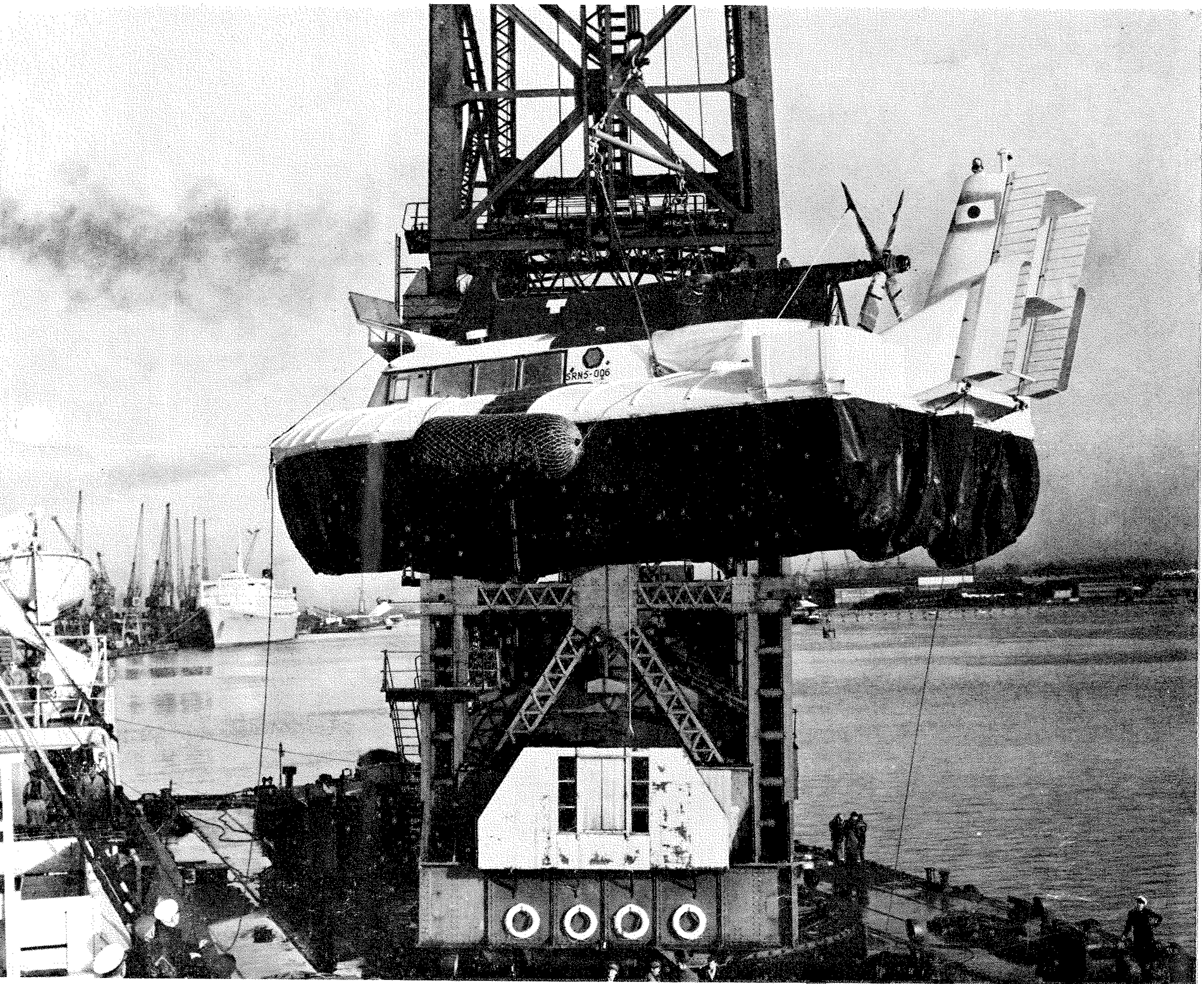
HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS



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HOVERING CRAFT
& HYDROFOIL

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First Hovering Craft & Hydrofoil Monthly in the World

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HOVERCRAFT FOR CANADA

An excerpt from an address by Mr Douglas Connor, DFC, President of the Montreal company Autair Helicopter Services Ltd, given to the Westmount, Montreal Rotary Club, on "Breaking Through the Transportation Barrier".

IT is probably no secret to you that we, at Autair, believe in the lift fan principle — in a more down to earth manner. In May 1963 we sponsored, in co-operation with Westland Aircraft in England, the first overseas demonstration of a hovercraft — the Westland SR.N2. Hovercraft are air cushion vehicles or ground effect machines and they are a most promising form of transportation for two reasons:

One: they demand very little social investment in landing pads, etc.

Secondly: they allow a new dimension in speed . . . safe speed . . . in an environment which, up till now, has seen no new developments for over fifty years. This environment is water.

The hovercraft in which we are most interested, will see its major application as an amphibious vehicle. But the hovercraft principle as such . . . using air to overcome friction between the ground and the vehicle itself . . . can be applied in many areas. One such area is the one out of which Mr Crump wants to get: tracked passenger transportation. The inventor of the hovercraft, Mr Christopher Cockerell, said recently that tracked hovercraft for intercity transportation could operate on simple concrete tracks at a speed of 300 mph. This craft would operate on a very fine air cushion . . . it would, so to speak, use air as a lubricant between itself and the concrete track. We would enter a completely new order of tracked transportation with a minimum of social investment . . . since we already have paid for the right of way through government grants many years ago.

However, we have placed our bet on the hovercraft as an amphibious vehicle at present developed in the UK. This is a development very much within the scale of things *we could have attempted in Canada.* Not much more than ten million dollars were expended all together, and in less than five years the development was taken from prototype to saleable vehicle.

In Canada, also, we have a vast territory almost prescribed for hovercraft use . . . our Northern territories . . . where our future is said to lie and where relatively so little development has yet taken place.

The Russians are at present working on year round transportation along their Northern river routes with air cushion vehicles. Here is a quote from one of their publications: "A great future belongs to this new means of travel which is destined to bring about a radical revolution in river transport.

(Continued on page 5)

IN THIS ISSUE

COVER PICTURE: *The first Hovercraft to be exported to Japan — a Westland SR.N5 — being loaded as deck cargo on board the 8,925 ton P & O Orient cargo ship "Surat" at Southampton on Friday, 15th January, 1965.*

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Editor:
JUANITA KALERGHI

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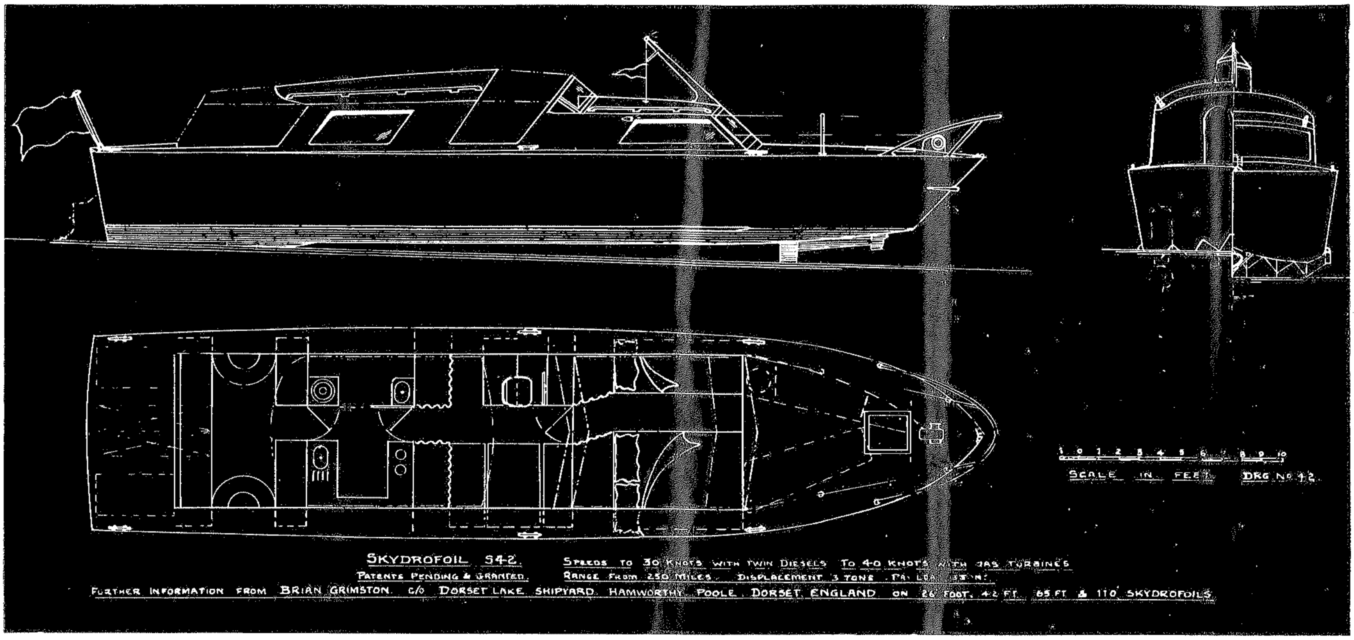


General arrangement of Mr Brian Grimston's Skydrofoil S 42. (See below)

People and Projects

Provisional specifications for **Mr Brian Grimston's** skydrofoil S 42 are as follows:

Length	42 ft
Beam	9 ft
Draught (hullborne)	less than 3 ft
Draught (foilborne)	less than 2 ft
Approx weight with fuel for 150 sea miles at 30 knots	6,000 lbs
Approx Speeds: Take-off	13/15 knots
Cruising	23/35 knots
Capacity	Up to thirty passengers
Foil system	Submerged foil sensed by patented mechanical system

Construction from folded rectangular 5% marine alloy 10 g sheet, bonded Araldite adhesives.

Propulsion

Designed for a wide range of standard diesel burning IC engines and gas turbines, driving submerged screws through Z drives, Vee drives, or short shafts, depending on speed and initial and running cost required. In each case the initial and running cost related to the speed obtainable is highly competitive.

Mr Grimston's first craft, the Skydrofoil S 45 was described in *Hovering Craft and Hydrofoil,* November 1961, and his Skydrofoil S 26 was described in *Hovering Craft and Hydrofoil* of October 1963.

* * *

Grumman Aircraft Engineering Corporation, Bethpage, Long Island, New York have announced that they have just signed a contract with Blohm and Voss, Hamburg, Germany for the construction of a commercial hydrofoil vessel to be marketed under the name of Dolphin. Construction on this prototype production vessel will commence in March 1965 and it is expected that the craft will be in commercial use during the first half of 1966.

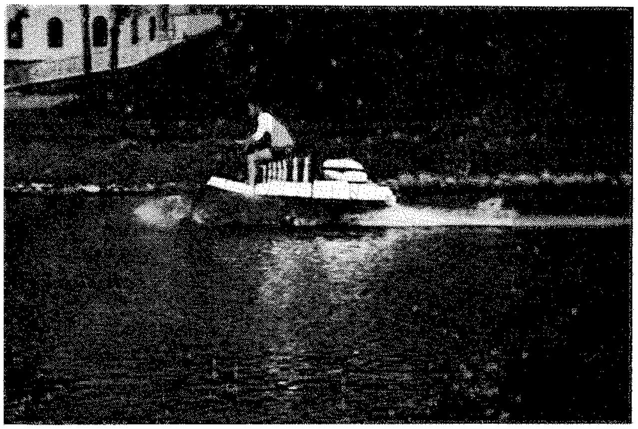
Grumman, manufacturers of American military and commercial aircraft, have been engaged in the development, design and construction of hydrofoils, ranging from ½ ton to 300 tons and speeds up to 80 knots, for the last ten years. Prior to the Dolphin programme, the HS *Denison* an 80 ton 65 knot open sea hydrofoil built for the US Maritime Administration, was demonstrated for two years in the open sea, concluding with an 11,000 mile cruise visiting all the major US Atlantic coast ports. The experience gained from this operation lead to the design of the Dolphin.

The principal characteristics of the gas-turbine powered Dolphin are as follows:

Length overall	75 ft
Maximum beam	19 ft
Draft, foils fully retracted	4 ft
Draft, foils fully extended	13 ft
Gross tonnage (estimated)	84 tons (registered)
Number of passengers with a crew of three	Ninety
Sea state 3 cruise speed	50 knots
Range (foilborne)	200 nautical miles

* * *

Take off



Foilborne at low speed

New Canadian private venture into small hydrofoil craft by Messrs S. Fritsch and Roy Braithwaite. (See below)

Flight Lieutenant S. O. W. Fritsch of the Royal Canadian Air Force and **Mr Roy Braithwaite** a professional engineer and former pilot with the RAF and RCAF, have announced a new small hydrofoil craft private venture. They are developing a small craft and preparing a study entitled "A paper on the technical and economic feasability of a small hydrofoil craft".

The study, which is going hand in hand with the prototype research covers the following areas: (1) The present state of the art. (2) Possible areas of application for a small hydrofoil craft. (3) Possible designs to fit areas of application. (4) A logical design and development of a small hydrofoil craft.

* * *

The Maritime Administration's hydrofoil **"Denison"**, constructed by Grumman Aircraft Engineering Corporation has now been restored to operating condition by her builders. The craft had been seriously damaged when she grounded in the Cape Fear River last March after a year and a half of trial operation.

The Denison will be kept available to all elements of the government and industry "for use as a valuable technological resource", and Grumman will pay over to the government one half of any profit in excess of 10% of expenses.

* * *

The US Navy experimental hydrofoil research craft **"Sea Legs"** was operated during December 1964 in New York Harbour for tests of the Ryan Aeronautical Company's AN/SPN-37 Electro Magnetic height sensor designed for hydrofoil craft requiring height control between 5 and 55 ft above the foilborne water line. *Sea Legs* was designed by Gibbs and Cox, Incorporated, New York City.

* * *

A Westland SR.N5 will be used by **Highland Engineering Ltd** of Edinburgh to operate a commercial hovercraft service on the Clyde starting in June. The service will link Gourock and Tarbert twice daily, and will also operate a Rothesay-Dunoon-Gourock-Helensburgh route, linking four of the more important points on north and south banks of the river. Highland Engineering Ltd, will base the service on Tarbert, Loch Fyne, where they already possess a boatyard and base, and the first six months of operation will be regarded experimentally until the time pattern of commercial operation can be assessed.

* * *

Engineers at the Krasnoye Sormovo yards in Gorki on the Volga have designed an aircushion vehicle which can operate on rivers during timber rafting operations, and which can travel over ice and snow. Naimed **Taiga** the craft has a cargo capacity of two tons and will carry freight to lumberjacks, and if necessary tug small barges in shallow water. The 30 centimetre air-cushion will be created by a gas turbine engine, and two lift beams will be installed to ensure good control and manoeuvrability. The Taiga is 13 metres long and 6 metres wide and will develop a speed of 50 kms per hour.

* * *

HOVERCRAFT FOR CANADA

(Continued from page 3)

Machines on air cushions can, during 24 hrs, cover tremendous roadless distances of a length of 1,000 kilometers and more. Their employment under northern conditions is economical and is necessary from the point of view of the introduction of new technical equipment."

We agree. We also think that hovercraft have a future in dense population centres. With the help of a one million dollar Federal subsidy, an experiment in mass transportation by hovercraft will be carried out in the San Francisco Oakland area in the United States next year. We still expect to inaugurate the world's first commercial hovercraft service, under the auspices of Canadian Air Cushion Vehicles in the Montreal area. We are convinced that Canada is the logical country for the employment of air cushion vehicles, with its vast Northern territories . . . its cities bordering on the St Lawrence. We intend two dramatic services: one in the Montreal area in connection with EXPO 67, and one experimental run in the North . . . from steel to steel over otherwise unpassable territory from Moosonee, Ontario to Hay River in Alberta. We . . . as private operators . . . have great faith in the hovercraft as a means of breaking through many a transportation barrier. However, it must not be forgotten that it is a new vehicle and that we must gain experience with it before we can put it on a pure profit basis. And profitable operations with hovercraft are profitable for the country as a whole because there will be no hidden charges . . . paid for by the community.

