HOVERING CRAFT & HYDROFOIL

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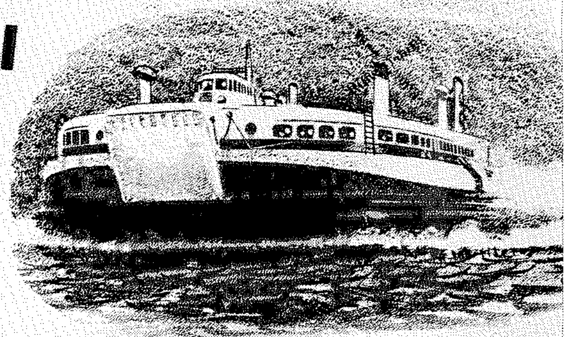

HOVERING CRAFT & HYDROFOIL

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First Hovering Craft & Hydrofoil Monthly in the World

BOEING HYDRODYNAMIC TEST SYSTEM

IN late December 1960, the Boeing Company announced it would test high-speed watercraft shapes on Seattle's Lake Washington, using a jet-propelled boat as a floating test laboratory. These tests began in June 1961, and some three years later the craft passed the 500-hour mark for test runs.

Designed to provide a level and stable platform for straight-away runs of up to 115 mph, the 38 ft lobster-shaped craft has two prows. Hydrodynamic models of hydrofoils and advanced marine vehicles are mounted on a controllable fixture between the prows and pushed through the water at high speeds. Although speed-boats had been used before to test water models, the Boeing test boat, known as the Hydrodynamic Test System (HTS), was the first of this unusual design.

Ordinarily, hydrodynamic testing is conducted in huge water tanks where the model can be pulled through a controlled environment at varying speeds. The HTS provides an extension of this technique and allows designers to test foil models at full-scale velocity.

Since the tow tank and jet boat are to hydrodynamic testing what the wind tunnel is to aerodynamic testing, research by this jet-engined test craft is helping to determine design features of future hydrofoil work by Boeing.

In addition to hydrofoils, the Boeing Aero-Space Group also tests surface and subsurface hull forms with the HTS.

All HTS runs are conducted on quiet water during daylight hours. Each of the two parallel prows of the jet test boat has a cockpit and an instrument compartment. The starboard cockpit carries the driver; the port cockpit, the test observer.

The craft is equipped with data collection equipment and, in addition, test runs often are conducted in conjunction with a barge equipped with a telemetry antenna and collection equipment to receive and store data signals from the HTS.

Detailed design work on the boat was done under Boeing contract by Philip F. Spaulding & Associates, Seattle naval architects and marine engineers. The hull was constructed by Blanchard Boat Co of Seattle. Total cost of the boat was about $25,000.

An Allison J-33 jet engine, developing 4,600 lb of thrust, is mounted above the waterline well aft of the boat's centre. The engine, equipped with sound suppressors, operates just as it would in an aircraft. No underwater propeller is used. A representative high-speed test run of the HTS lasts about one minute on a measured straight-line course.

Test runs are conducted on two courses at the south end of Seattle's twenty-mile-long Lake Washington. One course is 1¾ miles, the other 2½ miles long.

The HTS is steered by two cable-controlled steel forged rudders, one at each aft corner.

The fuel tanks are faired into the junction of the forward sponson and aft hull. These tanks are capable of carrying 2,000 lb of fuel, with about 1,000 lb used on high-speed runs.

Aluminium "skis" have been attached to the underside of the aft hull to reduce drag and to dampen any fishtailing motion at high speed. The "skis", two wedge-shaped hollow metal sponsons, act as a step in lifting the boat to a planing attitude.

Boeing HTS Specifications

Construction	Primarily mahogany plywood
Length	38 ft
Beam	17 ft
Draught	1½ ft
Gross weight	11,600 lb
Speed	100 knots
Power plant	Allison J-33 turbojet developing 4,600 lb thrust

IN THIS ISSUE

COVER PICTURE : *One of the new PT 32 hydrofoil craft built by Hitachi Zosen for the Philippines Navy. (For further details see People and Projects, page 4)*

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People and Projects

On November 17th, the two PT 32 type hydrofoil craft, the **"Bontoc"** and the **"Baler"**, ordered by the Philippines Navy through Tokyo Trading Co Ltd and built at the Hitachi Zosen Kanagawa Shipyard, were delivered to their owners.

The two craft will be based at Manila in the Philippines, and by utilising their 70 km/hr speed will patrol the neighbouring waters with a mission to prevent smuggling.

The craft are fitted with machine-guns fore and aft (the owners being responsible both for the guns and their installation), and are fully equipped with the most modern wireless and navigating equipment. The wheelhouses are protected against bullets by armoured plate.

The endurance of the craft is 650 kilometres, compared to the endurance of passenger-carrying PT 20 and PT 50 craft, which is 400 kilometres. They are each equipped with one auxiliary engine to enable operation in case of damage to the main engine.

The principal particulars of these boats are :

Length overall	21.00 m
Beam overall	4.80 m
Width over foils	7.50 m
Displacement (fully loaded)	About 32 kt
Gross tonnage	60.20 tons
Main engine	One Kegai Mercedes-Benz Diesel
Speed —	
Cruising	About 32 knots (abt 60 km/hr)
Maximum	About 38 knots (abt 70 km/hr)
Crew	Twelve persons
Officers	Three

★ ★ ★

In a recent talk to the American Association of Port Authorities, **Mr Jack M. Smith,** of Moore-McCormack Lines, stated : "The future of containerisation is wide open. We think that the day is not far away when even larger, faster ships of up to 40 knots will carry containers from base port to base port, with smaller fast ships feeding into the base ports. Hydrofoils could well be used for this feeder operation. This is not a dream — the drawing boards are now full of designs for these ships."

★ ★ ★

A contract has been signed for a 9-ton 38-passenger SR.N6 between the British Hovercraft Corporation and Marubeni Iida Co Ltd, acting on behalf of **Mitsubishi Heavy Industries Company of Tokyo,** who are licensees for the SR.N6. The craft will be handed over in the UK before the end of this year, then shipped to Japan. Basic cost of the hovercraft is about £102,500.

★ ★ ★

The prototype hydrofoil presently being developed for the Canadian Navy was damaged by fire on Saturday, November 5th, at the shipyards of **Marine Industries Ltd,** Sorel, Quebec, which is located some fifty miles north-east of Montreal.

Officials of the company estimate that overall damage to the hypdrofoil can be classed as "moderately heavy". The craft, which is being developed as an experimental submarine chaser, was apparently undergoing static testing at the time. During engine running the fire broke out in the vessel's hydraulic system.

Marine Industries are working on the hull of the vessel, which was built by the De Havilland Aircraft of Canada Ltd at its Downsview plant. Overall cost of this hydrofoil research programme is estimated to be in the $36 million range.

★ ★ ★

British hovercraft will be exhibited at EXPO 67, the world exhibition in Montreal next year, and they will also be used to ferry visitors between the island exhibition site in the St Lawrence River and the mainland.

The British Government, through the National Research Development Corporation, is underwriting part of the cost of establishing hover terminals in Canada for the service.

After running the service for 170 out of the total 184 days duration of the exhibition, **"Hoverwork"** (the company which has taken 440,000 passengers across the Solent since July) will set up a hovercraft charter company in North America and open a crew training school.

Mr Donald Robertson, Hoverwork's Chairman, has said : "We are taking hovercraft to Canada because they appear to be the ideal transport for snow-bound conditions. The Canadian Government sees their possibilities for military and commercial operation."

★ ★ ★

After a year's work, **Ford apprentices** have built themselves a hovercraft weighing nearly 1¾ tons, 24 ft long and 12 ft wide. They had been issued with the most cumbersome engine produced by the company — a half-ton, six-cylinder diesel (built to power a 15-ton truck) — and told to get it airborne.

The diesel drives two fans, each pushing 42,000 cu ft of air a minute down into the air cushion chamber. It is hoped that the craft, with materials costing £2,000, will lift off the ground and be thrust forward on air jets.

The craft was designed by five third-year engineering pupils.

★ ★ ★

The **Amateur Yacht Research Society** publication No 58, "Practical Hydrofoils", has just been published, and costs 5s. Membership of the association costs £1. Applications should be sent to Woodacres, Hythe, Kent.

★ ★ ★

Mr P. J. Young, a lecturer at the Technical College, Gurney Road, Kuala Lumpur, Malaya, has written to seek the help of readers of *Hovering Craft & Hydrofoil* who are not binding their back copies and would care to send them to him for the use of his students.

★ ★ ★

On November 24th a hovercraft made a ten-mile high-speed **emergency dash** through dense fog to save the life of sixty-four-year-old Mr Frank Joliffe, of Strathwell Park, Isle of Wight, who had to be rushed to the new Southampton neurological unit for an emergency brain operation after falling out of a tree.

During the run, in nil visibility, between Cowes and Southampton, the pilot had to dodge merchant shipping including the 81,000-ton *Queen Mary* on her way to New York. The Harbour Board radar control tower at Calshot gave the hovercraft a running commentary on shipping positions.

★ ★ ★

Plans for a military version of a hovercraft and jeep — a **"jumping jeep"** which could operate on land or water and surmount obstacles insurmountable by other types of vehicle — have been shelved. The project was known as the P-35 reconnaissance vehicle.

The British Aircraft Corporation said that the Ministry of Aviation had told it that the Army Department of the Defence Ministry had decided not to order further development of the P-35.

The tests and feasibility studies done had "established the practicability of manufacturing such a vehicle should a military requirement develop".

★ ★ ★

Captain Ian Campbell, captain of the **Navy's Fishery Protection Squadron,** has announced that hovercraft may soon be used against pirate sea fishermen who poach in British waters.

The Squadron, which had been using coastal minesweepers, has now conducted trials with an SR.N5 hovercraft. The trials were held with the British herring fleet, forty miles off Skegness, Lincs.

Captain Campbell said : "If tests are successful, hovercraft could be intercepting poachers within the new twelve-mile limit in the next year."

He said that he felt that hovercraft had great potential for seeking out poachers and other foreign ships breaking international fishing regulations.

★ ★ ★

On January 3rd, 1967, a public inquiry will be held at Ramsgate into a plan to build the first **international hoverport** at Pegwell Bay on the town's eastern boundary, at a cost of £500,000.

Residents are protesting against the plan, sponsored by Hoverlloyd, in which British Railways would co-operate in running a half-hourly service to the Continent with an SR.N4 hovercraft.

★ ★ ★

Hover pallets are to be used in the forward holds of the two new 4,600-ton ferries *Ulster Prince* and *Ulster Queen*, due to enter the Belfast Steamship Company's Liverpool–Belfast service next spring. These pallets will enable loads of up to 4½ tons to be moved on a cushion of air by one man.

