HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS

Volume 3 Number 1

OCTOBER 1963

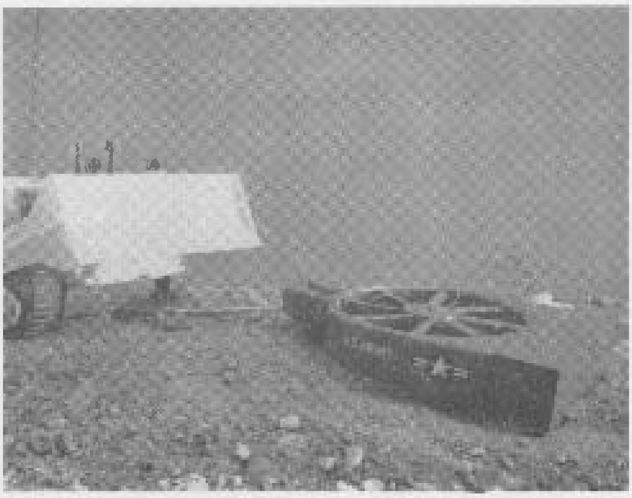
KALERGHI - McLEAVY PUBLICATIONS

HOVERING CRAFT

& HYDROFOIL

FOUNDED OCTOBER 1961

First Hovering Craft & Hydrofoil Monthly in the World



Small working model of a ground effect machine designed by Frost Engineering Company to carry a mine detector head for the US Army. Photographs and details of the full-size craft appear on page 4

ON CABS AND 'KEELS

As the revolution in marine design moves relentlessly forward it expands rapidly in its dimensions and shifts into bewildering new directions.

Two significant new advances are the captured air bubble vessel and the hydrokeel. Both concepts now have several years' research behind them, and the first generation prototypes are reported to be performing well.

Chief sponsor of the CAB vessel is the US Navy. In this concept air is trapped beneath the hull of the craft which has sideboards and moveable fore and aft seals extending into the water to minimize air escape. What air is lost is resupplied by a pair of fans located amidships and powered by an auxiliary engine.

The idea was first proposed by Allen Ford, a physicist at the US Naval Air Development Centre, Johnsonville, Philadelphia, in 1960. A foundational research programme was initiated at NADC in July, 1961, and is now being undertaken jointly by NADC and the Naval Engineering Centre, Philadelphia.

A 9 ton, 52 ft prototype CAB vessel, the XR-1, is now undergoing trials on the Delaware river. The XR-1's main powerplant is a 2,400 lb s.t. J-85 gas turbine above deck on the stern. A conventional 110 hp marine engine is used for docking. Top speed of the XR-1 is in excess of 35 knots. A coventional boat having the same weight and speed as the XR-1 would need more than twice as much power.

According to the Programme Director, Mr John Triem, of NADC, a characteristic of the CAB vessel is that it becomes increasingly efficient as size increases. For example, the XR-1's speed of 35 knots represents by dynamic scaling a speed of 100 knots in a CAB vessel the size of a 3,000 ton destroyer.

The hydrokeel was conceived by Robert W. Priest, a naval architect who formed Anti-Friction Hull Corporation in 1959. Since then four hydrokeels have been built, including a 38 ft cruiser which has attained 47 mph. The hydrokeel concept also utilises an air pocket or bubble as a means of lubricating the bottom of a hull to reduce water drag and attain high speeds. Air is forced downwards by forward mounted blowers between side keels to form an air pocket. The craft is propelled and controlled in the conventional manner.

Both CABs and 'keels have promise as a new class of open-ocean vessels and have stimulated a great deal of interest. Under a recent licencing agreement Bell Aerosystems has the right to manufacture and sell hydrokeel vessels throughout the world.

IN THIS ISSUE

COVER PICTURE : *Bell's 22½ ton SKMR-1 Hydroskimmer, largest air cushion vehicle to be built in the United States, seen on Lake Erie during its operational test programme. Bell has been awarded a $224,473 Navy contract to conduct the new test programme on Lake Erie. The SKMR-1 successfully completed its Navy acceptance trials in late August*

OCTOBER 1963 VOL. 3, No. 1

Joint Editors:
JUANITA KALERGHI ROY McLEAVY
Advertisement Manager: PETER BURGESS

HOVERING CRAFT AND HYDROFOIL is produced by Kalerghi-McLeavy Publications, 53-55 Beak Street, London, W.1. Telephone: GERrard 5895. Printed in Great Britain by Villiers Publications Ltd., London, N.W.5. Annual subscription: Five Guineas U.K. and equivalent overseas. U.S.A. and Canada $15. There are twelve issues annually.

The Hovering Craft and Hydrofoil Annual World Report, due to be published in early 1964, is Two Guineas ($6). Subscriptions placed to include this publication will be Seven Guineas and $21 respectively.

The Frost GEM mine detector carrier. It weighs 800 lb and has a hover height at sea level of 20 in — double the height at which it is seen in this photograph, taken during tests conducted at 10,000 ft above sea level. Photographs by Arnold Gassan

People and Projects

Frost Engineering Company of Denver, Colorado, have recently designed a ground effect machine to carry a mine detector head for the US Army. It is powered by a 72 hp McCulloch drive engine and is stable and free in pitch, roll and heave, but is propelled and steered by a boom from a jeep or other light vehicle.

The prototype has now been built and tested successfully as seen in the accompanying photographs and may well be the first GEM in the world to go into quantity production. It has also surpassed the design estimates of 6.2% D hover height with a gross power loading of 22 lbs per hp. Diameter of the craft is 8 ft; weight 800 lb; and hover height at sea level 20 in.

Frost Engineering is a small company which has made a series of minor experimental and theoretical studies for **US Army Transportation Command** in the last two years. Competition was keen on the TRECOM "Request for Proposal" — 7C-44-177-63, which initiated the projects, and it may be that some of the credit for the Frost success should be given to a small flying model (6 in dia) driven through the boom as a flexible shaft and propelled by a remote controlled tractor which was supplied to back up the proposal. Since the model itself exhibited excellent pitch, roll and heave stability it was obvious that these problems could be solved for the real machine, although some of the competitors had thought this would be difficult.

The use of a model as a demonstrator and research tool is not unexpected.

Mr. Peter R. Payne, who is Director of Research at Frost Engineering, and is responsible for the Frost GEM programme, is well known as an expert on rotary wing aircraft. It is not perhaps so well known that during and just after World War II he achieved an international reputation as an expert on the aerodynamics of model aircraft.

Lift power for the Frost mine detector carrier is supplied by a 72 hp McCulloch. Propulsion and steering is achieved through a boom from a jeep or other light vehicle

Lockheed-California has been named a major sub-contractor in the building of the AGEH, the US Navy's 300 ton hydrofoil. **Puget Sound Bridge and Dry Dock Company** of Seattle is prime contractor.

PSBDD, a Lockheed Aircraft Corporation subsidiary, recently won a contract from the US Navy's Bureau of Ships for the construction of the craft which is 200 ft long and designed for high speed research. Under a sub-contract Lockheed-California will build and test the three retractable hydrofoils. Detail design, fabrication and assembly will take place at the company's Burbank plant.

★ ★ ★

Rear Admiral Ralph K. James, US Navy (ex-Chief, Bureau of Ships) in testimony before a special investigative subcommittee of the science and astronautics committee of the House of Representatives, explained in these words the mission of the **Boeing PC(H)-1 High Point:** "This ship shows tremendous promise for anti-submarine warfare where we need speed as never before. The modern submarine is capable of operating at tremendous pace when submerged. To close within kill range before it outruns sonar range is an increasingly tough task. Ideally, too, hydrofoil patrol craft will operate together in a 'grasshopper' or 'leapfrog' technique. One will move slowly through the water in the displacement position listening for submarines . . . the other will fly ahead, then settle into the water and listen while its partner flies in turn. When the listener gets a submarine on its sonar, it will signal its partner to guide it to the target to track it down and drop a homing torpedo for the kill."

★ ★ ★

The **Cornell Aeronautical Laboratory** recently delivered to the Land Locomotion Laboratory at the US Army's Tank Automotive Centre a device with the capability of testing wheels, tracks and vehicle models, in various types of soil, under curved-path conditions. The device, an instrumented, powered, rotating arm has been designed for use with a soil-bin and will ultimately provide data on cornering and turning forces at the ground contact area.

Prior to the development of this curved-path device, soil-bin tests yielded only longitudinal force measurements. In use for about a decade, soil-bins enable scientists and engineers to obtain experimental data on the force relations between soil and propulsion elements, such as wheels, tracks, etc. The concept was adopted from towing tanks used for testing model ships.

Soil-bins are normally long, narrow tanks with an overhead carriage to tow a model in forced contact with the soil inside of the bin. The motion resistance of the model is measured through instrumentation.

CAL's soil-bin tester consists of a power-driven arm which rotates in a horizontal plane through an arc of about 170 degrees. A balance, equipped with strain gauges, is located between the arm and the model. Forces and moments generated between the test model and the test soil are transferred through the arm by the balance. The strain gauge outputs for the moments are recorded and transformed by computer into usable data. Longitudinal, lateral and vertical forces plus yaw moment are measured by the strain gauge balance system. The radius of curvature, velocity, heading and arm height are all adjustable and controlled.

★ ★ ★

It is reported from Budapest that the **Vac Shipyard,** on the Danube, are at work on the first hydrofoil passenger boat to be built in Hungary, though that country has for some time past been building and exporting two-seater sports boats of this type.

The boat now in question is of the Soviet Raketa type, carrying 60 passengers, such as have already been operated by the Hungarians on the river Danube, and will have a cruising speed of 40 knots. It will be completed in time to enter service next summer.

★ ★ ★

One of International Aquavion's **Aquavit** hydrofoils was used during Exercise Plafire, organised by the Port of London Authority, off Thameshaven in early October. It carried the **Thames Harbour Master, Commander G. Parmiter,** to the scene of the mock collision between a dummy oil tanker and a passenger vessel and was later used to inspect and report on the rescue operation.

The Aquavit has a great advantage in speed and manoeuvrability over all other craft at present used on the Thames and is able to use its speed to the maximum because its lack of bow-wave makes it of no danger or inconvenience to other river users.

Westland's SR.N3 has recently been completed by the company's Saunders-Roe Division and is now undergoing preliminary trials at Cowes, Isle of Wight. Largest ACV in the world, it weighs 37½ tons and has been built specifically for evaluation by the British armed services

Stardene Ltd, a London firm, are at present negotiating with **Denny Brothers** for the purchase of a D2 sidewall hovercraft now nearing completion at Dumbarton, and have an option on a second craft. The craft will carry tourists from Aswan in upper Egypt to the Abu Simbel Temple in Nubia.

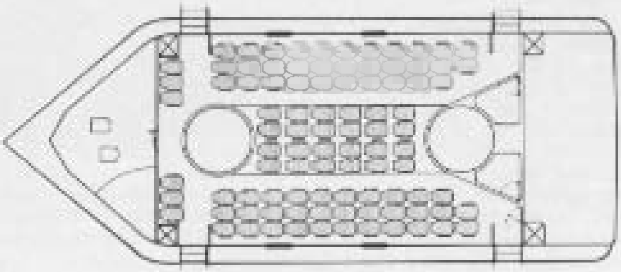
★ ★ ★

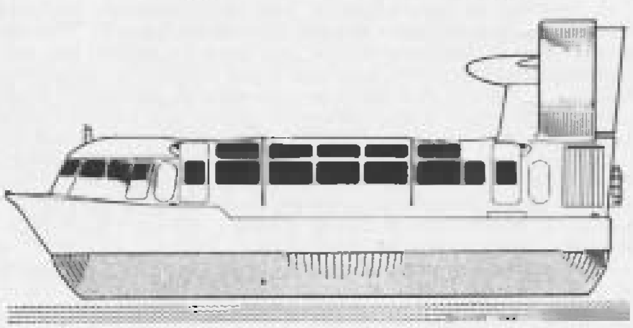
Further details of the **VA-3B** have been announced by **Vickers-Armstrongs (Engineers).** A 30 ton vehicle able to carry 94 passengers at speeds up to 80 knots (150 km/h), the VA-3B has been designed for short-haul ferry services.

In a cargo version up to 12½ tons of freight may be carried. A military variant is the VA-6, intended for such tasks as ASW, patrol, beach landing and mine countermeasures. Typical alternative loads as a military transport would be 40 troops plus 2 × ¾-ton trucks or 110 troops.

Particulars of the VA-3B are as follows: length 63 ft 6 in; beam 25 ft; basic weight (passenger version) 40,300 lb; disposable load 29,700 lb; all-up weight 70,000 lb. Performance: maximum speed 80 knots; still air range with normal fuel load, 155 nautical miles.

Plan and elevation of the Vickers VA-3B, a 30-ton development of the VA-3. Three Lycoming TF 2036 marine gas turbines will be fitted





Gas Turbines for Unconventional Craft

G.L.Graves and R.S.Carleton
Department of the Navy

Gas turbine engines are being used or will be used in a number of US Navy "unconventional craft". The characteristics inherent in the gas turbine make many of these craft feasible. The US Navy approach to the problem of assuring satisfactory operation of gas turbine engines in the environment in which they will operate in these craft is reviewed. A number of gas turbine installations are discussed, and the major Bureau of Ships' development effort in the field of gas turbines is outlined.