We believe that hovercraft are a true Twentieth Century vehicle — using Twentieth Century technology in a useful and rational manner. We are only at the beginning of developments in hovercraft and we believe Canada can, and will, play a leading role in the interest of its own progress as a nation.

A Survey of American Interests in Ground Effect Machines

Leslie Hayward

In December 1876, John B. Ward of San Francisco, California, made the first American proposal for a form of ground effect machine.

Air directed downwards by a large fan provides lift, and air drawn through forward-facing ducts, to be passed through control nozzles, provides forward movement and directional control.

In 1877 Ward made suggestions for improving his machine by coupling peripheral ram air ducts to the central fan arrangement.

American interest appears to have been dormant until 1907, when Joseph I. C. Clarke of New York designed a machine which had a large forward-facing air intake feeding a vertically disposed fan discharging air through a conical annular duct in an attempt to form an air cushion. A propeller provided forward propulsion.

The first American proposal for an air lubricated or supported railway type of vehicle was made in 1908 by Charles Worthington.

A somewhat similar proposal was made in January 1913 by A. F. Eells of Rochester, Monroe, New York, and a further proposal for air supported sliding railways was made in 1922 by F. G. Trask of North Dakota.

The American pioneer Douglas Kent Warner delivered an outboard powered, ram supported craft for testing on Lake Compounce, Connecticut, in 1928; and in 1929, at the request of the United States Navy Building in Washington, he delivered a second machine to Bolling Field for testing. He drove a machine in 1930 which obtained its initial lift from engine exhaust gases, at the Middletown Races over the Connecticutt River. This machine was unacceptable and from that time Warner's interests turned to air support and air propulsion. His research and investigations were continued up to the time of his death in November of last year, and from the period 1928 to 1954 he appears to have been the only American seriously working in this field.

In March 1942, Charles C. Cristadoro of Venice, California, proposed a large low-draft transport vessel having side-walls. The flat hull of the vessel was compartmented and an air cushion formed beneath the hull. A number of air screws were suggested at the stern of the vessel and were used for propulsion.

R. H. Goddard of Annapolis proposed a high-speed transportation system using the air-bearing principle in 1950.

Interest in the United States seems to have become more active since April 1957, with the publication by the Lewis Laboratory of the then NACA of a report describing some simple annular jet experiments.

The US Navy, stimulated by this report, established a research programme at the David Taylor Model Basin and in July 1957 David Taylor Model Basin produced a comprehensive report of the fundamental annular jet ground-cushion phenomena complete with working formulae. There is evidence within the report that individual work had been taking place by unknown inventors and hobbyists prior to its publication.

In view of the very considerable interest and diversified features of craft which have been proposed or manufactured within the last ten years, the remainder of this summary is classified under individuals, companies, universities or other organisations known to have been active in the field.

H. BARTLETT

Flying Saucer

Mr Bartlett of Washington has built a number of circular vehicles he has called Bartlett Flying Saucers.

Diameters vary from 6-10 ft. A 3 hp engine driving a centrally located fan delivers air to a plenum chamber. In some designs a skirt is fitted around the plenum chamber. Speeds of 25 mph have been attained and the clearance height with skirt is 12 in.

AIR SCOOTER

Bell Helicopter, now Bell Aerosystems, a division of Bell Aerospace Corporation, a member of the Textron group, designed and constructed a single-seater "air scooter" in 1959. This machine, constructed of fibre glass and aluminium, had a 14 hp two-stroke engine driving a fan of 30 in diameter, giving a hoverheight of approximately 1½ in from the ground. A speed of 25 mph was attained.

Basic design and development work for this plenum chamber machine was initiated by K. and R. Wernicke, Bell research engineers, who had previously constructed electric-powered model studies and a simple test vehicle capable of carrying a child.

BELL HYDROSKIMMER — XHS3

On November 17th, 1960, Bell delivered their outboard-powered Hydroskimmer, given the designation XHS3, to the American Navy Bureau of Ships for test and evaluation. This vehicle, constructed mainly from resin-impregnated fibre glass, was of the side-wall type, 18 ft in length. The air cushion was created and maintained by an independently driven horizontal fan.

BELL ACV

This amphibious vehicle, of the plenum chamber type, having a hoverheight of 3 in, powered by a 65 hp engine, was, in February 1961, the first air cushion vehicle to be granted a licence for operation on the roads of New York State. The vehicle, which has an integrated lift and propulsion system, carried three passengers at a top speed of approximately 15 mph. Side sponsons having special flaps were incorporated to assist in preventing the escape of cushion air and to assist directional control.

The Bell ACV, a civil version of the XHS3, was first exhibited at the Boat, Travel and Sport Show in Buffalo, NY, in February 1961.

BELL HYDROSKIMMER — SKMR-1 (Formerly XHS-4)

As a result of a United States Navy design competition, Bell obtained a contract in November 1961 for a design study of a larger vehicle known as SKMR-1. Manufacture was completed in April 1963 and in August of the same year acceptance trials had also been completed. This machine uses a peripheral jet concept, and has a payload of 4½ tons and a basic all up weight of 25 tons. Four 1,080 hp Solar Saturn gas turbines provide an integrated propulsion and lifting system. Hoverheight is approximately 18 in, depending upon loading.

BELL/PNYA ACV

The Port of New York Authority and Bell Aerosystems have jointly developed an air cushion machine for operation on and around airports. The vehicle is a five-seater, lift being provided by a 6 ft 6 in diameter horizontal fan, driven by a 350 hp engine. A 6 ft diameter tractor propeller, driven by a 180 hp engine, provides propulsion.

Bell Aerosystems have licence arrangements with Hovercraft Development Ltd and Westland Aircraft Ltd.

BELL CARABAO

A three-cell plenum chamber vehicle, known as the Carabao, was constructed in the early part of 1963. Having an all up weight of 1¾ tons, the vehicle has a Franklin 60 hp engine for lift purposes and a Lycoming 150 hp engine for propulsion. Obstacle clearance height is approximately 12-15 in. The Carabao, designed for a diversity of civil operations, was tested on Lake Erie at Buffalo in May 1963.

BERTELSEN MANUFACTURING COMPANY INC
WILLIAM R. BERTELSEN, MD

Dr Bertelsen's original experiments were conducted with electrically powered models. His first piston-engined model was of the plenum chamber type and embodied a 2½ hp engine. This was followed by peripheral jet research vehicles powered with a 35 hp engine. The second of these man-carrying research vehicles was tested in March 1959. Engine power proved to be insufficient and a 72 hp engine was installed in May 1959, the converted vehicle being designated as the Aeromobile A-72.

Aeromobile A-72

An eight-bladed fan of 30 in diameter, driven by a 72 hp four-cylinder two-stroke engine provides the air cushion and peripheral jet curtain; control flaps around the periphery of the vehicle are used to tilt the machine for attaining directional control. A forward speed of 40 mph was attained with a hoverheight of 6 in.

Aeromobile A-200-1

This amphibious vehicle, first tested in May 1960, is capable of carrying four passengers at a speed of approximately 60 mph. A 178 hp six-cylinder engine drives a sixteen-blade, adjustable-pitch fan, specially designed by Bertelsen to produce the air cushion and peripheral air curtain. The vehicle is 8 ft wide and 16 ft long.

Aeromobile A-200-2

Built for overseas exhibition to the order of the US Office of International Trade Fairs, the fibre glass body was designed by members of that Government department. February 20th, 1961, saw the first demonstration of this vehicle, which was 17 ft 6 in in length, 8 ft wide and had a range of approximately 75 miles with one passenger. Yaw control was effected by an automatic pilot.

Demonstrations took place at the Tokyo International Trade Fair in April 1961.

Arcopter GEM-1

A prototype ram wing type of ground effect vehicle powered by a 65 hp engine driving a two-blade propeller was developed by Bertelsen during 1961. The vehicle was 14 ft in length, 6 ft 8 in wide and had a maximum speed of 40 mph.

Arcopter GEM-2

Developed from the GEM-1, the two-seater Arcopter GEM-2 powered by a 115 hp engine made the first air cushion vehicle crossing of the Mississippi River on January 29th, 1962, at a time when the river was impassable to all other types of surface or displacement craft. GEM-2, 22 ft in length and 7 ft 8 in wide, had a top speed of 75 mph and a hoverheight of approximately 2 in.

Arcopter GEM-III

The GEM-III is a further development of the previous models. The ram wing conception is maintained and a 180 hp engine drives a two-blade retractable-pitch propeller. Steerable wheels enable this versatile amphibian carrying four persons to be driven as an ordinary motor vehicle.

Dr Bertelsen is an exponent of grooved roads, and suggests remote-controlled homing and spacing devices for what he terms as the wheel-less car of the future.

CONVAIR DIVISION — GENERAL DYNAMICS CORPORATION

In early 1960 Convair Division were engaged in development of the use of nuclear powered annular jet type air cushion vehicles of the order of 400 ft diameter, weighing approximately 4,000,000 lb and capable of a speed of 100 knots at a hoverheight of 12-15 ft. The vehicle, designed to carry 1,000,000 lb payload and built of aluminium, has gas turbines as additional power units.

WALTER A. CROWLEY

Walter A. Crowley, one of the American pioneers of air cushion vehicles, started work in this field during 1956 when he produced a 7 ft diameter plenum chamber vehicle which lifted his son.

In 1957 he produced a 9 ft × 16 ft plenum chamber vehicle which is now in the Smithsonian Air Museum. United States Patent 3,090,455 discloses details of Crowley's 1957 vehicle, which incorporated self-propulsion and steering arrangements.

United States Patent 3,090,327 discloses Crowley's proposals for an air cushion supported monorail vehicle. Spacetronics Inc was formed in 1958 to exploit Crowley's designs and a vehicle carrying sixteen people was demonstrated in 1959. This vehicle was 30 ft long, 24 ft wide and had a gross weight of 8,000 lb. Lack of money prevented further development.

Walter Crowley is now with the Boeing Company.

CURTISS-WRIGHT

Air Car

In 1959 Curtiss-Wright produced a plenum chamber Air Car prototype which had a 200 hp piston engine and supported a 200 lb payload at a hoverheight of 1 in.

Model 2500 Air Car

Production of the Model 2500 Air Car started in November 1959. Two 180 hp engines drawing multi-bladed fans produce an air cushion of 1/10th lb psi. Large shutters at the periphery of the plenum chamber structure enable air to be bled from the plenum chamber for control purposes. The length of the vehicle was 21 ft and the width 8 ft.

DOBSON AIR DART

The Air Dart, designed by Frank Dobson of Corona del Mar, California, is offered in kit form as a self-build vehicle by Aircars Inc of Los Angeles. Dobson's experimental work commenced in 1957, and his first experimental craft, a 6 ft diameter platform incorporating a small engine driving two independent fans, was built in 1958.

The Air Dart is powered by a 10 hp engine driving a multi-bladed fibre glass fan installed in the front face of the vehicle. Hoverheight is 4 in and an aircraft type rudder is used for directional control.

FLETCH-AIRE COMPANY INC

Glide-Mobile

Charles Fletcher designed and produced the Glide-Mobile in 1960. The vehicle, powered by a 72 hp engine, weighs 240 lb and has a speed of 25 mph. The base structure of the vehicle is an inflatable raft, and control of the air cushion is achieved by inflating or deflating the raft. A 4 ft diameter fan forces air through an annular passage to a plenum chamber to provide the air cushion. Directional control is attained by use of control panels around the vehicle structure.

FORD MOTOR COMPANY

Aeronutronic Division

Dr Andrew A. Kucher, who until his recent retirement was Vice-President of Engineering and Research at Ford Motor Company, is known to have been interested in the principle of supporting a vehicle on a thin film of air since 1928. The "Levapad" introduced in 1958 works on the principle of high-pressure air being injected through small orifices in the underside of a smooth pad. Air passing from the orifices supplies sufficient pressure to raise the pad free from the ground and also acts as a lubricant between the pad and a prepared ground surface.

Ford engineers David Jay, Harlan Peithman and Victor Raviolo have continued research and development of this principle, and Ford have produced a number of different models known as the Levacar since their first full-scale lists in early 1959. Recent interest has been in the adaptation of the Levapad principle to rail vehicles which are expected to attain speeds of up to 500 mph.

Ford FMC/ACV-1

June 1962 saw the first tests of an amphibious experimental air cushion vehicle weighing 7,000 lb and capable of carrying a load of 3,000 lb. The vehicle, 21 ft long and 8 ft wide, is powered by two 310 hp engines. Seven fans on each side of the vehicle provide the air cushion, and directional control is obtained by venting the air cushion through said louvres.

Many futuristic concepts have been suggested by Ford, including a Levacar monorail vehicle and transportation vehicles capable of carrying payloads of the order of 22,000 lb at a speed of 80 mph with a range of 300 miles.

GOODYEAR AIRCRAFT CORPORATION

An experimental air cushion vehicle built in early 1963 was used to test various forms of flexible understructures. The vehicle has a 35 hp engine driving two fans delivering air to a plenum chamber. It supported a load of 1,000 lb at a clearance height of ½ in. Flexible structures are also known to have been fitted around jeeps as part of the Goodyear experiments.

GYRODYNE COMPANY OF AMERICA INC

Gyrodyne Model GCA-55

In October 1959 the first tests were made of a single-seat annular jet type of air cushion vehicle, powered by a 72 hp engine. This vehicle, produced for the US Navy Bureau of Aeronautics, consists of an aluminium spun duct housing a fan forcing air through an annular duct and compartmenting slots.

The empty weight of the vehicle is 530 lb and it has a hover-height of 4 in.

HUGHES TOOL COMPANY

Hydrostreak XHS1

An overwater vehicle demonstrated by the US Bureau of Ships on the Potomac River in June 1960. Water is scooped up and then forced down in sheets at the front and rear of the vehicle to retain the air cushion. The vehicle, 21 ft long and 11 ft wide, weighs 2 tons, is of the side-wall type and equipped with three 80 hp engines for integrated lift and propulsion.

A development of the Hydrostreak (XHS1) is an eight-sided vehicle, 14 ft long and 9 ft wide, having a water wall extending around the entire periphery.

MARTIN MARIETTA CORPORATION

Aerospace Division (Orlanda, Flo)

Ejectijet

During 1962 a vehicle was developed under contract to the US Army Transportation Corps. The Ejectijet, built mainly of aluminium, weighs approximately 2,000 lb, is 20 ft long and 10 ft wide. A feature of this vehicle is that when the air cushion has been generated 90% of the air is recirculated, resulting in relatively small power requirements.

MATSON NAVIGATION COMPANY

In late 1962 Matson Navigation Company collaborated with Douglas Aircraft Co Inc on a study of large air-cushion vehicles reputed to be 200 ft long and 130 ft wide, with accommodation for approximately 300 passengers. The proposed vehicle is expected to have a top speed of 100 knots and a hoverheight exceeding 10 ft.

NATIONAL RESEARCH ASSOCIATES INC

Since 1958 National Research Associates Inc have built and tested thirty air-cushion vehicles.

GEM-1

This vehicle, built for the US Marine Corps, 15 ft in length and 8 ft in width, is powered by two 40 hp engines. Reputed to have an operating height of 15 in, the all up weight of the vehicle is 1,100 lb.

FASS

Similar to GEM-1, but built for the US Army Ordnance Tank and Automotive Command.

GEM-III

An amphibious peripheral jet vehicle, built for the US Marine Corps, 24 ft in length and 12 ft in width. GEM-III, powered by two 80 hp gas turbines, has an all up weight of 2,000 lb. Directional control is achieved by variable inclination vanes in the peripheral jet.

Aqua-Gem

Two engines of 40 hp each powered the first Aqua-Gem, weighing 2,200 lb, 28 ft in length and 8 ft in width. Hover-height is 1½ in. Various engine arrangements have been installed in later prototypes. This vehicle resulted from a contract placed by the Wilson Line, Washington, DC, for a six-place craft.

