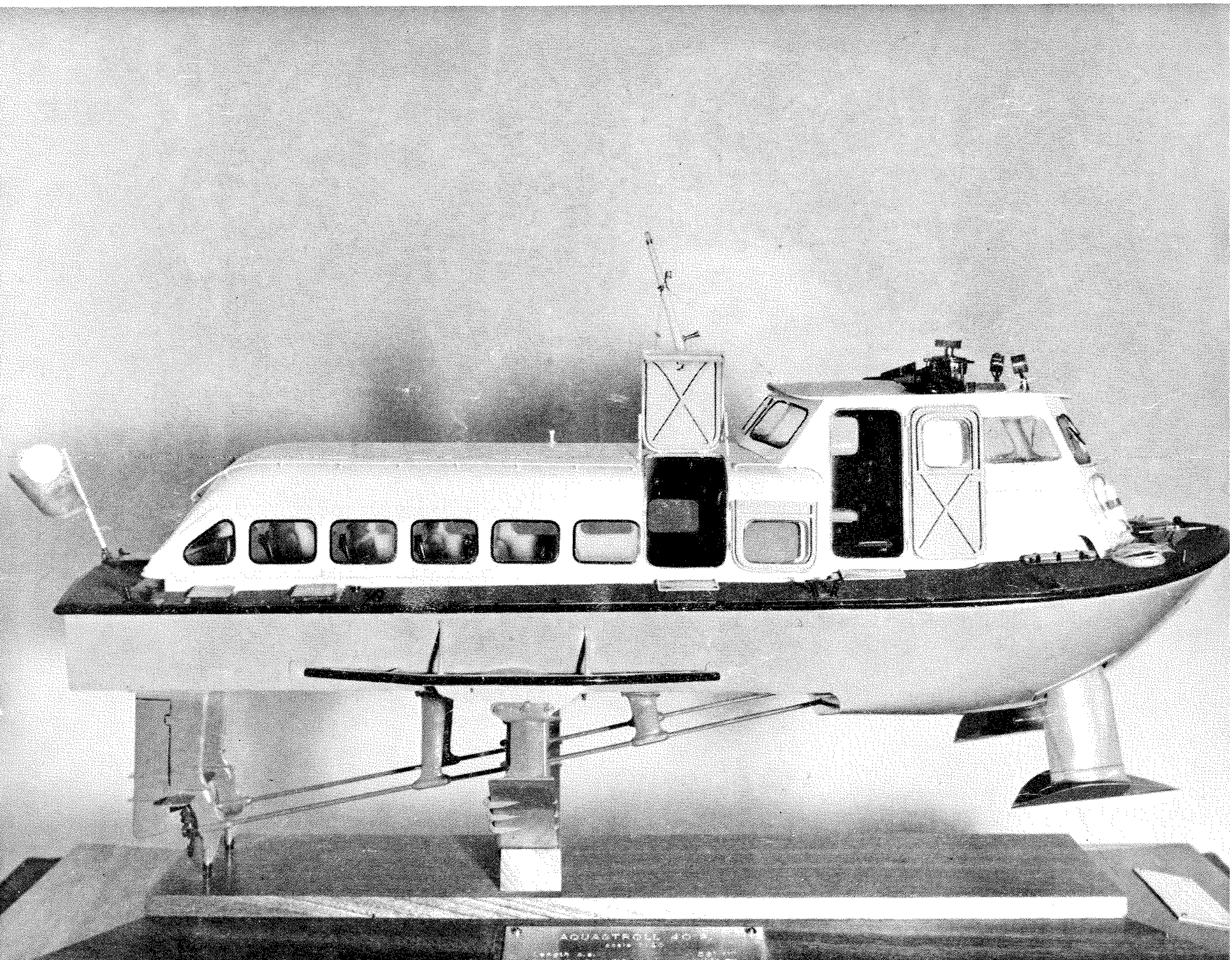
HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS

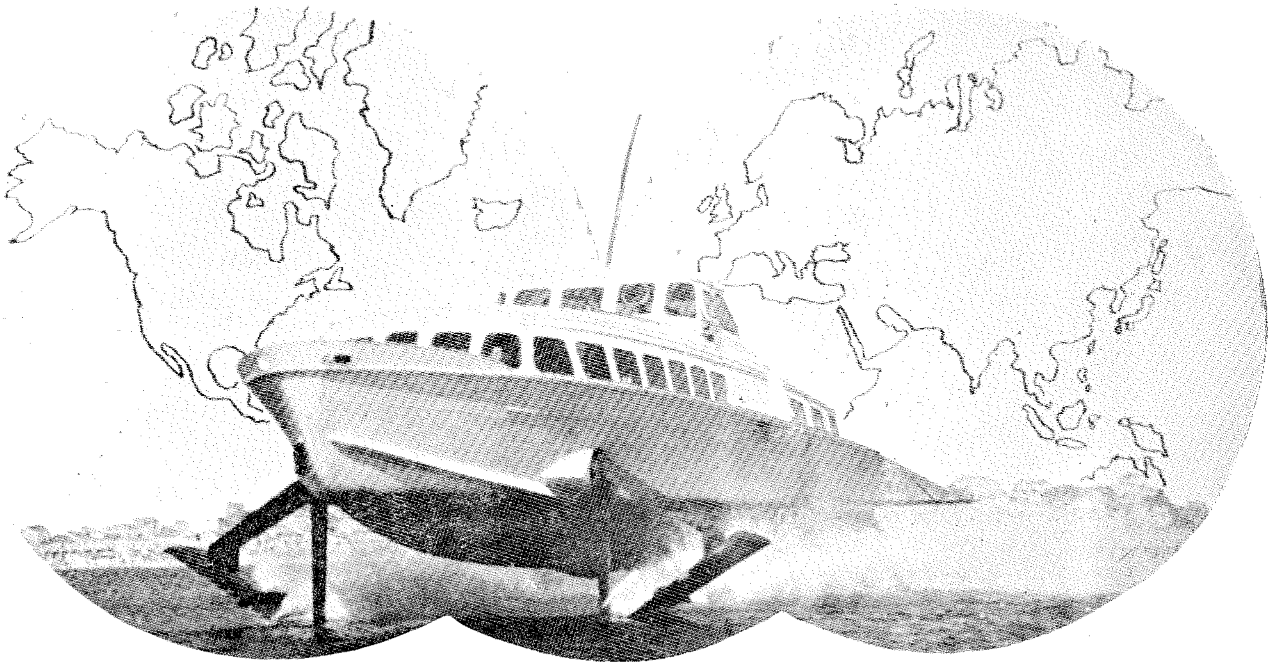


Volume 2 Number 2
NOVEMBER 1962

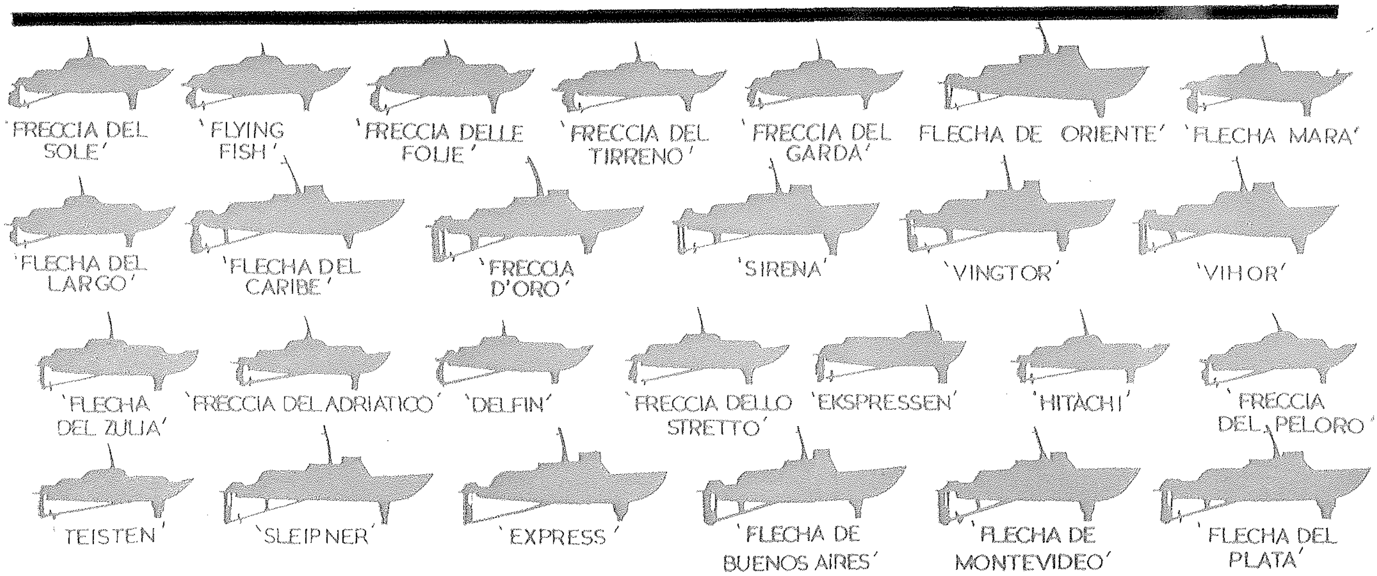
KALERGHI - McLEAVY PUBLICATIONS

Cantiere Navale RODRIQUEZ

MESSINA (Italy)



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



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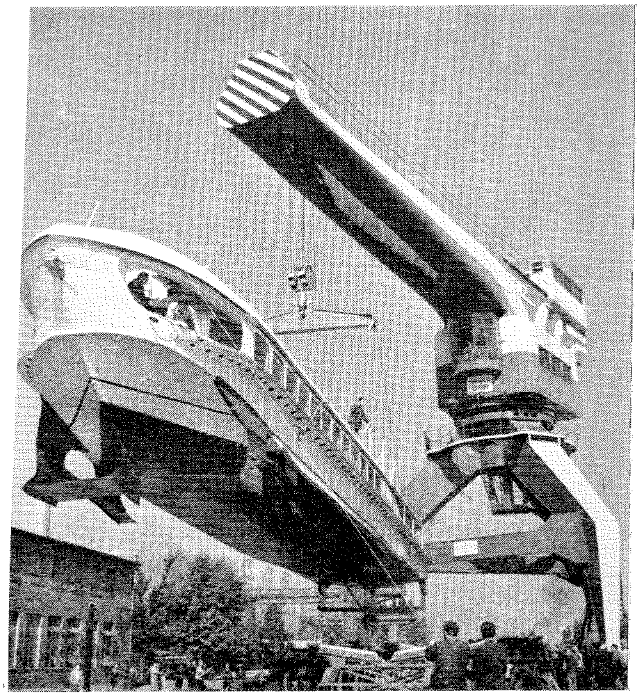
HOVERING CRAFT & HYDROFOIL

First Hovering Craft & Hydrofoil Monthly in the World

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS



Gull II, one of two Raketa hydrofoils being used for fast daily river services on the Danube from north to south Hungary. Eventual organisation of a 12-hour service between Vienna and Belgrade is under discussion. See report page 4

JAPAN'S GROWING HYDROFOIL INDUSTRY

JAPAN may soon become the world's largest manufacturer of hydrofoils, with an annual unit output many times greater than that of the Soviet Union. This is the belief of observers in Western Europe after an assessment of the growing numbers of orders being placed for these craft by Japanese and other Far Eastern operators.

The three main suppliers will be Hitachi, Mitsubishi and Shinmeiwa Industries. Hitachi, as reported in an earlier issue, has become a Supramar licensee and its first four PT 20s are already in service. The company is offering a range of six models from 3 tons to 100 tons at present and plans to build bigger craft later on.

Mitsubishi is at present concentrating on water-taxis for use along the Japanese coast, and reports a heavy demand for its new MH-30, an 80-passenger 40-knot craft with a surface-piercing main foil and submerged rear foil. Craft of this type will also be used for rescue work and for fire-fighting in Japanese ports. A general description of the MH-30 appears on page twelve.

Shinmeiwa Industries is already preparing to export its hydrofoils and enquiries are reported to have been made to the firm by the naval authorities in the Phillipines and in Thailand.

In Japan domestically-operated hydrofoil services have cut hours off the time taken on many of the inter-island routes, with the result that the boats have been running at an average passenger capacity of 70%. The craft also carry perishable freight.