MAJOR efforts are underway to develop and evaluate new concepts of unconventional ships and craft. The ultimate potential of these hydrofoil, hydroskimmer, hydrokeel, high-speed craft and amphibious vehicles is in large part dependent upon the utilization of gas turbine engine concepts. The purpose of this paper is to review some of the application problems associated with the utilization of gas turbine engines, and to outline the current Bureau of Ships gas turbine engine programme. The successful marriage of gas turbines to these unconventional ship concepts is dependent upon considering the gas turbine not as an entity in itself but as a component in the total machinery system. Further, if these unconventional concepts are to become conventional, they must include not only feasible but practical, low-cost machinery systems.

Background

Gas turbine engines have demonstrated the capability of packing more power in less space than any other engine. Most of the gas turbine engines presently being used in US Navy service represent 1950 state-of-the-art. These compact, inefficient engines have provided the Navy with an extensive background of experience. They have largely been applied to special military applications, such as emergency generator sets and minesweeper applications. Even as special military engines the high initial cost and the high cost of repair parts were major objections. It has been concluded that future emphasis must be placed on the utilization of high-performance engines with a broad production base.

In looking in perspective at past experience on gas turbines a number of major lessons have been learned. Prior to World War II, many prominent engineers concluded that gas turbines would never be used for flight propulsion. This conclusion was predicated on steam turbine experience. Today, nearly all military and commercial planes are powered with jet engines. The millions of dollars spent on jet engine research and development have made this possible. At the other extreme, some post World War II engineers conceived of gas turbines as the ultimate powerplant. There were many developments in which hardware was literally thrown together to bulldoze through engine programmes. Engines consisted of mismatched components and, in general, were not the result of logical programmes emphasizing materials improvement and a sound background of component development and testing. Considerable emphasis was placed on the fact that the gas turbine consisted of a continuous flow process amenable to calculation. Experience has shown that the design processes must be augmented by extensive component and engine test programmes to resolve matching, thermal, and vibration problems. The gas turbine engine has become a practical reality today because of the theoretical design limits and test techniques developed as by-products of aircraft engine programmes.

State-of-the-art

Application of the present technical state-of-the-art, combined with engine programmes emphasizing component development, provides the sound basis for advanced gas turbines. In particular, the state-of-the-art has been advanced in the following technical areas.

Materials — Improved alloys (in particular, the nickel base, vacuum melted alloys) are available which will permit increased turbine inlet temperatures and greater reliability of antifriction bearings. Thermal, fatigue, and other metallurgical problems are better understood as a result of continued research and operational experience.

Compressor and Turbine Performance — High component efficiencies are obtainable with fewer stages of axial components. Lower aspect ratio blades are not only more rugged, but provide better diffusion resulting in improved surge line and higher compressor efficiency. For nonaircraft engines, providing the small additional space required to obtain low duct and diffusion losses pays off in major gains.

Production Techniques — The production of complicated parts, such as cooled turbine blades, with good quality control is now possible. Previously the reliability of notch sensitive parts was a major problem. The level of quality control applied to engine programmes will determine to a large extent the success of any gas turbine engine concept.

Operational Experience — The gas turbine engine has benefited tremendously from the millions of hours of operational experience accumulated on jet engines.

Test Techniques — Application of strain gauge and aircraft test techniques is becoming common practice. While casing mounted transducers provide a good evaluation of rotating stall frequencies in order to avoid blade resonances, many

Delivered by the authors to the National Aero-Nautical Meeting, Washington D.C., April 1963

ADVANCED ALL-PURPOSE HOVERCRAFT RANGE

SR.N2

WEIGHT 27 tons
PASSENGERS up to 70
FREIGHT 8 tons
MAXIMUM CRUISING SPEED 80 knots

SR.N2, Mk.2

WEIGHT $37\frac{1}{2}$ tons
PASSENGERS up to 150
FREIGHT 12 tons
MAXIMUM CRUISING SPEED 74 knots

SR.N5

WEIGHT 7 tons
PASSENGERS up to 20
FREIGHT 2 tons
MAXIMUM CRUISING SPEED 70 knots

Following the recent dramatic advance in the development of the Westland-patented flexible "skirt", with corresponding improvements in performance, Westland now offers the most advanced range of Hovercraft available anywhere. Their general performance is outstanding, their over-wave and obstacle-clearance capability exceptional.

Already the Company is tooling up for batch production of the three craft in the range — SR.N2, SR.N2 Mk. 2 and SR.N5.

With the future well in mind, a strong team of project and design engineers is actively investigating even newer and better ACVs. Already in the advanced project stage is the 170-ton, 600-passenger SR.N4, capable of providing a fast, flexible ferry service across the English Channel.

WESTLAND **HIGH RIDING ACVs**

WESTLAND AIRCRAFT LIMITED YEOVIL ENGLAND
Incorporating
Saunders Roe Division Fairey Aviation Division Bristol Helicopter Division

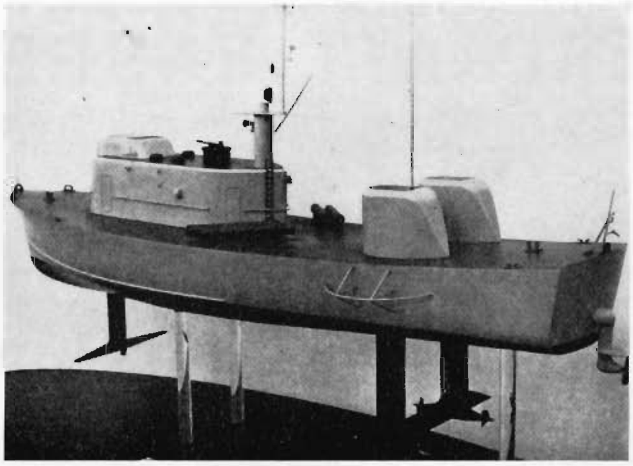


Figure 1. Boeing PC(H)-1 High Point

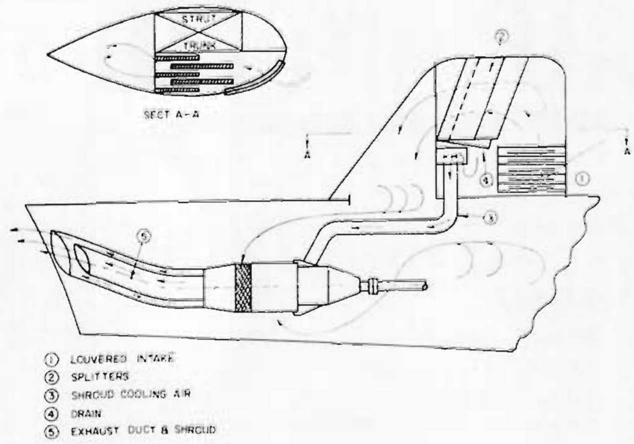


Figure 2. PC(H)-1 Proteus installation

companies have found that flutter and other stall effects cannot be evaluated with such a transducer, and more advanced strain gauge test techniques must be used to be certain that blades are operating at a safe stress level. Utilization of these and other advanced aircraft test techniques reduces the probability of a failure during engine development tests, and provides further assurance of reliable operational service.

Practical Considerations

Most discussions of the application potential of naval gas turbines have emphasized the problem of high fuel consumption. The basic simplicity of a simple cycle gas turbine has often been compromised by the addition of varying degrees of complexity to achieve better fuel consumption. In evaluating the various feasible engine concepts, the practicality of the concept must be evaluated and optimized in terms of application requirements. For US Navy requirements, emphasis will continue to be placed on relatively simple, automated engines wherever possible, with minimum requirements for operational and maintenance personnel and a minimum training requirement.

Practical Engine Concepts — In developing new engines or in considering existing engines for new applications, the importance of each increment of complexity must be weighed in terms of the application requirements (1, 2)*. Turbine inlet temperature and component efficiencies are of paramount importance in gas turbines. Good fuel consumption can be obtained with high pressure ratio nonregenerated engines, or with low pressure ratio regenerated engines. Regenerated gas turbines have the advantage of good part-load fuel consumption if the part-load component efficiencies are good. Further improvements in part-load fuel consumption can be obtained by inclusion of a variable power turbine nozzle. The higher the turbine inlet temperature, the greater the gain that be expected with complex cycles. But it must be emphasized that regeneration is no substitute for good component performance. In the case of high pressure ratio engines, a regenerator can be designed to improve part-load performance with partial bypass of the regenerator at full power. This concept was successfully evaluated on the Rolls-Royce RM60 marine gas turbine. In general, nonregenerated gas turbines are preferred, especially where the power requirements vary from 70-100% of the engine rating. Where a broad operating requirement exists, and where fuel consumption is an important parameter, the complexity of a compact regenerator and variable power turbine nozzles are considered justified.

Marine Environment Application Considerations

A gas turbine engine, perhaps more than any other prime mover, is dependent upon good initial installation practices for satisfactory operation.

**Numbers in parentheses designate References at end of paper.*

Past experience has indicated that a great many of the problems associated with gas turbines in naval application have been related to the installation considerations and the marine environment. It is considered desirable to minimize changes required within the engine because of the marine environment by eliminating the problems before these effects become problems in the engine. Further, wherever possible, the systems associated with an application should be tested with the engine prior to installation in the boat or craft.

Air Intake System — The temperature, pressure loss, turbulence, and salt water content of the intake air to the engine are all critical because of their effect on compressor reliability and engine performance. It is extremely important to provide air to the compressor intake with a minimum of salt water and moisture content at a temperature close to ambient, and with a uniform flow pattern around the compressor intake annulus. Water and moisture separators where possible, as well as flow straighteners, should be used as required. Ducting of the intake air to an engine inlet plenum is recommended. Baffling provisions in the intake ducting combined with the inlet plenum act to separate slugs of water from the air. Moisture must be eliminated with a separation system. Where the engine compartment space is used as a plenum, the heat released to the space from the engine and transmission system should be minimised by using insulating blankets or air casings. The extent to which the engine space may be used as a plenum requires careful analysis of the heat rejection to the space and the effects of the additional pressure loss and higher compressor inlet temperature on engine performance. The presence of oil vapours in the engine space would provide a basis for precluding use of the space as a plenum because of compressor fouling effects.

The important considerations affected by the intake system may be summarised as follows:

1. Compressor fouling reduces engine airflow and horsepower output. Periodic fresh water washing to remove salt deposits is required prior to shutdown, and is required more frequently with small engines than with large engines. Periodic cleaning with a solid, such as ground walnut shells or equivalent, may be necessary to remove oil vapours and other deposits. Satisfactory cleaning may be achieved with low pressure ratio engines by operating the engine at part power or idle while ingesting cleaning water. It is necessary to motor high pressure ratio engines at speeds below the idle speed while ingesting the water to obtain satisfactory cleaning. Fouling in the early stages can affect the part-load compressor efficiency and surge line characteristics and limit acceleration and operational capabilities. In general, it is always important to have a good margin between the surge line and the operating line in order to have reliable trouble-free operation at all speeds. Because of the susceptibility of compressor bleed lines to fouling, engines not requiring compressor bleed are preferred. Fouling of air cooling lines is also a consideration.

2. The temperature of the air to the compressor intake affects the engine airflow and horsepower. Each 20 F increase

in temperature results in a loss of about 10% in rated horsepower (this varies with specific engines). The temperature level also affects the relationship of the operating line to the surge line. Compressor failures have occurred due to excessively high engine intake air temperatures, resulting in the compressor operating in surge during deceleration or acceleration. The arrangement of the intake and exhaust stacks should preclude exhaust air recirculating into the intake ducting.

3. Compressor corrosion due to the effects of salt water in the compressor intake air has been experienced. The attack is usually intergranular. A notch sensitive condition is produced which results in fatigue failures. A comparison of compressor materials based on weight loss in a bench type corrosion test is not considered valid. Some coatings have been helpful in alleviating the problem; however, titanium appears to be the ultimate solution. Some engines in service have conservative stress levels and have been able to use twelve chrome type steels.

4. A non-uniform flow or condition of air turbulence at the compressor intake can result in a condition of aerodynamic vibration or stall within individual compressor stages, causing blade failure. The inlet ducting arrangement for a given application should be tested with the engine, if possible, prior to installation. Flow testing of a model of the inlet ducting is a good preliminary test but it is not a substitute for full-scale testing with the engine. Engine inlet plenum bulkheads should preferably be at least two compressor inlet diameters in front of the air inlet bellmouth. Multiple engine installations should preferably include separate ducting and plenums for each engine.

5. Pressure losses in the intake system have a major effect on the horsepower rating and they should be kept to a minimum.

6. General corrosion on the outer parts of the engine and particularly electrical and control components has been experienced. Magnesium and its alloys are not permitted in US Navy marine applications because of the corrosion and fire hazard problems associated with these alloys in a marine environment.

