HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS

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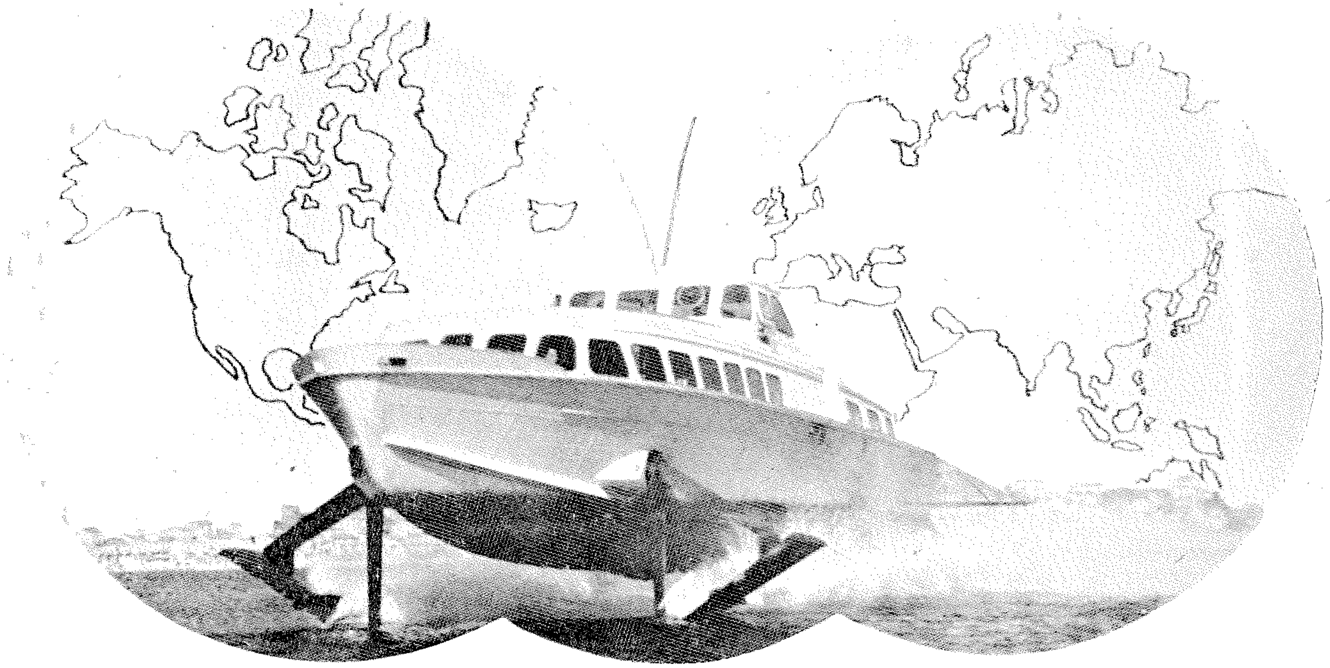
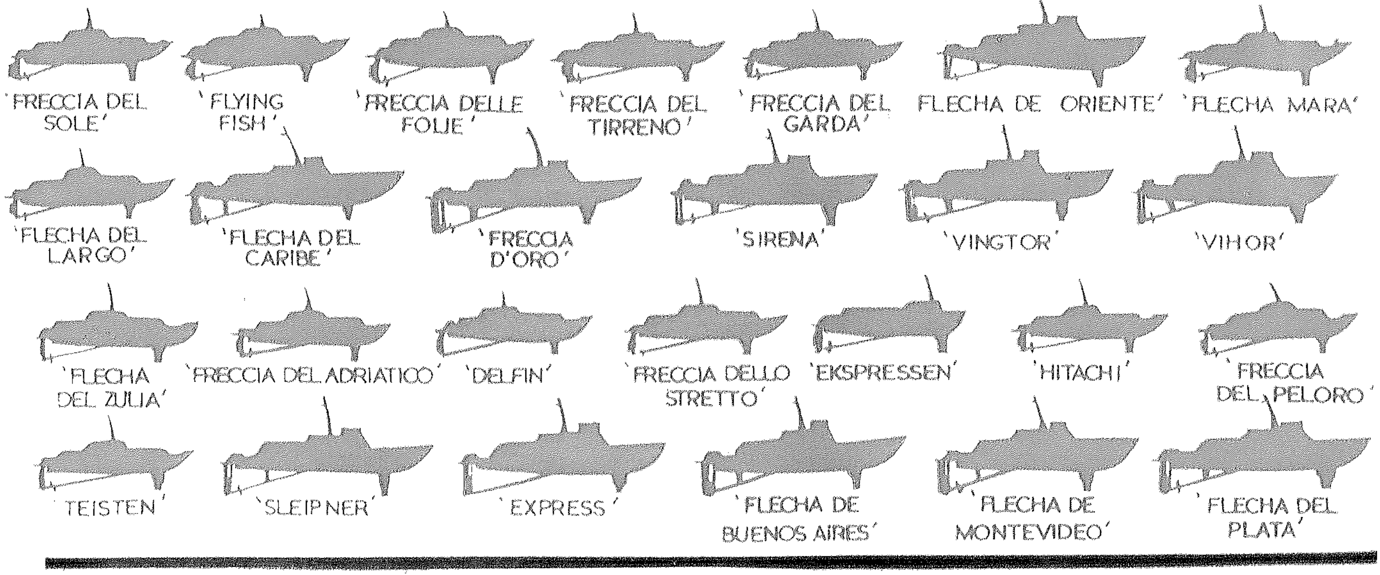
KALERGHI - McLEAVY PUBLICATIONS

Cantiere Navale RODRIQUEZ

MESSINA (Italy)



The greatest experience in the world in the construction of hydrofoil boats



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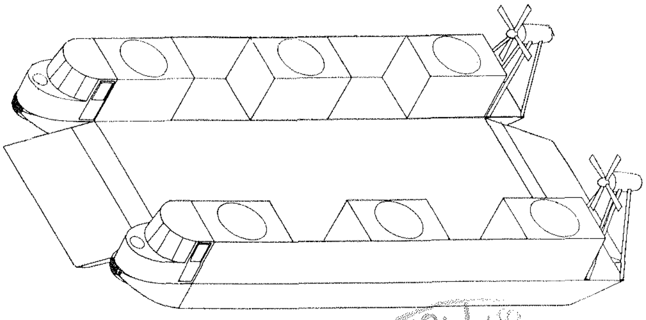
First Hovering Craft & Hydrofoil Monthly in the World



A typical GEM ship-to-shore lighter which could travel between 40 and 60 knots as envisioned by scientists at Booz, Allen Applied Research Inc. The lighter would be 70.5 ft long, 34 ft wide and hold 15 tons of cargo

"SHIPSHAPE AND WESTLAND FASHION"

As important a development as any in the realisation of the hovercraft's promise as "the most versatile vehicle of all" is the Westland flexible skirt.

For a given power this simple accessory increases the obstacle clearance capability by as much as ten times. This means the severe operating limitations of the smaller craft, due to their lack of hoverheight, no longer applies.

The Westland skirt is basically two flexible sheets of rubberised fabric and extends the jet formed by the solid structure. It brings several new terms to the field. One is skirt height—the distance of the hemline from the solid structure, and the other is daylight clearance—the distance from the hemline to the ground.

Skirts have now been developed that are 4 ft from the hemline to the solid structure. These have been proved by model tests and by full-scale tests on the SR.N1. Two foot banks, water jumps, four foot deep gullies, and virtually impenetrable thickets of saplings and gorse have all been cleared with ease and with practically no skirt abrasion.

In a recent air crash at night at Thorney Island, rescuers took nearly three hours to reach the scene of the accident and the crew were lost in the soft mud around the saltings. The SR.N1 simulated a rescue operation at the scene of the incident, about a mile from the airfield. It took only three minutes to reach the area of the crash and the craft was back at the control tower after a total elapsed time of seven minutes.

The development of the four foot skirt makes a small craft like the new SR.N5 suitable for a wide variety of duties, such as a rescue craft, firefighting vehicle, and a general purpose passenger and freight transport. Four foot skirts are by no means the practical limit of development. The 170 ton SR.N4 will have 8 ft skirts and will operate at 70 knots over 7 ft waves. This is a sea state that is only exceeded in the English Channel for approximately 5% of the year. The skirt will also allow the SR.N4 to pass over a 20 ft gulley and a sheer drop of 13 ft.

The skirts on a hovercraft are analagous to the pneumatic tyres on a car, and they have comparable durability. Without tyres a car would be a totally impracticable vehicle. Without skirts the hovercraft would have a very limited practical application.

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COVER PICTURE: *Prince Bernhard of the Netherlands leaving the Vickers VA-2 after its demonstration in Amsterdam Harbour on April 18th. A report appears on page 2*

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Joint Editors:

JUANITA KALERGHI ROY McLEAVY

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Mr. S. R. Hughes, Manager Hovercraft Division Vickers-Armstrongs, and Mr. S. P. Woodley, Assistant Managing Director of Vickers-Armstrongs (Engineers) Ltd., being shown the silver model of the VA-2 presented to Prince Bernhard of the Netherlands after his trip in the craft

People and Projects

On 18th April, the five-seater Vickers VA-2 Hovercraft was demonstrated before **Prince Bernhard of the Netherlands** and senior Dutch government officials at the new B.P. Harbour installation at Usselinckhxhaven, Amsterdam. Prince Bernhard, who took the controls for part of the demonstration, expressed his confidence in it as a new form of transport. He was presented with a silver model of the craft to mark the occasion.

On the previous day the VA-2 was demonstrated in Amsterdam Harbour during a Hovercraft Information Day, organised by British Petroleum's associated company in Holland. The Dutch Press was addressed by Mr. D. Hennessey, Chairman of Hovercraft Development Ltd. and Deputy Managing Director of the National Research Development Corporation, who spoke on the principles, application and future development of the hovercraft. Mr. L. R. Colquhoun, Operations Manager, Vickers-Armstrongs (Engineers) Ltd., answered questions.

* * *

Vickers-Armstrongs projects include the VA-3B Hovercraft which will utilize many of the components of the platform of VA-3 and will carry 75-94 passengers at speeds up to 70 knots (130 km/h). The VA-6, a further development, will travel at speeds of up to 80 knots (150 km/h) with a payload of thirteen tons (13,200 kg).

* * *

Hovercraft shares have been rising. Westland's have gone up to 18/- as against only 12/3 earlier in the year, and Vickers have risen to 31/6 from 26/10½ earlier in the year.

* * *

On 26th April a PT 20 left the yard of Leopoldo Rodriquez of Messina. It will arrive at Sandakan Borneo on 30th May and from there will go to Manila for delivery to Mr. Robert O. Phillip, President of the **Tourist and Travel Corporation of Manila.** The craft will be used for commuter service in Manila Bay.

* * *

Hitachi Zosen has delivered to the Kansai Kisen shipping company the first Supramar PT 50 to be built at Hitachi's Kanagawa shipyard. The craft, which is equipped with radar, is to be placed in service towards the end of April on the Seto inland sea route between the Osaka-Kobe district, Sakate and Takamutsu. Seats are provided for 140 passengers.

* * *

Fifteen different hydrofoil designs with seating capacities from 4 to 168 are either under development or in production in Japan at the present time. The craft are described in a booklet jointly published by the six main hydrofoil manufacturers—**Hitachi, Ishikawajima-Harima, Mitsubishi, Shin Mitsubishi, Shin Meiwa** and **Uraga.** Currently the three largest craft are Hitachi's licence-built Supramar PT 50 and PT 35, seating 140 and 100 passengers respectively, and Mitsubishi's MH-60, which seats 168. The two latter have still to be built.

In the 30-80 seat bracket are the PT 20 (76), the MH-30 (80), both of which are in full service, and the Ishikawajima-Harima IHF-8, with seats for 34. Retractable foils are fitted.

For 13-20 passengers Shin Meiwa offers the SF-30B (21); Mitsubishi, the MH-03 (also 21); Hitachi, the PT 3 (15); Ishikawajima, the IHF-3 (13); and Shin Meiwa, the SF-30 (14). The latter is in passenger service in the following areas: Takyo, Nagoya, Lake Buiu and Nagasaki.

A development, the SF-30A, is in service as a high-speed fire boat in Tokyo harbour and carries a crew of six.

Finally there are three 4-6 seat open-cockpit runabouts—Ishikawajima's IHI-16, Shin Mitsubishi's MHF-4, and Uraga's Sea Bird.

All the craft mentioned have surface piercing foils, and those on the IHF-8, the SF-30B and IHF-3 are retractable and auxiliary screws are fitted for operation in displacement condition with the stern foil raised. All the Shin Meiwa designs and the IHI-16 have twin sets of main foils in tandem.

* * *

A paper examining present-day hydrofoils with particular regard to their possibilities for connecting the United Kingdom with the Continent was read to the Academie de Marine in Antwerp on 4th April by **M. C. Pringiers,** Cie Maritime Belge.

The author presented a study of present traffic (ship and aircraft) and of the probable trend up to 1965. The increase via Ostend has been very great because from Antwerp by air it takes four hours to get to the centre of London, while by sea from Ostend it takes barely five hours and the cost is about half. Taking a conservative increase one can predict some 2,282,000 passengers per year by 1965. Assuming the travel time by hydrofoil from Ostend to London Bridge to be 2 hours 20 minutes (the same as from Middelkerke to Liverpool Street by plane and train) the author next asked what percentage of the travellers would be expected to adopt the new line. After considering American studies he takes only 15% of the boat and 10% of the air traffic to give 150,000 for the year.

He put forward a plan by which three boats, each seating 120 passengers, would handle the traffic. In August, the peak month, all three would be in service with departures every two hours. Summer and winter wave size observations made from the "Wandelaar" off Ostend and from the lightship "Smith's Knoll", led the author to conclude that struts of 4 m would be adequate for all foreseeable cases.

The plan calls for a craft of 55 tons, with incidence control, and powered by gas turbines. Crew would be four officers with two men and stewardesses. Three crew would be provided. Initial outlay required would be £1.4 million. We hope to publish at length from the paper in a future issue.

* * *

A consultant aerodynamicist, **Mr. K. G. Cross,** has evolved a new type of air cushion vehicle, designated ACV-4, which will have an operating cost of only 2½d. per passenger mile. The cushion is generated by three fans on each side of the craft, each with its own motor. The cargo space, or passenger cabin, lies inbetween them. The prototype is expected to be hovering by the end of 1964. It will be 88 ft long, 48 ft wide and 18 ft high. Propulsive power will come from two rear-mounted pusher propellers. It will fly at between 50-60 mph and is designed for use on sheltered stretches of water only.

* * *

Sweden's SAAB 401 Hovercraft is undergoing sea trials and we hope to report on these in an early issue.

* * *

Joseph L. Wosser, jnr., a pioneer in the field of ground effect machines (GEMs), has been appointed assistant manager of the Aerospace/Rockets Division of Textron's Bell Aerosystems Company.

He will be responsible for the direction of all ground effect machine and air cushion vehicle work within the division.

A veteran of twenty years in the U.S. Marine Corps, Wosser retired recently with the rank of lieutenant colonel.

Since September 1958, Wosser had served as head of the Air Vehicle Design Branch of the Office of Naval Research in Washington, D.C. In this post he was responsible for planning, coordinating, managing and providing technical supervision of a multi-million dollar contractor programme of research and exploratory development. These programmes included research in vertical/short takeoff and landing test vehicles and ground effect machines.