Flying Saucer

A number of different types of this 8 ft diameter 5 hp vehicle have been built, mainly for amusement park use.

GEM-JR

Another amusement park vehicle with a 5 hp engine, 9 ft in length and 5 ft in width.

GEM Litter

Known to have been purchased by the US Army, this is an inflatable vehicle that can be folded and carried in a back pack. Weighing 48 lb and powered by a 7½ hp engine, the vehicle capable of lifting 400 lb in the inflated condition, is 9 ft in length and 5 ft in width.

Air Carrier

The Air Carrier is a high-speed peripheral jet cargo vehicle having flexible bow and bottom. The air cushion is supplied from forward-mounted fans driven by an 85 hp engine; two shrouded propellers driven by a 155 hp engine provide forward propulsion. Maximum speed is 45 mph.

Air Liner

Similar to the Air Carrier, except that it has a totally enclosed cabin with seats for pilot and six passengers.

Air Sport

Similar to the Air Carrier, except that it is equipped as a high-speed luxury yacht with sleeping accommodation for four persons.

PRINCETON UNIVERSITY

Princeton University has conducted extensive work on two types of ACV known as the Flying Saucer and Air Scooter. The Flying Saucer X-3 is 20 ft in diameter and powered by a 44 hp engine. In late 1960 the engine was replaced with a 180 hp engine. A 5 hp engine drives a tail rotor which provides directional control.

In the X3-B, the modified X-3, the 5 hp engine was replaced by a 45 hp engine. The X3-C, a development of X3-B, has two fins and rudders and a geared trimmer, but is otherwise identical to the X3-B. The use of the trimmer increases longitudinal stability, permitting operational speeds high enough to take advantage of circulation lift.

The Air Scooter, X-2, an annular jet type ACV, is fabricated from steel tubing, aluminium ribs and skin. The 9 ft diameter vehicle is superseded by a more powerful vehicle, X-4, having a 15 hp engine.

Directional control is achieved by moving handlebars to operate small vanes in the exit nozzle and a conventional rudder at the rear of the vehicle.

REPUBLIC AVIATION

The RV-1, weighing 35 tons and seating ninety-four passengers, and the RV-2, weighing 53 tons and seating 224 passengers, are proposed; maximum speed will probably be over 90 mph.

US ARMY

The US Army are considering several types of air cushion vehicle for defence use in the USA. One proposal is the use of a small flying jeep which could be operated by anyone familiar with an automobile. A second ACV/helicopter combined, built by Curtiss-Wright, has been tested.

The vehicle is supported on an air cushion generated by four horizontal propellers when taking off and landing. The propellers can then be tilted for "helicopter" flight at altitudes above the air cushion.

The US Army plan another vehicle, capable of 150 mph forward flight, for use over rough terrain. This vehicle may incorporate conventional road wheels.

US NAVY

The US Navy have tested a model Skimmer and other ACVs. The Skimmer, a peripheral jet type machine, draws air in through fins at the top of the vehicle and then forces it below the craft to sustain it.

CARL WEILAND

Weiland Gem-2

Carl Weiland, the Swiss exponent of the labyrinth seal system, sold the second of his Swiss-built vehicles to the US Marine Corps. It is known that this vehicle, which carried twelve passengers, reached a speed of 43 mph. Two 270 hp engines were arranged to drive six 4 ft diameter forward-facing fans providing the air cushion and part of the propulsion force. Two 150 hp engines driving a pair of variable-pitch propellers provided forward propulsion.

Weiland Airboat Everglades Speedster

The four-seater Everglades Speedster was first tested in June 1961 on the Ohio River near Louisville. This vehicle, built for Reynolds Metals Company, USA, reached a speed of 70 mph.

Air for the peripheral air curtains was provided by a large horizontal fan driven by a 160 hp engine, forward propulsion being provided by a second light aircraft engine, mounted on the leading edge of the stabilising fin and driving a two-blade reversible-pitch propeller. A large rudder, operating in the airscrew slipstream, was used for directional control.

Carl Weiland, who is now with the Douglas Aircraft Company Inc, is known to be engaged on studies of large air cushion vehicles.

CATHOLIC UNIVERSITY, WASHINGTON

Dr Gabriel Boehler, Professor of Aeronautical Engineering, has made model experiments in wind tunnels and has carried out analytical work for the US Navy. In 1958, T. M. Clancy and H. de Ferrari experimented with water retaining curtains.

WOODS — WOLFE

Wager V/1

In May 1959, H. L. Woods and G. W. Wolfe designed an amphibious vehicle, 13 ft in length and 6 ft wide, powered by a 25 hp engine. A 40 in diameter fan delivers air to a peripheral jet and gives a hoverheight of 2 in. A 15 hp engine drives a two-bladed propeller for propulsion.

ACV No 2

A 12 hp engine provides power for providing the air cushion of a 300 lb load-carrying pallet.

ACV No 3

A seven-sided vehicle of 9 ft width and 13 ft length utilises a 72 hp engine to attain a hoverheight of 8 in. The vehicle has been built to evaluate a new control system designed by Mr Woods.

Pure fluid control for hydrofoil boat

J. Lowen Shearer
Arthur D. Brickman
Pennsylvania State University

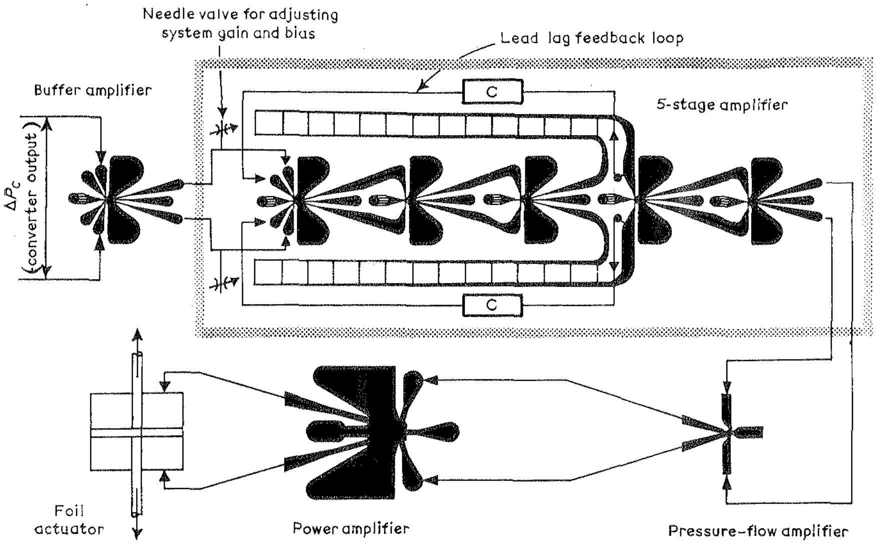


Figure 8

HYDROFOIL boats have become fairly common in commercial use, primarily for passenger service on inland waterways. Most of these craft use piercing foils which have a large V configuration when viewed from the front. These foils are inherently stable since any change in the height of the boat above the water will directly affect the amount of foil submerged and hence the amount of lift produced: if the boat rises out of the water, the lift decreases and *vice versa*. But under rough water conditions the ride produced by the V configuration system can become unsatisfactory and even unstable.

Much current development is directed towards the use of wholly submerged hydrofoils and the associated control systems capable of maintaining level flight of the boat despite rough seas. Bowles and Sowers, of the Bowles Engineering Corporation, report in a recent paper (1), the development of a prototype hydrofoil control system in which all the logic and amplification components are pure fluid devices with no moving parts. The system has performed successfully under test when applied to a submerged foil subject to simulated wave and velocity effects in a water tunnel. The initial design concerned the problem of controlling only the attitude of a single foil so as to maintain constant lift in the presence of unsteady flow over the foil.

Fig. 8 shows the main elements of the closed loop control system which includes a sensor for measuring lift fluctuations, a computer-amplifier to develop a corrective signal, an actuator to manipulate the foil position, and a means of providing position feedback. The foil itself is mounted on a fixed pivot at the 1/4 chord point with θ being its angle with respect to the horizontal and α its angle of attack with respect to the direction β of the water velocity V. Details of the lift sensor are shown in Fig. 9. The sensor consists of two symmetrically located holes in the leading edge that are connected to pressure chambers inside the hydrofoil and then to a pressure converter. There a constant pressure air supply P_0 drives air through two orifices connected to the output pressure lines and ultimately out through the leading-edge holes.

Steady state water tunnel tests showed that the differential water pressure built up across the two holes in the hydrofoil nose varied linearly with angle of attack (and hence hydrofoil lift) up to about $\pm 6°$. In addition, it was found that the differential air pressure ΔPc varied linearly with angle of attack over the same range and was nearly independent of the supply pressure P_0. The sensor system was incorporated into the closed loop control as shown by the block diagram of Fig. 10. Here $\rho V^2/2$ is the water velocity pressure, and ΔP_2 and ΔP_3 are pneumatic pressure differentials corresponding to the computer and amplifier outputs.

The pure-fluid controller elements of the system are shown in actual silhouette form, but not to scale, in Fig. 11. These consist of a buffer amplifier that operates from the converter pressure signal ΔPc, a five-stage analogue amplifier, a pressure-flow amplifier and a power amplifier; all except the latter are standard Bowles components. Gain and bias adjustments are made at needle valves downstream of the buffer. An *RC* lead-tag feedback loop, added to partially overcome signal phase lags introduced by the actuator, capacitance effects and sonic delay, appears around the five-stage amplifier. A ladder-type low pass filter between the third and fourth stages attenuates high-frequency noise. A preliminary frequency response analysis of the overall system, based in part on experimentally determined transfer functions, indicated that significant reductions of lift variation could be expected for frequencies less than 10 c/s.

A model system was built and tested in a water tunnel with input variables being water velocity and flow angle. Wave action was simulated by a large oscillating hydrofoil mounted upstream of the model hydrofoil in such a way that variable amplitude and frequency flow-angle disturbances could be produced. For identical series of tests, variations in lift force were recorded with the foil locked in a mean position and with the control system in operation. The results indicate that the control action reduces lift variation to about 35% of that observed under locked-foil conditions, and that the system is highly responsive to the changing velocity and wave action associated with hydrofoil operation under actual sea conditions.

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1. R. E. Bowles and E. U. Sowers, "A Pure Fluid Hydrofoil Control System".
2. C. A. Belsterling and K. C. Tsui, "Application Techniques for Pure Fluid Amplifiers".
3. S. Katz, J. M. Goto, and R. J. Dockery, "Experiments in Analog Computation with Fluids".

References were obtained from Proceedings of the Second Fluid Amplification Symposium, May 26th-28th, 1964, printed by the Harry Diamond Laboratories, Washington, DC. (See also earlier report in *Control*, August, 1964, p. 432).

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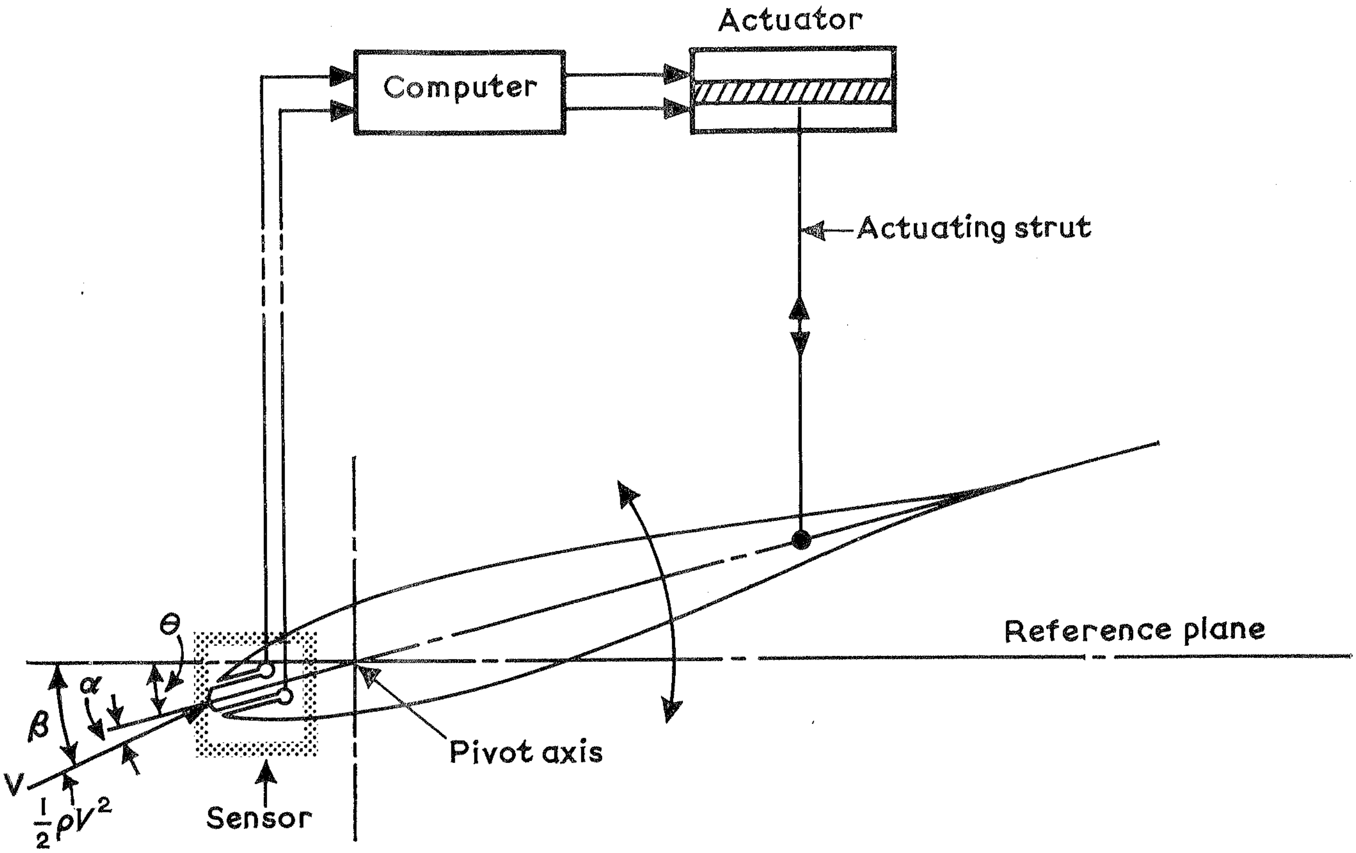

Figure 9

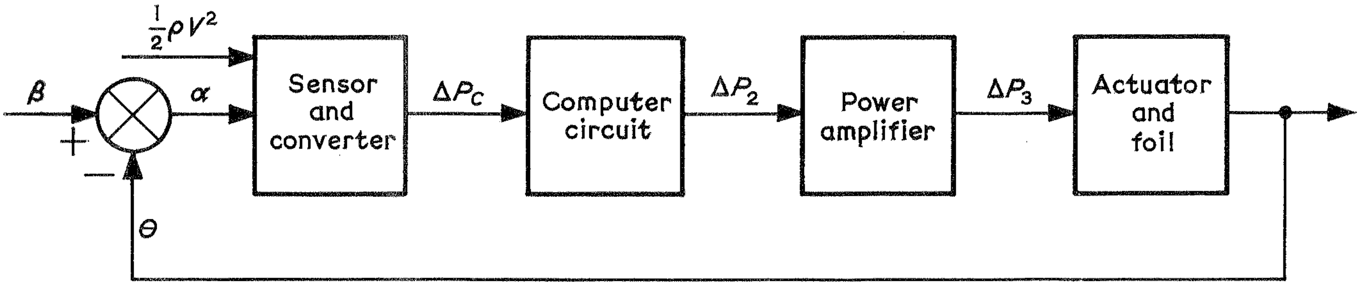

Figure 10

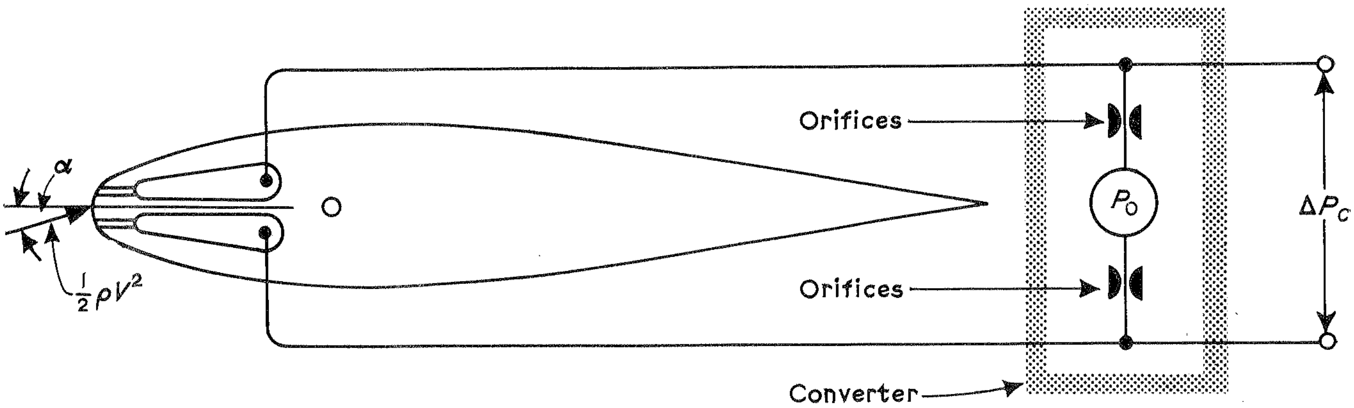

Figure 11

Establishing the Owner's Viewpoint

The Practical Aspects of Hydrofoil Operation

By P. L. DOREY—(CONDOR LTD., GUERNSEY)

WE read a great deal of theory and opinion regarding hydrofoils and hovercraft but not very much commercial operational fact. I welcome the opportunity to detail some of the actual experiences of Condor Ltd, Guernsey, and also to express opinions based on these experiences.

