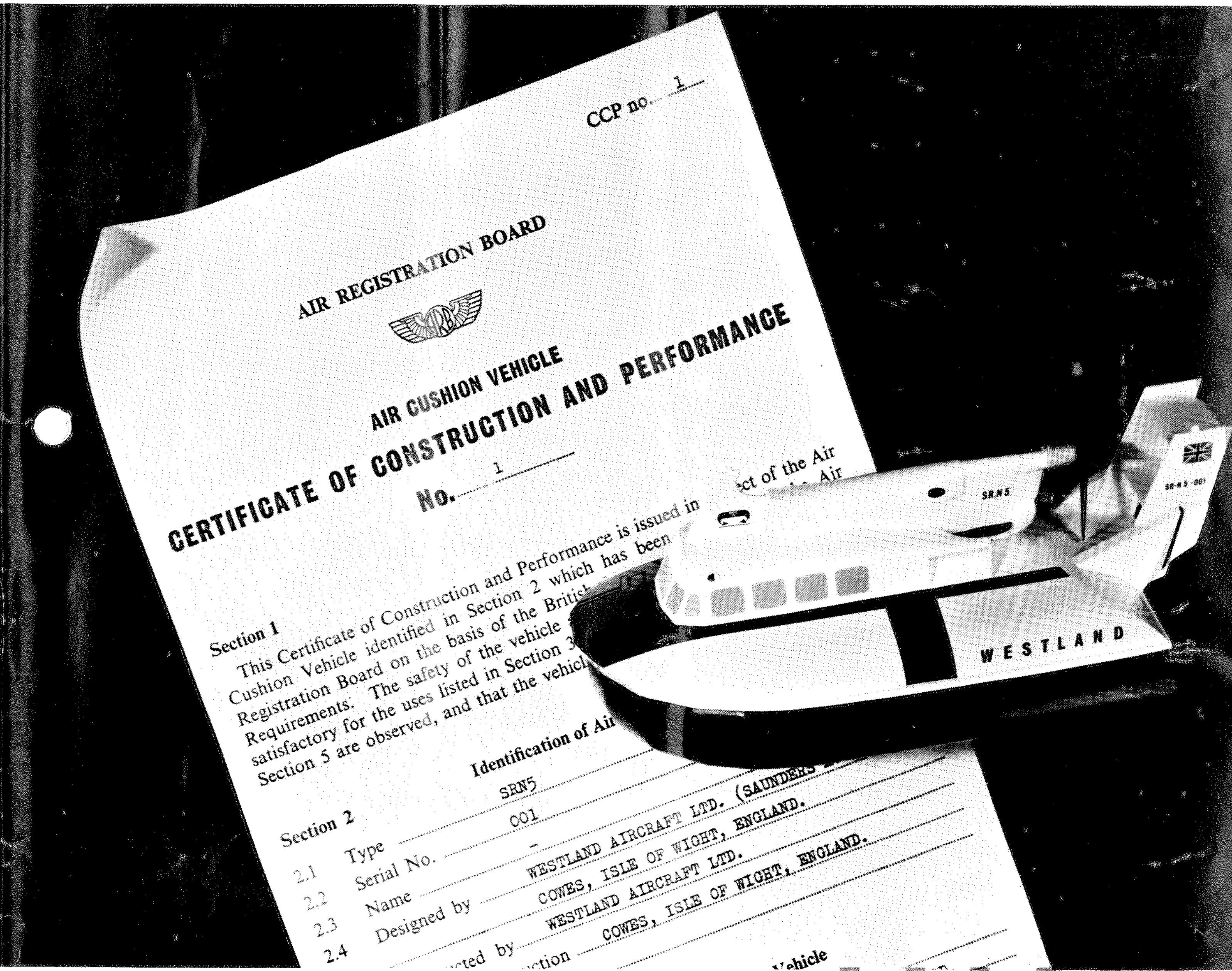
HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS



CCP no. 1

AIR REGISTRATION BOARD

AIR CUSHION VEHICLE

CERTIFICATE OF CONSTRUCTION AND PERFORMANCE

No. 1

Section 1

This Certificate of Construction and Performance is issued in ...ct of the Air Cushion Vehicle identified in Section 2 which has been ... Air Registration Board on the basis of the British ... Requirements. The safety of the vehicle ... satisfactory for the uses listed in Section 3 ... Section 5 are observed, and that the vehicl...

Identification of Ai...

Section 2

2.1 Type ... SRN5

2.2 Serial No. ... 001

2.3 Name ... -

2.4 Designed by ... WESTLAND AIRCRAFT LTD. (SAUNDERS ...

COWES, ISLE OF WIGHT, ENGLAND.

...cted by ... WESTLAND AIRCRAFT LTD.

...ction ... COWES, ISLE OF WIGHT, ENGLAND.

...ehicle

Volume 4 Number 7

APRIL 1965

KALERGHI PUBLICATIONS

WESTLAND EXPERIENCE UNRIVALLED

'Flight' photo

Westland has more hovercraft operating experience than any other manufacturer. Between them, SR.N1, SR.N2, SR.N3 and SR.N5 have to-date logged almost 2,000 hours in development and passenger-carrying operations, have covered 45,000 miles and carried more than 46,000 passengers.

All the craft have operated successfully in rough weather and high seas, and over testing rough-country areas and obstacle courses. Westland hovercraft—two SR.N5's and the 37¼-ton SR.N3 (illustrated)—were the only ones able to put to sea in a full gale, with seas between 5 and 6 ft, at a recent British Hovercraft Industry Demonstration at Lee-on-Solent.

Westland's technical achievements, backed by this very wide operational experience, have speeded up design progress on the 150-ton SR.N4, and given positive signs that design expectations for this cross-Channel hovercraft will be fully realised. This same wealth of experience will be invaluable in speeding the completion of Westland's study of the 250/500-ton hovership project

sustained
HOVERCRAFT LEADERSHIP

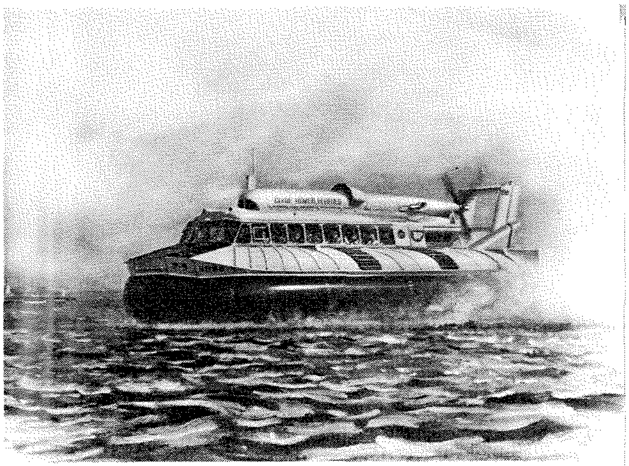
Reg. Trade Mark

WESTLAND AIRCRAFT LIMITED YEOVIL SOMERSET

HOVERING CRAFT
& HYDROFOIL

FOUNDED OCTOBER 1961

First Hovering Craft & Hydrofoil Monthly in the World



An artist's impression of the Westland SR.N6 which will be used in commercial service on the Clyde this year. For further details see People and Projects on page 4

HOVERCRAFT ON DISPLAY

The marked growth in recent years of international trading intensified by the creation of such organisations as EFTA and the Common Market, has given a new impetus to trade and technical exhibitions. These have long been a feature in the marketing field, whether of simple consumer goods or heavy industrial machinery, but they are now regarded as opportunities for hard selling with concise facts and figures rather than an excuse for representatives of companies in a particular industry to have an amiable get-together.

The British Hovercraft industry has not been slow in appreciating the value of such exhibitions in presenting their ideas to potential buyers and operators, and model displays have been shown at exhibitions all over the world, including Zurich, Utrecht, the Hague, Düsseldorf, London and Sydney. In addition, demonstrations of actual craft have been arranged to coincide with such events, ranging from the Farnborough Air Show to the British Fair in Düsseldorf. These are in addition to many public and military demonstrations which have been held in Europe, North Africa, Canada, the United States and South-East Asia.

Taking craft out on such demonstrations is an expensive undertaking, and also holds up necessary development work, and one must therefore admire the foresight of these manufacturers who continue to do so. They are, of course, trying to sell their products, but at the same time they are selling the idea of British industry and know-how, and in these days of tax adjustment and re-evaluation, the Government might well consider giving more financial assistance in the form of some tax relief for exhibitions and demonstrations of this sort. This is the kind of incentive needed for companies to exhibit, and thus sell, abroad.

One of the biggest trade exhibitions in the world is being held in Munich from June to September this year — the International Transport and Communications Exhibition. It is only held about once every twelve years, and more than 12,000,000 people are expected to attend. The Russians and the Americans will be there, exhibiting spacecraft amongst other things, but it is sad that only three British companies have thought it worthwhile to exhibit, and there will be no representation from British Aviation or shipping. One of the stands, fortunately, will be concerned with British hovercraft, showing again the forwardness of this industry.

At the same time as this exhibition, a hovercraft will be demonstrated at Cuxhaven and Hamburg, and prior to that, a demonstration is being planned to coincide with the British Week in Amsterdam in May.

Over the years, the British hovercraft industry has come in for its share of criticism — some just and some unjust, like all criticism. It is gratifying that in this field at least the industry provides such a good example to others.

IN THIS ISSUE

People and Projects 4

New York City and the Air Cushion Vehicle — The Challenge to the Engineer 6

Westland's New Hovercraft 15

The Canadian Hydrofoil Programme 16

COVER PICTURE: *An historic document — the first official Certification document to be issued for a hovercraft anywhere in the world, "Certificate of Construction and Performance No 1", was issued by the British Air Registration Board for the Westland SR.N5 on March 12th, 1965. For further details see People and Projects on page 5*

APRIL, 1965 VOL 4, No 7

Editor:
JUANITA KALERGHI

HOVERING CRAFT AND HYDROFOIL is produced by Kalerghi Publications, 53-55 Beak Street, London, W1. Telephone: GERrard 5895. Printed in Great Britain by Villiers Publications, London, NW5. Annual subscription: Five Guineas UK and equivalent overseas. USA and Canada $15. There are twelve issues annually.

ADVERTISING REPRESENTATIVES

GREAT BRITAIN & EUROPE: International Graphic Press Ltd, 2 Dyers Buildings, London, EC1; JAPAN: Japan Trade Service Ltd, Masami Building, 1-30 Kanda Jimbocho, Chiyoda-ku, Tokyo, Japan; HOLLAND: G. Arnold Teesing, Amsterdam-Z, Rubensstraat 68a, Holland.

River passenger traffic in the **Russian Federation**, the largest of the fifteen Soviet republics, is increasing every season. More than 110,000,000 passengers are expected to use the river boat service during the summer season. Eighteen express services will be opened this summer using hydrofoil craft capable of travelling at speeds of up to 80 km/hr. Raketas, Meteors and Sputniks will replace conventional boats on the largest rivers, and the first gas-turbine hydrofoil, the *Burevestnik*, which can carry 150 passengers at a speed of 110 km/hr, will make its appearance on the Volga this year.

☆ ★ ★

A 75 knot hydrofoil capable of carrying ten people is to be put on the market in Japan. It is powered by a 100 hp outboard engine and is 5.9 m long. The cost of construction of the hull is said to be about one-third of that for similar boats now available because of the use of a special plywood material. The boat is to be supplied by the **Eibai Co**, 15, 1-chome, Imabashi, Migashi-ku, Osaka, Japan.

☆ ★ ★

Westland's 7-ton SR.N5 became the first hovercraft in the world to receive full civil certification with the issue on March 12th, 1965, by the British Air Registration Board of "Certificate of Construction and Performance No 1". This corresponds to the Certificate of Airworthiness issued by the Board for all British civil aircraft and allows the regular use of SR.N5 for carrying fare-paying passengers.

In June 1964 a limited "Permit to Fly" was issued by the Board barely a month after the craft started its initial trials programme. On the same day, the SR.N5 was put on to an experimental passenger service between Southsea and Ryde, Isle of Wight, and in thirty-six days it carried 9,850 passengers, with a maximum of over 500 in one day. It often operated for more than eight hours without the engine being stopped.

The SR.N5, which can carry up to nineteen passengers or two tons of freight at cruising speeds up to 60 knots (110 km/hr), was the first hovercraft to be produced in quantity. A production line was laid down in August 1963 before any orders had been received. The craft are now operating in the USA and Japan, and are due to go into commercial service this summer in Norway and Federal Germany. Three SR.N5s are being operated by the British Inter-Service Hovercraft Trials Unit, two of them on exhaustive tropical trials in the Far East.

★ ★ ★

LETTER TO THE EDITOR

Dear Sir, — I read with much interest the letter from Mr G. G. Harding published on page 5 of the January issue of your magazine.

Being exactly in the same position as Mr Harding (I am an amateur designer-builder of small pleasure air cushion craft interested in exchanging ideas and experience with other people in my position), I would strongly suggest the establishment of a non-profit society of amateur hovering craft designers and builders.

Provided this society is made international, it will count on members from all over the world: UK, Australia, USA and Italy would be the first contributing countries, and it will become a source of reciprocal useful exchange of information and experience.

Yours faithfully,

FERDINANDO GALE.

Via Tito Speri, 14,
Abbiategrasso,
(Milan) Italy.

People and Projects

Textron's **Bell Aerosystems Company** has been awarded a patent for a small rugged machine which rides a cushion of air at high speeds over a variety of surfaces. The United States Patent Office issued patent number 3,174,513 to Bell for its 1½-ton *Carabao,* which features a unique tri-cell concept utilising a single fan to feed air to the three circular lift cells. Power is supplied by two air-cooled aircraft engines. A 150 hp engine drives the aft-mounted variable pitch propeller which is used for propulsion, directional control and braking. A 120 hp engine drives the fibreglass lift fan. The craft, which was invented by John B. Chaplin, is 18.7 ft long, 16 ft wide and has an over-all height of 10 ft. It has a top speed of 52 knots (60 mph).

★ ★ ★

On Monday, April 5th, 1965, a Westland SR.N5 hovercraft operated by **Scandinavian Hovercraft Promotion** of Oslo inaugurated the first hovercraft service to be run outside the UK.

From the main terminal at Aalesund the craft will provide a fast passenger service northwards to Molde and Andalsnes, and southwards to Orsta. Journey times over these thirty- to forty-mile stages will be between thirty-five and fifty minutes.

In June Scanhover is scheduled to take delivery of a 9-ton thirty-eight-passenger Westland SR.N6, an advanced development of the SR.N5.

Westland hovercraft will be used in four overseas services this year.

★ ★ ★

The **Nordorederiet Shipping Company** of Oskarshamn, in south-east Sweden, is having discussions with both Westland Aircraft and Vickers for the possible purchase of hovercraft for Swedish operations. The Managing Director of Nordorederiet, Captain Ebert Petersson, told the *Financial Times* that the first probable service for next year would be with a small craft on the short run between Oskarshamn and the island of Gotland in order to gain experience. In 1968 they hope to introduce a larger craft of about 150 tons for service between Stockholm and Gotland — a distance of about 130 miles.

★ ★ ★

At the Genoa Boat Show held in February the **Rodriquez** Shipyard of Messina gave daily sea trips with their 14 m hydrofoil which carries thirty-two passengers and cruises at a speed of 43 mph.

★ ★ ★

Swedish Lloyd Shipping of Gothenburg has been conducting negotiations with Westland Aircraft for the purchase of large hovercraft. They have been examining the economics of a cross-Channel hovercraft ferry, possibly using the giant SR.N4, on a run between Ramsgate, Kent, and the French coast.

★ ★ ★

Townsend Car Ferries, part of the Coventry-based George Knott Industries Group, has placed an order for a thirty-eight-passenger, 70 mph Westland SR.N6 hovercraft which they expect to use between Dover and Calais next year at passenger fares comparable to existing cross-Channel rates. The craft will cost them £100,000. Another subsidiary of the George Knott Industries Group, P and A Campbell, who operate passenger services in the Bristol Channel, may use the Townsend craft in the Solent for part of the year.