Mr H. Maitland Clarke, Executive Director of Coast Lines Group, has stated that he believes that this will be the first application of the hover pallet by the shipping industry in this country.

Two **"Stackertruck" hover pallets** will be included in each of the new ships. They will be operated from a 30 hp compressor in the engine room with air lines to the hold. This will provide sufficient air pressure to lift a 4½-ton load about one fifteen-hundredth of an inch to enable the cargo to be quickly and easily stowed. Cost of each pallet is £210.

Cargo for the forward hold will be unitised on the quay, lowered into the hold and stowed by means of the hover pallets.

The car deck in each of the two ships is capable of carrying 120 vehicles. This has been designed to carry containers and unit loads of up to 4½ tons in the off-peak season, and it has been specially strengthened to withstand pressures of up to 14 tons to enable forklift trucks to operate in the car space.

★ ★ ★

The *Svensk Sjöfarts Tidning* recently published specifications of the PT 150 DC passenger hydrofoil ordered from **Westermoen Hydrofoil A/S,** Mandal, Norway, for service between Gothenburg and Danish ports. Claimed to be the largest in the world, the craft has been ordered by a company formed by four Gothenburg firms : Göteborg-Frederikshavn-Linjen (Captain Ulf Trapp, who will act as manager); Eriksbergs Mek. Verkstads A/B; the Rederi A/B Bifrost; and the Nya Angfartygs A/B Heimdal.

With an overall length of 37.45 m, a maximum beam of 7.5 m and a maximum draught of 5.5 m, she will have a displacement of 150 tons and will carry 150 passengers and eight cars, or alternatively 250 passengers. Her range will be 300 miles and two Mercedes-Maybach diesels developing 7,600 bhp at 1,470 rpm will give a speed of 38-41 knots.

★ ★ ★

The Fan Division of **Airscrew-Weyroc Ltd,** of Weybridge, has designed a new type of mixed flow fan for cabin heating and ventilation in the new British Hovercraft Corporation SR.N4.

The company states that the fan has a high performance at a low noise level, and produces a mixed flow using an impeller which moves air through the rotor both axially and radially.

The fan is said to have the benefits of both the axial and radial types, and meets a requirement that calls for a very high duty with a configuration that is axial and compact so that the fan can fit into a run of ducting.

★ ★ ★

Two 100-passenger ocean-going hydrofoils have been sold to the American Satra Corporation by the Soviet **Sudoimport** organisation. The craft, which are of the Kometa type, will be delivered in 1967. The American company has also ordered ten six-seater Volga-type hydrofoils.

In 1965 Sudoimport exported one Kometa to West Germany and three to Bulgaria. It is now negotiating the sale of Kometas to Yugoslavia and Greece.

★ ★ ★

The Cape Cod *Standard Times* recently made this statement regarding the hydrofoil **"Flying Cloud" :** "The failure of the power plant to function in accordance with the requirements during the shake-down runs was the cause of the vessel's withdrawal from scheduled service." The power plant was built by Solar Gas Turbine. Representatives of *Gas Turbine* Magazine were present at the trial runs, and have stated: "The problems encountered were of a minor nature and were those normally anticipated with any type of new engine application. In fact, the boat was demonstrated in good running order the day after the announcement to return it.

"The problem areas were in the fuel system only, and specifically in a contamination which has not yet been positively identified, yet analysis is being continued. It is the opinion of the engine manufacturer that the boat was pulled out of service prematurely. Over 700 of these same turbines have been built and have logged over 1,500,000 hours in service. This magazine just wants to make this point clear."

★ ★ ★

The **Daily Express** purchased the first do-it-yourself hovercraft kit produced by a Peterborough firm headed by Lord Brassey, President of the Hoverclub of Great Britain, and has been running a series of articles by John Vass. The *Express* exhibited the completed "Air Rider" at the International Cycle and Motorcycle Show at Earls Court, and the craft has now gone to No 200 Hovercraft Squadron of the Royal Corps of Transport to be used at the unit's training school at Gosport to show trainee hovercraft commanders the principles of ACV travel.

The hull kit, which is mainly marine ply and spruce formers, costs £65. Engines, ducts and prop fans are extra.

★ ★ ★

A London company has dropped plans to run a **hovercraft taxi service** on the Norfolk Broads between Norwich and Great Yarmouth as naturalists have objected that the noise would disturb wild life in the area.

★ ★ ★

During recent sea trials of the **Dolphin** out of Kiel, the boat operated in measured waves up to 5.3 ft high. All modes of craft motion were measured with the following results :

Average vertical acceleration 0.08 g
Maximum vertical acceleration 0.25 g
Average roll angle 0.1°
Maximum roll angle 0.5°
Average pitch angle 0.1°
Maximum pitch angle 0.25°
Foilborne cruise speed sustained over measured mile 51.9 knots
Displacement cruise speed 9.2 knots
Foilborne turning diameter estimated to be 250 yards
Hullborne turning diameter 250 ft

Photographs of the trials will be published in the December issue of *Hovering Craft & Hydrofoil.*

★ ★ ★

The Future of Hovercraft

Sir Eric Mensforth, CBE, MA, CEng, FRAeS, MIMechE, MIProdE, Chairman, Westland Aircraft Ltd, and Past President of the Helicopter Association of Great Britain, delivers the seventh Cierva Memorial Lecture to the Rotary Wing Section of the Royal Aeronautical Society

by our Special Correspondent

THE seventh Cierva Memorial Lecture entitled "The Future of Rotorcraft and Hovercraft" was delivered to a gathering at the Royal Aeronautical Society by Sir Eric Mensforth, Chairman of Westland Aircraft Ltd, on October 26th.

There was little really new information to be gleaned by those working in the industry. In his introduction, the lecturer pointed out that the paper was in two parts, the first dealing with helicopters and the second with hovercraft. The latter had been included not for his interest, but because the Rotary Wing Section Committee of the Society is far-seeing enough to include the new means of transport.

After a short preamble through the years, the present situation was arrived at and described in terms of tons of hovercraft built, the number constructed, the fact that every five minutes a BHC hovercraft takes off or lands, and that operating experience is being accumulated at the rate of sixty hours per day.

Skirts

The mystery of who actually designed the flexible skirt is cleared up by his statement concerning the solution of the clearance problem. The lecturer said : "It arrived in the form of the long flexible skirt in 1962, following the basic invention of Latimer-Needham and the invention and development of practical flexibles by Stanton Jones."

It was during the building of the SR.N3 that the skirt breakthrough came about. Tests on the SR.N1 showed that smaller craft could be built with better capability (we assumed clearance-wise) than could be expected from the original large SR.N4 design. As a result the SR.N3 was dropped and the SR.N5 became the first production hovercraft. Manufacture of the SR.N5 and SR.N6 will continue, and the SR.N4 will be available from 1968.

Running through the types projected for the immediate future, reference was made to the BH.9. It is quoted as a "Double N6" powered by two 900 hp engines and employing the same basic components as the SR.N5/N6 family. Apparently the craft is awaiting the development of cheaper engines. Current units of around 1,000 hp are compared with larger units, disproportionately costly.

Having said this much on the question of power plants, it is surprising that Sir Eric Mensforth did not enlarge on the topic. Readers of this magazine are already aware how badly served the propulsion side of our hovercraft industry is, particularly so far as the lower-powered engines and special propellers are concerned. His mention of a cheaper engine may have been a hidden reference to the projected adaptation of the Rolls-Royce Dart, a unit that could really do a lot for the industry.

To have been really controversial and startling, he could have stated the fact that the Bristol Siddeley Gnome used in production designs is an American engine produced under licence in this country for many years. Furthermore, he could have added that the more efficient and advanced propellers being sought are most probably going to be American types produced in this country.

Other Projects

With regard to the 40-ton BH.7, it is apparently the largest craft that can be designed around a single Proteus engine of 3,400 hp. It will incorporate many SR.N4 components and it is currently in the detail design stage. A notable feature is that it will be almost identical in size to the SR.N3 but will carry twice the load. Payload is quoted at 20 tons and fuel load 3 tons.

The BH.8, virtually a "Double BH.7", is a proposal in the 80/90-ton category. Here the maximum beam is limited to 40 ft (12.2 m), so that it may be carried in heavy lift ships. Had the design been optimised, then a beam of up to 60 ft (18.3 m) would have been arranged. Studies of inflatable sides to give the more efficient beam are in progress.

With regard to the SR.N4, it appears that it has been designed with the logistic support role for military operations in mind. As a civil craft 165 tons is a sensible operating weight, but for military purposes Proteus engines of 4,250 or even 4,500 hp could be fitted and this would allow operation at up to 200 tons. No mention was made of a 4,500 hp Proteus engine being fitted in the BH.7 or BH.8, and one was left wondering.

Although the SR.N4 can be lifted in one piece it is too big for transportation by ship and it will have to move around the world under its own power. A speed of 50 knots (92.6 km/hr) can be attained on half power, and loaded with fuel it would have an endurance of forty hours. This would bestow a range of some 2,000 miles (3,220 km) in calm water, or a range of between 500 and 700 miles (800 to 1,130 km) carrying a useful load of 60 tons.

The Future

Propulsors are going to provide a lot of problems in the future. To ensure a high level of efficiency propellers should not exceed 25 ft (7.6 m) in diameter, and obviously the number employed will be limited by layout considerations. At somewhere between 700 and 1,000 tons weight, vehicles will require a change in the type of propulsors fitted. For high-speed craft

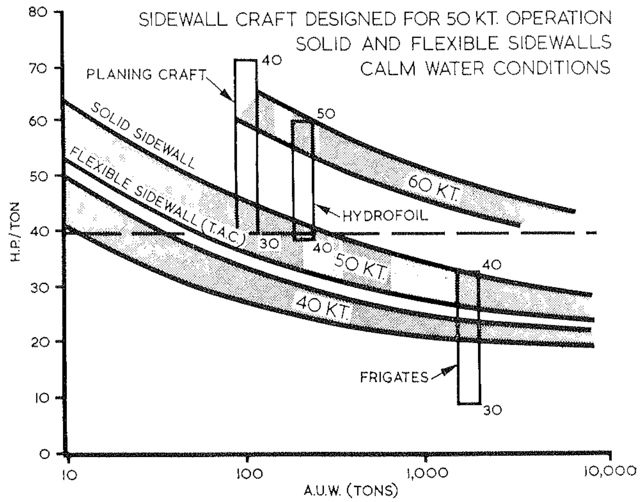
CRAFT	MAXIMUM A.U.W. (TONS)	MAXIMUM DISPOSABLE LOAD (TONS)	CIVIL	LOGISTIC SUPPORT	FAST PATROL (8 HRS. MAX. CRUISE OR 16 HRS. ON STATION)
SR.N6	12	6	38	4 TONS	MIXED WEAPONS 3 TONS
BH.9	25	14	80	10 TONS	6 TONS
BH.7	50	25	160	6 x 3/4T	15 TONS
BH.8	90	40	120 10	4 x 4 1/2T	25 TONS
SR.N4	180	80	250 30	2 x	50 TONS

TYPICAL LOADS CARRIED BY BHC. HOVERCRAFT air propulsion will probably remain the best, and this may dictate an optimum size of around 300 to 400 tons. For such types the airscrews will be specifically designed and not derived from aircraft types.