Joseph L. Wosser

Wosser authored some of the first technical papers on ground effect machines published in the United States, beginning in 1958 when GEMs were in their infancy.

A native of Mill Valley, California, Wosser became a Naval aviation cadet in 1943 after studying mechanical engineering at the University of California. During his twenty years as a marine pilot, Wosser accumulated 3,600 hours of flight time, including 350 combat hours.

He holds a master of science degree in aeronautical engineering from Massachusetts Institute of Technology and bachelor of science degrees in military science and aeronautical engineering, respectively, from the University of Maryland and the U.S. Navy Postgraduate School.

* * *

In the United States an 8 ft long 5 ft wide **Dobson Air Dart** is now being marketed for $595 assembled, or about $400 as a kit. Weighing 95 lb, the Dart can carry 300 lb at 30 mph over flat land or smooth water. Its 10 hp engine drives a fan which supports the vehicle on a column of air by the same principle as larger air cushion vehicles. It has a hoverheight of 9 ins.

* * *

A **Schottel Werft** propeller unit resembling a huge outboard motor has been attracting attention at the London International Engineering Exhibition. Rated up to 600 hp, it is being incorporated in the Denny hovercraft as a drive unit. Vickers and Westland have expressed interest, and Russian representatives are considering its suitability for hydrofoil application.

* * *

Olympia Enterprises Co. Ltd of Malta have recently formed a limited liability company to acquire and operate a PT 50 Hydrofoil. This will be in service between Malta and Syracuse with a daily return service. The trip to Malta will take only 2½ hours and the charge will be £4 return.

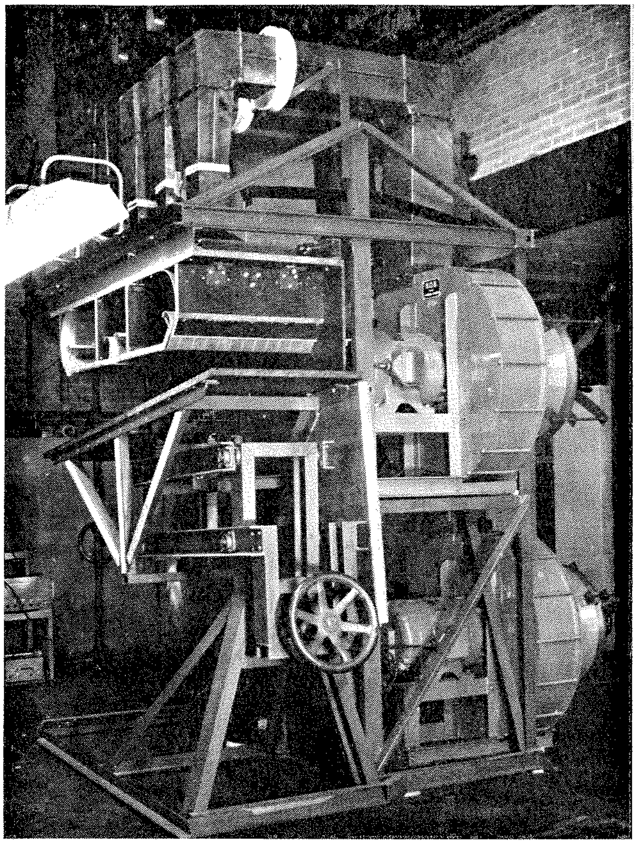


Figure 1. General View. The Rig

Hovercraft Stability Research at The University of Southampton

By A. J. Burgess*

* *Delivered to the Hovercraft Symposium, University of Southampton, March 23rd, 1963*

The Investigation

At the University of Southampton a study of two-dimensional static hovercraft stability is being carried out. We are looking for an understanding of the mechanisms of instability (for example, its dependence on cross flow or verticity) as well as trying to establish criteria for the strength of stability jets, the effects of cross flow and jet scale effect.

It will be rightly asked by some whether a further contribution in the static case is really required. Two-dimensional stability data is certainly in existence (both published and unpublished) but the available evidence, besides being fragmentary, does not correlate very well, and this would suggest that much of the work has not been of a sufficiently fundamental nature. This is not surprising, for industrial research must necessarily be directed to the more immediate needs of the subject, rather than to an exhaustive investigation.

The purpose of our work is, in fact, twofold. Firstly we wish to produce meaningful experimental results: secondly to propose a theory which adequately explains the observed phenomena.

In order to expand on these points, it is necessary to consider some of the principles on which our work is based.

(i) Meaningful Experimental Results

We have thought of the need for an experiment to be carefully controlled: that is we must know what is happening to the flows at any given condition. The tests must be representative of engineering and operational conditions, as well as being suitable for the development of a theory.

Having chosen to work in two-dimensions, we have made the model broad relative to its length in order to minimise side boundary effects. It is necessary to have uniformity of flow conditions across the model, and to achieve this we have included carefully designed entry nozzles, as well as plenum baffles and gauzes in the flow stream. We felt it was necessary to be able to control each jet independently, and have used separate blowers. A particular jet geometry has been chosen with a view to the study of scale effect and changes of convergence angle on the jet boundary layers. We are measuring overall forces on the model in addition to recording a comprehensive series of local pressure data.

As we were designing the model, it became very clear that little work had apparently been done on jet geometries. It was therefore necessary for us to choose a particular geometry without any experimental justification, and in the first instance we may have to publish our findings stating the conditions resulting from this "as built" state. Such conditions might include the presence of separation and the magnitude of the boundary layer on the inner or cushion side of the edge jets. With further work we hope to be in a position to suggest more suitable geometries for the jet, and to comment also on such things as ground and craft surface roughness.

(ii) The Theory

The need for a theory arises thus. It would be possible to vary every parameter in the experimental work, and then to reduce the data so that all dependent conditions were known, An engineer would like, say, at least five points for any given curve; but he is also inherently lazy in that he seeks to use his working time wisely and produce a result with the least personal effort (!) The combinations of hoverheight, jet thickness, jet angle, jet total head, etc. provide a permutation of fearful proportion if we are to consider experimental data reduction only. A theory is therefore developed which deals adequately with **a part** of the experimental work; then the parameters are varied (the digital computer now does most of our work); then any interesting, unexpected or unlikely events are confirmed with further experiment. This is the policy we are expecting to follow.

The Present State of the Project

What then is the present state of our work?

(a) **The Rig.** The rig is structurally complete, though we are still developing some of the systems.

We will see in Fig. 1 the position of the blowers, and the air delivery ducts which feed into the roof of the model. We can also see the principles of the moving ground, with balanced model, and the width of the model relative to its length. The wall of the side shown open is made of perspex to aid flow visualisation. Static pressure tappings have been placed on the model base longitudinal centre line, on the back

World's FIRST Order

for a Large Hovercraft

The Ministry of Aviation is placing an order for a Westland SR.N3. The craft which is scheduled to be delivered in early 1964, will be used to evaluate the Air Cushion Vehicle in various over-water and amphibious operational roles.

The SR.N3, which is powered by four Bristol Siddeley 'Gnome' H.1200 gas turbines, is a direct development of the 27-ton SR.N2 which has just completed an outstanding successful first year of trials. Components and systems fully proven in SR.N2, are retained in the new craft and all are now backed by considerable development and operational experience.

Like its predecessor, SR.N3 incorporates the Westland-patented 'skirt' giving outstanding over-wave and obstacle clearance capability. The hull, which is 10 ft 6 in longer than that of SR.N2, gives a load-carrying capacity of up to 150 passengers or 12 tons of freight, overall length is 77 ft, overall beam 30 ft 6 in and overall height 33 ft 9 in. Weight is 37¼ tons.

WESTLAND the first name in ACVs

WESTLAND AIRCRAFT LIMITED · YEOVIL · ENGLAND

Incorporating SAUNDERS-ROE DIVISION · FAIREY AVIATION DIVISION · BRISTOL HELICOPTER DIVISION

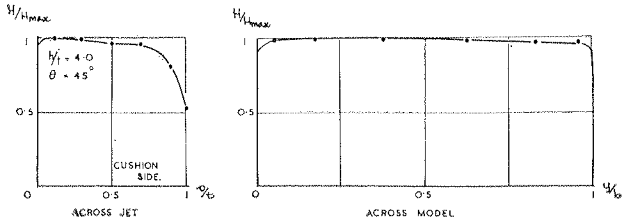
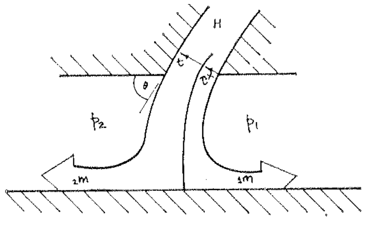


Figure 2. Total head distributions



τ^x MARKS THE STAGNATION STREAMLINE.

$$p_2 > p_1$$

$$x = \frac{t}{h}\left(1+\cos\theta\right)$$

$$\frac{p_2-p_0}{H-p_0} = 1-\left[1-\frac{p_1-p_0}{H-p_0}\right]\exp\left\{\frac{2t}{h}(1-\cos\theta)-\frac{4t}{h}\cdot\frac{\tau^x}{t}\right\}$$

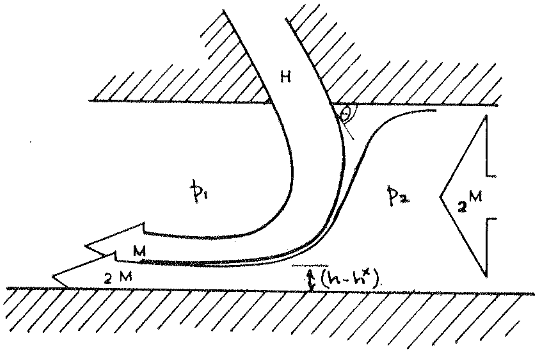
$$\frac{\tau^x}{t} = \frac{1}{2}(1-\cos\theta)-\frac{h}{t}\cdot\frac{1}{4}\ln\left\{\left[1-\frac{p_2-p_0}{H-p_0}\right]\Big/\left[1-\frac{p_1-p_0}{H-p_0}\right]\right\}$$

$$\frac{{}_1m}{h\sqrt{2\rho}\sqrt{(H-p_0)}} = \left[1-\frac{p_1-p_0}{H-p_0}\right]^{\frac{1}{2}}\frac{1}{1+\cos\theta}\left[1-\exp\left\{-x\frac{\tau^x}{t}\right\}\right]$$

$$\frac{{}_2m}{h\sqrt{2\rho}\sqrt{(H-p_0)}} = \left[1-\frac{p_1-p_0}{H-p_0}\right]^{\frac{1}{2}}\frac{1}{1-\cos\theta}\left[\exp\left\{\frac{t}{h}(1-\cos\theta)-\frac{2t}{h}\frac{\tau^x}{t}\right\}-\exp\left\{-x\frac{\tau^x}{t}\right\}\right]$$

$$\frac{L_j}{h(H-p_0)} = \left[1-\frac{p_1-p_0}{H-p_0}\right]\frac{\sin\theta}{1-\cos^2\theta}\left[(1-\cos\theta)+(1+\cos\theta)\exp\left\{\frac{2t}{h}(1-\cos\theta)-\frac{4t}{h}\frac{\tau^x}{t}\right\}-2\exp\left\{-2x\frac{\tau^x}{t}\right\}\right]$$

Figure 3. The overfed jet



CROSS FLOW ${}_2M$.

$$p_2 > p_1$$

DEFLECTED JET EQUIVALENT HOVERHEIGHT h^x.

$$x = \frac{t}{h}\left(1+\cos\theta\right)$$

$$\frac{p_2-p_0}{H-p_0} = 1-\left[1-\frac{p_1-p_0}{H-p_0}\right]\exp\left\{-2x\frac{h}{h^x}\right\}$$

$$\frac{h^x}{h} = 1-\left[1+\frac{2\rho h^2(H-p_0)}{{}_2m^2}\,\frac{(p_2-p_1)}{(H-p_0)}\right]^{-\frac{1}{2}}$$

$$\frac{m}{h\sqrt{2\rho}\sqrt{(H-p_0)}} = \left[1-\frac{p_1-p_0}{H-p_0}\right]^{\frac{1}{2}}\frac{1}{1+\cos\theta}\,\frac{h^x}{h}\left[1-\exp\left\{-x\frac{h}{h^x}\right\}\right]$$

$$\frac{L_j}{h(H-p_0)} = \left[1-\frac{p_1-p_0}{H-p_0}\right]\frac{\sin\theta}{1+\cos\theta}\,\frac{h^x}{h}\left[1-\exp\left\{-2x\frac{h}{h^x}\right\}\right]$$

Figure 4. The underfed jet

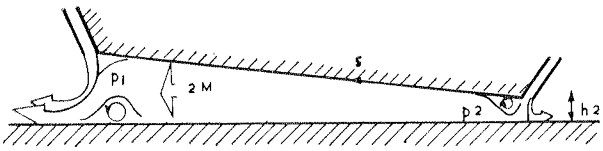
side-wall to record pressures through the jets, on significant parts of the jet boundaries to give an indication of boundary layer growth, and on the ground longitudinal centre line. Total head measurement in the jets is carried out with the use of rakes or single tubes as appropriate. Fig. 2 shows us typical distributions obtained across the jet and across the model. The presence of a large boundary layer will be seen on the cushion side of the jet, marked by the fall in total head. The distribution across the model will be seen to be satisfactory.

(b) **The Theory.** Any stability theory must itself be dependent on a performance theory, and upon one that accounts for the split or overfed as well as the deflected jet. It is probably considered that Strand's approach to the problem is the most thorough, but this theory is too unwieldy for stability work. The requirement is not primarily for an exact theory but for one that is simple enough for the ensuing work to be easily handled, whilst giving good experimental agreement. Such a theory is provided by the integration of the simple momentum element across the jet thickness, which has been attributed to Stanton-Jones. It also gives good agreement with experimental results (by suitable definition of cushion pressure) and has the mathematical convenience of yielding

$$Pc\big/_{Hj} \rightarrow 1{\cdot}0 \text{ as } h\big/_{\tau} \rightarrow 0$$

Its validity at low $h\big/_{t}$ can be improved by suitable detail correction, but these improvements are of small magnitude and may not be considered worthwhile.

The theory has been extended for the "split" or overfed jet case, as we see on the next figure (Fig. 3). Note the definition of the stagnation streamline station τ^x, and that when $t^x\big/_{\tau} = 1{\cdot}0$ the equations reduce to their more familiar form.



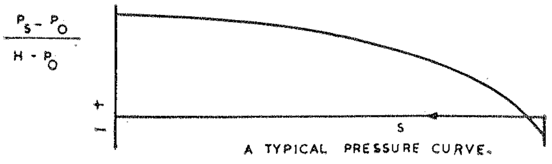
CROSS FLOW ${}_2m$ FULLY DIFFUSED.

$$P_2 < P_1$$

LOCAL HEIGHT h_s.

OVER THE REGION OF DIFFUSED FLOW.

$$\frac{p_s-p_0}{H-p_0} = \frac{p_2-p_0}{H-p_0}+\frac{{}_2m^2}{2\rho h_2^2(H-p_0)}\left[1-\left(\frac{h_2}{h_s}\right)^2\right]$$



A TYPICAL PRESSURE CURVE.