★ ★ ★

In June the first commercial hovercraft service on the Clyde will be inaugurated with a Westland SR.N6. The craft has been bought by **Highland Engineering Ltd,** whose subsidiary Clyde Hover Ferries Ltd will run the passenger service.

On May 17th **Cosmic Shipping Ltd,** associates of Jersey Lines Ltd (which runs the Channel Islands-France ferry *La Duchesse de Normandie*), will inaugurate England's first hydrofoil passenger service between Southampton and Cowes, Isle of Wight. They are using the gas-turbine driven *Cyra* built by International Aquavion. The craft carries forty passengers and luggage at nearly 40 mph, and will do the trip each way in about twenty minutes instead of the present crossing time of one hour.

The official timetable will be announced shortly, and it is planned to provide up to twelve round trips every day of the week. The first will leave Southampton at about 6.30 am and the last will leave Cowes between 10.30 and 11 pm every night including Sunday. Fares will be 7s single and 11s return, and half-fares for children aged three to fourteen.

Mr N. F. Cowasjee, Managing Director of Cosmic Shipping Ltd and Jersey Lines Ltd, says that he expects the hydrofoil will carry 50,000 passengers during the summer. He believes that the craft is the ideal form of transport for short sea crossing in sheltered waters, and that it will offer a completely new experience in sea travel.

Cyra carried out successful passenger trials in the Orkney Islands last year under the name of *Shadowfax.* Its air-conditioned passenger cabin is provided with forty foam-padded armchair seats, and the Boeing gas-turbine engines (the first to be used in a commercial hydrofoil) are fitted for their lack of noise and vibration. The craft has modern radar and navigational aids.

★ ★ ★

Under an agreement negotiated by the Maritime Administration, US Department of Commerce, the **Grumman Aircraft Engineering Corporation,** Bethpage, has bareboat chartered the hydrofoil ship *Denison* (which they built for the MA) for $1 per year — half of any profit in excess of 10% of expenses to go to the Government. The ship will continue to be available to all elements of the Government and industry for use as a valuable technological resource, although to a large extent the Government's technical goals in sponsoring the building of this ocean-going hydrofoil have been achieved. Propellers, engines and transmissions have been developed, and the ship has performed well in rough water (50 knots in 10 ft waves). The development of the *Denison* was a co-operative project of the Federal Government and industry, the Government paying about one-third of the $9,000,000 cost of building and operating her.

★ ★ ★

There will be no repetition of the experimental hovercraft service between Southsea and Ryde, Isle of Wight, this year. A spokesman for the operating company, **Hovertransport,** said that last year's trial service had been fairly successful, and that the experiment had provided all the research they needed. He added that they hoped to have bigger hovercraft capable of carrying both passengers and vehicles working in the next few years.

★ ★ ★

The **Italian State Railways** have taken over the hydrofoil service operating across the Straits of Messina between Reggio Calabria and Messina. The two PT.20 type hydrofoils formerly in service have been replaced by the larger PT.50 which carries 140 passengers compared to the previous seventy. Port improvements at a cost of £46,000 are to be carried out at Reggio Calabria.

NEW YORK CITY AND THE AIR CUSHION VEHICLE — THE CHALLENGE TO THE ENGINEER

J. B. Chaplin

Asst. Chief Engineer,
Integrated Systems Engineering Department,
Bell Aerosystems Company

W. J. Eggington

Chief A.C.V. Preliminary Design,
Bell Aerosystems Company

SUMMARY

The paper discusses the problems facing the engineer in developing the air cushion vehicle for passenger transportation, with particular reference to the New York City area.

The stages of development of the ACV are traced from its conception, through its present status, to large-scale passenger operation. Three sizes of ACV are applied to New York City routes and fares are presented in terms of the main operation parameters.

An analysis is given of the relative effect of engineering advances in reducing passenger fares. The results of this study show that improvements in craft durability and power requirements are the most promising and effective engineering fields of development. Some consideration is given to the form that such developments will take and their probable effects on the economics of ACV operation. It is concluded that the engineer has the opportunity of developing the ACV from limited operation on selected routes to a major means of transportation.

Introduction

The purpose of this paper is to analyse the challenge to the engineer of developing the air cushion vehicle into a major form of transportation. As a passenger-carrying craft the ACV has progressed through operational feasibility to passenger acceptance. In taking the craft through these stages of development the engineer has had to solve many problems to reach acceptable standards in stability, control, reliability, performance and many other aspects of operation.

In the next phase of development the engineer is faced with two main tasks. The first is to be capable of solving any new problems as they emerge during design and operational development. The second is to continue the development of the vehicle characteristics beyond the present acceptable standards to attain the best possible economic operation. Planning of the first task must wait until the problems arise and therefore this paper is concerned only with the task of improved economic operation.

No attempt is made to speculate upon the form of the future ACVs which will be operating in ten to twenty years from now or on the conceivable applications of such craft. Consideration is given only to foreseeable developments of vehicles typical of the present state-of-the-art and whose performances can be substantiated with existing data.

Transport System Development

All transport systems tend to follow a similar evolution or development method. In Fig. 1, the basic steps and achievement levels of this evolution are shown. An analysis of systems such as the aircraft or train will identify the stages of development shown. However, extenuating circumstances such as war have caused and supported the premature jump to the ultimate military applications.

The first step after the initial conception or invention is to establish the technical feasibility of the concept. The theoretical and experimental work required for this is quantitative as well as qualitative. The nature of this initial programme is dependent upon the type of vehicle, but broadly consists of a preliminary evaluation of performance, stability, control, model research and preliminary application studies.

Once the technical feasibility is established there is a marketing effort required to provide a preliminary assessment of the market potential and the possible customer requirements. Meanwhile the engineer is planning the next development stage phase, the operation of a full-scale research vehicle or vehicles, depending upon the complexity of the vehicle and the proposed application. This vehicle usually has a demonstration role in addition to the engineering requirements and the design is therefore frequently compromised.

The second generation of full-scale vehicles are usually built to establish the transport efficiency in general terms relative to other vehicles. Operational research testing is carried out for this purpose. Realistic production and operating costs are obtained. It is at this point that the military and the civil transport systems operate along independent paths. It is important to note that from this time the military development usually leads the civil.

In the military field the simulated operations are carried out using prototype vehicles in conjunction with existing military systems prior to the production vehicles going into service.

In the civil field the next step is to carry out complete but limited operations on realistic routes with production vehicles and potential operating companies. Clearly, a substantial investment is required for this phase and the operator may or may not show a profit. This is the point where official organisations such as the HHFA can take part in the development by providing financial subsidies for the application experiments.

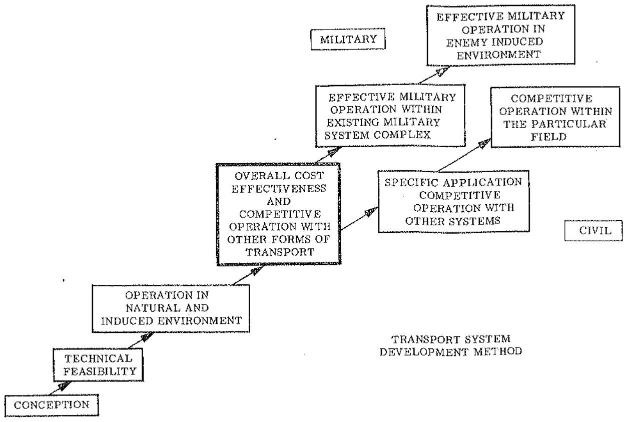


Figure 1

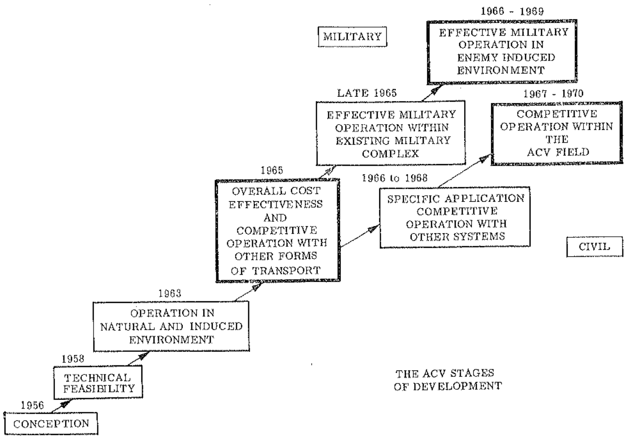


Figure 2

The initial results of these experiments often benefit from the novelty appeal of a new type of vehicle and the fact that the vehicle is operating over a carefully selected type of route. On the other hand, either a direct competitor or an unestablished transport requirement has to be contended with, together with the operational problems of the new vehicle. Under normal circumstances this phase would take one to two years.

Finally, the vehicles are put into operation on an intended permanent basis. All the calculations have been made to ensure success. The vehicle design and traffic patterns along the selected routes are carefully matched. In many cases a future expansion of the traffic is predicted and relied upon. Selection of the routes may depend upon any one of the following: traffic requirements including seasonal or hourly peaks, weather and waves, efficiency of competitive vehicles and the terminal facilities required and available.

It is at this stage that the primary task of the company producing the particular vehicle changes emphasis from establishment of the product line to sales competition within the vehicle industry.

The Air Cushion Vehicle Development

In order to establish the challenge to the engineer in the ACV field it is necessary to establish the stages of development as defined in the previous section.

Patents as early as the beginning of the century have been described as evidence of the original conception of the ACV. This may be true and of interest to the patent attorney in his attempt to establish the legal position. The principle of the air cushion vehicle was conceived prior to 1956.

The step to technical feasibility was through the British Ministry of Supply analysis work, the British National Research and Development Council funded SR.N1 vehicle and the US Office of Naval Research work. Technical feasibility was established in 1958.

The SR.N1, SR.N2, VA.1, VA.2, VA.3, BAC SK3 and the US Navy SKMR-1 vehicles established through test programmes the environmental operational capability by 1963.

Operational research tests of the US Navy SKMR-1, including the amphibious ASW and long-range missions, the British Navy testing of the SR.N3 and the civil experimental operations in Great Britain with the SR.N2, SR.N5 and the VA.3 have shown that by 1965 the ACV was competitive with other forms of transport. This is the present stage of the ACV.

For the military application the US Navy trials at Norfolk and the British Inter-Services Hovercraft Trials Unit tests with the Fleet and in the Far East will establish the feasibility of effective military operation by the end of 1965. It is the authors' opinion that full military effectiveness under enemy-induced environment will be achieved in the period 1966 to 1969.

In the continuation of the civil development one of the significant factors will be the HHFA-sponsored application experiment at Oakland, California. Two SR.N5 fifteen to twenty passenger vehicles will be used on the routes at present serviced by the SFO helicopters. These routes are between San Francisco, Oakland and the two city airports. Another development will take place in Great Britain where the final decisions are now being made for the establishment of car and passenger services across the English Channel and on domestic routes such as the Solent to the Isle of Wight.

By 1966 to 1968 the ACV will be in coupetition with other forms of transport on specific route applications.

The increasing customer requirements for ACVs to be used on new routes will by 1967 to 1970 lead to competition within the ACV industry.

The Present Stage

The present stage can be defined by:

(a) Consideration of the present vehicles and the operational achievements,

(b) Analysis of the possible application of vehicles representative of the present state-of-the-art on specific route applications.

The Present Vehicles

Some of the most significant air cushion vehicles are shown in Figs. 3 to 6. The US Navy SKMR-1 is a 28-ton annular jet vehicle now fitted with 4 ft flexible trunks. It was built to accumulate research data for the design of future Navy ACVs. At the present time this vehicle is undergoing Navy operational evaluation tests at Norfolk, Virginia. It has demonstrated the unique capabilities of ACVs in amphibious warfare and other Navy missions. Vehicles of this size can operate in gale force wind and sea conditions and still maintain their considerable speed advantage over other surface craft.

At the other end of the size range is the rugged 2-ton BAC SK.3 plenum Tri-cell vehicle. This small utility ACV has operated successfully in the marshes and shallow waters of Lake Okeechobe, Florida, and in contrast 700 miles from the North Pole over the Greenland Ice Cap. During this winter the vehicle has also operated over the frozen Lake Erie, traversing ice pressure ridges and open expanses of open water without serious icing.

The Westland SR.N5, now to be built under licence in the USA by Textron's Bell Aerosystems Company as the SK5, is the first ACV to go into quantity production. SR.N5s are now operating in Norway, Germany, Great Britain, Japan, Borneo and the USA. The US Navy operational test programme includes evaluation of the SR.N5, while two of the vehicles will be used in the HHFA Port of Oakland experimental application beginning this summer.

Specific Application Analysis

The analysis of the vehicle potential can be made on a broad parametric basis. Non-dimensional parameters can be devised in attempts to reduce the operational characteristics to

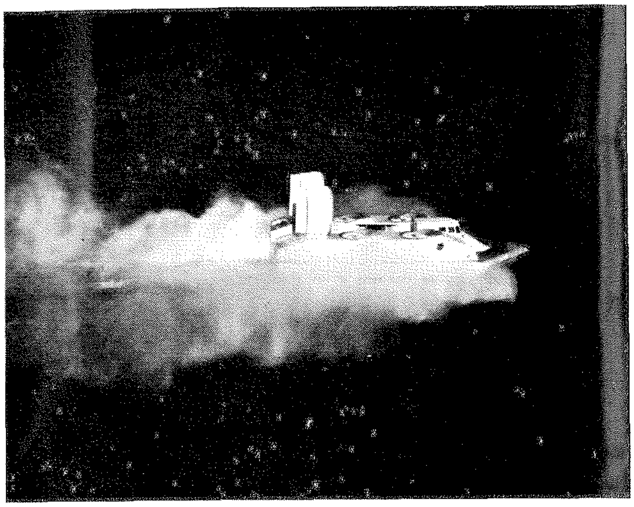


Figure 3. SKMR-1 at Norfolk

unique values suitable for comparison with other known transport systems. The result of such an analysis can be important in determining the over-all competitive position of a new system and the most advantageous application. However, it is difficult to determine from the results any guidance to the most profitable avenues into which the engineering effort should be channelled, with the present state of development shown in the previous section.

A more suitable method to derive this information is the detailed specific application analysis. The contributing factors to the direct operating costs can be determined and the effect of the operational factors and the vehicle characteristics evaluated.

In the commercial field one of the most suitable applications is that of mass transit in cities such as New York. In many cases there are large rivers or waterways close to the city with access to the centre of downtown. Many of the suburban housing areas are close to the water, while the major airports are often built on surrounding reclaimed land.

For this paper the New York area application has been selected and the use of three different types of vehicle analysed. The vehicles considered are:

(a) A twenty-passenger annular jet vehicle fitted with 4 ft flexible trunks (Fig. 7),
(b) A ninety-passenger plenum multi-cell vehicle fitted with 3 ft flexible skirts (Fig. 8),
(c) A 600-passenger annular jet vehicle fitted with 7 ft flexible trunks (Fig. 9).

The twenty-passenger and the 600-passenger vehicles with flexible trunks have the maximum performance for ACVs of that particular size. The ninety-passenger vehicle does not have the maximum performance possible for a vehicle of its size but because of the simplicity of the plenum concept it is a relatively low-cost vehicle.

The SR.N5 represents the twenty-passenger vehicle size discussed in this paper and has demonstrated all the performance capability assumed. The ninety- and 600-passenger vehicles are at the present time at an advanced state of design with detailed analysis and model test data to substantiate the assumed performance.

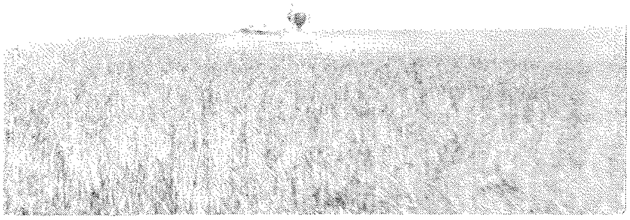


Figure 4. SK-3 on Strawberry Island

Figure 5. SK-3 at Greenland

All three vehicles are powered by gas turbine engines, constructed of aluminium, and represent the present state-of-the-art. The performance of these vehicles as speed against wave height is shown in Fig. 10. All the vehicles would be capable of ranges in excess of 150 miles with full payload. The prediction of this performance is based upon full-scale and towing tank test data.

