HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF AIR CUSHION VEHICLES AND HYDROFOILS

Volume 6 Number 12

SEPTEMBER 1967

KALERGHI PUBLICATIONS

SR.N4 – a new number for train spotters

British Rail hasn't quite taken all the glamour out of the train spotter's life. Although the romance and grandeur of steam locomotives are almost a thing of the past, there are a number of interesting developments off the beaten track – even as far off as the open sea!
Including SR.N4...
This is the world's largest hovercraft, ordered by British Rail to bring a new dimension to its ferry operations. Capable of carrying 250 passengers and 32 cars, this 165 ton hovercraft will bring speedier, more comfortable travel to everyone.
The world's fastest sea transport – cruising at 70 knots – the SR.N4 will maintain first class service day and night, regardless of rough seas, tide state, wind or weather.
The SR.N4 ordered for British Rail is one of four giants at present under construction on the world's first hovercraft production line at Cowes. The *firm orders already* placed for these craft are further tangible evidence of operators' confidence in British hovercraft. A transport revolution is underway, a revolution in which many enterprising ferry operators are already taking part.

BRITISH HOVERCRAFT – WORLD LEADERS IN THE HOVER TRANSPORT REVOLUTION

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NEW WORLDS TO CONQUER

by **Derek Weber**
Editor
The Geographical Magazine

HOVERCRAFT trials over differing types of terrain and under all types of climatic conditions are being studied with increasing interest by geographers in many parts of the world. They see in this machine a piece of equipment, which, if its uses are planned with skill and imagination, will increase the amount of work that can be carried out by any expedition and which can provide mobility for key men in a way which has never before been possible.

The subject of geography embraces many disciplines and the true geographer cannot easily be defined. The late Professor Debenham described geography as being "The pursuit of wisdom with respect to place". The problem has until recent times been for the geographer to get to his place and having reached it to move around there. Modes of travel since journeys have been recorded have varied very little until the present century and the arrival of the aeroplane. The ability to fly, however, has cut the world down in size in such a way as to make travel in itself a matter of small difficulty. It has also given man the opportunity to study his world from a distance and to see its surface in a new light.

Aircraft are fast and comparatively flexible but they are expensive to operate and difficult to stop. Helicopters are more versatile for the explorer who seeks to get close to his subject but they too have limitations and are costly to purchase and to operate. For travel on many types of land surfaces motor vehicles have now reached a surprising level of efficiency and tracked vehicles exist for use on ice and snow and in certain types of swamp regions.

For large expeditions it has often been necessary to provide all of these types of transport and almost always, boats as well.

Now comes the hovercraft. Last year a series of highly important and successful tests took place in the snow and ice of northern Canada. This year has seen similar trials in the deserts of northern Africa. More tests have taken place on tropical rivers and on rugged hillsides. In all of these regions the hovercraft has shown that, properly handled, it can cover long distances at high speeds over terrain which would defeat almost any other form of mechanical transport. It can stop when necessary, on land or water; it is safe and can operate under almost any weather conditions; load carrying capacity can be high and also flexible; and the cost, although difficult to estimate accurately at this stage of development, will compare very favourably with that of light aircraft.

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COVER PICTURE: *The Southampton terminal of British Rail Hovercraft Ltd. (See article on page 30)*

The Hovercraft Pioneers

By Brian Cooper

THE one man who more than any other deserves credit for the development of Christopher Cockerell's original hovercraft idea is a gentle, quiet-spoken civil servant in his late fifties. While the previous articles in this series have featured the men in private industry who did so much to make hovercraft possible, the test pilots, the operators and the designers, it was Ronald Shaw who as the Assistant Director of Aircraft Research at the Ministry of Supply first realised the potential of Cockerell's principle and brought it to the attention of Saunders-Roe.

By the end of 1956, Cockerell had already spent two years in trying to get people interested in his idea, without success. It was finally as the result of a personal letter to Lord Mountbatten that the Admiralty agreed to look into the matter further. On a cold morning in November, Shaw was sitting in his office when a telephone call came through from the Admiralty, saying that they had an inventor with them who seemed to be more in his line. Shaw agreed to see him and was directed to the basement of an old building in Chancery Lane. This was the office of a patent agency that had been employed by Cockerell. Here, Shaw met Cockerell for the first time and, together with the six other men present, they witnessed the demonstration of a crude hovercraft model. Because of the lack of space, they had to sit on tables while the model circled on the floor at a speed of about 10 mph at the end of a short string. An office ruler was used to demonstrate its ability to surmount obstacles.

Shaw was the only one of those present to express an interest in the idea and willing to talk about it further. He invited Cockerell to come and see him and bring his calculations. At their meeting a few days later in Shaw's office he checked Cockerell's preliminary figures and found them to be on the right lines. He also discovered, which was a surprise to both of them, that they had been up at Cambridge together, doing engineering in the same course. It was obvious from their discussion that a design team was necessary if the experiment was to be taken further, and Shaw began by approaching Shorts in Belfast, because of their experience of flying boats and vertical take-off aircraft. They were not interested, however, and Shaw then approached Saunders-Roe, a company that also had flying-boat experience. It so happened that because of aircraft cancellations, Maurice Brennan at Saunders-Roe had a number of designers available. They were also interested in the possibilities of this new concept. As the result of a £7,500 contract which Shaw was able to give them, they agreed to undertake a design study and model tests, and this occupied them for the next fifteen months. With this step the first real start on hovercraft development had been made, a start which was to lead to the SR.N1 and then on to the wide range of hovercraft of today. During this period Shaw arranged for Cockerell to be a consultant to the Ministry of Supply so that he could retain contact with the work.

The reason that Shaw was able to have such a ready appreciation of the hovercraft idea where others dismissed it lay in his long and distinguished career as an aerodynamicist. Born in Liverpool in 1910, he obtained a scholarship in Pure Mathematics to Downing College, Cambridge, and graduated in Engineering in June 1932, with a first class honours in the Mechanical Sciences Tripos. He was awarded an 1851 Exhibition bursary but relinquished it when he became one of two junior scientific officers appointed to the Royal Aircraft Establishment at Farnborough that year. He has warm memories of the pioneering spirit of those days, doing flight work and wind tunnel testing, for the aircraft industry itself was then still relatively new. Working under Dr G. P. Douglas, he was responsible in 1935 for evolving in wind tunnel tests the designs for the radiator cowlings of the first Spitfires and Hurricanes.

In 1938 he was promoted to senior scientific officer and sent to the Marine Aircraft Experimental Establishment at Felixstowe to take charge of research and testing on flying boats. Eighteen months later, on the outbreak of war, the Establishment was moved up to Helensborough on the Clyde, and it was here, while waiting for their main equipment to arrive from Felixstowe, that Shaw became interested in the possibilities of air lubrication to reduce the water drag on flying-boat surfaces in take-off. He actually built a simple model with which to test his idea, nothing more than a 12 × 18 in box with a Perspex bottom with a pipe along the front edge with holes in it through which air from a compressed air cylinder could escape. This was trailed along in the water over the side of a boat. What Shaw was interested in finding out was how the air jets merged to cover the bottom of the Perspex. The next step would have been to make some arrangements to measure the drag of the surface. Unfortunately, perhaps, the equipment for which they had been waiting arrived from Felixstowe and more important jobs had to be done. What Shaw didn't realise at the time was that he had built something very close to Cockerell's first hovercraft model. Had he been able to continue his line of thinking, he might well have come up with the hovercraft principle. As it was, this had to wait for another seventeen years. For with the advancement of the war and the increasing danger to shipping from enemy submarines, Shaw was given the job of setting up a team to do full-scale research and testing of underwater weapons.

This primarily involved depth charges, and here again, as happened so often in his career, Shaw was starting from scratch. Despite the fact that depth charges had been used in the First World War, virtually no work had been done on their use from aircraft, and in 1939 very little was known about the problems involved. During the four and a half years he was engaged on this research, which included a great deal of open-sea work, he built in a remote Scottish glen an experimental bomb-firing tank that was the largest

Ronald A. Shaw, OBE, MA, CEng, FRAeS

of its kind in the world. The virtue of the tank was that it enabled the underwater behaviour of the bombs to be studied at full scale under controlled conditions. The tank, 150 ft long and 45 ft deep, with a glass side, contained a million gallons of water and was big enough to accept full-size bombs entering the water up to 400 ft/sec and rockets up to 1,500 ft/sec. Three hundred killowatts of lighting and high-speed cameras were used in photographing the underwater path, and the behaviour of fuses and damage to the bombs themselves could be precisely recorded.

One of the most important projects on which Shaw and his team became engaged was Barnes Wallis's dam-busting bomb. The principle of the bomb was that it should bounce along the surface of the water and then, because of its spinning action, roll down the face of the dam to the bottom where it would explode to the greatest effect. Shaw was responsible for the recording team and the analysis when the full-scale trials on the bomb were done in a remote Scottish loch.

After the war, when the Marine Aircraft Experimental Establishment was disbanded, Shaw was offered three choices — either to return to Farnborough, go to Cambridge to undertake research work, or go to Australia on attachment to the Commonwealth Aeronautical Research Laboratory. He chose Australia, and it was while in the ship sailing out there that he was informed that he had been promoted to principal scientific officer, and the appointment back-dated two years.

Within a few weeks of arriving in Australia, he was put in charge of the Aerodynamics section. With an eighty-man team, working at Fishermen's Bend near Melbourne, he found himself engaged on some strange projects during the two years he was there, including the designing and testing of orchard sprayers, frost fans, mine ventilation systems, and gliders. This was in addition to more conventional work in the wind tunnels of the laboratory.

Back in England in 1947, he worked for three years on supersonic aerodynamics at the National Physical Laboratory. It was during this period that he evolved an acoustic theory of airflow which is still very controversial despite the fact that it explains and predicts vortex shedding when no other theory is able to do so. Then followed three years in Washington as liaison officer with the British Mission. In 1953 he was brought back to England and appointed Assistant Director, Aircraft Research and Development (Research), at what was then the Ministry of Supply. He held this appointment till last year, although during this time the Ministry changed its title from Supply to Aviation and finally to Technology.

In this capacity, Shaw was responsible for the oversight of the design and building and subsequent research work on such aircraft as the Fairey supersonic delta, which broke the world air speed record, the supersonic Bristol 188 and 221 (the half-scale Concord), the Short SCI and Hawker P1127 VTOL aircraft and the Fairey. Together with Barnes Wallis, he worked on design studies of variable swept-wing aircraft.

When that telephone call from the Admiralty in November 1956 first introduced Shaw to the hovercraft idea, he was particularly concerned with development of vertical take-off aircraft. One of the problems there was ground effect which generally caused loss of lift and instability; in Cockerell's suggestion he saw a means of actually exploiting ground effect. From that time on, he became an ardent supporter of hovercraft development and proved to be an invaluable "friend at court" to those in private industry who were trying to make progress against an attitude that was generally lukewarm. When Hovercraft Development Ltd was formed, Shaw became a director of the company (part time and unpaid) and remained so for two years, until 1960. During this time the prototype SR.N1 was built with NRDC funds and Shaw ran this programme as he would one of his research aircraft. The SR.N1 was of course an immediate success and a development programme followed. Other companies became interested and took out licences. The time came for Shaw to decide whether to work on hovercraft full time — he was offered a full directorship and the post of Chief Engineer — but he declined. He returned to full-time work on research aircraft at the Ministry. The hovercraft industry which he had done so much to nurture was however beginning to find its feet and now, from another point of view, Shaw was able to continue to be of help. Interest was being shown in the military application of hovercraft and the Inter-Services Hovercraft Working Party was set up in 1961. Research on military hovercraft was included in Shaw's programme and it was on this basis that Shaw was able to put through the world's first commercial sale of such a craft when the Ministry of Aviation bought Britten-Norman's CC-2. Then came the hiring of the SR.N1 and SR.N2 for trials by the Inter-Services Trials Unit which the Working Party had set up. Later on hovercraft were bought for trials in Borneo and elsewhere.

All this time, Shaw was the unassuming figure behind the scenes, providing encouragement as well as financial support in the way of Ministry purchases. He was spending about half his time on hovercraft, rather more than the money involved strictly merited, with the help of only one assistant on this work. His first assistant was Lieut-Cmdr Ashmead, attached to him from the Navy. He later became the first CO of the Inter-Services Hovercraft Trials Unit. It was Shaw who sent Ashmead to see the Mayor of Calais to organise the first Channel crossing of a hovercraft, the SR.N1 trip from Calais to Dover to commemorate the fiftieth anniversary of Bleriot's flight. It was an eventful trip in more ways than one, involving a slight altercation with the Customs over a celebratory magnum of brandy carried by one member of the party, running out of fuel within sight of Dover on the return run, and a bizarre experience during the demonstration on the beach at Calais when, although no one there had ever seen a hovercraft before, the SR.N1 circled within a few feet of a man digging for worms and he simply moved his bucket without even looking up at the strange craft.

It was Shaw who set up the Hovercraft Research Committee seven years ago, an unofficial body but representing everyone involved in the industry, the universities and the Government so that they could meet twice a year to discuss developments. A member of the Inter-Services Hovercraft Working Party from the beginning, he was Chairman of its Technical Committee. Last year, he set up the nucleus of a mixed Service–civilian hovercraft team within the Ministry.

Today, Shaw believes that only the surface of hovercraft possibilities has been skimmed. Now that the idea has become well established, it is necessary for more attention to be devoted to the building of craft more economically and for specific purposes. One of the main problems, as he sees it, is that many people think of hovercraft only as an alternative to existing forms of transport, whereas in fact it should be regarded as providing a means of establishing transport services in entirely new fields and in areas where other facilities would not be possible.

The nearest Ronald Shaw has ever got to owning a hovercraft machine — although he has of course travelled in every type of craft manufactured — is the possession of a hover-mower which he recently bought for the garden of his home in Hemel Hempstead. "It seems to have all the virtues and vices of true hovercraft," he says with a twinkle in his eye. "I've even found it can be made to plough in. Over level smooth lawn it moves with almost dream-like ease, on rough grass you can feel the resistance, and on slopes you have no doubt about the pull of gravity and you have to be careful with control."

SEASPEED

(*Continued from page* 31)

The SR.N6 is not particularly good for field maintenance, but some improvement is anticipated in this sphere in the near future. The maintenance of skirts and fingers are two of the most urgent problems, the first of these now having a TBO of something under half-way towards the 2,500 hr figure mentioned by Mr Lefeaux as the economic goal. Fingers are some of the most troublesome items, a TBO of 200-250 hr being realisable at present compared with the required TBO of 500 hr anticipated in the future. With the high utilisation of Seaspeed SR.N6s reaching 50 hr per week in the summer and 30-40 hr per week in the winter, it can be realised that higher TBOs are becoming an economic necessity.

Future Operations

There are three main ways in which the British hovercraft industry could be helped by the Government: by direct military financing, as in the USA; by the piecemeal financial support as in the UK at the moment; and by the provision of adequate finance to operators for the purchase of equipment. This last choice can be compared with the Viscount financial provision to BEA some years ago.

Next year, BRHL will take delivery of the first SR.N4 in May, and this is due to go into service on the Channel route on August 1st. An HM-2 rigid sidewall craft will be delivered to the company before the end of 1967 and this will go into service on the Solent. Planning for both these types and many others has been undertaken for a wide variety of routes, and the possible applications will be watched with considerable interest. In connection with the operations involving the SR.N4, it is anticipated that the maintenance of this craft will show some advantage over that of the SR.N6 because of the accessibility of components due to the scale effect, and the design advantages incorporated from the lessons learnt during SR.N6 operations.