Figure 5. Diffused Cross Flow

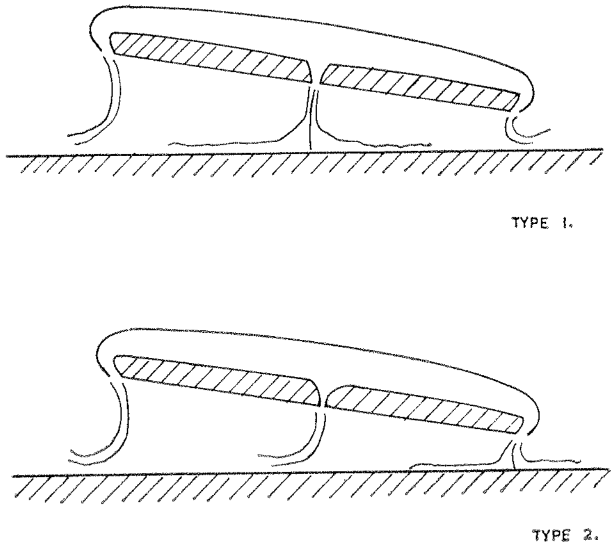


Figure 6. Three-jet Stability — Flow Types

It is also necessary to examine the "underfed" jet, i.e. that having a cross-flow passing underneath it. As will be seen from the next figure (Fig. 4) we have defined a modified hoverheight h_x, the jet then being considered as fully deflected away from the high pressure side. A uniform distribution of the mass flow $_2m$ in a sense normal to the ground has been assumed at all stations.

We must still account for the cross-flow within the cushion. The craft is generally least stable where the flow is fully diffused and suffers no loss of total head, and with these assumptions, the base pressure follows a parabolic law as shown in Fig. 5.

With a combination of these three concepts, and neglecting certain interpretive difficulties at the regions immediately adjacent to the jets, we may form sets of implicit equations which will yield the required unknowns by suitable iterative solution. Two types of flow can exist, depending on the relative strengths of the jets, as is shown in Fig. 6. It will be noticed that the difference arises from the splitting of centre or edge jets respectively. For any given combination of jet conditions, there will be a range of trim angles which allows the type 1 flow. Outside this range the type 2 flow will obtain. A typical stability curve will have a point of discontinuous slope as shown in Fig. 7.

The theory is currently being programmed for solution on our Pegasus digital computer.

So much for the immediate theory. I would like to mention in passing a feature of the work arising from the ability to vary the relative jet total heads. Fig. 8 shows us two pressure distributions for a craft at some angle of trim. That with a solid line is the distribution obtained with equal jet total heads, whereas that with the dashed line is the distribution with reduced total head on the downgoing side, increased total head on the upgoing side. It will be seen that in this latter condition, the moment resulting from the cushion will be near zero. Neglecting the contribution to moment of the jet lift, and considering the equilibrium condition for the edge jets, we obtain the conditions for neutral stability. These are shown in Fig. 9 for a typical operating point. The lines of neutral stability will be seen expressed with jet head or thickness ratios. In the unshaded area operation is unstable: tests suggest that operation is stable immediately adjacent to the line in the shaded region.

We thus see the possibility of a simple autostabilised jet system, where stability is gained with negligible increase of lift horse power.

Possible Future Work

This, therefore, has described some aspects of the work that we are doing toward the understanding of hovercraft stability phenomena. It represents only a beginning to the overall problem, and we are hoping to extend our work into the dynamic two-dimensional and static three-dimensional fields, as well as to continue the current series of investigations.

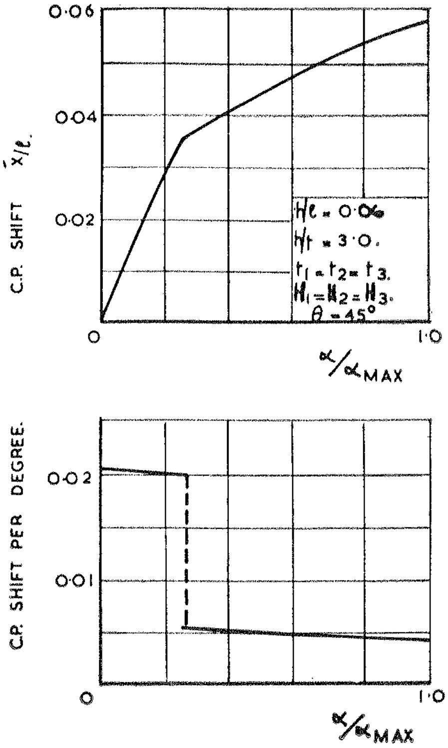


Figure 7. Three-Jet Stability — C.P. Shift Curves

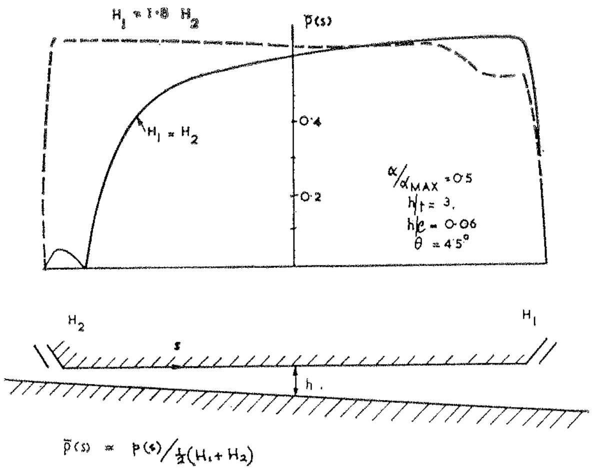
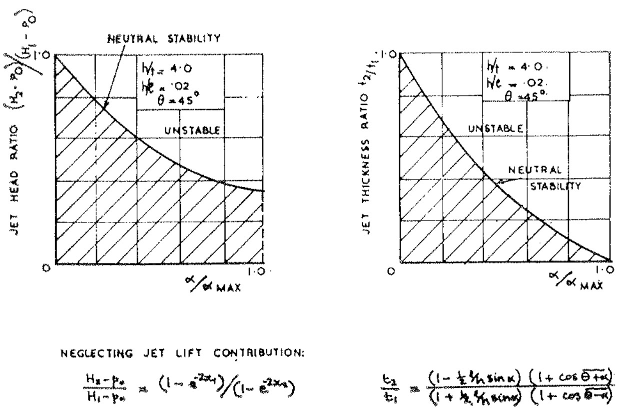
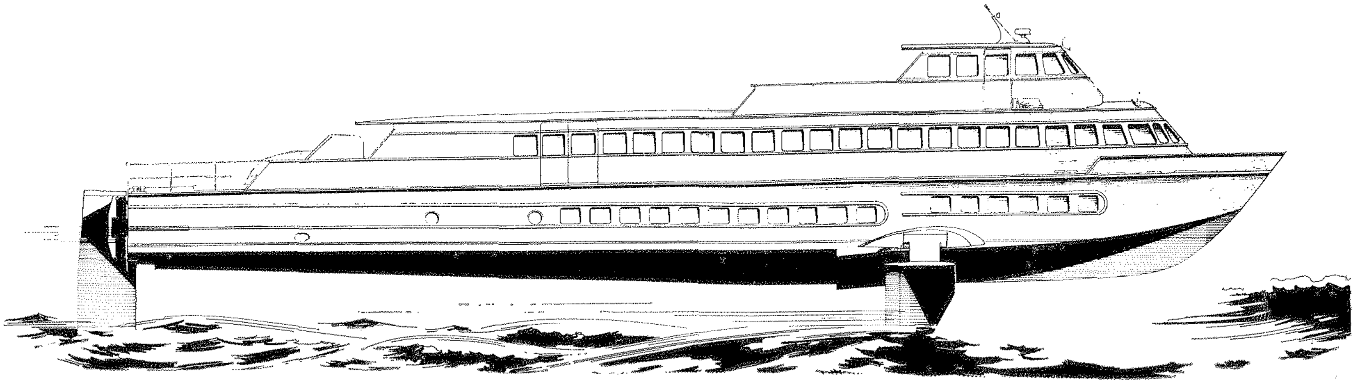


Figure 8. Two-Jet Neutral Stability



$$\frac{H_2 - p_0}{H_1 - p_0} = \left(1 - e^{-2x_1}\right)\Big/\left(1 - e^{-2x_2}\right) \qquad \frac{t_2}{t_1} = \frac{\left(1 - \frac{1}{2}\ell/h \sin\alpha\right)\left(1 + \cos\overline{\theta + \alpha}\right)}{\left(1 + \frac{1}{2}\ell/h \sin\alpha\right)\left(1 + \cos\overline{\theta - \alpha}\right)}$$

Figure 9. Two-Jet Conditions for Neutral Stability



SUPRAMAR'S 300 PASSENGER HYDROFOIL

Preliminary Details of the Gas-Turbine Powered PT 150

SUPRAMAR'S PT 150, a further development of the PT 90, has been designed for service over greater distances of open sea. Features of note are the power arrangements and the distribution of the passenger compartments.

Foils

To facilitate calls at smaller ports or the crossing of shallows and in order to facilitate clocking and slipping the craft, the foils as well as the rudders and propellers are retractable. To protect these against marine growth and corrosion they will be made from stainless steel. The front foils will be provided with hydraulically operated flaps which accelerate the process of emerging the craft and improve its behaviour in a seaway. They will be controlled electronically.

Hull

The hull will be built of anti-corrosive light metal which to a large extent will be welded. Plastics would be used for interior construction parts and equipment.

Engines and Transmission

Power is provided by two 8,700 hp Bristol-Siddeley Proteus. Tanks for either 250 or 450 nautical miles will be provided according to customer's requirements. A two-drive will be used. This not only ensures a favourable arrangement of the passenger compartments, which are kept free of noise and vibrations, but it also provides a relatively simple method of retraction for the rear foil, rudders and propellers.

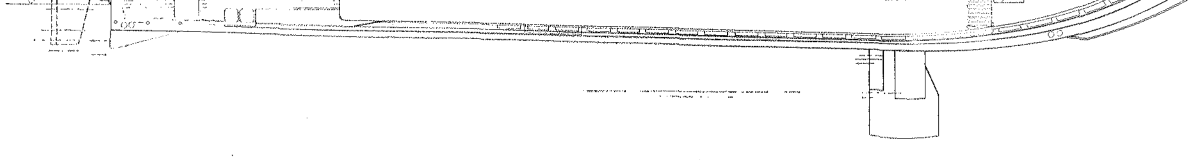
For manoeuvring in displacement condition an independent 200 hp gas-turbine, with it own propeller, will be provided.

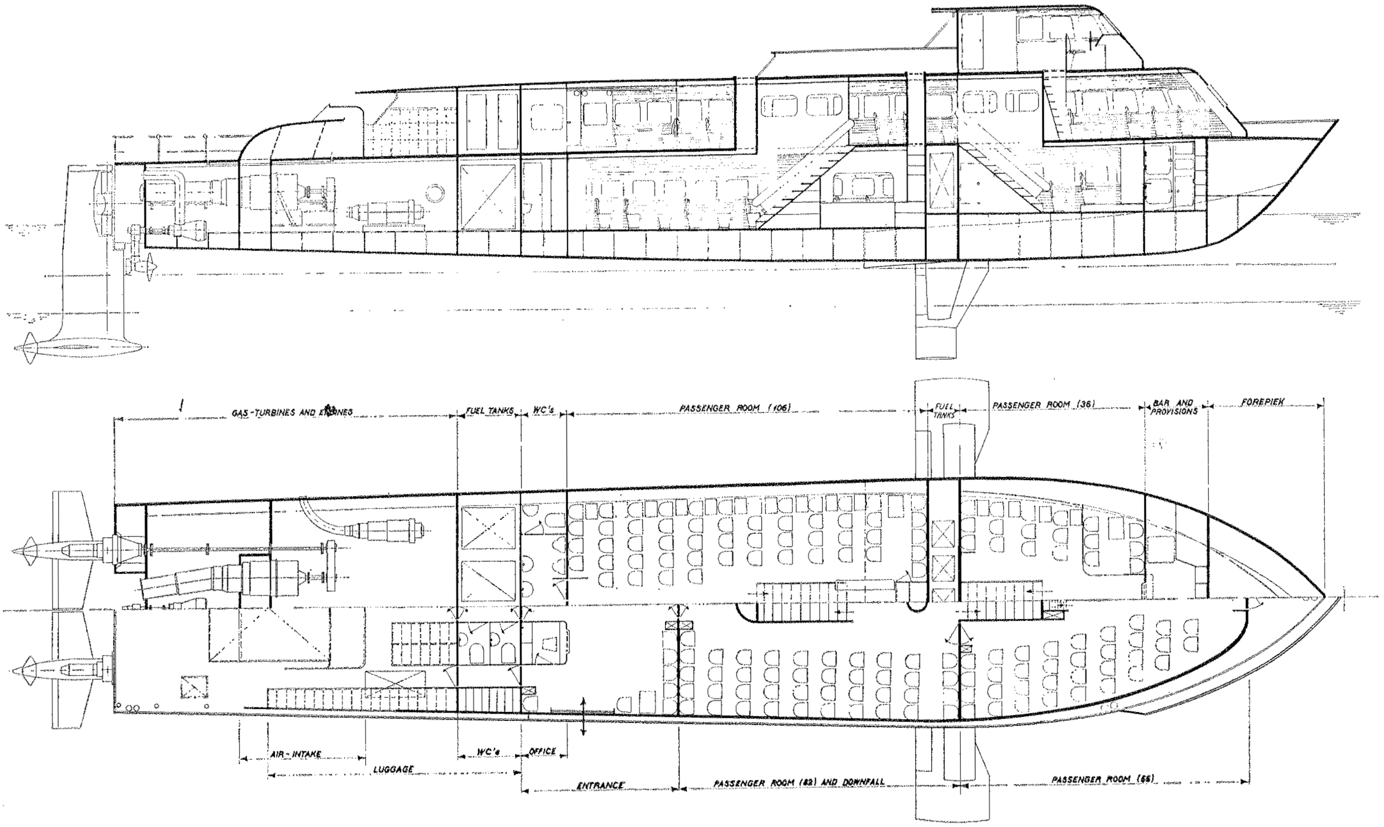
Sub-division of Compartments

Assuming that distances of about 150-250 nautical miles (3-5 hours) will be regularly covered by this type of craft, a high degree of comfort and freedom of movement on board will be offered to the passengers. To permit them to change their positions during the journey, thirty seats additional to the 300 will be arranged in lounges, and in suitable places on the open deck also.

Technical data

Length, 139 ft; Beam over deck, 26 ft 3 ins; Span of hydrofoils, 47 ft 3 ins; Draught floating, 15 ft; Draught floating with foils retracted, 6 ft 3 ins; Draught foilborne, 5 ft 9 ins; Maximum speed at 8,700 hp, gas-turbines, 48 knots; Cruising speed with gas-turbines, 45 knots; Displacement fully loaded, 150 tons; Number of passengers, about 300.