I still find it extremely difficult to think of a hydrofoil in the same affectionate manner and to take the same pride in one as I do with a conventional vessel. A hydrofoil is so clearly a machine for a purpose that thinking must be done precisely along these lines. Condor Ltd was founded partly in the belief that conventional passenger vessels over certain short haul and specialised routes are becoming obsolete, rather in the same way that steam superseded sail in the last century. One season's operations have basically confirmed this view.

Condor 1 is a Rodriquez-built PT 50 hydrofoil. The area in which the vessel operates must be one of the most difficult for any hydrofoil operator: the tidal conditions vary with a rise and fall at spring tides at Guernsey of nearly 30 ft, to those at St Malo of over 45 ft, necessitating pontoon berthing arrangements at all points; the area, whilst relatively sheltered to the east, is open to the west; air services are highly developed and there are operators of conventional vessels.

The first season's schedules were changed many times, to the confusion of many, partly because it was not possible to operate daily *regular* services everywhere with one craft (services were governed according to tidal variations), and partly because of the desire of the company to test traffic demand for this new form of transport between many ports, from Torquay to the north, to St Malo to the south.

The Advantages

There are certainly many advantages in operating a hydrofoil. To start with the points of embarkation and disembarkation are *centres* (i.e. not airports which are away from centres. Cost to and from the airports is therefore eliminated). Passage times are very much faster than conventional vessels and highly competitive with airlines, and waiting time by passengers can be greatly reduced by quick turnrounds.

As is well known, Rodriquez hydrofoils have been in operation in many parts of the world for up to eight years. It is doubted, however, if weather conditions are so exposed in any other operational area as in the Channel Islands. A survey of weather conditions over previous years showed that operations might be curtailed for up to 15% of the scheduled services. This figure is about correct and whilst the PT 50 is perfectly seaworthy and safe in even extremely adverse conditions, from the point of view of passenger tolerance we have found it to be wise to postpone or cancel voyages in doubtful weather.

Whilst testing *Condor 1* in high open seas, however, it was found that even in Force 8-9, little difficulty was experienced by the craft in maintaining 26 knots *across* the seas, although the movement was rather unpleasant. With the sea dead ahead this would be reduced to say 22 knots, but when from astern she could not remain foilborne in these conditions. Much depends on the nature of the seas themselves, i.e. whether they are long or steep; wind alone is never a problem.

In the event of extremely severe conditions, the hydrofoil can of course always operate as a conventional vessel, in which case the foils act as stabilisers.

We had ascertained from other operating areas that local feeling would be sceptical and indeed derisory at the commencement of operations. This, too, was our experience. Unfortunately, we also had so many teething troubles that for a while it seemed that the sceptic's attitude was well founded.

Weather Damage

In the space of six weeks from May 1st, 1964, *Condor 1* suffered: (a) bow damage to shell, due to heavy weather; (b) six days' delay ascertaining the cause of emulsified lubricating oil; (c) the loss of two propellers through faulty castings; (d) a nine-day inspection to ascertain if there were any contributory factors to (c) (it was not known at this time that the castings were faulty); and (e) numerous small defects.

Later in the season a fracture of the forward port foil flange materialised but was temporarily repaired, permanent repairs being deferred until the end of the summer season. A gear box also jammed but was repaired in thirty-six hours by the prompt action of Messrs Rodriquez. Naturally, word-of-mouth adverse publicity was considerable.

The builders were of course concerned at all these troubles since similar difficulties do not appear to have been apparent in other craft to any great extent. Propellers have been replaced by them and other matters rectified. Additionally, Mercedes Benz were greatly concerned that a heating coil in the starboard engine had been pierced by the dipstick, thus emulsifying the oil. This was permanently rectified after the summer season. Here it might be interesting to say that whilst we believe other operators obtain 500-700 hours from their propellers before repairing them, our propellers have had to be changed at 250-260 hours, due to cavitation erosion.

External corrosion to the hull has been negligible, despite the fact that over approximately one-quarter of the area of the wetted surface was without paint. No anodes were used. Corrosion to pipes, exhausts, on the keel internally, and certain deck fittings has been considerable. Most maintenance (including cleaning) must be done at night and our practice is also to have the propellers and underwater parts examined, by skin divers, every 100 hours of operation. Propeller changes are done merely by allowing *Condor 1* to ground as the tide recedes, the changes then being made in about two to four hours.

Fatigue Problem

Details of the PT 50 are probably widely known — the cruising speed is about 32 knots (37 mph), maximum $38\frac{1}{2}$ knots (45 mph), and the fuel consumption is about 75 gallons gas oil per hour. The crew is maintained at six persons: Master, first officer, chief engineer, second engineer/greaser, one AB and a hostess. Due to the rapidity of the service, careful consideration must be given to the fatigue question, particularly in bad weather.

Condor 1 is the first PT 50 in the world to receive a fully international passenger certificate (MOT Class II) and also has the greatest carrying capacity (140 persons) of any sea-going hydrofoil in the world. A typical schedule would be as follows:

dep	Jersey	0800
arr/dep	St Malo	0930
arr/dep	Jersey	1100
arr	Guernsey	noon
dep	Guernsey	1630
arr/dep	Jersey	1730
arr/dep	St Malo	1900
arr	Jersey	2030

The actual sea time between Jersey and St Malo averages 1 hr 12 min, while the Guernsey/Jersey leg is 47-50 min. The schedules thus allow time for embarking and disembarking passengers. A very reliable reputation for punctuality was finally built up by the end of the season.

Condor 1 actually travelled 19,836 miles on schedule between May 1st and October 3rd, 1964, carrying 31,082 passengers. Passenger miles were 1,036,649.

The company's original financial estimate was based on an operating period of 199 days. Partly owing to a later start than intended, the maximum possible schedule days were 156. Because of adverse weather and mechanical and teething troubles, actual operational days amounted to $121\frac{1}{4}$ days. The fare structure varies between 7d and 1s 3d per passenger mile and thus whilst all the operating expenses were covered, including interest, nothing could be set aside for depreciation over eight years (although the vessels are estimated to have an economic life of fifteen years).

Useful Experience

Since it is well known that conventional vessels have great difficulty in paying their way in the Channel Islands area, despite 800,000 visitors *annually* (by air and sea), while the year was somewhat disappointing when viewed against original estimates, the fact that the PT 50 has succeeded thus far is encouraging and the experienuce gained in 1964 should prove beneficial for the future.

Other areas are doubtless easier to work and may have a greater potential, but our main interest lies in these islands and in near French ports. A further twelve months will show the trend more clearly, particularly as the intention in 1965 is to offer a more concentrated service between Guernsey, Jersey, St Malo and, it is hoped, Sark.

Reference was made at the beginning of this article to hovercraft. For some reason, most writers on the subject of hydrofoils and hovercraft adopt the attitude that the two forms of transport are competitive. I do not share this view but believe they are complementary. There are many routes over which hovercraft have virtually no competition, e.g. over ice or marshland and shallow waters. In addition, their military capabilities are being examined, which apparently appear promising. On the other hand, the hydrofoil retains her status as a vessel and is controlled as such. Seaworthiness is assured in a hydrofoil, but it is questionable if a hovercraft would behave satisfactorily in mid-Channel in a Force 9 gale if her engines failed.

I am myself doubtful of the commercial competitive ability of hovercraft over routes which are "natural" for hydrofoils and I would doubt if any hovercraft has been purchased purely with commercial considerations in mind. Events these days move with great rapidity, however. Both craft are being developed and without doubt in a few years' time the virtues and failings of both forms of transport will be proved.

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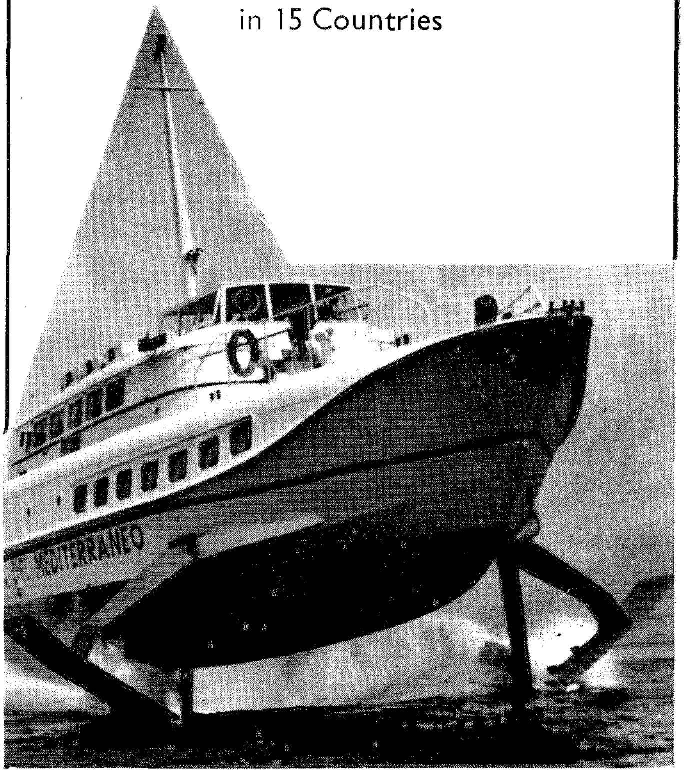