NEW WORLDS TO CONQUER

The geographer who proposes to take an expedition to any part of the world is obliged now to consider whether or not the hovercraft is to become an essential part of the expedition's equipment. Its versatility is perhaps its strongest point. Often the leader of an expedition must first make a difficult landing on a treacherous coast and must transport to the shore all of the stores and equipment needed for the work to be accomplished. The hovercraft answers this problem for it should be able to take everything not just to the shore but the site of the base camp, all in one operation.

When a camp has been established, groups of workers must be taken to the regions in which study is to take place. The hovercraft can perform this task and not only will travel be fast but it can be by almost the shortest possible route. Rivers can be navigated, even if rapids, floods or drought conditions would prevent travel in more orthodox craft; swamps can be crossed; pack ice, always a hazard in polar regions, or melting ice on thawing rivers can be negotiated; deserts can be traversed at speed; and direct communication can be maintained with groups of workers operating at considerable distances from each other. When the time comes for disembarkation, then the hovercraft can play its part once again.

Many tests must yet be made before the capabilities of the hovercraft can be assessed fully but enough has been accomplished already to prove that it must soon become an essential piece of equipment on almost every major expedition. The many benefits that the use of these craft can bring in "The pursuit of wisdom with respect to place" may not yet be understood. It is very clear that they are going to make possible proper communication in regions of the world which have remained undeveloped because of their inaccessibility. They are going to make it possible for the people who can provide answers to many of the problems of such regions, the geographers, to get quickly to the places which they must study and from the study of which mankind will benefit.

The hovercraft industry has suffered many setbacks in the past. The geographers, now that they are learning what is possible, will soon be clamouring for the craft which they must have if they are to ensure that the development of their knowledge keeps pace with that of this new technical achievement. It will be disastrous if, for any reason, development of this vital piece of equipment is hindered in any way — or if the needs and resources of geographers are not understood and catered for by the designers and manufacturers.

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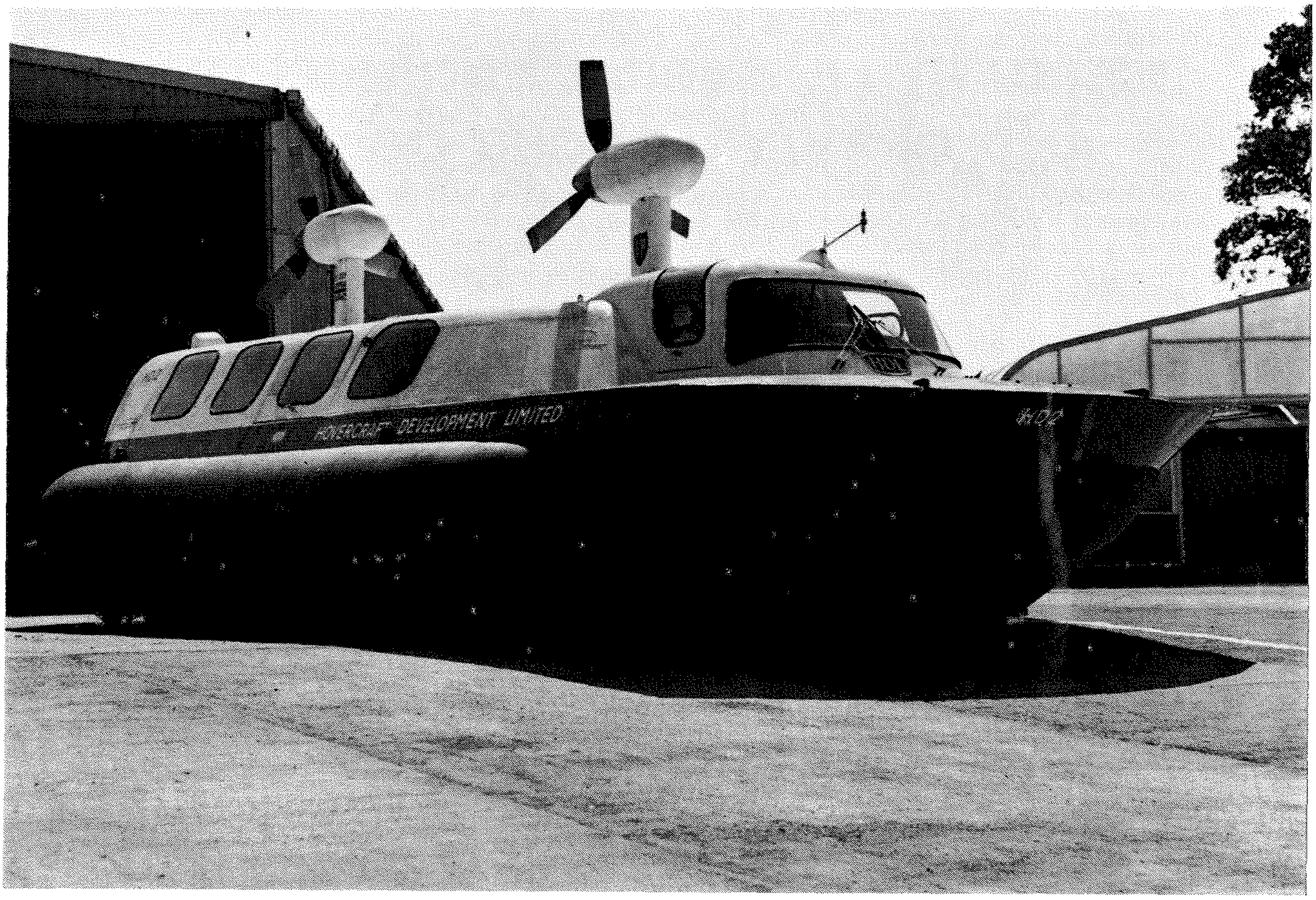

The HD2 research and development craft designed and built by Hovercraft Development Ltd at Hythe, Southampton, will be having trials this month. The craft, which weighs 4 tons and is a 30 ft long near-scale model of a 90 ton passenger/car ferry hovercraft, is powered by three Rover 150 hp gas turbines. It carries a crew of two and up to six technical observers. Its main purpose is controllability research and at its design speed of 50 knots it represents the larger craft travelling at 90 knots

People and Projects

The Minister of Technology, Mr Anthony Wedgwood Benn, has approved the proposals of the **National Research Development Corporation** for the further development of tracked hovercraft (hovertrain).

In approving the NRDC proposals the Minister said: "This marks another development of the hovercraft principle by Britain. The potential for the tracked hovercraft abroad is, I believe, very considerable, and I look forward to seeing this project attracting more of the best brains into this new industry."

The Minister's approval will enable the Corporation to go ahead with its plans to promote the world-wide use of high-speed guided land hovercraft transport systems. As already announced, NRDC will set up a subsidiary company, Tracked Hovercraft Ltd, and a suitable track test site has been found in East Anglia. Other preparatory work has also been going ahead smoothly. The experimental tracked hovercraft will be powered by a linear induction motor and is expected to be capable of speeds of up to 300 mph.

The company will continue the technical development and economic evaluation programmes already begun by another NRDC subsidiary, Hovercraft Development Ltd, at Hythe. The prospects for the economic success of the project will be reviewed at the completion of the first stage of the technical programme.

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Cushioncraft Limited a subsidiary company of Britten-Norman Ltd, who have designed and manufactured five different types of hovercraft since 1959, are now building a new craft, the CC-7.

The CC-7 is a quiet light hovercraft designed for amphibious use in relatively sheltered waters or over reasonably rough terrain. Experience gained by the company on their previous CC-4 and CC-5 fan-propelled craft has been widely used in the design of this machine. The CC-7 will carry up to nine passengers in addition to the driver and is readily convertible to a freighter. Dual controls may be fitted for driver training.

The principal structure is a simple and robust boat-like hull constructed mainly of salt water resistant light alloy. Great use is made of fibreglass and other non-corrodible materials. Skids which project below the hull bottom are provided for setting down. On the sides of the hull are attached inflated sidebodies of a simple mattress construction. Access to the cabin is gained by doors in the sides of the craft and at the rear of the cabin. A fireproof bulk-

Pictured on their return to Ramsgate after a trip to Calais in an SR.N6 hovercraft operated by Hoverlloyd Ltd are Sir Robert and Lady Menzies (centre), their daughter and son-in-law, and four granddaughters. Also in the group are Mr Leslie Colquhoun (extreme right), Managing Director of Hoverlloyd, Mrs Colquhoun (fourth from left), and Commander and Mrs Lloyd Price.

head divides the cabin from the engine bay. Either side of the engine bay there is a luggage space accessible from within the cabin.

No propellers are used on this craft. The engine drives centrifugal fans, which provide both lift and thrust. Hence the comparative quietness of this craft in operation.

The thrust of the propulsive fans is directed by rudders to give yaw control or reversed to give braking force either symmetrically or differentially resulting in good low-speed steering control. There is also provision for trimming the craft in pitch.

The skirt consists of a distribution bag with a lower skirt of segmented form. These segments take the bulk of the skirt wear, are readily replaceable and of low cost.

Large reserves of buoyancy are available in the inflated sidebodies.

CC-7 roles are as follows: Air/sea rescue, ambulance, amphibious ship's tender, Coastguard, Customs' patrol, executive, exploration, ferry, fire fighting, flood relief, freighter, harbour authority, ice reconnaissance, inshore rescue, land reclamation, medical services, military, oceanography, pilotage, police, postal and community services, sport fishing, taxi, tourist, training, water hyacinth control.

The power unit of the CC-7 is one United Aircraft of Canada ST.6B marine gas turbine developing 390 hp continuous rating.

Maximum speed of the craft is 50 knots, maximum gradient is 1:6, maximum range is 200 miles.

The craft will operate safely under the following conditions:

(a) Winds up to 20 knots
(b) Waves and surf 3–4 ft high
(c) Rocks up to 1ft above mean surface
(d) Ditches and holes 6 ft across
(e) Snow and ice conditions
(f) Mud, swamp and sand conditions
(g) Air temperatures between $-40°C$ and $+35°C$

The total direct operating cost for the CC-7 is approximately £10 per hour.

Dimensions:

Length	24 ft 6 in
Height	7 ft 8 in
Width	15 ft 2 in
Width (sidebodies deflated)	7 ft 6 in
Hard structure clearance	2 ft 0 in

Weights:

Tare weight	2,880 lb
AUW	5,000 lb
Payload	1,480 lb

Availability:

The CC-7 will be available for general commercial use in mid-1968.

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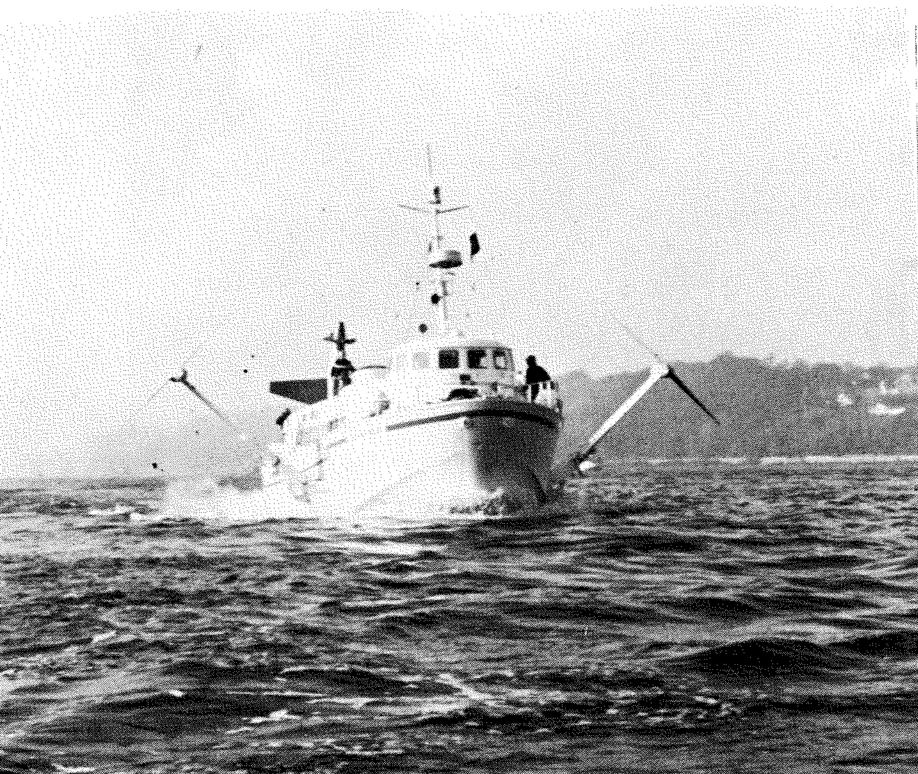
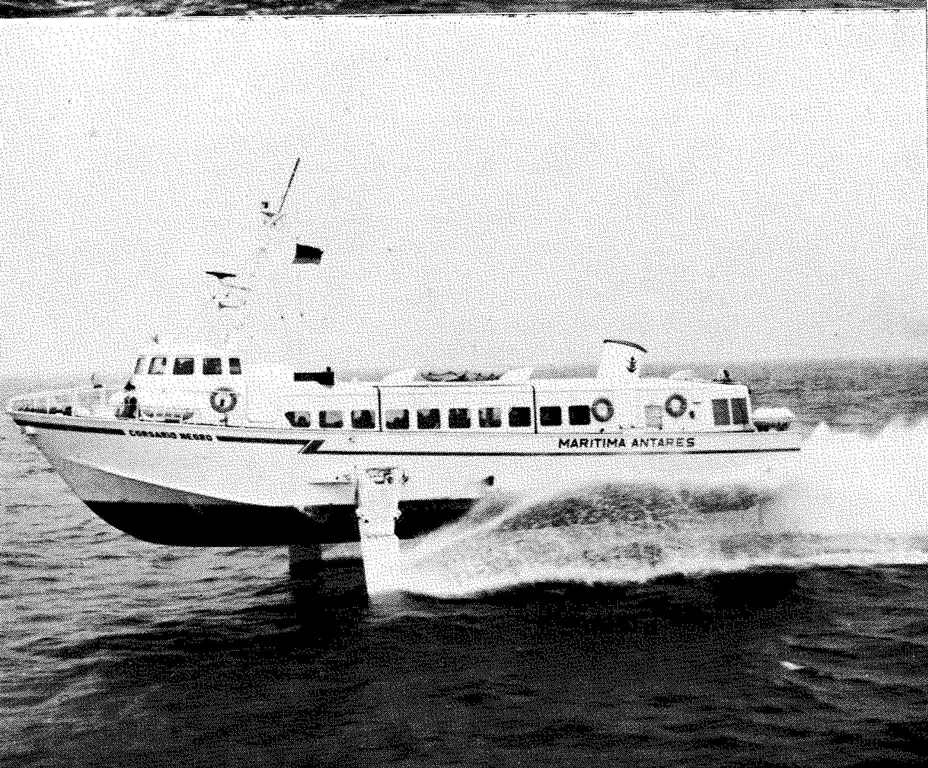
HAMBURG TO LAS PALMAS ON FOILS





by

G. M. Bailly-Cowell

On July 21st, 1967, the hydrofoil boat " Corsario Negro " reached Las Palmas after having made a three thousand and two nautical mile voyage from Hamburg during which the craft was foilborne for sixty-nine hours and thirteen minutes. This provided an excellent opportunity to familiarise and train its future Spanish crew, whilst invaluable data on many types of sea and weather conditions were recorded. No urgency was imposed to get the boat to Las Palmas on schedule, and no requirements for record-breaking were recommended, although all existing world records were, in fact, broken many times. The craft maintained an average speed of forty-five miles. Refuelling operations in ports were complicated because of the difficulty in obtaining the right kind of fuel at a preset time. A fuel dock filter had to be used permanently. Present on board the craft were representatives from Blohm and Voss (the Hamburg builders of the craft); Grumman Aircraft (the designers); Garrett Corporation (distributors and sales agents for the craft); and an engineer from Rolls-Royce (suppliers of the gas turbine engine). The following extracts from the log outline the voyage.