The East River, the Hudson River, Newark Bay, Upper Bay and the Long Island Sound provide ideal natural hoverways for these craft. The Hudson River or the Long Sound are excellent waterways for short-range applications such as the airport service or longer-range mass transit. The twenty- and ninety-passenger craft would be confined to the rivers and bays in order to guarantee operation for 95% of the time during the whole year. The 600-passenger vehicle could in addition to these areas operate in the Long Island Sound or through the Verrazzano Narrows to Kennedy International Airport. The floating debris in the East and Hudson Rivers would be no problem to these craft. The passengers would sit in bus-like seats without seat belts since the maximum accelerations, even those due to a high-speed power failure, will not be sufficient to throw them out of the seats. While the craft will respond to waves, the motion will not be unpleasant due to the softness of the air cushion system. The lack of any wave or wake when at speed will allow the vehicles to maintain their cruise speed even when close to other shipping or shore installations.

It is important to note that all the ACVs will not be suitable for all the possible routes in the New York area. Acceptance of the vehicle's limitation is just as important as the exploitation of its capabilities. Some of the earlier prognosticators of the ACV's future have in their enthusiasm ignored this fact and presented the ACV as a wonder vehicle. The development of the ACV has not benefited from such presentations.

As an example of this, the run from downtown Manhattan to Kennedy is not a good application for the smaller vehicles. The journey by water is longer than overland and the sea conditions possible in the Lower Bay and along the South Atlantic coastline would be beyond the capability of the vehicles.

For the purpose of this paper two routes have been selected as typical of those where the full potential of the ACV can be

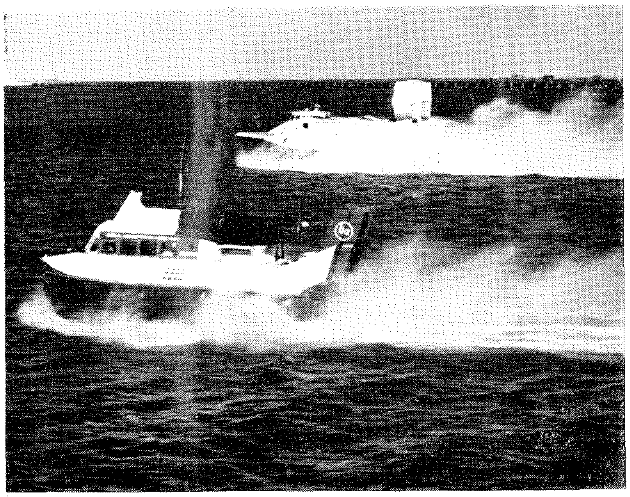


Figure 6. SR.N5 with SKMR-1 at Norfolk

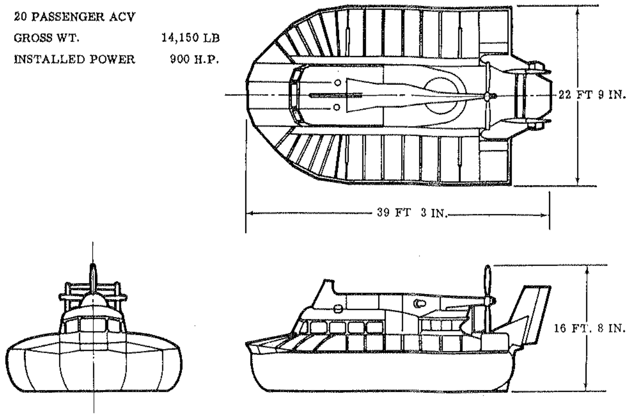
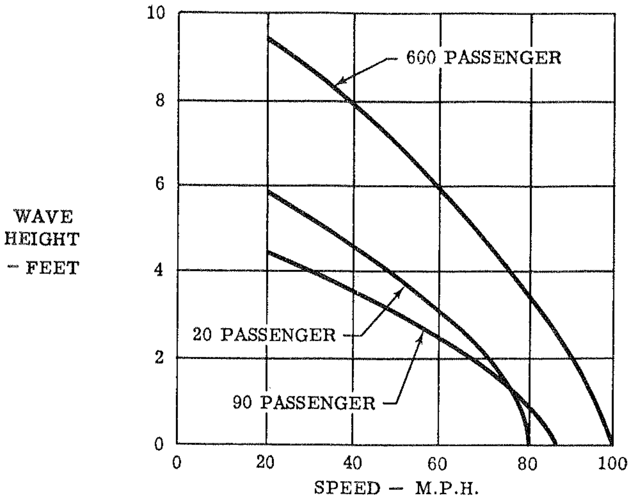


Figure 7



ACV OVERWAVE PERFORMANCE

Figure 10

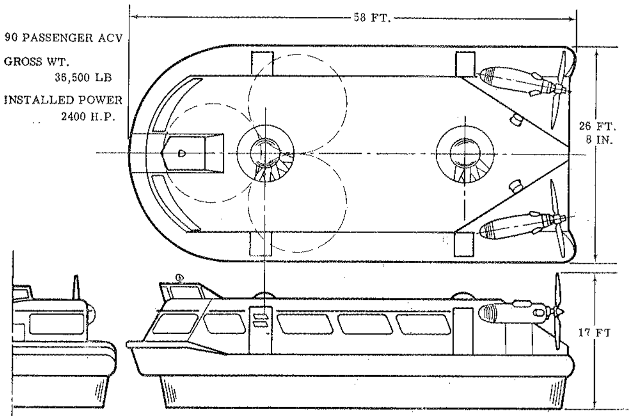


Figure 8

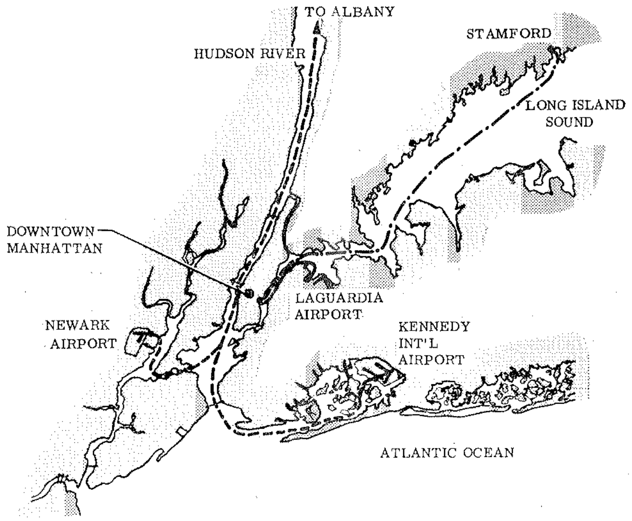


Figure 11

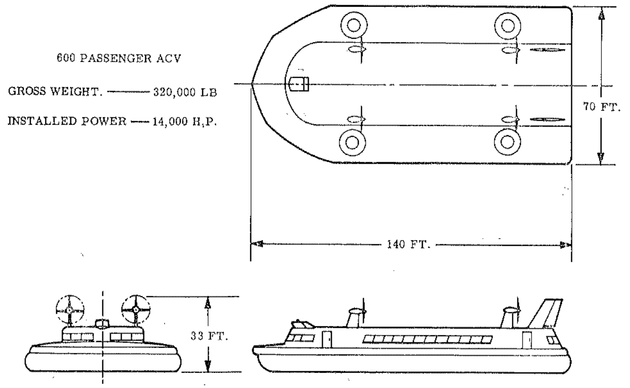


Figure 9

BASIC DATA

STAGE LENGTH	8 MILES
BLOCK TIME	10 MINUTES
TERMINAL TURN AROUND TIME	5 MINUTES
TIME FOR ROUND TRIP	30 MINUTES
VEHICLES USED	5

SCHEDULE

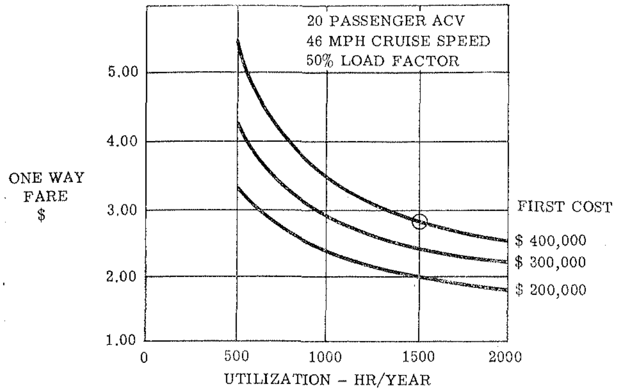
NORMAL DAYS	340
6 AM TO MIDNIGHT	20 MINS FREQUENCY
MIDNIGHT TO 6 AM	60 MINS. FREQUENCY
PEAK TRAVEL DAYS	25
6 AM TO MIDNIGHT	10 MINS. FREQUENCY
MIDNIGHT TO 6 AM	30 MINS. FREQUENCY

VEHICLE AVAILABILITY

ROUTINE MAINTENANCE	50 DAYS
SCHEDULED SERVICE	200 DAYS
STANDBY	112 DAYS
UTILIZATION	1520 HOURS

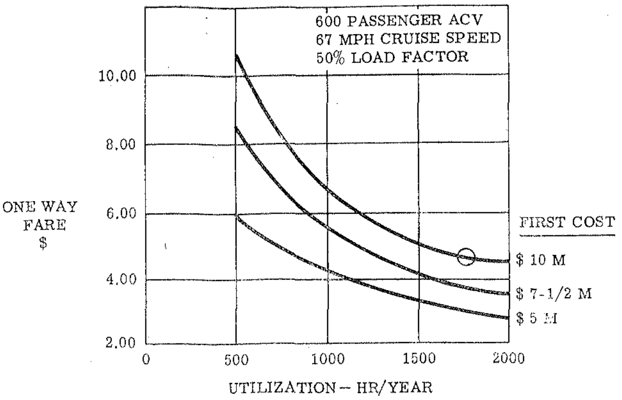
ACV SERVICE MANHATTAN TO LA GUARDIA AIRPORT

Figure 12



DOWNTOWN TO LA GUARDIA FARE — 8 MILE STAGE LENGTH

Figure 13



DOWNTOWN TO STAMFORD FARE — 30 MILE STAGE LENGTH

Figure 15

utilised. The twenty- and ninety-passenger craft have been considered on the Downtown Manhattan to La Guardia Airport route as feeder services to the airline traffic. The 600-passenger vehicle has been evaluated on the mass transit route from Manhattan to Stamford.

The Downtown-La Guardia Route

A regular scheduled operation has been assumed as shown in Fig. 12. For both the twenty- and the ninety-passenger vehicles, five vehicles will be used and a twenty-four-hour service provided. During all the operations at least one vehicle will be available as a standby, only three vehicles being necessary for normal travel day operation and four for the peak travel days. Night operation has already been proven to be feasible with ACVs and high-power lights and radar will generally be standard equipment in the future. Normal daytime operation of the smaller craft will require only one crew member, a second member being necessary only for night or limited visibility operation with radar.

It should be noted that the utilisation per vehicle of 1,500 hours per year is within the capability of vehicles now in operation.

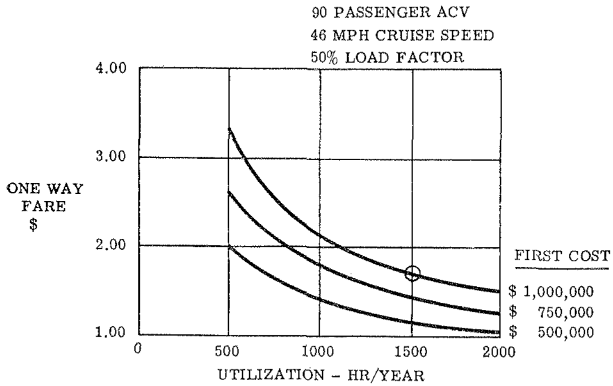
The variation of the one-way fare with utilisation and first cost of the vehicle is shown in Fig. 13 for the twenty-passenger vehicle and in Fig. 14 for the ninety-passenger. This fare covers the direct operating costs, the indirect operating costs which are assumed to be 50% of the direct, and a normal profit margin. In each case a point has been marked as representative of the present state-of-the-art.

It has been assumed for both vehicles that the traffic would allow a 50% load factor. It is obvious that the selection of one craft in preference to the other would depend on an analysis of the traffic demands.

A simple 60-80 ft wide ramp with a slope of one in ten would be required at the La Guardia Airfield to give access from the river. Some form of hoverway would be required to enable the craft to unload at the terminal building. This hoverway would be separate from the normal taxiways, but because of the low ground pressure of the vehicles it would not be expensive to construct or maintain. No passenger stairs or ramps would be necessary.

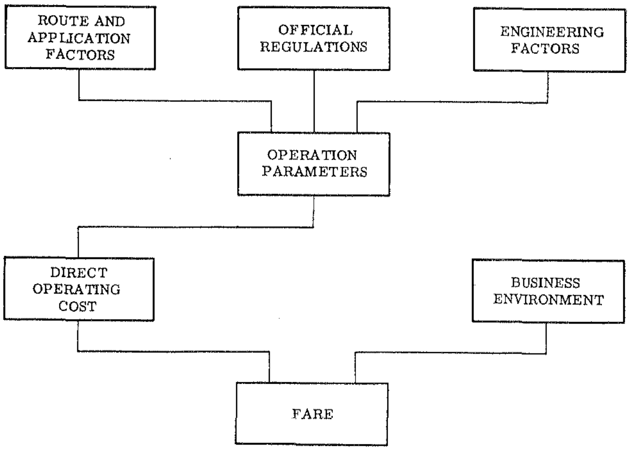
At the Downtown Manhattan terminal a large floating dock or barge would be used with a sloping end so that the ACV could drive up out of the water. A terminal building with ticket offices, waiting rooms, etc, would be required. A maintenance facility ideally at the airport would consist of one large hangar, the only major equipment necessary being a large crane or travel hoist to lift the vehicles for inspection of the trunks or skirts and for maintenance.

For each of these vehicles the fare indicated in Figs. 13 and 14 is conservative. It is considered that these fares could be achieved within the present state-of-the-art and the demonstrated operational capabilities of the vehicles. The first costs of $400,000 for the twenty-passenger and $1,000,000 for the ninety-passenger should be attainable with a limited production run when built in the USA. The influence of first cost and *increased utilisation is significant. Halving the first cost and* increasing the utilisation by 30% would decrease the one-way fare for the twenty-passenger vehicles from $2.86 to $1.85 and for the ninety-passenger vehicle from $1.72 to $1.08. Although the ninety-passenger vehicle appears to be the more competitive, the passenger traffic flow variation and the required frequency of service must influence the final selection of the vehicle.



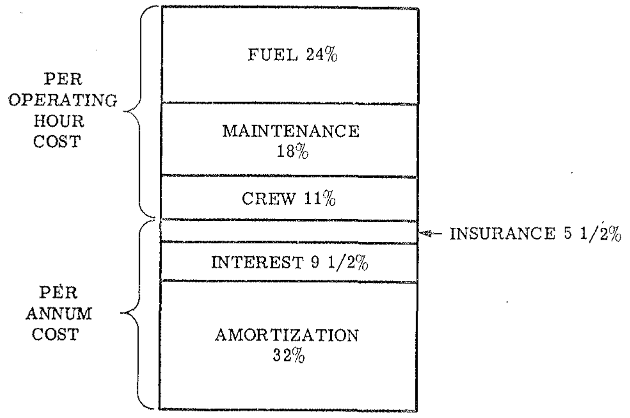
DOWNTOWN TO LA GUARDIA FARE — 8 MILE STAGE LENGTH

Figure 14



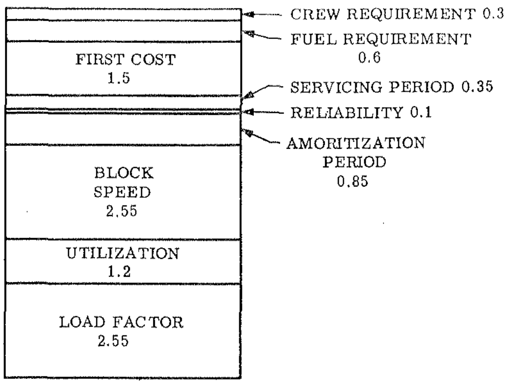
FACTORS INFLUENCING PASSENGER FARE

Figure 16



RELATIVE SIZE OF D.O.C. COMPONENTS

Figure 17



DIRECT EFFECTS OF OPERATING PARAMETERS ON D.O.C.

