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Research and Development

by

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Research and Development

John Rapson, until recently Head of the Hovercraft Unit of the National Physical Laboratory, has been involved in hovercraft development since 1956. Earlier in his career, he spent several years in the Ministry of Supply, engaged in aircraft project and experimental work. His interest in hovercraft led him to join the National Research Development Corporation in 1959, later transferring to Hovercraft Development Ltd. where he became Assistant Chief Engineer. He was made Chief Engineer early in 1966.

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J E. Rapson

THE phrase "research and development" could be applied to all the activity in the hovercraft field from the time of C. S. Cockerell's original coffee tin experiment. Such an interpretation is obviously beyond the scope of this Paper. It also appears to be impracticable to attempt to define the boundary between research and development. It is important, however, to consider the extent of the R. & D. effort which should be devoted to this entirely new form of transport.

One of the major difficulties in attracting funds for R. & D. is to convince the potential investor that hovercraft are here to stay and have the necessary potential for continued improvement. A low level of R. & D. expenditure may mean that advancement is so slow that the future looks doubtful. A very high level may produce rapid advances but will impede the manufacturing firms in producing a bread and butter, money-making craft. In the UK the British manufacturers have tended to develop craft for different purposes and there has not been a great deal of direct competition. The situation is likely to change as other countries become more seriously interested in hovercraft : a higher level of R. & D. activity will then be necessary for British companies to maintain their lead. This suggests that the existing lead could be increased by advancing the initiation of this increased R. & D. effort.

In a field as new as hovercraft, there are many developments having a claim on R. & D. funds. There is no clearly defined method of deciding which should be favoured and the R. & D. programme for a particular firm will be influenced by the inclinations of its technical staff, its production facilities and on the capital already allocated to the production of a standard machine. Realising that this situation could inhibit the development of new ideas, Hovercraft Development Ltd. set up in 1960 a technical group whose programme would not be restricted by such considerations.

This Paper is mainly devoted to a description of the R. & D. methods used by H.D.L. to develop cushion systems over the past four years. It is shown that not only has the cushion system been continuously improved but also the methods of carrying out the R. & D. have themselves developed. Facilities and techniques have been devised especially for hovercraft work and since results to an accuracy of about 5% have usually proved adequate, the very simplest equipment which will produce this accuracy has been used throughout. The rate of advancement will inevitably slow down and more effort will be required to achieve smaller gains. Great care will have to be exercised to ensure that hovercraft R. & D. is not expanded for its own sake. For the next few years, however, the potential improvements are such that a high R. & D. investment both by individual companies and by the nation will attract a high return.

cushion philosophy

In 1963 the HD.1 experimental hovercraft, which had been designed by the Technical Group of H.D.L., was commissioned with fixed sidewalls. At that time,

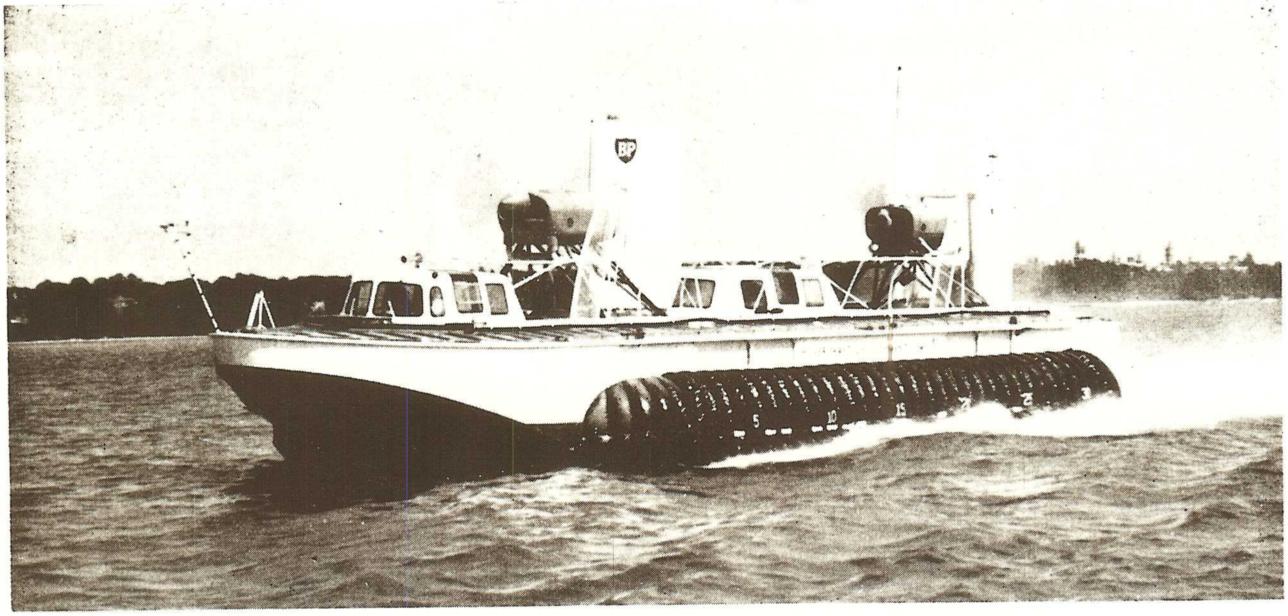

Fig. 1. The HD.1 experimental hovercraft in one of its flexible sidewall configurations

it was intended that the rigid walls would be replaced with flexible seals although their construction was an unknown factor. By the spring of the following year, a form of segmented sidewall had been devised and fitted directly to the main structure. Extensive testing convinced the team that separate segments offered a solution to the problem of providing an effective cushion seal with many advantages over other systems currently available. Fig. 1 shows HD.1 in one of its flexible sidewall configurations.