DATE JUNE 16th. Stretch from Hamburg to Calais. *Corsario Negro* starts on its three thousand and two nautical mile journey (3,002 miles) from Hamburg to Las Palmas. The craft leaves the Hanseatic capital and glides on its foils along the Elbe River to Cuxhaven, then proceeds to Calais, its first stop, through the Straits of Dover. In these waters, sandwiched between the Belgian and English coasts, the craft meets deteriorating weather and has to operate while foilborne against 8-12 ft waves and support a 25 knot tail wind. On that very day the *Corsario Negro* undergoes its first series of seakeeping capabilities as opposed to other existing hydrofoils by remaining in a foilborne state for nine hours over a distance of three hundred and ninety miles (390 miles).

DATE JUNE 18th. Stretch Calais to Cherbourg. *Corsario Negro* strolls along one hundred and eighty miles (180 miles) and remains foilborne four hours and seventeen minutes (4 hr 17 min) from Calais to Cherbourg Harbour under very pleasant weather conditions. This stretch of the journey will be the quietest passage of the entire trip.

DATE JUNE 20th TO JUNE 25th. Stretch Cherbourg to Roscoff. Leaving the French merchant and navy yards of Cherbourg, *Corsario Negro* is forced to seek refuge at Roscoff, after encountering a deadly Channel gale blowing from the English coasts. When approaching the famous Brittany isle of Ouessant, the craft faces a 7 knot current and 10 ft waves. After a three hour and twenty-eight minute (3 hr 28 min) foilborne voyage covering a distance of one hundred and sixty-seven miles (167 miles), the *Corsario Negro* shelters two days in Roscoff waiting for the weather to improve. The warm and friendly welcome of the local population, mainly composed of fishermen and yachtsmen, warms all hearts.

DATE JUNE 28th. Stretch Roscoff to Brest. One hundred and two miles (102 miles) are swallowed with the craft speeding foilborne on an 84-mile run in one hour and fifty-four minutes (1 hr 54 min) plus ten minutes at taxi speed. During this short voyage the *Corsario Negro*, under improved weather conditions, breaks a world record.

DATE JUNE 29th. Stretch Brest to La Pallice. The *Corsario Negro* rides uneventfully two hundred and thirty-eight miles (238 miles) and remains foilborne for five hours and thirty-six minutes (5 hr 36 min) under typical fine and clear Bay of Biscay weather. The craft enters La Rochelle Harbour (La Pallice) on its foils and takes off for a three-miles foilborne ride to satisfy the curiosity of the port pilot, amazed to realise the forty-seven mile speed of the boat. This indoctrination phase is part of the harbour's pilots' "get hydrofoil acquainted" programme.

DATE JUNE 30th. Stretch La Pallice to Bilbao. This section of the voyage introduces the *Corsario Negro* to its first Spanish port, after covering a distance of two hundred and twenty-five miles (225 miles), remaining the entire journey foilborne for five hours and twenty-one minutes (5 hr 21 min), during which another world record is broken. The coastal route was preferred to the open-sea La Pallice–Bilbao straight-line flight, with the boat keeping a distance of twenty to thirty miles off the coast to avoid fishing vessels.

DATE JULY 1st. Stretch Bilbao to Santander. Thirty-eight miles (38 miles) are covered in forty minutes under poor visibility, with an increasing north-westerly wind velocity and a sea state building up rapidly. Decision is taken to take shelter for the night at Santander.

DATE JULY 2nd. Stretch Santander to La Coruña. On that day another world record is broken, with the *Corsario Negro* covering a distance of two hundred and twenty-three miles (223 miles) in five hours and thirty-nine minutes (5 hr 39 min). The craft terminates this day's journey by sliding into La Coruña Harbour in total foilborne state.

DATE JULY 3rd. Stretch La Coruña to Vigo. Off Cape Finistèrre the *Corsario Negro* is met by heavy north-westerly winds, then gets into heavy swells while confronted with 8-10 ft waves. At one time the entire craft finds itself surfing on a swell speeding at 25-30 knots, thus increasing the speed of the vessel of 5 knots. The *Corsario Negro*, however, covers on that day one hundred and seventeen miles (117 miles), remaining foilborne three hours (3 hr).

DATE JULY 5th. Stretch Vigo to Lisbon. A distance of two hundred and fifty miles (250 miles) is covered under fine and clear weather; the boat is foilborne for five hours and thirty-three minutes (5 hr 33 min). Upon arrival at the pilot station at Cascais in Portugal, a pilot boards the craft and channels the *Corsario Negro* on a twelve-mile foilborne run to its dock in Lisbon. While passing alongside the world-wide-known Estoril summer resort coastline, the *Corsario Negro* achieves in fifteen minutes a ride which is normally accomplished in one full hour by ships speeding at twenty to twenty-five miles.

DATE JULY 17th. Stretch Lisbon to Cadiz. A pilot brings the *Corsario Negro* back to Cascais from Lisbon. Under clear weather and north-west winds, a distance of two hundred and fifty miles (250 miles) is covered with the boat remaining foilborne five hours and thirty-two minutes (5 hr 32 min).

DATE JULY 19th. Stretch Cadiz to Casablanca. In the middle of the Straits of Gibraltar, between the Spanish Peninsula and the desertic coast of Africa, the *Corsario* fights against heavy Levant winds blowing from Gibraltar to the Atlantic and is suddenly confronted with 8-10 ft waves. The craft is forced to proceed hullborne until it reaches the lee of Cape Spartel in Africa. This twenty-mile ride lasts two hours. After covering a distance of two hundred and ten miles (210 miles) while remaining foilborne four hours and twenty-four minutes (4 hr 24 min), and after avoiding fleets of tuna fishing trawlers, the *Corsario Negro* reaches Casablanca, where it remains for the night moored at a buoy in the harbour. As no rooms are available in town, the night is spent on board.

DATE JULY 20th. Stretch Casablanca to Agadir. Another world record is broken on that day, with the *Corsario Negro* covering a distance of two hundred and sixty-three miles (263 miles) in a complete foilborne mode during six hours and twenty-one minutes (6 hr 21 min). Population of Agadir is very friendly but the temperature ranges between 120 and 125° F or 50° C.

DATE JULY 21st. Stretch Agadir to Las Palmas. The final portion of the entire voyage reaches its end as the *Corsario Negro* covers a distance of three hundred and fifty miles (350 miles) while remaining foilborne eight hours and twenty-eight minutes (8 hr 28 min). The craft hits the port of Recife on the island of Lanzarote smack on due course and time after breaking out of a thick haze two hundred and twenty-six miles long (226 miles), exactly seven miles off the island. It then elects to proceed directly to Las Palmas. Having left behind the island of Fuerteventura, the *Corsario Negro* has its first casualty. A 75 lb dolphin is impaled on a pitot tube. The violence of the impact slows the boat by 5 knots without loss of control. The craft is stopped and the foils retracted in order to get rid of its burden. The *Corsario Negro* reaches its destination by arriving at Las Palmas in the evening, where it is met by the local Spanish civilian and military authorities and television.

DOLPHIN ITINERARY

Date	*From–To*	*Foilborne Time hr min*	*Distance miles*
16/6	Hamburg–Calais	9 00	388
18/6	Calais–Cherbourg	4 17	181
20/6	Cherbourg–Cherbourg ...	0 42	47
25/6	Cherbourg–Roscoff	2 46	120
28/6	Roscoff–Brest	1 54	102
29/6	Brest–La Pallice	5 36	238
30/6	La Pallice–Bilbao	5 21	225
1/7	Bilbao–Santander	0 40	38
2/7	Santander–La Coruña ...	5 39	223
3/7	La Coruña–Vigo	3 00	117
5/7	Vigo–Lisbon	5 33	250
17/7	Lisbon–Cadiz	5 32	250
19/7	Cadiz–Casablanca	4 24	210
20/7	Casablanca–Agadir	6 21	263
21/7	Agadir–Las Palmas	8 28	342 (+8)
	Totals	69 13	3,002

DOLPHIN TECHNICAL DATA

Main Engine
One Rolls-Royce Marine Tyne Mark 621

Maximum power ...	3,500 hp	
Cruise power ...	3,160 hp	

Auxiliary Engines
Two General Motors 6V-53N diesel engines of 216 hp each

Dimensions

Length overall ...	75 ft 0 in	
Length of hull ...	66 ft 8 in	
Beam of hull ...	18 ft 8 in	
Draft, foils retracted ...	4 ft 2½ in	
Draft, foils extended ...	13 ft 5 in	
Fuel tank capacity ...	9,000 lit	

Tonnage

Gross ...	83	
Net ...	52	

Weights

Gross weight (displacement) ...	60.0 metric tons	
Operating weight empty ...	48.0 metric tons	
	Max Payload	**Max Fuel**
Payload ...	8.2	4.7
Fuel (including reserve) ...	3.8	7.3
Range (nautical miles) ...	200	400

Performance

Take-off speed ...	25 knots	
Cruise speed ...	50 knots	
Fuel consumption ...	7.15 gal/NM	
Hullborne speed ...	8 knots	
Fuel consumption ...	1.23 gal/NM	

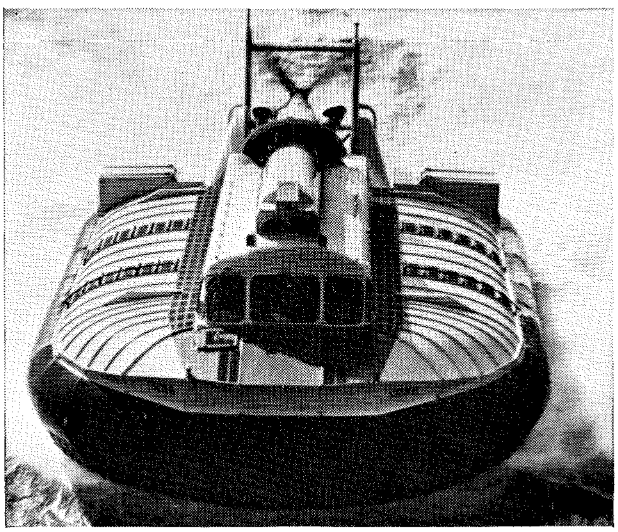
Seaworthiness

Sea state ...	3	
Wind velocity ...	17 knots	
Wave height ...	3-5 ft	

Manoeuvrability

Turning radius:		
Flat turn ...	760 ft	
Co-ordinated ...	840 ft	
Stopping distance from 50 knots ...	450 ft	

We power more hovercraft than anybody. How do we keep it up?



We know more about hovercraft gas turbines than anybody in the world. We've built more. For more types. For longer.

We've come a long way since the pioneering days of the 1950's. Take our Marine Gnome engines, powerplants of the BHC SR N3, N5, and N6. The Gnome has already achieved more than 25,000 hours' seagoing experience in hovercraft.

Then there's the Marine Proteus. That's the engine being installed in the new larger hovercraft. Like the 40-ton BH-7, the 80-ton BH-8 and the 160-ton, 500-seater BHC SR N4 which enters service in 1968.

And our Marine Olympus gas turbine has been specified for the BHC Hoverfreighter project. This is an ocean-going 480-ft., 4,000-ton hovercraft with a payload capacity of 1,600 tons and a top speed of 50 knots.

Hovercraft engines illustrate just one side of Rolls-Royce's marine expertise. In fact, we pioneered the use of lightweight gas turbines for naval craft. Now *eleven* of the world's navies have chosen our engines for their fastest fighting ships.

ROLLS-ROYCE

Industrial and Marine Gas Turbine Division,
P.O. Box 72, Coventry, England.

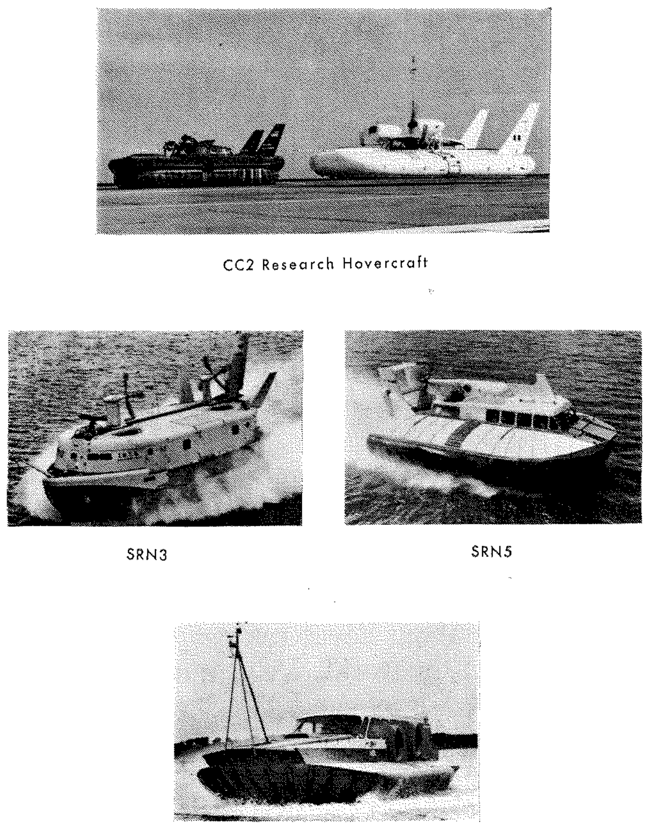
Hovercraft Research at Royal Aircraft Establishment, Bedford

by I. L. Keiller

Some recent work of the RAE on hovercraft research and development is briefly summarised. In addition to sections relating to the internal and external aerodynamics of hovercraft, some instrumentation requirements and test techniques are described

SYMBOLS

b	depth of fan exit	ft
$D_H, D_{ME}, D_{MF}, D_P, D_T$	components of drag (Fig 13)	lb
e	fan depth to radius ratio $= b/R$	
h	hoverheight	ft
$K_d = \Psi^{\frac{1}{4}} / \Phi_f^{\frac{1}{2}} e^{\frac{1}{2}}$	diameter coefficient	
$K_n = 0.399\, e^{\frac{1}{2}} \Phi_f^{\frac{1}{2}} / \Psi^{\frac{3}{4}}$	specific speed	
$K_p = P_f / \rho \Omega^3 e R^5$	power coefficient	
φ_p, φ_r	cushion reference lengths (Fig 12)	ft
N	fan rpm	
N_G	gas generator rpm	
P_f	input power to fan	hp
Q	volume flow	ft³/sec
R	fan outer radius	ft
t	jet thickness	ft
T_c, T_p, T_v	components of thrust (Fig 13)	lb
W	craft weight	lb
$\bar{x}_c, \bar{x}_g$	non-dimentional cp and cg movement, pitch	
$\bar{y}_c$	non-dimensional cp movement, roll	
η_h	hovering efficiency	
η_s, η_t	fan static and total efficiencies	
Θ	craft pitch angle	deg
ρ	air density	slug/ft³
σ	relative air density	
Φ	craft roll angle	deg
$\Phi_f = Q/2\pi\Omega e R^3$	fan flow coefficient	
Ψ_s, Ψ_t	fan static and total pressure rise coefficients	
$\Omega = N.\ 2\pi/60$	fan rotational speed	rad/sec



CC2 Research Hovercraft

SRN3

SRN5

CC5

Fig.1 Some Hovercraft tested by R.A.E.

