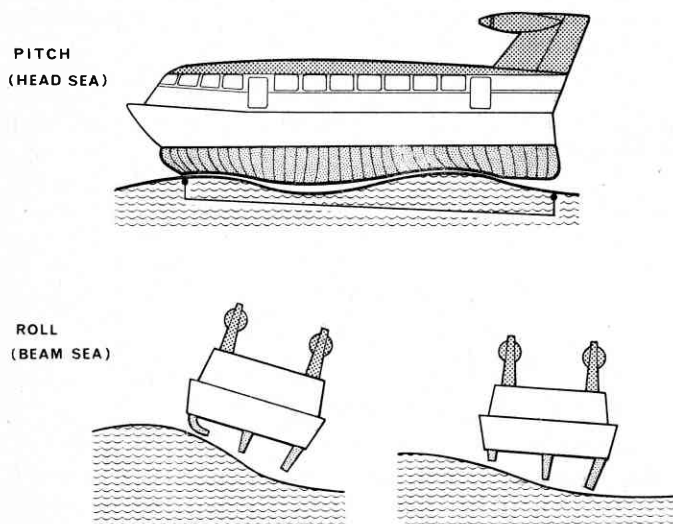


FIG. 11.—ACTION OF THE FLEXIBLE SKIRT

For a hovercraft 100 ft. long travelling in a 5-ft. sea the mean wave slope can apply to the craft a deceleration of 0.05 g. (1.6 ft./sec.²) followed by an acceleration of a similar value as wave crests and troughs deflect first the front skirt and then the rear skirt. At 60 knots this maximum amplitude of oscillation would occur with a frequency of 0.5 cycles/sec. The magnitude of this vibration increases as the mean water slope increases, so that larger acceleration forces may be expected when a shorter craft operates over steep waves; however, for the ferry hovercraft which is in excess of 100 ft. long, waves 5 ft. high would produce a perceptible deceleration and the 10-ft. high waves would border on the unpleasant. In a manner similar to that for the pitching movements, this vibration may be reduced by changing course.

In consideration of the rapid deceleration which may occur if the craft impacts a wave or alights on the water following an engine failure, one experimental craft was fitted with rearward facing seats; in another some seats faced forward and others aft, but the evidence is inconclusive as to whether forward or aft-facing seating is desirable.

The sea areas under review, the English Channel and Southern North Sea carry a large volume of traffic; this congestion of vessels across the route of a hovercraft ferry service requires prior consideration.

Sample radar counts obtained by Decca⁽⁹⁾ show that on the Dover—Calais route there were seven vessels within five miles each side of the direct route at the time the scan was made on May 23, 1956, and nine vessels in a similar area astride the Hook—Harwich route; most of the vessels were travelling across the routes considered.

The captain of the hovercraft travelling at 60–80 knots has the problem of observing the shipping in this vicinity and identifying those vessels for which he must take avoiding action. To be able to maintain speed with visibility less than 5 miles it is essential that radar aids are available; probably the best solution for a short journey of up to 80 miles would be to maintain surveillance from ground stations each end of the ferry route and advise the captain by radio communications.

English Channel sea traffic is concentrated in clearly defined tracks, ships hugging either the English or French coasts. Ref. (9) defines the route which most ships use and on which almost all collisions occur; if this area should not be well surveyed by the ground radar, ferryborne radar would be required. The problem has become similar to that of air traffic control, but whereas a State, by reason of ownership, controls the airspace above it, the three-mile territorial limit restricts the jurisdiction of France and England to a relatively small portion of the Channel. However, since 36 collisions occurred in the Channel in 1961 and 35 in 1962, some form of overall control would appear to be desirable. If an authority were introduced, the control of ship and hovercraft ferries could be readily integrated.

Complementary to observing an obstacle the hovercraft captain must be able to manoeuvre the craft to avoid it. Turning radius on present-day craft of 15 to 25 tons is about 500 yards at 45 knots; the larger craft for a more open-water route will take a radius of about 1,100 yards, since with increasing size the weight of the craft rises more rapidly than the elements which can generate a side force, e.g. propeller thrust or craft side area. For comparison a frigate at 33 knots turns at 475 yards radius⁽¹⁰⁾ and a cross-channel ferry 500 yards at 19 knots.