As the result of the HD.1 trials, the H.D.L. cushion philosophy began to evolve. This had as its main targets :

1. The cushion sealing system shall have low drag, both in calm water and in waves.
2. The elements of the seal shall have a low wearing rate and be easily replaced.
3. All parts of the seal shall be accessible when the craft is resting on the ground.
4. The sealing system as a whole shall be capable of being designed to provide pre-determined cushion characteristics; in particular, cushion stiffness and damping.

model tests

It was clear that much cushion development work could be done with the aid of dynamically scaled models tested over calm water and waves. Sophisticated ship towing tanks were available but had been designed to produce very accurate drag figures at moderate forward speeds. The requirements of model hovercraft testing called for a series of less accurate measurements covering a greater speed range and a large number of model configurations. Initially, all that was needed was a method of towing a model over water and measuring to the nearest 5% the drag and the speed.

This was provided by digging a rectangular hole in flat ground 150 ft. long by 40 ft. wide and 1 ft. 9 ins. deep. The hole was lined with an impervious sheet of the type used for swimming pools. A farm tractor was driven on to the site and once its wheels were removed it formed the power plant to drive an oscillating blade in the water for wave making. An electric motor driving a winch through a constant torque coupling provided the thrust. Measurement of speed was provided directly from the rotational speed of the winch drum and thrust from the torque level of the winch. Guide wires and arresting gear completed the facility in this initial configuration. Since many hovercraft models being tested were amphibious, the opportunity was taken of providing a circular course about a quarter of which was over the water of the tank and the remainder over a grass lawn. Later, the tank was developed in stages to provide an unsophisticated but effective hovercraft testing facility for all year round use with electric models.

The choice of model size has always been a compromise. Small models allow the testing facilities to be cheaper since scale speeds and wave heights are less, although the low absolute values of the velocities, forces and displacements produced makes measurement more exacting. Dynamic similarity dictates the weight of the model and it is more difficult to produce a small model to the correct weight limitation than a large one. The unknown effects of skirt scaling also influence the choice towards the larger models. Models of about 10 ft. long were initially chosen as a satisfactory compromise. A standard lift package which may be driven by small petrol engines or by electric motors has been used for all the initial assessment models of a given type of craft. Considerable model design work is saved using this technique and effort may be concentrated on the hull and the skirt attachments. The elapsed time for designing and building a new model has been reduced to six weeks by this approach. It is not suggested that a more accurate model with representative lift fans and internal aerodynamic lay-out can be dispensed with for the final evaluation of a craft configuration.

By the middle of 1964 the segmented skirt without internal compartmentation had been fitted to the CC.4 but the other manufacturers were not prepared to adopt the system solely on the basis of the HD.1 experience. The state of hovercraft development had not reached the point (and still has not) at which it is possible to select a cushion support system on the basis of superior speed alone. An attempt was made in 1965 to provide a visual comparison of two models representing the segmented skirt and the continuous jetted loop. Model 37, representing a possible Channel ferry, had been built using a standard power package. It incorporated the H.D.L. cushion philosophy features mentioned earlier. An identical hull was produced and fitted with a typical continuous jetted loop skirt with internal compartmentation. Both the 10 ft. models which had cushion depths of 5 ins. were towed on the Hythe testing tank and optimum trim conditions determined. Using the "round the pole" technique the models were demonstrated over calm water and a series of waves. Propulsion was provided by two sets of petrol driven air propellers which were moved from one model to the other. The lower drag of Model 37, the segmented skirt craft, was shown by the shorter time required to complete each circuit. Model 41 was found to plough in in certain wave conditions but with the propulsive thrusts available Model 37 could not be induced to do so under any conditions. A film was taken of each of the models with a camera mounted on the central pole. By interposing alternate sequences of Models 37 and 41 with identical water conditions an overall comparison could be made. It is significant that at this stage of development a qualitative comparison of this sort was more effective in making an initial appreciation of the two systems than an exhaustive series of measurements of drag, speed and accelerations over a range of wave heights, fan mass flows and fore and aft trim positions.

Drag measurements due to waves were established for Model 37 with optimum attitudes. These were encouragingly low with waves up to cushion depth but this represented only about 1/20th of the craft length. A deeper cushion would have to be designed in order to give a more acceptable performance in a full scale craft.

man-carrying craft

Late in 1965 agreement was obtained to the building of a series of man-carrying experimental craft. It was clear that much development remained to be done on the basic hovercraft systems. Previous experience had shown that the hovercraft manufacturers quite naturally wished to continue their own line of development and highly convincing demonstrations were called for before any major changes could be introduced. Ideally, therefore, there would be very great benefits in producing new experimental craft at short regular intervals. Not only would this policy build up a fleet of craft specifically designed to assess the effectiveness of various devices for improving say, control, sea keeping and propulsion, but would give manufacturers and operators the opportunity of experiencing at first hand the various alternative systems. It was realised that there was no "right" system but at least the opportunity would exist for evaluating alternatives.

Directional control was selected as the first topic for investigation and design work on HD.2, the first of the new series of craft, started late in 1965. Metal was first cut in March 1966 and construction continued (Fig. 2) until September, 1967, when the craft first went to sea. Since cushion development has been chosen as the example to illustrate the development of R. & D., little more will be said about the directional control aspects of HD.2. Apart from the use of radio controlled models, it is felt that the assessment of control systems can only be carried out with the pilot in the loop.