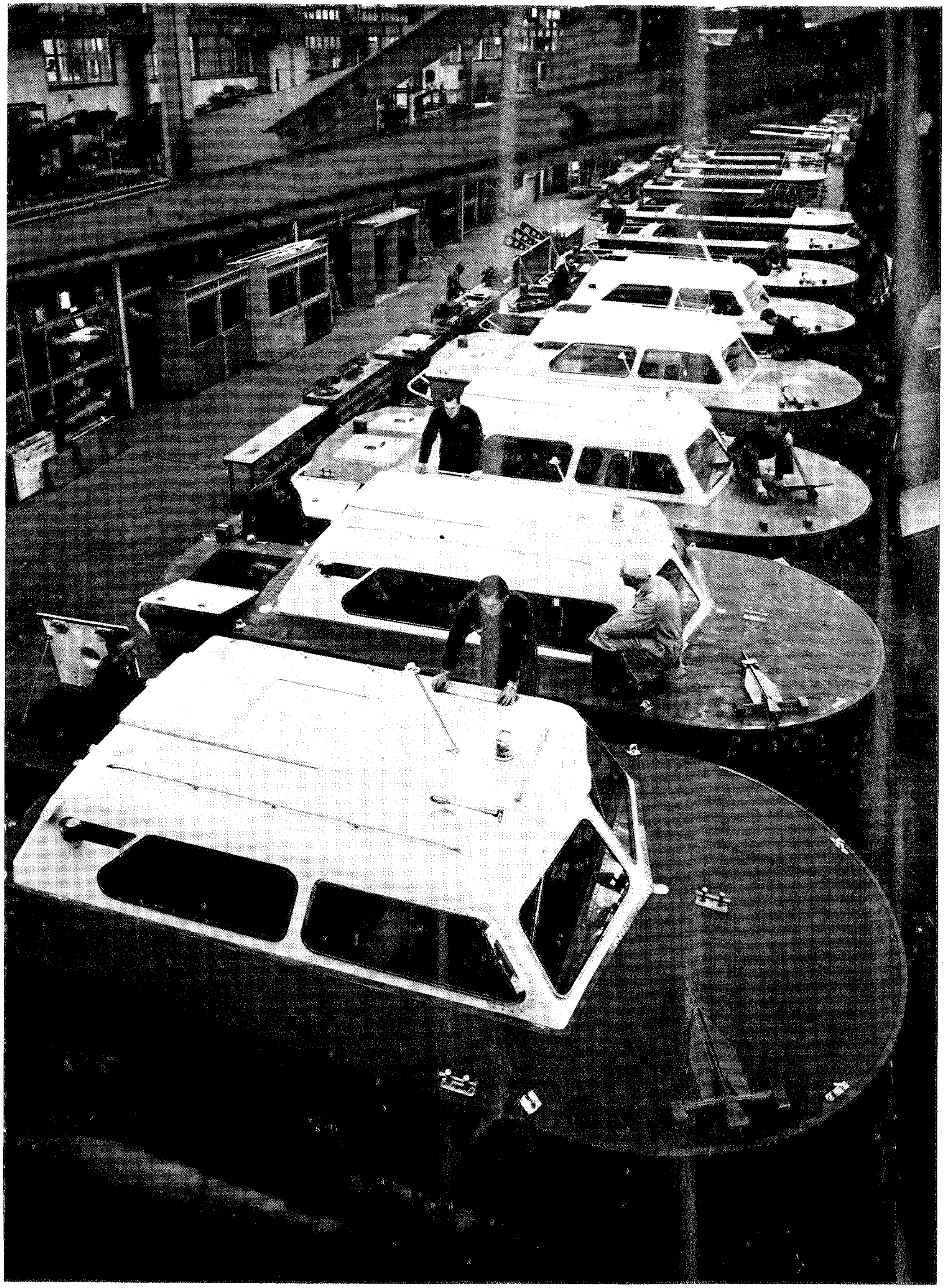

TWO VIEW
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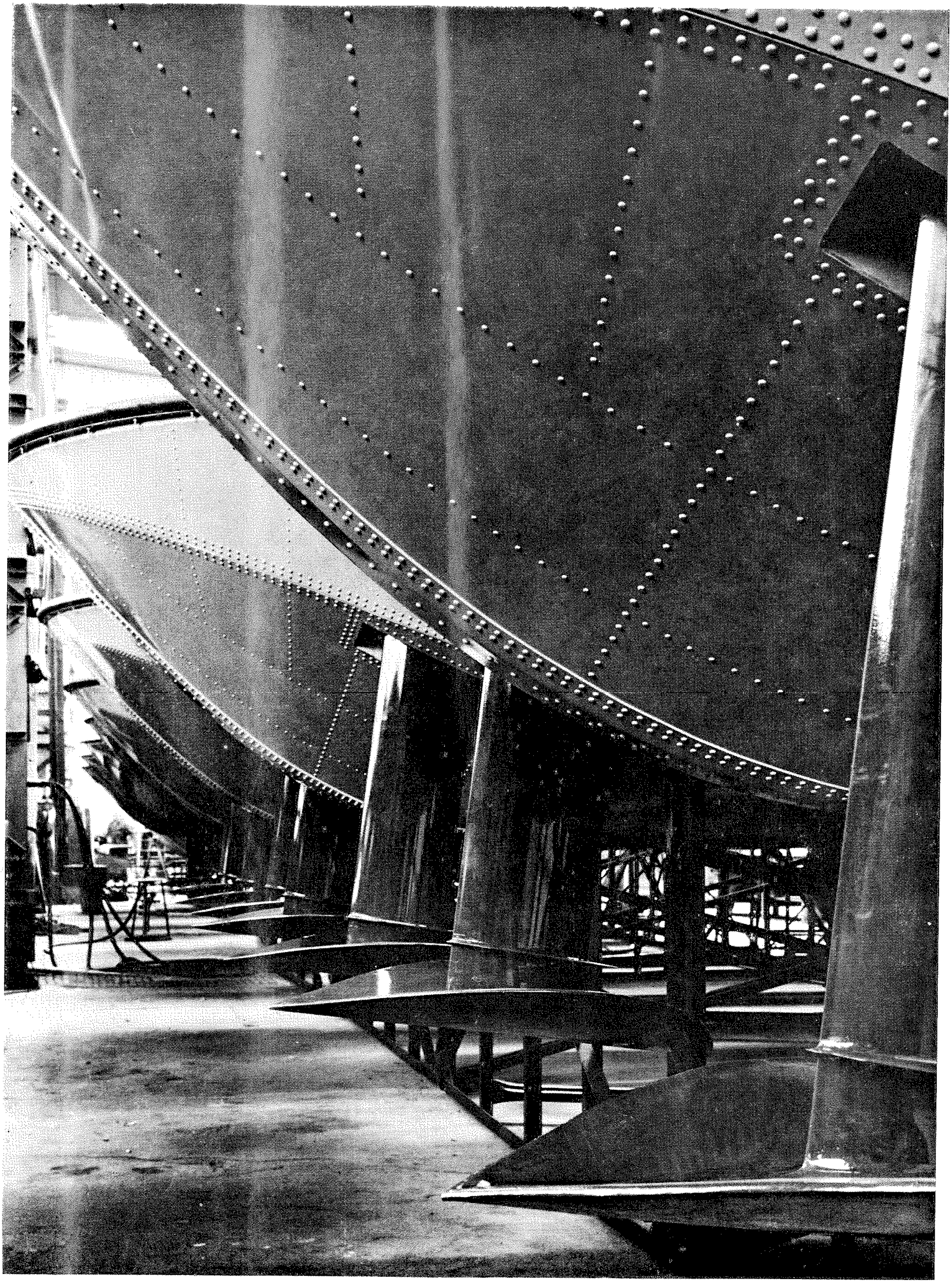
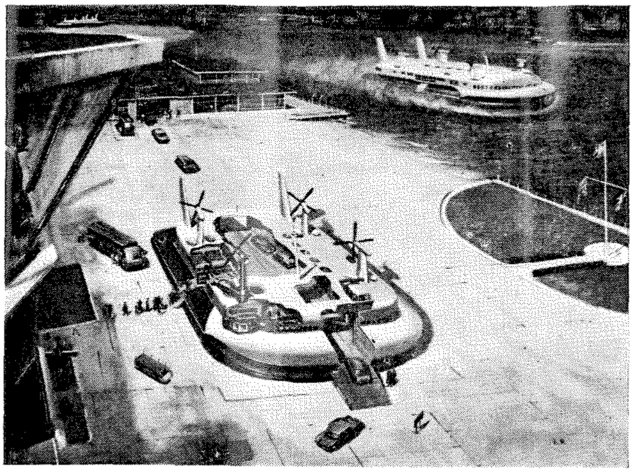


Westland count Hovercraft costs within 5 pc

Costs of operating hovercraft have until recently been mainly notional, but last year Westland Aircraft felt they now had had sufficient experience to produce a realistic cost analysis for Channel Service. Mr R. F. Bailey discusses the analysis from his company's viewpoint and points out that further significant cost reductions are expected as operating experience increases



The shape of things to come? An artist's impression of the SR.N4 at a typical future inter-Continental hoverport

Now that the hovercraft concept has been shown to be technically sound, attention is being increasingly concentrated on economics. One reason for this is that even at this relatively early stage, there is serious commercial interest in this new transport vehicle. As with any other vehicle, the cost of operating a hovercraft is made up of direct and indirect charges. The former includes the capital cost of the craft, amortisation, interest charges, insurance and running costs. Indirect charges cover terminal or docking facilities, ticketing and passenger handling, and the operators' overheads and profit. They are, of course, more widely variable than direct costs.

The hovercraft's unique amphibious capability enables great savings to be made on docking facilities. Only a simple, graded slipway is required, as against the piers and wharves needed for displacement craft. The type of terminal facilities needed would depend on the nature of the operation. At one end of the scale is the sophisticated hoverport for, say, a cross-Channel ferry service — with facilities comparable to those at a major airport, though on a smaller scale. At the other comes the almost rudimentary installation for handling the much smaller amount of traffic on local services. Detailed Westland studies have shown that, in the first case, indirect costs can be expected to vary between 40% and 55% of the direct costs, while in the second they could be as low as 15% or 20%.

Wide Experience

Already, Westland has built up a great deal of very encouraging data on direct operating costs through experimental scheduled passenger services with the 27-ton SR.N2 and 7-ton SR.N5. Naturally, SR.N2 experience is much the greater, covering cross-Solent operations last year and in 1962, and a service across the Bristol Channel in 1963. SR.N5 was put on to last year's cross-Solent run the very day its permit to carry fare-paying passengers was received, and in the remaining two months of the service period yielded invaluable smallcraft data.

In both cases, the figures obtained are, if anything, pessimistic. For one thing, operation of only one craft of a type almost invariably produces the highest costs. For example, as world-wide airline experience clearly shows, operating staff — possibly the biggest single item — does not increase in direct ratio to fleet numbers. Then, again, the SR.N2 used is still very much a development craft. The production version would incorporate many modifications — chief among them, more powerful engines — which would greatly improve the economics.

Although SR.N5 is a production-line craft — the world's only such craft, in fact — the figures were inevitably influenced by the operator being faced with a completely new type of craft towards the end of the service period. In fact, the end of the "shake-down" period involved with any new vehicle, coincided with the end of the service. There was, in consequence, no time for the economic effects of the streamlining of operational procedures to show themselves. Even so, this limited experience has confirmed that profitable commercial operation is already possible at passenger-seat-mile rates of around 1s 3d, depending on stage length. Significant cost reductions can reasonably be expected as experience with the craft increases.

Detailed Analysis

By early 1964, the company had built up enough experience to make a realistic cost analysis for hovercraft ferry services for passengers and road vehicles across the English Channel. This was incorporated in detailed proposals published in February, and written around the 150-ton, 660-passenger SR.N4, the basic design of which had already been completed. Total operating costs for various annual utilisations are shown in Fig. 1, and relate to one SR.N4 operated as part of a fleet. The various assumptions made in the calculations are as follows:

Direct Charges

(i) *Annual Costs*

Amortisation — Capital cost of the SR.N4 and spares holding less 14% residual value, amortised over ten years. This period of amortisation is a very conservative estimate since it only represents a craft life of 6,000 to 9,000 hours' operation on the Channel services detailed in the proposals (Dover/Calais; Harwich/Calais; Newhaven/Dieppe and Southampton/Cherbourg).

Capital Cost — Production cost has been estimated at £1,150,000 per craft.

Interest — Taken as 5% per annum on the mean value of the SR.N4 and spares.

Insurance — Taken as 2% per annum of the SR.N4 initial capital costs, remaining constant over the ten-year life of the craft.

(ii) *Maintenance Costs*

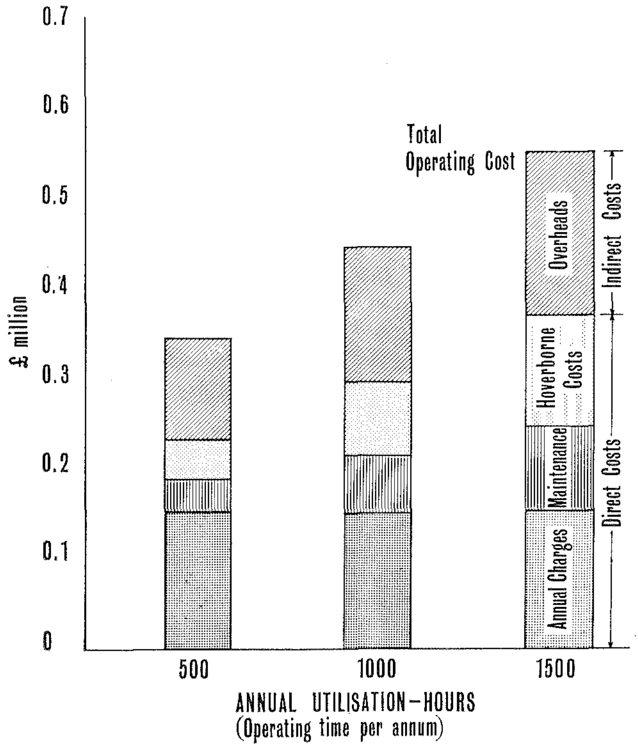
Engineering Labour — Based on average direct labour of twenty men per craft.

Engineering Materials — Materials used based on component lives of 1,000 hours and engine overhaul periods of 2,000 hours.

(iii) *Hoverborne Costs*

Crew Charges — Based on £2,600 per annum for drivers, £1,900 per annum for engineers, and £1,100 for stewards. The normal SR.N4 crew complement is: one driver, two engineers, four stewards.

Fuel Costs — Charged at 1s 3d per gallon.



This chart shows the total operating costs for the various annual utilisations written around the 660 passenger hovercraft the SR.N4

Indirect Charges

These have been taken as 50% of the direct costs, the mean of the levels indicated as realistic for this type of operation by the detailed Westland studies mentioned earlier.

In all cases, these assumptions were soundly based. By the time the proposals were published, the company had produced three different craft, the smallest weighing 7 tons and the largest 37¼ tons. All had been built well within the cost estimates, and the SR.N4 capital cost could therefore be squarely based on broad practical experience. Four years of development trials had allowed an accurate assessment of maintenance costs. The figures used can justly be claimed to be conservative since they relate to a development craft, the SR.N2. The smaller SR.N5 had not, as yet, made its appearance. As a matter of interest, the latest cross-Solent operation has fully confirmed the earlier figures. Other running costs (fuel, oil, and crew salaries) posed no problems. Reliable fuel consumption figures, albeit estimated, were readily available, while it was realistic to assume crew salaries comparable to those of commercial aircrews.

The only major item which could not be reliably assessed was the replacement of "lifed" components. This charge can only be finally determined by many thousands of hours of operation. Since, however, the major units involved are the engines, and as SR.N4 is designed to have the highly reliable "Marine Proteus", any error in the estimated total operating cost is unlikely to exceed 5%. The Westland proposals envisage that a hovercraft ferry service would be phased in with conventional ferries from 1967 onwards, and that the SR.N4 fleet would have built up to nine by 1975. On the basis of the passenger and vehicle rates quoted in the Ministry of Transport Report on the proposed Channel Tunnel, and the same rate of traffic growth, the ratio of revenue to total operating cost works out at 1.27.

It is now generally agreed that the hovercraft has completely proved itself technically. Westland is equally convinced, from its wide experience to date, that both its small and large hovercraft can be operated commercially at an acceptable profit.

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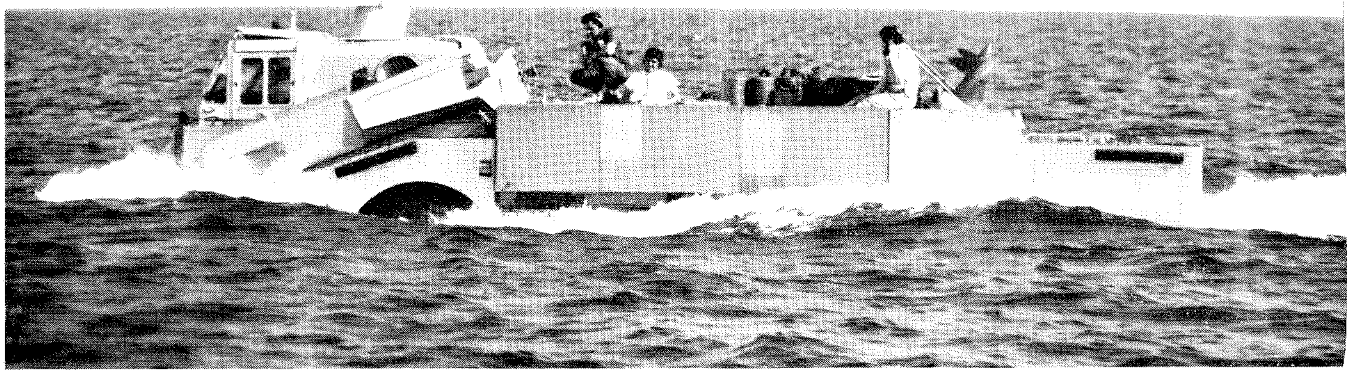


The LVHX-1 with foils and struts retracted boating in conventional fashion

LYCOMING'S EXPERIENCE IN AMPHIBIOUS HYDROFOIL ACTIVITY

Avco Corporation's Lycoming Division has been engaged in amphibious vehicle and hydrofoil activity for several years, and is the first company to have conducted a successful programme for high speed, rough water operation of a wheeled amphibious vehicle.

This programme was the "Flying Duck" project conducted by Lycoming in 1958 under contract with the US Army Ordnance Corps. A "one only" research vehicle, the *Flying Duck* was a gas turbine-powered, hydrofoil version of the famed World War II DUKW.

The *Flying Duck* combined an 860 hp Lycoming T53 engine with aerodynamically shaped hydrofoils. The craft demonstrated its ability to "take off" and operate successfully in rough water at speeds in excess of 30 knots.

In addition to the *Duck* programme, Lycoming also provided a T53 engine for a Navy LCVP which was converted to a hydrofoil configuration. This vehicle, called *Halobates,* was designed to test the feasibility of some advanced hydrofoil designs. It was flown successfully early in 1959 at a speed in excess of 30 knots. In both *Halobates* and the *Flying Duck* Lycoming's T53 engine demonstrated its ability to perform in a marine environment.

Lycoming's amphibious vehicle experience dates back to World War II, when it built for the military a then secret high speed craft known as the *Salamander* or *X Craft.* This vehicle was of a track-laying amphibious design, capable of moving through water and on land at speeds up to 20 mph.

Two such vehicles were built, using a Lycoming O-435-T engine as the power plant. The drive mechanism, transmission and related components were developed by Lycoming. Production of the vehicle was never released due to the termination of hostilities.

A new turbine-powered hydrofoil amphibian vehicle specifically designed to provide improved performance during amphibious assault operation, was delivered on December 8th to the US Marine Corps by Avco Corporation's Lycoming Division.

The amphibian vehicle, which is capable of operating over land on wheels or through the water on the hull or hydrofoils, has been designated as the LVHX-1, or Landing Force Amphibious Support Vehicle, Hydrofoil. It was turned over to Marine Corps Brig Gen Wood B. Kyle, Deputy Chief of Staff for Research and Development, in brief ceremonies at Lycoming's plant in Stratford. A demonstration of the LVHX-1's performance, including high speed "flights" was given for Gen Kyle, and other military officials, and members of the Press.