Current work shows that for large hovercraft a power expenditure of 40 hp/ton is anticipated, and future research may halve this figure. This requirement is associated with a speed of at least 50 knots (92.6 km/hr). For the larger craft water propulsion must be employed and this automatically makes them hoverships. Water jets are presently favoured for them. All indications are that gas turbines will still be the prime movers in the 1970s, although lightweight diesels and nuclear engines — the latter for larger designs — are awaited.

It can be shown that the peripheral jet curtain requires less total hp/ton than the immersed sidewall system at speeds in excess of 50 knots (92.6 km/hr). Thus it would seem sensible to employ solid sidewalls on the large craft having such an upper speed limit. However, it has been found that the peripheral jet system can be operated more efficiently than the solid sidewall type in what is known as the Trapped Air Cushion (TAC) mode. (This is equivalent to the Captured Air Bubble [CAB] concept favoured by the Americans — see *Hovering Craft & Hydrofoil*, September 1966.) In this mode the craft operates with the sidewalls contouring the surface so that in effect it is a flexible sidewall craft.

In the TAC mode flexible sidewalls are better than solid sidewalls down to 35 knots (65 km/hr) in calm water and as low as 20 knots (37 km/hr) in rough seas. Therefore it would appear that solid sidewalls only show advantage for slow-speed applications as may be found in rivercraft and harbourcraft. An informative diagram which we reproduce here illustrated the situation concisely. It also proved that the situation regarding skirts and walls appears to be well understood so far as performance is concerned.



HP / TON Vs A.U.W

It is intended that the projected 4,000-ton hoverfreighter will operate in the TAC mode and it is believed that such a design is a practical possibility. The programme for such a vehicle is already under way and this will include the use of an SR.N6 as a model, then a stretched version of the SR.N4, to be followed by the first ocean-going intermediate-stage vessel of some 400 or 500 tons from which the final design could be extrapolated.

A further short section dealing with hover-pallets and special lifting equipment for both civil and military use ended the paper.

The History of Hydrofoils

(Part XII)

by Leslie Hayward

Technical Contribution of Hans von Schertel

IN July 1934, Hans von Schertel proposed the design disclosed in British Patent Specification 493,176 and US Patent 2,257,405. Von Schertel investigated many different hull forms and discovered that the early hydrofoil craft, having foil systems fitted to existing hulls, suffered many disadvantages which could be overcome if the hull was designed to have a co-operate relationship with the foils. For instance, when the early craft with orthodox hull forms hit waves at speed in a rough sea, the resistance to forward motion was so great that the speed of the craft dropped below that necessary for the foils to support the hull and consequently it dropped back into the water.

Von Schertel realised that if the hull was designed to assist the stabilising action of the foils, to add to the lift force when striking the water and to have a small resistance opposing the forward run, a much smoother, more stable and more efficient ride could be obtained.

The craft proposed has a transversely stepped hull forcing the flow off the bottom of the hull and only permitting wetting of the bottom surface where it is provided with gliding surfaces. These gliding surfaces, set obliquely relative to the axial direction of the craft and given stepped set-offs arranged transversely to the direction of motion, are spaced apart as far as possible, one being under the bow for longitudinal stabilisation and others at the stern for transverse stabilisation. Stepped surfaces may also be positioned amidships, but apart from these surfaces the hull is arched or positioned high up to avoid frictional resistance.

The foils are spaced from, and mounted directly underneath, the gliding surfaces which can add to the lift effect without displacing the combined lift resultant, the foil remaining in its correctly trimmed position. During operation of the craft the foils are positioned partly above and partly below the waterline and vary spanwise with regard to their shape, profile and angle of incidence relative to their height above the water surface.

Considerable design information and a large number of alternative hull and foil forms are given in the relevant patent specifications.

One of the problems associated with craft having front and rear transversely inclined foils is that when operating in heavy following seas, the front foil is apt to leave the wave crest when the rear foil lifts in tending to follow a wave contour. This condition results in a decrease in the angle of attack and affects the lift on the front foil, causing it to undercut the following wave and giving rise to unstable operation.

In April 1951, H. von Schertel proposed the solution shown in British Patent 715,850 and US Patent 2,917,016. Front and rear surface-piercing foils are designed in such a way that the rear foil is more sensitive to changes in the angle of attack than the front foil. Stabilising forces on the front foil result from changes in the depth of submersion, while stabilising forces on the rear foil result from changes in the angle of attack. Details of the foil designs are given in the above patent specifications.

Fig 89 relates to British Patent 745,821 and US Patent 2,720,180, applied for in October 1952. To enable the inci-

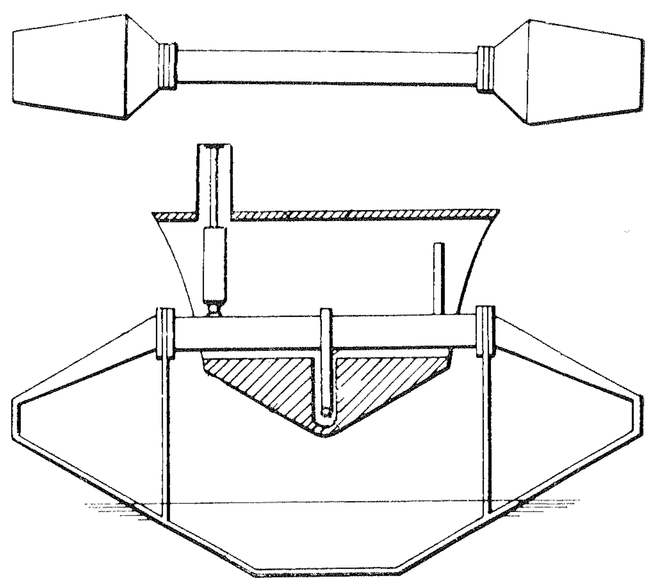


Figure 89

dence of foils to be adjustable when the craft is at rest, or in some cases under way, von Schertel proposed that a surface-piercing type of foil, together with associated support struts and load-carrying girder, should be combined in a single, self-contained framework. The framework is rotatably variable with respect to the hull and does not form any part of the hull structure. Lift-producing sections extending from the sides of the main support girder are linked with and gradually merge to the foil profile. Suitable spring-loaded or damped mechanism is provided for rotation of the entire assembly.

A proposal made in October 1951 relates to an automatic, rough sea, damping device for varying the lift force of surface-piercing foils. Power fluctuations arising from shocks encountered on entering and leaving a wave provide the motive power source. The foil lift force is transmitted through a damped resilient control device. The damping device ensures that small variations in lift force do not affect foil incidence while large changes in the lift force produce acceptable incidence changes. The delay periods of the damping device are manually or automatically adjustable. Details of this invention are given in US Patent 2,771,051.

During August 1955 another patent application was filed in Great Britain disclosing another arrangement for automatically controlling the hydrodynamic lift of surface-piercing foils. The foils are provided with mechanism which alters the lift by adjusting the incidence of the foils or by moving flaps at the trailing edge. The foils are arranged to move vertically against an elastic element when disturbed by waves so that they oscillate relative to the vessel's hull. The oscillations serve as control signals for adjusting the lift. The phase of the controlled alterations of lift of the foils is displaceable relatively to the phase of the transmitter of the adjusting mechanism according to the wave lengths of the sea. Displacement is 180° with the shortest waves, increasing to 360° with the longest waves, being automatically increased as a function of the wave length.

The foil is positioned at the foot of a double leg which, at the forward edges of its upper end, is pivoted to the shorter arms of pivotable horizontally extending levers. The longer arms of the levers are each attached to a vertically mounted spring unit. Another lever extends downwardly from a cross member secured between the top of the two elements forming the double leg and is pin jointed at its lower end to a hydraulic jack pivoted to the hull. A linkage interconnects between a slide valve on the jack and the longer arm of one of the horizontal levers, by way of a phase displacement control unit.

In operation, the foil is urged by action of the waves and by restraint of an inactive control unit to oscillate vertically relatively to the hull, the lifting forces being balanced by the spring unit. The oscillating movements are transmitted by the input portion of the linkage to the control unit which causes a delayed movement of the output portion to control actuation of the jack. Movement of the jack results in arcuate movement of the double legs and controls the pitch of the foil. Alternatively, the legs may be constrained to vertical oscillation only, and the foil arranged to pivot on the legs by direct action of a jack positioned in the bottom of a leg. The delay provided by the control unit responds to, and is regulated by, the wave length as indicated by the

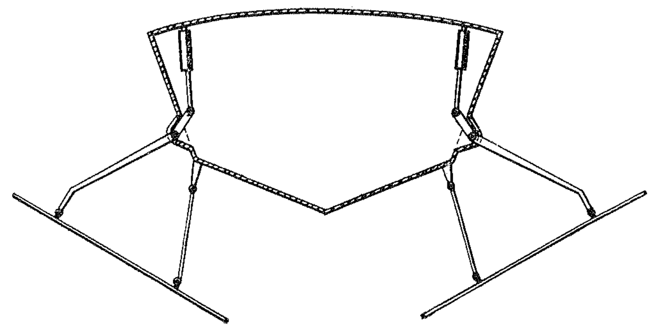


Figure 90

periods of oscillation.

In January 1960, H. von Schertel proposed a retractable surface-piercing foil system which has a separate foil on each side of a conventional hull, the foils being angled upwards and mounted on two links arranged so that the lower link is shorter than the upper link, the inboard pivots being closer together than the outer pivots. This arrangement, shown in Fig 90, permits the foils to be folded closely against the side of the hull when not in use. The inboard pivots can be mounted on the ends of a transverse beam capable of being bodily rotated about its major axis to alter the angle of incidence of the foils. Various suggestions are made to hold the foils in the folded position. Details are given in US Patent 3,099,239.

Proposals made during the later part of 1960, relating to automatic stability controls, are disclosed in British Patent 934,882 and US Patent 3,103,197.

The first disclosure suggests an automatic lift force control for foils, using air collected through inlet ports in the foil support strut. Air flowing from the strut in response to movement of the craft controls the lift force of the foils by mixing with the flow or the cavitation bubble on the upper surface of the foils. This arrangement results in a reduction of the sub-pressure in proportion to the amount of air introduced. Air added to the flow prevents cavitation and therefore the thickness of the foil section can be increased, resulting in a reduction of stress at high speed. If partial cavitation occurs in front of the foils, air fed slightly to the rear prevents collapse of bubbles in the high-pressure region and prevents erosion of the foils. With fully cavitated foils, the bubbles being collapsed at the rear of the foil, sub-pressure is reduced in proportion to the air supplied and the lifting force is automatically controlled.