Above all the hovercraft has an excellent emergency braking feature, by reducing lift power and trailing flexible skirts in the water a progressively increasing resistance can be secured; ultimately, to avoid an imminent collision by putting the craft down on the water, deceleration of 1 g. (32 ft./sec.²) is readily available, although some distress to passengers could result.

Current rules for right of way are contained in the Permit to Fly issued to the operator of the hovercraft. This states that the craft should comply with the various international regulations regarding collisions for seaplanes on the water, and further that "the 'aircraft' shall keep out of the way of other vessels."

Three aspects of the operational problem have been surveyed; wave and wind conditions, passenger comfort in terms of noise and vibration, and collision avoidance. However, many other problems may arise, for example difficulties in operating across a shore line, the nuisance in the terminal area from machinery noise and the spray generated by the air-cushion, or thirdly reconciling a hovercraft with shipping rules in respect of lights, safety equipment, and procedure.

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Part 3.—Design Considerations

No attempt is made to give simple rules for the design of a hovercraft, but overall aspects of performance are examined and some suggestions for improving the behaviour of the craft in waves are described.

Fig. 6, concerning sea state in the Channel, shows that waves of significant height in excess of 10 ft. occur 2 per cent of the time with a wavelength not shorter than 200 ft. These waves arising from winds with a long fetch and blowing up-channel become beam seas for the Channel-crossing craft.

A hovercraft with a flexible skirt at present state of design requires a skirt of vertical height about 8 ft. to cope with 10-ft. waves, and the remaining 2 ft. is made up by cushion-air and nozzle-air curtain at the bottom of a wave trough; at other points the skirt is in contact with the water. If the craft responds excessively to the wave shape, longer skirts would be required.

To ensure that a craft is stable in side winds and able to accept modest *CG* movements arising from fuel usage and passenger and freight load out-of-trim, the minimum dimensions of the craft should be at least five times the depth of the air cushion—flexible extension plus hovergap.

Thus the beam will be 50 ft. with 60 ft. more desirable, and an average length to beam ratio of $2\frac{1}{2}$ gives a length of 125 to 150 ft.

Excessive roll oscillation is likely to be encountered on about 10 per cent of all trips undertaken and roll stabilization would be most desirable. Where air-curtains contain the cushion in depth, e.g. large hovergap, control may be applied by operating airflow valves in the ducting. Where flexible skirts are used the hovergap will be small and flow control valves are ineffective in producing roll or pitch rotation; an effective method would be to adjust the length of the skirt below the hull as illustrated in Fig. 11.

The roll stabilization installation would lift up the skirt, along the length of the craft, on the side tending to rise, in response to a signal from a control circuit using a gyroscope as a reference for horizontal datum.

Waves are not so uniform that contact between the actuated skirt and the water would be avoided and similarly in travelling across waves the skirt will be deflected as waves pass under the hull. The energy expended in deflecting the skirts appears as an additional drag on the hovercraft, increasing with craft speed and the extent of skirt deflection, as shown in Fig. 12.

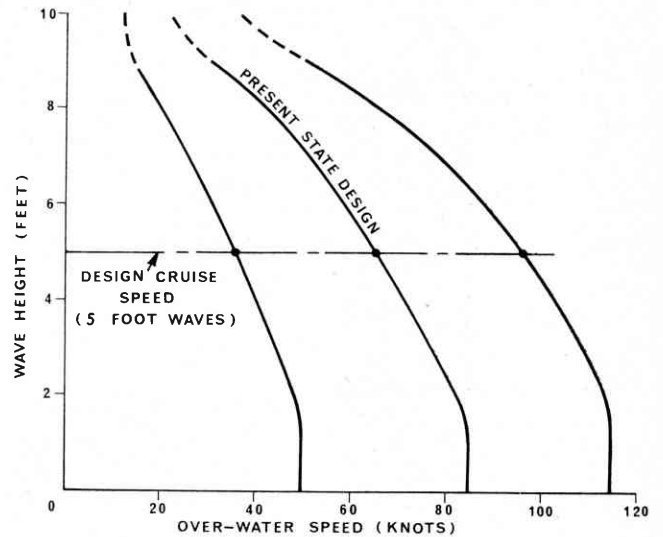


FIG. 12.—WAVE CAPABILITY

The craft speed is uniform for waves zero to 2 ft. high, a result of operating with an effective hovergap of 1 ft. and assuming no craft response.

For routes across the English Channel, waves in excess of 5 ft. occur for less than 17 per cent of the time; as a reasonable choice for nominal design conditions this wave height is used in defining craft speed.