The LVHX-1 was designed to operate from a "mother" ship fifty miles off shore to inland logistic support areas. It is designed to "fly" in rough seas at up to 35 knots, boat in conventional fashion at up to 12 knots, or drive overland at speeds up to 40 mph, all with 10,000 lb of payload. Its power comes from a 1,000 shp Lycoming TF14 marine turbine engine. Its "flight" capability is provided through the use of two large hydrofoils, one front and one rear, which are mounted on struts and are completely submerged when the vehicle is in flight. The hydrofoils provide lift, thus raising the vehicle itself approximately 30 in above the water. Struts and foils retract into the hull for boating through the surf zone and for driving on land.

Range of the LVH in flight is 210 nautical miles. On land, power from the turbine engine is transmitted directly to the four wheels. Individually controlled tyre inflation provides for maximum traction in traversing difficult beaches, sand dunes, mud, rough terrain and steep grades.

The LVH's stability in rough water of up to 5 ft waves (state three seas) is provided by a special autopilot system that senses the length and height of oncoming waves and activates controllable flaps on the front foil so as to "flatten out" the ride.

The LVHX-1 has two propellers, one at the base of the rear strut for "flying" operations, the second under the hull for conventional boating. Fully dynamic steering is provided by rotating either the boating propeller or flying strut.

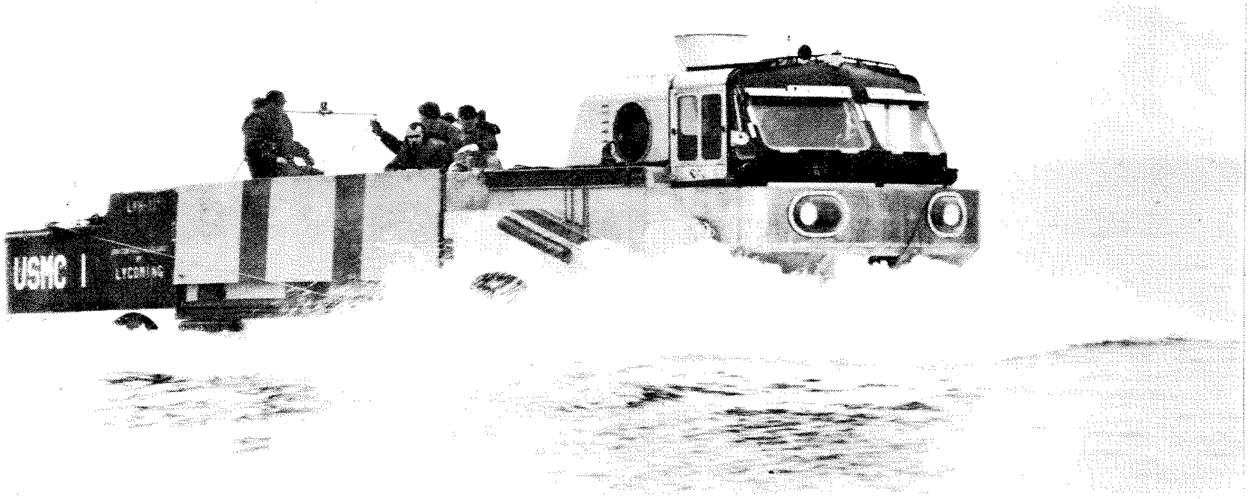
The wheels of the LVHX-1 retract into the hull to reduce drag while boating and, on land, can also retract to lower the vehicle to a "kneeling" position for easier loading or unloading. Side doors fold down and act as a loading ramp. The cargo bed is only 33 in above the ground when the vehicle is "kneeling."

The hull has been designed to provide maximum strength at minimum weight. It is an integrally stiffened box structure of aluminium and stressed skin based on aircraft design practice. The LVHX-1 is 36 ft 11 in long and 10 ft 10 in wide, allowing operation from virtually any Navy amphibious landing support ship.

Both the front and aft foils have a span of 17 ft 6 in. The foils are of high aspect ratio design and are self-cleaning. They are structurally designed to operate through floating debris without damage.

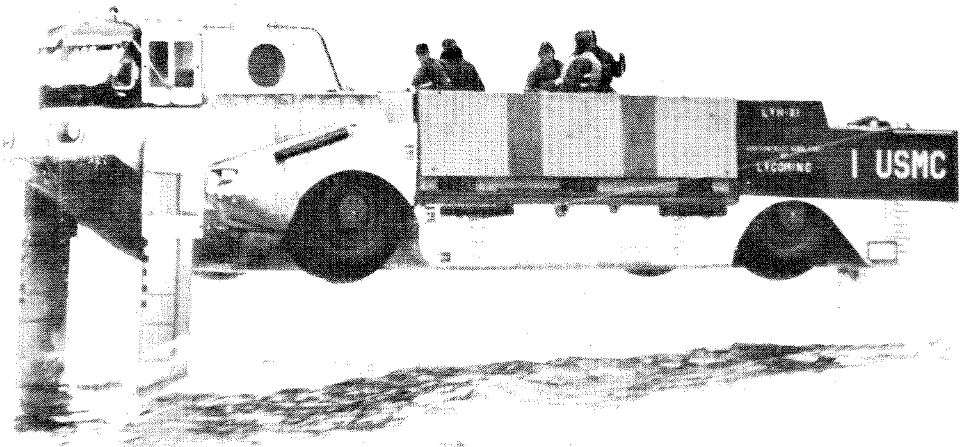
The TF14 engine that powers the LVHX-1 is one of a series of free turbine engines developed by Avco's Lycoming Division for industrial and marine usage.

These new turbines offer several advantages over conventional engines. They are far lighter and more compact, are

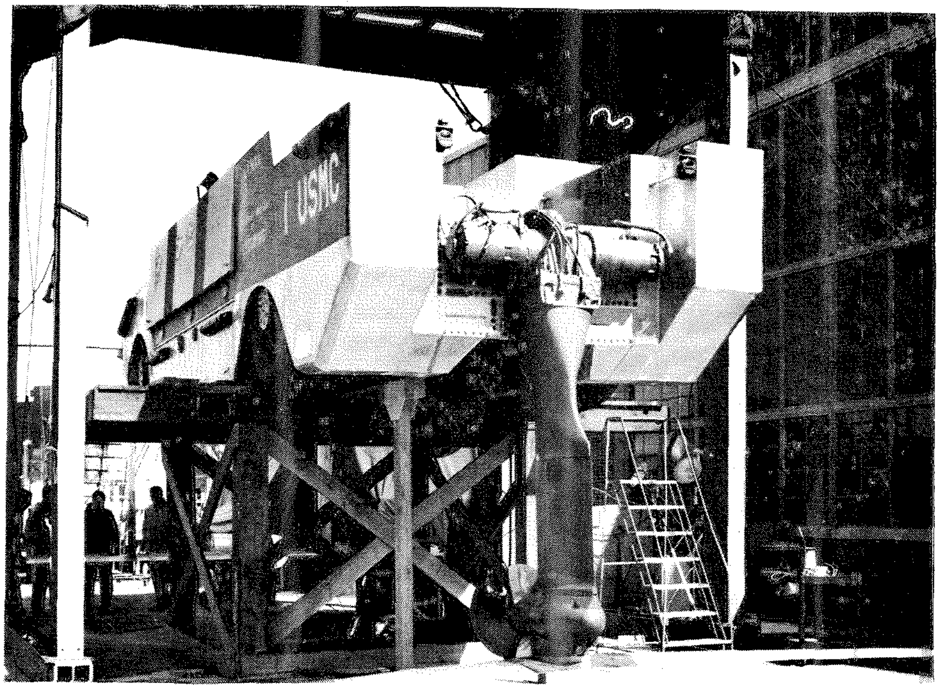


The LVHX-1 operating through water on its hull

The LVHX-1 operating on wheels



The LVHX-1 "flying" on its hydrofoils



The "flying" propeller of the LVHX-1 is mounted at the base of the rear strut. The lower section of the strut, the propeller and the foils are rotatable to provide fully dynamic steering. Span of the foil is 17 ft 6 in

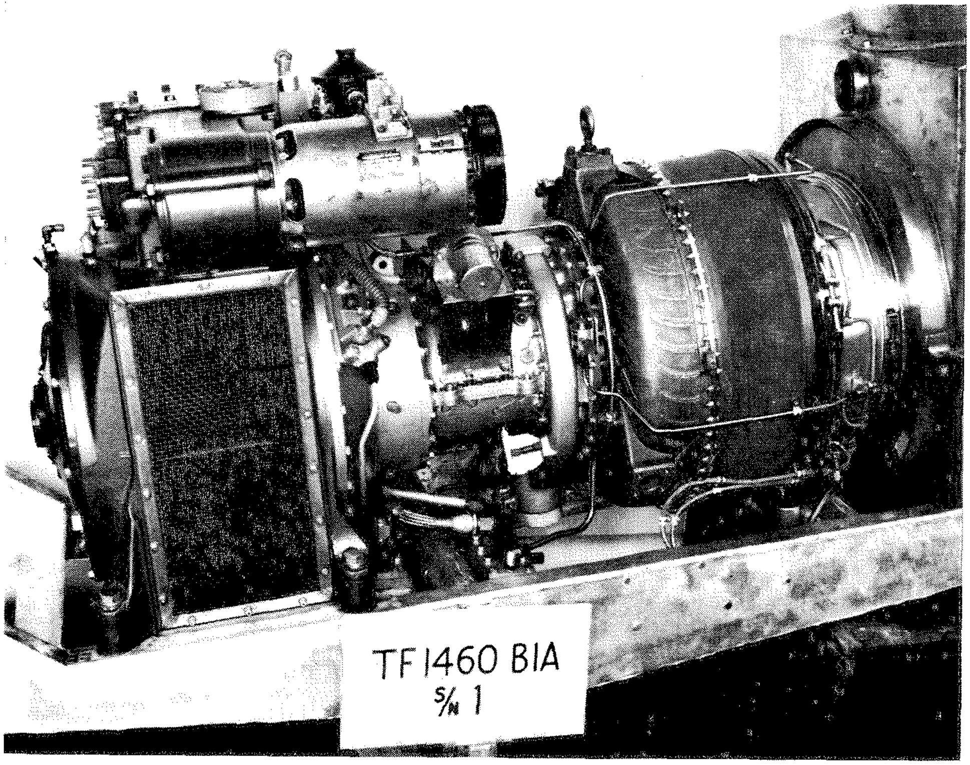
capable of running efficiently on a variety of fuels, have exceptional cold-starting capabilities, and require a minimum of maintenance.

Lycoming industrial turbines have been designed to provide reliability and endurance for all ground and marine applications requiring shaft power. Heavy duty output and accessory gear assemblies have been developed and power output has been reduced to conservative levels to increase time between overhauls and engine life expectancy.

Lycoming's experience with marine turbine applications dates back to 1958 when prototype engines were installed in two experimental hydrofoil craft, the US Navy LCVP *Halobates* and the US Army *Flying Duck.* More recently Lycoming turbines also have been installed in the US Marine Corps LVW planing hull vehicle and the Avco MTB-1, a 40 ft boat specially designed and built as an engine test bed. Testing with these craft has demonstrated the ability of Lycoming turbine engines to perform in a salt water environment.

All Lycoming industrial turbines feature modular construction to facilitate in-field maintenance. That is, each of the major assemblies can be removed, serviced or exchanged as a unit without disturbing the alignment of the driven load. All accessories are top-mounted for added convenience.

Lycoming industrial and marine turbines are available in the power range from 750 to 2,000 shp. They are available with various types of reduction gearing, fuel and control systems, and accessory drive systems in order to meet the specific requirements of each particular application.



The Lycoming TF14 turbine engine that powers the LVHX-1 is rated at 1,000 shp, and is far lighter and more compact than conventional engines of comparable power

WAKE UP, ENGLAND!

We can repeat what our grandfathers did with the steam engine if only we stop trying to make one formula fit every requirement

Christopher Hook

We are missing a fantastic opportunity of leading the world in novel transport devices by our failure to notice that it is a grave mistake to apply identical solutions to fundamentally different requirements, which are: mixed terrain on the one hand and the ocean on the other.

To start with an historical parallel: when man noticed that full advantage could only be drawn from the iron rail on condition that all inclines were limited (a requirement that Nature had not provided for) he did not hesitate, even at enormous cost for the period, to pierce tunnels, excavate cuttings and raise viaducts to meet this need.

Were it possible to undertake similar works on the ocean I would have nothing more to say, but because this possibility seems remote I feel that I have quite a lot to say and in fact I am about to repeat the words of Claude Graham White, *"Wake up, England!"* We are failing to see the wood for the trees (or is it the waves for the spray?).

Doubtless there were those who predicted that the iron horse would replace all other forms of transport but such claims did not deter Mr Ford, and in fact the whole story of transport is one of adaptability, considering the terrain, the expected speed, the state of the art, etc etc, and choosing the best compromise. I feel that it is time for me to point out the unfortunate timing which distracted all attention from the hydrofoil for the very difficult ocean wave.

The first and best-known difficulty is the fallacious objection of the type *You cannot run a train in a tunnel since all the passengers would suffocate with the smoke*, and this is the more insidious in that it is always slightly true, the matter being one of degree and for this there is as yet no yardstick.

The hydrofoil conception came in for more than its share of fallacious objections, not from the public but from the men placed in a position to help.

I would fail to make my point if I did not cite some of these, if only to counter the classical remark, "If it had been any good it would have been taken up." But first I want to point out some historical facts connected with hydrofoils.

It is important to realise that the citadel of orthodoxy in Britain quite successfully resisted the hydrofoil by the simple policy of the blind eye and it has required the more spectacular successes of the ACV to make a serious breach. This has been done by the application of large amounts of finance which were refused to the hydrofoil because the timing was bad and because of earlier costly failures, the basic reasons for which had first to be proved. This in turn was rendered even harder when the fallacious objections spread even into papers published by the RINA and available to all shipyards, but first let us note that because of this resistance (as well as real design problems) hydrofoils had to retire to the relatively minor role of take-off helpers for the early Italian seaplanes, an application which could shock nobody. This spread to England and resulted in the Burney hydrovane seaplane, an ill-considered design.

The more boat-like application of Forlanini, using step ladders of emerging foils, was bought up by Bell, whose work in Canada is better known; but Bell's design was somewhat outlandish and did not take on, the air drive and spider-like appearance being considered too great a penalty for the speed. (In 1954 I had the pleasure of taking two of Bell's daughters for rides in my Hydrofin just after I had won, with the help of an American partner, the first US Navy contract for an operational hydrofoil.)

Soon after Bell died von Schertel started experiments in Germany, and he tells us that he was undecided for a long time whether to use the emerging foil method of depth control (which may be either in step ladder or Vee foil form) or whether to try some method of incidence control. He saw the latter was going to be complex and very unorthodox in appearance and so he decided, probably rightly for the period, for the simpler Vee foil which, however, must remain always a wave follower since it has no special ability to platform a wave. Nevertheless the commercial successes of the Schertel/Rodriquez team have been very useful to the hydrofoil cause and without these it would have again died out as it did after Bell.

For myself, I had no such hesitations between the fully submerged incidence controlled foil and the emerging foil, for the very simple reason that I never thought of the latter idea until I saw my first pictures of other men's hydrofoils: and this happened only after I had ridden in my own in Kenya. I had made a study of flying boats and had approached the problem purely from the controls angle, discovering quite early that the quality of signal to be expected from a wave face was quite unsuitable for feeding to the foil and a lot of rate control was going to be required. I was, in fact, groping for a semi-automatic control to fly the hull on a line which could be much flatter than that of the wave profiles from which it was taken, and therefore well within acceptable comfort limits. For this task I needed some help, but with the exception of the RAE I encountered only hostility and even open opposition which manifested itself in the refusal of permits to build and permits for wood, even going so far as to refuse a permit for 3s 6d worth of 1 mm ply for the bottom of the Farnborough test model (which was eventually to spark off a $700,000,000 industry in the USA after I had been forced to go to that country and show my craft and its ability on the sea).