Exhaust System and Duct Sizes — The high rate which results in large exhaust ducts has been a major deterrent to the use of gas turbines. The problem is critical because of the effect of back pressure on engine performance and the effects of large ducts on ship structures and machinery spaces. At present, inlet velocities are about 75-100 fps and exhaust velocities are usually about 100-150 fps. Some installations with straight axial exhausts have discharge velocities up to 450 fps. Because of the high exhaust temperatures, the density effect results in large duct dimensions. Criteria are being developed to allow exhaust velocities up to 300 fps, minimising back pressure effects by diffusing the gas at the top of the exhaust stack in order to reduce duct sizes. The exhaust stack should be independently supported from the ship structure with provision to include a bellows or other device for providing continuity with the engine exhaust. Any duct loading transmitted to the turbine casing might result in turbine tip rubs and overheating of the blades.

The velocity energy in the exhaust gases may be used to educt hot air from the compartment instead of recovering the velocity energy by diffusion (3). This is a relatively simple method of compartment ventilation but may not be as efficient as a motor driven blower.

Recovery of some of the exhaust heat energy from the exhaust gases with a compact waste heat boiler in the exhaust stack merits consideration. A major increase in the overall thermal efficiency of the gas turbine is feasible while simultaneously reducing the exhaust temperatures and the sizes of the exhaust ducts.

Mounting Arrangements — A three-point mounting arrangement on the engine sub-base is generally required. Assurance should be provided that the dynamic effects of a flexible hull do not impose strain or excessive distortions on the engine system. This is an especially important consideration for high-speed craft and hydrofoils.

Transmission Effect on Engine — Vibrations induced in the transmission, propeller, or shafting system have occasionally been transmitted to the power turbine blades, resulting in resonant vibration and fatigue failure of the blades. Helical gears are preferred at the engine output to minimise gear induced vibration. Vibration surveys should be made during the laboratory test of the engine and transmission system and during early prototype evaluation.

Fuel System — A positive fuel pressure must be maintained at all times. Air or water pockets in the fuel lines can cause loss of combustion during engine operation. When reignition occurs, excessive fuel may be present in the combustor, causing overtemperature of the turbine blades. Vapour lock must be considered at all times, and air vents and water traps used as necessary.

Controls System — Salt water in the fuel or air may cause corrosion of controls system components. This can result in excessive fuel injection, overtemperature, and engine failures.

Lubrication System — Salt water, air, and fuel are all used as the coolant in lubricating oil systems on gas turbines. Where diesel fuel in accordance with MIL-F-16884 is used as the cooling medium, a problem of thermal instability of the fuel may exist for a small percentage of the available fuel. Aircoolers are preferred in general. However, lube oil coolers relying on JP-5 fuel as the cooling medium are acceptable. For ship installations, salt water coolers may be preferred because of the air handling problem associated with an aircooler and the ready access to salt water. The importance of assuring that salt water does not contaminate the lube oil is emphasized. The lube oil to the cooler should be at a higher pressure than the salt water coolant. Even this will not prevent contamination during shutdown. Further, the effectiveness of the lube oil seals in preventing salt water in the air from getting to the lube oil must be evaluated as part of the engine programme. It is noted that most aircraft engines use MIL-L-7808 lube oil which is not compatible with many materials, and this must be considered in the design of the lubrication system.

Turbine Sulphidation Corrosion — Salt water contaminated fuel and air combined with the sulphur contained in Navy fuels can cause intergranular corrosion of nickel base alloys in current use in gas turbine engines. In the past, with US Navy engines using cobalt base alloys and turbine inlet temperatures of about 1500 F no major problems have been experienced. The sodium sulphate resulting from the sulphur and sea salts causes corrosion at temperatures of about 1575 F. The exact nature of the corrosion attack is not fully understood. Present practice is to limit the continuous rating to a maximum average gas temperature of 1550 F when using Navy diesel fuel which can have a possible maximum sulphur content of 1% or 1600 F when using JP-5 fuel which can have a possible maximum sulphur content of 0.5%. It is recognised that this is not a valid criteria but it does provide a conservative margin. The metal temperature rather than gas temperature is probably the most valid criteria where the metal temperature is related to the effective gas temperature:

$$T_{EG} = T_S + RF(T_{T\,REL} - T_S) \qquad (1)$$

where:

T_{EG} = Effective gas temperature

T_S = Static temperature

RF = Recovery factor (usually about 0.87)

$T_{T\,REL}$ = Total temperature based on relative gas velocity

Variations in temperature and velocity profiles in the gas stream add another set of variables to the problem.

Eventually criteria will be developed as the basis for engine design which relate the material properties under corrosive conditions to the stress levels in the hot parts. For the present, it is necessary to establish engine ratings based on conservative temperature limits and conservative stress margins of safety.

Coatings for engine hot parts appear to offer considerable promise especially for hydrofoil type applications. They appear to be limited by quality control considerations and erosion of blade leading edges.

Engines should be capable of satisfactory operation with 0.01% by weight of sea water in the fuel and 1 ppm by weight of salt in the air. The compressor fouling tendency helps to keep salt from getting to the turbine in large quantities; however, as a compressor fouls, its effectiveness as a separator decreases and increased quantities of salt get through to the turbine. It is concluded that frequent washing of the compressor is desired, not only to maintain compressor performance but to assure that a minimum of salt reaches the turbine hot parts.

Availability of Auxiliary Power from Gas Producer Take-off Pads — A limited amount of auxiliary power is available from most engine gas producers. The more auxiliary power required, the closer the operating line comes to the surge line of the compressor. This problem is usually critical at part loads. The more surge margin used to provide auxiliary power, the less surge margin is available for rapid acceleration, deceleration, and deterioration due to environmental considerations. The surge margin consideration should be carefully

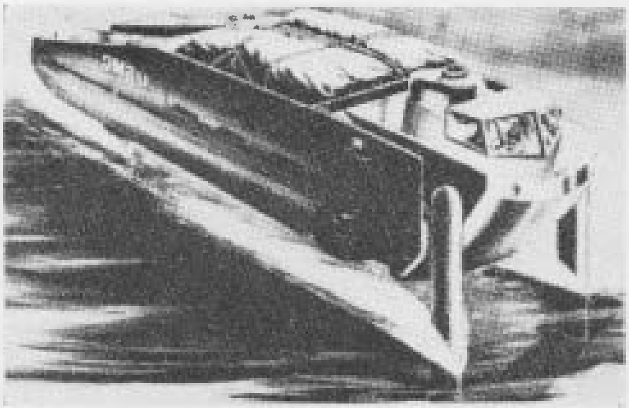


Figure 3. Lycoming LVHX1 hydrofoil landing craft

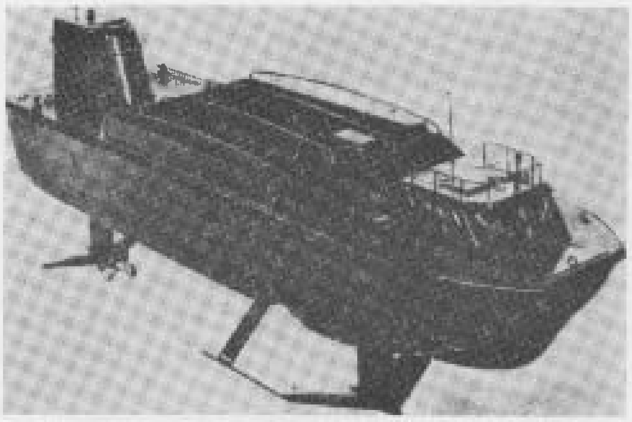


Figure 4. LVHX2, built by Food Machinery Corporation

analysed in terms of application and operational requirements prior to making engine commitments to provide auxiliary power from the gas producer. Acceptance tests should include provision for testing engines under conditions of acceleration and deceleration with the auxiliary power take-off pads loaded.

Starting Requirements — Rapid starting requirements impose high thermal stresses on the rotor assembly of a gas turbine engine. This has an appreciable effect on the life of any engine, particularly the less conservative designs. Further, rapid starting requires either a good part-load surge line or the further complication of compressor bleed. (Some engines require compressor bleed regardless of the starting rate requirement because of poor surge lines at part load.) In general, the torque available from the starting system at ignition speed should exceed the steady-state torque at ignition speed for all starting conditions by about 25%. Insufficient starting torque capability has resulted in numerous problems and even engine failures.

In many cases, the use of batteries for starting is the only practical source of starting power. Inadequate capacity, voltage drops through long cable runs, and deterioration of battery performance with age all contribute to poor starts or even hot starts which cause turbine burn-up. These are aggravated during cold weather because more air is going through the compressor at the same time that the battery energy is at a low because of the temperature. Some installations have this problem aggravated by the presence of a large power take-off being driven by the compressor turbine.

Programme to Reduce Problems in New Installations

There is still a great deal to learn about gas turbine installations in US Naval ships and boats. But a great deal more is known now than was known five to ten years ago. Every effort is being made to apply this knowledge so painfully learned to new installations.

Each new application is reviewed from the preliminary design phase through the actual installation by Bureau engineers and the engine manufacturer. Rating and testing conditions will be employed that impose realistic environmental conditions. On larger installations attempts will be made to duplicate the shipboard installation as much as possible during laboratory testing. Flow test mockups of inlet and exhaust configurations duplicating installation will be made whenever possible. As part of several existing programmes, investigations of corrosion phenomena and protective coatings are being made. The investigation of general problems will be accomplished with the results being made available to the entire gas turbine industry. To familiarise the operating personnel with the operation and maintenance of a new engine before it is introduced into fleet service, shipboard operators will receive training at the engine manufacturer's plant or at a Navy facility. The Bureau of Ships is working closely with the Navy repair parts centres to assure that new engines have adequate parts support.

Rating Standard

It has been emphasised that the magnitude of the problems associated with a marine gas turbine necessitate a conservative rating standard. A conservative surge margin, moderate turbine inlet temperatures, and a completely marinised and proven engine are necessities. Specification MIL-E-17341, as recently revised, outlines what the Bureau of Ships considers to be the minimum acceptable standards for US Naval shipboard applications. Though comments have been received to the effect that the rating conditions and test requirements specified in MIL-E-17341 are prejudicial to the gas turbine engine, these conditions and requirements must be retained to insure completely reliable units under any shipboard conditions likely to be encountered. This would include everything from extended operations during storms in the North Atlantic in the dead of winter to continuous duty with high ambient temperatures in the South Pacific or Indian Ocean during the middle of summer. In some noncontinuous duty operations such as hydrofoil takeoff conditions, engine ratings will be based on less stringent requirements.

Gas Turbine Applications

The impact of gas turbines on naval and marine applications has been previously discussed (4, 5, 6, 7). Gas turbine engines in the US Navy's programme for unconventional craft are used or are planned for use in hydrofoils, hydroskimmers, advanced landing craft, and a high-speed destroyer type anti-submarine warfare ship powered by gas turbines. The latter may be considered unconventional only because of the rather new concept of using aircraft type gas turbines to propel a major warship.

Extensive Bureau of Ships Hydrofoil Programme — Gas turbines help to make hydrofoils feasible. However, hydrofoils impose special penalties on gas turbine engines because of their very nature. Foremost is the sea water ingestion problem. It has been pointed out that this is a problem in all marine installations. First, the hydrofoil must fly. To do this it must be as light as possible. Therefore, water separation techniques must be kept to a minimum. Second, although displacement ships are limited in speed and power during heavy seas, military hydrofoils are designed to fly under these conditions. Therefore, at a time when spray and salt water in the air is at a maximum the gas turbines will be required to deliver peak power. Another special problem will also be imposed on engines installed in hydrofoils. These ships will have a duty cycle consisting of several minutes of flying, shutdown while sitting still for several minutes, and then take-off and flying for several more minutes. This cycle may be repeated for very extensive periods of time, thereby imposing severe thermal stresses on the gas turbine equivalent to hundreds of hours of operation during more normal operations. Every effort is being made to secure successful operation under these conditions in the hydrofoils now being built. But these craft are prototypes and lessons will be learned which will make the later hydrofoils better and more reliable. The following is a brief summary of the Bureau of Ships hydrofoil programme.

USS High Point, PC(H)-1 (Fig. 1) — This craft which is now undergoing preliminary testing was built for the Navy by Boeing. It is 110 ft long and weighs 108 tons. It is powered by two Bristol-Siddeley model 1273 marine Proteus gas turbine engines. Each engine is rated at 3,800 hp take-off and 3,100 hp cruise at 80 F ambient. These British engines were chosen for this first US Navy operational hydrofoil because of the extensive background of marine experience gained by these engines in the Admiralty "Brave" class highspeed patrol boats. Fig. 2 shows the engine installation in the PC(H). Engine air in this craft is taken through two towers built on the deck. The struts for the foils also retract into these towers. The air enters through louvers and then must rise before going through splitters and then down into the engine room which acts as a plenum. Engine intake air is taken from the engine room. Engine cooling air bypasses the splitters and is drawn down a pipe into a shroud covering the engine and is drawn out with exhaust air by an eductor effect.