A continuous lift control is achieved by distributing air over the entire chord of the foil, when, with increasing velocity, the transition stage from sub-cavitation to cavitation is passed.

The further disclosure relates to a modified arrangement for achieving similar results but is operated by dynamic water forces created by movement of the craft. The control utilises adjustable flaps hinged to the trailing edge of the foil. The foil support strut carries a series of pitot tubes and the dynamic pressure of water through these tubes is arranged to operate mechanism, in turn, connected to the flaps pivoted on the trailing edge of the foil, to give adjustment required to suit varying speed and sea conditions.

Further developments of these types of control arrangements are disclosed in detail in US Patents 3,146,751 and 3,146,457.

HOVERCRAFT SERVICING AND MAINTENANCE

by

A. Cadman Clinton,
CEng, FRAeS, FBIS, MSEE

LOOKING at a hovercraft, an engineer sees that aero engines are still being used, most of the power plants being marinised gas turbines, which are rather too sophisticated but do well on the job; a simpler engine is desirable with a longer TBO. Then it will be seen that the electronic systems for navigation and communications and the electrics are aviation items prone to troubles in the different environment, so demanding much care and attention.

While undoubtedly useful for the development batches of hovercraft, high-speed aircraft propellers are inefficient, noisy and need frequent servicing due to erosion.

These common problems affect the hover operating companies, consume valuable man-hours and make costs too high. But all the British operating experience will be valuable; it covers more than 20,000 hours, representing more than 750,000 miles. This suggests that over 1,000,000 miles will have contributed further to the experience that will launch the large SR.N4 craft into commercial use in 1968, this being the largest of the next generation of craft which includes British Hovercraft Corporation's BH.7 and BH.8, as well as craft developed by the independents, Britten-Norman, Hovermarine, Manx Hovercat Ltd and others.

Earlier this year the Air Registration Board circulated Notice No 74, issue 1, May 12th, 1966. This statement covers "Maintenance of Air Cushion Vehicles in United Kingdom Public Transport Operations". This statement was made in collaboration with the Ministry of Aviation and other interested Government Departments.

Certification, supervising arrangements for general matters and engineering aspects are briefly touched upon in paragraphs 3, 4 and 5.

At the start the Certificate of Construction and Performance identifies the vehicle and gives the information needed for its safe operation and maintenance by a competent organisation. It requires maintenance notes, with the appropriate log-books, inspection schedules and statistics.

Following the issue of this certificate the ARB can recommend to the Government, ie Board of Trade (Aviation), the issue of the first Transport Category "Permit to Fly". This in fact is a "Permit to Hover", and is so known by the operators.

The general supervisory arrangements, in paragraph 4, state that the MOA, now Board of Trade (Aviation), as the operational authority is responsible, in the overall sense, for ensuring that the operator takes all reasonable precautions to ensure safety, but here other bodies may join in, eg ARB, BoT, Ministry of Technology and local authorities.

The engineering supervisory arrangements, paragraph 5, mention inspection of the source of operations, to check the maintenance organisation, and the main requirements of this are:

1. Freedom of access of the Board's representatives.
2. Establishment of a proper chain of responsibility within the organisation.
3. The provision of sufficient, reliable and properly qualified maintenance staff.
4. The availability and use of adequate maintenance, storage and office facilities, and the keeping of proper records (including defects and action taken).
5. Consultation with the Board before modifications are made to the vehicle, except where these have already been accepted by the Board for the vehicle in question.
6. Adherence to maintenance and inspection procedures (including inspection schedules) accepted by the Board as covering the particular air cushion vehicle. *Note:* The operator may propose variations to any such accepted procedure, and these may receive provisional acceptance pending operational experience of the proposed change.

If the foregoing conditions are not observed or the vehicle is considered unsafe, then the Board takes action, and in any case all the costs incurred by the Board in providing supervisory service have to be paid by the operator.

Operators have therefore to develop more independence and they will no doubt always be a jump ahead of the ARB. The ARB is primarily an advisory body, but has some statutory power concerning the requirements for and the licensing of engineers.

The operational engineers responsible for the day-to-day servicing and maintenance efficiency, as well as the planning of technical work, have a developing experience which is valuable, and this is streamed into the design departments of the manufacturers. To emphasise design for maintenance, some of the design team should spend a few days and nights with the maintenance squad.

Basically, reliability is a technical management responsibility, and since something like one-fifth of all failures due to unreliability are caused during manufacture it is clear how essential it is to ensure efficient quality control and reliability at the outset. More attention to this means happier operational engineers whose field work will increase in efficiency, resulting in reduced overheads.

Quality and reliability in the operating companies is of a high standard, and is maintained by enthusiasm and hard work. Later, some details of DIs and periodical checks are given in the Appendix.

For background information it should be realised that the ARB has prepared over the last few years a series of five green books, the "British Civil Air Cushion Vehicle Safety Requirements", embracing: A. General Information and Procedure; B. Vehicle Design; C. (issue 2) Lift, Propulsion, and Auxiliary Machinery; D. Electrical; and E. Radio and Radar.

Hovercraft Development Ltd undertook the original work for the Hovercraft Technical Steering Committee, and so the series of the above green books was compiled, assisted by the manufacturers represented on the Committee.

In preparing the series the Panel had three guiding principles:

1. The safety of the occupants.
2. Third party risks.
3. The safety of the vehicle.

The green books are a useful design/engineering guide, but a designer would naturally build up his own book and specifications particular to his own independent organisation. It is extremely important to develop more independent and creative thinking on ACVs before initiative becomes cluttered.

While a designer is responsible for the intrinsic safety of the vehicle as a whole, including its engines, propellers and other components and equipment, he is not bound to use only such items as have approval for use in aeroplanes. ARB-approved items can never be sufficiently up to date for an enterprising designer.

The whole aspect is covered in "Provisional Arrangements for the Investigation and Approval of Air Cushion Vehicles (including Hovercraft)". This, as already mentioned, includes a form "Certificate of Design and Construction — Air Cushion Vehicle (prototype or series)", in which the applicant for a "Permit to Hover" certifies that the vehicle has been properly constructed in accordance with the specification covering all the many requirements, safety measures and maintenance necessary to ensure continuation of the level of safety achieved at initial acceptance.

A further publication, "The Safety Regulations of Air Cushion Vehicles", June 1965, is a study by the ACV Co-ordinating Committee, including representatives from the ARB, Ministry of Transport, Ministry of Aviation, Inter-Services Hovercraft Trials Unit, the hovercraft industry, Hovercraft Development Ltd and the Hovercraft Operational Requirements Panel.

Details of requirements for operations are outlined, together with servicing and maintenance, but it is the operational engineer, in the civil and military fields, who is building up the very necessary practical operating experience.

Air cushion vehicles are in a class of vehicle in their own right and cannot be classed with ships or aircraft, and at present there are almost no statutory requirements in existence for air cushion vehicles. Any enterprising person can design, manufacture and operate an ACV, although if insurance cover is sought the odds are that application would be made to Lloyd's, when a certificate of hoverworthiness would be needed. The hazards of collision, fire and tempest are insurance risks.

It is clear that there must be statutory requirements. Lloyd's Register of Shipping entered the ACV field some time ago. A technical committee comprising representatives of the industry, operators and an observer from the ARB is on the way to formulating classification requirements for ACVs.

As in the case of rules and regulations for ships, there is likely to be a similar publication for ACVs. With their vast international experience, Lloyd's could do a great deal to set the ACV on the right lines for operation, reliability and safety.

Lloyd's Register of Shipping is classing the SR.N6 craft, which have achieved so much in military and civil operations and continue to be the most widely used vehicles in these fields. It should be borne in mind that Lloyd's Register is also surveying the SR.N4.

In view of the expanding ACV industry, no doubt the Society of Licensed Aircraft Engineers and Technologists will make some provision for licensed ACV engineers, before the emergence of, say, the Institution of Air Cushion Vehicle Engineers.

The progressive inspection system developed by the operating companies has laid the foundation on which will be built the expanding requirements for the SR.N4 and future craft.

Present check periods are based on operating hours and elapsed months and, as experience is accumulating, these periods are being continuously extended.

Hovercraft maintenance engineers over the whole field of civil and military operations are accumulating running experience which, at present, continues daily. Maintenance is planned on a progressive system, and an outline of some of the work follows:

Gnome Engine

This marinised aero-engine has a new control system, and includes modifications to some of the components to avoid deterioration due to salt-laden atmosphere. They include:

1. Anti-corrosion treatment of compressor stator and rotor blades.
2. Pack aluminised turbine blades and nozzles.
3. The power turbine wheel is painted with silicone aluminium.
4. Magnesium alloy castings are replaced by aluminium alloy.

On short ferry routes an engine once started runs all day, the craft hovering hours being 30% to 40%, but on the cross-Channel run the engine is shut down at each terminal, so a bigger proportion of running time is on hover power.

Engine washing takes place at the end of the day, with demineralised water for preference mixed with kerosene (6 pints of water to 2 pints of kerosene). Drinking water may be used when demineralised water is not available. The engine is run at 16,000 to 18,000 rpm, the water-kerosene mixture being injected at the rate of 4 pints per minute. After washing, the engine is run for five minutes for drying out before final shutting down, and during the rundown half a pint of specified inhibiting fluid is injected.

An alternative method of cleaning compressor blades after running in a salty atmosphere is to use "Carboblast" at the end of the day, ie ground walnut shells that scour the blades without damage.

On long routes and particularly in rough weather, more salt water enters the engine than on the short routes, and at the end of the day after the engine has cooled, kerosene is injected during a starting run and allowed to soak for an hour, then follows a hot water wash during a starting run. The engine is then dried out and inhibited.

When an engine is operating in a non-salt-laden atmosphere, below 4°C, the water in all procedures is replaced by the mixture: water 60% and isopropyl alcohol or methanol 40%.

The nylon knit mesh intake filters, also, are washed daily. Experience has shown that this procedure maintains the engine in good condition, and the TBO is being extended, the target being 2,000 hours.

Sand may be sharp or soft according to the geological conditions. In some cases engines have lasted only a few hours because the filters were inefficient for the very fine particles; the most promising type is the vortex filter.

Flexible Skirts

These are made from synthetic-rubber-coated fabric and they resist abrasion, but the nature of the short ferry routes subjects the skirt to frequent wear on the landing ramps, and this in addition to the normal wear and tear at sea means that there are a few repairs requiring attention at some convenient time.