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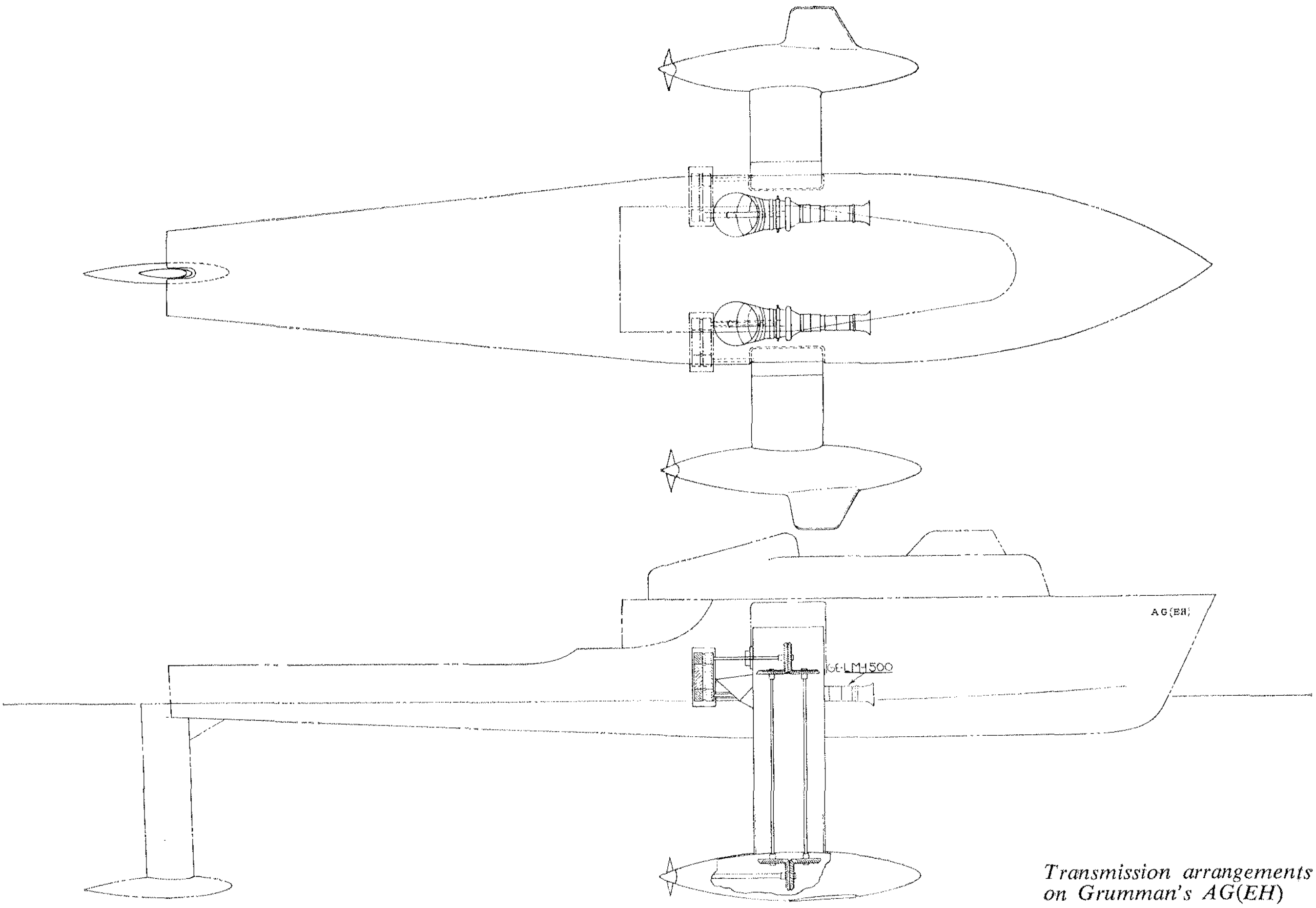


Transmission arrangements on Grumman's AG(EH)

The Future of the Hydrofoil

by Curt Borgenstam, Captain (E), Royal Swedish Navy

ALTHOUGH basically the idea of the hydrofoil is an old one it is still regarded as something of an inventor's daydream and shipbuilder's nightmare. Even the more conventional planing craft, which made use of the dynamic pressure under an inclined bottom as a means of making relatively high speeds feasible, was looked upon as an exclusive toy, hardly worth serious mention in shipbuilding circles. The fast naval motor torpedo boats of the last war were, technically speaking, the fruits of the knowledge and enthusiasm of specialists in racing boat and aero-engine techniques, rather than of theoretical shipbuilding. This attitude was also applied to the hydrofoil which seemingly was of a still more obscure nature. Few realised the virtue of utilising the suction on the back side of a submerged hydrofoil section and the potential ability of the hydrofoil to reach an appreciably better drag/lift ratio than the ordinary planing craft.

This scepticism was often confirmed by the difficulties of the few daring experimenters to fulfil their theoretical predictions. There were several good reasons for this often repeated discrepancy between theoretical and practical performance:

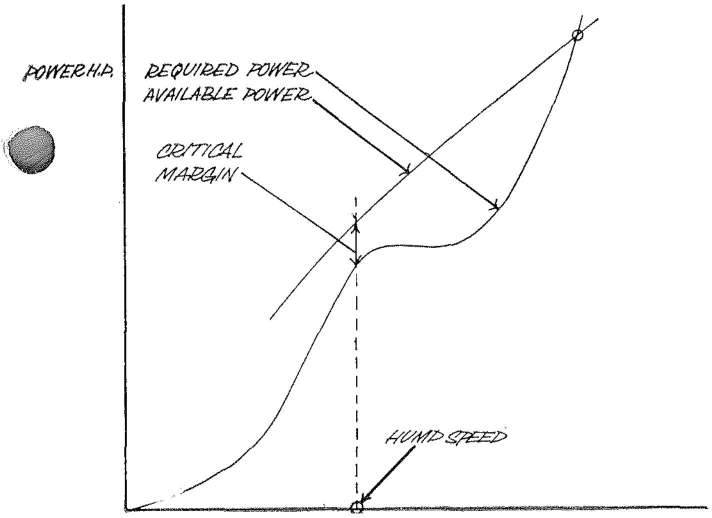
Firstly the use of suction to support a ship is in itself a potential risk of cavitation which in turn can result in loss of drag/lift ratio, erosion and unstable flow conditions. The suction is also an invitation for air to be drawn down from the free surface, which can also be detrimental to performance.

Secondly it is in the nature of the hydrofoil that the resistance curve is favourable only above a certain speed when the hull has become fully foilborne. Below this speed the curve has got a "hump" which is usually still more pronounced than that of a planing craft. Many a hydrofoil inventor has been so influenced by wishful thinking that the hump problems were overlooked. With piston type engines and fixed pitch propellers there is an acute risk that the two curves of available and required power plotted over speed come dangerously close to each other in the region of the hump. In unlucky cases the result is not just a loss of a few knots top speed but complete failure to lift the hull clear of the water. Even if the hump is overcome, the form of the power curve is far from ideal for a piston engine as it can result in risk of overrevving at high speed and of overloading at intermediate speed. The situation was not facilitated by the fact that the hydrofoil inventor was usually much less interested in engine characteristics, than in hydrodynamics.

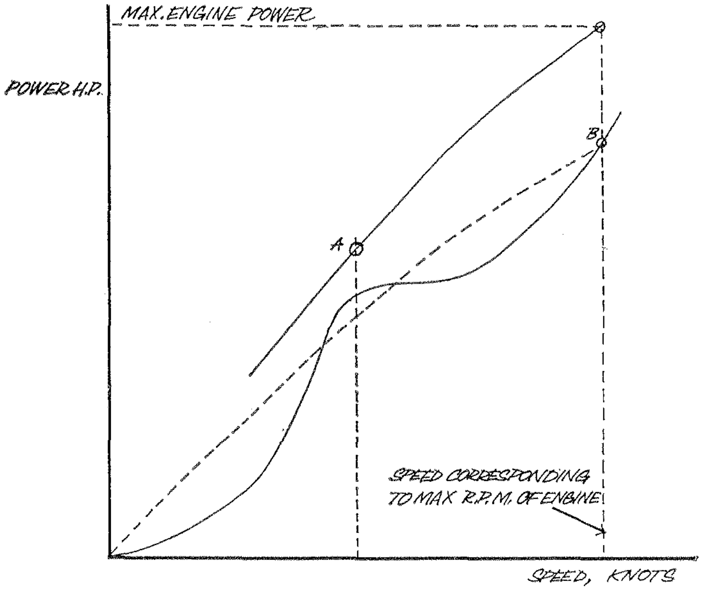
The power transmission from the engine in the hull to the propeller in the water could in itself present a very difficult problem. The solution could be a compromise between a long vibration-inviting shaft and a steep inclination of engine and propeller. An alternative was the inboard-outboard-drive with double conical gears and vertical driveshaft, a solution which is inherently expensive and complicated and means extra power losses in the gears.

These and other difficulties made life a hard-fought battle for the hydrofoil inventors and enthusiasts, most of whom gave up because of lack of financial or technical resources to overcome the practical problems. The hydrofoil continued to attract and fascinate the few shipbuilders who for one reason or another had to seek means to achieve really high speeds on the water. But the hydrofoil as a commercial proposition remained an unsolved problem.

It is only in the last decade that we have seen a turn of the tide, notably in two fields of application, namely the fast passenger service in the straits of Messina and along the Italian coast on one side, and the Soviet river traffic on the other. In both cases the development can be said to emanate from one and the same person, namely Baron Hans von Schertel who started his experiments in Germany in the early thirties, met the same difficulties as related above, but was too convinced of the commercial future of the hydrofoil



Curves of required and available power. Piston engine and fixed pitch propeller



Extreme case of disagreement between available and required power curves. The engine must be throttled back at top speed to avoid overrevving. The two major points of utilization of the engine are (A) = medium rpm, heavy load; (B) = max rpm, light load, neither of which is attractive for a piston engine. Solutions (1) Reduction of hump resistance or (2) Use of gas turbine with fuller power curve or (3) Use of variable pitch propeller

to give up his idea. The work he and his team did in the Sachsenberg Company before and during the war was taken over by the Soviets after the war together with several complete and half-ready experimental boats. Baron von Schertel and a few members of his old staff founded the well-known company Supramar in Switzerland and continued their work. They were lucky to place their first passenger craft, the PT 10, on a very favourable route, namely on Lago Maggiore. The competition from slow steamers and from very winding roads and railroads was not very strong. They could enjoy a tourist season which lasted almost the whole year round and last but not least, the route went between two countries, Switzerland and Italy, with all that this brought in extra passenger traffic.

Still it seems doubtful if this would have led to a wider application had it not been for the boldness of the Rodriquez yard in Italy who believed in the Supramar hydrofoil for fast passenger transport between Italy and Sicily.

It would be unfair in this connection not to mention the way in which Daimler-Benz AG came to contribute to the development. Like all high speed craft the hydrofoil requires a reasonably low specific engine weight, and for commercial use the engine must necessarily be a diesel or possibly a gas turbine. Such engines of about 1,000-1,300 hp were developed in competition by Daimler-Benz and Maybach and M.A.N. The railway market was ultimately mainly dominated by Maybach whereas Daimler-Benz also went to sea with their engine, the famous MB 820 and its derivates, which were "marinized".

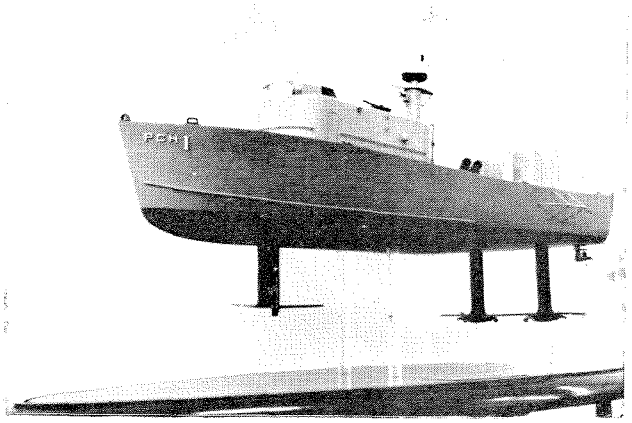
The first of the Supramar passenger craft, the PT 10, was fitted with a war-built Daimler-Benz engine of the type MB 507, developed for "LS-Boote" (Leichte Schnellboote) as a diesel version of the aero engine 605. The first positive contact with the company came when the need of spares was filled by stripping one of the few surviving engine specimens in the Stuttgart museum! This led to the introduction of the MB 820 as a standard engine for the Supramar projects, a purpose which it has since filled very well. It is light and has a comparatively simple and sraightforward layout facilitating service and overhaul. On the European market there exists probably only one lighter and more compact engine, the new Italian CRM 18 D with 1,000 hp and an all up weight of 4,000 lbs. complete with reverse gear.

The two Supramar types PT 20 and PT 50 with one and two MB 820 engines have been built and sold by Rodriquez in quite large numbers and licence agreements have also been signed between Supramar and several foreign undertakings. Both these types have fixed, surface piercing hydrofoils and have about 40 knots top speed.

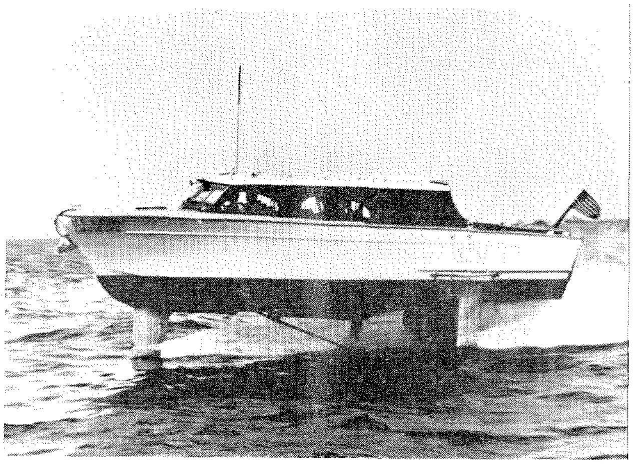
For fast passenger traffic in congested and inhabited archipelagos the very low wave-making of the hydrofoil offers a valuable advantage. Experience from the traffic between Stockholm and Mariehamn on Aland with a Supramar PT 50 proves that it is well possible to maintain a cruising speed of 30-35 knots even in tight traffic through the archipelago without risk of damage on shores, boats, quays, etc.

The limitation of the surface piercing hydrofoil lies in its seakeeping properties. It is true that the hydrofoil has a much softer ride against the wind and sea than most planing craft. Also the pitching motions are much less violent. In other directions of the sea the behaviour can however be rather problematic. Following sea is usually the worst case for all craft, but the surface piercing hydrofoil is affected in a special way, namely through the change of angle of incidence caused by the orbital movement of the surface water. The effect of this is that the lift can be lost occasionally and irregularly so that the forebody will tend to dig into the sea and become displacement borne instead of foilborne.

With the sea on the beam the transverse movements can



Boeing PC(H) High Point



Gibbs and Cox Sea Legs

become rather jerky. Even if the angular amplitudes of roll are less or the same as with an ordinary planing craft, the angular speed and acceleration can be much higher because of the comparatively long lever arm between the low centre of roll and the passenger compartment.

Generally speaking a surface piercing hydrofoil is rather influenced by the movements of the water surface, in principle in almost the same way as a displacement craft. For instance, the necessary margin of transverse stability at speed dictates that the foil must have such a configuration and area distribution that it will in practice become rather "stiff" and will tend to be influenced by the inclinations of the waves, just like a too beamy and shallow displacement craft.

Seakeeping is always a matter of much controversy. There are few facts and figures available, and the properties are also difficult to express in clear figures. There have also been very few opportunities to make correct comparisons between hydrofoil and conventional craft of roughly the same size and speed in the same adverse sea condition. The above opinions are however based on systematic full size tests with hydrofoil and planing craft both of about 40-50 tons and 35-45 knots. The two types of craft were run simultaneously in hard weather and wave heights up to four feet.