Figure 19

The Downtown-Stamford Route

Although the airport route application is the more immediate, the longer route application for mass transit could in the long term be the most significant. For the megatropolis of the type forecast to develop from Boston to Baltimore or San Francisco to Los Angeles the waterways could be an important transport system. The large ACV with its speed capability is the ideal vehicle for this application, either for passenger or automobile transporters.

As an example of this application a 600-passenger vehicle operating on the Downtown Manhattan to Stamford route has been considered. Analysis of the sea state data shows that the vehicle could operate and maintain the cruise speed of 67 mph for 97% of the time anywhere in the Long Island Sound. During the remaining 3% of the time it would have to reduce speed but would still be able to operate. Since the route considered is over the south-western landlocked end of the Sound, it is reasonable to assume that an even higher operating capability than this would be possible. It is of interest to note that while the two smaller vehicles are not proposed for this application, the ninety-passenger would be able to maintain its cruise speed of 46 mph for 83% of the time and the twenty-passenger for 87% of the time. During rough weather, however, the passengers would not have as comfortable a ride in the smaller vehicles as they would in the 600-passenger vehicle.

The one-way fare variation with first cost and utilisation is presented in Fig. 15. Because of the increased stage length a higher utilisation can be realised than for the La Guardia operation. As in the previous example, a conservative fare value for the present state-of-the-art has been indicated.

The Challenge to the Engineer

In this section consideration is given to the influence that the engineer has on ACV operations. Fig. 16 shows the factors that affect the fare paid by the passenger. One of the two main factors affecting the fare is the business environment. This includes the indirect cost of the operation, the profit margin being sought and any subsidy that may be placed upon the venture. The other factor is the direct operating cost upon which the engineer has significant control.

It is not possible, however, to directly relate the factors that the engineer controls with the breakdown of the DOC. In order to show the dependency it is necessary to consider an intermediate group of parameters which may be called the "operation parameters". These comprise the following:

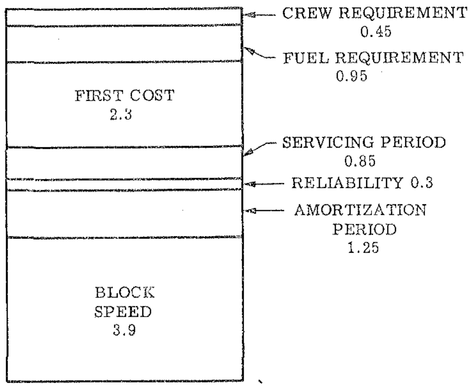
Load factor
Utilisation
Block speed
First cost
Fuel requirement
Amortisation period
Servicing period
Reliability.

Some of these influence the DOC directly and others both directly and indirectly. The only operation parameter upon which the operator has a dominant effect and the engineer practically none is the load factor. With regard to the other operation parameters there is a significant engineering influence. The engineer does not have complete control, of course, for factors associated with the application and official regulations do provide limitations. For example, operation through

OPERATION PARAMETER	D.O.C. COMPONENTS					
	AMORTIZATION	MAINTENANCE	FUEL	CREW	INSURANCE	INTEREST
LOAD FACTOR	X	X	X	X	X	X
UTILIZATION	X				X	X
BLOCK SPEED	X	X	X	X	X	X
FIRST COST		X			X	X
FUEL REQ.			X			
CREW REQ.						
AMORTIZATION PERIOD	X		X			
SERVICING PERIOD		X				
RELIABILITY		X				

RELATIONSHIPS BETWEEN OPERATION PARAMETERS AND D.O.C. COMPONENTS

Figure 18



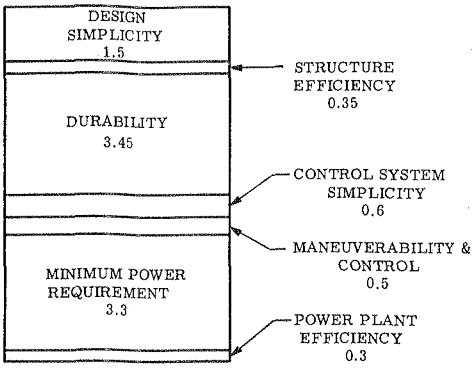
EFFECTS OF OPERATION PARAMETERS UNDER ENGINEER'S INFLUENCE

Figure 20

ENGINEERING FACTOR	OPERATION PARAMETERS BLOCK SPEED	FIRST COST	FUEL REQ	CREW REQ	AMORTI-ZATION PERIOD	SERVICING PERIOD	RELI-ABILITY
DESIGN SIMPLICITY		X					X
STRUCTURAL EFFICIENCY			X				
DURABILITY					X	X	X
MANEUVERABILITY AND CONTROL	X		X	X			
CONTROL SYSTEM SIMPLICITY				X			
MINIMUM POWER REQUIREMENT		X	X				
POWER PLANT EFFICIENCY			X				

INFLUENCE OF ENGINEERING FACTORS UPON OPERATION PARAMETERS

Figure 21



RELATIVE SCOPE OF ENGINEERING DEVELOPMENT FOR D.O.C. REDUCTION

Figure 23

other traffic limits the craft's cruising speed. The manner in which the engineer affects the operation parameters is through "engineering factors" which are directly related to the operation parameters. The main engineering factors are:

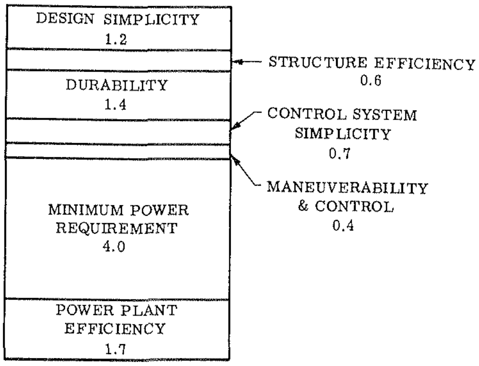
Design simplicity
Structural efficiency
Durability
Manoeuvrability and control
Control system simplicity
Minimum power requirement
Power plant efficiency.

Certain factors such as cabin design have been excluded as their effects were found to be very small in terms of offering significant improvements in DOC.

An analysis follows of the effects of engineering factors upon the fare through the operation parameters and direct operating cost components. The operation of the twenty-passenger ACV on an eight-mile stage length is used as a basis. The objective of this analysis is to determine the engineering advances that have the most significant effects on the fare.

In Fig. 17 the direct operating cost is broken down into components. In terms of the most efficient operation with present-day ACVs this breakdown is typical. Some differences would occur with larger craft as with longer stage lengths, for example. It is significant to note that, as indicated in Fig. 17, certain of the DOC components represent a cash outflow on a "per annum" basis while the remainder are an outflow on a "per operating hour" basis.

Now where there is a relationship between a DOC component and an operation parameter, it is indicated in Fig. 18. It is seen that both load factor and block speed affect all the DOC components. This is because any improvement in either parameter increases the number of passenger miles achieved by the craft for the same total direct operating cost. Most of the operation parameters affect only one DOC component. For example, the servicing period only influences the routine maintenance of the ACV which represents about 80% of the total maintenance. The unscheduled maintenance is associated with the reliability of the craft.



RELATIVE EFFECT OF ENGINEERING FACTORS ON D.O.C.

Figure 22

The separate effects of the operation parameters upon the components of direct operating cost are integrated and summarised in Fig. 19. The relative strength of each of the parameters is indicated. For example, 1% increase in block speed or load factor has three times the effect on DOC as 1% increase in the amortisation period. This figure shows the direct effects of the operation parameters on the DOC. As mentioned earlier, the engineer has little influence on load factor. Furthermore, the engineer does not influence utilisation directly, but does so indirectly through three other operation parameters — servicing period, reliability and block speed.

The relative effects of the operation parameters directly under the engineer's influence are shown in Fig. 20. Utilisation and load factor have now been eliminated, but the effects of the other operation parameters upon utilisation are included. This figure is very instructive in considering the comparative strength of the operation parameters on DOC. For example, 1% increase in block speed is equivalent to approximately 4% decrease in the fuel requirement. An important fact to bear in than others. A substantial improvement in reliability, for example, will be more forthcoming than a corresponding improvement in block speed for a given application.

Now consider the engineering advances that can realise improvements in the operation parameters. The main individual relationships between the engineering factors and the operation parameters are shown in Fig. 21. There are many secondary inter-relationships that are not indicated on the figure. For example, design simplicity can have beneficial effects upon both amortisation period and servicing period. These effects are small, however, compared with the effect of design simplicity upon first cost. Again, all the indicated relationships are not comparable. For example, durability has a significantly greater effect on reliability than design simplicity does. Furthermore, a reduction in the power requirement is far more effective than an improvement in manoeuvrability and control in terms of reducing the fuel requirement.

Integrating the major relationships shown in Fig. 21 together with minor relationships not shown, the strength of each engineering factor upon DOC is evaluated. The relative strength is shown in Fig. 22. This figure shows that a 1% reduction in power is more powerful in reducing DOC than a corresponding improvement in any of the other engineering factors.

It must be noted that in the analysis each engineering factor is considered in isolation, i.e. an engineering advance is taken for each of the factors in turn, with the state-of-the-art assumed unchanged for the remaining factors. In practice a compromise is sought between minimum power requirement and first cost — small craft having a relatively large power requirement with

POWER REQUIREMENT	ASSOCIATED WITH	DEVELOPMENT	COMPONENTS
LIFT SYSTEM	a) CUSHION AIR DISCHARGE	i) SMALL CLEARANCE ii) EFFICIENT AERODYNAMIC SEALING	TRUNKS NOZZLE
	b) INTERNAL EFFICIENCY	i) EFFICIENT FAN ii) LOW-LOSS DUCTS	FAN AIR DUCTS
MOMENTUM DRAG	CUSHION AIR DISCHARGE	i) SMALL CLEARANCE ii) EFFICIENT AERODYNAMIC SEALING	TRUNKS NOZZLE
TRUNK DRAG	TRUNK/SURFACE CONTACT	IMPROVED TRUNK RESPONSE	TRUNKS
PROPULSION SYSTEM	PROPULSIVE EFFICIENCY	HIGH $\frac{\text{THRUST}}{\text{POWER}}$	i) PROPELLER ii) CUSHION AIR THRUST SYSTEMS

POWER REDUCTION DEVELOPMENTS

Figure 24

COMPONENTS

MAIN STRUCTURE
ENGINES
TRANSMISSION
FANS & PROPELLERS
TRUNKS
SYSTEMS

REQUIREMENTS

RELIABILITY
LONG LIFE
LOW ROUTINE
MAINTENANCE

ENVIRONMENT

NATURAL	INDUCED	OPERATIONAL
TEMPERATURE	SPRAY	SEA STATE
WINDS	DUST	EMERGENCIES
HUMIDITY	VIBRATION	TERMINALS
	NOISE	OTHER TRAFFIC

DURABILITY FACTORS

Figure 25

low first cost and larger craft requiring less power but having a higher first cost. When dealing with minimum power requirement, an engineering advance resulting in a reduction in power for a given size of craft is considered. Having made such an advance, a different compromise between power and first cost may be sought.

As mentioned earlier there is a difference in scope in achieving each of the engineering advances from the present state-of-the-art. This is because some components are more developed than others. The efficiency of power plants, for example, has received considerable attention and is well advanced compared with the durability of the flexible trunks. In consequence the engineer may more profitably direct his efforts to areas in which the increased scope could more than offset the apparent lower effect on DOC as derived above. Each of the engineering factors given in Fig. 22 has therefore been allotted a "scope factor" which is a measure of the scope that the engineer has in improving each of the factors. The scope factor is a relative term and has been determined by defining the present scope in reducing the power requirement as the base with a value of unity. The factors are as follows:

Minimum power requirement	1.0
Design simplicity	2.0
Structure efficiency	0.4
Durability	3.0
Manoeuvrability and control	1.5
Control system simplicity	1.0
Power plant efficiency	0.2

Applying the above scope factors to the numbers representing the relative strength of engineering advances given in Fig. 22, a measure is obtained of the relative scope in each of the ACV engineering developments as a means of reducing direct operating cost. The values obtained as a result of this are shown in Fig. 23. This figure shows quite clearly that the most profitable areas are improvements in durability and power requirement. Durability is an example of considerable engineering scope applied to a relatively minor part of the DOC, whereas minimum power requirement has reduced scope but affects a large proportion of the DOC. These two areas represent the real challenge to the engineer in his attempt to improve the operating economics of the ACV. The only other area that shows promise of significant improvement is the introduction of design simplicity. The main scope here is to reduce the number of parts, standardise parts and simplify attachments. With regard to the other factors, engineering efforts must be applied, of course, as new designs emerge and requirements change. No degradation can be afforded in these fields, other than that of compromise as a result of changes in the trade-offs between engineering factors.

Going back to the two most profitable areas of engineering development, consideration is now given to specific objectives. In Fig. 24 the various ways are shown in which ACV power requirements can be reduced. The power improvements included are the lift system, momentum drag, trunk drag and propulsion system. Other components of power are wave-making drag and aerodynamic profile drag, but it is felt that there is less scope in reducing these. However, as the lift system efficiency is improved and the craft speed increases, the engineer could find that aerodynamic profile drag has become significant and that more effort would be required to improve the aerodynamic shape of the vehicle.

In the lift system, the power used is dependent upon the volume of air flowing through, the blade efficiency of the fans and the air pressure losses in the system. The volume of air may be reduced in two ways. One way is to reduce the clearance between the trunks and the surface over which the craft is operating and the other way is to develop more efficient means of aerodynamically sealing this clearance. In order to achieve these objectives, further developments of the trunk, and its nozzle in particular, are required. In addition such developments automatically reduce the momentum drag, which is in proportion to the volume of air used in the lift system. Reduction in duct losses can best be accomplished by fully utilising the space available both in the hard structure and the trunks themselves. Structural members and other obstructions in the ducts must be minimised and well designed. To obtain maximum internal efficiency the integrated fan/duct system must be treated as one.

The intermittent contact of the trunks and the surface when operating over waves and other undulations is a source of performance degradation. Reduction in the amount of contact also increases the life of the trunks and reduces craft motion. Very sophisticated systems have been proposed to reduce trunk contact, such as sensing waves ahead and actuating the trunk before the wave arrives. There is much that can and has been done, however, to reduce contact by trunk design alone without incorporating a servo system.

	PRESENT ACV	DEVELOPED ACV
STAGE LENGTH	8 MILES	8 MILES
NO. OF SEATS	20	30
FIRST COST	$ 400,000	$ 400,000
POWER	900 H.P	900 H.P.
BLOCK SPEED	46 MPH	50 MPH
UTILIZATION	1500 HOURS	1800 HOURS
LOAD FACTOR	0.5	0.5
DIRECT OPERATING COST		
AMORTIZATION	0.45	0.23
INTEREST	0.13	0.07
INSURANCE	0.08	0.04
CREW	0.15	0.10
FUEL	0.34	0.17
MAINTENANCE	0.25	0.13
TOTAL DIRECT OPERATING COST	1.40	0.74
INDIRECT OPERATING COST	0.70	0.60
PROFIT	0.76	0.61
FARE	2.86	1.95

EFFECT OF ENGINEERING DEVELOPMENT ON OPERATING ECONOMICS

Figure 26

In the area of propulsion systems the two most promising approaches are the air propeller and an integration of the lift and propulsion systems. Air propellers are well developed and their accommodation on ACVs is a compromise between thrust, control, noise, erosion and protection against other bodies. Use of the lift fans to provide propulsion thrust has many attractions and a number of ACVs have been built that use the principle. There is appreciable scope in developing such systems to be more economic in terms of power requirement and control.

Durability of all the ACV components is the other major area of engineering development to reduce direct operating cost. Improvements in reliability, life and routine maintenance are required. Fig. 25 contains some of the factors that ACV components have to withstand in normal operation. The environment is split into three parts:

(i) the natural environment, which obtains in the absence of craft and has to be endured by all craft,

(ii) the induced environment, which is due directly to the operation of the ACV,

(iii) the operational environment, which is associated with the particular application and route.