IN THIS ISSUE

COVER PICTURE: *A model of International Aquavion's 40-seat Aquastroll, now nearing completion in Holland. The craft will operate under a Lloyds 100A.1 coastal service certificate and also a certificate for cross-channel service. It will be powered by two 270 hp Boeing marine gas turbines and have a speed of 32 knots*

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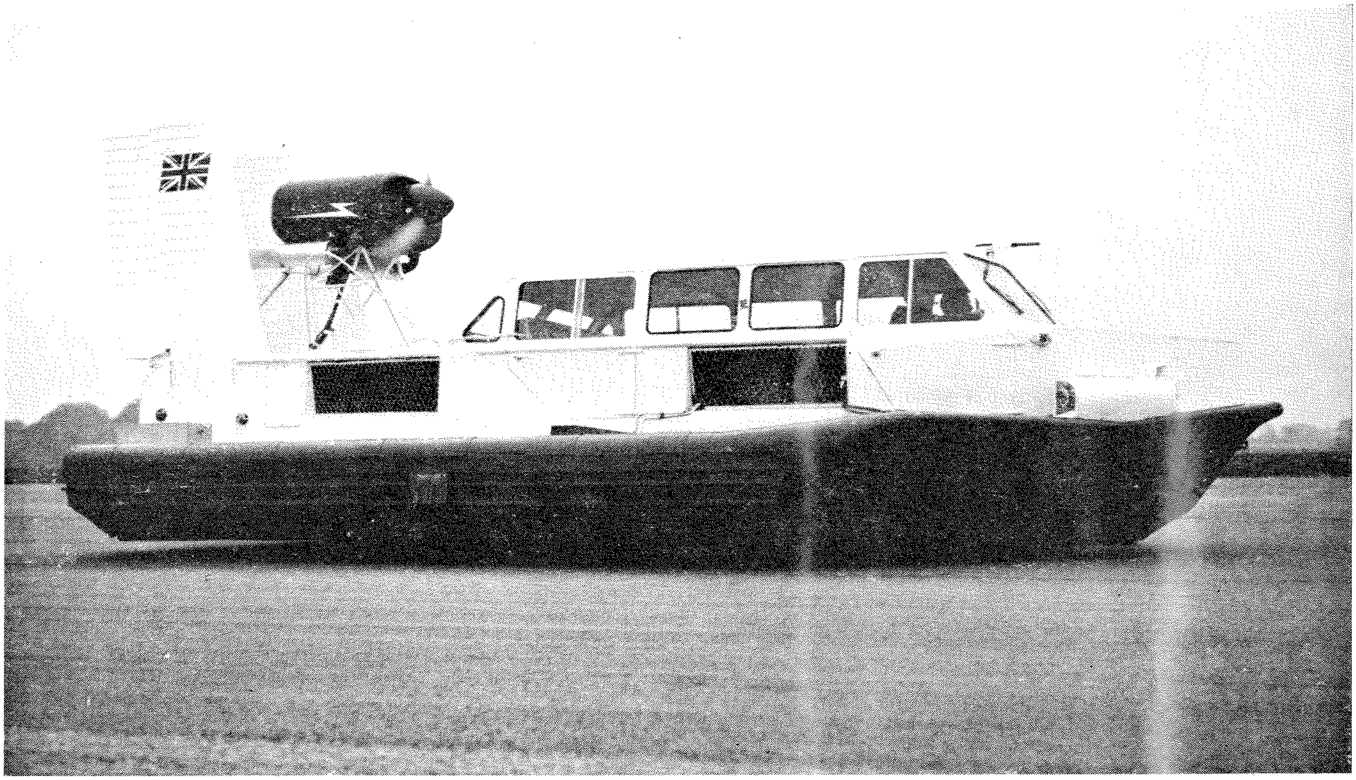


Preliminary trials of the Vickers VA-2 are now under way on the runway at South Marston. The craft, which has two Continental O-300s for lift and one Continental O-470L for propulsion, carries four to five people and has a top speed of 70 knots

People and Projects

Further details have come to hand recently concerning the **Ford ACV-1,** built for a Ford research programme to investigate operational problems of off-the-road travel at high speed and demonstrate the value of the fully-skirted concept. A preliminary description of the craft appeared in our April 1962 issue.

Normal payload of the ACV-1 is 1 ton but this can be doubled for short-range work. The air cushion is created by 14 side mounted fans, and propulsion, control and braking are effected by venting cushion air through control vanes located around the vehicle's periphery. Gross weight of the craft is 3½ tons; speed: 60 knots; ground clearance 2-3 ft.; range 100 miles; grade capacity 20%.

Dimensions: length 21 ft.; width 8 ft.; cargo space: 4 ft. by 13 ft.; cargo deck height on cushion: 4 ft.; off cushion 2 ft.

☆ ★ ★

The Soviet **Raketa** type hydrofoil boat which undertook a demonstration cruise up the river Danube this summer has evidently created a favourable impression on the riverain countries through which she passed. Early in July Hungary placed an order for two of these to which the names Gull I and Gull II have been given. The first of these has been in service for some time now between Budapest and Mohács, 118 miles south, near the Yugoslav frontier, and now that the second has become available, this has been supplemented by a service northwards from Budapest, to Estergom.

The Raketa type hydrofoil vessels carry 64 passengers. They have an engine of 1,200 hp, which gives a speed of 50 knots (reached within 60 seconds). The duration of the journey, by water, from Budapest to Mohács is now therefore only 3 hrs. 55 min. (as compared with the former 12 hrs.), and that of the journey from Budapest to Estergom is only 1 hr. 20 min. The return fares for these journeys are 225 forints (about £3 10s. 0d. at tourist rate), and 81 forints (about £1 5s. 0d.) at tourist rate), respectively.

The service from Budapest to Mohács leaves Budapest at 2 p.m. on Mondays, Wednesdays and Fridays, leaving Mohács on Tuesdays, Thursdays and Saturdays at 6 a.m. It has three stops in each direction at Dunaújváros, Paks and Baja. The service to Estergom runs on Saturdays, Sundays and Public Holidays, leaving Budapest at 2.30 p.m. and returning the same day.

The **Hungarian Navigation Company,** which operates these services, is now in negotiation with the Austrian authorities for the institution of a Budapest-Vienna service which would take 12 hours in each direction.

★ ☆ ☆

The **U.S. Bureau of Ships** has a development programme for a 30,000 hp gas turbine engine for possible use in a large hydrofoil ship. Jointly with the U.S. Army, the Bureau is also sponsoring research on three different 600 hp advanced gas turbines having fuel rates comparable to that of a diesel engine. Research on small units of this type will provide background data needed for large engine design.

Under an agreement dated October 26th, **Douglas Kent Warner,** of the **Warner Research Laboratories,** Sarasota, Florida, has granted sole and exclusive rights of his United States patents and applications pending to **Bertelsen Manufacturing Company** of Illinois.

The patents all embody claims relating to air cushion vehicles and the licence is granted for the full term of the patents.

☆ ☆ ☆

International Aquavion (GB) Ltd., are exhibiting for the first time in Britain at the *Daily Express* Boat Show, Earls Court, from January 2nd-12th, 1963. On their stand will be their 9-seat **Aquavit-class Waterman,** and a model of their new 40-seat **Aquastroll-class** hydrofoil. The Aquastroll is the second stage in the development of much larger craft using the Aquavion principle.

☆ ☆ ☆

Westland's SR.N2 has now completed the second phase of its development programme. At the start of this phase, which followed a strip examination of the transmission and structure, it had operated for 50 hours using only three engines. Operating weight had been raised to around 18 tons.

The main object of the second-phase trials was to clear the craft to the standard necessary for a very limited fare-paying passenger operation to be undertaken. The greater part of the trials programme was devoted to satisfying the Air Registration Board by simulating all kinds of failures, and to checking the reliability of all mechanical and electrical systems. In the course of the trials, operating weight was increased to 22 tons, using only 600 shp from each engine instead of the original design rating of 815 shp. SR.N2 reached a maximum speed of 73 knots and was repeatedly operated in 4 to 5 ft. seas. A.R.B. clearance was obtained in July, and a Permit to Operate issued early in August.

The experimental passenger service operated for 2 hours each day for a period of eight days, between Ryde Sands, Isle of Wight and Eastney Beach near Southsea — a distance of about 6 n. miles. 37 of the 50 scheduled runs were completed, the overall reliability of 74% being considered most satisfactory in all the circumstances. Four trips were cancelled because of technical trouble, and nine through adverse weather. Of the latter, the majority were cancelled only because the sea state exceeded the limits laid down in the Permit to Operate.

Throughout the operating period, the weather was far from ideal, with Force 4 to Force 7 winds, steep short seas, and waves up to 4 ft. Average cruising speed for the whole operation was around 40 knots, and the best cruising speed around 53 knots. A total of 1554 passengers were carried out of 2,100 who booked.

Despite the fact that SR.N2 was operating off natural beaches with only temporary barriers and no surface preparation whatever, turn-round times as low as three minutes were repeatedly achieved. Experience proved that the craft could equally well have operated from almost any point along the entire coastline.

In spite of the rough weather, the outstanding impression of the passengers carried was the extreme smoothness of the ride. On several occasions troublesome children and dogs were, without difficulty, walked around the cabin during the ride, to keep them occupied. Only one case of sea-sickness occurred — a small boy who had clearly eaten too much ice cream!

Following the experimental service, intensive development began to increase still further the effectiveness of the flexible rubber skirt — the primary reason for SR.N2's outstanding over-wave and obstacle-clearance performance — and to increase the directional stability of the craft. When total operating time reached 150 hours the machine was given its second strip examination.

This examination has shown that the transmission is barely "run in", and has stood up remarkably well to the trials. There has been virtually no sign of corrosion and only minor structural repairs to surface dents have been necessary.

To date, SR.N2 has covered approximately 3,500 miles, and carried a total of 3,700 passengers. It is now being strain-gauged in preparation for rough-water trials during the winter, when it is also hoped to extend navigation and night trials, to gain more experience in all-weather operation.

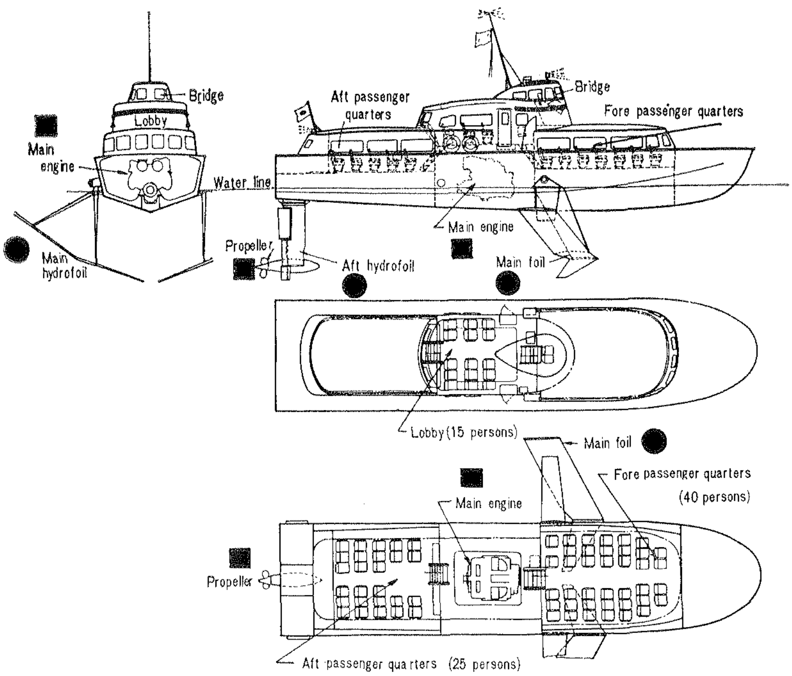
★ ★ ★

The **Kessock Ferry Joint Committee** are looking for an air cushion craft to operate the crossing between Inverness and the Black Isle. The length of the crossing is one-third of a nautical mile. The new ferry would replace the present two twin-screw diesel vessels. One carries four cars and 100 passengers and the other ten cars and 100 passengers. The committee would like a craft capable of carrying 20 cars and 250 passengers.

★ ★ ★

The **Hong Kong and Yaumati Ferry Co. Ltd.** is considering buying hovercraft from Britain for its cross-harbour and inter-island services.

A number of passenger services are run by the company which also operates the colony's car ferry between the island and Kowloon.



General arrangement of the Mitsubishi MH-30, first large hydrofoil to be designed in Japan. The craft seats 80 passengers and has a top speed of 40 knots

First technical details of the **Grumman AG(EH)** experimental ASW ocean-going hydrofoil were given by **Richard V. Cyphers,** Grumman's project engineer, and **Owen H. Oakley,** Preliminary Design Branch, Department of the Navy, at the recent National Meeting on Hydrofoils and Air Cushion Vehicles, in Washington. The craft will have an overall length of 212 ft., a beam of 40 ft. and weigh 314 tons.

Together with the Denison it will afford full-scale rough sea evaluation of the hydrofoil in a variety of foil configurations. The AG(EH) is first expected in service in 1965 and at a later stage it is to be converted to a high speed supercavitating foil system.

Two General Electric MS 240s have been chosen to power the craft in its sub-cavitating form. These provide an adequate margin of power for take-off to allow for rough water conditions and permit cruising at efficient power settings. Four of these engines — marine versions of the J-79 rated at 17,000 hp for take-off and 14,000 hp continuous — will provide sufficient power for high-speed supercavitating experiments.

The transmission finally selected is the best compromise between weight, development experience from the Denison, and adaptability to the addition of two more engines for supercavitation trials. It consists of a power splitting pair of spiral bevel sets on the engine shaft of nominal 1:1 ratio running through two athwartship shafts to a similar pair of bevel sets at the side of the ship. The shafting is turned forward here running through a reduction spur gear to a pair of spiral bevel sets at the top of the strut. The power is transmitted down the strut in two shafts to a similar spiral bevel set in the pod where the power is then turned aft into a single propeller shaft.

The foil arrangement is a conventional one with the major portion of the weight on the two split main foils. All three foils are incidence-controlled and retractable.

Autopilot and height sensor requirements on the craft are necessarily stringent since it will be flying at high speeds in the interface between air and water. The autopilot has to stabilize the ship in pitch, roll and heave, nullify the effects of orbital wave velocities while platforming; control contouring of waves that cannot be platformed; provide control for coordinated turns.