1 Introduction

Hovercraft research has been a part of the RAE programme for the last five years. It was decided, when the hovercraft section was formed, that the emphasis should be on full scale flight research and that the work should grow out of this experience.

The Britten-Norman CC2-OC1 was acquired as the basic research vehicle and over the years a considerable research programme on internal and external aerodynamics has been undertaken. Provision was later made for model test programmes to complement those at full scale. In addition to the overland tests at Bedford with the CC2, work has been undertaken on the overwater performance of the SR.N2, SR.N3 and CC5 craft, and tests are in hand on the SR.N5.

In this paper, summaries are given of some aspects of the research work on hovercraft that has taken place recently at the RAE. The information is based on both published and unpublished work.

2 The Development of Improved Fans

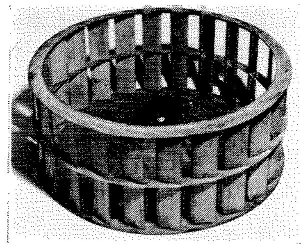
The development of improved fans was specifically initiated by the RAE in support of the CC2 flight research programme, but it soon became apparent that there was a wide hovercraft application for radial flow fans of high efficiency.

The work has been based on principles put forward in a German handbook for ventilating fans, which describes the performance of fans required to have a large capacity for their diameter. These fans are characterised by having relatively few blades of large chord, twisted to accommodate the spanwise velocity gradient at their leading edge, and of low trailing edge angle to obtain a high value of static efficiency. Following experimentation in a fan test rig with a series of differing designs, total and static efficiencies of 0.90 and 0.70 were finally realised in the types designated E1 and G1. These fans are shown in Fig 2 in comparison with the original manufacturers' fan, with peak efficiencies of only 0.69 and 0.43, and an Airscrew-Weyroc Heba fan of efficiencies 0.90 and 0.61.

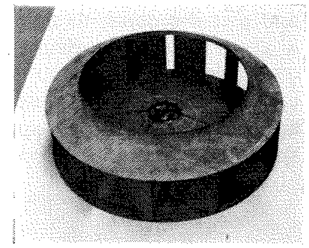
Both E1 and G1 fans have been manufactured and tested full scale in the CC2-001 hovercraft. Because of the extremely low thickness-chord ratio of the type E1 fan blades, their construction in light alloy would have been difficult and so they were made by bonding glass fibre skins to a light alloy honeycomb core. This method was not considered to be practical for commercial construction and the G1 fan was designed using thicker aerofoil section blades. The shape of the G1 blades is such that the inner and outer surfaces are of single curvature, simplifying blade manufacture.

Fan performance may be presented in the form of characteristic curves in which the variation of total and static efficiency η_t and η_s, pressure coefficient Ψ, and power coefficient K_p are shown against flow coefficient Φ_f. Unique functions are obtained if Reynolds number effects are small. The model fans tested ranged between 24 and 28 inches in diameter and were tested over the speed range 900-1500 rpm. The efficiencies obtained are probably conservative when predicting the performance of larger fans. Typical characteristic curves are shown in Fig 3.

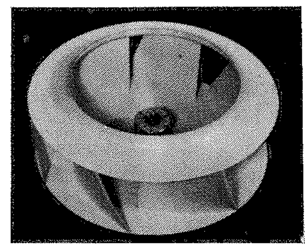
The full scale hovering performance of CC2 when fitted with various fans is shown in the following table. The improvement is demonstrated in two ways: the increase in weight supported at 220 hp and 1 ft hoverheight and the reduction in power required at a weight of 6000 lb and 1 ft hoverheight.



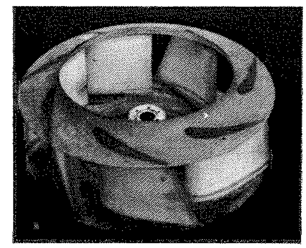
Original Fan



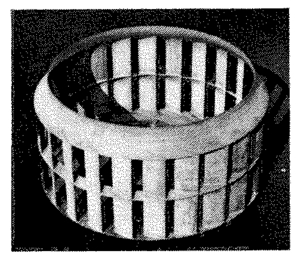
Heba Fan



High efficiency E1. fan - thin blades



High efficiency G1. fan - aerofoil blades



Low diameter coefficient experimental design H

Fig.2 Different fans

	CC2-001 original fans	CC2-002 Heba fans	CC2-001 E1/G1 fans
Fan diameter	5′ 5″	6′ 11″	6′ 11″
Increase in weight at constant power relative to original fan: 220 hp, 1 ft	1.0	1.16	1.58
Reduction in power at constant weight relative to original fan: 6000 lb, 1 ft	1.0	0.81	0.50

The E1, G1 and Heba fans show considerable advantages over the original design, and much of this improvement is due to their increased diameter with correspondingly lower exit velocities. For the tests with E1 and G1 fans, some increase of efficiency is attributable to improved intake design and reduction of plenum obstructions: model tests have nevertheless shown the superiority of the E1/G1 fans over the Heba under identical conditions.

The requirement of minimum fan diameter for a given volume flow has led to the definition of a diameter coefficient, K_d, where

$$K_d = \frac{\Psi^{\frac{1}{4}}}{\Phi_f^{\frac{1}{2}}\ e^{\frac{1}{2}}}$$

and e is the depth to diameter ratio at the fan outlet. For a given duty, fan diameter is proportional to diameter coefficient. Another commonly used parameter for discussing the suitability of a fan design for a particular application is that of specific speed. For a given duty, speed of rotation is proportional to specific speed and is given by

$$K_n = 0.399 \frac{e^{\frac{1}{2}} \Phi_f^{\frac{1}{2}}}{\Psi^{\frac{3}{4}}}$$

It will be seen that

$$K_d \propto \frac{1}{\Psi^{\frac{1}{2}}} \cdot \frac{1}{K_n}$$

Low diameter coefficient is therefore seen to be associated with high specific speed.

The original design of fan had a low diameter coefficient but also a low efficiency. There was a bad flow separation from the small radiused inlet of the upper shroud and also from the central blade support ring which was badly misaligned to the direction of flow. Development of this original design has since been continued and resulted in the experimental design type H shown in Fig 2. This fan achieves efficiencies of 0.83 and 0.56; this is a useful improvement over the original fan, and it is thought that the application of a modest degree of twist to the blades would bring still further improvement.

The maximum fan static efficiencies for the fans discussed are shown in Fig 4 as functions of diameter coefficient and specific speed respectively. It will be seen that the fans with lower diameter coefficient are less efficient than the other fans.

RAE participation in fan development is currently being reduced, the programme being taken up by the National Engineering Laboratory, East Kilbride.

3 The Performance of Fans in Hovercraft

When considering the performance of a given fan in a hovercraft, it is necessary to know the fan behaviour under conditions of both changing weight and rise height. A powerful reduction method has been developed for the treatment of experimental results. It has been shown that in the absence of Reynolds number effects the coefficients of fan volume flow and power, Φ_f and K_p and the parameters

$$\frac{Q\sigma^{\frac{1}{2}}}{W^{\frac{1}{2}}} \quad \frac{N\sigma^{\frac{1}{2}}}{W^{\frac{1}{2}}} \quad \text{and} \quad \frac{\text{fan power } \sigma^{\frac{1}{2}}}{W^{3/2}}$$

have unique relationships with hoverheight providing there is no deformation of the structure forming the air ducts. This leads to a considerable simplification of flight test performance evaluation, and enables the effect of flexible structure deformation with changing weight conditions to be assessed.

The application of the method is typified by the results of an overload trial on the VA3 hovercraft fitted with flexible skirts carried out under MOA contract. Fig 5 (a) shows the relationships between craft weight and mean rise height for three fan rpm, and Fig 5 (b) shows the data in the reduced form. It will be seen that with the exception of the lightest weight tested, the data can be considered to fall on a single line. Similar results have been obtained using the method to reduce volume flow and power data on other hovercraft tests where these have been measured.

Little work has apparently been carried out on the *in-situ* performance of radial-flow fans in hovercraft. NEL have built an environmental model for this purpose, with the intention of using several of the fans developed by the RAE. The fact that a unique relationship exists between fan flow coefficient and hoverheight suggests that a similar relationship also exists between fan efficiency and hoverheight. Using full scale measured values of volume flow and rpm, and the fan performance characteristics gained from the similar model fan in a radially symmetric environment (Fig 3) the change of flow coefficient and corresponding fan total and static efficiencies are shown with hoverheight for the CC2 hovercraft in Fig 6. It will be seen that above h = 0.7 ft (h/t = 2) the change of Φ_f with h is relatively small, and the corresponding fan efficiencies remain near the maximum value for all greater hoverheight tested. By suitable matching, therefore, it is possible for a radial flow fan of fixed geometry to operate at high efficiency over a large range of hoverheight.

Work on the performance of fans in hovercraft is continuing as part of the programme to optimise lift system efficiency. Besides the duct pressure loss associated with obstruction to the airflow, there appears to be a substantial "installation" loss, possibly associated with diffusion and the change of velocity profiles downstream of the fan. On the SR.N3 hovercraft, in a region of the distribution duct where there was no obstruction to the flow, a total pressure loss of 10% was measured within approximately 4 ft of radial distance downstream of a $6\frac{1}{4}$ ft radius fan, see Fig 7. It is hoped that the work on the NEL environmental model will lead to a clearer understanding of the losses inevitably associated with a hovercraft fan installation.

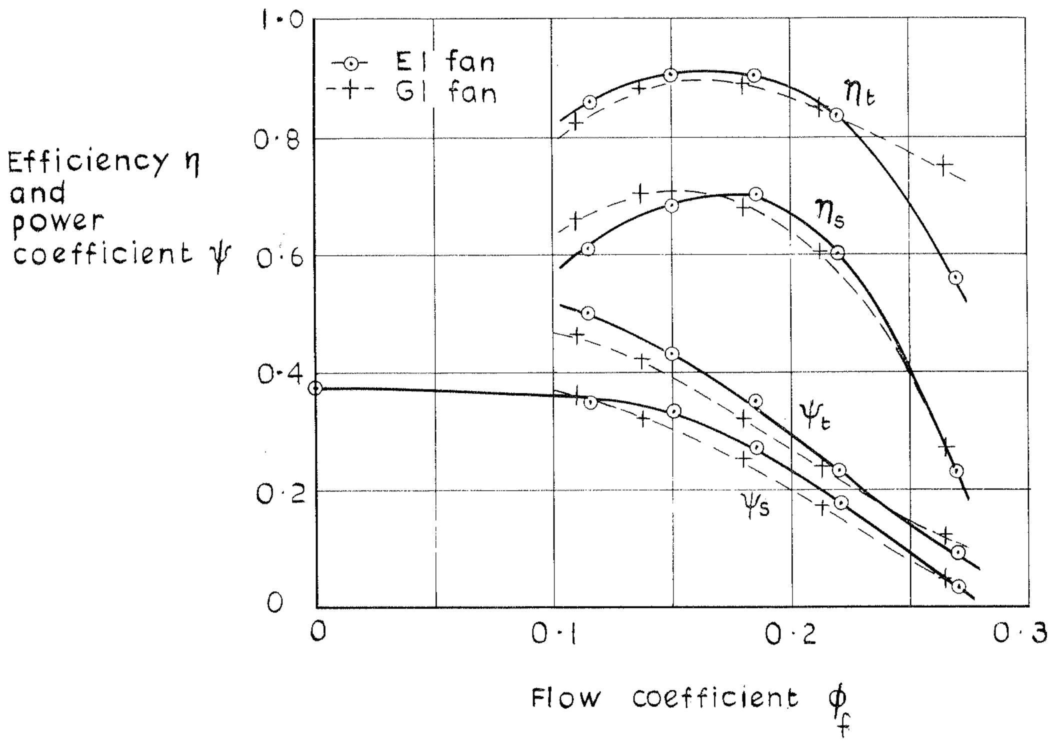
4 Hovering Efficiency

To enable comparisons to be made between hovercraft of different types, a hovering efficiency parameter has been proposed. The hovering efficiency, η_h, has been defined as the ratio of theoretical edge jet power to fan input power, and therefore includes fan efficiency, duct losses, effects of stability flow requirement, jet energy maldistribution, etc. The theory due to Elsley is used to determine the edge jet power. For the case of plenum chamber craft or those where an annular jet cannot be defined, the reference jet power is calculated on the basis of the optimum value of the jet geometry parameter,

$$x = \frac{t}{h}(1 + \cos\theta) = 0.7.$$

The hovering efficiency of a peripheral jet machine varies with hoverheight, as is demonstrated by results obtained from a 1/3 scale half-model of the CC2, Fig 8. The hovering efficiency, η_h, is seen to reach a maximum at a hoverheight of between 2 and $2\frac{1}{2}$ inches depending on model configuration, compared with expected peak fan efficiencies at hoverheights between $3\frac{1}{4}$ and $4\frac{1}{2}$ inches. Peak hovering efficiency always occurs at a lower hoverheight than that of peak expected fan total efficiency due to the presence of duct losses. The effect of obstructions, obstructions plus severe plenum leakage, and severe jet energy maldistribution is seen to reduce the maximum hovering efficiency progressively from 0.67 to 0.50.

Tests on several types of full scale hovercraft have shown that most have hovering efficiencies lower than 50% at their normal operating hoverheight. Fans placed asymmetrically on the planform, bracing structure obstructing the airflow, and losses in the differing types of flexible understructure all lead to a reduction of efficiency, with consequent economic penalty.