The Farnborough report having left no doubt at all concerning the Hydrofin's ability to outclass all other marine craft over waves, Lord Shackleton, then a Member of Parliament, called an Admiralty meeting in the office of the Hon John Dugdale, as a result of which a letter was written to me agreeing to watch demonstrations of a full-size craft. I was faced with the necessity of building a new demonstrator but unable to obtain a permit for this until I had sold a Hydrofin to the USA for dollars, the only method whereby a building permit could be obtained and which could be likened to a thirteenth labour of Hercules. It took a year to accomplish this with the help of a devoted staff at Cowes, but I knew by then that America was my only hope of survival and that I should want a *small boat* that could be taken from place to place on a car trailer (a prediction which turned out to be 100% correct). Taking the smallness of the boat as their excuse, the Admiralty backed out of their engagement and this was a blow that was the harder to bear in that my personal expenditure amounted at that time to several thousand pounds. Several months later and after a fresh attack by Shackleton on my behalf the negative decision was reversed, but by that time my house was sold, my staff dismissed and the boat crated and ready to leave for the New York Boat Show. Nothing could be done.

I did not escape so quickly from the dead hand of official controls since my dollar allowance was only for the stand, my hotel and coffees. By cutting nickels in half I managed to gain some four days of grace during which I would have to sign a contract or take ship home and forget hydrofoils for life. This fourteenth labour was also accomplished and I left for Washington with my boat on a trailer behind a car for which I could not pay, trusting only in a phone call from a man who had given the name of Dr F. H. Todd (of our NPL) as reference. Not only did the man pay up as he had promised (thus saving me from being repatriated by the Consul *without* my boat), but within the prescribed time limit I found myself working for him for a salary and demonstrating my Hydrofin to carload after carload of top-ranking Naval officers, not one of whom ever even noticed that my boat was small. The man's name was Stanley Reed, of Reed Research, Washington.

(Those who want a taken-from-life account of how British ideas are snapped up by America for no advantage whatever to our country have here a perfect example.)

In England my obvious requirement for help (and one to which the Farnborough report certainly entitled me) could have been satisfied by any one of the following agencies: NRDC, DSIR, MAP, NPL or RN.

But three resounding and costly hydrofoil boat failures had led to the conviction that there could not possibly exist a solution that would yield to my type of programme, which was of the cut-and-try variety inspired mainly by an admiration for the Wright Brothers. I alone knew that I had in fact discovered the key but communication was very hard. The marine Press rejected descriptive articles on the ground that these were not boats, the aircraft Press on the ground that they were not aeroplanes — so there was no tribune. I was never once invited to explain my ideas to any of the above agencies. Being unaware of what had gone wrong with previous hydrofoil boats (no information being given), it was doubly hard to explain wherein my solution was superior — as I was in fact later to find out. I had in fact found out about air bleed and applied a cure which would have made the Samuel White boat work had it been applied at the time. I did not know the value of what I had discovered.

The trouble with NRDC was that if the Admiralty were not interested, then they were not either (Blackett, July 17th, 1951), but the Admiralty had refused to look.

In April 1954 DSIR wrote:

"If an inventor came to me and said that whereas most motor cars roll about on wheels he could construct a transport device which would walk about on stilts I should feel rather as I do about your hydrofoil: I should not query the physical possibility of it at this stage but would rather ask: 'Assuming that you can do . . . this . . . what happens next? What precise advantages would a motor car on stilts have over a motor car on wheels either in prime cost or power-to-weight-carrying-capacity ratio or operating expenses or performance? . . .' I cannot get anybody to tell me clearly what advantage it would have over an orthodox boat if the development was successful, as I am prepared to assume that it will be. . . . Marine engineers tell me that they can construct boats by orthodox methods to go as fast as they have any need for. If therefore a hydrofoil boat is to serve a useful purpose it must in some way achieve what an orthodox boat can be made to do, but more cheaply."

These being the fallacious objections put up by the agency responsible for judging inventions in Britain at the time, how could one *possibly* expect to have any success whatever in other directions? It should be noted that this was written in 1954, when the Schertel Sachsenberg boats were already starting commercial operations with success. In such an atmosphere how could one even begin to explain the vital matter of platforming waves, which has to be *seen*?

Dr Allan at NPL was willing to look, but he imposed his own set of conditions, which were that the Hydrofin should not run under its own power but should be towed to eliminate the propulsion efficiency from the resulting calculations. Now seeing that I was pursuing an aim other than that of efficiency pure and simple (for which I was badly placed, having no method of foil manufacture other than that of hand-finished castings), I obviously could not accept towing, which would be impossible in the kind of rough sea which I wanted to use to show my platforming ability. Efficiency could come later, or from a test tank or again, for that matter, from pure theory. The one thing that theory could *not* demonstrate was a rough-sea performance and this is precisely what nobody wanted to see.

Finally, all hope of any help from MAP was killed by a letter from Sir Stafford Cripps which is even more astonishing than those of NRDC:

"The proposed method of obtaining longitudinal stability whereby only a jockey skate riding on the surface of the wave controls the angle of incidence of the hydrofoil is not considered satisfactory, as the contour of the wave beneath the surface is flattened and the flattening is a function of the length rather than the height of the wave." Whatever that may mean. One more fallacious objection which a few minutes on the sea could have killed.

I have no wish to labour the point. Recrimination is sterile and unproductive by itself, but too often is it assumed that a given idea at a given period *must* have been well considered and its rejection based on some snag which the exponent is careful to hide. This article will have missed its mark if it does not very clearly demonstrate the contrary and underline the complete lack of any tribune for the exchange of ideas of this class. This is my justification for bringing up these facts now that we require industries of this type.

The Hydrofin had no sooner escaped from the danger of the dead hand at home than it fell into another overseas.

I have never been a rich man and if my need for help at home was great, in the USA it was of the meal-to-meal type because no dollars were allowed to me. I had to sign something before I got the soup and a lot more before the cheese! I was a poor Limey, and the Navy having seen that the incidence control method was streets ahead of the ones they were developing at the time, I had to sign a contract with an American yard in respect to my American patent rights.

Now in 1950 nobody could sell hydrofoils of *any* system to *any* Navy in the abstract and it was my misfortune that Dr Todd's advice, namely that first of all a large Hydrofin should be built to find out what it could be best used for, was not accepted. The reason for this is easy to see. Whereas all the classical ship uses are strongly defended by a queue of hungry supply firms, the only way to escape this pressure is to start where there is no queue because the specification could not be filled by any displacement craft. It was this that forced the hand of the Navy to apply hydrofoils first of all to a landing craft, required to come in to a beach at five times normal speed. The next disaster was that the only yards likely to go for such extreme specifications were those that were bankrupt or in receivership, and these were so scared of *not* getting the job that they proposed the moon too. Thus, whereas the Navy would have been satisfied with a landing craft able to come in at five times landing craft speeds, sit down and fold its legs smartly before proceeding to beach, this firm had to go and add to the specification *their* proposal, to wit, that the retraction of foils and struts should be done *in full flight* and timed to finish during the passage through the breakers (the reasoning being that the last bit of vertical area would maintain good directional stability and prevent broaching-to).

Now in view of the vertical retraction of some seven extra feet, the triangle formed by the water, the strut and the feeler arm had to have all its dimensions doubled, and the result was a maritime freak of frightful cost and loathsome appearance which was never brought anywhere near a beach. In fact it soon became clear that no attempt would be made to improve the Hydrofin in its mechanical feeler form but that this would be used as a stepping-stone towards other methods of water-level sensing.

Whether the Americans have been right or not to take this step we shall discuss later.

Now at this time the controversy around the different systems that had been developed in the USA and in Germany and Sweden was in full swing and it was not without considerable trouble that the first Naval contract was conceded to a British, shoe-string developed, boat to the exclusion of such American firms as Gibbs & Cox, Baker, Grumman and Dr Vannevar Bush. (Lockheeds, Lycomings and Boeings had not yet come on the scene.) The Miami Yard was very much aware of its inability to maintain its place in view of the magnitude of the industry.

Now since a landing craft is, by definition, a craft that operates always in a following sea, it was here that the special ability of the Hydrofin for this case won the day and my type was the only possible choice.

A 13 ft Hydrofin rises with ease over a 5 ft wave without any hull contact and this is by no means the limiting case. In fact I shall show by means of wave frequency calculations and a graph that once the wave height of about one-quarter of hull length has been passed the negotiation of higher and higher waves becomes progressively *easier*. It is the very small and therefore very short wave which is the problem for the hydrofoil boat generally, since it would normally impose response frequencies which would become quite intolerable vibrations in the head-sea case.

Here I am afraid I have to cross swords with Peter Crewe, who wrote in his RINA paper of March 1958:

"A particular merit of incidence control is that the craft can be made to travel in a path which follows the wave contour so that the hull remains effectively above the water, without having to provide so large a clearance between it and the hydrofoils as would be otherwise necessary."

This is the exact opposite of the whole point of developing this method over a period of twenty-three years. To return to the analogy of the railway viaduct, this would be like explaining that these had been built to increase the inclines of an otherwise flat countryside! Since the mathematics of passenger comfort for a given speed, wave size, craft size, wave heading, water clearance, etc, are far more complex than the very simple case of the 2% or 3% incline and since these results would never have been "swallowed" if they had not been backed up by practical demonstrations on the sea, it is easy to see why this was a much harder task than that of obtaining acceptance for the railway.

I should point out here that the Americans had it all on a plate. Not only did they have my small demonstrator to play with (and this was soon joined by larger boats sold to private customers by Sandy Holt and myself to procure bread and butter) but they also had the benefit of the Farnborough report, which had spelled out just what was to be done to improve the performance — for instance, on page six:

"The incidence control of the main hydrofoils is a very powerful method of draft control — at running speeds a change in attitude of 2° produced 1 g normal acceleration on the boat. The response of the boat to changes in hydrofoil incidence is therefore very rapid and in waves the motion applied to the main hydrofoils must be accurately representative of the path the boat is required to follow. The hull is carried well clear of the water so that the boat need not be affected by small waves or irregularities, responding only to waves or swell longer than about twice the length of the boat."

The model, of course, had relatively short legs since the idea of platforming was only just germinating in my mind at the time. All craft built after Farnborough were given longer legs because Smith had pointed directly to platforming and had furthermore explained that this presented no problem or penalty in view of my very powerful lateral recovery forces generated by the differential action of the two independently moving lateral hydrofoils. In fact this idea can now be pushed a stage further. Seeing that there is a universal demand for small beam and for as little obstruction to coming alongside as possible, it follows that the designer has to try to increase the effect of the differential in order to maintain lateral stability in an otherwise somewhat unnaturally narrowed design. Modern control systems offer all sorts of possibilities of this type.

But while, due to the Farnborough report and the long series of Naval demonstrations, my thesis was understood by the Americans and acted upon, I was still receiving from DSIR letters of which the following is an extract:

"There are very few people who support your claims, and some who consider them to be greatly exaggerated."

To this I replied that my claims were merely based on the Farnborough report on the one hand and practical sea demonstrations on the other.

A short time after the Farnborough report Imlay had written a mathematical analysis of all possible hydrofoil configurations in an NACA paper in which he concluded that what was wanted was "some device" that changed the angle of attack when the depth varied, and this was in fact just what I had produced at just the right time.

The fact that my solution was tied up in patents did not make matters any easier, but what the Americans really could not understand was how I could possibly be *allowed* to show such a development at a Boat Show where the nationals of . . . shall we say . . . "any" country could put questions to me and would receive full and complete replies. The position of Sandy Holt and myself during the Naval development work in Miami was very difficult because we had to build and sell conversion kits and at the same time avoid all reference to the fact that we were also working on the much larger landing craft project which was confidential, and this for three very good reasons: (1) it had a military application of some tactical surprise value; (2) it was highly unorthodox and might not be fully satisfactory; and (3) it was a frightful-looking freak craft and it was obviously already planned to use the mechanical feeler system only as a means to an end.

I have already questioned whether the Americans were right to abandon so soon a mechanical system which had produced a remarkable sea performance for a novel system whose adoption would entail the loss of some important points. Already a similar change from Bell's air drive to marine shafts had caused the Samuel White programme to end up in a total loss because no investigation of air bleed to the propellers and to the grid foils had been undertaken. I will not repeat here all the uncomplimentary epithets that had been used to describe my feeler arms! It will suffice to say that they were never popular, but in throwing them overboard one has to know exactly what is entailed since they do more jobs than may appear at first glance. They double as crash preventers and take a load when the boat stumbles due to air entry to the front foils. This is another way of saying that in matters of fully submerged foils the tandem arrangement just will not do unless we mean by that a tandem such as the Aquavion wherein the front foil is not a foil at all but a skid, and by that I mean a plane that is so lightly loaded as to continue to carry its load even when fully ventilated.

The Aquavion tends to be unpopular because the large area of the front foil results in rather violent decelerations each time it enters a wave and, as Barkla puts it in his letter to the *Yachting World* of November, this system, to control the main foil, has to wag the whole boat.

Allan Hazard was the only man who dared to run a fully submerged system without a crash-preventing device or any automatic pilot, but he only did this in a 10 ft sports boat "for kicks". He would accelerate and then pull his stick right back and fly his foils right out of the water. On landing, the foils would have no circulation and before this was re-established air would be sucked down so that the boat would crash violently on to its planing bottom. Nobody has ever suggested that similar "kicks" could possibly be contemplated for any craft above, say, $\frac{1}{2}$ ton.

This means, then, that by abandoning the feeler with its advance prediction and bow-up trimming moment as an emergency measure in the early stages of the crash, the Americans have accepted the restrictions of more foil and strut depth, much lower water clearance and very limited sea states since they have no crash prevention.

To illustrate this better I may say that while in Miami at the time when the various systems were still being evaluated by the Navy, Commander Stilwell asked us permission to take away our boat for a full day. Knowing that the anti-crash qualities of the Hydrofin were important, we took the precaution to rig the craft to fly a shade lower than usual. (This being a controls matter, it is easy to see that any change in the length of the connecting rod will result in a lower line of flight with reference to the surface.) When Stilwell returned he said that this was the first hydrofoil he had been totally *unable* to crash, however hard he tried and despite all possible combinations of wave headings, bankings, etc.

Had we rigged the boat to fly higher, with a smaller margin of water covering the main foil, then it is probable that he would have had some mild crashes or rather "limps" that recover before the hull touches the water. Had we taken off the shock absorbers, for example, then he would have experienced something which would have cured his curiosity for the rest of his life and caused him to take the pledge!

This means, of course, that one can envisage this thing in one of two ways: either one thinks of a marine craft pure and simple, which an enthusiastic operator will drive hell for leather through rough seas, revelling in its astounding ability to fly through anything, therefore a boat that must have built-in ability to deal with any situation; or one thinks in terms of an instrument-controlled flight in the hands of a well-trained captain, surrounded by measuring devices which make allowances for the exceptionally high wave and reserve a respectable margin of safety corresponding to a large reduction in wave state ability compared to that which would be acceptable to the first type.