LVHX1 (*Fig.* 3) *and LVHX2* (*Fig.* 4) — These two experimental hydrofoil landing craft are designed to lend mobility to amphibious forces. Their high speed will allow them to discharge troops and cargo and return to widely dispersed high-speed attack transports in a fraction of the time required with existing landing craft. Both craft will cruise at speeds above 30 knots, are about 36 ft long and will carry a 10,000 lb payload. The LVHX1 is presently under construction by Lycoming: it will use the 900 hp (1,225 hp peak) (80 F ambient) Lycoming model TF14 engine. This is a marine version of the T53 aircraft engine. The LVHX2 is being built by Food Machinery Corp.; it will use the 1,100 hp (80 F ambient) Solar Saturn (10 mv). Fig. 5 shows the engine installation in the LVHX2. As can be seen, the Solar engine provides the power in both the land and sea modes through a rather complex power train. The propeller pod is retracted when operating on land. Engine inlet air and engine and transmission cooling air is drawn in at the forward end of the vehicle. The air passes across and along the drive mechanisms and driveshaft to the engine compartment. Part of it is then drawn into the air inlet while the rest goes through the engine compartment to cool the engine and is drawn out by an exhaust eductor. Some of the engine cooling air also passes through the oil cooler.

AGEH (*Fig.* 6) — This experimental hydrofoil will be 212 ft long and will weigh about 320 tons. It has been designed by Grumman. The engine to be used for foil-borne propulsion is the General Electric model LM1500 gas turbine engine. This engine which is an aircraft J79 jet engine with a free power turbine is rated at 17,000 hp for take-off and 12,750 hp for cruise (80 F ambient) in this application. The AGEH will be built first with subcavitating foils and will be powered by two LM1500 engines. It will be later fitted with supercavitating foils and powered by four LM1500 engines. Fig. 7 shows the engine installation. The air inlet is at the aft end of the deck house and just forward of the exhaust outlets which are tilted towards the stern. The air enters a large plenum and then passes through spray separators in which the air makes a 90 deg turn, goes past a water dam, and then down into the inlet plenum from which the gas turbine engines draw their air. Secondary cooling air which passes through the engine shroud is drawn from the engine space.

Fresh 1 (*Fig.* 8) — This is a high-speed hydrofoil test craft also being built by Boeing. Different types and configurations of foils will be tested. Propulsion is provided by a Pratt and Whitney JT3D turbofan engine providing an 18,000 lb thrust. No attempt at water separation is being made. Testing started on this floating test platform during December 1962.

Harpy — The Hydrofoil Advanced Research Project envisions a high-speed 500 ton hydrofoil powered by aircraft gas turbine engines such as the Pratt and Whitney FT4 or the General Electric LM1500. It will use the results of the current naval hydrofoil programmes. Studies and development of transmission systems, guidance systems, clutches, etc., for a ship of this speed and size are currently underway.

Bureau of Ships Hydroskimmer Programme

Fig. 9 shows the 2 ton SKMR-1 being built by Bell and powered by four Solar Saturn 1,100 hp engines. These engines will be arranged so that each engine can be used for either propulsion or fan lift. SKMR-1 will be flown at speeds up to 70 knots. It will carry four men and a useful load of 7,300 lb.

Fig. 10 illustrates the SKMR-1 engine installation. It shows how each of two engines can be used for propulsion or fan lift. The installation is duplicated on the other side of the craft. It can also be seen that air to the engines is drawn from the pressurised "cushion" air, hence a certain amount of engine supercharging is obtained.

At present, the Bureau of Ships is also studying a larger hydroskimmer. Though plans are not firm it will probably be about 250 tons. Successful completion of these projects will open the door to unlimited possibilities for the use of hydroskimmer craft in US Naval service.

Advanced Landing Craft

Gas turbines are presently being used in four other new type landing craft. In these others as in the aforementioned types of craft, the light weight and small volume of the gas turbine permit much higher speeds and effective useful payloads than in conventional landing craft. These four include:

LCSR (*Landing Craft, Swimmer Recovery*) (*Fig.* 11) — The Bureau of Ships has contracted for the building of ten of these high-speed craft. At least four more will be built in the near future. Their job is to pick up Underwater Demolition Team personnel on the run and they have been designed for this specific purpose. Power is provided by two 1,000 hp (100 F ambient) Solar Saturn (10 mv) engines. United Boatbuilding Corp. is the boat contractor. Fig. 12 shows the installation of the engine. This boat is expected to operate in all types of sea conditions at maximum speed. It can be seen that the air intake system is designed to have several changes in direction, and the engine space serves as a plenum. An experimental installation of the Solar Saturn in a 40 ft LCPL had a similar air intake system and has operated for several hundred engine hours with very little fouling and no apparent corrosion of any type.

LCA (*Landing Craft, Assault*) (*Fig.* 13) — This is a 60 ton amphibian now undergoing preliminary testing. Two propellers driving through swiveled turrets which rotate up when operating on land propel this vehicle in the water. During land mode the drive is through tracks. This craft will carry 60,000 lb at 12 knots in the water and 20 mph on land. Food Machinery Corp. was the builder. Here again, two 1,000 hp

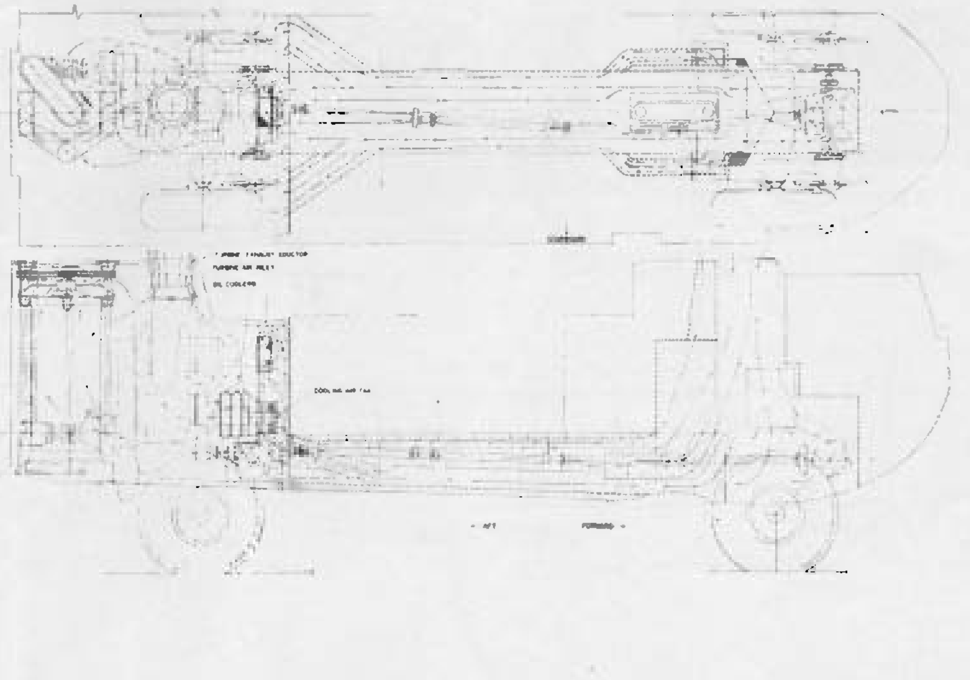


Figure 5
LVHX2 turbine installation and air intake arrangements

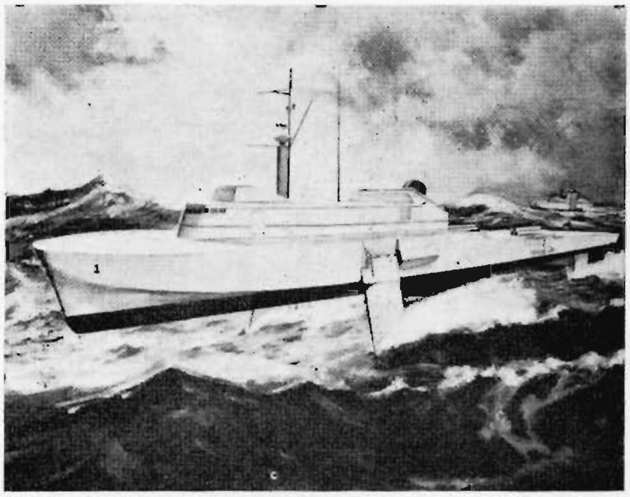


Figure 6. Grumman AGEH, fitted with a General Electric LM 1500 gas turbine rated at 17,000 hp for take-off and 12,750 for cruise

Solar Saturn engines are being used. One of the problems encountered in this installation was the large amount of auxiliary power demand on the compressor turbine. The largest portion of this was needed for the hydraulic system used to raise and lower the stern ramp and to rotate the propeller turrets, as well as to activate the power train. While well within the capacity of the engine when running under power, this did provide problems during starting and at speeds near idling. Since this large auxiliary load is quite common in landing craft and amphibians, it seems to be necessary to test the engine with these loads before installing it in the vehicle. Any problems can be worked out much more easily on the test stand.

LVW (*Landing Vehicle, Wheeled*) (*Fig.* 14)—This unique vehicle has been built by Borg Warner. It has a planing hull for high water speed and large rubber tyres for land operation. The wheels, which rotate up when operating in the water, are individually suspended and will operate on all types of terrain, including soft sand and swamp. It will carry 10,000 lb of cargo at 30 knots in the water and 35 mph on land. Propulsion is furnished by one 1,500 hp (100 F ambient) Lycoming model TF20 engine. This is a marine version of the T55 aircraft engine. Fig. 15 shows the engine installation.

*LVTPX*10 (*Landing Vehicle, Tracked, Personnel*) (*Fig.* 16)—This is a 42 ton armoured, amphibious, tracked vehicle similar to other amphibious tanks previously built with gasoline engines. Power is furnished by a General Electric model T58 aircraft engine rated at 800 hp (100 F ambient). The small size and weight of this engine allows an increase in vehicle payload of 66% and eliminates the fire hazard involved when using gasoline.

Engine inlet and cooling air enters the compartment through a Donaldson filter separator. All of the air then passes through the engine.

High-Speed Antisubmarine Warfare Ship

The development of highly reliable aircraft gas turbines and the success of gas turbine propulsion in the British "Ashanti" Class frigates and "Devonshire" Class destroyers (7) has greatly increased the Bureau's interest in the use of gas turbines in larger ships. The advantages offered by gas turbines in this type of operation are many. The advantages include, of course, very light weight and small volume in comparison to present steam plants. However, other factors tend to be even more important. These are the very fast startup time, ease of automation with the attendant need for fewer and less highly trained operators, ease of removal, and lower first cost when using aircraft engines because of the large aircraft production volume.

The Bureau of Ships is very attracted to the use of marine versions of aircraft engines in combined plants, whereby one or more engines carry the base load and are sized for all speeds up to cruising, and one or more engines can be used for boost propulsion when higher speeds are desired. This allows more efficient operation since the boost plant, which carries the largest share of the power, can be shut down during the majority of operations. This is in contrast with the need to size a steam plant for the high-speed operations which are carried on for just a small percentage of the total time. When operating during a patrol or under wartime condition, all boilers must be on the line, even when the ship is engaged in slow speed operations because the power must be available when needed. Only the fast startup time provided by the gas turbine allows complete shutdown except when needed. Another point is the need for extreme quiet operation during antisubmarine warfare patrols. Since hydrodynamic noises prevail during high speed it may be possible to treat only the base load units for quiet operation.