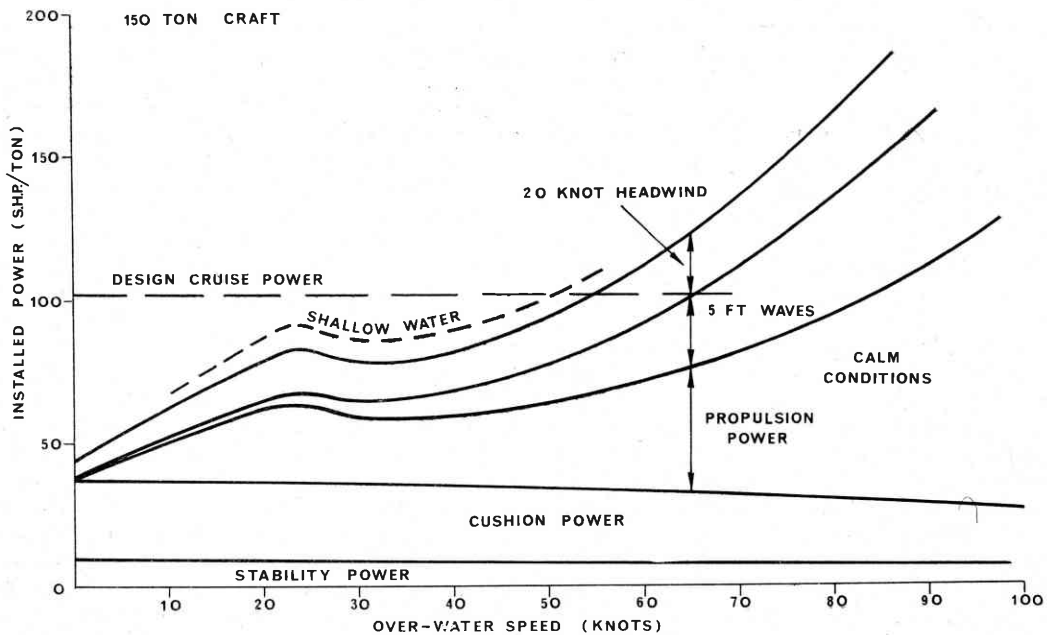


FIG. 13.—POWER REQUIREMENTS

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Power is required to lift, stabilize and propel the hovercraft; these components of the total power requirement are shown in Fig. 13.

Shallow water, that is locations where the water depth is less than 50 per cent of craft length, increases the magnitude of the wave-making resistance at the hump speed ($F_r = 0.65$).

It is important to note that the magnitude of wave making drag at the "hump" increases as weight² and that the total power required to ensure that hump drag can be overcome is sufficient to give the hovercraft a speed of 75 knots in calm conditions. Increased weight in itself increases the lift power requirement but the increase in wave-making drag with weight is far more serious and may become the basic design consideration in a moderate speed hovercraft.

Turning to the craft structure, the effect of size is shown in Fig. 14. The term cushion pressure (displacement

weight/cushion plan area) is an inverse measure of craft size through the constant weight lines; the combined effect of increasing size is to induce a rapid increase in the moments applied to the structure from wave impact and consequently the weight of material built into it. Thus at a given weight the proportion taken up by the structure increases at the expense of payload.

Three loading cases define the overall bending and torsional resistance requirements. As discussed in Part 2 the load applied to the bottom plating from water impact increases with craft speed and weight. The formulae currently used give impact loads of two or three times the displacement weight in the case of small high-speed craft, but the analysis is considered inappropriate for large craft since it indicates loads less than those encountered when floating on the water. A minimum impact load of 1.5 times displacement weight is currently applied to ensure adequate strength in large craft.

Hull plating pressures increase with craft speed; the effect on structure weight is shown in Fig. 15. The water pressures quoted are distributed pressures, the assumption being made that locally sustained pressures may reach 1.4 times the distributed value.

Published data on bottom pressures on planing boats at sea⁽¹¹⁾ and aircraft models during ditching trials⁽¹²⁾ give local pressures considerably in excess of the mean shown here. The latter reference draws attention to the fact that pressure transducers placed in the centre of skin panels indicate lower pressures than transducers mounted on rigid frame positions, clearly the result of flexibility of the transducer mounting. This probably gives the clue why hovercraft designed using data similar to that in Fig. 15 have operated successfully without plating damage. Not only does the detail design result in local flexibility, folded thin sheet frames, etc., but the whole structure is relatively flexible; if the design is based upon rigid body analysis considerable alleviation results from the flexible nature of the structure.