Experience shows that normally tears do not have much effect on control, but where a length of skirt is worn on one side by abrasion, due to frequent turning in one direction on the ramp, the time comes when there is a noticeable lag on lateral response. Inspection notes the wear, and repairs are made when below-deck items are ready for Check 1. For this work the craft is single-point lifted from four slinging points and supported on six jacks.

.On the longer routes wear and tear accounts for about 70% of the trouble and much of this results from the flutter and vibration induced by various wave conditions, the worst of these being the short choppy sea.

Little skill is required for the repair and replacement of skirts, and ordinary tools suffice. Since the skirt is now made in segments, replacement of any particular area takes little time. For the record the number of man-hours against skirt-hours is noted.

Buoyancy Tanks

These and much of the general structure are made from light alloy material, and little trouble is experienced as it is well protected from corrosion, being etch-primed before assembly and where necessary painted inside and out with an epoxy-based paint.

Equipment : Three Main Groups

1. Operational. Cabin ventilation system, cabin heating system, VHF radio, driver's windscreen washing and wiping, navigation lights, instruments lights.
2. Safety and marine. Stowed life jackets and two inflatable life rafts, two portable fire extinguishers and axes, anchor complete and floating rope, signal pistol and cartridges, Aldis lamp, torch, first-aid kit, door key.
3. Special. Radar, steerable searchlight, gyro compass, rate of turn indicators, journey time recorder, intercom (driver–navigator).

Electrical systems, like those in aircraft, suffer from similar unserviceability, and tend to be aggravated by more environmental corrosion trouble. The unserviceability is being partly overcome, but detailed design for the specified environment is needed for some components in the system.

Propellers

The blades run continuously in a salt spray, sometimes with the addition of sand, so although they start off with an anodised and painted surface, this is soon lost and they erode rapidly unless the surface is immediately re-treated. The bare metal is washed in fresh water, painted with etch-prime and varnished.

Another form of blade protection is to fit anti-erosion strips. These synthetic-rubber mouldings are grooved to fit the leading edge to which they are bonded. To ensure a secure bond between the strip and the chemically cleaned metal, the strip must be maintained at 60°F for about six hours; if the whole process is not completed accurately the strip will fly off in use. This was very common before the improved fitting techniques were developed. Blade life may vary from 500 to 750 hours according to conditions.

Windscreen and Windows

On short routes the wipers work continuously keeping clear vision for the driver, and at one time heated glass was used. This became a useless aid since the heat dried the salt spray and the particles scratched the surface, spoiling the vision. The windscreen was replaced by automobile Triplex, and the surface was kept clean by a water/detergent spray.

The position is different on the longer routes, with fewer landings. Heated glass has been found useful and wipers are used when required.

At turn-rounds it is usual to hose the windows.

Arctic Conditions

The SR.N5 has undergone thorough trials in Canada and Scandinavia, where temperatures have varied from −25°C at night to −14°C during the day. Regular operational sorties were made over varying terrain of ice, snow and ice floes. Over smooth ice the speed was faster than over water, but the craft encountered rough hummocky ice and jagged crags, as well as piled-up chunks on the floes.

Speed was slower over the rough terrain, but the skirt suffered negligible damage and was not torn by sharp edges, this being due to the low coefficient of friction. In fact very little service and maintenance was required during the whole series of tests, there being no major refit, the systems were satisfactory, and in spite of rough handling no structural damage was sustained.

The main trouble in Scandinavia arose during unusual weather conditions, when the temperature was just above 0°C and there was about 6 in of wet snow on top of the ice. A mixture of ice, snow and water was trapped in the skirt and aft bags, amounting to several tons; control was lost and the craft stopped. Suitable modifications have since been made.

Where ice is liable to form on vital parts of the craft, arrangements can be made for the ducting of warm air from the plenum chamber.

Both civil and military operators have benefited from these trials.

Military Role

Military air cushion vehicles operate under varying adverse conditions that would not be considered by commercial users, and the results of various trials undertaken by the Inter-Services Hovercraft Trials Unit have demonstrated the potential of the ACV. The experience is valuable to the designers of the craft, equipment and systems, as well as to the operators who sooner or later will benefit from it.

Tropics

The Far Eastern Unit of IHTU operated in both a peaceful and hostile environment when it used two armed SR.N5s for patrols, logistic work, emergency missions and so forth.

The maintenance engineers frequently had to improvise methods for repair work from local resources, an outstanding task being that of repairing an unserviceable engine with outboard engine parts found in a neighbouring village.

Humidity and high temperature naturally caused some operational problems, which resulted in less payload being carried in the hottest part of the day. Humidity so affected the bonding of the anti-erosion strips that these were soon shed from the blades.

Greater Use of Aircraft Items

The start of these notes mentioned the use of aircraft items, and as these become more adapted to ACV requirements some maintenance problems should cease, but it is hoped that the creative ideas of the dogged and talented few will enlarge the scope of the hovercraft, recently defined by Mr Christopher Cockerell as "a very expensive motor car with a very large puncture".

The author acknowledges with grateful thanks the help received from the British Hovercraft Corporation, Hovertravel Ltd, Hoverlloyd Ltd, British Rail Hovercraft Ltd, Townsend Hover Ferries, Bristol Siddeley Engines Ltd, the Air Registration Board and Lloyd's Register of Shipping.

Appendix

A page from the technical log of Hovertravel Ltd: Maintenance Schedules (SR.N5/N6).

Operator HOVERTRAVEL LTD. TECHNICAL LOG HOVERCRAFT TYPE .... No. .... END OF DAY

COMMANDER'S DEFECTS	RECTIFICATION	CLEARED BY SIGN.	MAN/HRS.	DAILY STATS.
				ROUTE
				SORTIES
				CRAFT HRS.
				POWER HRS.
				No. STARTS
				AV. SORTIE TIME
SERVICING DEFECTS (unscheduled)	RECTIFICATION	CLEARED BY :	MAN/HRS.	ACCUMULATED STATS.
				CRAFT HRS.
				ENG. POWER Total
				PROP. HRS.
				SKIRT HRS. Sorties
				NEXT CHECK
				DUE AT
SCHEDULED SERVICING	NOTES	CLEARED BY :	MAN/HRS.	FUEL/OIL UPLIFT
				OIL DAILY UPLIFT
				FUEL IN CRAFT a.m.
				DAILY UPLIFT
				FUEL REMAINING
SERVICE DELAYS	CERTIFICATION :	SIGNATURE	TIME / DATE	FUEL USED
TECHNICAL	CRAFT			AV./G.P.H.
HOURS LOST	PROPULSION			NOTES
WEATHER	RADIO/ELEC./INSTRUMENTS			
HOURS LOST	Certified that the craft is maintained in accordance with approved schedules and is fit for operation.	ENGINEER i/c.	PILOT'S SIGNATURE	
NOTES		TIME DATE	DATE	Training/Non-Scheduled Operations/Incidents, etc.

MAINTENANCE SCHEDULE (SR.N5/N6)

Craft No...............................

Maintenance Cycle

PRE-OPERATIONAL — Not certificatable.
POST-OPERATIONAL — Valid for 72 hours if not operated.

Check 1 between 50- 70 operating hours.
Check 2 between 100-140 operating hours.
Check 3 between 280-320 operating hours.
Check 4 between 600-650 operating hours.

Note 1. Pre-operational + post-operational — daily, but may be separated.

Note 2. If the craft does not achieve Check 1 hours in one month, a Check 1 is required every thirty days.

Note 3. All checks are cumulative.

Note 4. "Operating hours" are defined as "power hours" and do not include "idle hours", in respect of craft, transmission and propellers. *Engine operation hours* will be accounted for in agreement with BSE Ltd.

Note 5. Overhaul periods will be in accordance with latest issues of manufacturers' technical information.

Note 6. Definition of terms. The word "check" used in this schedule is to be interpreted to mean that the item has been inspected sufficiently to ensure continued serviceability until the next check becomes due.

Note 7. Amendments.

PRE-OPERATIONAL CHECKS

Check externally — damage — obstruction.
Check propeller and fan assembly — free.
Check control systems.
Check marine equipment — secure.
Check fire-bottle safety pins.
Check hatches and cowlings, panniers — secure.
Remove pitot and jet pipe covers.
Check serviceable batteries — fitted.

POST-OPERATIONAL CHECKS

Wash craft, flush oil cooler.
Wash engine and inhibit compressor.
Check for fuel and oil leaks.
Check PTET trip operation.
Check engine run-down time.
Check propeller and apply anti-corrosive.
Check ignitor plugs.
Check fuel and oil state.
Check air-conditioning drive belt.
Clean and secure engine intake filters.
Check cowling seals and locks — secure.
Check washers/wiper/demisters.
Check passenger seats and life belts.
Check skirt lift jack assemblies.
Check for structural damage.
Replace pitot and jet pipe covers.
Check batteries (2).
Rectify defects in Technical Log.

CHECK 1 — MAINTENANCE SCHEDULE (SR.N5/N6)

Craft No................................

HU	HULL (UPPER)	
Item	*Description*	
1.	Check elevator assemblies, hinges, linkages.	LUB
2.	Check rudder assemblies, hinges, linkages.	LUB
3.	Check fin structure.	
4.	Check panniers — leaks — secure.	LUB
5.	Check propeller shaft struts.	LUB
6.	Check dorsal cowlings and seals.	LUB
7.	Check aerial assemblies — secure.	
8.	Check yaw doors, jacks, hinges.	
9.	Check skirt attachments.	
10.	Check all structure — damage — corrosion.	
11	Drain buoyancy tanks. Note excess quantities.	
12.	Check radar scanner — security — corrosion.	
13.	Check ballast tanks — contents and cocks.	

HL	HULL (BELOW DECKS)
Item	*Description*
1.	Check ballast tanks, pumps and electrics.
2.	Check buoyancy tanks, drains — secure.
3.	Check flexible skirts throughout (wire lock).
4.	Check control cable and lever assemblies.
5.	Check hydraulic pipe assemblies.
6.	Check all structure — damage — corrosion.
7.	Check side buoyancy tank attachments.

C	CABIN GROUP	
Item	*Description*	
1.	Check cable door, ramp, locks and hinges.	LUB
2.	Check cable floors.	
3.	Check windows — damage and leaks.	
4.	Check and clean below pilot seat and controls.	LUB
5.	Check rudder pedal assembly.	LUB
6.	Check throttle control assembly.	LUB
7.	Check elevator control and ratchet.	LUB
8.	Check ventilation controls.	LUB
9.	Check screen wiper assemblies.	LUB

M	MARINE AND SAFETY GROUP
Item	*Description*
1.	Check anchor, stowage, line — secure.
2.	Check floating line — stow.
3.	Check engine fire-bottle assemblies.
4.	Check cable fire extinguishers (2).
5.	Check front step stowage — clean.
6.	Check first-aid kit.
7.	Check pyrotechnics and signal pistol.
8.	Check fog horn and spare cannister.
9.	Check signal lamp equipment.
10.	Check dinghy installations (2).
11.	Check life jackets (1 per seat).