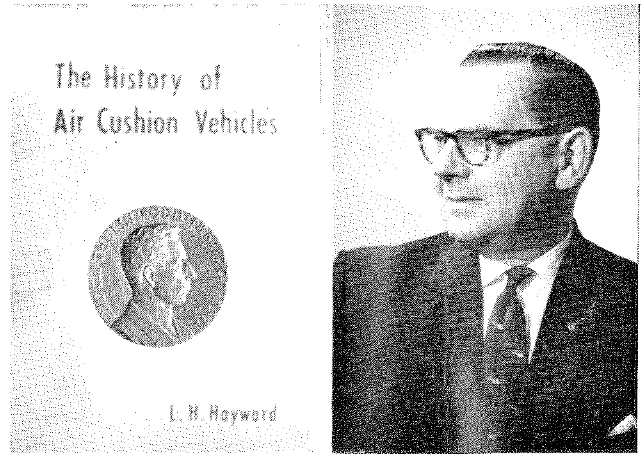
In order to meet these requirements, height sensors must be selected and integrated into the autopilot and an autopilot computer must be designed and built. Height sensors have not yet been selected but both sonic and radar types are being evaluated.

★ ★ ★

One of the most simple air cushion craft concepts brought to our notice is a ram wing boat designed by **Norman Dickinson,** of Essex, U.S.A.

Powered by a rear-mounted 190 hp lightplane engine driving a two-bladed pusher airscrew, the craft is built from slabs of extremely tough, rigid polystyrene foam. The sections are bonded with an epoxy resin and the all-up weight is only 1,000 lbs. The craft is 26 ft. long and has two planing floats 22 ins. wide. The aerofoil centre section is 16 ft. long and 8 ft. wide.

According to Mr. Dickinson, the craft reaches 60 mph, at which speed it draws only 5 in. of water at the stern. It spins in its own length and cuts through choppy water with 1 ft. waves with ease.



L. H. Hayward, Group Patents Manager of Westland Aircraft (right), has been awarded the Bronze Medal of the Swedish Society of Aeronautics for his paper "The History of Air Cushion Vehicles" which he recently read in Stockholm. The Medal was presented by the President of the Society, and the reverse reads "for aeronautical technical studies". See news item below

★ ★ ★

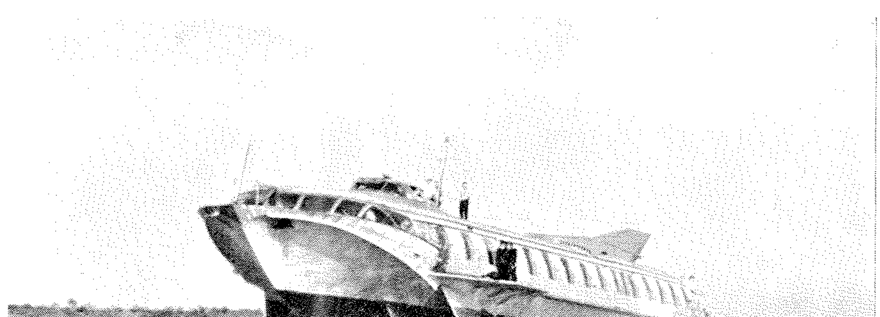
At the invitation of the Swedish Society of Aeronautics, **L. H. Hayward,** the Group Patents Manager of **Westland Aircraft,** recently presented a paper entitled "The History of Air Cushion Vehicles" at the Society's Stockholm headquarters. The paper traces the development of air cushion vehicles from the first proposal for a machine of this type in 1876 to the appearance of today's advanced designs.

It covers such interesting applications as air cushion boats, the first of which was built in Sweden as long ago as 1882. It also reveals that the hovertrain or sliding railway dates back to 1889 when a small experimental sliding railway operated in Paris from July to November of that year, the 3-coach train covering a distance of approximately 900 miles.

Interest in this paper has already been shown outside Sweden and Mr. Hayward has been invited to lecture to the Aeronautical Section of the Institute of Danish Civil Engineers in March.

★ ★ ★

The names of the two authors of "A Theoretical Study of the Relative Behaviour of Three Fully Submerged Hydrofoil Configurations with Regard to Dynamic Longitudinal Stability and Incidence-Cavitation Boundaries" which appeared in our October issue were styled incorrectly. They are Norman K. Pascoe and S. W. Hobday, M.I.R.E., Associate I.E.E., both of the Research and Development Company and Seaglider Ltd.



Russia's biggest and latest sea-going hydrofoil is the Vikhr (Whirlwind) recently launched by the Sormovo shipyards. The craft seats 300 passengers. It has three lounges, a restaurant and a fresh-air deck

WESTLAND SR.N2

the World's biggest and first practical hovercraft has now successfully completed its experimental passenger service between Ryde, Isle of Wight and Southsea.

No unforeseen problems have arisen in operating in a busy waterway, and the schedule was well maintained, average speeds of 60 m.p.h. being achieved. Turn-round times were as low as 3 minutes.

WESTLAND *the first name in HOVERCRAFT*

WESTLAND AIRCRAFT LIMITED YEOVIL ENGLAND

Incorporating: Saunders-Roe Division · Bristol Helicopter Division · Fairey Aviation Division

Leader of the Vickers-Armstrongs (Engineers) team is S. R. Hughes, Manager of the company's Hovercraft Division. His VA-3 operated the world's first scheduled hovercraft service

Chief Designer of the Saunders-Roe Division of Westland Aircraft is R. Stanton Jones who heads the team responsible for the SR.N1 — the very first hovercraft — and SR.N2

Hovercraft Industry's Rapid Progress

In barely four years the British hovercraft industry has transformed an idea into a range of commercially viable vehicles soon to be launched on the world's markets. Examined here is the approach of the four companies concerned and their design philosophies

● VICKERS-ARMSTRONGS

WHEN, towards the end of 1959, Vickers-Armstrongs decided to turn their attention to air cushion vehicles, three factors soon became apparent: first, that to be able to offer craft with a wide commercial appeal it would be necessary to build hovercraft of at least 100 tons a.u.w.; secondly, that before being able to design and manufacture vehicles of this size it would be essential to produce at least two generations of research "tools"; and that, thirdly, the development programme would have to be sustained for a number of years.

Air cushion vehicles have a variety of applications, some being as replacements for conventional forms of transport, others in more adventurous roles. Vickers decided to direct the major part of their initial research into the development of high-speed craft with an amphibious capability — a true hovercraft. This meant employing their previous experience as aircraft designers and manufacturers in applied aerodynamics and the use of lightweight materials in the production of fast lightweight craft of high structural integrity.

The Vickers "first generation" hovercraft, the VA-1, was completed in November, 1960 and during the following 18 months provided a great deal of useful research data and practical experience. During this time, the original re-circulating lift system was changed, the all-up weight increased and the bow-shape modified.

On April 11th, 1962, the VA-3, the Vickers "second generation" hovercraft made its appearance and, while its initial trials were in progress, it was announced that an operational trials programme was to take place within three months across the estuary of the River Dee. This, it was emphasised, would provide those participating with practical experience in the handling and maintenance of the craft in realistic conditions; would provide a guide to passenger reactions and show whether there were any special problems in passenger handling, and would demonstrate the safety-with-speed characteristics of hovercraft. It was hardly surprising that such a bold step should have attracted a great deal of attention to the world's first scheduled hovercraft service; and it is understandable that much of the interest was focussed on the service to the public as such, which tended to overshadow

John Britten (left) and Desmond Norman of Britten-Norman Limited, whose 10-seat Cushioncraft CC-2 is the first hovercraft to go into series production.

the other essential features of the operation. This, for the press, radio and television, was a newsworthy item indeed. Grateful as they were for all the publicity as far as the participants, Vickers, British United Airways and British Petroleum were concerned, this was first and foremost an operational trial, designed to accelerate the pace of the Vickers development programme.

Not being a publicity stunt or a sales drive, it was not necessary to cap the Rhyl-Wallasey exercise with something even more eye-catching. Instead, VA-3 has returned to base to continue the pre-determined development programme, using the experience gained during the summer's operations. These have shown that the vehicle can operate safely from crowded beaches, over sand flats deeply rutted by the receding tide, through waves more than three times the design hover-height of the vehicle, and from an embankment of about 1 in 5 gradient. Experience has been obtained of the extent to which the structure, control systems, engines, fans and air screws can withstand the corrosive affect of sea water and the abrasive affect of blown sand. The trial has confirmed the basic design assumptions and has shown that a craft can be maintained without complex engineering facilities.

While these trials were carried out in the United Kingdom, albeit some 200 miles from base, future opportunities appear to include not merely the operation of ferries at home, whether between existing terminals or, as in the case of Rhyl-Wallasey, off the beaches; attention must be focussed on areas overseas, particularly where existing forms of transport cannot effectively fill the need, or where the special advantages of amphibious hovercraft can obviate the necessity for complete terminal installations.

It is relevant to note here that another Vickers "second generation" craft, the VA-2, which is now beginning its trials, it not only large enough for full-scale evaluation, but also small enough for ease of transportation overseas.

The introduction of flexible members which will follow from research work now in progress, is a step towards improved wave-riding ability of "pure" hovercraft. By employing structural flexibility, the hover-height can be less under all conditions, and a saving in power and operating costs obtained. Thus the development programme, the end of which has not yet been reached, goes on towards the large viable vehicles which have always been the ultimate aim. But it is acknowledged that it would be desirable to have a number of craft operational to ensure that the pace of development of the engineering aspects is maintained in step with the technical advances. For example, the most practical way of achieving longer intervals between engine overhauls is through actual operations. Nevertheless, Vickers are confident that a large craft, either commercial or military, of, say, between 100 and 150 tons can be produced to meet the requirements of various routes and duties.

● WESTLAND

WESTLAND'S design philosophy is based on high speed coupled with amphibious capability. This combination, feasible only with an air cushion vehicle, seems to the company to offer by far the best prospect of successful, large-scale commercial exploitation. Apart from enabling transport to be provided in areas barred to conventional vehicles, it gives promise of making the larger air cushion vehicles fully competitive with conventional means of transport, such as sea ferries. It makes the air cushion vehicle completely independent of costly dock and terminal facilities and gives a degree of operational flexibility previously unobtainable.

This basic philosophy led naturally to the adoption by Westland of the flat-bottomed, annular jet configuration. Whilst, from the outset, the company never doubted that its approach was correct, it obviously had to prove the soundness of its ideas with a carefully-phased development programme. The 5-ton SR.N1 — Britain's first air cushion vehicle, and the first all-metal craft to be built — quickly showed that the basic approach was sound. Less than two months after it was launched, it crossed the English Channel from Calais to Dover to mark the 50th Anniversary of the first cross-channel flight by Louis Blériot in 1909.

As SR.N1 experience built up, confidence grew. It was recognised, however, that before the company could be really certain it was on the right lines, its ideas would have to be evaluated with a craft more nearly representative of the 50-ton vehicle then thought to be the minimum size for efficient commercial operation. To avoid the obvious risks of jumping from a 5-ton research craft to a 50-ton, high-speed vehicle, it was decided to build the smallest machine which could carry the fan, transmission and control systems projected for the even larger craft the company already had in mind. This led directly to the 27-ton, 66-seat SR.N2 which had its first sea trial on January 8th of this year.

After intensive basic development trials, during which SR.N2 if anything exceeded expectations, the company decided to obtain certification to carry fare-paying passengers, with a view to operating an experimental passenger service before the end of last summer. Whilst the performance of SR.N2 had given every reason for confidence, the company recognised that experience under actual operating conditions was vital. The experimental passenger service, operated jointly with Southdown Motor Services Ltd. between Southsea and Ryde, Isle of Wight, last August, proved a great success. Two aspects — turn-round times and passenger reaction, both vital to the successful commercial use of air cushion vehicles — were most satisfactory. Turn-round times as low as 3 minutes were achieved, and passenger reaction was, to quote Southdown's Area Manager, Mr. J. Armstrong, "extremely favourable". Possibly the outstanding impression of passengers generally was the smoothness of the ride even in roughish seas, an encouraging reaction as on several occasions there were 4 ft. seas running, with winds up to 30 mph. This outstanding "rough water" performance stems, of course, from the use of a flexible skirt, and an intensive development programme is now in hand to increase its effectiveness still more.

That the company's general confidence is justified is borne out by the recent conclusion of an agreement with Autair Helicopters Limited of Montreal, Canada, for the joint operational exploitation of Westland air cushion vehicles in Canada. Mr. D. W. Connor, President of Autair, has gone on record as saying that he sees the most promising future for this type of craft in the Canadian Arctic, along the Mackenzie and St. Lawrence rivers, and in the Great Lakes area. The company regards this demonstration of confidence by Autair in the future of air cushion vehicles as a most gratifying confirmation of its own assessments.

There is evidence, too, of lively military interest in the possibilities of air cushion vehicles as aircraft carriers, landing craft in amphibious operations and anti-submarine craft. Practical experience to date indicates that much larger vehicles than SR.N2 are technically feasible. British Services' interest was clearly shown by the recent establishment of a Joint Services Trial Unit at Lee-on-Solent.

Far from sharing the recently-published view that hovercraft have fallen down badly, Westland firmly believes that if anything, future prospects are growing even brighter as practical experience bears out, and in some cases exceeds, theoretical expectations. As the company's Chairman, Sir Eric Mensforth, said recently: "We are arranging further demonstrations at home and in the world-wide market which completely transcends the relatively limited opportunities here, much as we hope to see these developed, for example the ferry requirements of the Clyde, Humber, Severn and Solent".