Though the British (7) have been very successful using combined steam and gas turbine (COSAG) plants, the Bureau of Ships has been most attracted to the use of combined diesel

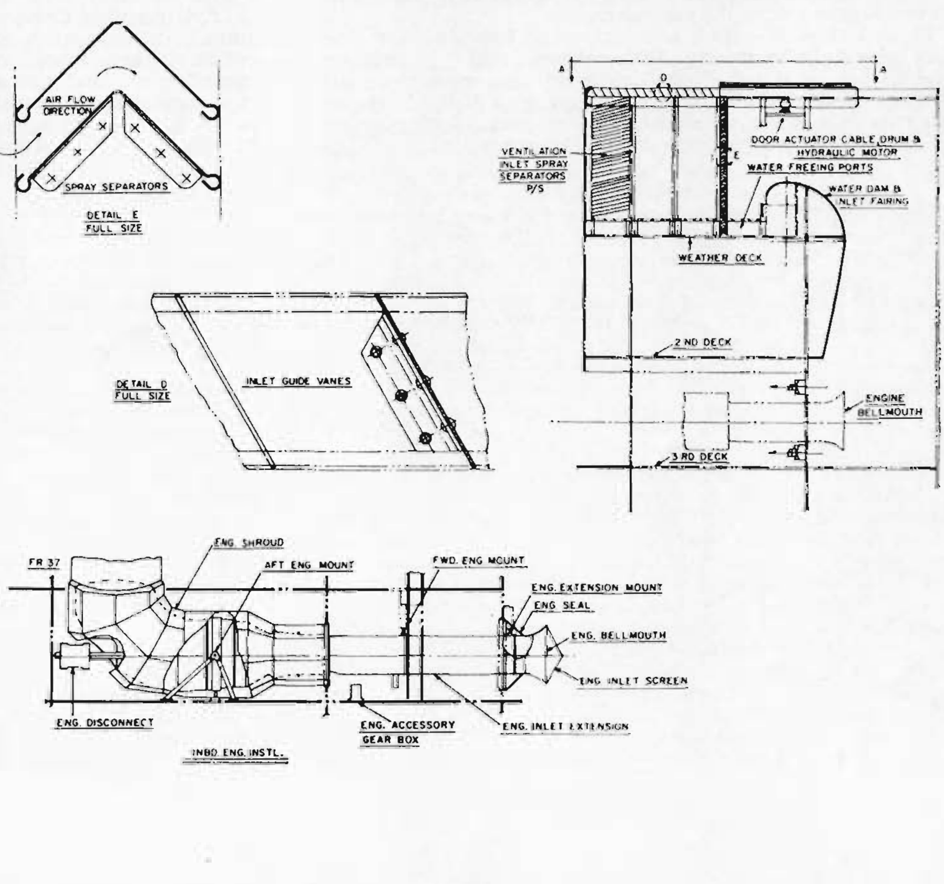


Figure 7. AGEH gas turbine installation and air intake system

and gas turbine (CODAG) and of combined gas turbine and gas turbine (COGAG) plants. Both diesels and gas turbines allow a very high degree of automation and startup time which is very desirable in base load units as well as boost units. Both type plants would appear to be easier to silence and protect from shock than steam plants. The diesel offers greater cruising radius because of better efficiency than present gas turbines but limits the cruising speed since size, weight, and horsepower rating of existing lightweight diesel engines limits the total installed horsepower capability. The Bureau of Ships is studying the possibility of developing a regenerated base load gas turbine that would have the efficiency of a diesel engine and the compactness of a gas turbine. This programme would include complete and extensive testing of the engine and all components, as well as laboratory testing of one complete shaft set of machinery duplicating as closely as possible the actual shipboard installation and operating conditions.

Inboard Outboard Gas Turbine

The Navy has contracted with Outboard Marine for prototype 125 hp diesel oil burning gas turbines for propulsion of a 26 ft personnel boat. The gas turbine engine will be mounted inside the boat, connecting through a flexible coupling at the transom to the externally mounted outboard drive assembly which can be rotated for steering the boat. Either the engine or the outboard drive assembly can be removed and replaced in a matter of minutes.

Bureau of Ships Gas Turbine Engine Development Programme

Engine-at-Sea Evaluation — The Bureau of Ships has presently underway three programmes in which gas turbine engines are installed in Navy owned boats for at-sea evaluation and working out of marine installation problems. These include:

Installation of Solar Saturn (10 mv) Engine and Reverse Gear in 40 Foot LCPL — The boat was operated for several hundred hours by Solar Aircraft Co. and Navy personnel. Most of this operation was at high speed and included hundreds of crash stops and reversals. Many control problems were worked out in this installation which has forestalled similar problems in the Saturn installations in the LCA and LCSRs. As previously related, an air intake system similar to that designed for the LCSRs was used in this craft and has worked out very well. During later operation of this craft, the air intake system will be modified to provide for greater intake of salt water. The craft will then be operated with a water separator to determine the efficiency of the water separator.

In the existing air inlet system which has worked so well to date, the air is taken in through an aft facing hood. This is located at what was known to be one of the driest spots on the boat. The air enters into a large space. It then travels through ducting on either side of the boat and is dumped at the forward end of the engine space. The inlet of the engine is at the aft end of the space. Inlet air flows across the engine to reach the inlet, thus cooling the engine. This does cause some power loss due to the 6-10 deg rise in temperature. The drive end of the engine faces forward and drives through a reverse gear and a vee drive.

Lycoming T55 Engine — This engine is in mass production for helicopter applications. A programme to qualify the marine version of this engine for marine service has been established. For a nominal Bureau of Ships contribution of funds Lycoming has contracted to provide an engine, and install and test the engine in an experimental boat. The programme was originally based on utilisation of a government furnished LCPL hull; however, detailed studies have shown the necessity of a new hull to safely handle the 1,500 hp (100 F ambient) continuous power rating of the engine.

Lycoming has selected a 40 ft hull design of stepless, constant deadrise form which is based on David Taylor Model Basin test reports. The boat which is under construction will be of high grade steel and stressed to absorb loads resulting from 45 knot speeds in a state 2 sea.

The propeller design is a potentially low-cost, simple, controllable pitch type to provide smooth manœuvring between ahead and astern operation. In forward speed it would normally run at a fixed pitch. The 34 in diameter propeller is designed to absorb 1,500 hp at 1,455 rpm. Utilisation of this propeller will provide a marine propulsion package with a simple reversing system. Elimination of the requirement for a reverse gear will provide a more compact, less costly, and less complex power plant package with the potential of simpler maintenance as well as a simpler and more flexible operational capability.

(This paper will be completed in our next issue)

Figure 8. Boeing HTC (formerly FRESH-1)

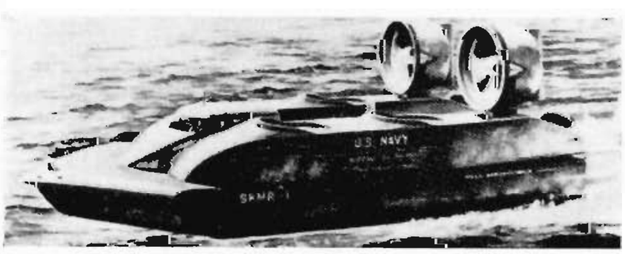
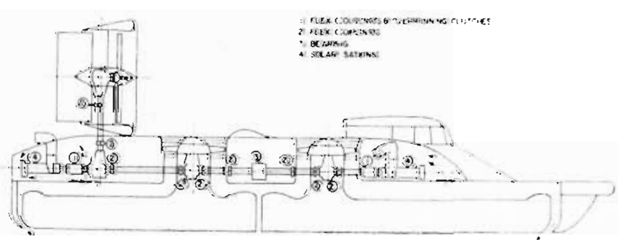


Figure 9. Bell's 22½-ton Hydroskimmer

Figure 10. Hydroskimmer machinery installation



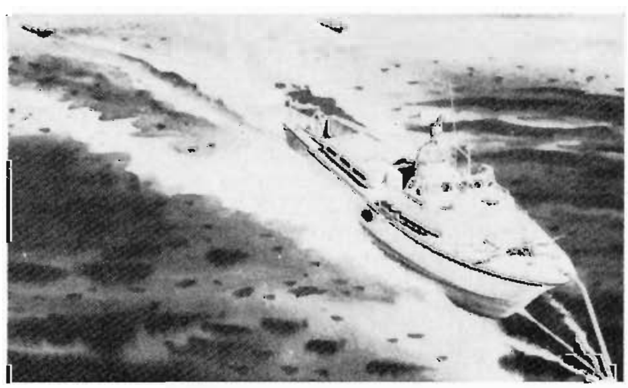
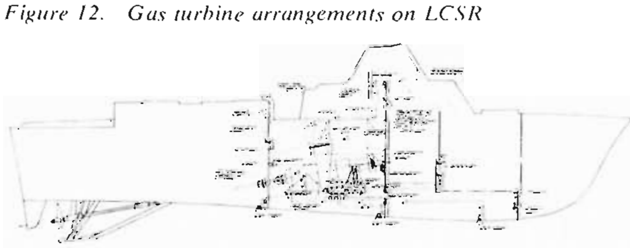


Figure 11. Impression of LCSR

Figure 12. Gas turbine arrangements on LCSR



AIR CUSHION VEHICLE DEVELOPMENT AND IMPROVEMENT

L. Boddington, C.B.E., M.I.Mech.E., F.R.Ae.S.
Assistant Managing Director (Technical)
Westland Aircraft Limited

Presented to the International Institute of Communications, Genoa, October 9, 1963

Introduction

WHEN the subject of hovercraft (Air Cushion Vehicles) is raised, it is not long before the question is asked "Is it an aircraft or a ship?"

The answer is of course — neither although it exhibits features which can be likened to both.

Thus although this first Air Cushion Vehicle paper is being presented to the Air Communications and Transport Section, I would like to feel that this is only a temporary measure, and that in due course it will prove expedient to include a separate section at the Annual International Meetings covering this new form of transport.

Growth of World Interest

No other form of transport has been so rapidly developed from the laboratory experiment to operational feasibility as the ACV.

It was only five years ago, in 1958, that serious interest started, although the basic idea of utilising the ground effect phenomenon can be traced back through patents to the late 19th century.

The rapid growth of interest in ACVs since 1958 is substantiated by the increase of world expenditure since that time, and the number of different craft types built to date.

It is estimated that the total world expenditure will have reached 9 to 10 million pounds by the end of 1963, of which about half will have been spent in Great Britain. (See Fig. 1).

The present world rate of expenditure has reached 4-5 millions per year, illustrating the confidence in the potential of the ACV as a new medium of Civil and Military transport.

This expenditure is reflected in the production of a wide variety of ACVs built over the last five year period although of course the total expenditure includes basic theoretical and experimental research as well as the manufacture of hardware.

Fig. 2 shows that about 75 craft types have been built since the first British research ACV — the Westland SR.N1 — in June 1959, of which 20% can be attributed to Great Britain.

However only about 20 of these ACVs are serious research or operational craft, and Great Britain can claim to have produced nearly 50% of these.

The other 50 to 60 craft consist in the main of one-man carrying platforms for demonstrating the basic principle.

Estimates of tonnage that these craft represent can be summarised as:

World tonnage	250 tons approximately
Great Britain	175 tons
Westlands	80 tons by end of 1963.

These figures appear ridiculously small when compared to ships, but when it is appreciated that a projected 150 ton ACV can carry 50% more passengers across the English Channel per day than a 4,000 ton channel ferry, it can be seen that comparing tonnage alone is not justified.

ACV development has been directed largely to overwater application as a high speed, low density cargo, transport for which passengers and cars form the principle traffic.