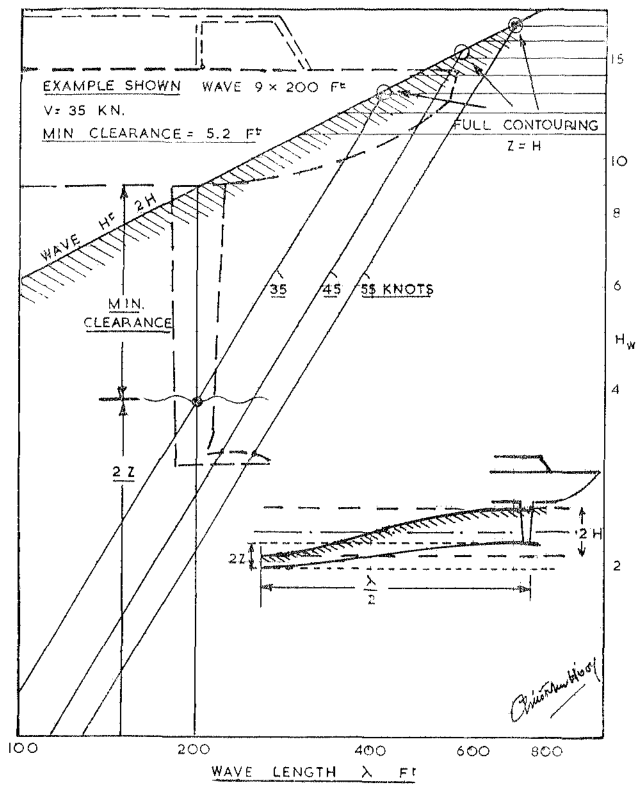
I am quite sure of my conception of a craft wherein the wave height difficulty increases up to the critical size of twice or three times boat length and thereafter *decreases* until full contouring becomes possible because of wave geometry (the difficult small wave area being overcome by sheer water clearance): this conception, I say, has been missed by the Americans because they have abandoned anti-crash and as proof of this one has only to look at their Grumman *Dolphin* and North West Hydrofoils *Victoria*, both of similar size, both fully submerged foil systems and both announcing a severe sea state limitation due to a failure to take advantage of the true *raison d'être* of the hydrofoil and fly high.

It is, of course, true that in the absence of any anti-crash device, high flight is dangerous, as I have explained. The *Dolphin* clears the water by only 4 ft for a hull length of 70 ft, giving a ratio of 17½, and the *Victoria* is similar. Both give 8 ft waves as a maximum.

To quote again from Barkla:

"When large firms, and particularly aircraft firms, latch on to an idea like hydrofoils they have a vested interest in suppressing a simple solution if a more complicated one will give employment to their cohorts of technicians. We are so hypnotized by the wizardry of computers that we acquiesce in rejecting the simple and possibly more reliable solution. Hook's Hydrofin has suffered as much from this modern snobbery as from misunderstanding."

That a more acceptable solution to incidence control would have to be thought up was obvious to me many years ago but it was not easy to find one that retained the essential crash prevention and still looked neat and tidy. Was it justified to go to such extremes as the sonar beam or was there not some middle course that could satisfy all these needs and remain essentially simple and straightforward? That an aircraft flying at 400 mph in dense fog and obliged to make contact with the earth at high speed should have little choice other than a radar or sonar beam is understandable, but is a marine craft *only 5 or 6 ft away from its plane of reference* in the same predicament? Should the railway locomotive have the flanges machined off its wheels under pretext that this method of directional control is crude and could be replaced by a steering device based on electronics and a photocell? Should the blind man's cane be taken from him as primitive? It is true that the blind man has sometimes to deal with situations where he has no definite plane of reference to work from, but if we suppose that he had always to walk along a wall with undulations and had to maintain an average distance from this, surely the case would be so simple as to call for nothing more than a long cane with a wheel at the end.



Assuming that "g" is limited to g/2 for passenger comfort, then the 35 knot line for head seas enables a 13 ft wave to be fully contoured while for smaller waves the strut length must increase as shown. For example the 9 ft x 200 ft wave requires a clearance of 5.2 ft while the smallest shown is 6.2 ft calling for about 5 ft. For higher speeds these proportions have to be increased unless more "g" is accepted, easier wave proportions or headings other than that of the head sea. Wave proportions taken are those of K. C. Barnaby for "average rough sea" and the graph illustrates the complete impossibility of demonstrating the full possibilities of hydrofoils with the use of small craft

But I have shown that even this is not a fair comparison since the introduction of sonar introduces a hazard as compared to the mechanical method. Both Hanning Lee with his *White Hawk* and Wendel in Hamburg have sunk or nearly sunk as a result of a sea crash. To have taken a ride as a passenger in a given hydrofoil still proves little, and it is necessary to obtain permission to take the controls and provoke the crash in order to learn how a particular boat is able to survive this.

The cost of the sonar type of controls is of the order of $25,000, which is a lot for a small boat but relatively unimportant in a large one, this expense tending not to scale up with the tonnage. The reliability is good and is not really an important factor after all: so that it is the absence of the crash prevention (along with the hull height limitation that this entails) which is the whole point.

Turning back, therefore, to the Grunberg idea of 1932 but avoiding the known snags thereof, one must envisage a *non*-hull-wagging, *non*-crashing high flyer, and this is done very simply by retaining the advanced skid as an emergency plane and a sensing device platform.

Relieved of all crash-preventing duties, the sensor can now be made as a "whisker" and all we ask of it is to transmit the *"raw"* wave curve to the inboard filter box wherein all the elements that existed on the feeler arm are contained (but in miniature form), thus eliminating all mass effects.

Another cleaning-up job has been done on the main struts. Whereas the feeler arm required a rather high tubular spar to wrap itself round (and it was logical to use the same spar for the main strut), now this is all changed and the strut can quite selfishly cut itself down to much more logical proportions: retract, a lot easier and be much lighter. A "Y" configuration gives the required lateral stiffness and the whole can be short enough to be under water (in the floating position), thus giving the boat a very neat appearance when afloat.

Having greatly reduced the power of the wave signals, we can no longer feed them directly to the foils as with the arms, and thus we must introduce hydraulic boost between the filter box and the foil incidence command rod.

Times have changed.

Whereas when I started (or roughly from 1942 to 1955) the lifting of a boat out of water was considered a kind of miracle which had to be seen to be believed (so that one had to have a demonstrator constantly on tap ready to convince the incredulous at any hour of the day or night), now this is no longer so and we can return to methods of work which more closely resemble aircraft practice. Tank test models can be made and loaned to foreign experimental centres from whom information can be obtained. I say "foreign" advisedly, since we have here the rather incongruous situation that test tanks in foreign countries or even Navies will do work and supply information, whereas if I require this in Britain the work would cost me about £200 per day!

As from the time of my return from the USA I have constantly had to work abroad to progress at all. The advice of Lord Halsbury and Sir Henry Tizzard (which I considered sound advice, things being what they were) was to go to Germany and work in with Herr Sachsenberg of Bremen, the German branch of Supramar. Sachsenberg had very good scientific contacts in Hamburg and I was able to arrange cooperation with my friends at the FCM at La Seyne, near Toulon, so that measurements could be taken of the French-built Hydrofin. I gained more experience by working for the Israeli Navy, and here again I was helped by a French shipyard at Veilleneuve le Roi which accepted the sea state stipulation for the trials in Haifa which no other hydrofoil craft (even twice its size) could have filled. These were for 30 knots in a sea state 3 or waves of 3-5 ft high. To do this with an ACV would have required a craft about fifty times this size.

To sum up, then: Britain was the first to develop the fully submerged incidence controlled hydrofoil for the sea and we have here a steady lift device that can carry a vehicle on a *level* path with constant lift even over large waves. Apart from aircraft it is quite unique in this respect and it therefore supplies the ideal answer for ocean travel.

Experimentation is not easy because of wave geometry, the mathematics of which are rather more complex than those of the simple inclined plane. A high water clearance is essential, not for the large but for the small waves since these cannot possibly be contoured *by any vehicle* except at certain headings with low speed and high "g". A practical minimum size is about 50 ft with a 6 ft water clearance.

The new industry requires the combined skills of the marine, aircraft and controls experts and this cannot be organised by an individual. The days when a miracle boat of small dimensions had a job of propaganda to do are over: all this has been recorded on film and there is no point in doing it any longer.

This is a golden opportunity to resume our historical role as innovators in matters of world transport devices, but if we fail to do this others will — and very quickly.

HOVERCRAFT NOISE

by A Cadman Clinton FRAeS, FBIS, MSEE

(continued from previous issue)

3. Attenuating structures of various types will reduce the noise, but as the method is developed to improve the conditions weight, complex arrangements and cost tend to increase. Little increase in weight can be permitted, and cost increase has to show worth while achievement, e.g. obtaining speech level conditions making happy people in a happy craft. This emphasises the need for noise considerations at the design study stage.

While attenuation may succeed in some noise conditions care must be taken to check that there is the minimum sound level ventilation ducts, liquidborne noise from systems or solid borne vibration, these are mentioned later.

When power units are installed in a self-contained room the noise problem can be dealt with by the main structure, and attention given to noisy auxilliaries that may have to be installed at points remote from the engine room; then again how much sound proofing of these small units should be done depends on the accessibility required during use. Hoists, winches and ramp-handling gear are sources of intermittent noise that must be accepted.

Engine room doors should be fitted with air-tight seals similar to those used in engine test cells.

Intake air to the engines passes through special filters combining noise absorbing qualities.

Synthetic materials are useful in liquidborne systems, where noisy pumps need anti-vibration mountings, and if metal piping is transmitting noise in various ways it can be replaced wholly or partially by an appropriate plastic type.

The degree to which noise attenuation is necessary depends on the acceptable noise level, and it may be that only certain parts of the system will need modifying, e.g. where normal speech is necessary.

A particularly useful attenuator is lead impregnated vinyl sheeting, it is efficient, convenient to handle and frequently more satisfactory where space is limited and thus restricts the use of bulky low density materials.

Glass fibre materials are used in combined filters and splitters on engines, the air intake to the lift fans, and should be good for the propeller shrouds where in some designs the shroud section could be hollow and filled with a visco-elastic attenuator. It might be recollected that the old-fashioned lathe and plastic ceiling, a form of reinforced plastic, was one of the best attenuators used in building.

Conclusion

Some hovercraft in their present development stage are noisy but it must be remembered that in the rapid development and evaluation noise reduction was of low priority. A good deal of thinking about noise had taken place when current types were being planned and the experience now available will be embodied at the design stage of new craft at the same time that reliability and maintainability are progressively included.

Benefiting from the experience of piston and gas turbine engines required in high speed patrol boats further marinization of engines is proceeding and resulting in noise-reduction, and the turboshaft engines are most promising.

Propellers will be used for some time, although the proposed design modifications suggest that the high frequencies will be much reduced by changing to slower revving larger diameter types using six to eight blades.

The developments in hand and those now at the project stage will bring the hovercraft into the acceptable noise field and increase the optimism of the engineers who are confident that craft from 500 to 3,000 tons are feasible.* Such craft would have existing marinized gas turbines and these could be installed in suitable combinations to provide a selection of powers estimated at from 1,000 to 100,000 hp.

This forward thinking means that hovercraft will increasingly develop a ship capability.

Reference

Journal Acoustical Society of America, Vol 25, May 1953.

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* *Flight International,* December 19th, 1964. Connor.

U S NAVY TESTS HYDROFOIL PATROL CRAFT

A NEW series of rough-water tests for the US Navy's first hydrofoil patrol craft, *High Point* began last fall in the waters off Cape Flattery, the northwestern-most tip of Washington State. The series resumed a test schedule in June of the craft's performance in varying sea states.

The *High Point,* designated PCH-1 by the US Navy, is operated by a Navy crew, with technical assistance during the testing supplied by The Boeing Company. Results of these and other tests could well point the way towards future hydrofoil development in America.

Boeing built *High Point* under a Navy contract, with the craft entering Navy service in September of 1963. Since that time, the PCH-1 has operated out of the Puget Sound Naval Shipyard at Bremerton, and has carried out an extensive test programme.

High Point is equipped with submerged foils and, when foilborne, is powered by two gas-turbine engines each rated at 3,800 hp. Two nacelles are connected to the aft foil struts, and the propellers are driven through two right-angle drives. A propeller is located at each nacelle end, making a total of four propellers for foilborne operation. Speed when "flying" is in excess of 40 knots.

A 600 hp diesel engine supplies hullborne power, providing speeds up to 14 mph. When *High Point* goes to its foils, the diesel powered propeller is retracted to reduce drag.

High Point is 115 ft long, 31 ft in the beam and has a design displacement of 110 tons. It is all aluminium except for the steel foils. Draft is approximately 17 ft with the foils extended and 6 ft when the foils are retracted. Average draft when foilborne is 6 ft 6 in.

Altogether, nearly two dozen take-offs were conducted over the two-day test period, thirteen of them on the first day. The PCH-1 was foilborne 1 hr 39 min during the initial day of testing, with a lesser time logged on the second day.

Water conditions off Cape Flattery varied as the tests progressed. Generally, the sea was characterized by ground swells with some chop. Average distance between wave crests was 175 ft, with an average wave height of 5½ ft. Occasional waves exceeded the 8 ft 8 in length of the forward strut, and although some instances of broaching of the forward foil occurred in these seas, *High Point* platformed well. Subsequent adjustments to the automatic control system additionally improved this characteristic.

Later, a 22 knot westerly wind generated and superimposed on the swells a great number of 3 ft white caps. *High Point's* performance, however, remained consistent, showing that the craft can routinely negotiate greater sea states. The new test series will seek out more demanding conditions to further establish the craft's capabilities.

Prior to the *High Point* foilborne tests, some time was given to the craft's performance while hullborne. In an effort to determine the damping effect of the foils in a seaway, *High Point* tested the foils in both extended and retracted positions at a speed of 10 knots. Results were tempered by the fact that, while *High Point's* foils can be retracted, they cannot be removed from the water.

However, valuable data was gathered about seaway effects. Accelerations resulting from hullborne slamming were found to be greatly more severe than those resulting from wave furrowing while foilborne. Hullborne, average peak accelerations at the steering station were 14.2 ft/sec^2 at 8 knots. Foilborne, average peak accelerations in the same seaway were 2.9 ft/sec^2 at 43 knots.

A technical consideration of any open-sea test programme is precise definition of the water and wind conditions prevailing at the time of the tests. Stated another way, test conductors face an age-old problem in determining whether their craft actually meets designed operating specifications. The unaided eye is not nearly enough.

The reason lies in the nature of the sea. A particular sea condition is not composed of equal waves which march past in regular files, or of winds which produce a wave train in which all waves have equal heights and periods. Although an average wave length is quickly identified, analysis shows that a particular sea condition actually has components ranging from ripples to waves far in excess of the average figure.

The question becomes one of determining a scale of sea conditions from which operating specifications can be formulated for a craft, accounting for such elements as wind velocity, how long the wind has been blowing, the total area over which it has blown, wave heights and periods, ground swell, chop and currents. The problem is combining this and other data of the sea into a scale which is meaningful to designers, builders and operators.

The sea-state scale used for *High Point* is a standard US Navy system which classifies sea conditions by numerical rating of 1 to 7. Each state is defined in terms of wind which generates wave conditions. The waves are classified into *average* wave height and the *significant* wave height, which is an average of the upper one-third of the highest waves. A still further descriptive line can be drawn computing the average of the upper one-tenth of the highest waves.

These measurements are plotted on a chart to display and closely define the water conditions in which a particular test is conducted. The information is obtained through electronic sensor equipment and recorded on data tapes. When a given test is completed, test conductors have "hard" data for analysis.

To describe the water as sea state 4 during *High Point* testing resolves through the system to a wind factor of approximately 20 knots, an average wave height of 5½ ft and a significant wave height of 7 ft. The average of the upper tenth of the highest waves approached 10 ft.

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The Bristol Siddeley Marine Proteus gas turbine delivers at least four times more power per pound weight than any other type of marine propulsion unit.

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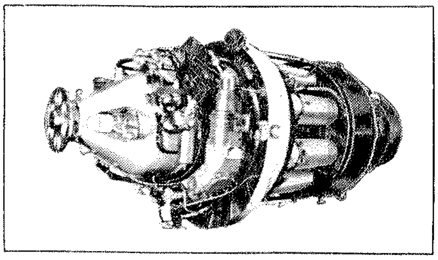

The Bristol Siddeley family of marine gas turbines ranges from 900 to 22,000 shp. Their proved reliability, compactness and power-to-weight ratio make them the ideal choice for either lift or propulsion in hovercraft.

For further information on these engines, please write to: The Sales Manager, Industrial Division, Bristol Siddeley Engines Limited, PO Box 17, Coventry, England.

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