Design work on the 37-ton SR.N2, Mk. 2, a "stretched" civil variant of SR.N2, is in the final stages. This craft will be capable of carrying up to 150 passengers or 12 tons of freight at cruising speeds of more than 70 knots.

Westland is continuing to devote substantial resources to the development of air cushion vehicles. It has no doubt that the military and civil potential for these craft fully justifies the great effort it is making.

● CUSHIONCRAFT

THE CC-2 Cushioncraft is built at Bembridge Airport on the Isle of Wight — the headquarters of Britten-Norman Limited. John Britten and Desmond Norman are two unusual young men who have built up a world-wide crop-spraying business. They invented an advanced form of atomiser, which they now build in quantity and supply to crop spraying contractors all over the world as well as using it throughout the fleet of more than 70 aircraft that they operate in areas of the Caribbean, Latin-American, Africa, and Australia.

It was their familiarity both with aviation in remote places and the frequently associated difficulties of surface transport that turned the thoughts of Britten and Norman towards adapting Cockerell's hovercraft concept to these ends. Characteristically they decided to "have a go".

Their analysis of the fundamentals led them to the decision that the prime criteria were a low cushion pressure, a simple aerodynamic system and a simple fan drive system. With the support of Elders & Fyffes Limited these were translated into actuality in the CC-1, an experimental vehicle designed to explore the basic problems of control, stability and propulsion.

● The Role of Hovercraft Development Limited

This Report appeared in the October, 1962, issue of the N.R.D.C. Bulletin

CONSIDERABLE progress has been made since the autumn of 1958 when the order for the first hovercraft, the Saunders Roe SR.N1, was placed by N.R.D.C. A subsidiary of N.R.D.C., Hovercraft Development Limited, has financed, together with the firms concerned, a first and second generation of craft. It has also set up a Technical Group at Hythe, Southampton, to provide a technical service to the industry.

The SR.N1 has been modified in successive stages to the point at which it is almost twice its original weight and can travel at more than twice its design speed. It has been used to study problems associated with a gas turbine in a hovercraft, to improve directional, pitch and roll stability, to test flexible trunks in order to increase the effective hoverheight and to develop a form of automatic pitch and roll control.

The SR.N2, a design based on SR.N1 experience, was launched in January this year and is capable of carrying sixty-eight passengers at 70 knots. Although it is probably too small to be a truly economic commercial vehicle, it will provide valuable operational experience for larger annular jet craft. It has been used during the summer to provide a trial service across the Solent.

The VA-1, built by Vickers-Armstrongs, was used during 1961 to gain experience on rectangular planform hovercraft. It was constructed mainly of wood and used one engine for lift and one for propulsion. The VA-3, also rectangular in shape, launched in April this year, carries twenty-four passengers at 60 knots. Its use is to assess operational characteristics and it has run trial-scheduled passenger services this summer between Wallasey and Rhyl. Although this craft is of the annular jet type, it differs from SR.N2 by having rudimentary non-immersed sidewalls and a lower cushion pressure. This firm have also built the VA-2, an air transportable demonstration vehicle, now being tested.

William Denny & Bros. have built two immersed sidewall craft in which it is only necessary to seal the cushion at the ends with an air curtain. This concept requires low power and is suitable for speeds up to 50 knots. The D.1, a first generation craft of this type, was first tested by Denny Hovercraft Ltd., and is now being operated by H.D.L. The D.2 is a commercial passenger carrying craft capable of 25 knots and carrying sixty people.

Folland Aircraft Ltd. built their GERM to examine the possibilities of overland hovercraft, but due to a decision of the Hawker Siddeley Board, have discontinued their work.

The CC-1 was built by Britten Norman in 1960 as a test vehicle. This has led to the CC-2, a ten-seat craft which is being built by Cushioncraft Limited under licence from H.D.L.

The Technical Group of H.D.L. has kept closely in touch with the development of these craft while investigating the potential improvements in the efficiency and stability of hovercraft systems. One specialist application, the Hovercar, is being studied in detail. This is a projected 300 mph inter-city transport, supported by "air-bearings" in a shallow V-shaped concrete track. Various forms of propulsion are being considered, including the linear motor under investigation at Manchester University. A scale-model test track is being built in Hythe.

As more hovercraft operational experience is gained the role of H.D.L. has tended to change. It now has the task of providing the answers to technical queries raised by the industry and at the same time attempting to look ahead sufficiently to be able to provide the answers to future problems as they occur.

The CC-1 admirably served its purpose : it pointed the way toward the design of a practical amphibious air-riding vehicle. The result, the CC-2, first flew in August 1961 and was almost immediately purchased by the Ministry of Aviation.

The first prototype of the CC-2 was a ten-seater, powered by a Rolls-Royce V-8 automobile engine driving two large-diameter centrifugal fans and discharging through annular slots with guide vanes. With a designed clearance height of 12-24 inches according to load, the vehicle combined a cruising speed of about 40 mph and a range of around 500 miles.

The Ministry of Aviation has been using the first CC-2 for a research programme on air cushion vehicles at the Royal Aircraft Establishment, Bedford. Before delivery to Bedford the craft was exhibited at the International Boat Show in London and aroused a great deal of interest — not so much from yachtsmen as from harbour authorities, rescue organisations, oil companies and other people faced with personnel communication and general transport problems in remote parts.

To carry forward the building and marketing of Cushioncraft, Britten-Norman formed an associated company with J. Samuel White & Co. Ltd., the Cowes shipbuilders, which, under the name of Cushioncraft Limited, was capitalized at £100,000.

Work was started almost immediately on the second CC-2, the design of which has been modified in detail as a result of further development work. The chief differences are a change of profiles of the bow and stern, and the use of rather larger diameter fans. The power output of the engine has also been increased and new gearboxes adopted for the fan drives.

The second CC-2 has been bought by the War Office for experimental work at the Fighting Vehicle Research and Development Establishment. The craft is nearing completion and will be delivered at the end of its trials.

What of the future? Britten-Norman have evolved what is, perhaps, the only practical air cushion vehicle with which potential operators can economically gain a workable tool with which to amass experience in the operational pros and cons of this new form of transport.

There is a large number of companies around the world which, individually, are only too conscious of the fact that sooner or later they will have to operate air cushion vehicles. There are, equally, companies who see in the air cushion vehicle a possible solution to many of the transport difficulties with which they now have to deal. But to gain working experience, even on a small scale experimental basis, is an expensive undertaking. At a U.K. price of about £25,000 the CC-2 is a relatively low-cost solution to the problem.

● DENNY HOVERCRAFT

DENNY HOVERCRAFT LIMITED, a subsidiary of the old-established Scottish shipbuilding firm of William Denny and Brothers Limited, was formed to develop hovercraft for high-speed passenger and freight services on rivers and estuaries. The company is at present concentrating on sidewall types and forsees the eventual development of river hovercraft of up to 1,000 tons a.u.w. and with speeds up to 60 knots.

Construction of the company's first craft, the Denny D.1, began in November 1960 and it was completed in May 1961. Built of plywood and mahogany and with a ducting system and nozzles of sheet steel, the D.1 was built to carry a trial crew comprising a driver and two instrument observers.

The lift fans are driven by two 25 hp 3-cylinder Excelsior water-cooled engines and the propulsion propellers by two 50 bhp Mercury 500s.

The speed attained as a mean of two runs in good conditions over a measured mile was 17.6 knots. Agreeable characteristics demonstrated by the craft included the good stability and comfort provided by the air cushion, which appeared to iron out small waves; and that no noticeable waves developed when the craft was travelling above 5 or 6 knots — an attractive feature since it means that it would not upset small craft in the vicinity nor damage the banks of rivers. The craft steered and handled well and compared favourably in this respect with most conventional water craft of similar size and speed.

After completion of the first part of the trials of the D.1 it was decided that sufficient proof had been established as to the practical commercial value of the sidewall hovercraft and the design of a larger craft was started — the D.2.

Four craft were to be built and these were to be of the same arrangement, carrying 70 passengers. The length of the D.2 is 83 ft. 6 in., width 19 ft. 3 in., estimated service speed 25 knots, and pay load 5½ tons. The two propulsion engines are Caterpillar D.333s and the two fan engines are Caterpillar D.330s. Both types are turbo-charged aftercooled marine diesels. Propulsion is produced through two Schottel rudder propeller units attached to the transom. These units can turn through 360° in the horizontal plane and therefore the craft can be steered by turning the propellers to face any direction required for any manoeuvre.

Designer of the Denny range of hovercraft is C. F. Morris, who forsees the development of sidewall hovercraft with speeds up to 60 knots.

Because of the need to be able to produce, if required, large numbers of craft of this type and to keep an acceptable weight to the structure, the material used had to be carefully considered. Experiments were undertaken over a period of six months and finally a decision was made to use glass-reinforced plastic. The result of experiments was satisfactory and a large building shed was specially fitted out to enable construction to start. Fabrication in G.R.P. can only be undertaken satisfactorily if the temperature of the air in the workshop is stable within the limits of 60° F minimum and 70° F maximum and therefore thermostatically controlled air heaters were fitted in the shed and the walls and roof were insulated. Large plywood moulds were made for the sidewalls and frames and construction started in April 1962.

The craft is designed structurally to be capable of withstanding the following conditions which could arise in service :

a. Bending forces (transverse and longitudinal) caused by a wave of the length of the craft (and L/20 in height) in the sagging and hogging position.

b. Local wave impact forces on the bottom and bows of the craft.

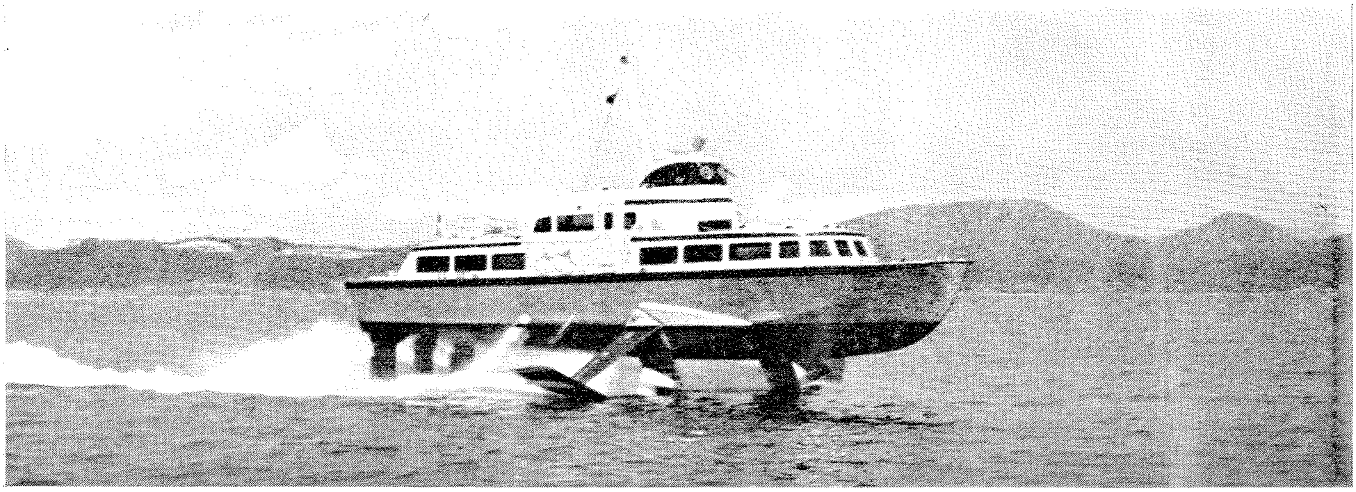
c. Propeller thrust forces on the transom beam.

d. Docking and shipping loads.

e. Crash acceleration loads on the engines and seats.

The preparation of moulds for the building of G.R.P. components involved a great deal of time and in order to produce a craft of the D.200 series quickly the first one was built in plywood employing the same type of construction as that used for the D.1. The structure of the D.2001 has the designed strength of the G.R.P. craft in the series and in appearance is almost identical to them.

The D.2001 was launched in July 1962, and it had been hoped to introduce the craft into service on the Thames in early August for London holidaymakers. It was found necessary however, to introduce some minor structural modifications which took longer than expected, and the season was missed The D.2001 and at least one of its sister craft will be in service experimentally next year.



MITSUBISHI MH-30

FIRST large hydrofoil craft developed in Japan, the Mitsubishi MH-30 is an 80-seat passenger craft designed for use in the rough waters round the Japanese islands.

It operates through waves up to two metres with very little pitching or rolling and has a top speed of about 40 knots.

The main foils are surface piercing while the aft foil, which carries the propeller nacelle, is fully submerged. Both foils are built in steel and are supported by long struts. Foilborne, the craft maintains a clearance of 170 centimetres between the sea surface and the bottom of the hull enabling it to ride smoothly over quite rough water. The propeller is described as being of "solid three-bladed crescent type, one metre in diameter."

Power is provided by a 12-cylinder 12WZ-AK high-speed diesel operating on kerosene. A Z-type drive is used, which according to the company, not only reduces the chance of occasioning cavitation, but improves seaworthiness since it permits the hull to ride higher above the water.

Hydraulic steering is fitted and the main engine is remotely controlled from the bridge.