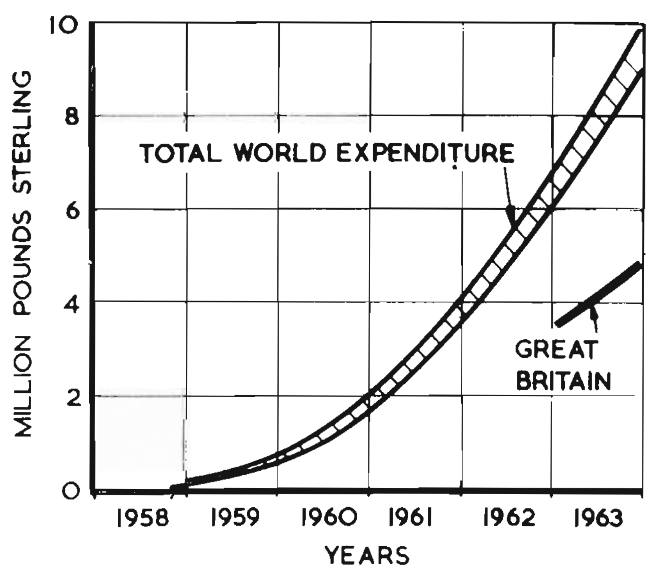


Figure 1. World expenditure on ACVs

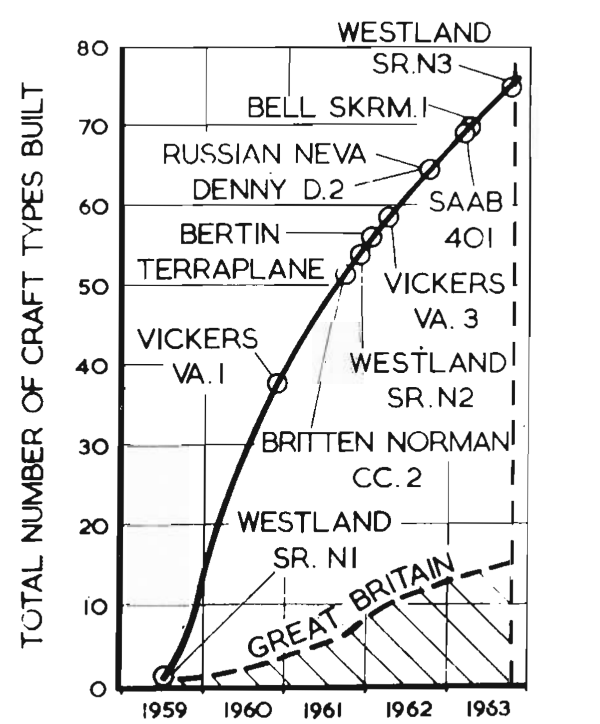


Figure 2. World hovercraft production

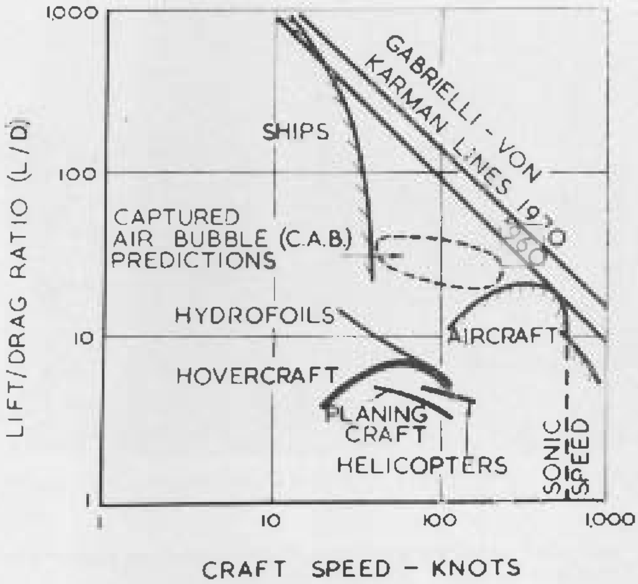


Figure 3. L/D vs speed of various sea and air vehicles

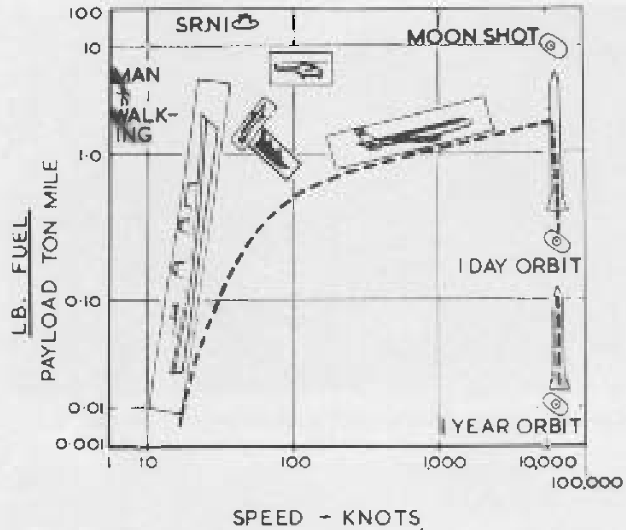


Figure 4. Vehicle efficiency vs speed

Overall Efficiency

When examining the present modes of transport, it is plainly evident that there exists a definite speed gap between the envelopes of the fastest ships (40 knots) and lower speed aircraft (100-120 knots). It is this speed region, 40-120 knots, that is being filled by the ACV and the hydrofoil boat.

Fig. 3 illustrates the order of L/D ratio achieved by various conventional sea and air vehicles compared with ACVs and hydrofoils sited in the speed gap between the large load carrying, low speed ship and the low load carrying high speed aircraft.

The diagonal lines in the right hand corner are the well known envelope lines of Gabrielli and Von Karman representing the "state of the art" in terms of maximum efficiency (L/D x Velocity) for 1960 and 1970. All vehicles fall to the left of these lines.

On this basis, the ACV L/D ratios of 6 and 7 do not indicate a very efficient machine, although the claims of the Captured Air Bubble concept — a variable of the ACV principle — are exceptionally high, but these claims have yet to be proved.

However, Fig. 4 is considered more indicative of the usefulness or efficiency of vehicles. Here, the parameter used is the lb of fuel required to carry one ton payload one mile. The lower the value, the more efficient the machine.

This parameter automatically takes account of (a) engine development because power/AUW ratio and specific fuel consumption are included, and (b) the efficiency of structural design because the payload/AUW ratio is included.

A value of 1.0 to 2.0 is indicative of a reasonably efficient vehicle and is achieved by passenger ships and aircraft. It is worth noting that exceptional efficiency is attained by bulk cargo ships which have values as low as 0.01. Although slow, their efficiency is due to low power/weight ratio and very high payload/weight ratio.

It can be seen that the ACV efficiency increases with speed and is in the overall efficiency class of aircraft. This is mainly due to the high payload/AUW ratio inherent with the ACV which is not reflected in the L/D comparisons shown earlier.

Typical values of vehicle payload/AUW ratios are:

ACVs	45-55%
Aircraft	25-30%
Passenger ships	5-25%

Thus the ACVs place in the transport system can be justified.

Design Trends of ACVs

By far the most developed form of ACV to date is that which employs the peripheral jet system, which, in its simplest form is shown on Fig. 5.

The peripheral jet craft is essentially flat-bottomed, is truly amphibious, having no physical contact with the surface over which it is travelling. The cushion of air on which the craft rides is created and contained by a continuous curtain of air flowing between the peripheral jet and the surface over which the craft is moving.

Figure 5. The principle of a simple hovercraft

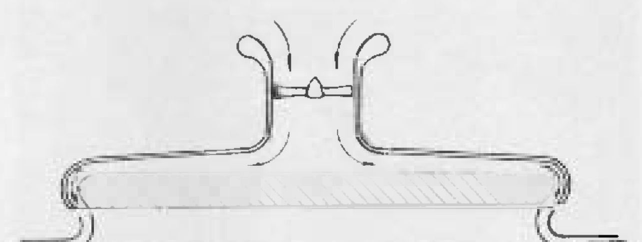


Figure 6. Great Britain. Westland SR.N2

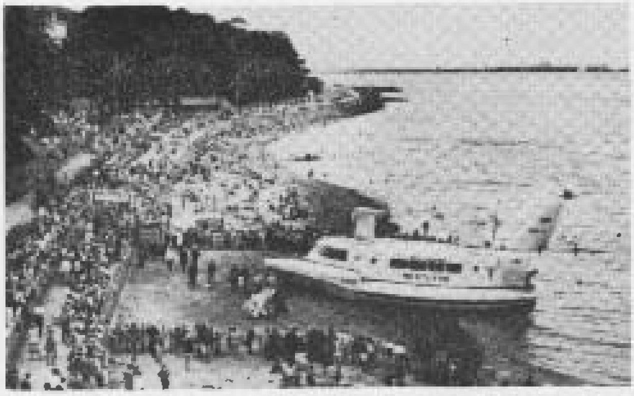


Figure 7. Great Britain. SR.N2 operating from beach

Figure 8. Great Britain. Vickers VA-3

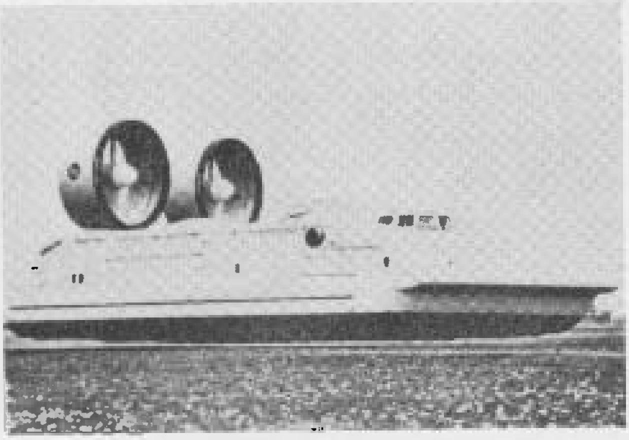


Figure 9. USA. Bell SKMR-1 Hydroskimmer

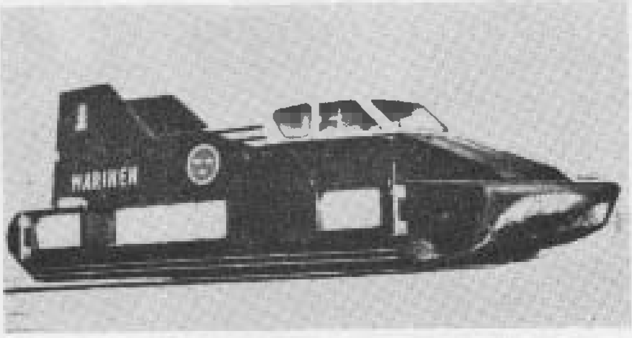


Figure 10. Sweden. SAAB 401

Examples of ACVs employing the peripheral jet system are:

(1) (See Fig. 6) Westland SR.N2
AUW 27 tons
Length 65 ft
Passenger capacity 70

Since January 1962, SR.N2 has operated 400 hours, carried 13,000 passengers, covered 7,500 miles, and achieved 90,000 passenger miles.

It has been employed on two fare paying passenger experimental services in conjunction with potential operators. The first was during August 1962 between Ryde on the Isle of Wight and Portsmouth on the South Coast of England, a distance of six nautical miles. The second, over a six week period ending August 30th this year between Weston-super-Mare and Penarth a distance of twelve nautical miles across the Bristol Channel.

On both the services, SR.N2 operated directly from the natural beaches with no special terminal facilities can be seen on Fig. 7.

(2) (See Fig. 8) Vickers VA.3
AUW 10 tons
Length 50 ft
Passenger capacity 20

This craft also completed an experimental fare paying passenger operation during 1962 between Rhyl and Wallasey on the North coast of Wales.

(3) (See Fig. 9) Bell Hydroskimmer
AUW 22 tons
Length 65 ft

Built for the United States Bureau of Ships for military evaluation.

(4) (See Fig. 10) Saab Marinen
AUW 2 tons
Length 24 ft
Passenger capacity 4

Ordered by the Swedish Naval Board for trials over land, water and ice.

Figure 11. Japan. Mitsubishi research craft

Figure 12. Russia. Krasnoye Sormovo Raduga

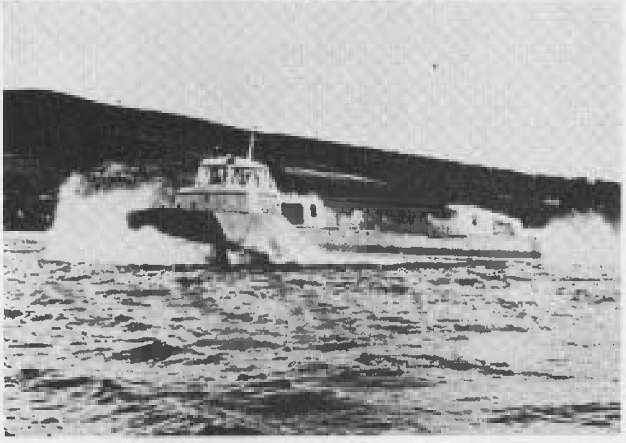


Figure 13. Great Britain, Denny D2

(5) (See Fig. 11) Mitsubishi research ACV
AUW 3 tons
Length 27 ft

(6) (See Fig. 12) Russian Rainbow research ACV
AUW 3 tons
Length 30 ft
Passenger capacity 5

An alternative type of over water ACV is the sidewall version which, as its name implies, employs solid immersed sidewalls or skegs to contain the air cushion created by continuous air curtains at the ends only. Power requirements to create the cushion are less, but additional propulsion power is required to overcome water drag of the sidewalls, particularly in other than smooth water. Generally, top speeds are about 35 knots but could be about 50 knots compared to peripheral jet craft speeds of 70-80 knots for the same total power.

Sidewall craft are less versatile since they are non-amphibious — subject to debris damage and suspect in cross sea operation.

Examples of this type of ACV are:

(1) (See Fig. 13) Denny D.2
AUW 25 tons
Length 68 ft
Passenger capacity 70

This craft has recently completed an experimental fare paying passenger operation on the River Thames.

(2) (See Fig. 14) Russian Leningrad craft
AUW 13 tons
Length 60 ft
Passenger capacity 38

This craft employs a plenum chamber system to create the cushion as distinct from discreet air jets at the ends of the craft.