HD.2 was designed to be a small man-carrying machine which could be regarded as a scale

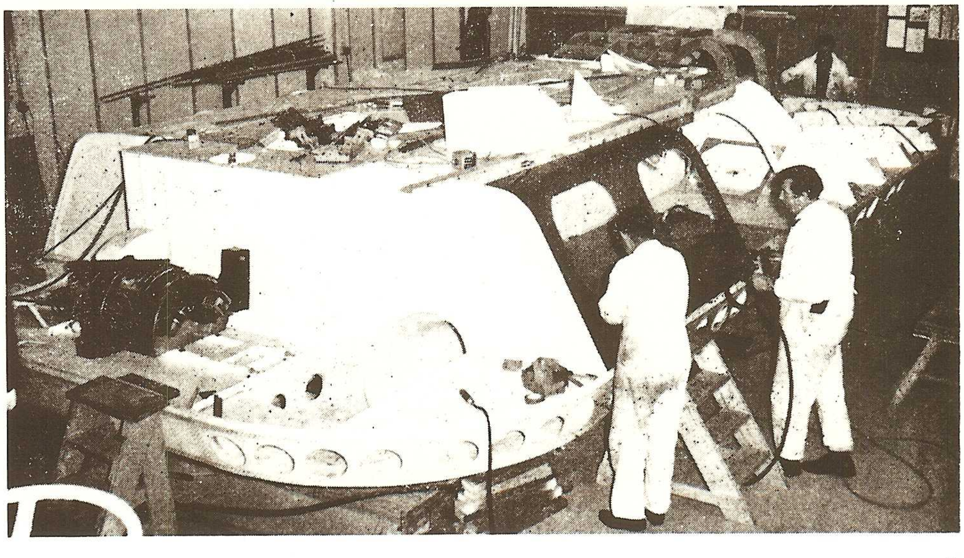

Fig. 2. The HD.2 in course of construction

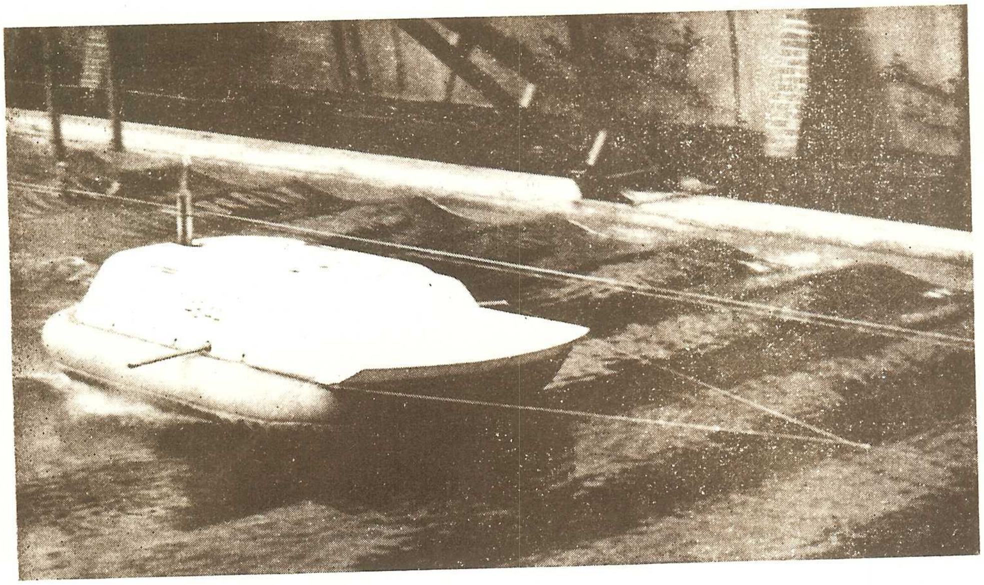

Fig. 3. Model 48 undergoing towing tests

model of a twin Proteus passenger/car ferry. A pair of swivelling propellers mounted in tandem on the centre line of the craft was chosen as the main means of propulsion and control. The design was also to incorporate puff ports and means for shifting the lateral and fore and aft positions of the centre of pressure of the cushion. As an experimental craft there was considerable scope for positioning equipment and services, but by referring always to the layout of the hypothetical full scale ferry it was possible to design a craft which was at the same time aesthetically pleasing and practicable for scaling up to a commercial size.

These considerations lead to a craft with a structural length of 30 ft. and a beam of 15 ft. with a two feet deep cushion. It was regarded as a 30% version of the full scale ferry. HD.2 had dual control and provision for carrying in addition six technical observers.

cushion design

Much work was required in order to specify the cushion geometry. The first step was the building of a model for tank testing in glass reinforced plastic. Designated Model 43, using a standard lift package, it represented a one-third scale version of HD.2. The full-scale experimental craft was being designed with axial fans delivering air into a plenum chamber covering the whole of the plan area with provision for feeding air into the cushion in a number of ways. This approach enabled the skirt design and the air distribution to the cushion to be chosen with comparative freedom. At this stage Model 43 was fitted with radio control and operated as a free flight model.

A second model was constructed from the same mould (Model 48) and an intensive programme was begun to select the first cushion system for HD.2 (Fig. 3). Five basic segmented skirts were designed for Model 48, but a preliminary selection reduced these to variations on configurations 48/2, 48/4 and 48/5. Each basic configuration had changes designated by letters and 12 variations were tested on the Hythe tank. Configuration 48/5E was selected in February 1967 for more detailed testing in the N.P.L. No. 3 tank at Feltham.

In the chosen configuration, the separate segments occupy the full depth of the cushion between the hard structure and the supporting surface. By arranging for the segments to be mounted under a loop of material