Passenger accommodation is set on two levels. Working from stem to stern, the fore passenger quarters, set on the lower deck, seats 40; immediately behind at main deck level is a lobby for 15 passengers, and aft of this, on the lower-deck, is a saloon for 25 passengers.

A crew of three is carried, comprising captain, engineer, and purser.

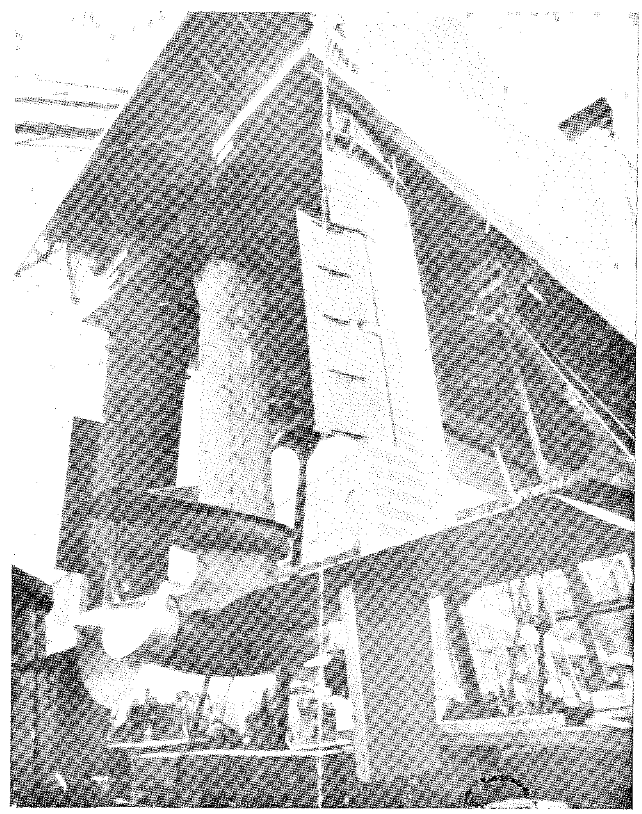
Principal Data

Length overall: 20.60 m; breadth (maximum) 5.00 m; breadth (at waterline): 4.34 m; breadth (maximum at hydro-foils): 12.50 m; depth (hull): 2.50 m; depth of hydrofoils (from bottom of keel): 3.15 m. Designed draught at full load (to bottom of hydrofoils in displacement condition): About 4.10 m; foilborne draught: about 1.65 m.

Weights: Gross tonnage, about 75 tons; displacement at full load: about 35 tons.

Powerplant: Mitsubishi Toji direct-injection, turbocharger with intermediate cooler, 2-cycle diesel engine, 12WZ-AK Type. Maximum output x revolutions: 1,500 PS x 1,600 r.p.m. Normal output x revolution: 1,350 PS x 1,500 r.p.m.

Performance: Max. speed, about 40 knots; service speed, about 35 knots; cruising radius, 250 nautical miles.



Details of the aft submerged hydrofoil, propeller and rudders are seen in this stern view of the craft

STRUCTURAL LOAD CRITERIA FOR NAVY HYDROSKIMMER AIR CUSHION VEHICLES

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Introduction

THE authors will set forth the assumptions of structural load criteria adopted for use in the present design of the SKMR-1, the Bureau of Ships 20-ton research air cushion vehicle (ACV). These criteria are regulated to a degree by the ship sizes now being studied. The paper will cover the philosophy and data which are used as a basis on which to establish the assumed criteria. The data which must be used includes ACV model test results, seaplane landing test results, ACV craft trial results, and planing craft trial results. The discussion of philosophy will cover model tests, flying height, cushion attenuation, hull form, expected usage, and how each influences the establishment of the criteria used when considering the conflicting and sometimes insufficient data. The authors hope for critical comments on the design philosophy and criteria adopted. Indeed, the value of this paper will be measured by any improvement in structural design criteria which it can generate, for it is the structural design criteria which has such a great bearing on whether or not the craft will meet its performance requirements.

Philosophy

In discussing the design philosophy for Hydroskimmer (Bureau of Ships ACV) structure we must give consideration to the types of operations which are most likely to be required. The Bureau of Ships is charged with the development of these craft as military vehicles. Logical missions will include open ocean operations, beaching and amphibious operations and high-speed off-shore operations. All of these missions will require a design criteria which imposes significantly greater structural loading than that required for the normal non-military mission. A point-to-point ACV ferry to be operated in Chesapeake Bay, for example, would hardly be expected to experience the loadings of an ASW Hydroskimmer. The result is a significantly different structure for the two designs and certainly a different structural weight as a percentage of all-up weight.

The design philosophy discussed herein has been applied to the design of the Navy's SKMR-1. It is expected that much of it can be applied to larger craft. One of the major missions of SKMR-1 will be to verify that the assumed structural criteria are adequate for military operations in rough water.

The SKMR-1 has the following principle characteristics :

The length overall is 65 feet.

The beam is 28 feet.

The longitudinal C.G. is 6 inches forward of the Cushion C.G.

The vertical C.G. is 70 inches above the flat bottom.

The design weight is 45,000 pounds. The craft flies at 1.5 feet at a speed of 70 knots over smooth water at this weight. The craft is assumed to travel at 50 knots at the same height and weight when travelling in state three sea. These are the

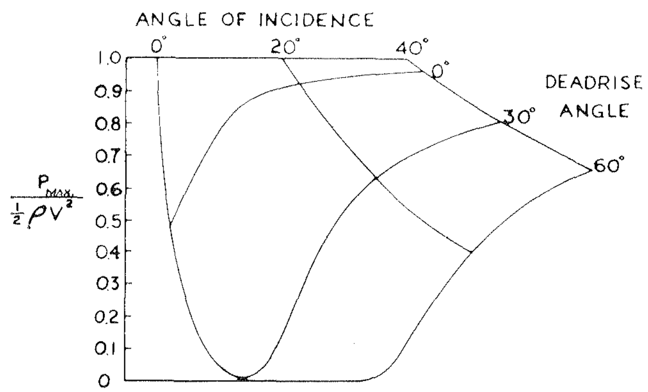

Figure 1

conditions considered for the structural design when cushionborne.

The maximum weight is 55,000 pounds. The craft flies at 1.25 feet at a speed of 70 knots over smooth water at this weight. This is the weight of the craft in a state three sea considered for the structural design when hullborne.

The Hydroskimmer, when cushionborne, is under combined hydrodynamic and aerodynamic forces which cannot be separated for analysis. Different model tests with varying hull forms and cushion arrangements will provide some guidance as to the relative effects, but model scaling factors for performance in waves still require verification.

It is assumed that the cushion has an effect of attenuating the loads experienced in a rough sea. This is considered to take the form of deformation of the wave tops by the high energy air curtain of the cushion and of the ship moving in anticipation of the sea force by sensing and reacting to it through the cushion action. The designer assumes a reduction of some loads because of this cushion attenuation when using test data from hulls having no cushion.

The hull form of the Hydroskimmer, which must be designed for rough water operation at high speed, is a complete compromise of good form for both the cushion lift and seakeeping. An efficient cushion for lift requires a large flat base; good seakeeping in rough water requires anything but that. Because the Hydroskimmer is designed primarily for rough sea, there is a tender balance between the seakeeping hull form and a high flying cushion, both of which will tend to reduce the structural loads experience in rough sea.

* *Presented at the National Meeting on Hydrofoils and Air Cushion Vehicles, Washington, September 17th and 18th, 1962, sponsored by I.A.S. and U.S. Navy.*

The expected usage of the ship will have a direct influence on the structural load criteria. If the craft or ship is to be an amphibian, it will require a higher effective cushion lift and a higher flying height. Of necessity, to keep the weight down, the structural design criteria must be eased. This can be justified by the fact that the craft is flying higher over the waves and land and will contact less severely. Even with this flying height, it is necessary to set down in rough sea and this will control the degree to which the structural design criteria may be eased.

It is considered that trunks, skegs, and skirts will appreciably reduce the loads experienced by the ACV. These must be tested on large scale vehicles to get significant data.

Data

The data which will be given will only be a cross section of that which is available. The few reports containing information of this type are readily available to the reader and it will serve little to attempt to do more than summarize some of the more important loadings from the references.

The Bureau of Ships initiated Hydroskimmer model tests in an attempt to supplement the data already available at the time. Convair, General Dynamics, ran tests of two dynamic models of different basic configurations.[1] One was rectangular in plan form and had side skegs piercing the water. The other was ogive in plan form and had a flat bottom. The wave system was contacting the models when the maximum accelerations were recorded. Vertical accelerations measured at the bow and C.G. of both models, run over uniform waves intended to simulate as closely as possible a state five sea to a 200 foot ship, were the same value of about 2 g.s. Power failure runs of both models showed vertical accelerations at the C.G. of about 3 g.s. Davidson Laboratory, Stevens Institute of Technology, ran tests on a dynamic model configured to represent a compromise between the side skeg and flat bottom configurations tested by Convair.[2] This model was run in a simulated random state three sea to investigate pitch and heave characteristics. The vertical accelerations agreed well with the Convair tests. The average of the highest 10 per cent of the maximum vertical accelerations of the C.G. at a corresponding full scale speed of 50 knots was about 2.5 to 3 g.s. The weight distribution characteristics of these ships would indicate that the best assumption for the Hydroskimmer would be vertical accelerations near the end of about 8 g.s. at the bow and negative 2 g.s. at the stern with a resultant 2.5 to 3 g.s. at the C.G. for the prominent condition of bow slap. This data strongly governed the design criteria assumed.

The planing hull, seaplane and other data are best utilised to supplement the Convair and Stevens data. Full scale tests on the SR.N1 indicated vertical accelerations of 8 g.s. at bow and the mean effective pressure on the bottom not exceeding 10 p.s.i.[3] The planing hull data depends to a large extent on the hull form. Heller and Jasper found in the testing of a full scale aluminium torpedo boat vertical acceleration at

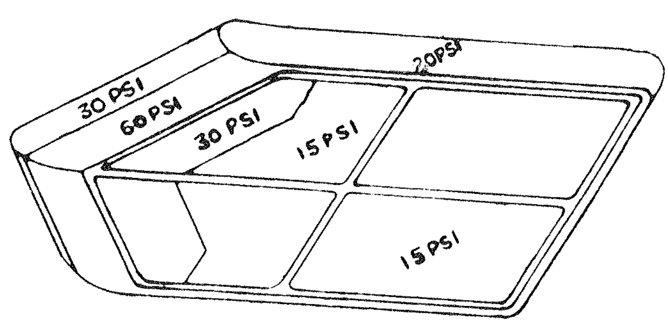

Figure 2

the bow of 11 g.s. and at the stern of negative 2 g.s. and a maximum effective pressures on the bottom up to 36 p.s.i. under conditions of 35 knots in a state four sea.[4] Ljungstrom notes vertical acceleration of 7 g.s. in the bow and maximum local bottom pressures of 20 p.s.i. have been measured on normal V-bottom boats at 45 knots in a heavy sea.[5] DuCane records vertical accelerations of 8 gravities at the bow and maximum pressure measurements of 12 p.s.i. on the bottom of a 63 foot high-speed launch operating at about 40 knots.[6] As can be seen there is a large difference between these data for planing craft. Ditching tests at Wageningen were run to determine pressures and accelerations on the flat bottom of a circular and an ogive plan form model.[7] The vertical accelerations for the circular model varied from 5 to 15 g.s. whereas, the vertical accelerations for the ogive model varied from 5 to 30 g.s. These models have no air cushion and accelerations registered have been discounted for Hydroskimmer design. Maximum bottom pressures of 20 p.s.i. with no attenuation credited to the air cushion were recorded.

The data may be tabulated as follows :

Reference	*Maximum Accelerations (g.s.)* Bow	C.G.	Stern	*Maximum Pressures (p.s.i.) Bottom*
1	2–3	2–3	—	—
2	3–9	2.5–3	—	—
3	8	—	—	10
4	11	—	–2	36
5	7	—	—	20
6	8	—	—	12
7	—	5–30	—	20
SKMR-1	8	2.5–3	–2	15–20

Figure 1 is based on data contained in a NASA report of pressures recorded on flat bottom and vee bottom models planing over water.[8] It is used for determining the pressures on the bow and bottom of hull forms which may have an angle of attack or a deadrise angle entering the water. Knowing these and the craft velocity (feet per second), the maximum pressure, P max. (p.s.f.) can be determined. The tabulated data above and Figure 1 were used to determine the pressures assumed for the SKMR-1 design as shown in Figure 2.

Criteria

Using the data and following the philosophy even here, the Hydroskimmer design load criteria was derived. Figure 2 gives the pressures assumed on the shell of the SKMR-1. These assumptions were mainly based on Figure 1 and the SR.N1 test results. Figure 3 gives the vertical water forces (pounds) and translational and rotational accelerations (g.s. and radians per second,[8] respectively) assumed for SKMR-1 and to a number of different hydrodynamic load conditions as indicated by the sketches in Figure 3. These accelerations are used in the design of the major structural girder of the hull and for the foundations of the equipment and machinery. The conditions are for a speed of 50 knots in a state three sea.

Conclusions

The following conclusions are made :

a. The philosophy given in this paper is that applied to the SKMR-1 structural design.

b. It is believed that the criteria shown is realistic for open ocean applications.

c. The criteria shown is basically ACV model test and test craft results modified by planing craft data.

d. An extensive test programme of the SKMR-1 will verify the assumptions made and the model test scaling techniques used for the structural design criteria of the SKMR-1.