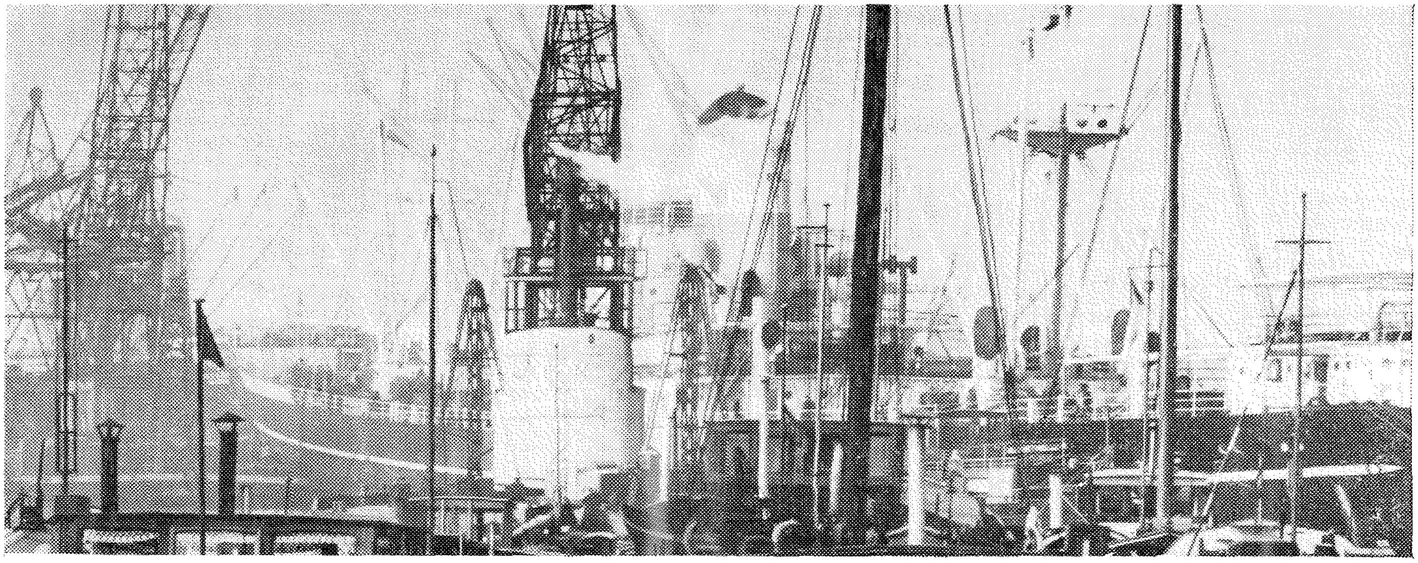
Of the ACV components listed in Fig. 25 for which maximum durability is required, the flexible trunks are in greater need than the other components. This is because the trunks are subjected to the bulk of the contact with other bodies, as is the tyre of the motor car and the track of the tank. Further, the trunk was developed specifically for the ACV and is in a relatively early stage of development compared with the tyre. Engine ingestion of dust and salt and propeller erosion are problems that have been solved for other vehicles, but in which there is scope for improvement as far as ACV operation is concerned.

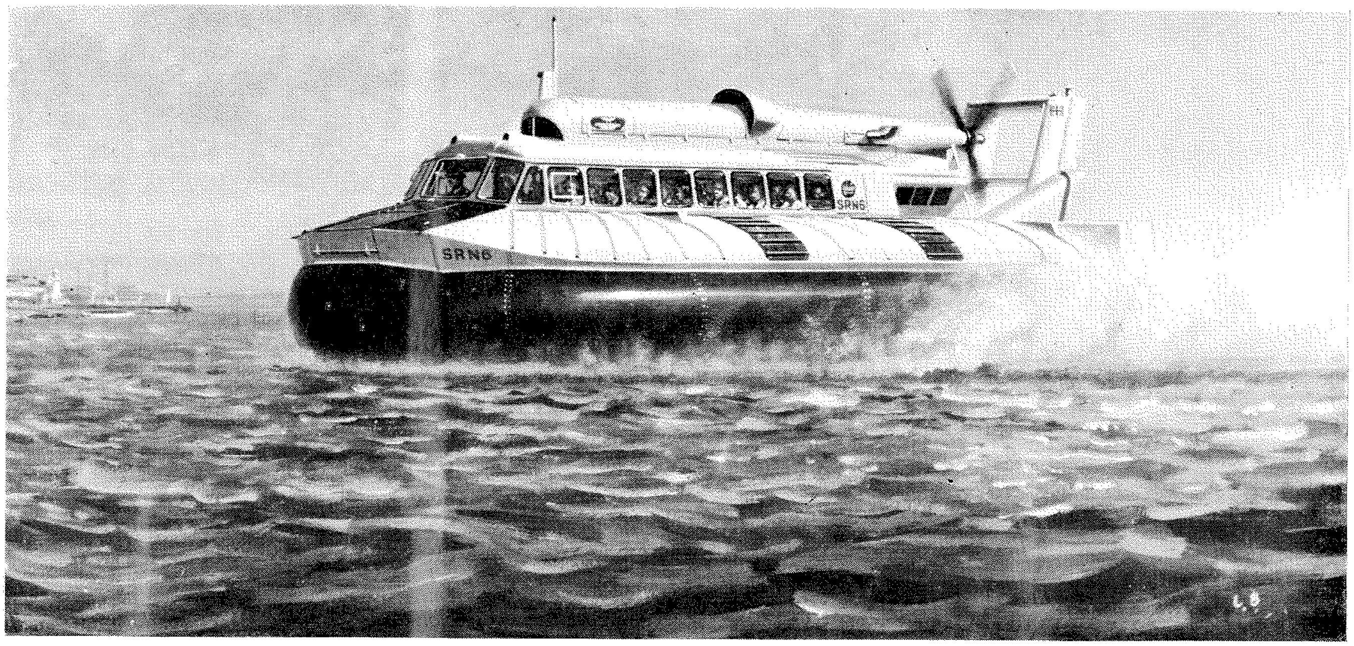
It is interesting to speculate on the probable effect of engineering developments on the operating economics of the ACV. In Fig. 26 operating data for the twenty-passenger craft operating on an eight-mile route are again shown. This craft is in existence and could achieve these values right now. From present technology this craft could be developed into a thirty-seat ACV with the improvements in operating cost as shown in the second column of the figure. Note that the fare is reduced from $2.86 to $1.95. Further, the return on investment before tax is increased from 20% to 30%. These improvements in operating economics have come about by building a craft of $1\frac{1}{2}$ times the capacity for the same first cost and power and with some improvements in block speed and utilisation.

It is felt that as a result of research and development programmes now in progress, further substantial improvements could be made, particularly with respect to durability in the improvement of utilisation and the reduction of maintenance cost. A fare of about $1.50 is foreseen for an eight-mile trip using a craft of this size. If the traffic requirements were such that larger craft could be employed without a drop in load factor, then fares of $1.20 or less could well be achieved.

In conclusion, the authors feel that the ACV represents a real challenge to the engineer in the next few years. This craft has proved its operational capability, which is unique among surface vehicles. Passengers have readily accepted it and there can be little doubt that five years from now will see a number of these craft carrying passengers throughout the world on similar routes to Manhattan to La Guardia. The achievements of the ACV engineer in the next few years will decide whether these craft will have a minor role in passenger transportation similar to that of the hydrofoil and helicopter today on selected routes, or whether its role will be a major one comparable with the ship and the aircraft. In the opinion of the authors the latter will be the case.

This paper was presented to the Metropolitan Section of the Society of Automotive Engineers at New York on March 18th,





WESTLAND'S NEW HOVERCRAFT

ON March 2nd, 1965, Westland Aircraft Ltd announced the addition of SR.N6 to their existing range of hovercraft. This thirty-eight-passenger vehicle is specifically directed at meeting the needs of passenger ferry routes. Scanhover of Oslo (who took delivery of an SR.N5 on April 5th) have already ordered an SR.N6 for delivery in June this year.

The SR.N6 is developed from the SR.N5 and is powered by a 900 shp Bristol Siddeley "Gnome" gas turbine engine. The first SR.N6 has commenced operating trials and production craft will be ready for delivery from June onwards.

LEADING PARTICULARS

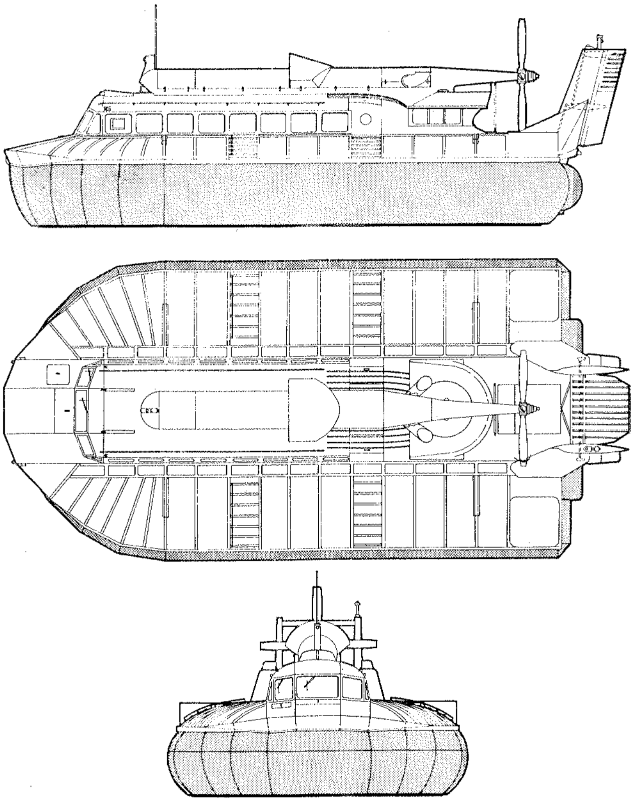
Dimensions	
Over-all length	48 ft 5 in
Over-all beam	23 ft 0 in
Over-all height	17 ft 4 in
Cabin floor area	166 sq ft
Door aperture height	5 ft 9 in
Door aperture width	3 ft 3 in
Power Plant and Systems	
Engine	One Bristol Siddeley "Marine Gnome" engine BS.GN 1051, 900 shp max continuous power
Propeller	One four-bladed variable pitch 9 ft dia Dowty Rotol
Lifting fan	One 7 ft dia centrifugal
Fuel	Standard kerosene
Fuel capacity	265 Imperial gallons
Performance (mean AUW of 17,000-18,500 lb)	
Max speed over calm water	64 knots
Range (still air, calm water, standard tankage)	220 nm
Endurance at max cont power	3.6 hr
Wave clearance at 40-50 knots	4-5 ft
Max height of vertical step or wall	3 ft 6 in
Max height of rounded rock groyne	4 ft 0 in
Max height of grass or shingle bank	6 ft 0 in
Max height of scrub or sapling	7-8 ft
Negotiable gradient, from standing level start	1 in 9

Typical Uses

Primarily as a passenger or general freight carrier

The craft can be readily adapted to a variety of other roles; examples are:

- Search and Rescue
- Fire Fighting Platform
- Weed and Pest Control
- Amphibious Assault
- Coastal Patrol



THE CANADIAN HYDROFOIL PROGRAMME

John W. Milman BSc

Commander R. E. Fisher BASc, RCN

SUMMARY

The history of the Canadian Hydrofoil Programme is outlined starting with the work by Alexander Graham Bell and F. W. "Casey" Baldwin in 1911 to 1920 at Baddeck, Nova Scotia, which culminated with the breaking of the then water-speed record using the HD-4. The work during World War II on Smoke Laying Craft for the Canadian Army is mentioned. The concept of Bell and Baldwin was developed after the war by the Defence Research Board at the Naval Research Establishment at Dartmouth, Nova Scotia. Three craft were built, the 8-ton Massawippi, *the 17-ton* Bras D'Or, *and the 3-ton "Rx" research craft. The design and performance of these craft are discussed.*

The Naval Research Establishment, as a result of its programme, developed a concept for a 200-ton open-ocean hydrofoil ship. The concept was investigated by De Havilland Aircraft of Canada Ltd and their design study conclusions and proposals were endorsed by the Royal Canadian Navy. De Havilland was given a contract in April 1963 to design and construct a Development Prototype Hydrofoil Ship. This paper reviews the NRE concept and the current RCN development programme, including salient features of the FHE 400 prototype ship design.

Highlights of some of the theoretical work and research in the development of the ship are outlined. Considerations in the design of the subcavitating and the superventilating foil sections are also reviewed.

I. HISTORICAL REVIEW OF CANADIAN HYDROFOIL RESEARCH

HYDROFOIL research in Canada has its origins in the work of Alexander Graham Bell and F. W. "Casey" Baldwin at Baddeck, Nova Scotia, during the period 1911-20. Mr Philip L. Rhodes, the well-known naval architect of New York, also contributed to this work by his assistance in the closing phase of experiments. Their research was a development of earlier work by Enrico Forlanini of Italy from 1898 to 1905 and was confined to surface-piercing "ladder" type foil systems.

Experiments by Bell and Baldwin culminated in the development of the "HD-4" hydrofoil. In 1919 this remarkable craft achieved a world water-speed record of 61.5 knots. Over thirty years were to elapse before this record was exceeded by another hydrofoil, the American Grumman XCH-4. The HD-4 was 60 ft long by 5 ft 9 in beam of the main hull, with an all-up weight of 11,000 lb and was powered by two 350 hp Liberty aero-engines driving pusher airscrews. The foil sections were developed empirically by Baldwin and Rhodes. It was claimed that these produced a maximum lift/drag ratio of eight at 30 knots. This dropped to four at 60 knots, indicating that severe cavitation was occurring. See Refs (1), (2), (3) and (4).

Regrettably, little work on this novel concept was conducted after 1920 in Canada until, in 1943, the National Research Council undertook the development of expendable smoke-laying hydrofoil craft for the Canadian Army. These were termed the "Comox" boats. Equipped with surface-piercing foils, these craft were 20 ft in length and were capable of operating at speeds up to 35 knots in wave heights of 6 to 9 ft.[5]

In 1947-49, a 45 ft hydrofoil craft powered by a Rolls-Royce "Merlin" aircraft engine of 1,200 hp was designed by Philip Rhodes, based on the HD-4 experimentation, for Cdr D. M. Hodgson, RCNR, of Montreal. The craft was to be used in an attempt to set a new water-speed record. At about this time, the Defence Research Board (DRB) became interested in the potential naval applications of hydrofoils and the craft was built with some design modifications under DRB direction. It was designated R-100 and named *Massawippi* after Lake Massawippi, Quebec, the site of its construction and first tests. The craft was then shipped to Halifax for further trials and in 1951 the responsibility for the project was transferred to the Naval Research Establishment (NRE) of the Defence Research Board.

Early trials were conducted at all-up weights in the 8,000 to 10,000 lb range. Good performance was achieved at speeds up to about 55 knots. However, it was considered that craft weight in relation to size was not representative of the length/weight ratios for operational naval roles then envisaged for hydrofoils. In consequence, *Massawippi* was ballasted for an all-up weight of 12,000 lb and instrumented for further tests. At this weight, the craft exhibited an instability in pitch associated with cavitation on the foils. It is interesting to note that a similar tendency to porpoise was evident in the HD-4 characteristics.

Concurrent with the R-100 trials, a contract was awarded to Saunders-Roe Ltd of Cowes, Isle of Wight, England, for the design study of a 100-ton hydrofoil craft (designated R-102) for naval employment. The British Admiralty supported a series of model tests for this design study and the investigation of R-100 behaviour. The study concluded, however, that a craft of this size was not feasible within the limitations of power plants and structural materials then available.

In consequence, a further design study contract was established with Saunders-Roe to design a craft (known as R-101), based upon existing materials and power plants. The study considered two versions of a craft of about 80 ft in length, each having an all-up weight of 47 tons, but designed for diametrically opposed proportions of hullborne and foilborne time in their respective missions. One version was an "orthodox" craft, analogous to a "boat that flies", and intended for missions where hullborne operation would predominate (about 80% of mission time). The other version was an "unorthodox" craft, likened to "an aircraft that acts like a boat" and intended for missions where foilborne operation would predominate (about 80% of the time).