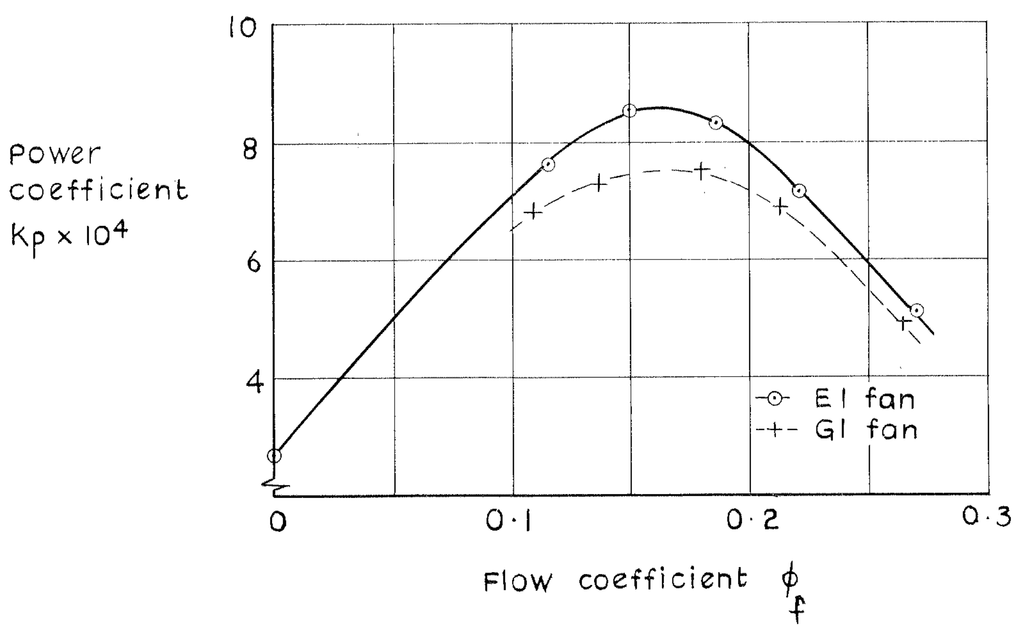
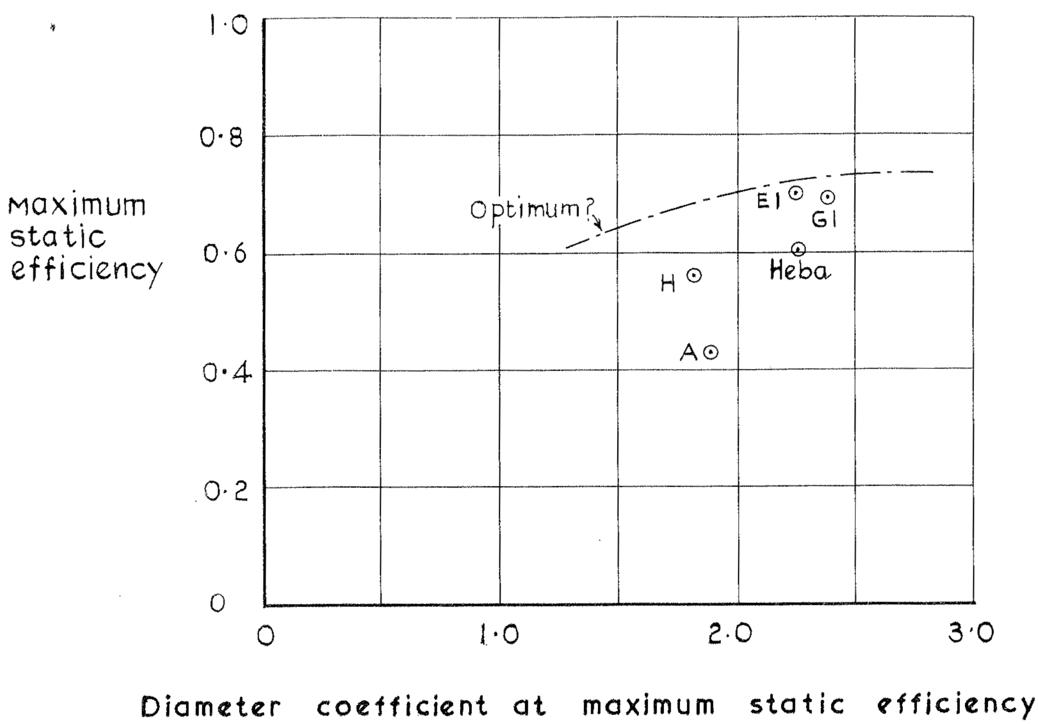


Fig. 3 Fan types E1 and G1 characteristic curves



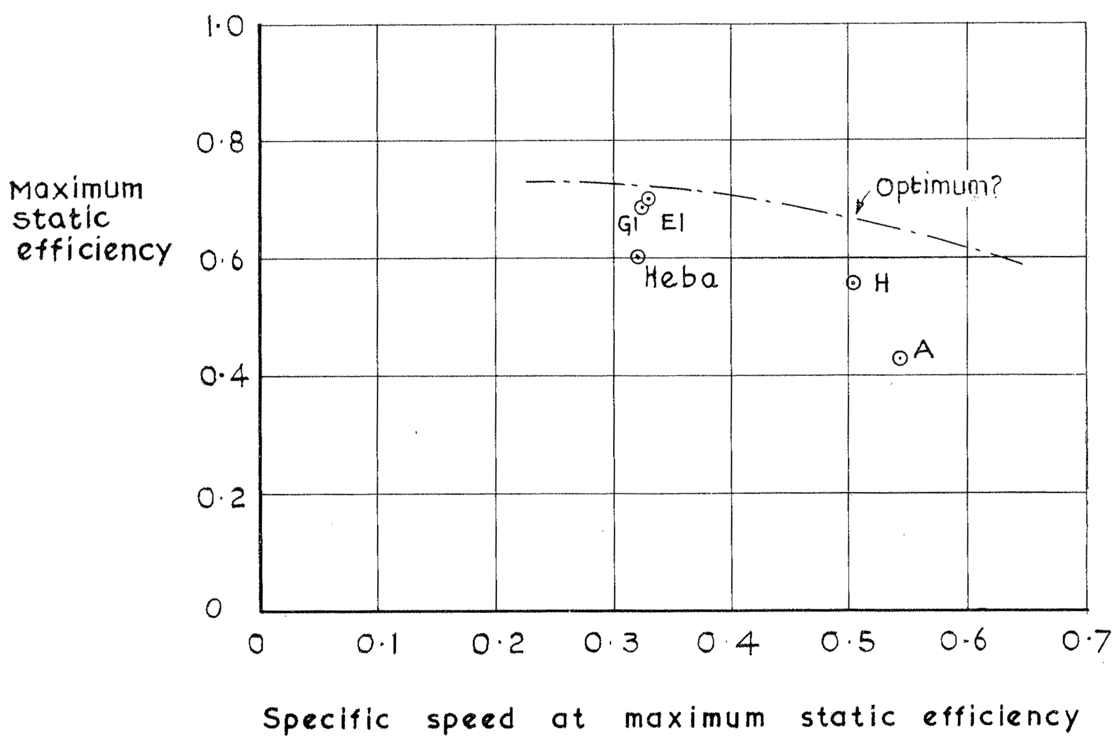


Fig 4 Fan efficiency, diameter coefficient and specific speed

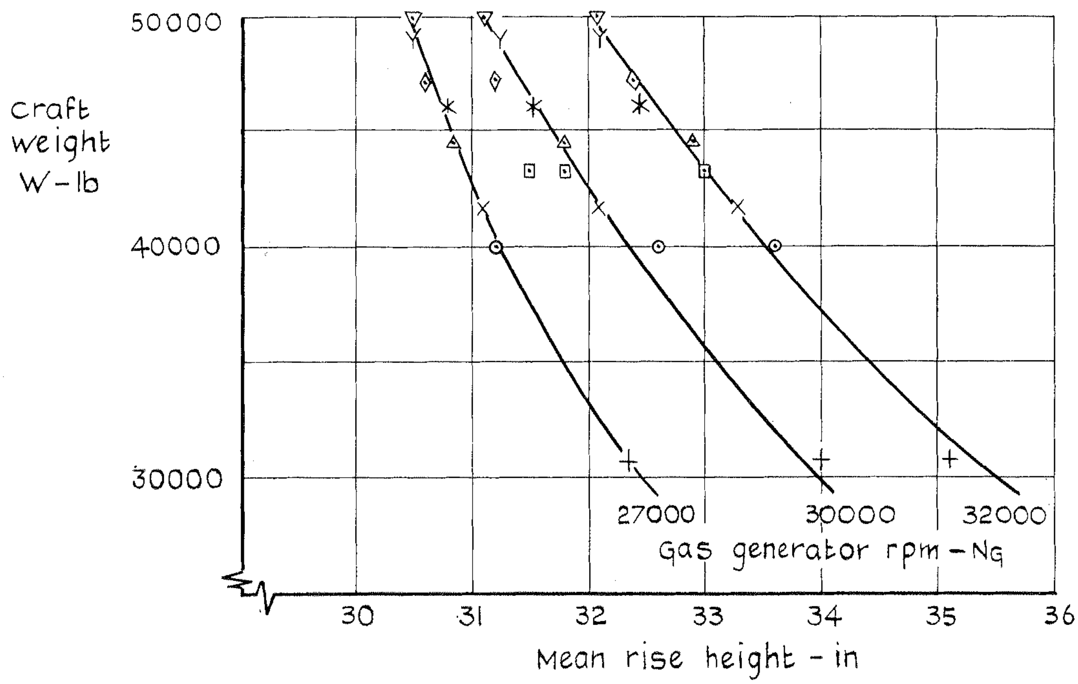


Fig.5a Variation of craft weight, gas generator rpm and rise height - VA3

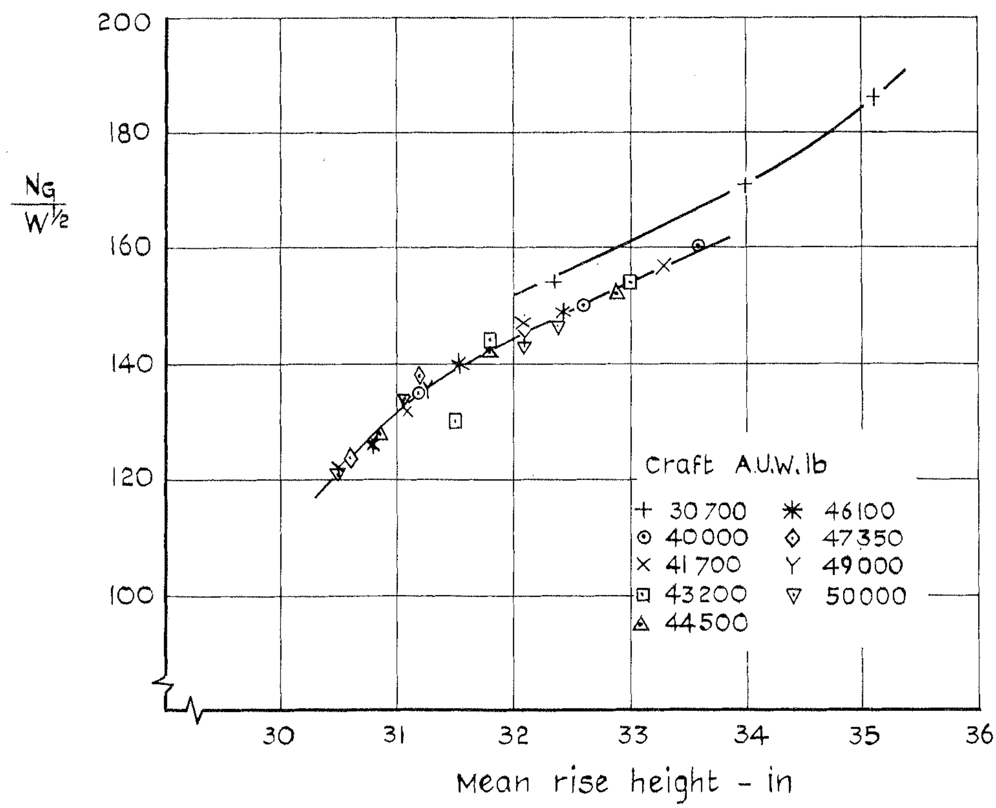


Fig. 5b Reduced rpm / weight / rise height data - VA3

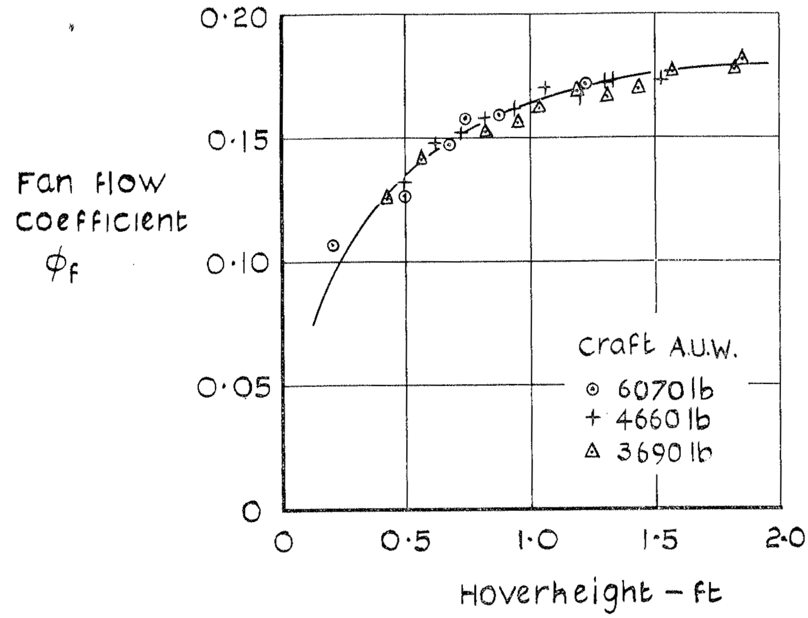


Fig.6 a Change of fan flow coefficient with hoverheight CC2-001, E1 fans

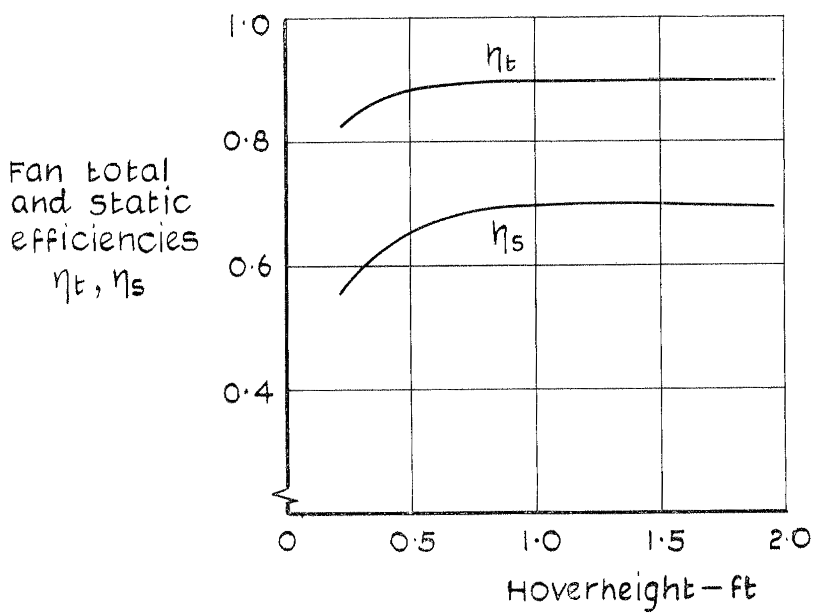
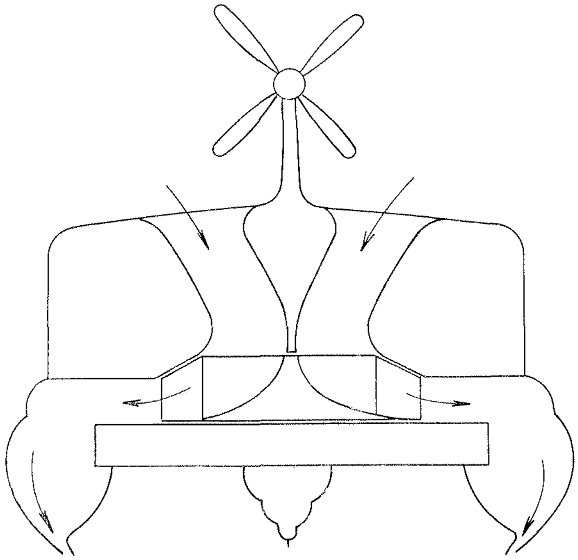
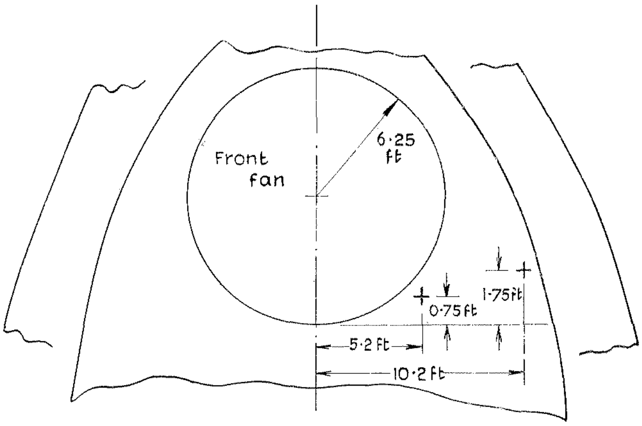


Fig.6 b Change of expected fan efficiencies with hoverheight — CC2-001, E1 fans



Section at front fan



Traverse positions marked +

Fig.7 Diagram showing plenum traverse positions – SRN 3

5 Cushion Aerodynamics

A programme of tests is being carried out in conjunction with R. & D. E. Cardington to examine the lift performance of a variety of designs of flexible skirt sections, some of which have been tested at 1/3 full scale on the CC2 model rig, and full scale on CC2-002. Examples of these skirts are shown in Fig 9. The purpose of the tests is to produce a design of skirt which has the best possible lift performance commensurate with satisfactory wear and behaviour in use. Results obtained on the CC2 model rig for one of the designs are shown in Fig 10 in comparison with those of the original hull. It will be seen that in the skirted configuration, some 84% of the original hoverheight is achieved for constant power input. The work is continuing and CC2-001 is shortly to be rebuilt in a form suitable for further development work in this field.