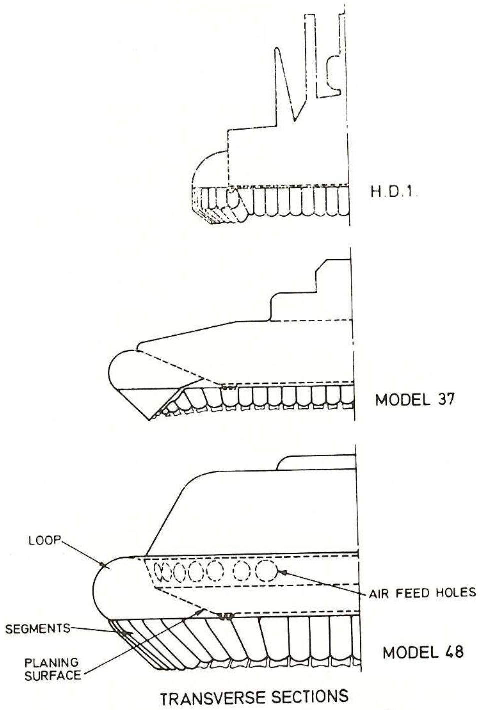

Fig. 4. Development of cushion seals

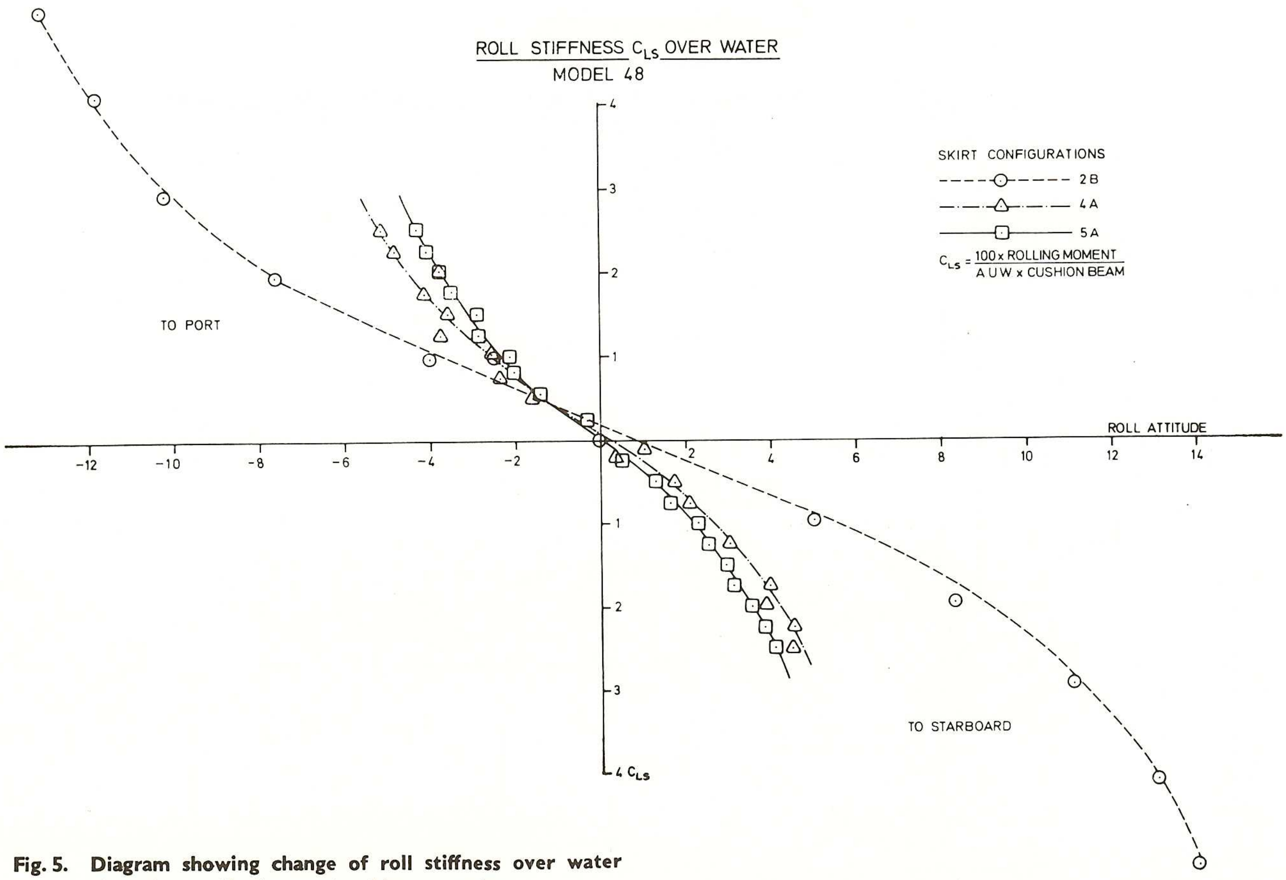

Fig. 5. Diagram showing change of roll stiffness over water given by small changes in skirt geometry

attached to the outboard extremities of the craft, it is possible for the boundary of the cushion to remain under the structural edge of the craft. If it were not for the loop, considerable cushion area would be lost due to the inward slope of the segments over the cushion depth. This configuration allows the planing surface, considered essential as the ultimate safety factor, to be incorporated. The curvature of the loop of material is drastically reduced around the bow in order to eliminate the possibility of the segments moving rearwards and causing a nose down pitching moment. Fig. 4 shows diagrammatically the development of cushion seals from the original HD.1 concept to that of HD.2.

One of the factors influencing the choice of skirt geometry was the pitch and roll stiffness obtained over water and over ground. Fig. 5 is an example of the change of roll stiffness over water which may be obtained by comparatively small changes in the skirt geometry. In this example, the roll stiffness is doubled in developing from configuration 2B to 5A.

The vertical accelerations experienced by the models when operating over waves also influence the choice. Fig. 6 shows how accelerations at the centre of gravity vary with Froude Number and wave height expressed as a fraction of cushion depth. This type of diagram is useful when checking that a possible cushion system is acceptable, but since acceptable levels of acceleration

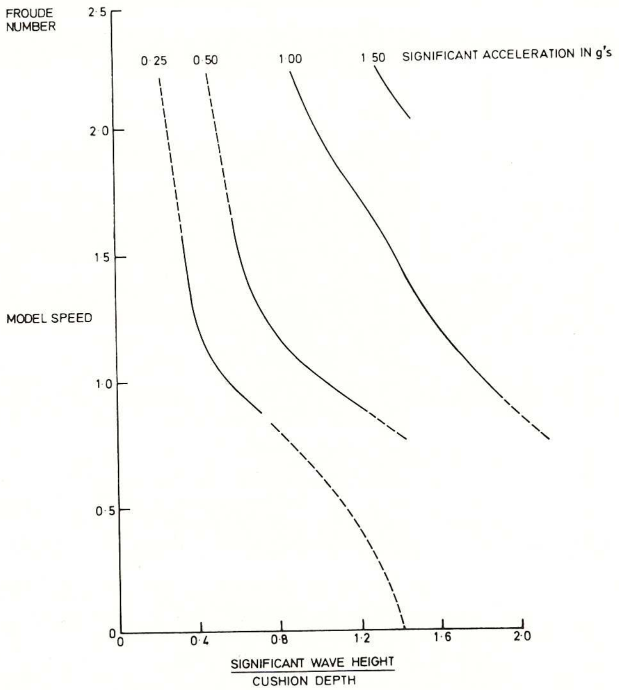

Fig. 6. C.G. vertical acceleration contours for a typical H.D.L. segmented skirt model