EL	ELECTRICAL, RADIO, INSTRUMENTS	
Item	*Description*	
1.	Check battery condition — levels — corrosion.	
2.	Check 100A inverter — condition — voltage.	
3.	Check PTET and TRPS units — corrosion.	
4.	Check instrument panel assembly — corrosion.	
5.	Check fire extinguisher circuits (safety ohmmeter).	
6.	Check radio and PA equipment — corrosion.	
7.	Check internal lighting equipment.	
8.	Check external lighting equipment.	
9.	Check spare fuses.	
10.	Check power plant electrics — corrosion.	
11.	Drain and check air speed indicator system (if required).	
12.	Check Group C wipers.	LUB

P	PROPULSION GROUP	
Item	*Description*	
1.	Check filter/water separator and drain.	
2.	Check fuel tank sump for water.	
3.	Check booster pump and pipe assemblies.	
4.	Check low-pressure cock.	LUB
5.	Check fuel supply lines.	
6.	Check engine oil pressure and clean filter (if required).	
7.	Check oil tank and pipe assemblies.	
8.	Check and clean IGV system.	
9.	Check throttle controls.	LUB
10.	Check propeller-pitch controls.	
11	Check turbine O/strip wire.	
12.	Check engine mounting spherical joints.	
13.	Check alternator drive assembly.	LUB
14.	Check gearboxes — corrosion and leaks.	
15.	Check lift fan assembly.	LUB (2)
16.	Check barrel couplings.	LUB
17.	Check fire-walls, shrouds and jet pipes.	
18.	Check cabin heater and pipe assemblies.	
19.	Check power IO and auxiliary gearbox.	
20.	Check and service air-conditioning equipment.	
21.	Check engine intake area — clean.	
22.	Check debris guard — secure.	

BULLETINS

Description

CHECK 2 — MAINTENANCE SCHEDULE (SR.N5/N6)

Craft No................................

ELECTRICS

Description

Check alternator — corrosion.
Check Electrical Groups D and F — corrosion.
Check Electrical Group G — corrosion.
Check Electrical Group L — corrosion.
Check Electrical Group V — corrosion.
Check electrics, fin area — corrosion.

PROPULSION

Description

Replace fuel filter and element, and leak test.
Clean and leak test centrifugal filter.
Check magnetic plugs.
Check gearboxes, mounts — corrosion.
Check power plant bay — corrosion.
Replace and leak test Purolater oil filter.

BULLETINS AND TIME-EXPIRED ITEMS

Description

CHECK 3 — MAINTENANCE SCHEDULE (SR.N5/N6)

Craft No................................

Description

Check gearbox tooth patterns.
Check insulation — aerial feeders.
Check insulation — thermocouple harness.

BULLETINS AND TIME-EXPIRED ITEMS

Description

CHECK 4 — MAINTENANCE SCHEDULE (SR.N5/N6)

Craft No................................

Description

Check barrel gear — couplings (internal).
Check hydraulic pump drive keys.
Remove and clean oil jets.

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SOME ASPECTS OF THE AEROTRAIN SYSTEM

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TRANSPORTATION problems are becoming a subject of renewed interest, not only because actual means of transport are saturated or unadapted in many densely populated areas of the world, but also because new means of transportation are appearing. The "Aérotrain" system now being developed by the Société d'Etudes de l'Aérotrain is one of these new means of transportation, and I should like to present its major aspects.

The criteria for a transportation system set forth in most of the actual studies are generally: frequency of departure, capacity of traffic (nominal and peak), time of transit, aptitude to penetrate urban areas, investment costs, exploitation cost, attractiveness and comfort.

No system of transport can claim to appear first in all of these criteria and a new system such as the Aérotrain, essentially based on a new principle of transmitting forces, has to be evaluated and compared with other systems accordingly.

The development programme of the Aérotrain started during the second quarter of 1965, and accurate figures are therefore not available for all the factors involved, but the results and experience obtained during the last nine months with the experimental vehicles and guideways have enabled engineers and economists to assess potential trends. This is what I will try to do, but before doing so I will say a few words about the principles underlying the concept of the Aérotrain and its actual developments.

The idea of an aircushion is very simple : the principle is to create a bell-shaped cavity turned towards the ground in which one induces a pressure slightly above the atmospheric pressure so as to compensate for the weight of the train, and maintain the cavity above the ground, and supply air to compensate for the leakage along the periphery.

This idea, while not new, has required many years of development before becoming a workable means of levitation. Names of precursors like J. Scott Russell 1865, Girard 1880, Von Thomenkul 1916, are associated with this development; since then, different companies (Lima in Brazil, General Motors and Ford in the United States, Cockerell in Engand, Bertin in France) have carried forward research in the field and presented different vehicles. It can be said that a real breakthrough has been made with a feature first developed in France as a leak-control system called a "flexible skirt". The sides of the bell are not rigid but supple.

FREQUENCY OF DEPARTURE

This property for a guided vehicle will essentially depend on a combination of economical and technical factors. Technically the vehicle's aptitude to decelerate and accelerate is important because it will determine the safe distance between the units of transport. The Aérotrain having no "grip" limitation and the reaction to its motion forces being taken by the guide or the ambient medium, or both, can use all actual known means. As long as the guide has compatible strength and weight, braking by pitch reversal, airbrake, friction shoes, tyres with disc brakes, and acceleration by propeller, electric linear motor, linear turbines, or propulsion tyres are possible. In practice acceleration and deceleration will be limited only by the needs of passenger comfort. The Aérotrain system can, with regard to this criterion, be considered as having no technical limitation. Economically the Aérotrain adapts itself very well to single units of the optimum capacity or to combination of units as indicated below.

CAPACITY OF TRAFFIC

Nominal and peak values have to be considered. High-speed transportation will probably use more and more self-propelling units or moduli of transport (for the concept of a single propelling unit pulling a train of vehicles as do locomotives has serious limitations when high speeds have to be obtained). The capacity of traffic in seats offered per unit time is then given by the product of the frequency of departure by the capacity of the modulus of transport multiplied by the number of moduli grouped together. The grouping can be done by actual mechanical linkage, or by a "burst of vehicles" following each other at a safe spacing. The only limit is therefore in the size or length of vehicle which can be built, and this limit is set by the rise (maximum distance between the arc of curvature of the track and chord or length of aircushion) that the edge of the aircushion can take in a curve. One can today produce an aircushion with an edge or lip controlling the air gap, capable of giving several inches of displacement in a direction normal to the surface. This allows one to consider vehicles of 70 to 100 seats as capable of negotiating curvatures of the order of 1,000 metres of radius without active suspension system or gimbals.

One should also mention that owing to the exceptional capacity of accelerating and braking, the Aérotrain system can be conceived with a single track and "avoiding platforms" to keep a high frequency of departures and still achieve interesting traffic capacities with almost half the track investment required for more conventional systems.

TIME OF TRANSIT

The time taken from one station to another depends on the maximum speed and, mainly for short distances, on the acceleration/deceleration capacities of the vehicle. The principle of aircushions allows the highest speeds, because unevenness in guiding surfaces will not generate acceleration or shock increasing with the square of the speed as in the case of a wheel.

Unevenness in track profiles as long as they do not extend over a length comparable with the length of the aircushions appears merely as noise filtered by the aircushions. For perturbation extending over great length the Aérotrain is like any other vehicle: as good as its suspension system is for low frequency, and it is possible to build an aircushion vehicle with a band width below 1 c/s without any active elements in the suspension or air gap control.

The only limits, not yet encountered even on a small-scale vehicle, can be auto-oscillation by interaction between external drag and lift forces and internal guiding forces themselves. Should these kinds of instability appear, the means of counteracting them are readily available by pure fluidic control. One can already expect to keep, by proper design and from experience acquired on the experimental vehicle, the actual simplicity up to speeds in excess of 250 km/h. Beyond this range, which is not yet completely defined, a more involved suspension system and track profile might be necessary and will have to be selected on economical grounds. One can, however, conclude that concerning time of transit the Aérotrain system is next to the aeroplane transportation system.

APTITUDE TO PENETRATE URBAN AREAS

It can be said that, because of its relatively light weight for track and vehicle, because of its aptitude to climb slopes in absence of grip limitation, and because of its smooth and noiseless travel, the Aérotrain system is well suited to this task.

COST OF INVESTMENT AND EXPLOITATION

Accurate figures are not yet available, but extensive studies have shown that the absence of concentrated stresses on the vehicle and on the track allows the use of a light structure. Elevated tracks with relatively long span beams should provide the lowest investment cost, lower than railroads or even highways. The reason for these conclusions are the weight of the structure and the tolerances imposed on the guiding surfaces.

As regards exploitation costs, if the fact of using an air-cushion for levitation and support increases the power requirement per seat compared with railroad or buses, for instance, the energy consumption per kilometre/passenger is only increased by 15 to 25% with regard to railroad at 250 km/h. Considering that the cost of energy in the price of kilometer/passengers is for all transportation systems between 4% and 12% of the total and anyway is much smaller than the cost of maintenance, this small handicap will certainly be compensated for by the decrease in maintenance cost resulting from the simplicity of the system.

CONCLUSIONS

The attraction that such a system of public transportation might exert depends on the services it can give, and upon the comfort it can provide. Comfort can be achieved either by the smoothness of the track surface and profile, but at increasing cost, or by the quality of the suspension system. Because of the economical implications of the tolerances of the track on the investment cost and its influence on the comfort of passengers, the knowledge of the practical limit which can be achieved at increasing speed for different aircushion systems is one of the main tasks now being pursued on our experimental system.

This paper was presented to the Institution of Mechanical Engineers' Convention on Guided Land Transport held in London on October 27th-28th, 1966.

APPLICATION OF AIR CUSHIONS TO HIGH SPEED GUIDED LAND TRANSPORT

D. S. Bliss
Head of Tracked Hovercraft Division
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INTRODUCTION

THE subject of this paper is the application of the air cushion method of vehicle suspension to a new system of high-speed land transport.

The purpose of this new transport system is to provide a frequent direct service offering a combination of speed, safety and reliability in all weather conditions which cannot be equalled by other means.

It is proposed that this system should be applied between selected centres which have sufficient traffic potential to justify the expense of a new track across the geographical features which separate them.

To introduce such a new transport system is clearly a long-term project and, even if the necessary development programmes were initiated today, it is doubtful whether commercial services could be in operation before the 1980s. By then transport problems are likely to have increased and it is these worsened conditions which should be taken into account when considering possible applications of high-speed land transport. The contribution of high-speed land transport to the solution of the traffic problems of 1980 and beyond is that it offers the opportunity to disperse geographically an area of intense business activity without destroying its unity.