The smaller the dimension the lower will be the manufacturing cost of the craft. A high-speed passenger-carrying hovercraft will have installed power of about 100 shp/ton and, to minimize

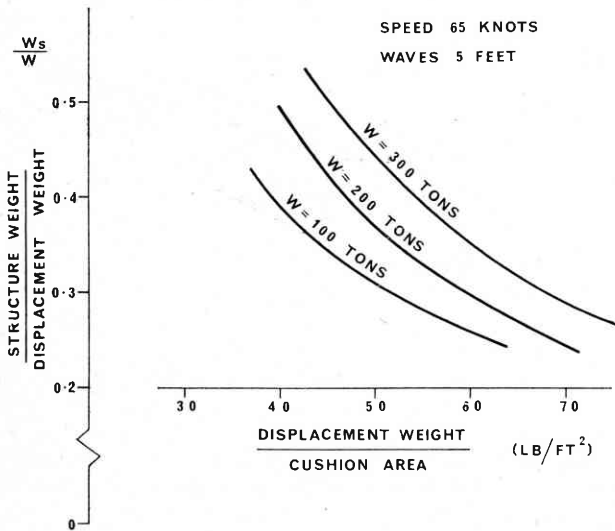


FIG. 14.—STRUCTURE WEIGHT

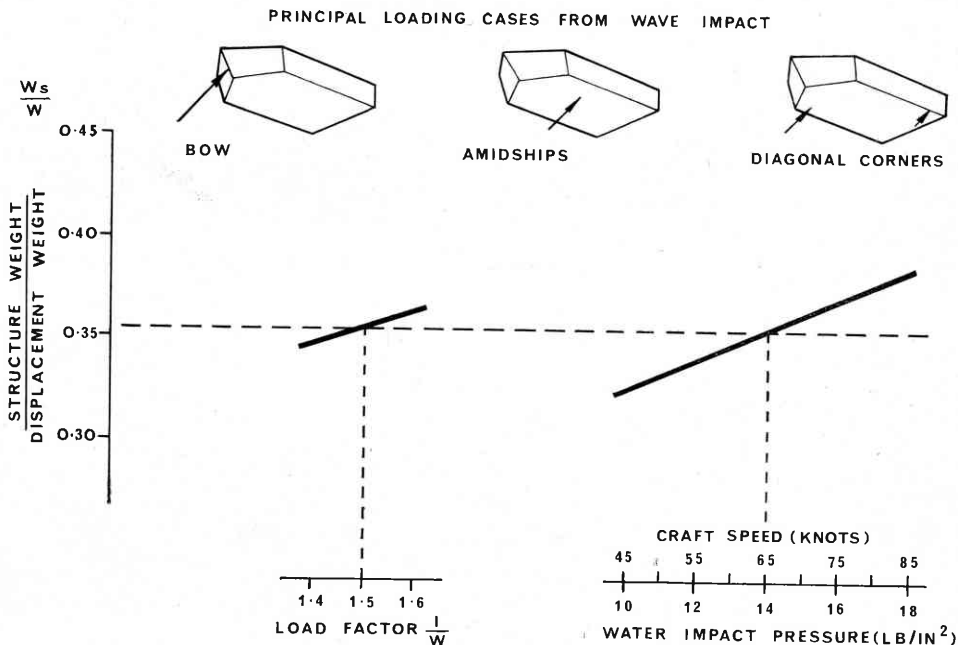


FIG. 15.—STRUCTURE STRENGTH

THE HOVERCRAFT FERRY

size, a cushion pressure as high as "hump" drag considerations allow, say 60-85 lb./ft.² for craft 160 ft. long. As far as accommodation is concerned the craft will be space limited and in the larger sizes where motor cars may be carried, a twin deck craft may be worth while. The area of deck available for accommodation on present-day craft is shown in Fig. 16.