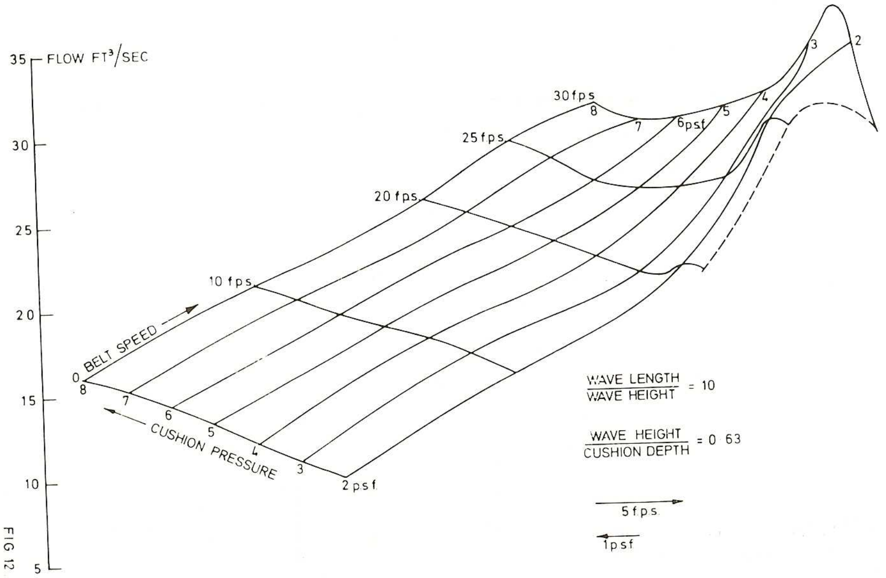

Fig. 7. **Characteristics of a segmented skirt model over wave belt**

from the passengers' point of view are not well defined, it can only act as a guide.

The H.D.L. cushion philosophy requires that the seals should have low drag in waves. One of the tests applied to a cushion seal is an evaluation of its effectiveness in responding to waves. Good response not only goes with low drag, but also with low air flow requirements. This characteristic is assessed on a moving belt having waves mounted on it. A model is mounted at a fixed height over the belt and by varying the belt speed and the model air mass flow and measuring the lift, a diagram of the type shown in Fig. 7 may be produced. As speed is increased, the segments will respond rapidly at the higher cushion pressures, but at lower pressures the restoring force on each individual segment is insufficient to overcome the inertia of the segment before a significant leakage occurs. This type of test confirms that segments of low stiffness and specific weight will give better sealing characteristics than seals of high inertia or stiffness.

The sophisticated Feltham No. 3 tank has a large carriage capable of towing models at speeds of up to 50 ft./sec. over a tank 1,300 ft. long by 25 ft. deep and 48 ft. wide. It has a wave-maker for producing regular or irregular seas and carriage-borne instrumentation on which pitch and heave attitude accelerations, fan r.p.m., speed and drag may be recorded. The presence of the large carriage does, however, produce some aerodynamic interference for which corrections should be made.

Testing on this relatively expensive facility has to be planned carefully to make the best use of the time booked. Having evaluated the model performance and established that the selected cushion system would be

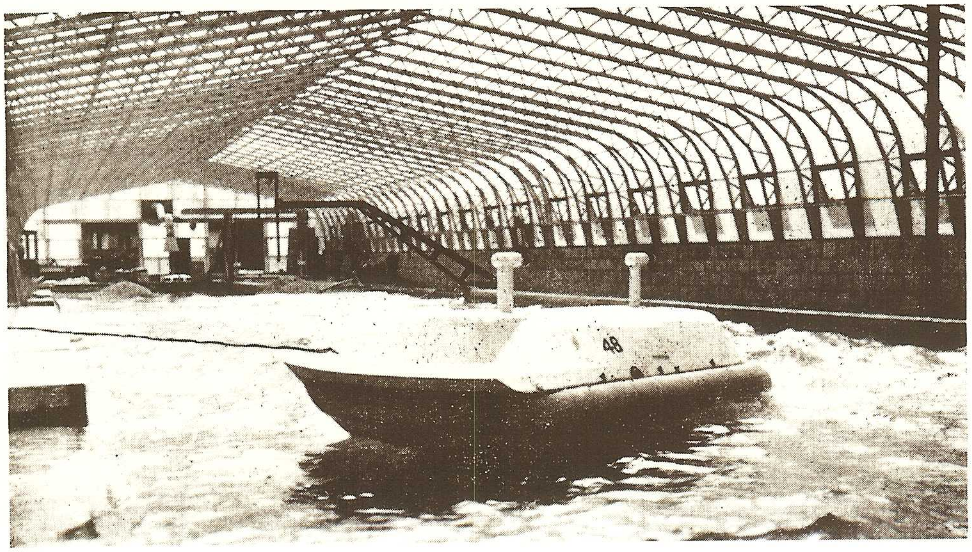

Fig. 8. **Model testing in the covered test tank**

adequate for the 50 knot design speed of HD.2, further checks were carried out on the Hythe tank. For example, lift engine failure under various yaw conditions was simulated. The various types of plough-in and heave-in were investigated at different fan speeds. The Hythe tank has been used continuously to assess the effects of small variations in skirt geometry due to the detailed engineering requirements of HD.2 itself.