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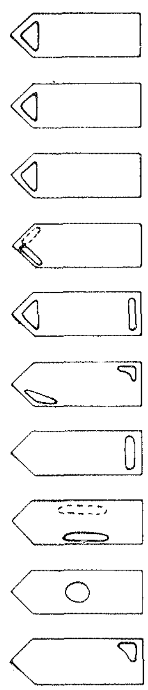


	VERTICAL FORCES (LB) BOW	MIDSHIPS	STERN	TRANSLATIONAL "G" VERT.	LONG.	TRANS.	ROTATIONAL ACC. PITCH	ROLL	YAW
I	67,500	0	0	2.5	-1.0	0	6.0	0	0
II	45,000	0	0	2.0	0	0	3.3	0	0
III	90,000	0	0	3.0	0	0	6.0	0	0
IV	67,500	0	0	2.5	-1.0	±1.0	6.0	±2.0	±0.2
V	45,000	0	45,000	3.0	-1.0	0	0	0	0
VI	45,000	0	45,000	3.0	-0.5	0	0	0	±0.5
VII	0	0	45,000	2.0	-0.1	0	-3.0	0	0
VIII	0	45,000	0	2.0	-0.1	±0.5	0	±5.0	0
IX	0	45,000	0	2.0	-0.1	0	0	0	0
X	0	0	45,000	2.0	-0.1	0	-3.0	±2.0	0

Figure 3

by E. L. Eveleth,
Marine Systems Corporation

So far most of the hydrofoils built have either been of the rather large surface-piercing type or based on small surface piercing kits for outboards and small run-abouts.

The Marine Systems Corporation thought that there was a very definite need for small submerged foil hydrofoils and consequently designed the XI-C, a 40-foot vessel carrying 24 passengers. This craft has two gasoline engines and uses out-drives with extended shafts to each propeller on the two stern foils. It also has a conventional standard out-drive in the stern for use when the vessel is operating as a displacement craft. These small vessels can be built in approximately eight months at a cost of less than $100,000 each, depending on the equipment required. There is an alternate power arrangement using three small turbines.

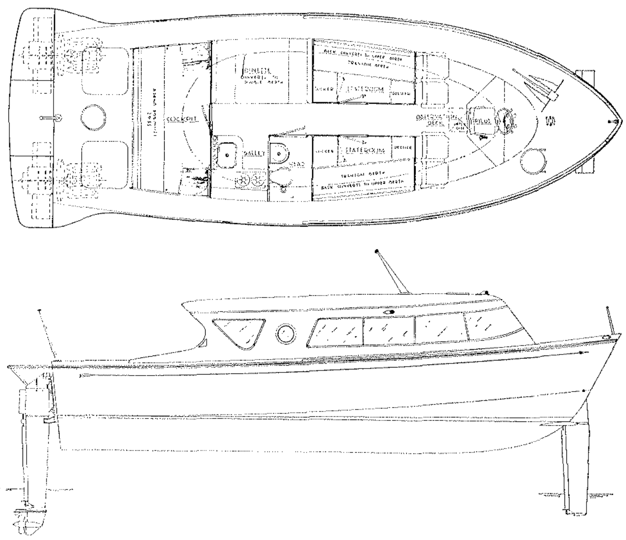
The next model which the company is offering is the Model XVIII, a 52-footer carrying 48 passengers and using a lightweight 900 hp diesel engine with a vee transmission. This craft is also under consideration in a slightly stretched version — 55 to 65 feet — using two 900 hp lightweight diesels and carrying a much larger passenger load.

Marine Systems Corporation designed for the oil industries as hydrofoil work boats, the Model IV-B, a 45-footer, and the Model IX, a 65-footer. The IV-B was to be powered with one 1200 hp gas turbine and the Model IX with two 1200 hp gas turbines.

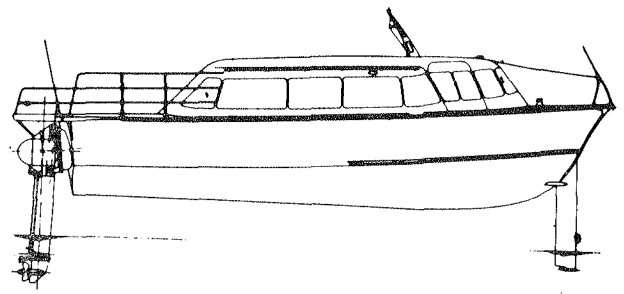
At the same time the company designed the Model V, a 44 passenger hydrofoil vessel, 45 feet in length, with one 1200 hp gas turbine, and the Model VII, an 86 passenger hydrofoil of 65-foot length, with two 1200 hp gas turbines. The Model II was a 90 passenger 75-foot vessel with two 1200 hp turbines. None of these vessels have been built to date but they have all been laid out in engineering concept and designed to operate efficiently, with low maintenance. As the studies proceed with craft of various sizes and configurations, it is interesting to note that when route surveys were made, the operational costs afloat versus block distance came out in every case from $2\frac{1}{2}$ to 5 cents per seat mile. The other interesting part of the surveys revealed that the hydrofoil was showing the same improvement over conventional types of marine transportation that the jet aircraft showed over piston aircraft. Also it was discovered that the hydrofoil, when compared to a similar cost helicopter, could carry four times the load at slightly better than half the speed and at one-third the cost of the helicopter. Practically all of the hydrofoils contained in this study cruise at 50 miles an hour which is approximately three to four times the speed of conventional sea-going transportation.

Submerged foil craft can run smoothly in any sea up to and including the clearance from the bottom of the hull to the surface of the water. On the larger seagoing craft the clearance from the bottom of the keel to the ocean is approximately $4\frac{1}{2}$ feet, so for the first $4\frac{1}{2}$ feet of sea the vessel feels no effect whatsoever. With seas over $4\frac{1}{2}$ feet automatic stabilization equipment begins to give the vessel a slight heave over the seas encountered. This device is actuated electronically by a sensing device which determines the size, amplitude and characteristics of the seas encountered. The result is, of course, high speed marine transportation with an absolute minimum of seasickness. So much interest has been shown in the smaller craft, i.e. in the $100,000 category, that Marine Systems have laid out a Model XI-E as a hydrofoil yacht.

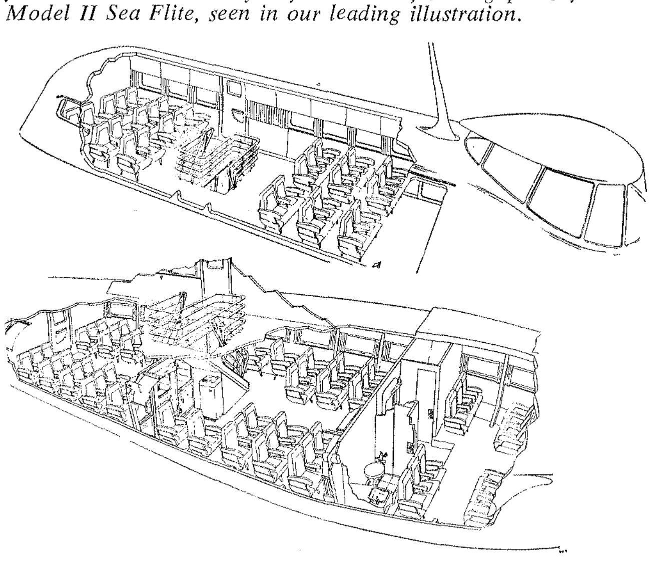
At this point it is of interest to review some of the typical studies made of estimated operating characteristics. The first one showed a Model XI Sea Flite operating four round trips per day between Ft. Lauderdale and Miami Beach. The total annual operating cost appeared to be about $91,220 per year with a maximum possible estimated return of profits of $110,280 per year. This is all possible with a vessel costing $100,000. The second study was of a Model V running from Miami Beach to Bimini on 3 round trips per day. The cost of this vessel was approximately $330,000 and its annual total operating costs would be approximately $210,500 per year with a possible profit of $384,500 per year if run at 100% density. The third run was a study of a Model VII costing approximately $660,000 running from Ft. Lauderdale to Freeport, Grand Bahama, two round trips per day. The total annual operating costs would be approximately $377,000 per year and the potential yield of profits is $655,000 per year.



Model XI-E — A Sea Flite arranged as a hydrofoil yacht.



Model XI-C — a 24-passenger craft of the type being built for North American Hydrofoils. Below, seating plans for the Model II Sea Flite, seen in our leading illustration.



Where has there been a piece of capital equipment designed that has the astonishing potential if run on an appropriate schedule at 100% density of writing off its entire cost in the first year and a half of operation ?

I believe that it is important to bury some of the skeletons and slay some of the dragons that lay in the way of this new programme. Nobody in their wildest dreams ten years ago would have thought of paying five to eight million dollars for a jet aeroplane and yet their very speed and fast turn around have proved them extremely successful because they have replaced a large number of other aircraft and still do not have to carry excessively large crews.

The hydrofoil is here to stay and it is our belief that the submerged foil vessel with variable incidence controls will be the type used for off-shore work and that 1963 will be hydrofoil year in the U.S.A.

In the United States suburbia is breaking the backs of railroads. Commuter runs are too short for aircraft, too expensive for helicopters. Monorails and like possibilitites for high speed ground transportation will one day be a fact but are not with us yet.

Most major cities are on the waterfront of oceans, lakes or rivers. Suburbs tend to fill up first along the water, so commuters become familiar with the water, have an affinity for it. Occasional sporadic attempts on the part of water carriers have failed for a number of reasons, principal among which has been the relatively low speed of their vessels.

Hydrofoils can fill the water gap, and hence the commuting gap. They are capable of higher average speeds than even railroads in congested urban complexes; they can be run at a profit, and they can bring an advantage pleasantly novel to marine transportation : freedom from seasickness.

For many years Europeans have been routinely ferried back and forth over commuter distances in hydrofoil vessels. The success of these ventures has been marked, both from the standpoint of passenger comfort and satisfaction and from that of carrier profit.

No type of transportation is wholly weather-proof. Gales, ice, fog and other natural disturbances cause trouble with all schedules. Hydrofoils are just as susceptible to these disturbances. In wave conditions too heavy for conventional craft of similar size, hydrofoils will, however, be far more comfortable, since their appendages act as stabilizers. Fog will be a problem until a type of radar is perfected which can "see" objects sufficiently far ahead to enable the operator to change direction at the relatively high speeds utilized. Such radar will be available soon.

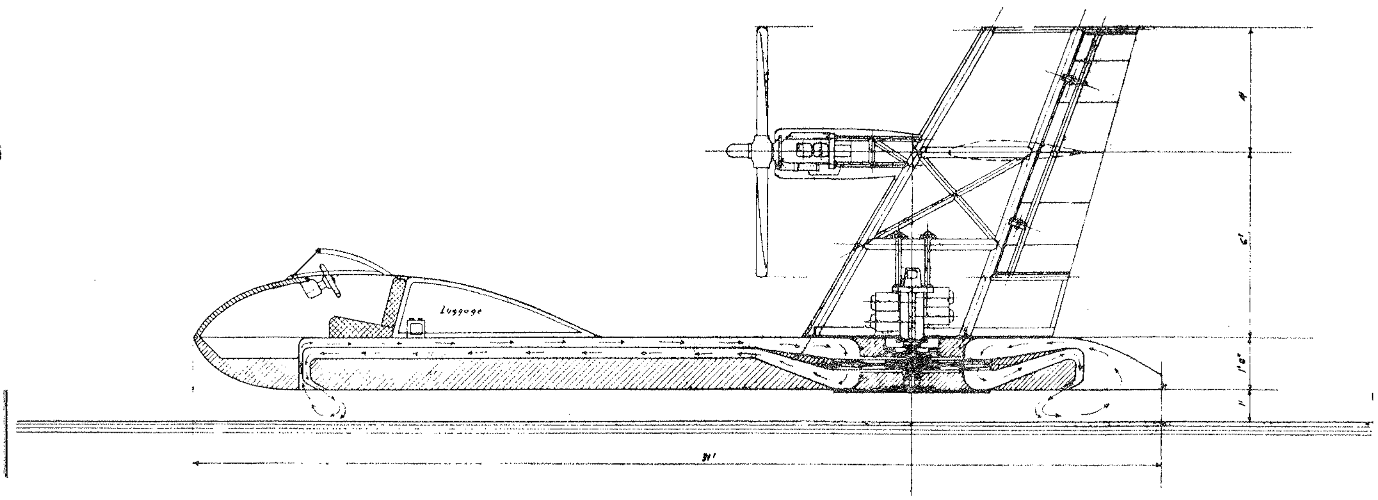
The first commuting venture of hydrofoils in the U.S. will be inaugurated in early 1963 from Atlantic Highlands, N.J., to Manhattan by North American Hydrofoils, Inc. This route was selected for two very practical reasons. First, New York and environs is an ideal location as a "springboard" for a new idea because of the vast quantity of indigenous water lore, promotion media, venture capital — and traffic congestion. Second, the run mentioned will save participating commuters approximately one hour each way, due to the shape of the Lower Bay and the resulting necessity for long mileage overland from the Highlands area.