As noted on Fig. 3, the Captured Air Bubble is a device for which much is claimed. On a CAB no continuous air curtain is provided, instead, as its name suggests, a bubble of air is contained between solid sidewall and sprung end

Figure 17. Great Britain, Converted Landrover

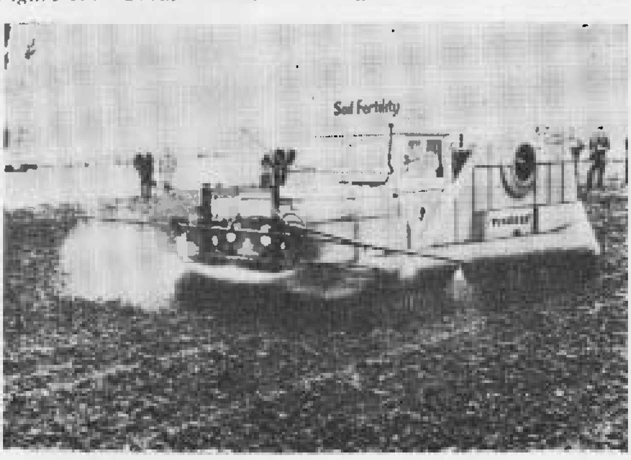


Figure 14. Russia, Leningrad Institute of Water Transport 38-seat plenum chambered craft

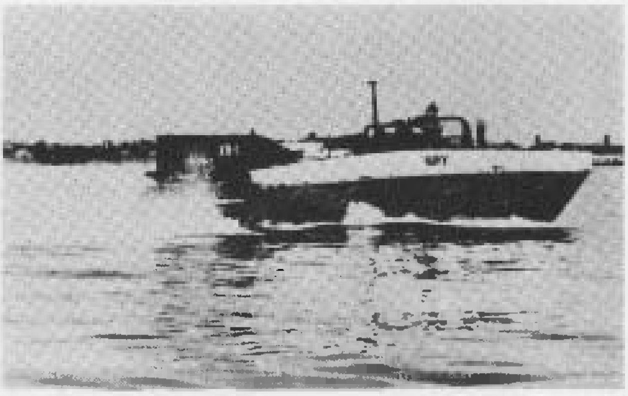


Figure 15. USA, XR-1, US Navy's CAB test vehicle

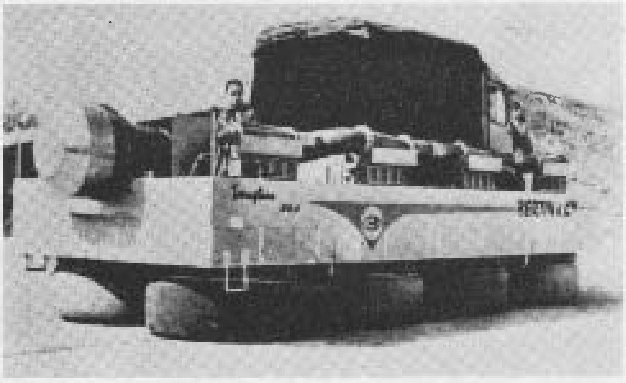
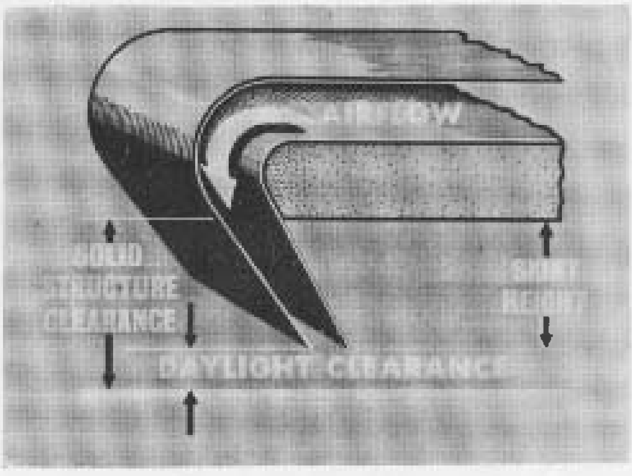


Figure 16. France, Bertin BC-4 Terraplane

Figure 18. Westland flexible skirt



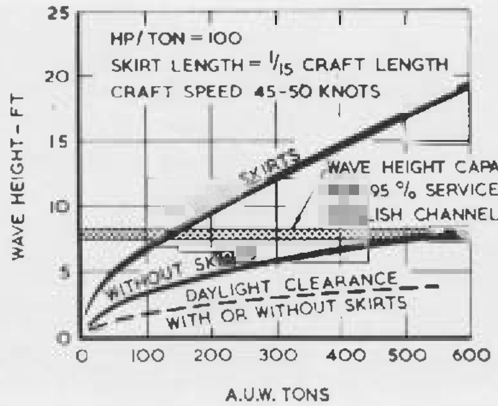


Figure 19. The effect of skirts on ACV overwave performance

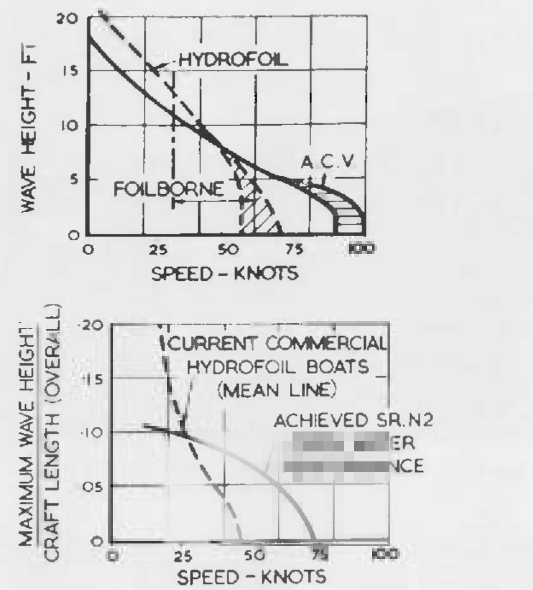


Figure 20. Overwave performance Hydrofoil/ACV comparison

platefoils which plane on the water profile and seal in the air bubble. Thus, it is claimed less power is required since it is only necessary to "top up" the bubble if and when it partially escapes.

An experimental example of this system has been built in America as shown in Fig. 15.

It remains to be seen whether this system will justify its claims, since tests made by Westland on similar devices showed that the the bubble "burst" (disappeared) in other than smooth water or if a change of trim was initiated.

Also, the drag of the planing end foils was found to be high. As with sidewall craft, this type of craft is non-amphibious.

An interesting development, rather unusual in appearance, is the French Bertin Terraplane as shown in Fig. 16. Eight individual circular lift cells support the load-carrying platform. The primary use is for moving loads over land, although it is capable of operating over water.

Vickers have followed development of applying the air cushion principle to existing land vehicles so that some of the vehicles weight can be taken on an air cushion for operating off-the-road.

Fig. 17 shows a converted Landrover. The assistance of an air cushion enables it to operate where conventional wheeled vehicles would become bogged down, and over crops where fully-loaded wheels would cause damage.

Operational Claims of ACVs

As previously stated, the peripheral jet craft is by far the most developed form of ACV, and is certainly the most versatile being completely at home over land or sea. We have seen how it fits into the transport system, efficiently filling the speed gap between ships and aircraft. By virtue of its low cushion pressure (70-100 lb/sq ft) ACVs are ideally suited to the carriage of low density payloads such as passengers and cars.

The majority of routes where the passenger/car traffic exists are over water, and peripheral jet craft can offer a fast service (70-80 knots) on these routes with the advantage of making the transition over the shore to relatively simple terminals outside the normal conjested ports. Tides, shallows, etc. are of no consequence.

However, the limitations of ACVs are that in order to operate efficiently in the ground effect, the hover height/craft length ratio is restricted to about 1/50th to 1/70th for a power/weight ratio of some 100 hp/ton at 70-80 knots.

In practice, this means that large machines of about 100 tons AUW and measuring over 100 ft long are required to provide a daylight clearance of 2 ft.

Such a craft would only be capable of clearing less than 2 ft obstacles over land and critical waves (say two times craft length) of up to 4 ft before the operating speed is restricted by water impact and hydrodynamic drag on the structure.

The physical hover height (daylight clearance) is proportional to installed lift power, therefore to double the hover height would mean at least doubling the lift power which is clearly inefficient.

On this basis the ACV would be of little practical value. However, the development that has made ACVs a truly versatile and useful vehicle is the flexible skirt.

A skirt is a flexible extension of the peripheral lift nozzle, see Fig. 18, and this device has been actively developed by Westland under full scale conditions. Skirts up to 4 ft in depth have been successfully engineered on the SR.N1, as will be seen on one of the films.

The advantage of the skirt is that the solid structure clearance height can now be increased by a factor of eight to ten with no increase of power.

The economic feasibility of quite small ACVs is now greatly improved, not only is the solid obstacle clearance over land increased, but also the wave height capability is increased by an amount almost equal to the length of the skirt.

The effect of skirts on the overall size of ACV to cope with a given critical sea condition (wave height) is shown on Fig. 19.

The effect of fitting a skirt equivalent to 1/15th craft length (an 8 ft skirt on a 150 ton ACV) shows that for maintaining

Figure 21. SR.N1 in its original form

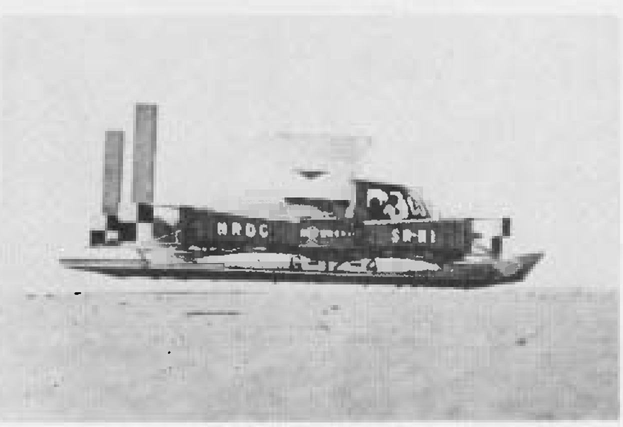


Figure 22. SR.N1 with skirts

Figure 23. SR.N2 over pack ice

Figure 24. SR.N3

a 95% regular service across the English Channel, when 8 ft waves can be encountered, an ACV of 150 tons is now practical whereas without skirts one had to think in terms of 500-600 ton ACVs as a minimum size.

In general, skirts have reduced the size of the ACV to do a specific task by a factor of four.

Comparison with the Hydrofoil Boat

Many arguments can be put forward by the exponents of the hydrofoil and the ACV as to which is the better vehicle.

However, for the purpose of this paper, a general comparison only is included as summarised in the following table.

Craft	Hydrofoil	ACV
Principle of operation	Lift derived from partial or fully submerged foils to raise hull out of the water.	Lift derived from air cushion on which it rides.
Versatility	Limited to water application. Non amphibious.	Water, land, marsh, ice, etc. Amphibious.
Disadvantages	Foils prone to damage by debris. High degree of engineering for accurate manufacture of foils required in high grade steels.	Control of craft in beam winds greater than 30 knots.
Maximum speed of currently operational designs	40-50 knots.	70-80 knots.
Predicted speed of projected 200 ton design	55-70 knots.	90-100 knots.
Primary field of development of advanced designs	Naval.	Civil Markets.

Comparisons of the overwave performance for hydrofoils and ACVs are shown in Fig. 20. The upper curve shows the mean line for current hydrofoils, obtained from analysis of published data, compared with the achieved performance of the Westland SR.N2 ACV.

The lower curve compares the predicted speed — wave height boundary for a projected 200 ton hydrofoil and ACV.

The general conclusion that can be drawn here is that the ACV has a distinct advantage at high speed whereas the hydrofoil has a better overwave performance at low and medium speeds.

Present and Future Developments

It has been shown earlier in this paper, both by the world expenditure and craft production, that the ACV is being actively developed in general. Certainly this is true in the particular case of Westland, where in addition to its many helicopter activities considerable effort and resources are committed to the advancement of ACVs.

The SR.N1, built in 1959 under contract to Hovercraft Development Limited, is continually in use as a research and demonstration craft. Originally it weighed $3\frac{1}{2}$ tons was capable of only 25 knots, and limited to wave heights of $1\frac{1}{2}$ ft or six to nine inch obstacles over land (See Fig. 21). It has been so developed that it is now capable of over 60 knots at a weight of 7 tons, and has been used primarly for the successful engineering of long skirts which has given it the capability of operating in 4-5 ft seas and clearing 3-4 ft obstacles over land as shown in Fig. 22.

The SR.N2, built in 1962 has been operating since that time fitted with 2 ft skirts, and has been used primarily to demonstrate the potential of ACVs as a passenger carrying over water transport. Fig. 23 shows it successfully operating over pack ice experienced during the last winter.

At the present time, SR.N2 is being fitted with 4 ft skirts to further its overwave and obstacle clearance capability.

Recently completed, and at this moment undergoing preliminary trials is the SR.N3 a $37\frac{1}{2}$ ton development of SR.N2, built specifically for the British Joint Armed Services.

Figure 25. SR.N2, Mk 2

Figure 26. SR.N5

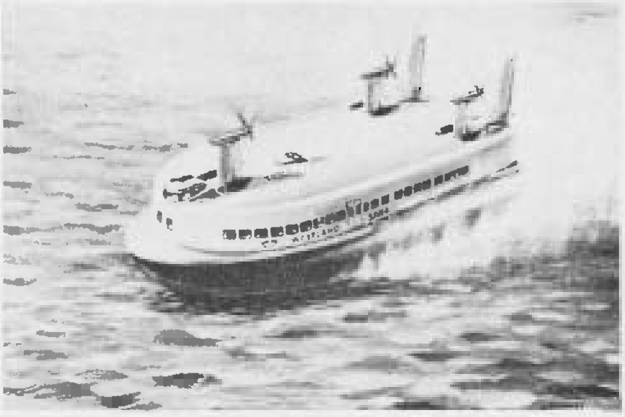


Figure 27. SR.N4

An artist's impression of it at sea is shown in Fig. 24. SR.N3 is the largest ACV built in the world today.

Fig. 25 shows the commercial counterpart of SR.N3 designated SR.N2 Mk.II, capable of carrying up to 150 passengers at 75 knots.