The correct applications for the new transport system will be found as the result of a study of the engineering, operational and financial aspects of any given route. In these applications new techniques of vehicle design will be called for, especially in the fields of suspension and propulsion.

It is believed that air cushions can be used with advantage as a means of suspension for high-speed tracked vehicles and some aspects of this application are discussed below.

TYPES OF CUSHION

Some basic types of air cushion which may be used in guided land transport are illustrated diagrammatically in Fig A.1. In the majority of these the air for the cushion is supplied by a fan through suitable ducting.

The air film type, Fig A.1A, only provides a relatively thin air lubricating film and as a result a very smooth track is required. Proposals for its use have generally specified a special steel rail and relatively high bearing pressures. This is not a true air cushion, but is included for completeness as it formed the basis of some early work in the field of high-speed land transport by the Ford Motor Company. In all the other cases shown, an air cushion is generated which is sufficiently thick to allow steel rails to be dispensed with and the vehicle to run on the bed of the track at a lower bearing pressure.

The plenum chamber, Fig A.1B, is probably the simplest way of providing an air cushion thick enough to allow the use of tracks with step discontinuities at the joints. Here, the cushion is generated by allowing air from the fan to diffuse into a cavity formed between the base of the vehicle and the track. The cushion air subsequently escapes and must be continuously replaced.

The air curtain cushion system, Fig A.1C, may be regarded as a development of the plenum chamber in which an air jet is directed across the air gap between vehicle and track to form a barrier, or curtain, to restrict the rate at which the cushion air escapes. In practice a separate cushion air supply is not required — the curtain air provides the cushion as well as sealing it. When established, the cushion consists of relatively stationary air and this distinguishes it from the air bearing and plenum chamber types previously described.

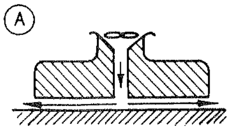
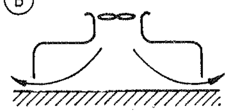
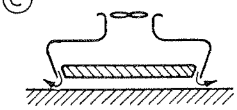
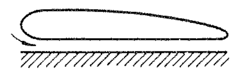
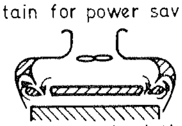
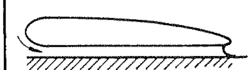
	A	B	C	D
CUSHION: Type	 Air Film	 Plenum	 Simple Air Curtain	 Ram Wing
Source	Air Fan	Air Fan	Air Fan	Forward Speed
Pressure	Very High (15–100 P.S.I.)	Low (1–3 P.S.I.)	Low (1–3 P.S.I.)	Proportional to Speed ^{2} i.e. 0·16 P.S.I. at 100 M.P.H.
Air Clearance	Very Small (0·01–0·02" TYP)	Small (0·1" TYP)	Increased for Same Power (0·5–1·0" TYP)	
TRACK	Steel Very smooth, very accurately aligned surface required.	Concrete Smooth, accurately aligned surface required.	Concrete Smoothness and alignment not so important as in A and B	Concrete Smoothness and alignment not so important as in A and B.
DEVELOPMENT POTENTIAL			1. Recirculation of air curtain for power saving.  Injector recirculation 2. Integral second stage suspension system (Sect. 4)	 Air curtain at trailing edge to increase clearance.
REMARKS	Ford Levacar.	Bertin Aerotrain	Hovercraft Development Limited. Tracked Hovercraft	Requires separate lift system until operating speed is reached.

Fig. A.1. Cushion systems for high-speed land transport

The ram wing shown in Fig A.1D is basically different from the systems previously described as the lift developed is related to the speed of the vehicle as with an aircraft. Some additional form of support up to the normal operating speed is, therefore, required. While the method is clearly inadequate in itself, for the reasons given above, it is possible that it may be usefully employed to off-load other types of air cushion at high speed.

Summing up the merits of these basic types of air cushion, the air film type can do little more than remove frictional resistance, while the ram wing method is not self-sufficient, and its lift is related to forward speed. The plenum chamber and air curtain methods both enable a cushion to be generated at all speeds which is thick enough to allow the use of tracks with relatively rough surfaces and joints. These two systems, therefore, merit closer attention.

As stated previously, the purpose of the air curtain is to restrict the rate of escape of cushion air. This enables the same clearance to be obtained with less power than required by the plenum chamber. It can be shown that with all other things equal, the plenum chamber requires at least twice as much power as the curtain jet to obtain the same air clearance. Furthermore, a plenum chamber, especially an efficient one, will have considerably less restoring force when displaced vertically from its normal operating height than a cushion bounded by an air curtain. This might prove to be a serious deficiency in high-speed tracked vehicles.

A possible development to save power is that of collecting the discharged cushion air and recirculating it back into the air-producing system. This has been achieved with air curtain systems and may also be possible with the plenum chamber type. One possible method which would be very convenient for tracked vehicles using the curtain jet as the primary of an injector is indicated in Fig A.1. This particular scheme is obviously not applicable to the plenum chamber. It is probable that plenum chamber recirculation would involve returning the air to the fan intake.

With marine hovercraft it has been found that power requirements can be reduced considerably by the use of flexible skirts. This permits a considerable structural clearance to be achieved with a very small air gap at the expense of contact between skirt and water. This has the effect of narrowing the difference in power required (in absolute values) by the two systems and plenum chamber techniques are currently being used in some marine applications. However, it is considered that similar techniques involving contact between a flexible extension and track at speeds of 200-300 mile/hr are not permissible as a design feature and that a definite air clearance must be maintained (although an expendable rim of non-rigid material will doubtless be provided to allow for intermittent unintentional contact). A development capability of considerable significance which is possible with the air curtain system

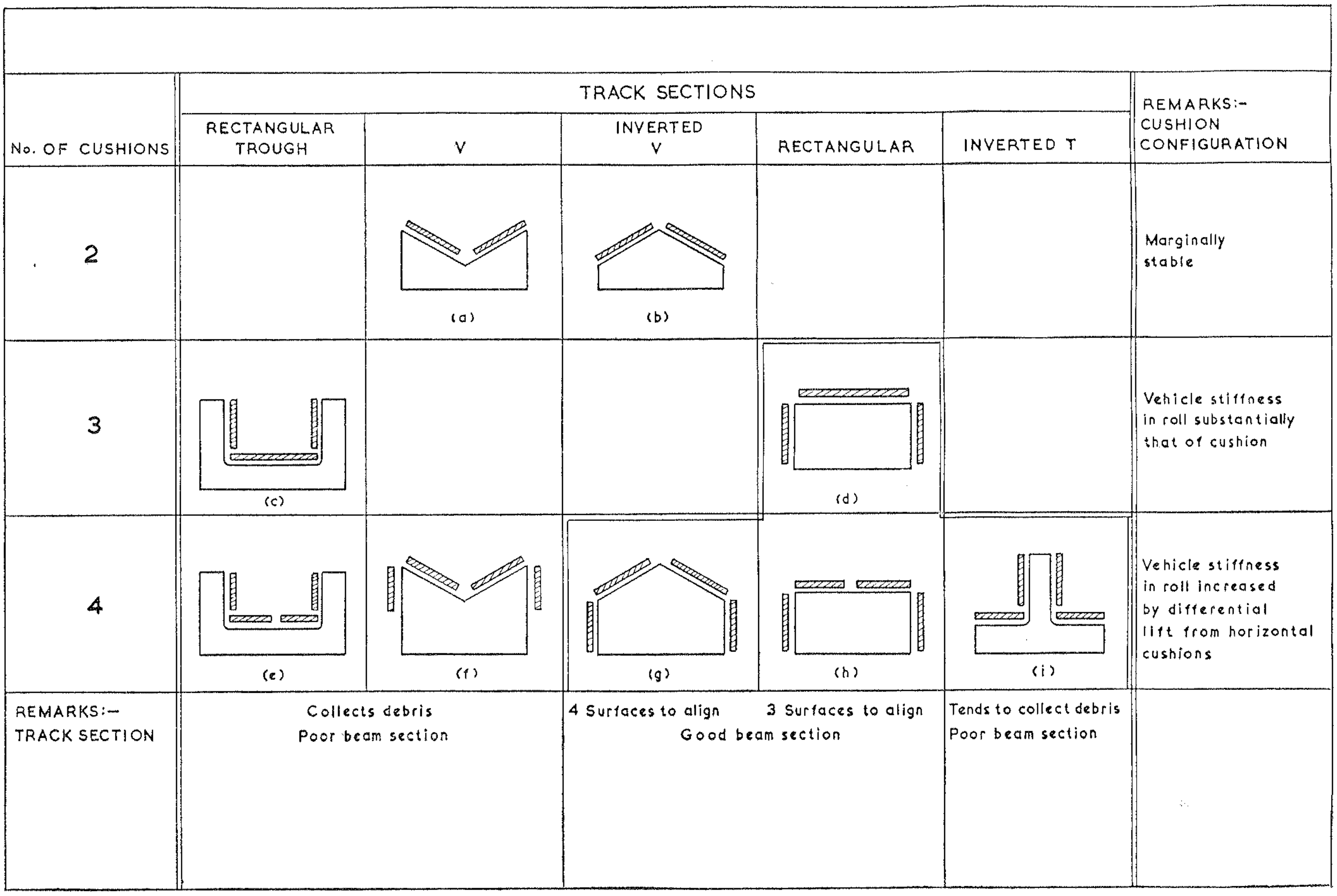


Fig. A.2. Air-cushion and track-section combinations

is the integration of the air cushion and a secondary air spring to form a complete suspension unit. This type of development, which is discussed further under the heading "Second stage suspension", may be more difficult to apply effectively to the plenum chamber.

For these reasons the curtain jet method of cushion generation is considered to be the most suitable for high-speed land transport and all further discussion is centred on this method.