For off shore purpose the submerged hydrofoil would seem to be the logical solution. This will in principle be much less influenced by the irregularities of the waves. Of course the orbital movements have an influence, but this fades out appreciably with increasing depth. (This in fact applies especially to the vertical movements. It can be shown theoretically that the circular form of the surface particle paths takes the form of horizontally flattened elliptics with increasing depth.)

The residual impulses can be efficiently counteracted with the aid of actuated foils or horizontal rudders.

The basic problem of the submerged foil is in fact not so much the design of the foil itself but the control system. It is interesting to note that the often criticised "Hydrofin" type of Christopher Hook has submerged foils actuated by forward pointing "feelers" which follow the wave contours ahead of the craft. The drawback is the vulnerability and fragility of the mechanical part of the system, which does not lend itself to development to larger sizes.

The German inventor Wendel has been testing craft with hand-actuated submerged foils, but this is hardly acceptable for larger sizes. The natural solution seems to be an autopilot of electronic type. The first operational large craft with this system will be the Boeing PC(H) High Point. There is a good chance that this will represent something of a break-through for the ocean-going hydrofoil, provided that the single forward strut arrangement does not give rise to dangerous transverse forces during a turn in a seaway.

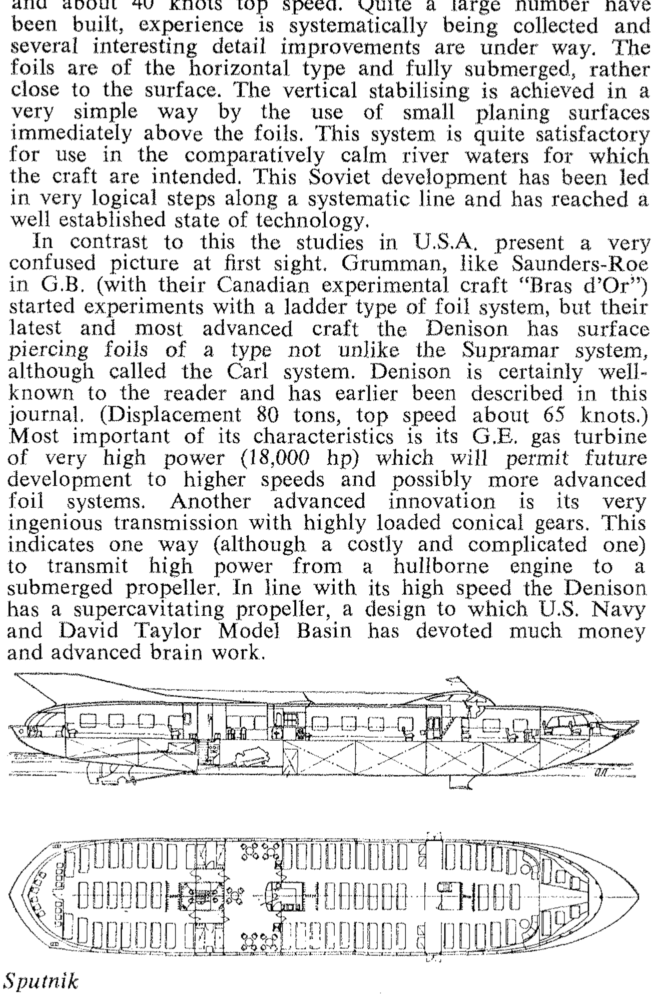
Other ways of control have been tried, for instance, based on hydraulic height sensing, without the aid of electronics.

The objection against the electronic autopilot system is its high price and complexity and the danger that the craft will become uncontrollable in case of failure of a component. However, similar control systems will become more and more commonplace in many other modern technical applications. A high reliability is also very often required, for instance, in space flight and nuclear power technique. It is thus probable that a great many of the components of such a system will very soon become available at low price "from the shelf".

Space and weight will also be drastically cut by the modern electronic technique with printed circuits and transistors. The vital units can thus be duplicated for safety reasons, without too much weight and space increase. Also the shock resistance and ruggedness will profit from the same development. The system will also have the advantage that the characteristics of the craft can easily and quickly be changed by simply varying the electronic response delay and dampening factors of the apparatus.

The modern development of the Soviet river fleet has technically followed a different path. Three basic hydrofoil boat types have been developed, the Raketa, Meteor and Sputnik with one, two and four 1,200 hp light diesel engines, and about 40 knots top speed. Quite a large number have been built, experience is systematically being collected and several interesting detail improvements are under way. The foils are of the horizontal type and fully submerged, rather close to the surface. The vertical stabilising is achieved in a very simple way by the use of small planing surfaces immediately above the foils. This system is quite satisfactory for use in the comparatively calm river waters for which the craft are intended. This Soviet development has been led in very logical steps along a systematic line and has reached a well established state of technology.

In contrast to this the studies in U.S.A. present a very confused picture at first sight. Grumman, like Saunders-Roe in G.B. (with their Canadian experimental craft "Bras d'Or") started experiments with a ladder type of foil system, but their latest and most advanced craft the Denison has surface piercing foils of a type not unlike the Supramar system, although called the Carl system. Denison is certainly well-known to the reader and has earlier been described in this journal. (Displacement 80 tons, top speed about 65 knots.) Most important of its characteristics is its G.E. gas turbine of very high power (18,000 hp) which will permit future development to higher speeds and possibly more advanced foil systems. Another advanced innovation is its very ingenious transmission with highly loaded conical gears. This indicates one way (although a costly and complicated one) to transmit high power from a hullborne engine to a submerged propeller. In line with its high speed the Denison has a supercavitating propeller, a design to which U.S. Navy and David Taylor Model Basin has devoted much money and advanced brain work.



Sputnik

The 110 ton Boeing PC(H) will be supported by three fully submerged foils and stabilised by an autopilot system working with signals from gyros and accelerometers which are transmitted via hydraulic power to flaps on the foils. The two 3,100 hp gas turbines will give a top speed of over 40 knots. The craft is largely based on the positive experience from the smaller experimental craft Sea Legs built by Gibbs & Cox and stabilised in a similar manner.

A 300 ton Grumman project, the AG(EH) is under way, also based on three submerged foils but arranged two forward, one aft, contrary to PC(H). This new project will, like the Denison, have sufficient installed power to be capable of exploiting the properties of hydrofoils at very high speeds.

After this summary of today's state of the art we can ask: Where is the hydrofoil going? Will it have a future, and if so, for what applications?

For pure river traffic or otherwise in sheltered waters the Soviet system with horizontal foils stabilised by surface touching planes has great attractions. It is simple and has a very low draught. The experiences seem to be positive, partly thanks to a good hull design and the availability of a good light-weight engine. Similar craft should have a market also, for instance, on the German and French rivers and on the Bodensee.

Although a great deal of well written articles about the Soviet river craft have been published, it is difficult to get a clear view of their profitability. This is, of course, natural in a government-owned undertaking. Expenses and incomes are only small parts of a much larger budget system, where everything is financed by the taxpaper. It must, however, be admitted that there is a tendency for traffic undertakings also in democratic countries to be more and more state subsidised. The need for a novelty to prove its value in economic competition will thereby be gradually reduced, and it will be increasingly difficult to differ between good and evil in the technical world of new products.

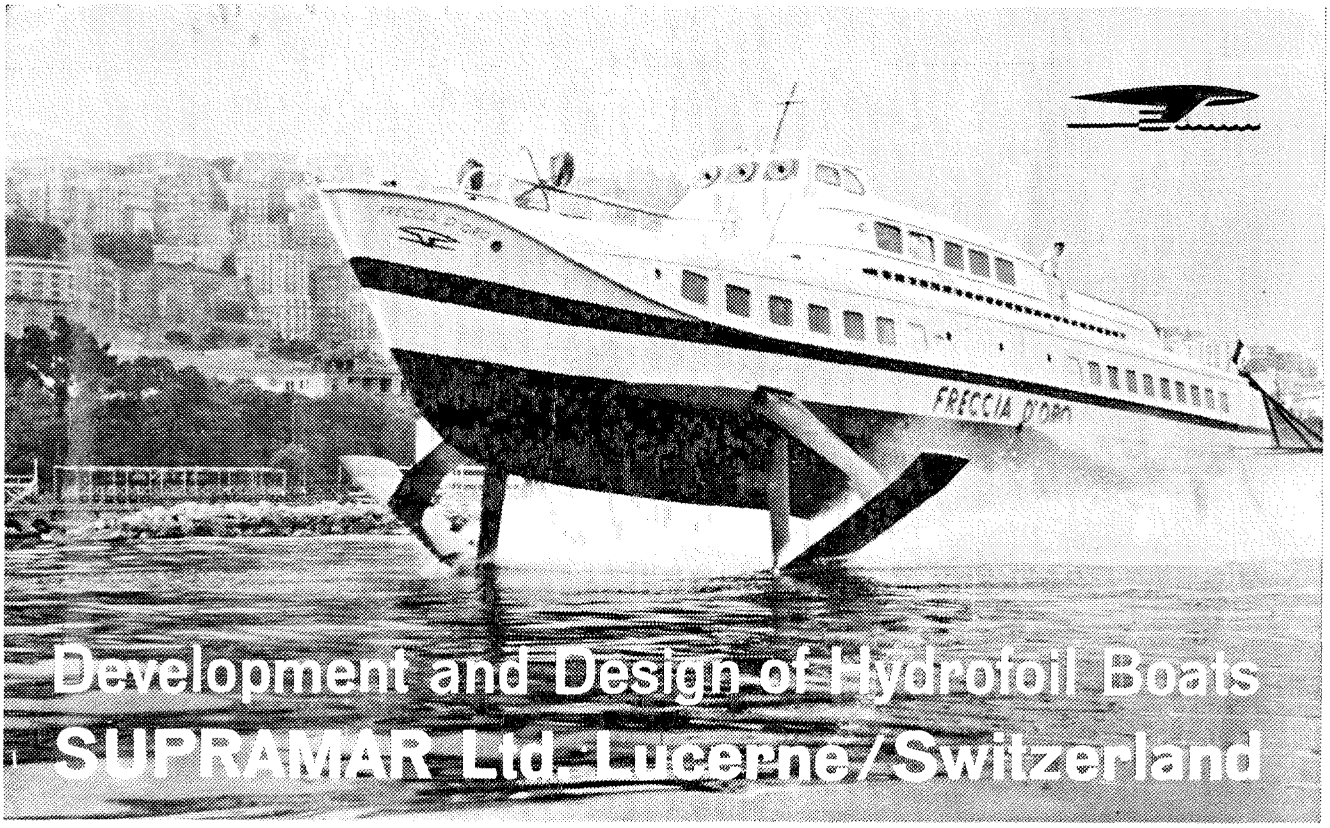
A valuable amount of running experience has by now been collected from the Supramar-Rodriquez PT 20 and PT 50 types. These and similar craft with fixed, surface piercing foils of rather simple design will have a commercial justification in certain restricted areas and under certain conditions. Broadly speaking these conditions would seem to be:

(1) Fairly sheltered waters with such weather conditions that the wave height during the operational season seldom exceeds about 4 feet.

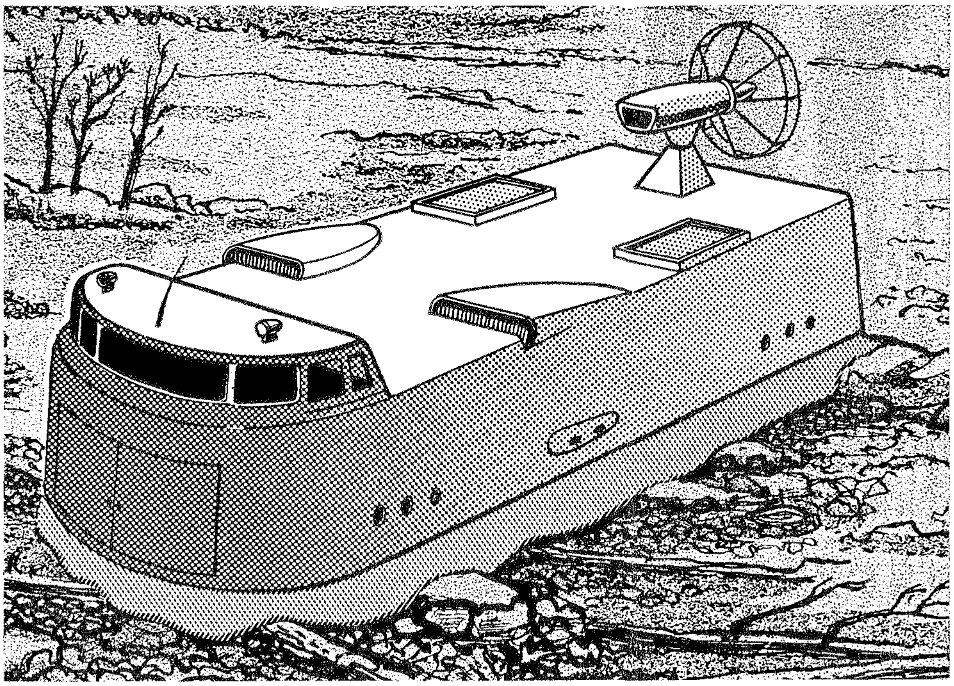
(2) A rather high rate of passengers who are in a hurry and who are willing to pay for the time saved compared to the use of displacement craft.

(3) A medium length of journey, sufficiently long to let the speed gain over conventional water craft play its part, but sufficiently short to make air transport unprofitable due to overwhelming terminal problems.

Foils must, of course, be made retractable, and the power transmission must be based on z-drives. Such a craft will obviously be very complicated but will certainly have a high performance potential. Apart from the ground effect machine this seems to be the only way to reach speeds higher than about 50 knots for operational seagoing military craft. With the introduction of the fast atomic submarine there is sufficient need for high-speed anti-submarine craft to justify the development of submerged foils of advanced design. Whether the civil market will have need of large ocean-going hydrofoils is difficult to predict. Much depends on the rate of growth of the tourist traffic to still unexploited areas and of future competition from ground effect machines and VTOL airplanes. To sum up there seems to be a future for the hydrofoil in certain specific fields of application. The development and building costs are high, however, compared to conventional craft. For this reason it is essential to avoid technical pitfalls and to concentrate resources on such lines of development which can be expected to be profitable in the future. There are many interesting detail problems to be solved in connection with the hydrofoil, which will offer an extremely fascinating field for the engineer and shipbuilder with a mind for high speeds and unconventional designs.



W. J. Eggington,
Assistant Chief
Designer Vickers-
Armstrongs
(Aircraft) Ltd.*



Slide 1

OVERLAND APPLICATIONS

Introduction

COCKERELL'S concept of sustaining an air cushion beneath a vehicle was to provide a combination of speed and proximity to the sea which had not been achieved by man before. Substantial progress has been made in developing the marine ACV over the last four years.

The air cushion can support a vehicle over land as well as over water, however, and some consideration has been given to ACVs that spend all or most of their life over land. I propose to consider one or two possible uses for ACVs over land, some vehicle configurations that can meet the requirements, and some problems that might be encountered. It should be pointed out, however, that overland ACV development is very much behind overwater work; hence what is fact for marine craft is merely anticipation for overland vehicles in many cases.