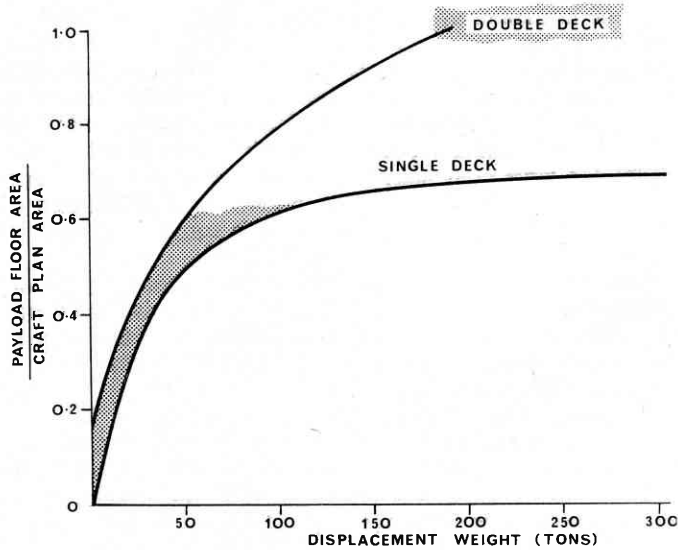


FIG. 16.—EFFECTIVE DECK AREA

Drawing upon the various aspects reviewed it is possible to set up a picture of the hovercraft ferry. An efficient hovercraft is the smallest craft, and hence the cheapest product, which will carry the load and perform as desired. Since headwinds and waves have a marked effect on hovercraft speed and range it is essential to take the performance in the average sea condition. If water is shallow over significant parts of the route, engine power may have to be increased and there could be a minimum size or maximum cushion pressure to permit the craft to accelerate satisfactorily.

Fig. 17 illustrates the trend of costs with increasing cushion pressure for a single deck craft of 150 tons displacement weight.

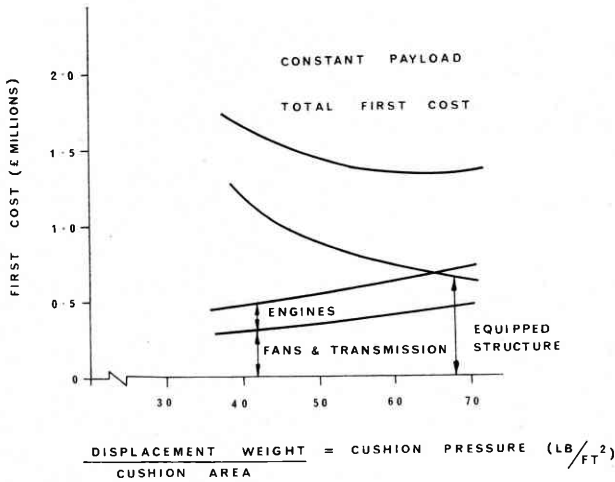


FIG. 17.—ECONOMIC SIZE

Data refer to a passenger ferry carrying about 500 passengers and their luggage and capable of maintaining 65 knots in 5-ft. waves. If it is to carry a large proportion of cars, 28 cars and 140 passengers for instance, the craft must be larger to accommodate the motor cars, and thus the cushion pressure is lower.

For minimum operating cost this is not necessarily a disadvantage.

Hovercraft first costs, Fig. 18, are high compared with ferry boats and series production aircraft in terms of work capacity, payload and cruising speed.⁽¹³⁾ This state of affairs may be expected to change with technical development and the establishment of a design from which a number of substantially similar craft may be built; however, at the moment the first cost makes a considerable contribution to hourly operating costs by way of interest on capital, depreciation, and insurance. The method of costing is similar to that used for aircraft since no suitable formulae are available for ship costing. Maintenance costs are, of course, less than for aircraft since the structural and mechanical components are less sophisticated.

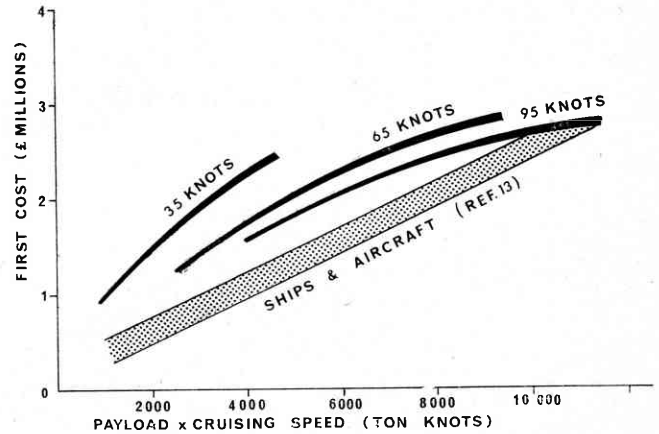


FIG. 18.—WORK CAPACITY

Using this procedure, Direct Operating Costs of two to three shillings per ton mile are obtained for short journeys, e.g. ferry stage length of 50 miles, which limits utilization to about 1,500 hours.