North American Hydrofoils has investigated something like 70 commuter runs offering advantages of a like nature. By no means are all so dramatic in time saving as that from Atlantic Highlands, but each is of interest. Seventy is nowhere near the saturation figure.

Another first for North American Hydrofoils will be the introduction of submerged foil vessels to a commercial enterprise. North American Hydrofoils selected the submerged type in the belief that speed and comfort are advantages requisite to earn passenger loyalty, and also that competition would inevitably come to submerged foils in a short time. Why, then, not start with the most advanced ?

The first two hydrofoil vessels to be operated by N.A.H. are being built by Marine Systems Corporation of Miami, Florida. These modern craft will be launched late in 1962 and will be tested exhaustively in southern waters prior to the inauguration of the New York commuting runs.

North American Hydrofoils, Inc., is led by three marine-minded people whose names have for decades been known to the yachting world on the Atlantic Coast and the Great Lakes. President is Harry G. Nye (formerly of Murphy and Nye), who has earned international yachting fame. He is president of Nye Tool Company and Galesburg Malleable Iron. Leeds Mitchell Jr. is vice-president, yachtsman, and aircraft pilot in the USAF. Secretary and Treasurer is Pauline S. Goltra, president of Goltra Foundries, and a well-known yachtswoman.



Slide 1. Elevation section of Everglades Speedster.

MATERIALS AND FABRICATION TECHNIQUES IN AIR CUSHION VEHICLES

by B. F. Holcombe,
Project Director,
Reynolds Metals Company

WHILE the cushioning effect of the ground on lifting surfaces such as wings and helicopter rotors has been known for more than fifty years, it has only been in the past five years that serious proposals were made to build machines which would make a significant use of the ground cushion principle.

As you all know, it has become customary to refer to those devices which use the ground cushion as their principal support as "Ground Effect Machines" — thus distinguishing them from airplanes and helicopters which only incidentally use the ground cushion as a support.

Reynolds Metals Company became interested in this relatively new field because we felt that GEMs offered a large potential use for aluminium. We felt that aluminium would be a natural material for GEMs because of its light weight, good strength to weight ratio, workability, corrosion resistance, and ease of fabrication. In addition, two key industries in the development of practical GEMs — the aircraft and boat industries — are familiar with aluminium.

We also felt, after a preliminary investigation of the field, that a realistic approach toward GEM design must include a lightweight metal.

While the GEM is neither a boat nor an airplane, it does use aerodynamic principles in its construction — which means it should be built as light as possible.

On the other hand, the GEMs — in a principle of construction completely foreign to aircraft engineering — have to be designed to be homogeneously elastic. Because GEMs operate close to the water and can, therefore, hit the crests of waves, they must be able to absorb this impact "elastically" and distribute it to the rest of the craft. A rigid hull would be very dangerous. If it were feasible, a hull made out of rubber would be ideal because of the great elasticity. Aluminium meets the requirements best because of its low modulus of elasticity and its good strength to weight ratio.

Another factor that supported the use of aluminium in the design of a GEM is that the weight of a GEM is supported directly by the cushion, which is underneath the whole craft. As a result of distributing the weight equally over the bottom of the craft, the hull itself could be made from thin, stretch-formed aluminium.

Convinced that the concept of vehicles which skim over land and water on a cushion of air was sound, Reynolds decided to encourage the development of this new code of transportation by developing economical fabrication techniques — using aluminium, naturally.

In the past three years Reynolds has participated in many phases of the design, fabrication and testing of four GEMs.

1st — The "Ilen" (now called GEM II)
2nd — The McCreary Machine
3rd — Our latest GEM is called the "Everglade Speedster" — and was completely designed and fabricated by Reynolds. Mr. Carl Weiland was retained by Reynolds Metals Company as a consultant on this work. It went on the drawing board in July, 1960, and was completed in May, 1961. To date it has accumulated more than 150 hours of service. It holds sustained speeds of 75 miles-per-hour, a lift of 16 inches.

The fourth machine, a 16 passenger vehicle, has been designed but not constructed.

The craft is designed to operate either on land or water, but it was built primarily for use on water. It is completely floatable. The interior of the hull is lined with six inches of polyurethane foam, with a buoyancy double the weight of the craft. Thus, it could be sliced into sections and each section would still float.

The "Everglade Speedster" also has distinct advantages over boats using hydrofoils, including better visibility, ability to operate over ice, snow, swamps and shallows, and freedom from damage from logs and other debris frequently encountered on rivers and lakes.

Let me emphasize, however, that the "Everglade Speedster" is only a *prototype*. Certainly it is a successful prototype of a practical, operational craft, but I consider it only the first step in a series of design and construction stages which eventually will result in practical, high-speed, low-cost, operational GEMs of sufficient size and versatility to accomplish many missions.

The next stage in the development programme of GEMs will be the construction of a larger craft. Such craft might perhaps weigh 20-tons and be capable of making a speed of 100 knots, and might possibly be similar to the Navy's " Hydroskimmer ".

This large craft would give us the required data for the design and construction of other large air cushion vehicles for such purposes as:

1. Anti-submarine warfare
2. Rescue operations
3. Fire-fighting
4. Assault landing craft
5. Torpedo boats
6. Cargo craft
7. Passenger craft
8. Commercial service vehicles

Before discussing the design details of the " Everglade Speedster " and some of the drawing board dreams of our engineers — all of which I know will be of interest to you — I have a short film I would like you to see. It shows three Reynolds GEMs in operation.

(The movie shows (1) The " McCreary " machine being test-run for study of controls, (2) The " Ilen " machine being test-run for the Marine Corps at Quantico, Virginia, and (3) The Reynolds " Everglade Speedster " tested at speeds up to 75 miles per hour on the Ohio River at Louisville, Kentucky.)

Film

The film you have just seen should give you a good idea of the extent of Reynolds' participation in the early development of Ground Effect Machines. The results of our efforts are wrapped up, to a great extent, in the " Everglade Speedster." This vehicle has been credited with being the fastest GEM in the free world, and possibly the whole world. It has proved to be a reliable machine, requiring very little maintenance. The " Everglade Speedster " is by no means the ultimate in Ground Effect Machines, but we sincerely believe it will be a valuable tool in the development of larger, faster, more versatile vehicles for commercial and defense applications as well as for private transportation and sports vehicles.

Now let's discuss, and take a look at — with slides — the design and fabrication details of the " Everglade Speedster " and some GEMs of the future.

Slide 1. Our first illustration (slide) indicates the basic construction details of the " Everglade Speedster." The craft was designed primarily for use over water, but it will operate just as well over land. The hull is 31 feet long, 14 feet wide, and two feet deep. It is constructed of aluminium-magnesium alloy sheet and lined with six inches of polyurethane foam — shaded areas — which give buoyancy. The blister on the front encloses the controls, the operator and three passengers, and a compartment behind the seats.

The "Speedster" is powered by two 180 hp aircraft engines. One is mounted vertically in the tail section and drives a horizontal fan that provides lift. Air is taken in through vents on the deck and around the edge of the craft and is blown out through a peripheral annular jet on the flat hull bottom. This creates a cushion of air on which the craft rides free of friction, or other resistance. The other engine is mounted horizontally on the tail fin and drives an aircraft-type prop that propels the craft forward at high speeds. Directional control is by means of the rudder. The entire craft, built of aluminium sheet for strength, lightness, and freedom from rust, weighs only 4,000 pounds.

Slide 2. The next illustration shows a plan of the hull and vertical midship section, front to back. Weight of the hull is 660 pounds.

Slide 3. The third illustration shows construction details of the forward part of the hull of the " Speedster." The heaviest metal in the super-light hull construction is the bow. The sections here are of .032-inch sheet. The bottom and the deck are of .020-inch sheet. The air passages and the aircraft-type stringers, or stiffeners, are of .016-inch sheet. Riveted construction was used throughout. Aluminium alloy 5052, a magnesium bearing alloy, was used in the construction of the " Everglade Speedster " because of its good strength characteristics and corrosion resistance. The craft gets much of its rigidity from the six-inches of polyurethane foam, which also gives sufficient buoyancy for twice the weight of the vehicle.

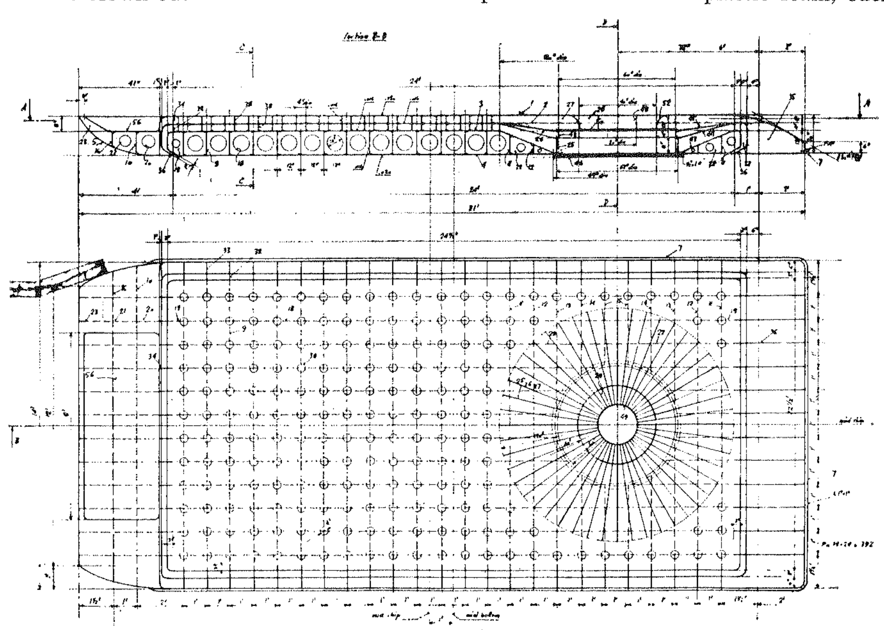
Slide 4. This drawing illustrates the use of similar construction methods in the proposed fabrication of a considerably larger Ground Effect Machine for research. The craft would seat 16 passengers and crew members and would have extensive cargo capacity. Shaded areas in the lower part of the hull indicate the amount of plastic foam that would be required to float the craft when it is at rest on the surface of the water with normal loading. For heavier loading, more plastic foam would be needed to provide greater buoyancy.

Slide 5. The next drawing suggests methods for beefing-up the structure of Ground Effect Machines that would be used to carry heavy machinery or vehicles on the deck. For example, the strong, extruded aluminium tracks — seen in cross section — would distribute the weight of a military vehicle or an engineering construction vehicle, or perhaps a helicopter or auxiliary vehicle. This is only one of the many possible ways of making the GEM of the future into a new breed of work horse.

Slide 6. This drawing may seem a bit fantastic and incredible to some of you. But then, a few years ago most of us would have pooh-poohed the idea of a modern version of Jules Verne's atom-powered " Nautilus," which has since become a reality several times over. Designed as a mobile missile base, this craft would be 400 feet wide, 1,000 feet long, and have a hull as high as a ten-story building. The huge propulsion units would extend another 70 feet into the air. An air cushion 20 to 40 feet thick would hold the vessel above the waves as it was propelled across the open sea. It would be much faster and have greater maneuverability than our mighty battleships and aircraft carriers.

Slide 7. Here are shown a few of the alternate methods of providing the buoyancy needed for GEMs that will operate over water. At the top we see the use of plastic foam, such

This paper was presented by the author to the National Meeting on Hydrofoils and Air Cushion Vehicles, sponsored by the IAS and U.S. Navy



Slide 2. Hull plan and elevation, Everglades Speedster.

as the polyurethane foam used in the "Everglade Speedster." The next illustration shows the use of water-tight flotation chambers. These chambers might also be used in some vehicles to house lift and propulsion units or for cargo space. The bottom diagram shows the use of large cylindrical floats or pontoons running the length of the vehicle. Here again some of this space could be put to other usese.

Slide 8. The next illustration shows some of the joining methods that can be used in the construction of Ground Effect Machines. The aircraft industry has used these methods for years and has found them to be reliable and efficient. The I-beam fabrication techniques — and by this I don't mean starting with I-beams, but, rather, assembling the components in such a manner that they serve as, and are in effect, I-beams — can be used in the construction of GEMs of all sizes. Rivets were used in assembling the structure and covering skins of the "Speedster." Resistance welding might well be used for similar structures. Fusion welding would be appropriate for the joining of heavier structures of large GEMs. The aircraft industry has had excellent results from the adhesive bonding of structures and skins for high-performance aircraft, and there has been some development activity in the use of adhesives for assembling aluminium pleasure boats. Epoxy resins have very good shear-strength characteristics and would be excellent for the fabrication of GEMs. Tensile and impact strengths are not as high as for fusion welded joints; but both tensile strength and elongation of epoxies can be greatly improved by mixing with polysulfides. Polysulfides are also excellent joint sealers when used alone. Extrusions of various types can be used also. Interconnecting extrusions can be welded or adhesive bonded, and in some cases the joint will be rigid without help from these joining methods.