Measurements have been made of the static stability of a number of different hovercraft types, and evidence is being gathered concerning the change of static stability with hoverheight and configuration, and the effectiveness of cushion and skirt lift controls. Static stability is normally expressed in terms of both centre of pressure and centre of gravity movement, the cg stability always being less than the cp stability due to the destabilising effect of the cg height above the cushion. Some typical static pitch stability and pitch control effectiveness results are shown in Fig 11. For this craft and configuration, the free flight (cg) pitch stability is seen to be very small, with good control effectiveness.

The static stability of a hovercraft is often nearly linear for small displacements either side of level trim, and it is convenient to use the slope of the stability curves for comparison between configurations. The results of some of the tests carried out are shown in Fig 12 as a function of mean hoverheight to appropriate cushion reference length. A practical stability boundary for three-dimensional craft is also shown on the figure.

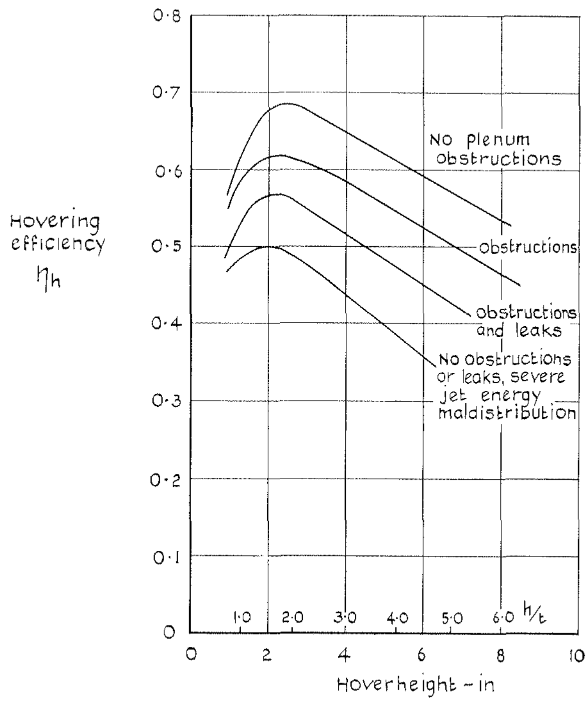
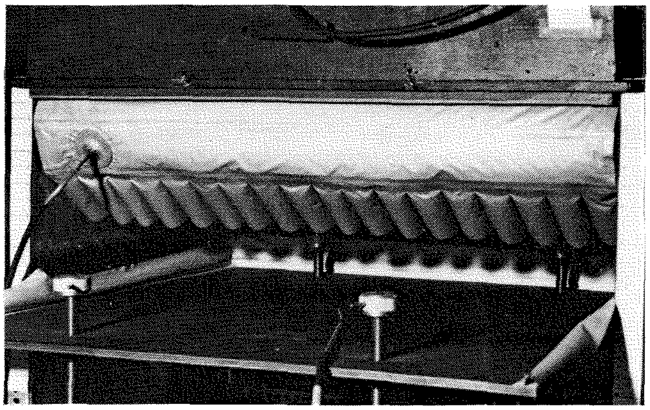
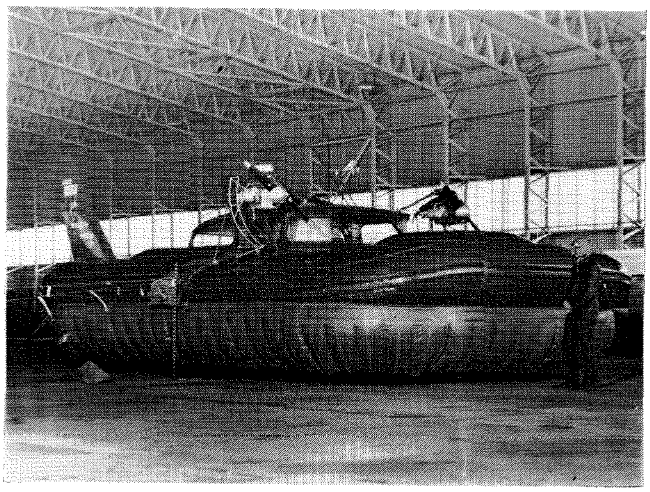


Fig.8 Effect of changing configuration and hoverheight on hovering efficiency



2 - dimensional model test



Full scale test (CC2 - 002)

Fig.9 Development work on flexible skirts

6 The Forward Performance of Hovercraft

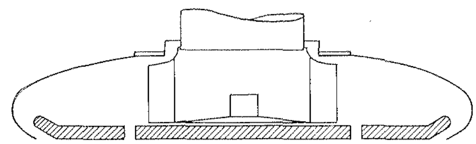
The forward performance of a hovercraft over water is dependent on the relationships between thrust and aerodynamic drag with air speed, and hydrodynamic drag with water speed. The hydrodynamic drag over given surface conditions will be a function of the particular design of skirt fitted to a craft, and may be influenced by craft roll and pitch motions. The aerodynamic drag is a function of lift volume flow, and the net propeller thrust may be less than expected due to propeller/intake interaction effects. Programmes of tests to determine the performance of hovercraft at forward speed are currently being carried out on an SR.N5 and on CC2-001, and brief tests have been made on CC5.

Typical results obtained on the SR.N5 are shown in Fig 13. Lift volume flow and propeller thrust were measured with the craft flying under steady forward speed conditions at known mean pitch attitude. The gross cushion + plenum vent thrusts at speed were assumed to be those measured during tethered tests when hovering, suitably corrected for changes in cushion pressure and fan total pressure. At each of the forward speeds tested the craft had nominally the same pitch attitude and lift fan rpm. These results were obtained in very calm seas, and work is continuing to determine the dependence of drag on wave condition and differing types of skirt.

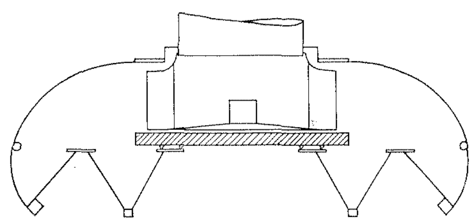
The relative positions of propellers and lift fan intakes on hovercraft can be important, as a significant proportion of propeller slipstream can be drawn into the fans with consequent reduction of net thrust. This effect is illustrated by results obtained on the CC2-001 craft, and in Fig 14 the change of net thrust with propeller rpm is seen for different aft lift fan rpm. Similar results have been observed at both model and full scale on the SR.N3. Total pressure measurements recorded in the aft intake of the SR.N3 model show clear evidence of the presence of propeller slipstream, as can be seen in Fig 15.

7 Instrumentation and Technique

In full-scale flight testing of hovercraft, certain problems are presented which are unique to this type of vehicle. Because of their relatively low air-speeds, they can be considerably influenced by frequently encountered wind conditions; the presence of winds introduces problems arising from the inequality of ground or water and airspeeds; and for overland operation the craft is as greatly influenced by small changes of gradient as it is by contact with waves over water. These particular problems demand that special instrumentation and techniques should be employed for meaningful analysis of craft performance.



Original configuration



Flexible configuration

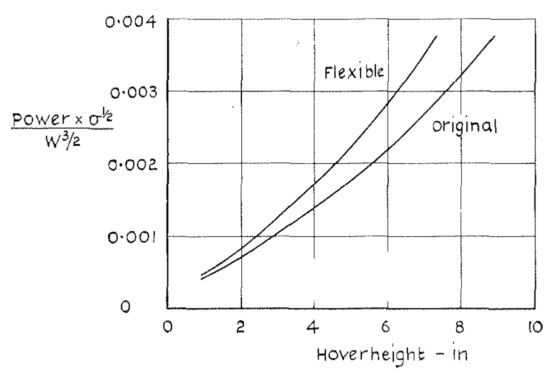


Fig.10 CC2 Half-model in two configurations

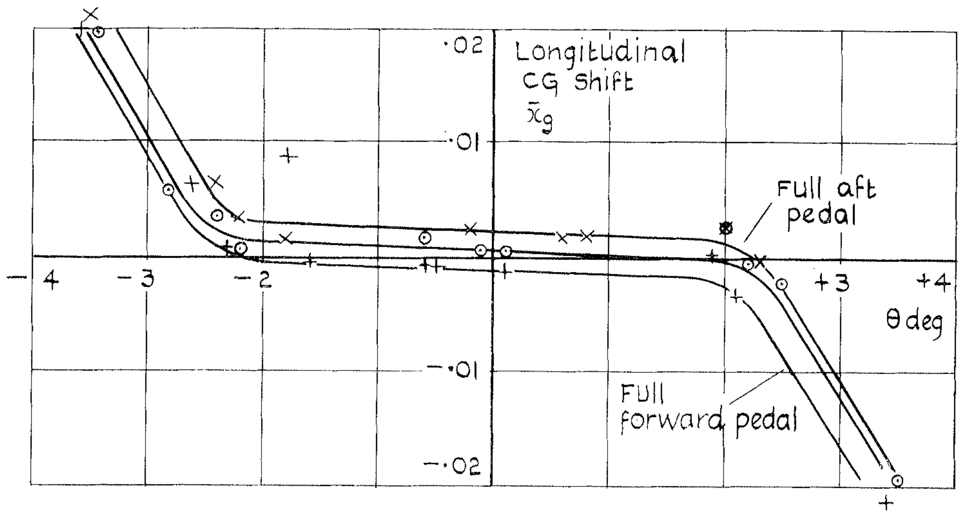


Fig.11a Static stability and pitch control effectiveness free flight-CC2-002 config^{n} flex-1

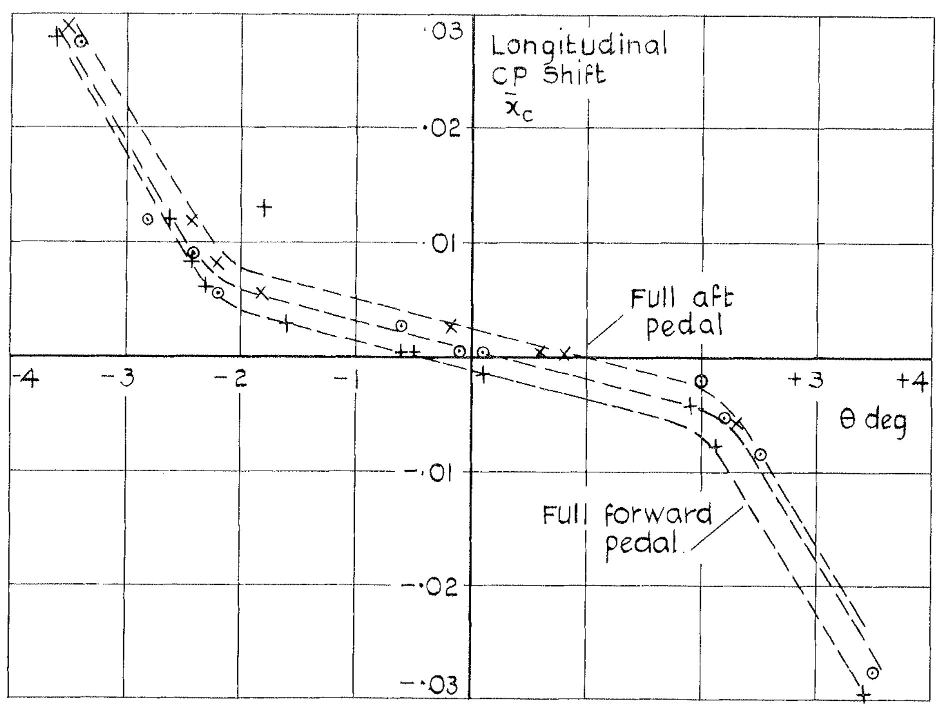


Fig.11b Static stability and pitch control effectiveness as a function of C.P. shift — CC2-002 config^{n} flex-1

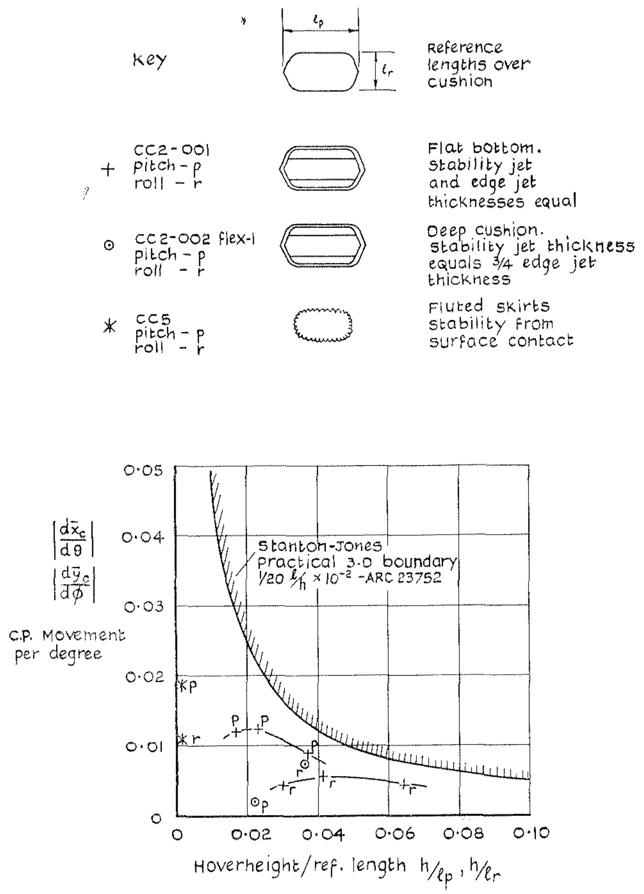


Fig 12 Change of static stability with hoverheight and configuration

Because the lift force on the craft is largely generated by the cushion, considerable translational forces can be introduced as a result of changing craft attitude. To give an appreciation of the magnitude of the effect, the force introduced due to tilting a hovercraft is of the order 0.0175 x craft weight per degree. A typical craft may have a cruise lift/drag ratio of the order 7, equivalent to $D = 0.14\,W$. It is therefore apparent that one degree of pitch change may introduce a longitudinal force change of over 10%, and in order to define the forces to an accuracy approaching 1%, the pitch attitude of the craft must be measured to an accuracy of 1/10 degree. This demanding standard has been adopted for RAE trials. Due to the drift problems encountered with most gyros, attention has been directed towards the use of pendulous devices, but these require steady flight conditions to be maintained as they are susceptible to longitudinal or lateral acceleration errors. A remote reading pendulum which meets the accuracy requirement and has variable damping characteristics is currently in use.