During the course of the HD.2 model testing programme, improvements to the Hythe tank were being introduced. These changes were planned so that the tank was out of action for the shortest period on each occasion. It can be argued that all of the changes made could have been foreseen and carried out when the tank was first built, but it should be remembered that the rapid development of hovercraft calls for equally rapid developments in testing techniques. When the tank was first built in 1965, it was not known whether the simple approach would be adequate. The use of the facility during the summer of 1965 made it clear that a greater tank length would considerably increase the time of a model run at a stabilised speed. It was felt that a width of 30 ft. instead of 40 ft. would be quite adequate. At that time, however, the comparatively crude wave-maker was giving sufficiently repeatable seas to make testing realistic. The facility was, therefore, completely re-built early in 1966; on this occasion it was out of action for eight weeks. The concrete lined tank had an accelerating bay at the starting end which enabled models to be run for approximately three seconds at the maximum speed of 50 ft./sec. During the winter of 1966/67 much testing time was lost due to the aerodynamic effects of cross winds and it was decided to fit a light enclosing structure (Fig. 8). On this occasion, the tank was out of use for six weeks. Later still, an electrified rail was fitted which, with a light (10 lb.) carriage, enabled electrically powered models to be run. Apart from the lack of fumes and lower noise level, it became easier to establish and maintain constant engine speeds with more accuracy.

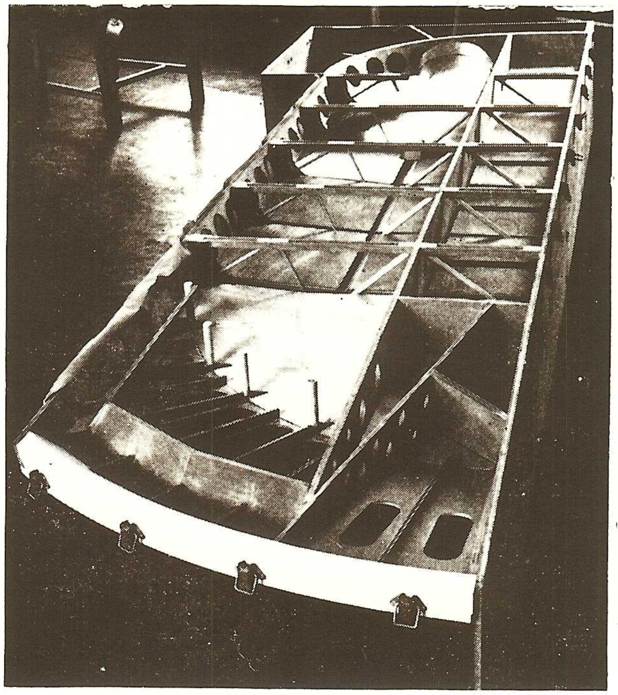

Fig. 9. Rig for testing internal aerodynamics

further tests

During the development of HD.2 itself, advances took place in model making techniques and a new model of HD.2 to quarter scale was designed and