It was decided in late 1953 to design and build an approximate one-third scale model of the "orthodox" version. This project was undertaken by Saunders-Roe and resulted in the delivery in mid-1957 of the 17½-ton, 59 ft *Bras D'Or* or R-103. It was powered by two 1,500 hp Rolls-Royce "Griffin" aero-engines and designed for a top speed of 55 knots. Extensive trials in 1958 revealed several areas in which further tests and modifications were required.

During the work by Saunders-Roe on the R-101 study and the *Bras D'Or*, NRE designed a new set of foils for the *Massa-*

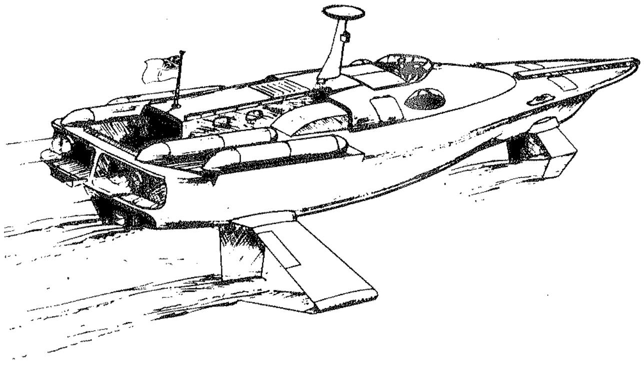


Figure 1. Artist's impression of NRE 200-ton design

wippi. In 1956, *Massawippi* was tested with the new foils at an increased all-up weight of 16,800 lb. The craft performed well in all of these tests, including a single sea trial, without the porpoising associated with the original foils.

Foil systems of the R-101 designs and the *Bras D'Or*, including the set designed by NRE for *Massawippi*, were of the "V" ladder type. This marked a significant departure from the earlier straight dihedral ladder type foils employed on the HD-4, the original foil system of *Massawippi* was in the R-102 design. In the later designs, a cavitation-delaying foil section was adopted. This was originally developed by Walchner during World War II[6] and is known as the "Walchner 'C' section".

In addition to the craft previously described, NRE developed and constructed a small hydrofoil as a basic research vehicle, starting in 1954. Designated "Rx", it has a simple scow-like form, an all-up weight of approximately 6,000 lb and is powered by a Chrysler "Imperial" marine gasoline engine up-rated to 335 hp. The foils are mounted on parallel rails along the gunwale to permit convenient alteration in their longitudinal position when required. Rx is fully instrumented to enable motions in the six degrees of freedom to be measured as well as thrust, torque, rpm and foil unit lift. It is being employed extensively in model tests of the FHE 400 hydrofoil ship design as described in the later sections of this paper.

A central theme of hydrofoil research in Canada, as illustrated by the preceding review, is the concentration upon surface-piercing foil systems and their development by NRE for application in relatively small craft capable of open-sea operations in the 45-60-knot speed range. It is against this background that considerations leading to the RCN programme for an ocean-going hydrofoil ship are traced in the following section.

II. CONCEPT FOR AN OPEN-OCEAN HYDROFOIL SHIP

1. Concept Originated by the Naval Research Establishment

A conclusion of studies in 1953 was that fixed, surface-piercing hydrofoil craft in the 40-60-knot speed range would be limited in size to about 50 tons. However, by 1959 NRE considered that this limitation was no longer applicable. Developments in the intervening years by the aircraft industry now offered the prospect of efficient lightweight, high strength materials and structures and high power, lightweight propulsion units essential to the feasibility of large hydrofoil craft. At about the same time, Grumman Aircraft Engineering Corporation also concluded that larger hydrofoils would be practicable and envisaged commercial craft in the 500-3,000 ton range.[7]

NRE therefore investigated the requirements for the smallest, simplest, and most economical vehicle which could operate in the open ocean with acceptable seakeeping, comfort and reliability and achieve a high degree of effectiveness in anti-submarine or other appropriate naval roles. It concluded that a 200-ton ship with a surface-piercing foil system and 50 to 60-knot speed capabilities would be highly effective in many open-ocean ASW roles. Equally significant was the conclusion that the relatively low cost of the system would make it feasible as a "Small and Many" concept at a cost effectiveness superior to conventional surface forces.

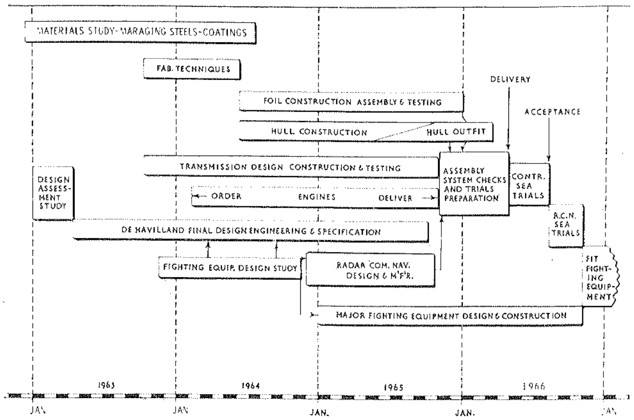


Figure 2. The 400 hydrofoil programme

Consideration of various craft configurations resulted in the form shown in Fig. 1. It will be noted that the foil system combines features of the Grunberg and the Bell-Baldwin systems employing a fixed, surface-piercing hoop main foil generating 90% of the total lift and a "V" ladder bow or pitch stabilising foil unit. The canard configuration of foils inherent in this system offers some decided advantages in craft intended for rough water operation. It avoids a long bow overhang and permits fine lines forward, thus reducing wave impact loads. The canard configuration also promotes good internal and propulsion machinery arrangements, is well suited to towed sonar installations and can achieve good foilborne stability in following seas. Since it was anticipated that, in the roles envisaged, the craft would operate largely in the hullborne mode, displacement seakeeping qualities were considered of paramount importance.

The principal characteristics of the NRE design were:

Length over-all	130 ft (39.6 m)
Beam of hull	28 ft (8.5 m)
Depth of hull	14 ft (4.3 m)
Span of main foils	64 ft (19.5 m)
Foil base length	81 ft (24.7 m)
Draught in displacement mode	23 ft (7.0 m)
Draught in foilborne mode	6 ft (1.8 m)
Foilborne power	16,000 hp
Displacement power	3,000 hp
Maximum foilborne speed in calm water	60 knots
Foilborne speed in SS 5	50 knots
Normal cruise displacement mode	12 knots
Maximum speed displacement mode	18 knots

At a tripartite conference early 1960, a group of specialists from Britain and the United States reviewed the NRE report. The conference concluded that the concept was feasible and warranted further study.

2. Feasibility Study by De Havilland Aircraft Co of Canada Ltd

While concluding that the development of high strength materials, lightweight marine gas turbines, transmissions, and supercavitating propellers placed the concept within the bounds of practical realisation, NRE recognised the need to establish design criteria for ocean-going hydrofoils. It noted that aircraft companies were particularly well equipped for this task by virtue of their experience in lightweight structures, fluid dynamics and in computer systems enabling the simulation of a craft in its environment.

The review of the tripartite conference led in 1960 to the award of a contract to De Havilland by the Department of Defence Production (DDP) for a comprehensive design study of the NRE concept. Objectives of the initial phase were to examine the concept in depth, pursue parametric studies and to ascertain the engineering feasibility of the proposed design. The basic equations of motion were written and a computer simulation of the craft in sinusoidal seas was conducted while a method of representing random seas was being developed.

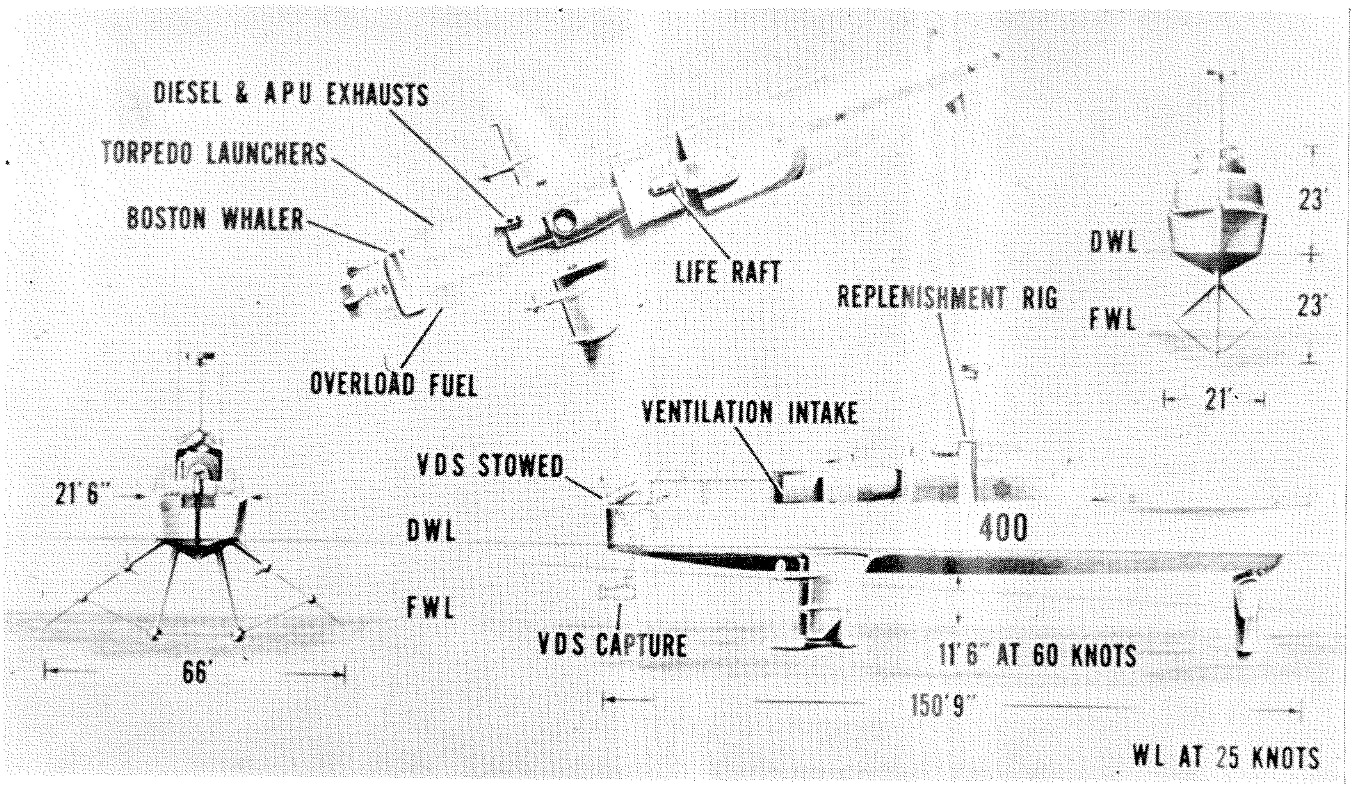


Figure 3. RCN prototype ASW hydrofoil ship. Plan and profile views

Recommendations for a separate foil materials study and proposals for a model test programme in the Phase II study were also formulated.

The report of this first phase rendered in June 1961 concluded that the hydrofoil craft design conceived by NRE and developed by De Havilland was technically feasible. In particular, the study confirmed that a canard configuration and a 150- to 200-ton design weight were optimum for the roles envisaged.

The succeeding Phase II study was aimed at developing a preliminary design for a 200-ton ship for employment primarily in open-ocean ASW roles. An objective was to develop the engineering basis to establish feasibility in detail and produce cost estimates together with proposals for a full-scale prototype ship construction programme. An extensive theoretical and model test programme was carried out. These included:

(a) Resistance measurements on a one-twenty-fifth scale model of the ship at hullborne and take-off speeds and a qualitative assessment of hullborne seakeeping. These were conducted at Stevens Institute of Technology, New Jersey.

(b) Tests of one-eighth scale models of the main and bow foils at the National Physical Laboratory, England, to establish the basic stability derivatives of the units and pressure distributions over critical regions of the main foil.

(c) Tests of a representative one-quarter scale model of the foil system on the Rx research vehicle at NRE. These were primarily intended to check the validity of the analogue computer simulation of the full-scale craft at De Havilland.

(d) A random seaway analogue computer simulation of the full-scale craft and the one-quarter scale Rx vehicle in foilborne operation. The full form and its hydrodynamic effects in take-off and landing were not simulated. The computer was used to simulate the non-linear equations of motion of the foil system in six degrees of freedom in random Sea State 5. It also accounted for orbital velocities in head, beam, and following seas, unsteady flow hydrodynamics, partial ventilation of foil and strut elements, virtual inertia effects in waves, and the onset of local cavitation. A wave pole was developed by NRE to measure wave height and frequency during Rx tests. This enabled comparisons between the Rx craft analogue simulation and its actual behaviour by means of taped records later reduced at the National Research Council spectral analysis centre in Ottawa. A comprehensive description of this work is contained in Ref. (8), including the comparison between analogue simulation and the Rx trials results upon which the reliance on computer predictions for the full-scale craft have been based.

It was recognised in the Phase I study that efficiency, strength, weight, and operational life considerations would impose severe requirements upon the foil system materials. During this period, data on the new "Maraging" Ni-Co-Mo steels were released. Although these steels appeared to offer some considerable promise, little data on characteristics and fabrication were available. Accordingly, a separate materials research programme was sponsored by the RCN and a contract was awarded to De Havilland for the investigation of high-strength steels and protective coatings to determine their relative suitabilities for hydrofoils and other marine applications. Highlights and conclusions of this study are presented in a later section.

The most important conclusion was that the computer studies and model tests had shown that a fixed, surface-piercing foil system can be designed to operate successfully on all headings in sea states up to and including SS 5. This and more recent work has completely discredited widely held views that surface-piercing systems cannot be expected to perform satisfactorily in certain following sea conditions.

Study predictions that only a supercavitating bow foil could provide acceptable response characteristics were vindicated by NRE trials of the one-quarter scale Rx craft. While the supercavitating foil has a lower lift-drag ratio than a sub-cavitating foil, it constitutes a relatively small penalty because the bow foil supports only 10% of the static weight.

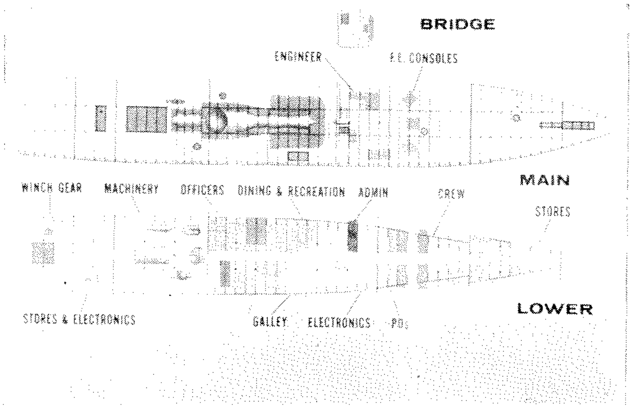


Figure 4. RCN prototype ASW hydrofoil ship. Deck plans

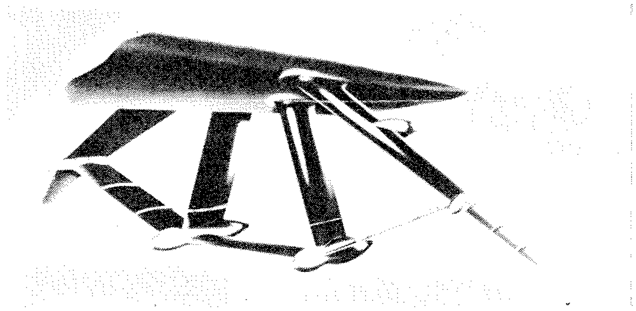


Figure 5. RCN prop RCN prototype ship. Main foil

Based upon the previous expectation that the full-scale ship would spend the majority of its time at sea in the hullborne mode, hull lines were optimised for low displacement resistance and to minimise wave impact loads. The damping provided by the large immersed area of the foil system yields displacement seakeeping comparable with a much larger ship. As demonstrated in the early trials of the one-twenty-fifth scale model, this damping results in a surprisingly low increment of resistance from calm to rough water conditions. Thus, while the non-retractable foils impose a drag penalty in calm water, they confer a decided advantage in rough seas.