One application of the air cushion to overland transport that I do not propose to discuss is the hovercar. This project could well have a tremendous future, but has little in common with other overland ACVs.

General Considerations

In marine applications two basic properties of the air cushion are exploited, viz.:

(i) The complete or part isolation of the vehicle from the surface.

(ii) A low surface bearing pressure.

The first property means almost the complete removal of hydrodynamic skin friction; the second property gives considerable reductions both in wave making drag and accelerations experienced by the craft and its occupants compared with conventional marine craft.

In overland applications the ACV uses the low surface bearing pressure property of the air cushion, which enables it to negotiate soft ground.

For overland routes along which regular traffic in sufficient numbers is required, the surface is suitably prepared and hardened — railway tracks and metalled roads for example. Vehicles operating on these prepared surfaces are reasonably efficient and fast. Construction and maintenance of these surfaces is expensive, however, and only justified if regular traffic is envisaged. For more casual overland operation it is considered that the air cushion can make a contribution. I think it fair to say that overland ACVs will tend to tackle jobs that cannot be successfully carried out by other vehicles, without elaborate treatment of the terrain, whereas overwater ACVs might well be in direct competition with other vehicles.

Continuous Soft-Ground Operation

The first application I would like to consider is the transport of personnel and equipment over unprepared terrain, including very soft ground and stretches of water.

SLIDE NO. 1

For this application one immediately considers the conventional overwater type of hovercraft and this is a good starting point. The requirement is sufficiently different to suggest major differences in design. For overwater transport of passengers we think in terms of regular ferry services with the hovercraft enjoying a high utilisation. The emphasis here is getting the operating cost down to a minimum value and sophisticated designs are justified, although the capital cost may be relatively high.

In the main, overland craft will not be used so intensively and, with the lower utilisation, capital cost becomes more important. Furthermore, maintenance facilities for overland vehicles may not be as elaborate as for their overwater counterpart operating from well-equipped terminals. One result of these considerations is that the plenum chamber type of vehicle becomes rather more attractive. It promises simplification of structure and associated lower capital cost compared with the annular jet configuration.

As with overwater vehicles, flexible trunks or skirts are fundamental to efficient operation overland. The requirement is somewhat different however. In general, the size of overland obstacles to be encountered is more predictable than the size of waves — they are not transient and the larger ones may be avoided. The more critical terrain can be tackled at reduced speed and in consequence flexible members overland are not required to respond in the same manner.

The nature of the obstacles is different however; they tend to be harder and skirt wear and tear become greater problems. Furthermore, for ground operation the drag associated with flexible parts bull-dozing through mud could be prohibitive, even at low speed. Hence, the stiffness of the flexibility is

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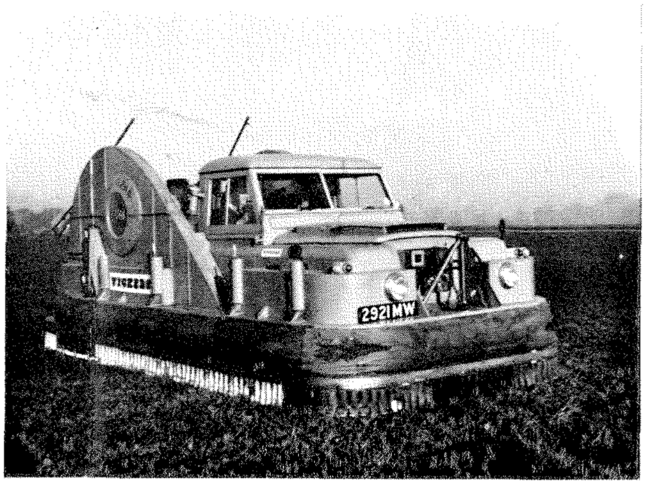
* *Delivered to the Hovercraft Symposium, University of Southampton, March 23rd, 1963*



Slide 2

critical. For these reasons flexible members that are satisfactory overwater may not meet the overland requirements and vice versa.

This slide illustrates a typical configuration of a craft intended primarily for continuous operation overland carrying passengers and/or equipment. It can operate over marsh, water and surfaces having limited degrees of roughness and slope. It has a plenum chamber type of cushion, the air escaping beneath the flexible skirt. This is of sufficient length to ensure that the rigid main body passes over the maximum obstacle height for which the craft is designed.

This particular craft has air propulsion, which is used when operating over liquid and extremely soft surfaces. In addition, this type of vehicle would probably have wheels which partly support it over the more solid surfaces, a high proportion of the weight being taken on the cushion. The wheels are used for traction in addition to providing steering and stability.

Overland craft of this type could operate over some parts of the world where there are virtually no competitive vehicles, in Canada for example.

One application of this class of ACV is survey work in swampy areas, carrying personnel and equipment. Another application is the transport of a wide range of perishable cargoes; its speed of travel over varied difficult terrain can result in reduced handling in some cases. Cargo deterioration can be prevented and expensive processing obviated.

Typical operating data for this type of vehicle is: 25 tons payload; 50 knots speed; 5 ft. obstacle height; 3,000 installed shp; 1 in 6 slopes.

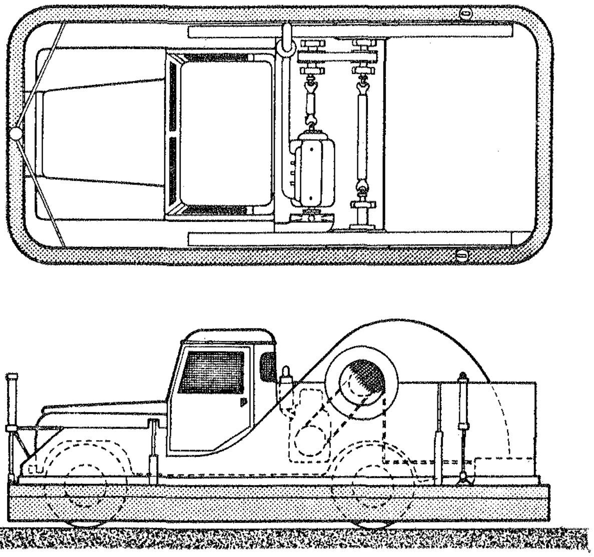
There is a considerable effort being made to develop tracked vehicles of very low ground bearing pressure to negotiate soft ground. ACVs of the type illustrated can, of course, operate over ground of any degree of hardness, they are amphibious and must be preferred to the more conventional tracked vehicles provided they can be produced at the right price and can be made to operate efficiently.

I think it worth noting that for ACVs overwater there is probably a limit to reducing the air gap between the surface and the bottom of the skirt, from stability considerations. Over ground, if wheels are stabilising the vehicle, no such limitation exists and time might show that the lift power can be reduced to a lower order.

SLIDE NO. 2

Occasional Soft-Ground Operation

A second class of ACV required is one that spends most of its life operating on metalled roads or good tracks, with occasional operation over soft ground. In some cases conventional wheeled vehicles are capable of negotiating the soft ground, but the effects of the wheels digging into the ground are unacceptable. For this type of application there is a good case for taking an existing land vehicle and modifying it so that some of its weight can be taken on an air cushion for operating off the road. Such a conversion can give certain beneficial operating characteristics over a standard vehicle without increasing its price considerably. The three main operating advantages are:



Slide 3

(i) When operating over bumpy ground the use of the air cushion improves the crew and passenger comfort considerably and reduces the loads that are taken by the suspension system. This means that a substantially increased cross-country speed is possible.

(ii) The reduced bearing pressure between the wheels and the ground means that the soil is not compacted so heavily. This is of importance to the agricultural industry, for crops cannot germinate in compacted soil.

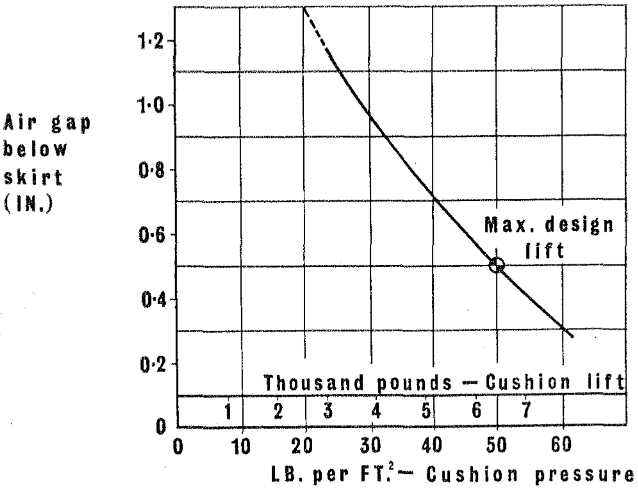
(iii) The most important feature is that when a proportion of the vehicle's weight is taken off the wheels the vehicle can operate over soft ground conditions in which a standard vehicle can get bogged down.

This is a photograph of the first Land Rover which was modified in this way by Vickers-Armstrongs. The air cushion is contained within the flexible skirt which extends around the whole periphery of the vehicle and air leaks out below the bottom of the skirt. With this type of vehicle the skirts can be raised so that it can operate on roads in the usual way.

SLIDE NO. 3

This GA perhaps shows more clearly the form of the modification made on the Land Rover.

Around the vehicle is built a light metal body incorporating, in the truck sides, the housings for two fans. The fans are of the centrifugal type, 25 inches in diameter and double sided. They are mounted separately and connected by a universally jointed shaft. This is belt driven from a counter shaft



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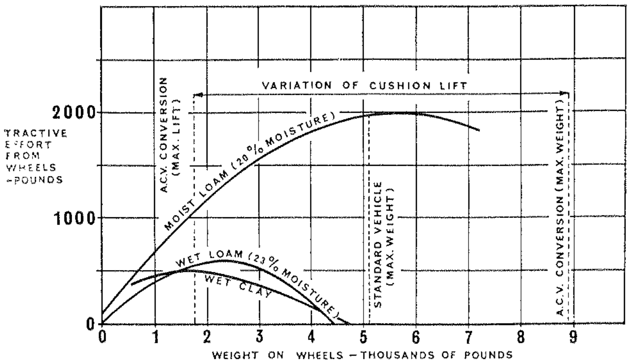
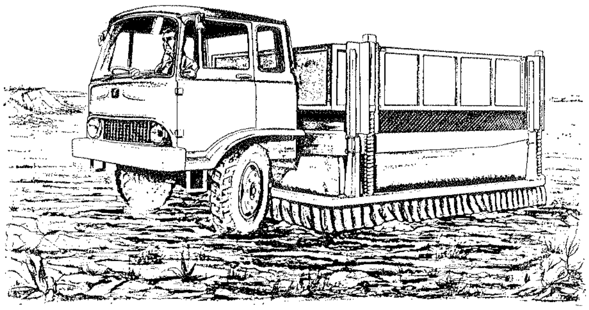
* *Delivered to the Hovercraft Symposium, University of Southampton, March 23rd,* 1963.



Slide 5

Slide 6



connected to the end of the crankshaft of a 2¼ litre Rover petrol engine, identical to the main power unit of the vehicle, but mounted transversely behind the driving cab.

A framework surrounds the vehicle and carries a flexible skirt, which retains the cushion pressure, while offering a low resistance to obstacles. The skirt is of special convoluted design and made up from reinforced neoprene sheet. It is designed to withstand cushion pressures of up to 50 pounds per square foot. At pressures below this the skirt retains its shape except locally when passing over solid obstacles. Wear and tear of the skirt proved to be difficult problems in the early days, but we think that they have been substantially overcome. The skirt framework is adjustable in both height and tilt by means of three hydraulic jacks. When the skirt is lowered the cushion pressure increases and reduces the load on the road wheels. When the skirt is raised to the highest position the fans can be stopped, permitting the vehicle to be operated as a conventional wheeled vehicle.

The experimental vehicle has been in operation since January of last year. It has been used for research and demonstration purposes. The vehicle was operated for about two months by a crop treatment company who carried out trials to assess its suitability for agricultural purposes. Following this work certain parts of the vehicle have been re-designed, and three craft are now in operation.

SLIDE NO. 4

This graph demonstrates how the weight taken on the cushion can be varied. The size of the gap through which the air is escaping between the ground and the bottom of the skirt is plotted against the cushion lift. For small gaps below the skirt little air escapes and a high cushion pressure builds up. When the skirt is raised, however, the gap increases, more air escapes, the cushion pressure drops, the weight taken on the cushion reduces and the weight taken on the wheels increases.

The fans and skirt on the Land Rover are designed to deal with a maximum cushion pressure of 50 pounds per square foot. This corresponds to a cushion lift of 6,500 lb which represents about 80 per cent maximum loaded weight. The mean air gap for the maximum cushion pressure is only half an inch. When the vehicle is operating over rough ground some parts of the skirt are brushing the ground and in other places the air gap exceeds half an inch.

When operating over very rough ground at high speed the motion of the skirt would be such that the mean air gap would exceed half an inch. To maintain a cushion pressure of 50 pounds per square foot at a higher air gap we would require a higher curve on this graph. To achieve this a more powerful engine would be required to drive the fans. If we wish to double the air gap for a given value of cushion pressure, the lift power would have to be doubled approximately.

SLIDE NO. 5

This graph is an attempt to illustrate how the air cushion can prevent a vehicle getting bogged down in soft soils. The tractive effort obtained from a Land Rover in four wheel drive is plotted against the weight on its wheels.

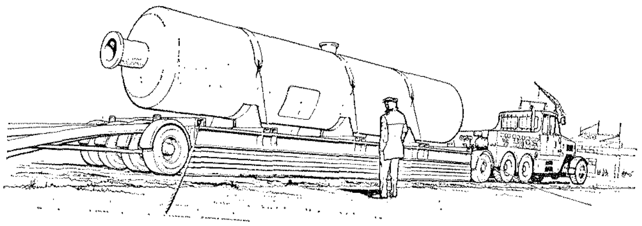
Consider for example a uniform moist loam. When there is little weight on the wheels there is a small cohesive traction. As the weight on the wheels increases the tractive effort increases, for although the rolling resistance goes up the frictional traction goes up at a greater rate initially; for larger weights on the wheels the rolling resistance gradually takes over and bends the curve over. This is because the frictional traction is in proportion to the weight on the wheels, but the rolling resistance is proportional to the square of the weight on the wheels. When the weight on wheels reaches a certain value the tractive effort is at a maximum and with additional weight the tractive effort drops.

All soft soils have this characteristic shape. With increase in moisture in the soil a lower curve obtains, however. Hence for very soft soils the maximum tractive effort is small and is obtained when there is little weight on the wheels. For these very soft soils the tractive effort disappears entirely at larger weights on the wheels. With this state of affairs the vehicle cannot proceed under its own power and is bogged down.

We must bear in mind that these considerations apply only to soils of sensibly uniform moisture content. If, for example, a soil is soft for some inches in depth, but there is a hard layer of soil beneath this, then it pays to load up the wheels so that they get good contact with the hard soil. This state of affairs is usually obtained when a substantial amount of traffic has gone over the same spot. For little-used country the top soil is uniform in general.

We can see from this graph the advantage of using the air cushion. It is a simple means of off-loading the wheels by any desired amount. For example when operating over very soft loam, one should arrange for about one ton weight on the wheels. With two tons weight or more on the wheels the vehicle gets bogged down. On the moist loam we do not require the air cushion at all. Hence the technique of using this type of vehicle is to vary the cushion pressure according to the soil over which one is operating.