Also in production at this time is the SR.N5 (See Fig. 26) a versatile 7 ton craft equally suited to operation over land or sea. Fitted with 4 ft skirts SR.N5 can carry up to 20 passengers at 70 knots and is a direct result of the research and development into long skirts undertaken with SR.N1.

Finally, Westland have completed design studies of a 150 to 170 ton cross channel ferry shown in Fig. 27. Fitted with 8 ft skirts this ACV will be capable of operating in the sea conditions experienced in open water such as the Straits of Dover where 10 to 12 ft waves can occur.

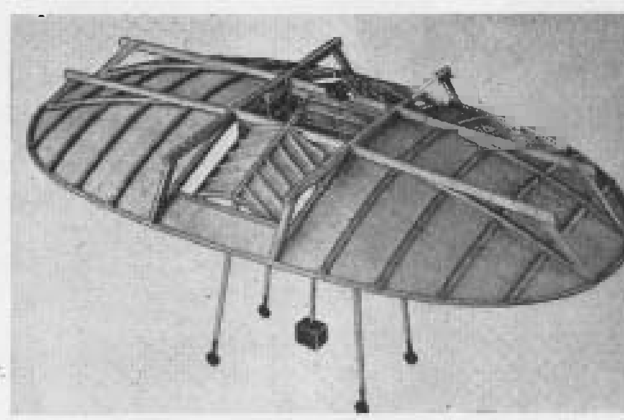
Up to 600 passengers or 40 cars can be accommodated, and with its inherent amphibious capability will be able to operate from relatively simple bases situated outside normal conjested harbours as shown in Fig. 28.

The significant feature of all the Westland ACVs is that they utilise the simple peripheral jet system.

Research into such schemes as recirculation which could improve the overall efficiency are being studied, and advanced schemes for future craft, such as the ram wing surface effect ship under development by the United States Maritime Administration, claiming speeds of 150-200 knots are being followed with interest.

It may well be that the next 10 years of development will see ACVs operating at 200 knots i.e. about double the anticipated speed for craft now being projected utilising the simple peripheral jet system, although the immediate development effort as far as Westland is concerned is on the successful and reliable engineering of long flexible skirts.

Figure 28. SR.N4



Skydrofoil SS 26C on test

SKYDROFOIL PROGRESS

BELIEVED to be the first commercial hydrofoil designed and built in the United Kingdom for export, the 26 ft Skyrofoil SS 26 successfully completed its maker's trials recently.

Ordered by a ferry operator on the European continent, the Skydrofoil SS 26 is the smallest of a range of craft designed by Brian Grimston and built at the Dorset Lake Shipyard, Hamworthy, Poole. The biggest Skydrofoil planned so far will carry up to 500 passengers at 50 mph.

The concept is a new one. The first craft of this type, the SS 45, was described in *Hovering Craft and Hydrofoil* in November 1961.

As seen from the accompanying photograph, the Skydrofoil achieves the objective of reducing the wetted surface by a particularly simple approach. It employs a foil to raise the front end of the vessel only, leaving the remaining two-thirds of the weight supported by the stern corners of a planing hull of simple design.

One big advantage is that the main foil, which can be of either the surface-piercing, or preferably the more efficient submerged type, can be sufficiently small to reduce static draught to that required by the propellers, confining drag of the foil system to that of a small proportion of the strut supporting the foil.

The wetted surface of the hull decreases rapidly at speeds above 15 mph, where resistance is comparitively low, until less than 5% of the static surface is submerged at cruising speeds over 25 knots.

The air rammed under the prow of the Skydrofoil at speed, and trapped under the hollow sea sled type hull, reduces the lift needed from the foils and provides a means of absorbing wave impact.

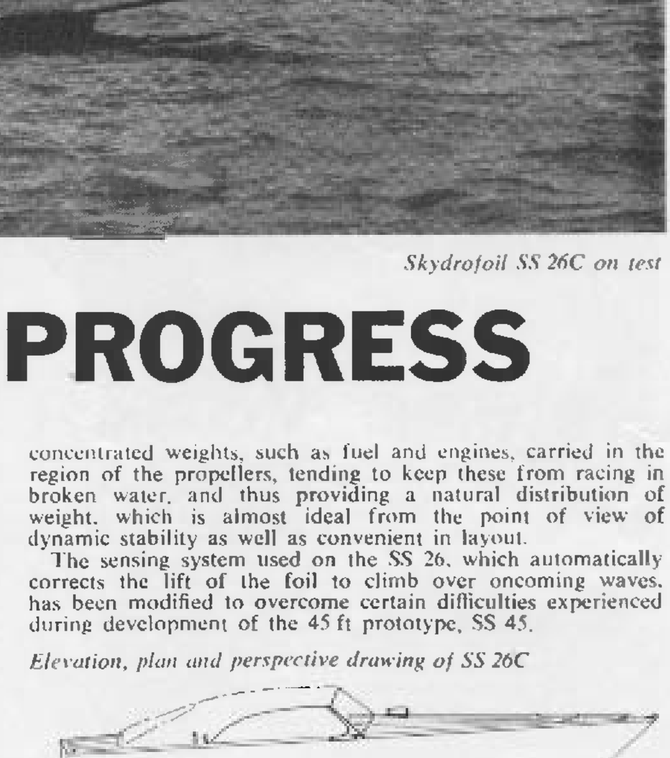
By using air support, the foil of a Skydrofoil requires less than 25% of the surface of foils employed by other systems, and offers less resistance when carrying a comparable load.

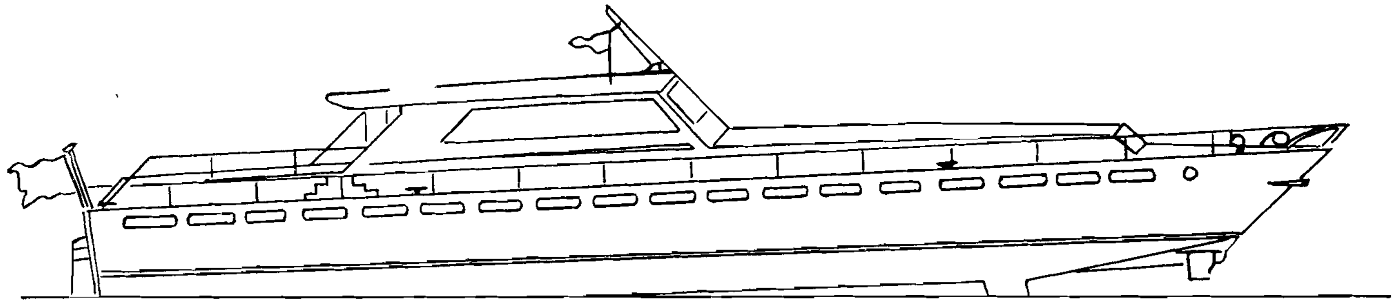
Up to 85% of the hull can be constructed from a single section folded from rectangular marine light alloy sheets. Eliminating practically all under water jointing by riveting or welding, this system of construction is not only exceptionally light and strong but inexpensive to construct.

It will be seen that the centre of gravity lies directly over that of the triangle of the supporting surfaces, with the main concentrated weights, such as fuel and engines, carried in the region of the propellers, tending to keep these from racing in broken water, and thus providing a natural distribution of weight, which is almost ideal from the point of view of dynamic stability as well as convenient in layout.

The sensing system used on the SS 26, which automatically corrects the lift of the foil to climb over oncoming waves, has been modified to overcome certain difficulties experienced during development of the 45 ft prototype, SS 45.

Elevation, plan and perspective drawing of SS 26C





Design for a large Skydrofoil ferry

When the latter was designed, the original system had been simplified to a stage where it became difficult to apply it to the higher loads and variations likely at greater speeds.

In SS 26, the foil system is virtually an enlarged and controlled version of the stabiliser protected by the original patent applications. It consists of a submerged foil, whose inclination is automatically increased by leverage from the small stabilising foil under the forefoot, and which becomes submerged only on encountering a wave of sufficient size to disturb the trim of the Skydrofoil. Where necessary this device can also be adjusted for trim sensing.

In this form the foil system permits the helmsman to control the inclination of the main foil to suit variations in speed, payload and wind strength. It has now been developed to a stage where it can be applied to the 65 ft Skydrofoil SS 65, designed to carry up to 70 passengers, and the 110 ft Skydrofoil with seating for up to 500 passengers.

Specification SS 26

Speeds considerably in excess of 30 knots have been achieved with the SS 26 without using full power, and the ride is exceptionally smooth and free from shock in waves up to 2 ft.

This compares with similar speeds limited to 30 knots achieved by planing launches using 32% more power.
added risk of only a single engine.

Dimensions Excluding Transom Drives
LOA 26 ft, Beam 8 ft, Draught 18 in, Freeboard 3½ ft

Aluminium
12 swg sheet hull to specification NS.5 half hard

Accommodation
Sleeps 4, 2 in saloon and 2 in forepeak

Upholstery
Foamed plastic covered Lionide

Interior Floors, Joinery and Deck
Marine plywood to specification BSS 1088

Foil Mountings
Stainless steel

Galley
2 burner cooker, methylated or camping gas. Stainless steel sink, with fresh water supply from portable plastic container, lockers for storage, cutlery, etc.

Engines
Single or twin Rootes Alpine 85 hp petrol engines driving Perkins Transom Drives, giving speeds to 40 mph. Alternatively, single or twin 50 hp Perkins Diesels Type 4.107 with transom drives, approved types of outboard motors, singles up to 100 hp or twins up to 85 hp each

Fuel Tanks
Two, each of 20 gallon capacity

Buoyancy
Built in to float hull and engines

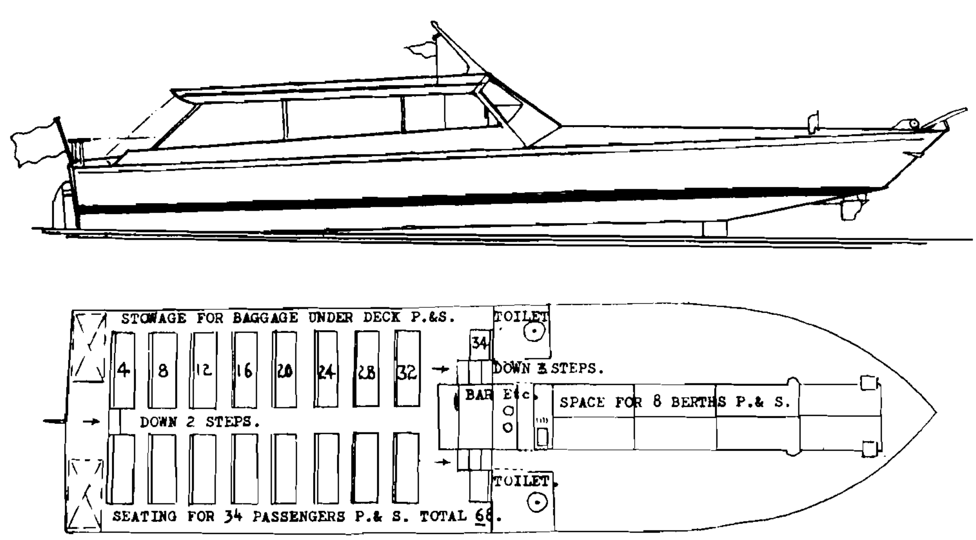
Controls
Combined gear and throttle controls as supplied by engine manufacturers. Teleflex steering by two-spoke car type wheel

Toilet
Marine type wc with Henderson diaphragm pump, with cock and suction hose for pumping bilge

Standard Equipment
Port, Starboard and stern navigation lights with switch. Engine makers' instruments. Telescopic ensign staff bow and stern warps. Battery to each engine fitted. Helmsman's folding seat. Fire extinguishers. Mirror and Burgee staff. Cocktail cabinet.

Optional Equipment at Extra Cost
17 lb anchor with nylon cable, proofed Terylene stern screen to cockpit. Curtain partitions and curtains for wardrobe, wc and forepeak. Mooring fenders, speedometer, transom ladder, refrigerator. Additional cockpit seating. Carpets. Additional fresh water containers

Shipping Dimensions
Length with transom drive removed 26 ft. Breadth including cradle, 8 ft. Depth including cradle, 8 ft. Weight of hull without engines, 800 lbs approximately



Skydrofoil SS 65G arranged as a 68 seat ferry. Speed, 50 mph; length, 65 ft; beam, 17 ft; draught (static), 5 ft; mobile, 2 ft 6 in; range, 260 miles. Cost (ex works), from £23,000

"HOVERING CRAFT & HYDROFOIL WORLD REPORT"

The first number of this detailed and fully illustrated annual review of the air cushion and hydrofoil industries will be published in early 1964, price Two Guineas

★ New readers may, for convenience, include the "HH" World Report in their subscription. Revised rates to include twelve issues of the journal and this invaluable reference book will be Seven Guineas in the United Kingdom and the equivalent overseas, and $21 in the USA and Canada.

Orders should be placed early if you want to ensure obtaining a copy

Remittances should be sent to

Hovering Craft and Hydrofoil
53-55 Beak Street, London, W.1