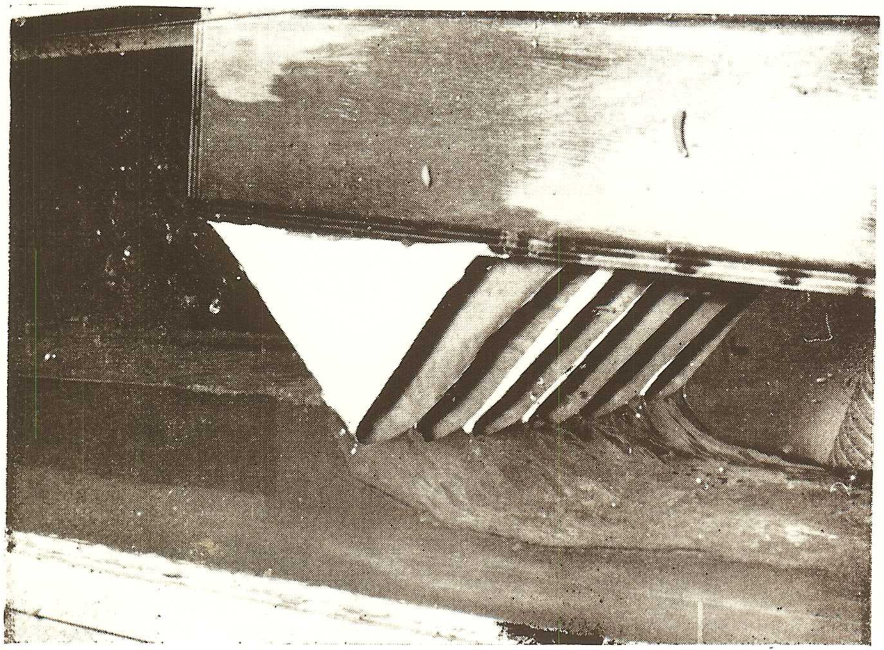

Fig. 10. Flume test on skirt characteristics

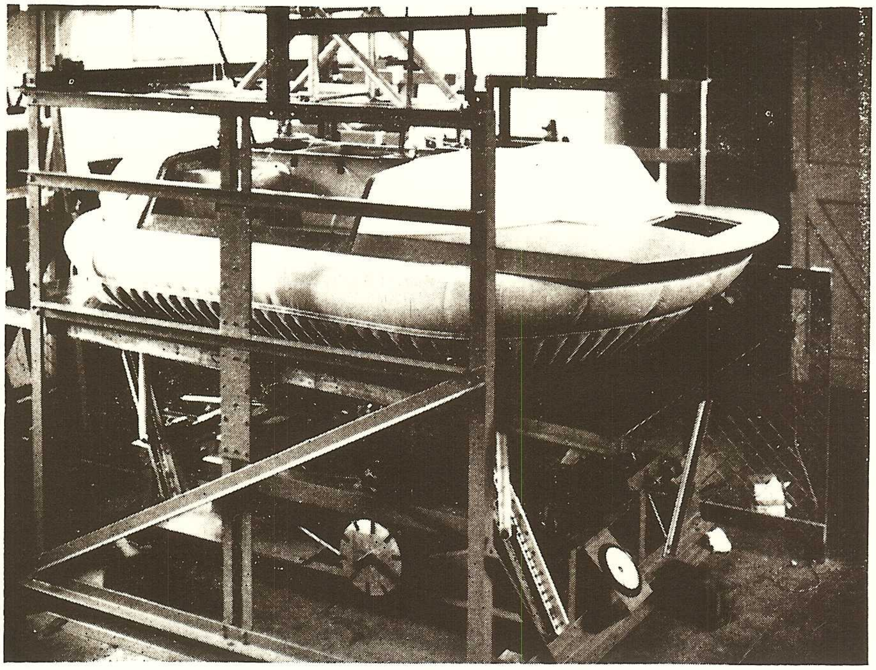

Fig. 11. Model testing on pitch and heave table

built. This model (Model 50) incorporated axial fans in the appropriate positions and represented the experimental craft closely in terms of air distribution and skirt geometry. It is tank tested concurrently with the HD.2 trials programme and is providing important data on the correlation between model and full scale hovercraft. It is also continuously available to investigate phenomena which may occur on HD.2.

The development of the HD.2 cushion system also called for rig tests to simulate the internal aerodynamics (Fig. 9), wind tunnel tests to assess the aerodynamic derivatives and flume tests to evaluate the hydrodynamic effects on the hull and the skirt (Fig. 10). A flat table capable of being pitched and heaved (Fig. 11) was used to simulate the forcing of the cushion when the craft passed over uneven surfaces. The wave belt facility (Fig. 12) has already been mentioned.

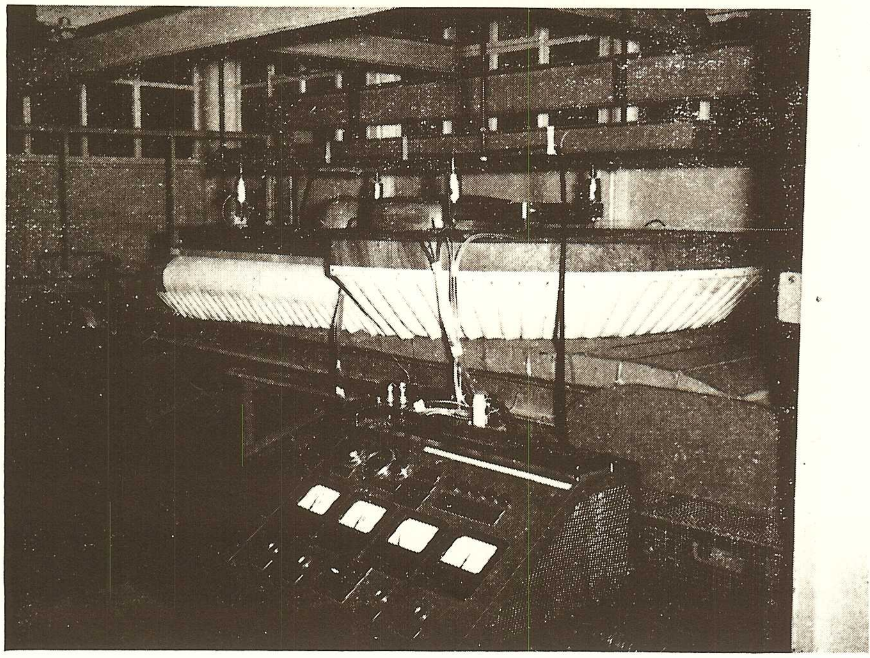

Fig. 12. Wave belt test facility

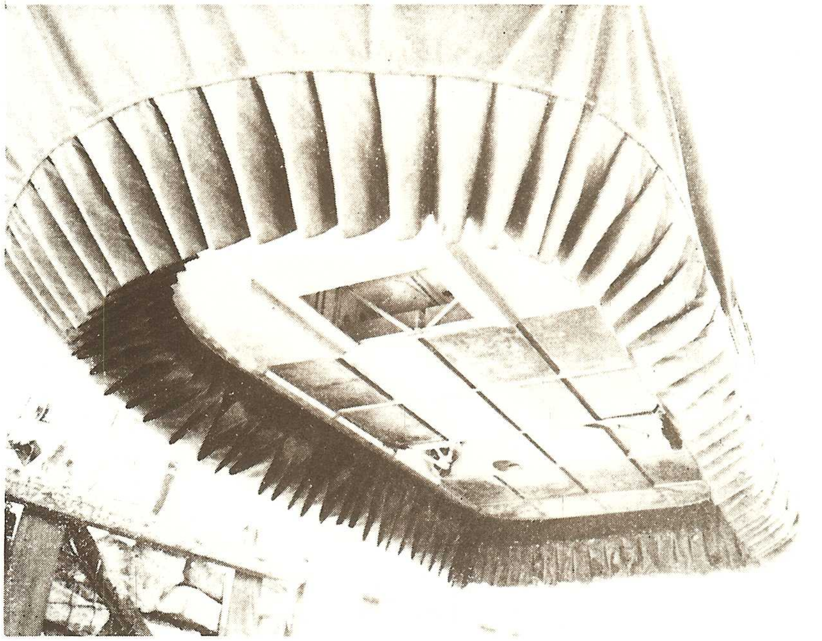

Fig. 13. Underneath view of HD.2 skirt configuration

The equations of motion of promising hovercraft configurations were set up on an analogue computer in order to establish the response of the craft to a variety of input conditions. Before these results could be used, some confirmation had to be obtained that the assumptions necessarily made were correct. In simple cases it was possible to obtain this from a two-dimensional section of a craft hovering over the pitch and heave table. The inputs and outputs were recorded and the adequacy of the simulation evaluated. Every opportunity has been taken to check on the validity of the simulations either with three-dimensional models or full scale craft. A simple set of controls was linked to the computer to introduce the pilot to the control method. This crude simulator provided an additional assessment of the effects of varying yaw stiffness and damping.