These considerations are, of course, applicable to any ACV operating over soft ground when traction is obtained from wheels or tracks.



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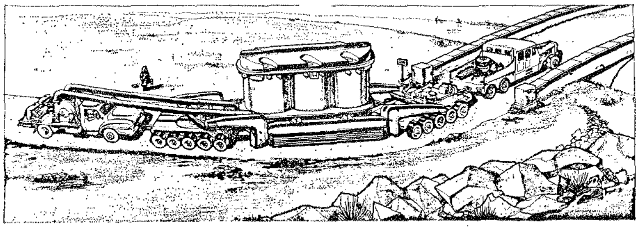

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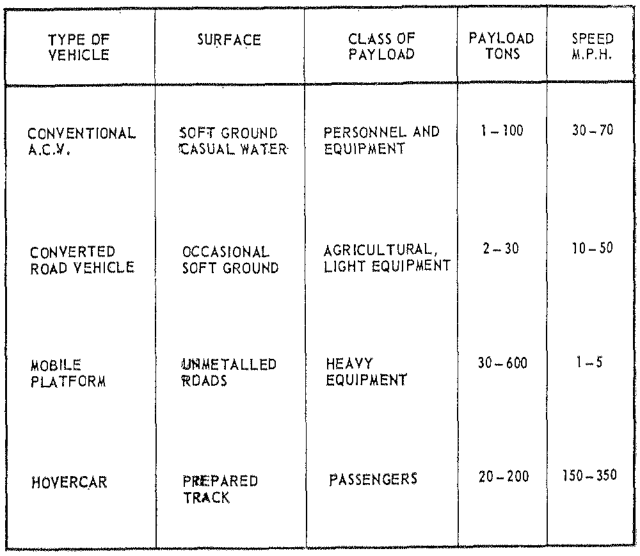

TYPE OF VEHICLE	SURFACE	CLASS OF PAYLOAD	PAYLOAD TONS	SPEED M.P.H.
CONVENTIONAL A.C.V.	SOFT GROUND CASUAL WATER	PERSONNEL AND EQUIPMENT	1 – 100	30 – 70
CONVERTED ROAD VEHICLE	OCCASIONAL SOFT GROUND	AGRICULTURAL, LIGHT EQUIPMENT	2 – 30	10 – 50
MOBILE PLATFORM	UNMETALLED ROADS	HEAVY EQUIPMENT	30 – 600	1 – 5
HOVERCAR	PREPARED TRACK	PASSENGERS	20 – 200	150 – 350

SLIDE NO. 6

This is an illustration of a larger vehicle, for which the major part of its weight can be transferred from its wheels to an air cushion for soft-ground operation. It is a three-ton truck and is typical of vehicles of this type. You will note that unlike the smaller Land Rover, this vehicle has a respectable space for accommodating its payload. It is in fact identical to that of the standard vehicle. The lift engine and fan are tucked away and lose their prominence.

Vehicles of this type have a total installed power, i.e. lift and traction of about 30 hp per ton of loaded weight. This power/weight ratio is less than a quarter of that for the present generation of over-water hovercraft and about half of what we might expect for the continuous overland air cushion operation.

There is the possibility for vehicles of this type that the air cushion equipment will take the form of a conversion kit which can be buttoned on in a short time with a ready reversion to the standard vehicle when the air cushion is not required.

SLIDE NO. 7
Transport of Heavy Equipment

The third class of ACV for overland operation goes even further in striving for low capital cost and low power/weight ratio. As this does not pretend to be a complete vehicle, it might be called more appropriately "a mobile platform". It can take the simple form of a relatively shallow flat structure, from which a peripheral flexible skirt hangs. Again a plenum chamber type of cushion would be employed, the air probably being supplied from an external source. For example, a tractor vehicle could carry the blowing equipment in addition to towing the platform.

The purpose of the mobile platform is the low speed transport of very heavy equipment over inferior surfaces. To carry heavy equipment on a conventional wheeled vehicle means a high wheel bearing pressure and a metalled road surface. When such heavy equipment has to be transported in small numbers, construction of heavy-duty metalled roads is not justified and there is a case for the mobile platform. The low bearing pressure offered by the mobile platform means that heavy equipment can be carried even over fairly soft terrain.

With reasonably flat surfaces and modest speeds not exceeding 5 mph the air escape gap between skirt and ground can be reduced to a small fraction of an inch. This means that the lift power requirement can be reduced to a few horse power per ton loaded weight. Further, with the lift power being so small, there is little penalty in carrying additional weight and the structure can be made crude and cheap by conventional ACV standards. This application of the air cushion is of particular interest to oil companies and manufacturers of heavy industrial equipment.

SLIDE NO. 8

One interesting off-shoot in this type of air cushion/flexible skirt configuration is an application to road vehicles. The large trailers we sometimes see on British roads carrying heavy industrial equipment are restricted in their operation over bridges. Many bridges are of very limited strength having been built a century or so ago and the Ministry of Transport quite naturally are not prepared to risk a vehicle of several hundred tons breaking through them. Taking head-room and width considerations into account it is not possible to support large transformers for example with wheels other than providing a large bogey at each end. In consequence, a large bending moment is imposed upon the bridge when one of the bogies travels over it. When an air cushion is accommodated between the two bogies, the load is more uniformly distributed and, for a bridge whose span is less than the vehicle length, the bending moment is reduced. Having crossed the bridge the air cushion is switched off and the skirt raised until it is required again. This application of the air cushion is of considerable interest to the manufacturers and operators of heavy industrial equipment.

SLIDE NO. 9

This tabulation reviews the overland applications of the air cushion which I have mentioned. The classes of vehicles shown in the top three lines have a considerable range of payloads, speeds and terrain.

The configurations have a number of common features however. The plenum chamber air cushion is preferred, of necessity the power/weight ratio is of a lower order than that of over-water ACVs and the construction is more simple and cheap. Perhaps even more than with overwater ACVs, however, the success or failure of an overland ACV depends upon the design of flexibility.

Summing up, the overland ACV future is by no means clear. The case for the air cushion in the commercial field depends upon one of two things, either (i) removing the necessity for expensive surface preparation, or (ii) considerably reducing any adverse effects upon the surface itself. These vehicles are behind the overwater ACV in development. One important factor that must be remembered is that overwater ACVs will, by and large, be offering some improvement to existing services, whereas overland the air cushion can in some cases satisfy a need not fulfilled by any other vehicle. Many of us are extremely enthusiastic about the future of ACVs overland.

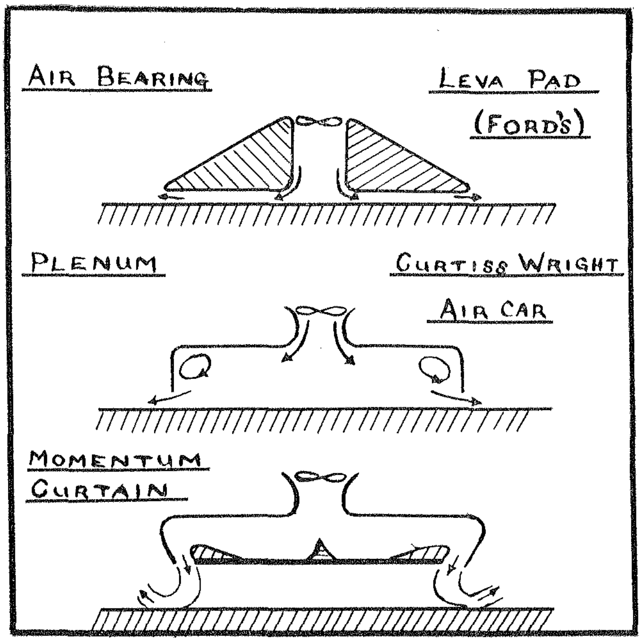

Figure 1

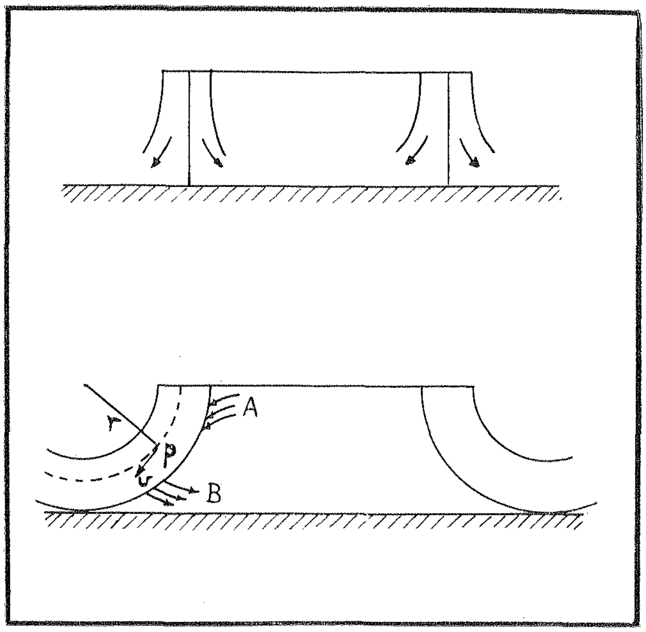

Figure 2

GENERAL PRINCIPLES OF THE HOVERCRAFT

By H. J. Davies, B.Sc. Ph.D.*

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THE main purpose of this lecture is to acquaint those of you who are not directly concerned with research in the Hovercraft field with the basic principles and attendant problems of such craft. This, in the main, will be a repetition of the words of more competent workers than I, coupled with some suggested lines of research.

Fig. 1

Three of the best-known lifting systems for ground effect machines are shown in Fig. 1. The Air Bearing operates at very low heights and is associated with the problem of lubrication as well as a transport bearing device along a monorail or guide plank.

The Plenum is a highly stable configuration provided that the supply jet hits the containing sides. Once its behaviour becomes that of a free jet it is then violently unstable. As far as height clearance is concerned it is an improvement on the Air Bearing.

A further height improvement is obtained with the Momentum Curtain, this configuration being stable up to about 3% of the diameter. However, the degree of stability is still small. This statement requires further investigation as it is based on jets supplied from a single source, i.e. it is assumed that the total heads in the jets are equal. From the work that has already been done here in the University there is evidence that with separate powered jets — allowing variation of total heads — the degree of stability may be substantially improved.

We are also investigating the result of marrying the Plenum and Momentum Curtain, i.e. using the Momentum Curtain to replace the solid walls of the Plenum. We then have an automatically adjusting side wall which would seem to give us an inherently stable system.

There are, of course, other systems such as those adopting the principles of re-circulation as was attempted by the Swiss and the Miller Company in the States.

I shall now confine my remarks to the Momentum Curtain or Peripheral Blowing type of machine. There is nothing new about the concept of motion on a cushion of compressed air. Indeed, many of us have arrived here today in vehicles sustained by, in general, four cushions of compressed air. What is new is the brilliantly simple means of containing the cushion — having an air curtain functioning as the container of the compressed air and replacing the rubber tyre. As in most worthwhile advancements the old is not done away with entirely but the best of both worlds is adopted and merged into a harmonious whole. So it is that most cushion craft today have a flexible wall or half a tyre along the curtain periphery contributing to a further augmentation of the cushion pressure above that of the ambient. This flexible wall is usually referred to as the skirt — which is in keeping with the characters that indulge in such research! Let us then act in character and remove the skirt in order to have a clearer look at the basic principles of the machine. These basic principles are quite simple to explain.

Fig. 2

At the commencement of the operation the jets hit the ground and split. The in-flowing part of the jet "pumps up" the pressure of the air beneath the craft. As the pressure of the air increases a larger quantity of the jets are turned outwards until a steady state is reached. In this state the entrainment, A, of air from the cushion into the jet is exactly balanced by the in-flow, B. The jets then curve outwards along an arc of radius r defined by the equation of motion

$$\frac{v^2}{r} = \frac{1}{\rho}\frac{\partial \rho}{\partial r}$$

from which, together with the condition for irrotational motion $vr = \text{constant}$, the cushion pressure may be calculated. There are several simple methods of calculation based on the assumption of the invariance of the velocity along a stream-line. Such theories, by their good agreement with experimental measurement of the cushion pressure within the limitations of height greater than jet thickness, are acceptable for performance analysis. The assumption of the simple theories are, however, invalid for heights less than the jet thickness which immediately invalidates the comparative arguments that have been put forward based on the limiting value of the cushion pressure as the height tends to zero. A two-dimensional jet theory has been evolved which is exact under the assumptions of the usual fluid perfections — incompressible, inviscid — for all thickness-height ratios. The usual criticism made of this

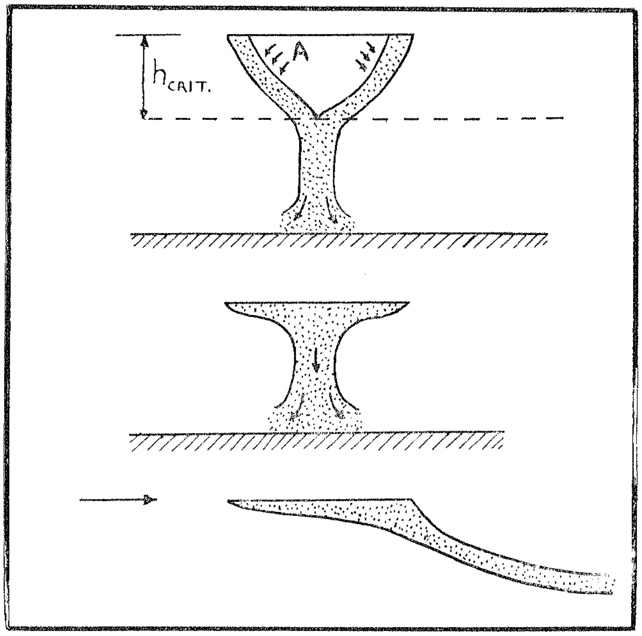


Figure 3

theory is that it is complicated which, in this computer age, is rather surprising.

There is, however, a limitation placed on the hover height by the existence of a critical height.

Fig. 3

This height is defined as that at which the edge jets meet at a point above such a height. There is no inflow of air to compensate for the entrainment, A. We are then left with a negative augmentation. In addition to which we have the instability associated with a free stagnation point. An attempt was made to overcome the disadvantages of this tulip configuration by "coandering" the jets on the undersurface to form a vertical take-off configuration; but the rapidly changing position of the Centre of Pressure in transition to forward flight as a jet wing created stability and control problems that have not, as yet, been solved.

Finally, let us look at the static stability of these air-cushion machines. Let us examine the flow configuration when the craft is at incidence.