Operating costs are marked up by a factor of 2.5 to give a realistic fare after paying for the establishment to operate, publicize, and profit from the ferry operation, and allowing for a load factor. These fare levels lie between those currently charged by ship and air ferries, Fig. 19.

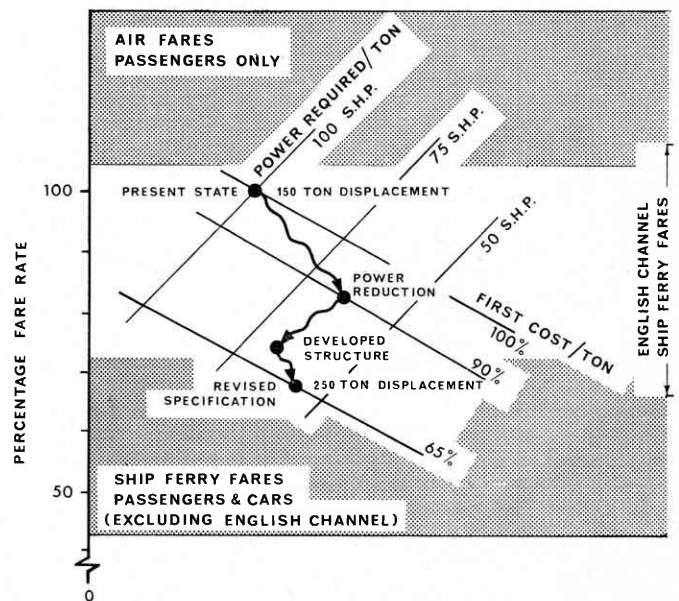


FIG. 19.—HOVERCRAFT ECONOMICS

THE HOVERCRAFT FERRY

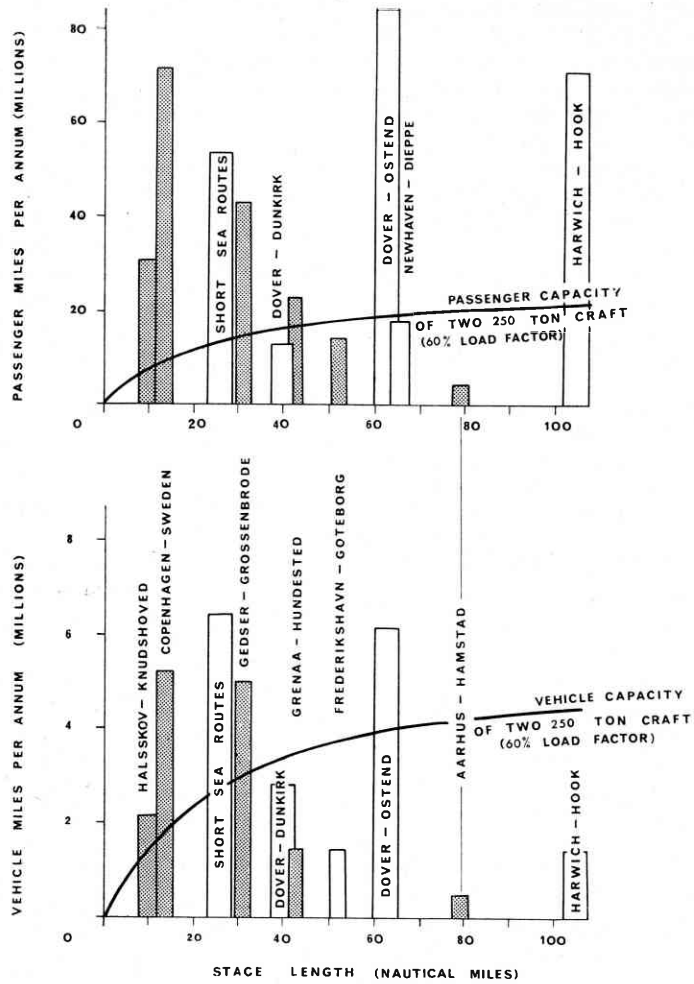


FIG. 20.—TRAFFIC VOLUME

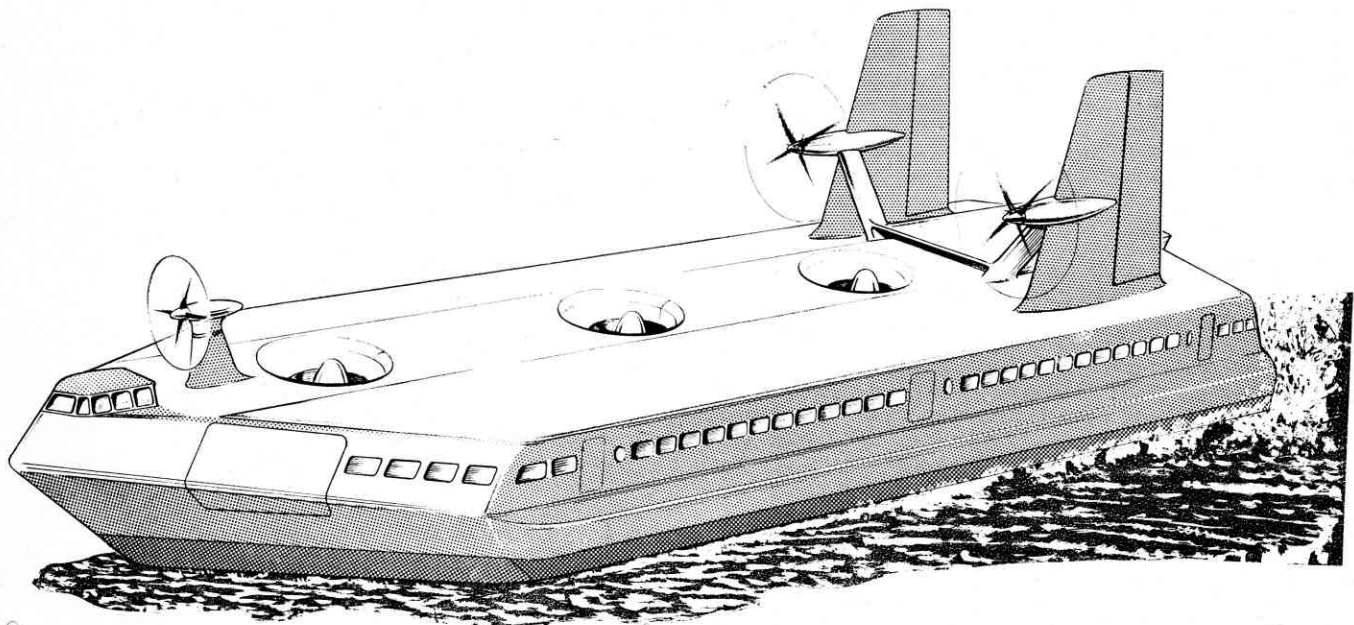


FIG. 21.—VA-4 PASSENGER/CAR FERRY

THE HOVERCRAFT FERRY

Fares are shown per unit weight based on five passengers and one car. In terms of a fare stage of 25 miles the fares are £5 10s. 0d. per car and £1 18s. 0d. per passenger. These fares can be maintained if 60 per cent of the overall capacity throughout the year is maintained, and with seasonal traffic variations this may be a difficult position to hold. Clearly, hovercraft should be introduced on a route with a high traffic volume, anticipating that there will always be a section of the travelling public willing to pay a little more than the minimum for a shorter or more comfortable journey.

Fig. 20, showing traffic on some northern Europe short-sea routes, enables the routes likely to prove attractive to be picked out.

An illustration of a practical layout follows in Fig. 21. For control, the driver adjusts the propeller blade angle to obtain differential thrust, and over hard ground retractable wheels are lowered to prevent side drift. The craft shown here can be built using information available now; however, this is hardly big enough for all-the-year operation on the Channel routes. The development foreseen in Fig. 19, shows a larger craft can be available in the next year or two. This will have substantially better economics; the ship and aircraft ferry operators have a formidable contestant standing in the wings.

Conclusions

Practical overwater hovercraft have operated since 1959, but in spite of the short period of development, experimental summer services have shown that hovercraft are seaworthy and have public appeal. Increased size is required to enable hovercraft to operate in the waves encountered on the short-sea routes in northern Europe; the layout and operating features of a realistic design are discussed.

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