"Cushion" forces, control effectiveness, and thrust measurements are determined at zero forward speed for various cg positions with the craft restrained by four tethering cables, a technique which has been successfully employed both within large hangars and in the open. Strain links are provided in each of the tethering cables, and sufficient sensitivity is obtained without the use of amplifiers by direct coupling to the galvanometers of a UV recorder. The geometry of the tethering arrangements is usually such that the change of attitude with cg movement is less than would be obtained under free flight conditions, and a computer programme has been developed to calculate the necessary corrections. As has been discussed in para 5, results are presented in terms of both free flight cg movement and cp movement with attitude, the latter being equivalent to the cushion aerodynamic moment in the absence of cg toppling effects. Typical results for CC2-002 in a flexible skirt configuration were shown in Fig 11.

In order to determine the magnitude of momentum or lift air intake drag, it is necessary to measure the lift volume flow under forward speed as well as static conditions. Also it is often desirable to monitor fan, plenum and cushion pressures in order to estimate the effectiveness of supplementary thrust devices. A technique involving readily interchangeable Kiel, total and statio pressure probes has been adopted, mounted on rakes in appropriate positions in the intake, behind propellers and fans, etc, with the pressures recorded either by fluid filled manometer or using a pressure transducer/scanning valve combination. Whilst the use of a manometer is the most straight-forward method for pressure measurement, and reasonably satisfactory results have been obtained by mounting the manometer vertically across a cabin bulkhead such that it is not influenced by craft pitch motion, vertical oscillations of the fluid columns invariably lead to read-out difficulties, and the more accurate transducer/valve method is preferred. A cycling time of about 5 sec has been found to be satisfactory for a valve scanning 50 pressure points, and mean pressure levels on consecutive scans show good agreement under uniform forward speed conditions. When operating over water, severe spray conditions are frequently encountered at the lower speeds, and an air purging system has been employed to keep the pressure measuring instrumentation free of contamination.

Typical intake velocity contours obtained at forward speed are shown in Fig 16 with the positions of the total and static pressure measuring points marked. It is interesting to note that a volume flow derived from the mean values of the 16 static and 21 total pressure points agrees within experimental accuracy with the value computed by planimeter integration of the contours, leading to a simplification of flight data analysis.

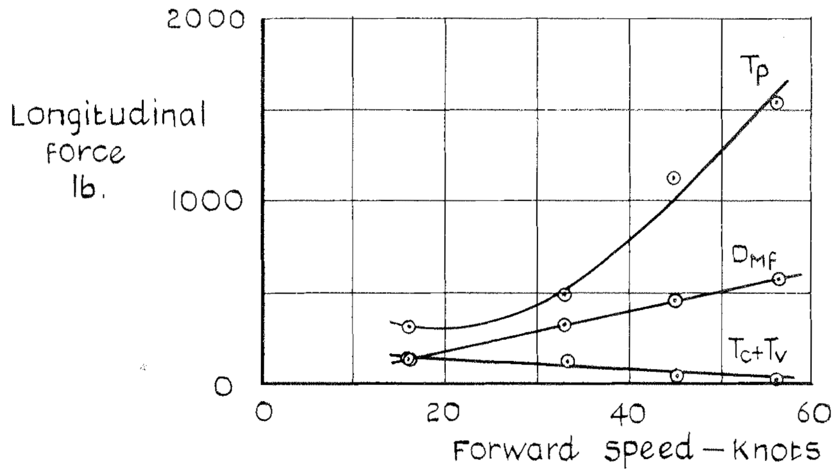
For all pressure measurements on the craft at forward speed, it is necessary to have known reference pressure. Cabin pressure on a hovercraft cannot be assumed to be ambient, and because static pressure probes are subject to significant errors under even moderate sideslip conditions, free stream total pressure as determined by a shrouded pitot head has been adopted as the most suitable reference. This reference pressure is particularly appropriate to propeller and intake work, whilst plenum and cushion pressure measurements can readily be related to ambient pressure from a knowledge of airspeed. When using the pressure transducer/scanning valve technique, it has also been found desirable to scan a calibration pressure on each cycle.

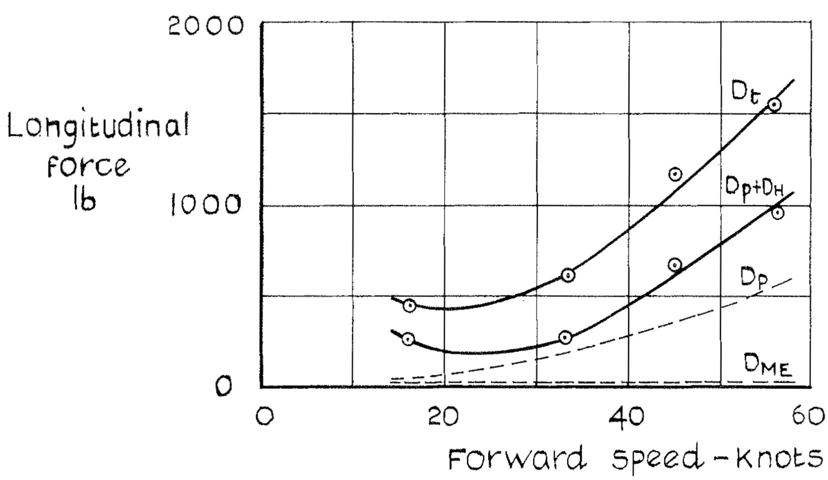
Work on a high-sensitivity cup anemometer for measuring airspeed was initiated by the RAE some years ago, and an instrument well suited for the requirements of hovercraft trials has been developed. This is shown together with a wind vane in a typical installation in Fig 17. Airspeed and relative wind direction (sideslip) are displayed to the pilot on large, easily read instruments, and independent outputs are provided for recording purposes to prevent meter/recorder galvanometer coupling effects. Forward performance data suitable for drag analysis must ideally

Total drag (D_T) =

Aerodynamic profile drag (D_P)
+ Hydrodynamic drag (D_H)
+ Fan momentum drag (D_{MF})
+ Engine momentum drag (D_{ME})

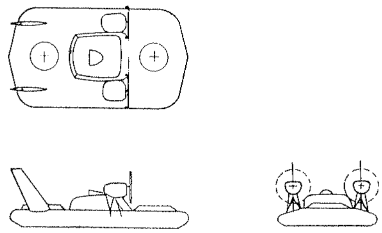
= Net prop. thrust (T_P)
+ Gross cushion thrust (T_C)
+ Gross plenum vent thrust (T_V)





Mean trim 1·5 deg. bow up. Turbine RPM 17200
A.V.W. 12500 lb., D_P estimated on $C_D = 0{\cdot}3$

Fig 13 Drag and thrust figures for SRN5 in calm water, zero wind



CC 2-001

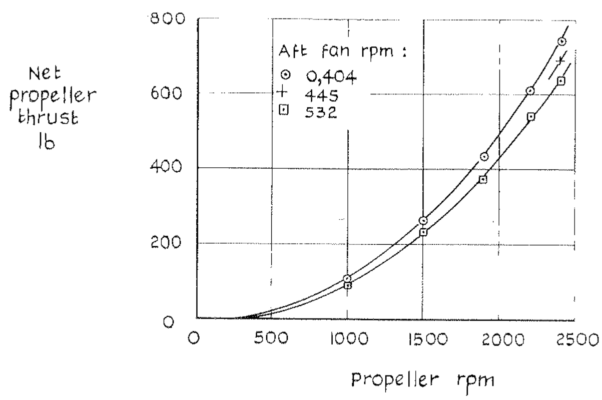


Fig 14 Change of net propeller thrust with aft fan rpm – CC2-001

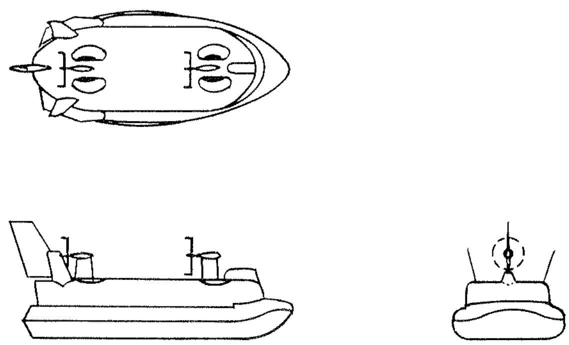
be obtained under zero-sideslip conditions, and the pilot is asked to fly within sideslip limitations of ±2 or ±5 degrees depending on the accuracy requirements of the test. Ground or water speed is obtained from the use of a Marconi Doppler speedmeter unit where possible.

For several years work has been progressing under contract on the development of an ultrasonic height indicating meter*, which has now reached a reliable operating condition for tests over concrete and grass. Tests are shortly to be carried out over water. The instrument provides for both recorder and display meter outputs, and is capable of indicating displacements between 8 in and 6 ft. The transmitter/receiver head, electronics, and a typical display meter are shown in Fig 18. Development work is at present centred on an installation of three instruments so placed on a craft that a combination of outputs can give pitch and roll angles, and mean hoverheight or rise height relative to the local surface over which the craft is operating. This is particularly important for overland testing where the local gradient must be known in addition to craft attitude.

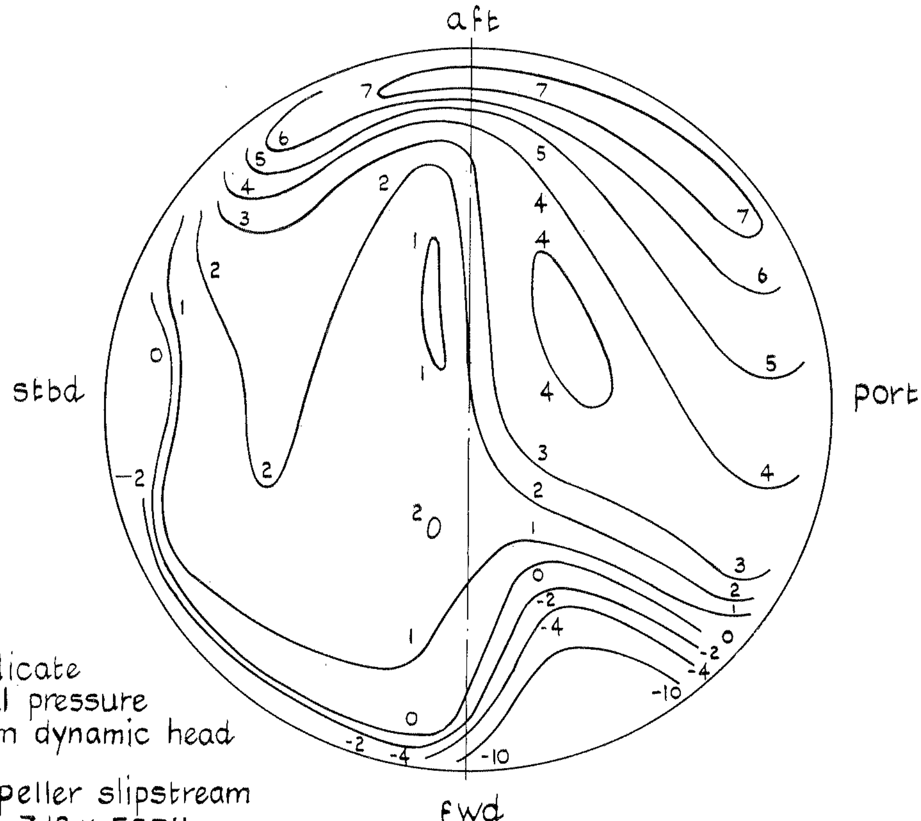
Acknowledgments

The assistance of British Hovercraft Corporation, East Cowes, Isle of Wight, in providing the photographs of the SR.N3 and SR.N5 hovercraft shown in Fig 1 is gratefully acknowledged.

* Gemco Altimeter, Astaron-Bird Ltd, Cyldon Works, Fleets Lane, Poole, Dorset.



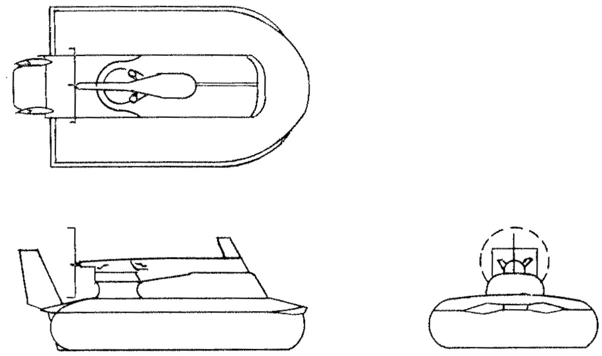
SRN 3



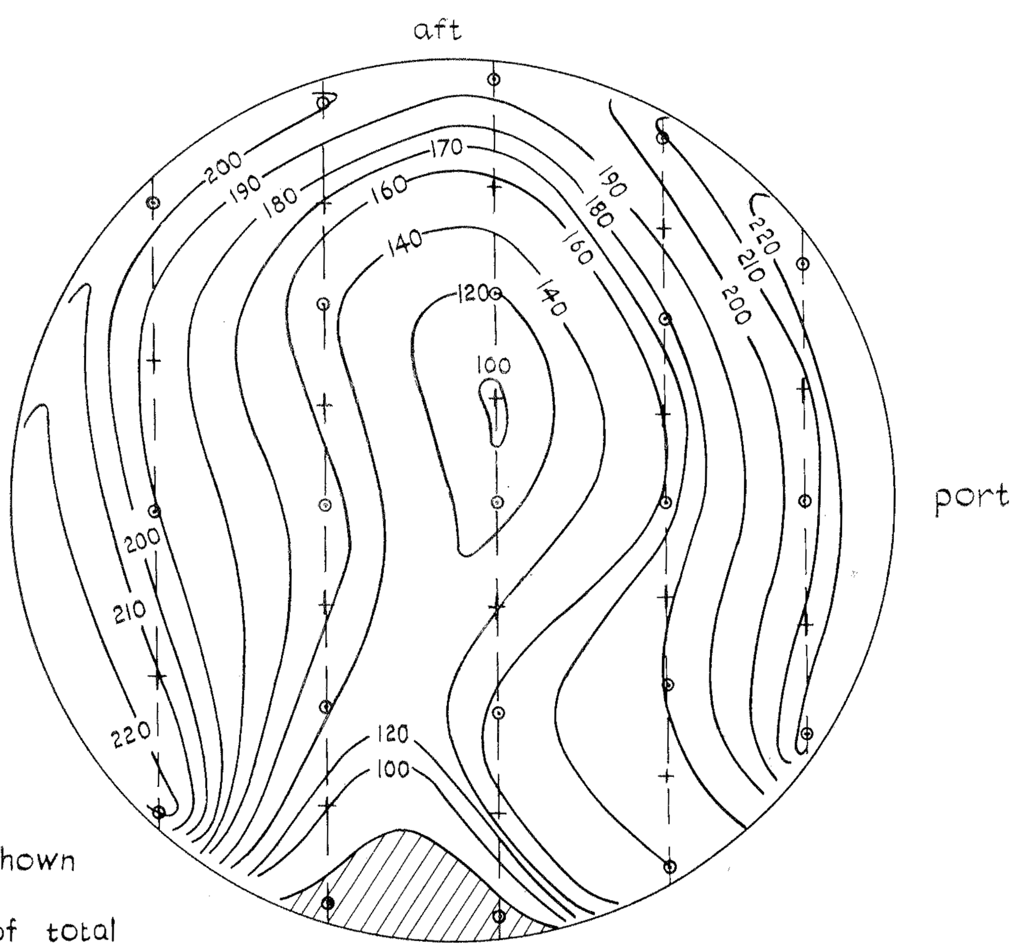
Numbers indicate ratio of total pressure to free stream dynamic head

Forward propeller slipstream estimated at 7·12 × F.S.D.H.