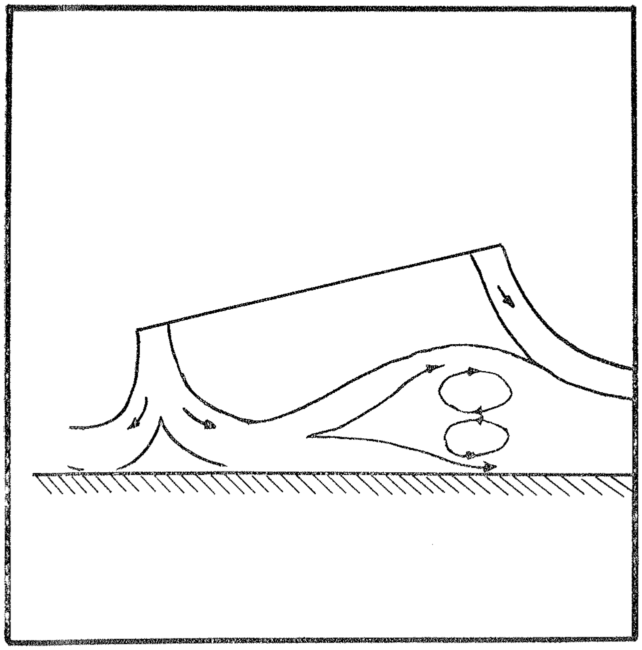


Figure 4

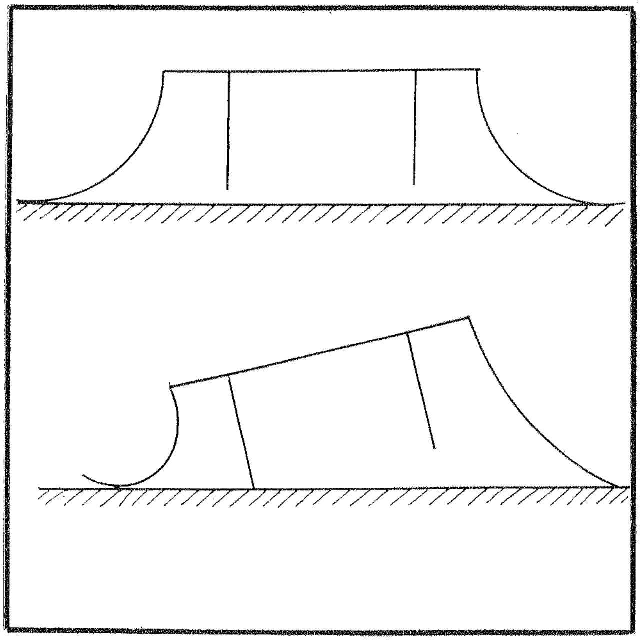


Figure 5

Fig. 4

At zero incidence both the jets are balanced. When the craft is placed at incidence the down going jet splits into two. Since this jet is closest to the ground only a small proportion of the thrust is required to maintain the cushion pressure. The remainder splits and flows across underneath the craft. Here we have two effects:

(1) The cross flow expands contributing to the instability of the craft.

(2) There is a friction effect which would cause a negative pressure gradient contributing to the stability of the craft.

At small angles of incidence the friction effect is dominant contributing to stability. At larger angles of incidence the expansion effect is dominant.

It is obvious that any device that delays the cross flow will increase the range of stability. To increase the pressure in the cushion the angle of ejection of the jets is inwards; but if the angle of ejection of the jets is outwards it will delay the cross flow of the downward going jet. We are thus faced with the usual design compromise. It is, however, important to have a high cushion pressure in order to give a good design clearance height. Thus, it is necessary to retain the inward angle of deflection of the jets which compels us to look elsewhere for a means of controlling the cross flow. This can be done by the erection of a wall which would entirely prevent the cross flow.

Fig. 5

In this case the maximum pressure would result on the down going side of the machine giving a righting moment.

At first sight this may not seem to be a very practical scheme but the same effect may be produced as follows: The wall may be replaced by the use of another jet giving us a twin-jet system.

Fig. 6

At first the outer jet behaves in a normal fashion, turning outwards, and the cushion pressure between the two jets is increased, causing a strong stable restoring moment. The inner jet splits into two portions and as the incidence increases the greater proportion of the jet moves inwards underneath the model. However, at a certain point, the pressure between the jets becomes too great, and, due to Coander effect, the inner jet clings to the bottom surface of the model. The outer jet also passes underneath the model, causing a loss of lift and a strong destabilising moment. The effect of the

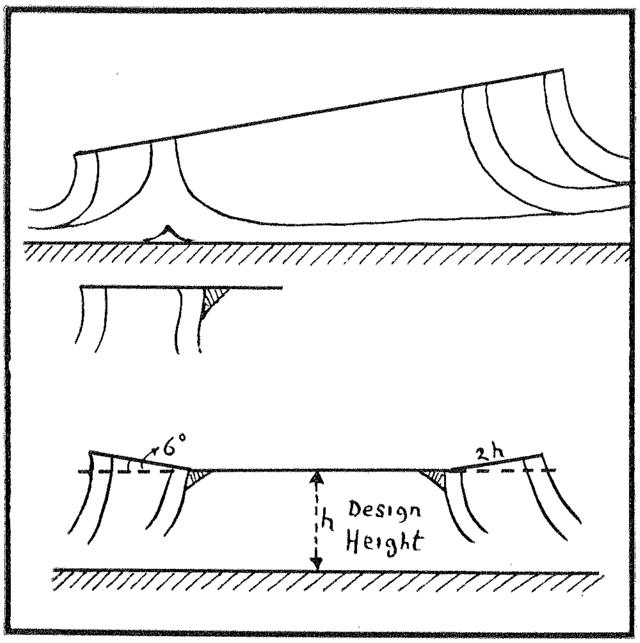


Figure 6

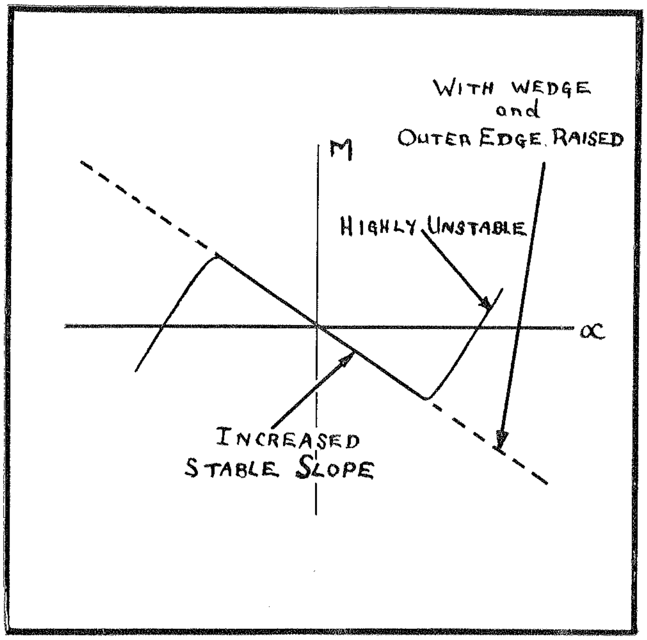


Figure 7

inner jet is to greatly increase the stable slope compared with the simple jet system. The incidence range can be increased by delaying the Coandering of the inner jet by fixing a small wedge on the inner side.

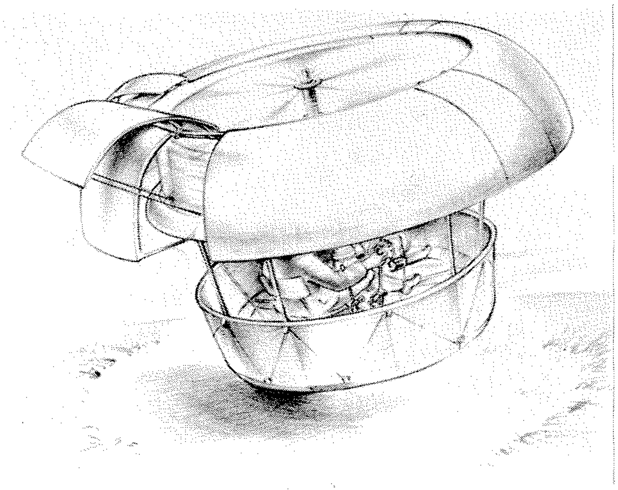
A still further increase in incidence range can be achieved by adopting another method of simulating the wall effect. This is to incline the outer edge of the craft so that stability is maintained in the limiting case when the machine is at its maximum incidence with one edge about to touch the ground. The final configuration is then as shown in this figure.

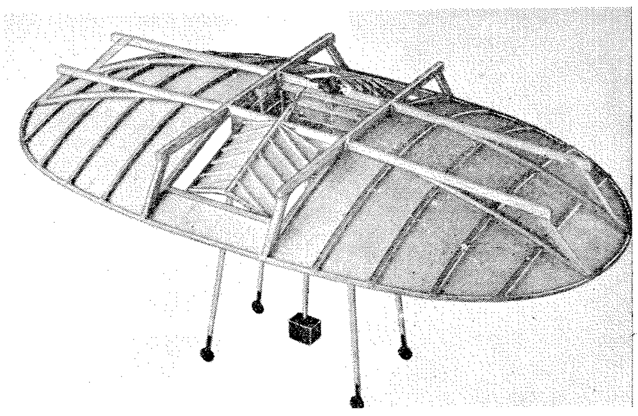
Fig. 7

Illustrates the increased degree and range of stability achieved. An attempt is now being made to correlate the stability behaviour and degree of stability with the rate at which the cross-flowing jet diffuses within the pressure cushion and the point at which this jet hits the base of the craft. Such work, if successful, would put the descriptive behaviour principles as given by R. Stanton Jones at the Princeton Symposium in 1959 on a somewhat firmer footing.

There are, of course, many problems, of a fundamental as well as a development nature, that face us. The picture I have given you is far from complete. You notice that a cross flow involves a horizontal induced force. Thus, to achieve a static state an external horizontal thrust is required; and so, we cannot separate stability from control. Again, the problems of transition to free flight via the Jet Flap or partial flight via the Ram Wing are intriguing developments worthy of investigation.

* *Delivered to the Hovercraft Symposium, University of Southampton, March 23rd, 1963.*





Successful skirt development

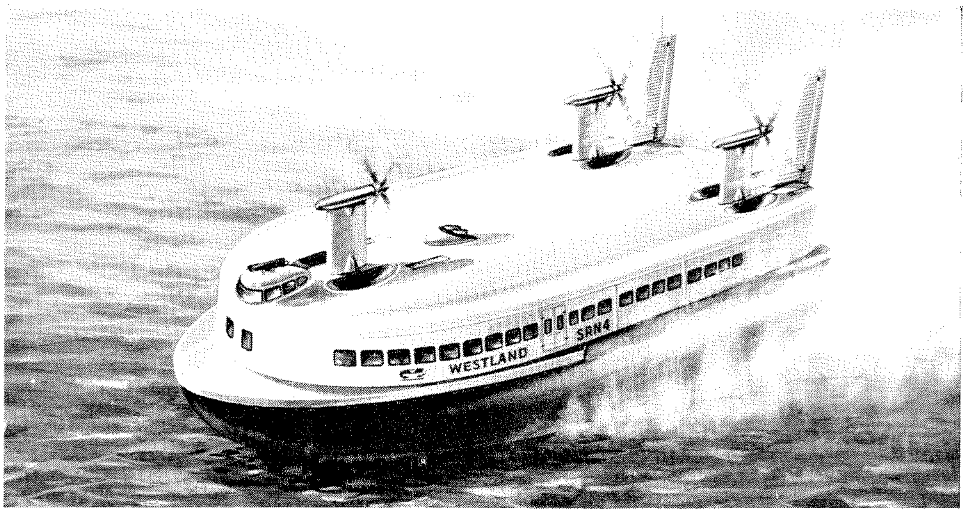
✶

Prices and delivery dates

✶

New hovercraft designs

✶



SR.N4

NEWS FROM WESTLAND

NEWS of two major developments that will undoubtedly expedite the wide-scale commercial application of Westland ACVs, was given by the company at a "Hovercraft Presentation" as the Grosvenor House, London, on April 18.

First, the company announced the successful engineering of the Westland patented flexible skirt, which offers an immense improvement in overland obstacle and overwater wave performance without any increase in engine power. Secondly, firm prices were quoted for the SR.N2, the SR.N2 Mk 2 and the new SR.N5, in passenger or freight form. Craft ordered now will be delivered in March next year or in nine months from the receipt of orders. To ensure these deliveries, Westland is planning and tooling for batch production.

The SR.N2, with an all up weight of 27 tons and a maximum cruising speed of 80 knots is priced at £325,700. It will carry 70 passengers or 8 tons of freight.

The SR.N2 Mk 2, with an all-up weight of 37½ tons and a maximum cruising speed of 74 knots, is priced at £450,600. It will carry up to 150 passengers or 12 tons of freight.

The third model, the SR.N5, with an all-up weight of 7 tons and a maximum cruising speed of 70 knots is priced at £75,600. It will carry 20 passengers or 2 tons of freight.

Operating costs for the SR.N2 will be 4d-5d passenger seat mile, for the SR.N2 Mk 2 3d-4d per mile, and the SR.N5 4d-5d.

In addition to this programme, Westland has reached an advanced stage in the engineering studies of the SR.N4, a 170 ton craft designed for ferry work across the English Channel. Travelling at a speed of 90 knots it could carry 600 passengers or 350 passengers and 26 cars or 65 tons of freight.

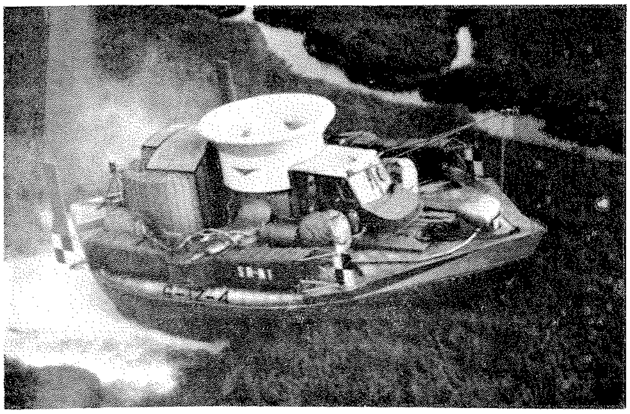
Sir Eric Mensforth stated that ten Hovercraft of the SR.N4 type could carry annually across the Channel the passengers, cars and light freight visualised for a Channel tunnel in 1970.

Eight-foot skirts would be fitted to the SR.N4 which would allow clearance, at a reduced speed, of waves up to 75 ft high.

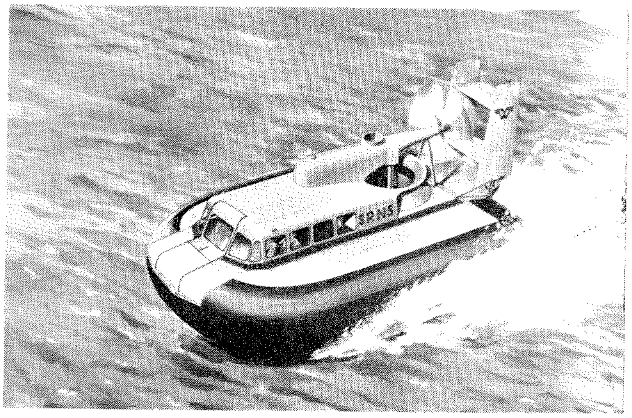
Westland think it is likely that they will build the SR.N4 without any definite order on hand as a prototype. The company has been encouraged generally by the more serious interest shown by potential operators over the past twelve months, and could have the SR.N4 operating in four years' time.

The development of the flexible skirt means that it is possible for ocean-crossings to be made with a 200 ton craft fitted with 10-15 ft skirts whereas a year ago the minimum size for a hovercraft capable of this performance was considered to be at least 100 tons.

Equally the skirt gives a significant increase to the performance of smaller craft, enabling them to operate over terrain impassable to any known wheeled or tracked vehicles of similar capacity. The SR.N5, for example, is fitted with 4 ft skirts developed on the SR.N1 and will clear a 4 ft wall or a 7-8 ft scrub.



SR.N1



SR.N5