In its Phase II design report submitted in late 1962, De Havilland presented a development in detail of the NRE conceptual design, together with a formal proposal to the RCN for the construction of a full-scale prototype ship. A thorough technical assessment of the proposed design was made by the RCN, including consideration of a suitable ASW system outfit. In early 1963 approval was given to a programme for the design and construction of a full-scale development prototype ASW ship. The latter was subsequently assigned designator and hull number FHE 400 by the RCN.

III. RCN DEVELOPMENT PROTOTYPE HYDROFOIL SHIP — FHE 400 PROGRAMME

Based upon the NRE concept and its examination in depth by the 1961-62 De Havilland feasibility studies, a programme for the development and evaluation of a full-scale prototype ship was launched in April 1963. Its fundamental objectives are:

(1) To establish the feasibility of the proposed size and form of ship for open-ocean operations and to test the validity of design predictions.

(2) To develop a Fighting Equipment system attuned to the characteristics of the vehicle design which will permit a thorough assessment of the prototype ship's capabilities in ASW operations.

RCN interest in the hydrofoil is centred on its potential as a practicable and effective element of ocean-going ASW forces. As such, the first objective is a prerequisite to the second and the latter will be fundamental to the consideration of any subsequent warship production programme.

Fig. 2 outlines the major components of the programme and their phasing. Prime contractor for the design and construction of the ship is De Havilland Aircraft Co of Canada Ltd. Design and production of Fighting Equipment which includes the complex of navigation, detection, communication, armament, and tactical data sub-systems is under contract to Canadian Westinghouse. Construction and outfitting of the ship is being undertaken by Marine Industries Ltd, Sorel, PQ, on sub-contract to De Havilland. The ship programme is phased to accommodate the sequence of construction and outfitting at the shipyard for the earliest possible delivery date. Thus, design of some systems and manufacturing of others are proceeding concurrently in many instances. At this stage, the detailed design is well advanced in all areas. Foil system manufacture and hull construction are under way. The latter, as lead item, is due for completion in September 1965. The schedule is a demanding one considering the attendant uncertainties of an extensive development programme and the reliance upon a large number of firms and agencies in the fulfilment of individual tasks. The PERT (Programme Evaluation and Review Technique) method is being employed in the two prime contracts to assist in management of the project which is drawing upon a wide variety of support from research agencies and suppliers in Canada, Sweden, Britain, and the United States.

After launching, instrumented calm water and rough water trials will be conducted prior to the installation of Fighting Equipment in late 1966 for operational evaluation in the anti-submarine role. The base of operations will be RCN facilities at Halifax, Nova Scotia. Plans for shore support include the construction of a docking facility adapted to the special needs of the prototype ship. Preliminary studies have now been completed and design work is progressing on a facility which will embody a marine elevator type dock and meet the needs of other RCN vessels as well. Construction is scheduled for completion in April 1966.

2. FHE 400 — Prototype Ship — Design Basis

The design basis for the prototype ship established by the 1961-62 De Havilland studies of the NRE concept has been closely adhered to. In its design development, apart from the specified aims for high speed and manoeuvrability, emphasis has been placed upon the need for good seakeeping in foilborne and particularly hullborne operation.

An objective which is fundamental to the NRE concept and its realisation in the RCN development programme, is to achieve the minimum size and cost of ship practicable for open-ocean operations in the ASW role. Early parametric studies by De Havilland confirmed that about 200 tons was the optimum size for the requirement. A smaller ship would be deficient in range while a larger one would not yield a significant increase in payload because of the rising proportion of foil system weight with increasing size. On the other hand, seakeeping ability improves with size. These were important considerations in the final decision on form and size of the ship from the standpoint of habitability and operational effectiveness in open-ocean employment, particularly for extended periods in the hullborne mode.

Accordingly, a fundamental aim has been the achievement of the smallest practicable ship with hullborne seakeeping qualities equivalent to conventional warships of over ten times its size. This is made possible by a design of the hull complementary to the non-retractable foil system. The latter is a natural ally which, through its extensive immersed area, exerts a powerful damping action on ship motions, particularly in roll.

A notable feature of the ship is its broad foilborne speed range capabilities compared to contemporaries employing submerged automatically controlled foil systems. This is due in

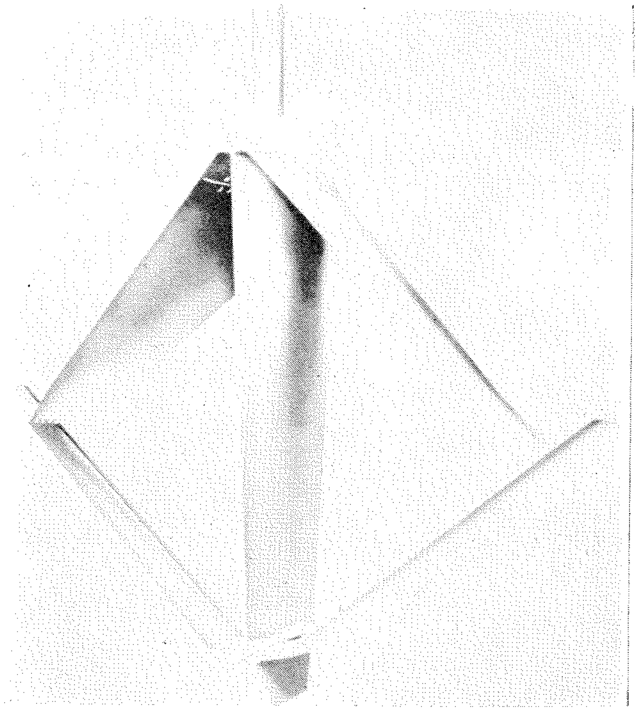


Figure 6. RCN prototype ASW hydrofoil ship. Bow foil

part to the rapid low speed take-off provided by the surface-piercing foils and also because the fundamental design aim was to achieve the maximum speed, particularly in rough water. Detailed consideration of operational requirements have also been a heavy influence in the refinement of the over-all design of the ship and its facilities. However, the generally sensitive interdependencies of speed, payload, range, size, and cost in a ship of this type have been a decisive factor in limiting deviations from the basic design.

The foil system of FHE 400 has no direct precedent. As a key feature upon which the feasibility of the concept hinges, its design has been supported by a comprehensive programme of material research and hydrodynamic development, beyond that of the earlier Phase I and II studies.

A specific aim in the prototype design is to employ proved equipments where suitable and to restrict operational features to those essential to proof of feasibility. The general approach, however, has been to minimise the transitional development which would be necessary for a warship class.

3. Related International Designs

International developments in hydrofoil craft have been prolific and widely reported in recent years. These have marked a growing interest in commercial applications, exemplified by the *Denison* and the Supramar series of hydrofoils. None of these, however, have been designed for long-range open-ocean employment and are generally limited to operation in low sea states.

In the military sphere, the Canadian FHE 400 programme is joined by the United States Navy PC(H) and AG(EH) projects described in a recent paper[9] by Mr Ralph Lacey, Bureau of Ships. Of these three ships, only the AG(EH) and FHE 400 have been specifically designed for ocean operations. The fundamental differences between the latter two, as illustrated by Mr Lacey's paper, lie in size, foil configuration, and end purpose. In contrast to the 320-ton experimental AG(EH) employing a "conventional" configuration of automatically controlled, submerged foils capable of retraction, the 200-ton FHE 400 development prototype is based upon a "canard" disposition of surface-piercing, non-retractable foils with an over-all design and outfit specifically oriented to an ASW application. The pivotal point in the design of either ship is the type and configuration of foil system. While each has its own particular virtues and disadvantages, the choice of foil system for FHE 400 was influenced by the requirement for good seakeeping qualities and a high degree of inherent simplicity, ruggedness, and reliability in the demanding environment of ocean-going naval operations. In many respects the development of hydrofoil craft and equipment are in their infancy. Contributions to the advancement of these developments, especially in the military sphere, are being made by the USN and RCN programmes. A close identity of interests links these two projects and the attendant co-operation has been of great benefit in the progress towards allied goals.

4. FHE 400 Design

Principal Features

The form and external features of the ship are shown in the views of Fig. 3. The general layout of main and lower decks, including bridge and operations room, is illustrated by Fig. 4. These are in the course of mock-up development in a full-scale wooden replica of the hull and superstructure at De Havilland.

Leading particulars are summarised in Table I and do not differ substantially from those of the Phase II design proposal.

Hull and Superstructure

The hull structure design involves some departures from normal practice. It caters for hull bending while foilborne, high bottom impact loads at take-off and foil attachment fittings.

Hull and superstructure will be of all aluminium welded construction, fabricated from ALCAN D54S or equivalent plate and extrusions except for the foil attachments which are 7075(T73) aluminium forgings bolted to the welded structure. Extensive use has been made of large extrusions of combined stringers and plating.

The slender hull, designed for minimum resistance, is highly stressed. In consequence, structural joints must be carefully designed and marry up precisely.

The hull is being constructed in the inverted position on an erection bed. When completed, it will be rotated to an upright position for the erection of superstructure, outfitting of systems and attachment of foils.

TABLE I

PRINCIPAL PARAMETERS AND FEATURES — FHE 400

Dimensions	
Length over-all	151 ft 5 in (46.2 m)
Length of waterline	146 ft 6 in (44.6 m)
Beam of hull	21 ft 6 in (6.6 m)
Foil base	90 ft 0 in (27.5 m)
Bow foil span	22 ft 6 in (6.6 m)
Main foil span	66 ft 0 in (20.1 m)
Hull depth	15 ft 0 in (4.6 m)
Keel clearance at 60 knots	11 ft 6 in (3.5 m)
Draughts	
Hullborne draught	23 ft 6 in (7.2 m)
Foilborne (60 knots) draught	7 ft 6 in (2.3 m)
Displacement	about 200 tons
Main, Auxiliary, and Emergency Power Plants	
Foilborne gas turbine (Pratt & Whitney FT4A-2)	22,000 shp cont
Hullborne diesel (Davy Paxman 16YJCM)	2,000 bhp cont
Auxiliary gas turbine and hullborne boost (Canadian Pratt & Whitney ST6A-53)	390 shp cont
Emergency gas turbine (AiResearch GTCP85-291) (AiResearch GTCP85-291)	200 shp cont
Propellers	
Foilborne — twin supercavitating props (fixed pitch)	3 ft 8 in dia
Hullborne — twin controllable pitch props	7 ft 0 in dia

Foil System

The system consists of two surface-piercing, non-retractable units, the bow foil supporting 10% of the ship's weight with the remaining load on the main foil.

The bow foil (Fig. 6) is a supercavitating design for good response in a seaway and acts as a wave sensor to trim stabilise the ship when foilborne. The centre strut is coupled to a shaft which rotates about its axis for steering control at all but low harbour speeds when the use of the controllable pitch propellers is necessary. The shaft can also be raked fore and aft to adjust the pitch angle of the bow foil for hullborne or foilborne attitudes.

The main foil (Fig. 5) has elements with delayed cavitation sections and is an unusual combination of surface-piercing and submerged foils. The large anhedral foils provide reserve lift at the low take-off speeds. Anhedral tips are rotatable and can be manually or automatically controlled in incidence to ensure adequate roll stability at very low foilborne speeds. These can also be employed at higher foilborne speeds to decrease turning diameters in "co-ordinated" turns. Fences are fitted to the high-speed foils and struts to inhibit ventilation.

The foil system is constructed of welded 250 ksi maraging steel of the 18% nickel variety, to which a protective coating, being developed by De Havilland, will be applied. Foil elements are bolted to each other and to the hull. Leading edges of the foils are replaceable and made of INCO 718 stainless steel.

Although the hull and foil elements are relatively simple structures, an analysis by conventional means would be unreliable because of the multiple load paths. Matrix methods have therefore been adopted in critical areas such as the foil elements and main foil foundation.

Although the ship is relatively small, the foil system acts as a strong damper to hullborne motions. Model tests indicate that hullborne motions will be less severe than those of a destroyer escort.

Foilborne Propulsion System

The roughly ten to one difference in foilborne and hullborne power requirements dictate separate propulsion systems for economical performance.

The foilborne system is powered by the FT4A-2 turbo-shaft engine rated at 22,000 shp continuous duty and mounted in a protective cowling headed by an air intake abaft the operations room on the main deck. This arrangement minimises noise and heat transfer to the living spaces of the ship and avoids large structural cut-outs in the highly stressed hull. Power is transmitted from a dual output gearbox abaft the engine via downshafts in the main foil struts to a pod-mounted gearbox and supercavitating propeller at the foot of each strut.

The propellers are fixed pitch, three bladed and 44 in in diameter. The design is currently under joint development by the National Physical Laboratory, England, and De Havilland, Canada. Overrunning clutches in the pods automatically disengage the propeller during hullborne operations.

Both hullborne and foilborne transmissions are being designed and built by General Electric, Lynn, Massachusetts, under contract with De Havilland. Previous experience with the transmissions designed by GE for HS *Denison* and the AG(EH) will be a significant benefit to the FHE 400 transmission development.

Hullborne Propulsion System

The hullborne system is powered by the 2,000 bhp Paxman 16YJCM diesel centred in the engine room as shown by Fig. 4. Power is transmitted by a dual output gearbox and downshafts to an outboard gearbox and propeller at a pod on each anhedral foil. The propellers are 84 in in diameter, three bladed, controllable in pitch and feathered to minimise wave impact loads during foilborne operations. These are being designed and built by KMW, Sweden.

Auxiliary Machinery and Systems

Engine room. The engine room shown on the lower deck plan of Fig. 4 contains the propulsion diesel and all auxiliary systems, including the 390 shp ST-6A auxiliary gas turbine and 200 shp AiResearch emergency gas turbine driving generators, hydraulic and salt water pumps. The auxiliary system is designed around a dual input auxiliary gearbox driven via clutches from either the diesel while hullborne or the ST-6A while foilborne. The gearbox is also capable of coupling the ST-6A to the displacement transmission for "boost" power with the diesel or by itself for emergency propulsion. The emergency gas turbine pack provides a secondary source of electric and hydraulic power, firefighting services and bleed air for main gas turbine starting. The engine room is unmanned and controlled from the bridge and a machinery console in the operations room.

Sub-Systems

The hydraulic system operates bow foil steering and trim, anhedral tips, VDS and anchor winches and various lubricating pumps.

The pneumatic system provides compressed air for gas turbine and diesel starting, torpedo launching, and other services.

Fresh water is supplied from two distillation units. Diesel-engine jacket water is the heat source for the units.

Electric power is generated at 115/200 v, 400 cycle, three phase.

The ship is heated from an exhaust gas heater exchanger operating from the diesel or ST-6A turbine. Electrically driven air-conditioning units are employed.

Firefighting services include a remote-controlled CO_2 flooding system for the engine room, fire hydrants on upper and lower decks, and a portable gas turbine powered emergency pump.

The fuel system is designed to accommodate any diesel or turbo fuel suitable for the four engines. JP5 will be the standard fuel in FHE 400. Four tanks are incorporated below the lower deck.

The bow foil steering system includes features for manual or automatic control of heading, the latter operating from the ship's gyro compass.

Seamanship Outfit

Outfit plans include anchor and associated facilities on the quarterdeck, with a lightweight winch in the compartment below. Hydraulic-powered bollards and other normal fittings for line handling are being provided. A 13½ ft Boston whaler with an 18 hp outboard motor will be carried as shown in Fig. 3.

Facilities for refuelling and replenishment at sea are being incorporated.

Variable Depth Sonar Winch and Handling Gear

Facilities for the streaming and recovery of a towed VDS body are being developed based upon handling gear designed to recover over-the-stern. These are in the course of design. A representative installation is shown in Fig. 3.

Accommodation

Feasibility of the ship is dependent upon its habitability in open-ocean operations. Environmental considerations have therefore heavily influenced accommodation design. Planning has been based on a crew of four officers and sixteen men with provisions for operations in excess of two weeks at sea. This is subject to possible change when operating and maintenance tasks are more fully explored during the evaluation. Because of the uncertainties, an aim is flexibility of arrangement. The general arrangement which has now been mocked up is shown in Fig. 4.