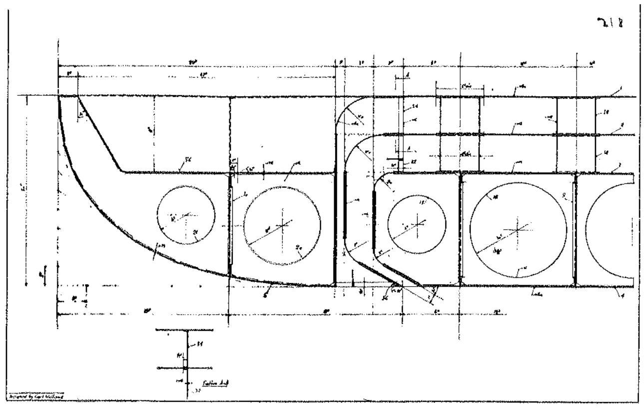
Slide 9. Care should be used in designing the Ground Effect Machine to assure that salt water traps will not be built into the vehicle. Good drainage of the understructure will minimize maintenance and will enhance the operating characteristics of GEMs.

Selection of the proper alloy should be one of the primary concerns of the designer of Ground Effect Machines, and this becomes much more important if the vehicle is to be used over or near salt water. Many of you here are aeronautical engineers, and in your work you have made extensive use of the copper-bearing aluminium alloys in designing and building aircraft. These alloys, such as 2014, 2017, and 2024, are good high-strength materials that were developed for and are ideally suited to airframe construction. However, and I cannot emphasize this too strongly, they are not preferable for GEMs which are to be exposed to marine atmospheres. The copper-bearing alloys are susceptible to intergranular corrosion in the presence of strong electrolytes, such as sea water. We think aluminium is the ideal material for the construction of Ground Effect Machines, but we must emphasize the need for proper alloy selection.

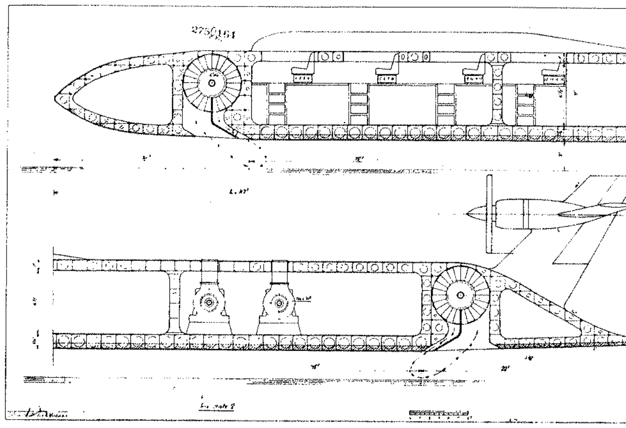
In recent years, several aluminium-magnesium alloys have been developed that have good mechanical properties and are highly resistant to salt-water corrosion. We strongly recommend the use of alloys 5086 and 5456 for GEM construction, especially when joining is by means of fusion welding. Alloy 6061, in which magnesium-silicide is the major alloying constituent, is also a very desirable alloy when joining is by means of mechanical fasteners. As I told you earlier, alloy 5052 was used for the "Everglade Speedster," and riveting was used as the joining method. This alloy has lower mechanical properties than the other alloys I have just mentioned, and its weld properties are not as good; but it has excellent resistance to corrosion and is suitable for craft of this type and size. For structures assembled with mechanical fasteners, alloy 6061 provides good strength and corrosion resistance. However, welded components made of this alloy lose much of their strength in the heat-affected zone.

Slide 10. Alloy 5086-H32, as seen on this graph, loses comparatively little of its strength in the heat-affected zone. Alloy 5456 has even higher properties than 5086 or 5083 after welding.

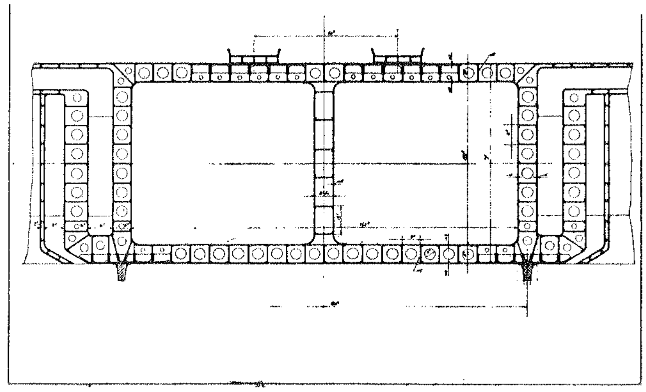
There has been some evidence of stress corrosion in the high-magnesium alloys, which include alloys 5483, and 5086, especially where service temperatures of 150° - 400° F. are involved. For this reason we strongly recommend that the -H32 temper be used for material that must be formed and that the -H34 temper would be better for non-formed parts. The material recommended for extrusions is alloy 5083-H112. Another advantage of alloy 5052 is that it is generally considered non-susceptible to stress corrosion or intergranular corrosion in all of the cold worked tempers.



Slide 3. Forward hull details.

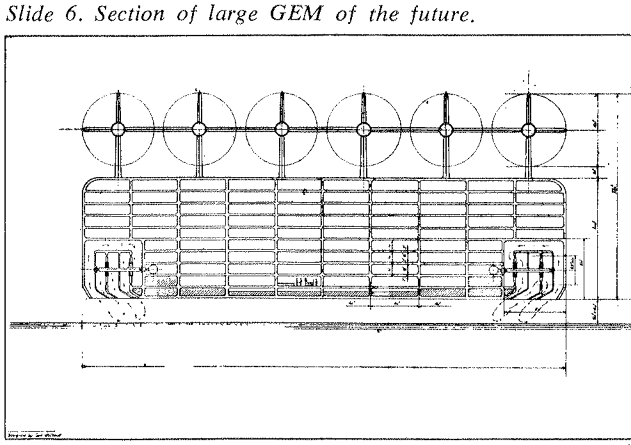


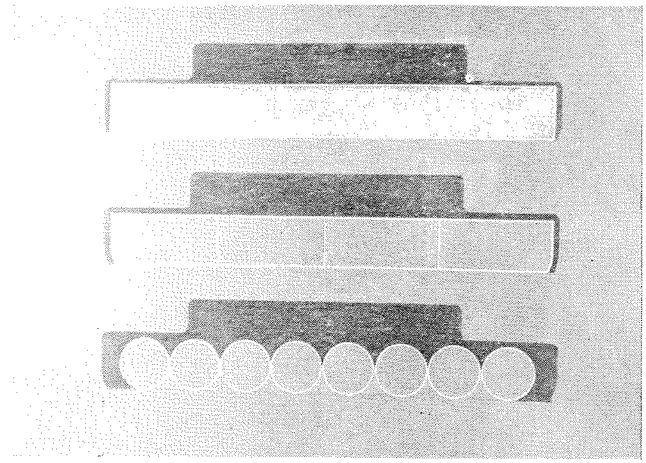
Slide 4. Elevation section, proposed 16 passenger GEM.



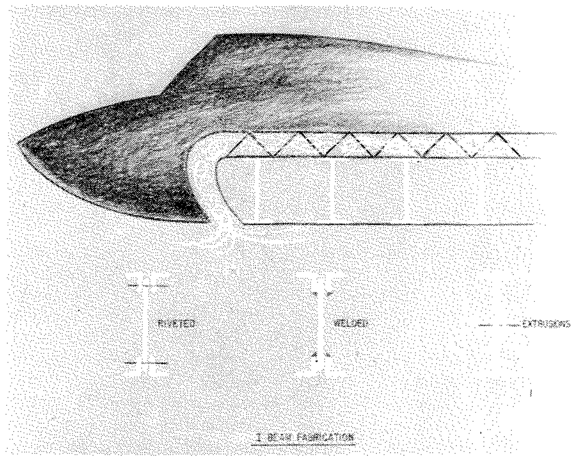
Slide 5. Typical details of strengthened GEM hull.

Slide 6. Section of large GEM of the future.





Slide 7. GEM flotation methods.



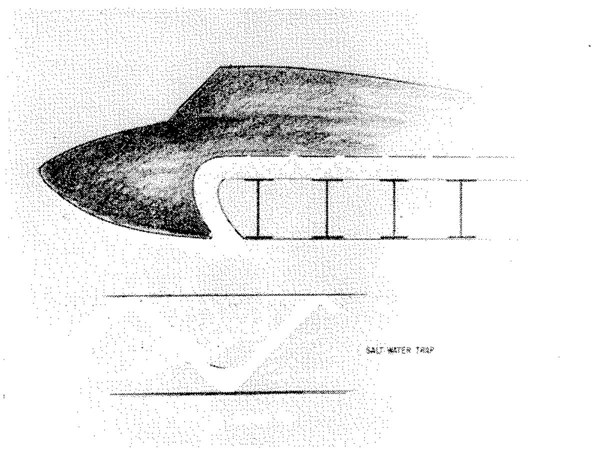
Slide 8. Beam fabrication methods for GEMs.

Another point I would like to make has to do with the joining of dissimilar metals in craft such as the Ground Effect Machine, especially if the vehicle is to be used in a moist environment. Dissimilar metals should be completely insulated from each other to prevent galvanic corrosion. When hull fittings or engine mounts of metals other than aluminium are bolted to the aluminium hull and structure, they should be insulated by use of a polysulfide sealant, after priming with zinc chromate. Plastic sleeves and washers or plastic tape can be used to insulate steel bolts from both the aluminium and/or another metal.

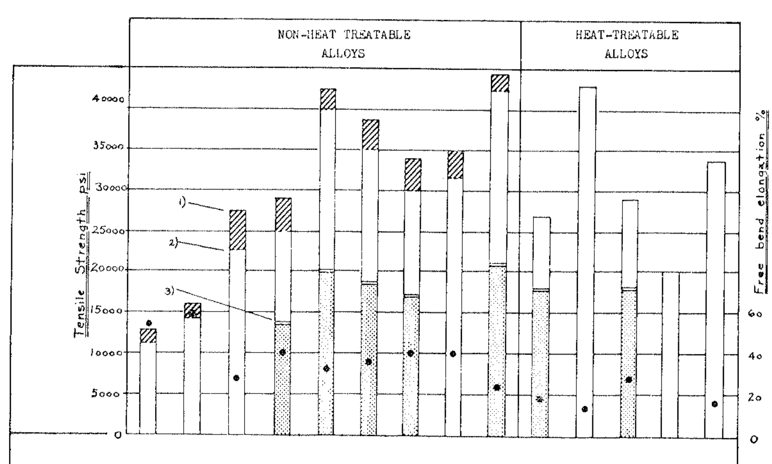
Summing up, I think I have clearly demonstrated that aluminium is the natural material for the GEMs of today. Certainly Reynolds intends to continue its work in this field — particularly in the area of developing even better aluminium alloys which will hasten the departure of GEMs from their present position of a novelty.

Personally I think we are merely at the "Model T" stage in the development of air cushion machines.

In the future we may see huge ocean-going vessels a thousand feet long which would sail smoothly 30 or 40 feet above the ocean waves at 200 miles per hour; year-round use of major seaways such as the St. Lawrence by big air cushion cargo vessels speeding over snow or ice; and swift, highly maneuverable crash and rescue boats which could race to the scene, settle in the water, pick up survivors and quickly return them to shore.



Slide 9. Salt water traps.

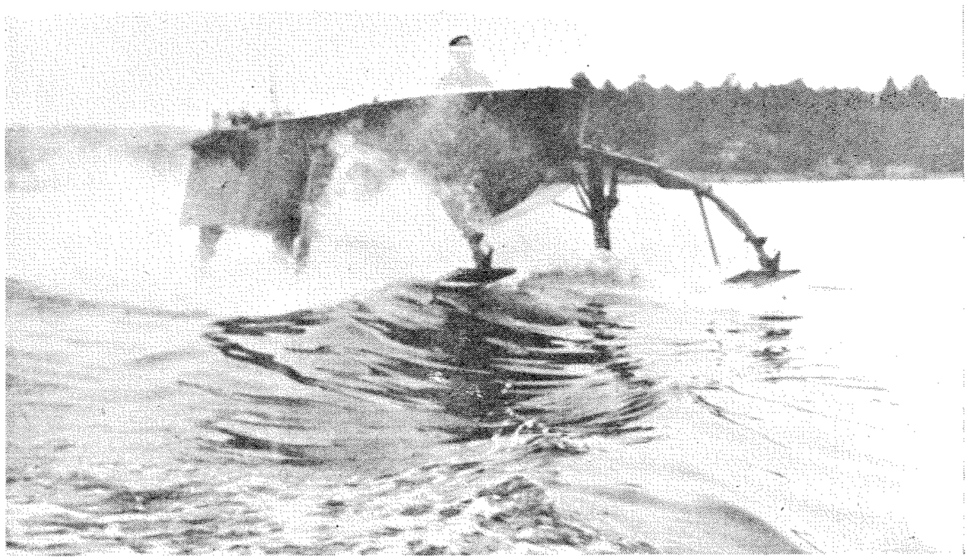


Alloy	1100	3003	3004	5052	5652	5056	5083	5086	5154	5254	5356	5456	6061-T6	6061*	6061-T6	6063**	2014-T6
Filler Rod	1100	1100	3004	5052	5652	5356	5356	5356	5154	5254	5356	5356	4043	4043	5154	4043	4043
2nd Choice	1160	4043	4043	5154			5183	5183	5356			5556			5254		
3rd Choice				4043			5556								5356		

1) Average tensile strength across weld
2) Minimum tensile strength of annealed plate
3) Average welded yield strength

* Heat treated and aged after welding
** Includes -T5, -T6, -T83, -T831, and -T832 tempers
● Average free bend elongation

Slide 10. Strengths of welded aluminium alloys.



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