In the design of HD.2 one of the major unknowns was the minimum stiffness in pitch and roll which could be accepted on the full scale craft. Experience with HD.1 had shown that roll stiffness of 0.3% per degree was just acceptable, but a target figure at least twice this value was set for the first configuration of HD.2. Only the testing of a full scale craft can enable a realistic assessment to be made of the target values chosen. In order to be able to lay down such design criteria for future use, it may be necessary to extend the craft operation towards the boundary of its safety limits.

HD.2 has puff ports incorporated in its flexible skirts in two positions on each side. These could be operated satisfactorily in model form, but failed to work initially when installed on the craft. Successive modifications were necessary before satisfactory performance could be obtained on HD.2. This emphasised that the successful operation of a flexible device in model form does not necessarily mean that the scaling up process may be carried out with impunity. Another example of a development problem was the incorporation of a device for moving the cushion centre of pressure laterally. The basic scheme was tried out in a two-dimensional model of the preferred skirt system. It worked well with relatively low loads in the attachment links. The engineering of the device into the craft proved to be somewhat complicated and at one stage it seemed that although it would clearly perform, the need for additional control systems might render it impracticable. Eventually it was successfully installed on HD.2 with great effect. The craft could be rolled through 4 deg. on each side of the level position, in about two seconds. The skirt configuration finally fitted for the initial trials of HD.2 is shown as viewed from the under side in Fig. 13. Fig.14 shows the craft on trials in the Solent.

Much speculation has taken place about the mechanism of skirt wear. The skirt geometry has a major effect, but the issue is sometimes clouded by evidence of rapid wear being eventually tracked down to a sub-standard batch of material. HD.2 has therefore, been fitted with a rotatable periscope, through which the segments can be watched during operational sorties. Even on a dull day in winter, there is sufficient light to be able to view the working of the skirt clearly. A similar installation in HD.1 was used to obtain still and cine films as a permanent record. Fig. 15 shows material weighing only 5 oz./sq. yard acting as side-wall segments for the 10 ton HD.1. The craft is moving towards the left of the picture and the effect of a wave on the seal may clearly be seen.

other applications

The major part of the Paper has been concerned with the example of cushion development for marine hover-

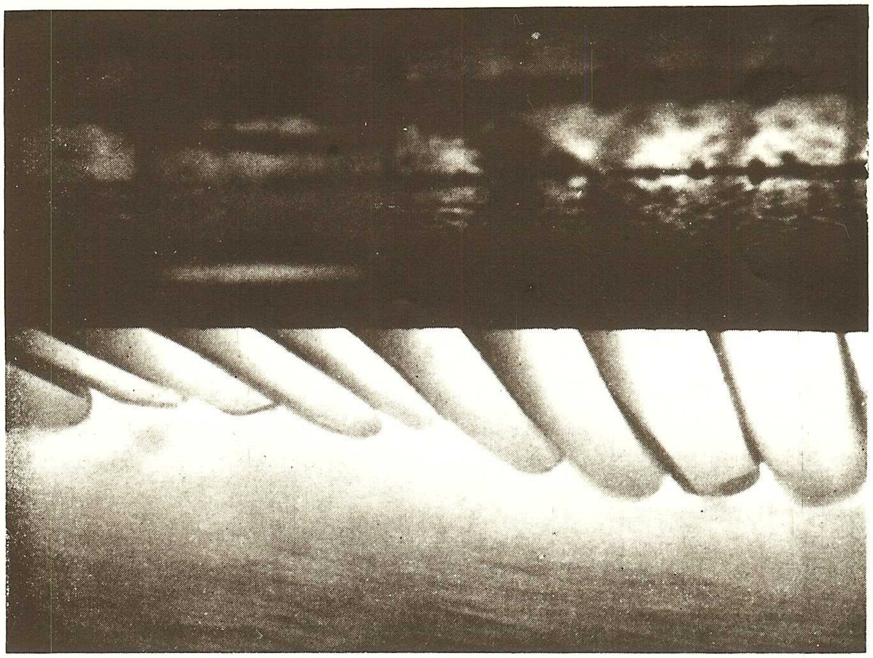

Fig. 15. Underwater periscope view of skirt action, showing effect of a wave on the seal

characteristics of waviness, steps and porosity. In the case of the hoverbed for treating badly burned patients, the development has reached the point at which a further reduction in the mass flow requirements might begin to affect the rate of healing of the burned tissue.

the future

Returning to marine applications, a promising next step to follow HD.2 would be the building of a craft of about the same overall dimensions having the capability of operating in waves twice as high as those limiting HD.2. It is argued that on many commercial routes the craft size is dictated not by the traffic available, but by the ability to operate with acceptable regularity throughout the year. Although a smaller craft may have a lower individual efficiency than a larger one, the operational framework is likely to be such that this is more than compensated by the increased frequency of service that can be offered and the ability to reduce the number of craft in service in realistic increments as traffic falls in the off-peak seasons.

With the object of promoting this philosophy, a model has been built using one of the standard lift packages representing a craft with a cushion depth twice that of HD.2. This concept is aimed at providing a better ride for a given size of craft, or a smaller craft to cope with waves of a given severity. In practice, the advantages may be taken out as a combination of these two. Operators may be prepared to accept a higher specific lift horsepower if the capital investment required for the smaller craft is considerably reduced. A convincing demonstration with a manned experimental craft showing that the concept is a practicable one would allow it to be given appropriate consideration as a basis for a new hovercraft design.

This last example shows that although hovercraft have been under development for 10 years, there are still several different ways of producing economically viable craft. The eventual choice of design for a given duty will always be a compromise, but it should be the aim of a research and development team to evaluate the merits of the different approaches. Discouraging or negative results are often at least as important as successes and should be recorded equally diligently. The objective must be to provide data in aid of the design of future hovercraft. The state of the art is such that significant advances can still be made in craft efficiency and the point has not yet been reached when a major effort is justified in order to achieve modest improvements.

acknowledgments

Thanks are due to the members of the Hythe team for the assistance given in the writing and checking of this Paper. Acknowledgment is made to Hovercraft Development Limited and the National Physical Laboratory for the use of material.