Fig 15 Aft intake total pressure contours — SRN3 model



SRN 5



velocities shown
ft/sec
⊙ position of total pressure probes
+ position of static pressure probes
▨ shaded region shows zero or negative flow

Fig. 16 Intake velocity contours at 56 knots – SRN 5

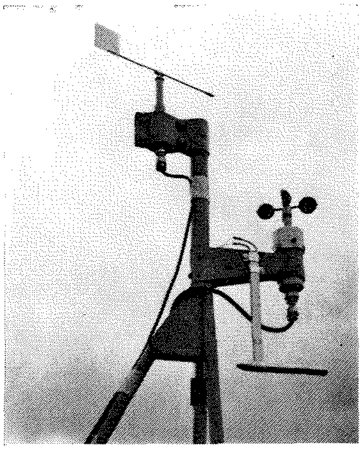
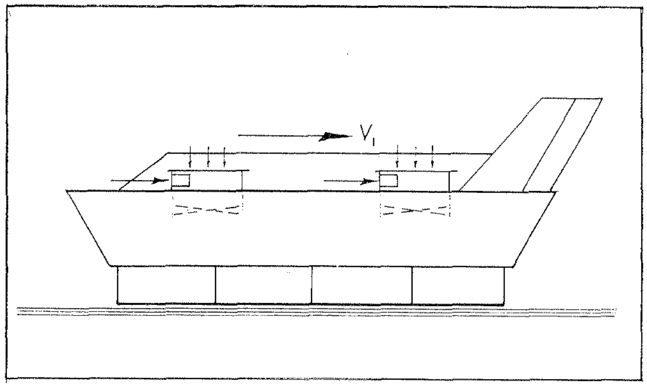


Fig.17 Anemometer and wind vane installation



In the presence of an overall velocity there is a vertical component entering the lift fan intake. The static pressure in this region is at below atmospheric pressure

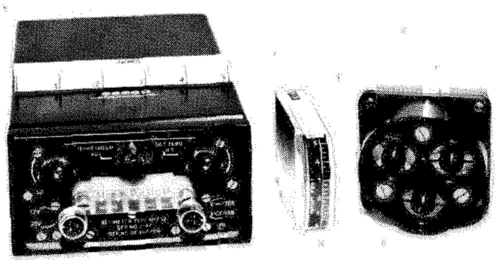


Fig.18 Gemco altimeter

FAN AIR INTAKES ON THE NAVIPLANE N.300

by

R. A. Cole

PRESSURE recovery inlets on the lift fan intakes of the French Naviplane N.300 represent a very interesting feature. Study of the models and photographs shows them situated in the forward facing wall of the short intake funnel at deck level. It is rather surprising that such inlets have not been featured on other designs.

When under way at cruising speed and above the static pressure in the vicinity of the fan intakes will be at less than atmospheric value. In saying this we are assuming the simplest case of the air being speeded up and will neglect the additional effect caused by body displacement. This will of course emphasize the effect still more.

Referring to the well known expression derived from Bernoulli's Equation we have simply,

$$p + \frac{1}{2}\rho V^2 = \text{Const.}$$

where p is the static pressure, ρ is the viscosity and V the free stream velocity. The constant at sea level is 144 x 14.7 lb/sq in.

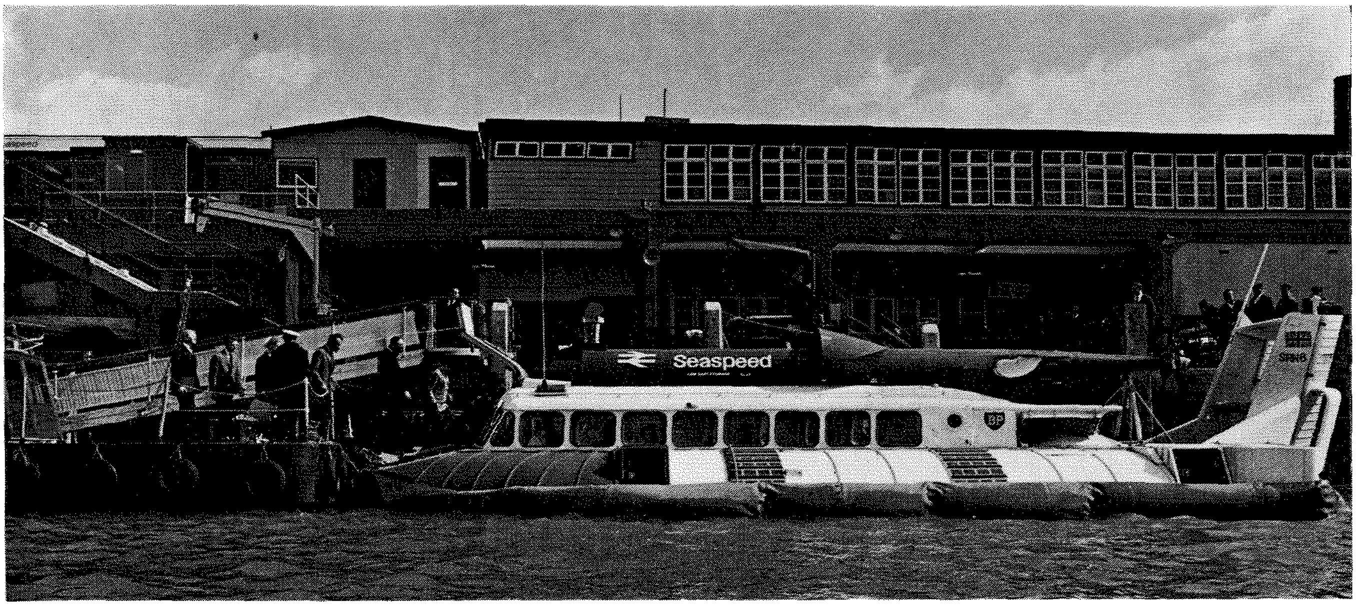
From this we may calculate the reduction of static pressure due to the velocity of the air stream. Assuming a velocity of 100 ft/sec, a shade under 60 knots, the dynamic pressure is 11.89 lb/sq ft (0.0825 lb/sq in). Thus the static pressure will be reduced by this amount.

One requires the fans to deliver a quantity of air to the cushion system at a pressure slightly above that of the atmosphere; 0.348 lb/sq in under the tuyeres in this case. If the fans have to draw from a region of low pressure then they will have to produce a greater pressure rise than if the region were at atmospheric pressure. Hence more power will be consumed and the efficiency lowered.

Clearly then it is desirable that the air supply to the fans shall be at the highest practical pressure. The "pressure recovery inlets" on the N.300 will reduce the horizontal component of the air velocity to zero in the mouths of the funnels and so produce a stagnation pressure. A slight difference between the actual pressure obtained and the atmospheric value will be a measure of their efficiency.

One notes that the variations on the pressures are of a low order but then so is the pressure necessary to sustain the craft. It is only 0.348 lb/sq in and the reduction in static pressure due to velocity is 0.0825 lb/sq in. Thus without the special inlets the fans would have to produce a pressure rise of 0.4305 lb/sq in, an increase of 25% which represents a considerable increment in power requirements.

It is very significant that nearly all of the aircraft fitted with special vertical lift engines are equipped with small doors, or cascades. These devices are employed to produce a stagnation pressure at the engine inlets during slow speed flight or to turn the airflow into the engine chamber The inlets seen on the N.300 are an extension of this thinking.



Passengers embarking at the Portsmouth terminal of British Rail Hovercraft Ltd

Seaspeed

by Terence Ford C.Eng., AFRAES

ON July 6th last year, British Rail Hovercraft Ltd (BRHL) operated its first Seaspeed service between the mainland and the Isle of Wight. The completion of the first twelve months or so of service seemed to be an appropriate time to see how it was progressing and how the organisation had benefited from the experience gained on the SR.N6 hovercraft. Accordingly, a visit was recently made to BRHL headquarters at Cowes, IW, where the Director, Mr C. A. Brindle, explained the factors present in this type of operation and answered many questions about the development of this service in particular and the company's plans in general.

A service from Southampton was used on the outward journey, the return being by way of Portsmouth. Several impressions were retained which were later amplified in discussion, notable among them being the high passenger load factor typical of summer operations, the acceptability of this type of transport among travellers whether visitors to the Island or "locals", and the noticeably wider range of weather conditions in which the SR.N6s of BRHL now operate compared with those possible in the first few months of service. Winds of moderate strength are very often met with in the Solent, together with generally unstable sea conditions. On the outward trip, Force 6 winds were encountered, and Force 8 (about 35 knots) on the return to Portsmouth. This enabled a realistic appraisal to be made of the handling qualities of a fully loaded craft in various sea states, and the general impression was that the SR.N6 can "take them all in its stride".

Company Development

The history of BRHL goes back to October 1965, when the (then) Minister of Technology, the Rt. Hon. Frank Cousins, MP, announced that British Rail would take delivery of the first SR.N4 craft, to be used on a Solent route in 1968. Shortly afterwards, it was decided that hovercraft operations would be performed by a subsidiary company which would be specifically for the purpose of undertaking operations with this form of transport, and Mr C. A. Brindle was appointed to run the company on its formation. It became quickly obvious to him that the prime route which had to be studied in terms of SR.N4 operation was the English Channel, and that the Solent did not offer the economic or operational conditions which would make such a service viable. It was also realised that hovercraft service in terms of the SR.N4 could not be contemplated without full and adequate knowledge of all the facets of operational and engineering practice appropriate to such a size of craft in a cross-Channel environment.

Looking ahead to the establishment of such a service, potential captains must be selected and trained, as well as engineers, ground staff and commercial staff. A background knowledge must be built up, particularly in terms of commercial approach and passenger acceptance, and hence hovercraft operations would have to be undertaken as soon as possible with SR.N6 craft, as this was at the time the only craft with any commercial potential. The SR.N6 would go into service with two main objects: familiarisation of both passengers and crew with the craft operations, and the preparatory work essential to the establishment of a fund of operational knowledge for further ventures of this kind. There were three ways of preparing for SR.N4 commercial operations: to undertake the training of personnel by another operator, this being considered not desirable because as a national company BRHL felt that it should be able to judge for itself not merely the degree but also the standard of professionalism which is going to be desired in the long term. The second course open would be to operate the SR.N6 on the larger craft's route, with all the limitations that this would imply. The third way would be to make a craft model situation in terms of route, weather, conditions and timetable, close enough to the SR.N4 Channel service, against which there would be a clear norm on which to measure performance. This choice was recommended by Mr Brindle to the Board of BRHL, and it was found that the Solent route offered a means of fulfilling the conditions laid down while at the same time providing a useful public service. The craft limits of the SR.N4 on the Channel service, in terms of knowledge of sea states, are remarkably akin to the craft limits of the SR.N6 on the Solent. In addition, it was realised that the very congested shipping situation in Southampton Water could materially assist in improving the general approach to hovercraft control and operation. The Southampton–Cowes route was accordingly selected for the initial services. It is intentionally not an easy run, but it was considered that the amount of worth-while experience to be gained would justify the choice.

How close the conditions in the Channel are to those existing in the Solent, having regard to the SR.N4 and SR.N6 difference in size, could be seen by reference to diagrams at BRHL illustrating the wind forces and sea states precluding operations to the Isle of Wight and comparing these with conditions existing in the Channel and the anticipated limitations of the larger craft. It was seen that only 3% of occasions called for suspension of the SR.N6 service; and with the SR.N4 in the Channel, conditions severe enough for this craft not to operate were almost exactly the same — 3%.

Seaspeed Operations

Over the past year, Seaspeed has endeavoured to attain a high degree of availability and efficiency, and the following figures for July 6th, 1966, to July 5th, 1967, show the reliability achieved:

Operating hours	4,000
Scheduled trips	8,384
Passengers carried	106,000
Freight containers carried	5,000

Of this total of passenger trips, 290 have had to be cancelled for mechanical reasons. This represents a mechanical reliability of just under 97%.

In addition to the above, 170 trips had to be cancelled because of weather conditions, but this was during the early months of the Seaspeed operation. During 1967, no services have been cancelled for this reason.

Mr Brindle, who is himself from a shipping "background", detailed the methods by which BRHL selects its hovercraft captains, and he was careful to emphasise the importance which is placed by the company on a marine background. Other authorities may differ, but a hovercraft is considered to be primarily a marine craft, and hence only master mariners are taken by BRHL for training as captains. An aviation background, while not necessarily a disadvantage, is not considered essential since the hovercraft commander has to be completely accepted by mariners in their own environment. BRHL has successfully trained its Seaspeed crews by this philosophy and the results obtained justify some confidence.

Mr C. A. Brindle, director of British Rail Hovercraft Ltd

Inevitably, some comparisons will be drawn between the services operated by Hovertravel and BRHL. These are in fact of a somewhat different nature, the Hovertravel one being of four miles in length and that of Seaspeed 12½ miles. The former does not carry a radar operator, while the BRHL craft has full provision for one but he is not carried unless night operations are contemplated or visibility is below one mile.

On Seaspeed craft, five-channel radio communication is available, one of these channels being available for the normal marine listening watch. Normal daily safety is ensured by an engineer inspecting the craft each day before the start of operations, and the hovercraft captain undertaking his own DI after this. Safety equipment on board the craft includes life jackets, signalling lamps, towing apparatus and radio.

In addition to the Southampton route, a service from Cowes to Portsmouth and return was started in March this year, and the results so far available indicate a similar demand. On both these routes, Seaspeed has proved that the hovercraft can be very reliable, although at this point in their development reliability is a fairly costly item. Mr Brindle emphasised that it is envisaged at BRHL that the cost per seat mile will be reduced as the technical development of hovercraft progresses and the TBOs of items such as engines, propellers, structures and skirts are increased.

It is notable that on the year's Seaspeed operation between Southampton and Cowes, an average load factor for the whole year of 45% was realised, with 80% representing the average load factor for a summer week and 86% for a summer day.

Discussion with Mr J. M. Lefeaux, the Chief Engineer of BRHL, elicited much information about the maintenance problems with the SR.N6 and the efforts that have been made to keep to the timetable schedules. The engineering staff number seven, and Mr Lefeaux emphasised that this particular operation is, in effect, a training exercise for the SR.N4 and the progress of the maintenance work on the SR.N6 is watched very closely. Some SR.N6 components have had concentrated usage with the high utilisation level essential to the economic operation of these craft, and in consequence have produced evidence of wear and failures not foreseen with aero applications. TBOs have been slowly improving — for example, with the Marine Gnome, 1,000 hr was enforced at first, and this is being increased by 250 hr increments. A TBO of 2,000 hr is considered an economic figure for these engines, and this is estimated to take two to three years to achieve.

(*Continued on page* 6)