The galley provides for storage, preparation, and cafeteria style serving of all food. Meals will largely consist of precooked and frozen foods, selected in portions on board according to the menu and served after rapid heating in a micro-wave oven. Conventional foods can be prepared when practicable. This approach has been dictated by weight, space, manpower, and foilborne motion considerations.

Bridge and Operations Room

A general arrangement of bridge and operations room is shown in Fig. 4. The bridge is confined to ship control and navigation functions and provides for two manned positions, a primary and secondary. The operations room is the centre for tactical control of the ship and its weapons system. A representative arrangement of manned consoles is shown. The engineers' console is also fitted in this space. Systems engineering analysis techniques, including work study, have been applied to the design of arrangements and definition of operator duties and qualifications.

5. Problem Areas

Some degree of uncertainty on the full attainment of objectives is inherent in any development programme, however well founded. The FHE 400 prototype will in many respects be the product of recent research and developments. Herein, certain possible difficulties, which may emerge in evaluation, have been acknowledged and highlighted as "key problem areas" in the project. These bear upon questions of operational as well as technical feasibility of the design and include foil materials and coatings, supercavitating propeller design, seakeeping and noise influences on the habitability of the ship.

IV. RESEARCH AND DEVELOPMENT ASPECTS

1. Introduction

The FHE 400 programme constitutes the development of a complete "weapon system" based upon a relatively unprecedented vehicle design which, compared to conventional warships, places stringent limitations on the size and weight of its elements, including systems and payload. This has necessitated some research and a considerable dependence upon development or adaptation of lightweight hardware. The latter is, unfortunately, a costly process, particularly for a single experimental ship. The foil system is, however, the focal point of development effort upon which the success of the entire programme depends. Theoretical studies and research have also played a considerable role in the work to ensure a sound foil system hydrodynamic, material and structural design. These encompass an extensive range of studies and tests over the past four years.

The scope of this paper permits only a brief review of the vehicle considerations. Highlights are grouped and summarised in the following sub-sections.

2. Hydrodynamics

In the process of developing a specific foil system for FHE 400, it is considered that significant contributions have been made to the design of surface-piercing hydrofoil craft. This applies particularly to the dynamic simulation of craft motion in a random seaway and in subcavitating foil design. Other contributions are also being made to the art of superventilating foil sections and supercavitating propeller design. Some considerable effort has also been applied to hydro-elastic studies and tests on divergence and flutter clearance margins of the main and bow foil.

(a) *Craft Motion in a Random Seaway*

A fundamental aim of the NRE concept was an all-weather craft capable of open-ocean performance. A major problem in the feasibility design studies was, however, the estimation of the degree of stability for foilborne operations in a random sea. Up to 1960, little work had been published on this subject. Accordingly, De Havilland, as previously noted, undertook the development of the equations of motion and a method of representing a random seaway for an analogue computer simulation of craft in six degrees of freedom. The initial simulation was in sinusoidal seas and results were correlated with model tests at NPL, London.

Subsequently, random seaway simulation was incorporated during the Phase II studies, and has since been extensively employed in the design development and proving of the foil system. The forthcoming phase of computer simulation studies will be applied to the anhedral tip and bow foil control systems to establish gains and stiffness requirements.

A comprehensive treatment of the theory of craft motion and the correlation of computer predictions with trials results is contained in the paper of Ref. (8) presented by Davis and Oates to the ONR Symposium at Bergen, Norway, in August 1964.

(b) *Subcavitating Foil Design*

The main foil design requirement is for cavitation-free operation at 60 knots in calm water and for a wide angle of attack range at 50 knots in Sea State 5.

Design of a satisfactory non-cavitating foil involves the determination of the shape required to support a given pressure distribution. At infinite depth, this problem is identical to the airfoil, for which methods of computation already exist.

However, the free surface can cause significant effects on the pressure distribution at practical depth/chord ratios and Froude numbers. Thus an extension of airfoil theory is necessary to account for the effect of the free surface.

Such a technique was developed for the FHE 400 design programme using the method of singularities in which the lift is represented directly by vortices, and thickness by doublets. This work is described in Ref. (10).

Using this technique, hydrofoils can be designed to have a minimum cavitation number for a given thickness and lift, by specifying flat-topped types of pressure distributions. However, at off-design angles of incidence, these profiles have poor cavitation characteristics, since the additional lift due to change of incidence causes sharp (negative) pressure peaks near the leading edge. The objective therefore is to design a profile having as wide a cavitation-free range as possible. This can be achieved by designing a profile which will have a positive pressure peak near the leading edge on both upper and lower surfaces at the design angle of attack. The negative pressure peak due to change of incidence will then "fill in" this part of the pressure diagram, leading to a flat-topped pressure distribution on one side at each extreme of the cavitation-free incidence range.

(c) *Fully Ventilated Foil Design*

The environment and stability requirements for the bow foil favour the use of a fully ventilating foil section. However, it is difficult to design such a foil which would have satisfactory characteristics due to the wide range of angle of attack experienced in a seaway and the need for a section with good low speed resistance. In developing the foil section, it is first necessary to define the pressure face for normal supercavitating or fully ventilating operation. A Tulin-Burkart pressure face is used with a design C_L of 0.1 and a nominal operating C_L of 0.2, using the method outlined in Ref. (11).

For minimum resistance in the displacement mode, the foil should have an upper surface shape approaching that of a circular arc, the ordinates of which should have the minimum included angle compatible with structural requirements. In a seaway, however, very small relative angles of attack occur, and under such conditions, the flow will re-attach to the circular arc top surface, with a consequent large lift increment in the fully wetted condition, due to the camber of this type of foil. Since re-attachment leads to violent pitching motions, it is necessary to provide a spoiler on the upper surface, in the form of a "step" to prevent flow re-attachment over the rear portion of the foil during foilborne operations.

3. Materials Investigation

One of the major problems in the development of a surface-piercing hydrofoil craft of the FHE 400 size is the limited selection of structural materials with the high strength/weight ratio and other properties required for an efficient and durable foil system.

As previously mentioned, De Havilland were assigned a contract to conduct a comprehensive investigation to determine the best materials and protective coatings available in the time scale for production of the FHE 400 foil system. The Department of Mines and Technical Surveys was also engaged as a consultant.

A number of materials were investigated for various properties in tension, shear, fatigue, impact, weldability, and for resistance to normal corrosion and stress corrosion.

The results of these studies led to the selection of an 18% nickel maraging steel with a 250,000 psi yield strength. An extensive series of tests were conducted. Fatigue characteristics were determined by random load tests using the load spectrum derived from the analogue simulation of the ship.

The need for coatings to provide adequate protection of foils against corrosion was established. Investigations were conducted on a large variety of types for adhesion, water absorption, resistance to cavitation erosion and other critical properties. These have resulted in a concentration on two of the most promising, both of organic composition. Small-scale tests of these coatings have been run in cavitation loops developed by De Havilland at speeds of 65 knots. Larger-scale tests are in progress at Grumman Aircraft Engineering Corporation facilities. Qualitative trials on large underwater sections of two RCN destroyers are being conducted. Arrangements have also been made for tests of these on the bow foil of the USN Hydrofoil PC(H).

The Department of Mines and Technical Surveys is investigating the properties of the new 12% nickel maraging steels (180 ksi yield) which appear to offer attractive advantages as a replacement for the 18% material in any future foil manufacture. This is subject to determination of suitable fatigue properties and other qualities.

The necessity and feasibility of a cathodic protection system for the ship is also under investigation.

4. Habitability

In the final analysis, the feasibility and operational capabilities of the ship will be dependent upon the habitability of the ship and thus the efficiency of its crew. The nature of FHE 400 and its envisaged operation presents some unusual environmental conditions, particularly while foilborne. Accordingly, considerable attention has been given to habitability aspects in the design of accommodation and operator facilities. Factors which have influenced these are ship motions, noise, and vibration, together with space, weight, manpower, and equipment limitations.

Extensive use has been made of "Method Study" in establishing requirements and the design of arrangements. Its applications by the RCN are described in Ref. (12), including the study from which the FHE 400 galley design was developed. Accommodation, bridge and operations room arrangements and management have also been defined by RCN method studies. These have been of great assistance in charting requirements and designs which have, in most instances, little precedent in conventional warships. In keeping with the concept, every effort has been made to minimise operating and maintenance requirements, thus to achieve the smallest crew for efficient, "round-the-clock" operation at sea. While living accommodation is not cramped by submarine or MTB standards, the limitations of layout and other criteria have required careful design of arrangements and the development or adaptation of lightweight, easily maintainable equipment and furnishings.

Measures to ensure adequate levels of comfort and efficiency while foilborne have received particular attention. Human thresholds of tolerance to ship motion are not well defined. While hullborne motions are predicted to be less severe than a destroyer escort, there is the uncertain effect of the stiff damping action of the foil system. Finally, there is the entirely different nature of foilborne motions and the difficulty of predicting crew reaction to these. While tests in Rx craft indicate that levels of acceleration should be acceptable, it should be noted that a surface-piercing foil craft such as FHE 400 is a semi-contouring or partial response system with less potential for smoothness of ride than an equivalent craft with submerged automatically controlled foils.

In the study of FHE 400 environmental factors by the Canadian Forces Institute of Aviation Medicine, attention has focused upon foilborne motion considerations. Part of the investigative programme includes the study and test of sleeping and operator console arrangements under simulated foilborne motion conditions using "live subjects". A motion simulator platform which can reproduce foilborne motions in roll, heave, and pitch has been constructed for this purpose at the National Research Council laboratories in Ottawa. It is operated from magnetic tapes of the predicted random seaway motions of FHE 400 derived from the De Havilland computer simulation.

Experimental mock-ups of crew bunks and operator control positions will be instrumented and tested to assess comfort and efficiency of arrangements, including modifications to their form or employment to minimise any adverse effects of foilborne motion. Trials are now under way on an experimental version of the bunk design concept developed by IAM.

REFERENCES

(1) Bell, Alexander Graham and Baldwin, F. W.: "Report to Admiral Griffin on the HD-4." *Beinn Breagh Recorder*, Vol 23, 1919.

(2) Nutting, W. W.: "The HD-4, a seventy-miler with remarkable possibilities." Reprinted Smithsonian Report for 1919, Publication 2395, Government Printing Office, Washington, DC, 1921.

(3) Crewe, P. R.: "The hydrofoil boat: its history and future prospects." *Trans. INA*, Vol 100, 1958.

(4) Eames, M. C.: "The influence of cavitation on hydrofoil craft design." *Canadian Aeronautical J*, Vol 6, 1960.

(5) Kuhring, M. S.: "The Comox torpedo — a Canadian contribution towards hydrofoil development." National Research Council, Canada, Report No ME210, June 1958.

(6) Walchner, O.: "Contribution to the design of ship propellers without cavitation." Translation by Saunders-Roe Ltd, Isle of Wight, of an AVA Monograph, *c* 1945.

(7) *A Study of Hydrofoil Seacraft.* Grumman Aircraft Engineering Corporation, Long Island, NY, for US Department of Commerce, Maritime Administration, Oct 1958.

(8) Davis, B. V. and Oates, G. L.: *Hydrofoil Motions in a Random Seaway.* De Havilland Aircraft of Canada Ltd, Aug 1964.

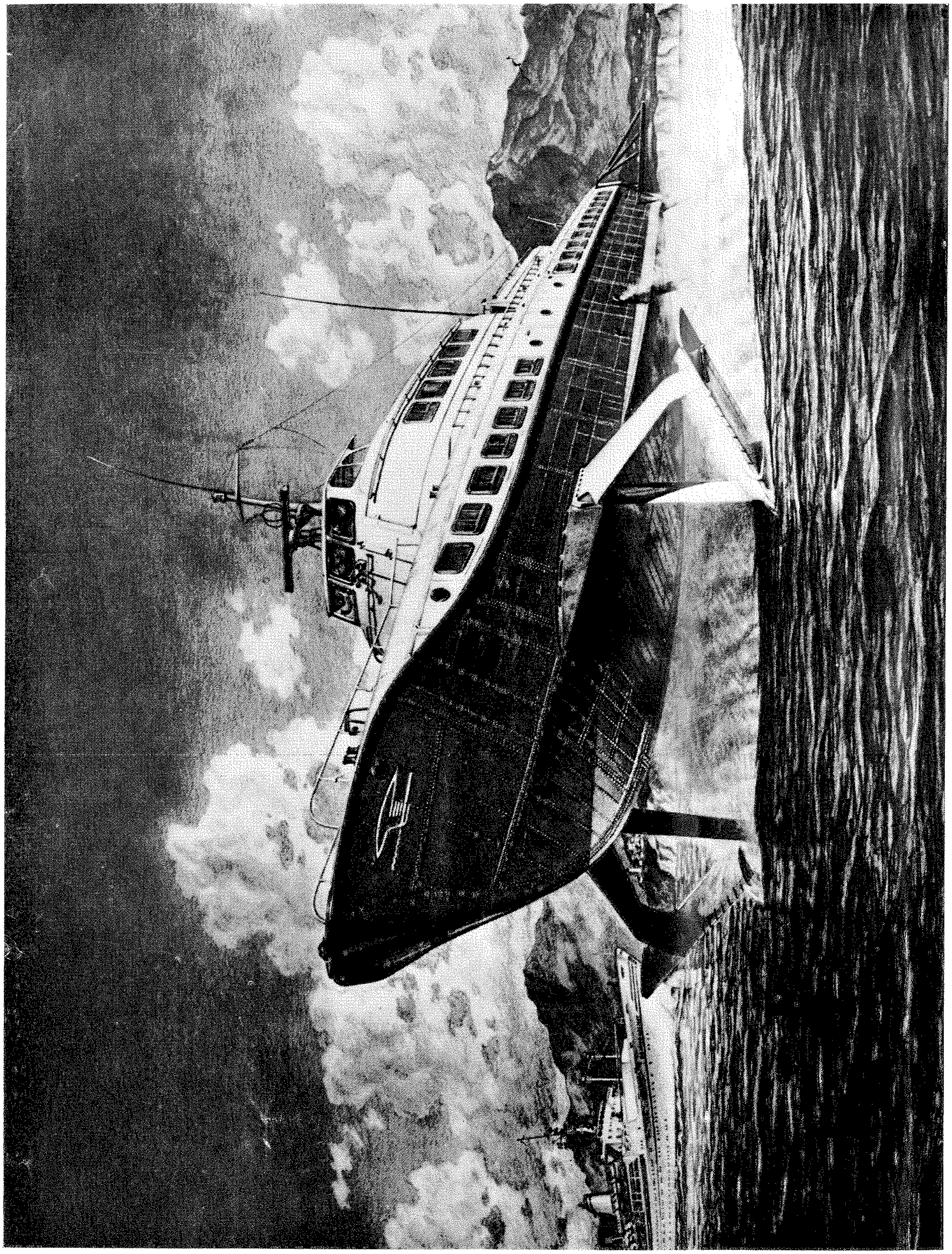
(9) Lacey, E. Ralph: "A progress report on hydrofoil ships." *Trans. RINA*, Vol 106, 1964.

(10) Richardson, J. R.: "Theoretical pressure distribution for two-dimensional, sub-cavitating hydrofoils near a free surface." Engineering Research Association, Toronto, Canada, June 1961.

(11) Johnson, V. E.: "Theoretical and experimental investigation of supercavitating hydrofoils operating near the free water surface." NASA TR-R93, 1961.

(12) Farrell, Capt K. P., RCN, Judge, R. and Engh, Lt I. B., RCN: "The RCN's application of method study to ship design." Eastern Canadian Section, The Society of Naval Architects and Marine Engineers, Jan 1965.

This paper was presented to the meeting of The Royal Institution of Naval Architects in the Weir Lecture Hall, 10 Upper Belgrave Street, London SW1, on March 24th, 1965.



This black-and-white artist's pencil sketch of a Supramar PT.50 Hydrofoil Boat in the Straits of Messina is available in 46 x 31 cm on special white paper 74 x 60 cm. Apply for free copies for wall decoration

SUPRAMAR LTD, Friedenstrasse 2, Lucerne/Switzerland