AIR CUSHION CONFIGURATIONS AND TRACK SECTION

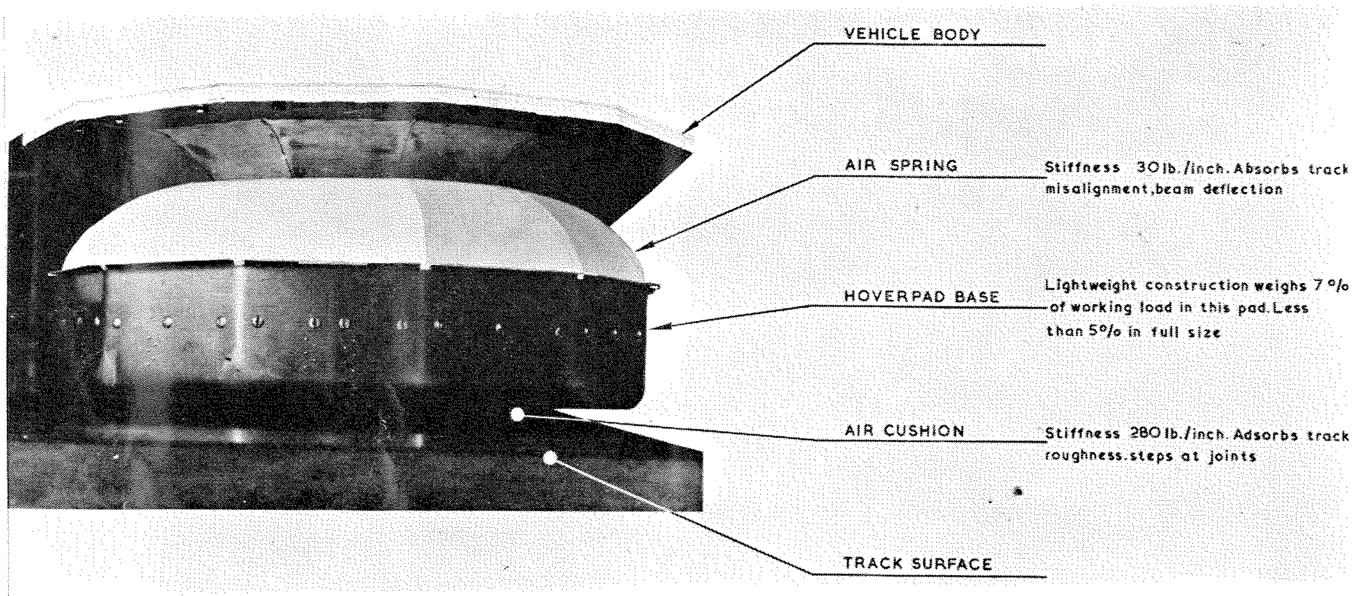
Conventional hovercraft are supported by a single air cushion acting directly on the bottom of the vehicle. In land transport applications additional cushions are required to provide guidance. The guidance cushions are required to overcome side forces on the vehicle resulting from track curvature and operation in side winds. Permissible side loads due to track curvature are limited by passenger comfort to small values and the design side loads will usually be determined by aerodynamic side forces. As these will generally be resisted on track surfaces which are below their line of action, a rolling moment will be imparted to the vehicle. The amount of roll which can be tolerated at high speed is obviously limited and it is the restriction of displacement in roll, rather than the overcoming of the side force itself, which is likely to be the major problem in vehicle guidance.

Fig A.2 shows some combinations of air cushions and basic track sections which have been studied for use in high-speed land transport applications.

Attempts to economise on the number of cushions by using the horizontal component of an inclined lift cushion for guidance (Figs A.2*a* and A.2*b*) normally result in a vehicle which is marginally stable or unstable. The most effective configurations in counteracting vehicle roll are those where four cushions act on the horizontal and vertical surfaces of a rectangular or inverted T track. This is because air cushions are stiff in vertical displacement and hence the rolling moment on the vehicle is best reacted as a difference in lift forces. These configurations also allow the differential lift effect to be enhanced by feeding each lift cushion from an independent fan with suitable characteristics. Three cushions positioned on a rectangular track as in Fig A.2*d* may be adequate in cases where the track is sufficiently wide, but in this case the stiffness of the vehicle in roll is substantially that of the cushions themselves. The effectiveness of this configuration can be increased by the addition of central jets to the lift and guidance cushions.

As "all weather" capability is an important potential advantage of high-speed land transport over air transport, the prevention of debris collection on the track is important. This consideration eliminates tracks of trough section (Figs A.2*c*, A.2*e* and A.2*f*) as impractical for outside use. If these sections are split to overcome debris collection they result in a dual track requiring a further dimension (gauge) to be maintained during construction, which increases costs. Also, an inverted T section track is more likely to collect more drifting snow and other debris than a flat surface, especially when track banking is required.

Summarising, Figs A.2*d*, A.2*g*, A.2*h* and A.2*i* are all practical track sections, but a rectangular track section with three (or four) air cushions acting on three of its faces has much to commend it for use in high-speed land transport. Also, from the civil engineering standpoint, a rectangular track section is relatively easy to mould in concrete and has good torsional stiffness. It is probable that the cushion configurations shown in Fig. A.2 would be repeated at each end of the vehicle, so that it would be supported and guided by a total of six (or eight) air cushions. This number of pads follows from fundamental considerations which do not depend upon the size of vehicle.



End view of experimental unit showing the principal components. Working load = 350 lb

Figure A.3. Hovercraft Development Ltd Air Spring Hoverpad

SECOND STAGE SUSPENSION

The Hovercraft Development Ltd (HDL) Air Spring Hoverpad

Although an air cushion can be generated which is sufficiently thick to accommodate track surface roughness and step irregularities at the joints, it is not likely that such an air cushion in itself will provide a complete vehicle suspension —that is, one which will give a comfortable ride at high speed over all the track deflections and misalignments which are likely to arise in service. A second stage of suspension is required between the air-cushion lift surface and the passenger accommodation. The vehicle is thus envisaged as being supported and guided by a number of separate air-cushion pads which are connected to the main body of the vehicle by a suspension system with an operating stroke of several inches.

Studies have been made at Hovercraft Development Ltd of the desirable characteristics of suspension systems for high-speed tracked vehicles. These show that a soft suspension is essential and, to cover the whole speed range, a means of adjustable damping or its equivalent is required. Also, as would be expected, the unsprung weight should be as low as possible. It has been found possible to obtain some of these characteristics by using the air supply to the curtain jets to form what is effectively an air spring between the base of the Hoverpad and the vehicle proper.

An example of this type of suspension unit, the HDL Air Spring Hoverpad, is shown in Fig A.3. The air cushion only provides sufficient separation from the track to allow for surface roughness and discontinuities at the joints. At speed the path of the base of the Hoverpad follows the track profile fairly closely owing to the stiffness of the air cushion, and the resulting accelerations on the pad base can be relatively high. The upper section forms the air spring with a much lower rate than the air cushion, providing a soft suspension with an appreciable stroke. The resulting two-stage suspension system is extremely simple and compact and it can be readily designed to provide the required stiffness. By these means high-speed transport without the need for extreme accuracy of track surface finish and constructional alignment becomes possible and this will result in reductions in capital and maintenance costs.

An early model of such a Hoverpad (the one shown in Fig A.3) has been tested over a dynamic table which can be oscillated vertically and tilted to simulate travel over an uneven surface, for example, owing to the deflection of an elevated track under load. As an example of its performance, an input of 2 in vertical displacement of the table at a frequency of 3·5 c/s (which on an elevated track of 100 ft spans would represent a vehicle speed of almost 250 mile/h) was reduced to about $\frac{1}{4}$ in of movement at the top of the assembly representing the vehicle floor, ie a peak acceleration of about 0·18*g*. While is is recognized that is is too great for passenger comfort over long periods, the soundness of the basic principle has been established. As tested, this particular model Hoverpad did not incorporate any means of damping or springing other than that in the air supply to the air-curtain jets. The performance will undoubtedly be improved by refinement to the basic design and the addition of damping devices.

AIR CLEARANCE REQUIRED

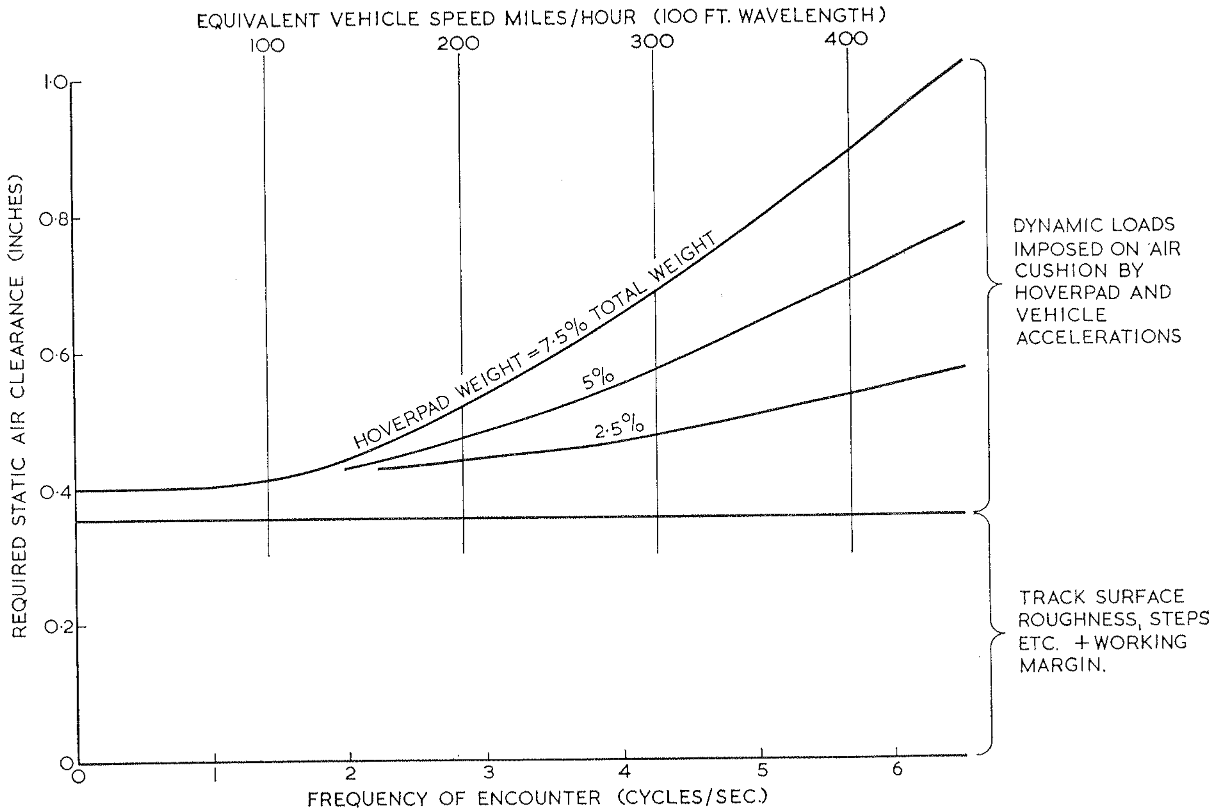
The air clearance required between the base of the Hoverpad and the track can be considered as consisting of two parts:

(1) That required to overcome the dynamic loads imposed by the vehicle as a whole and the pad base in particular.

(2) That required to overcome the track surface roughness and discontinuities at joints.

The first of these two components depends upon track and vehicle parameters such as the depth and frequency of encounter of the irregularities (for example, track deflections), the weight of the pad base, and the cushion and suspension characteristics. The second component is dependent solely upon the accuracy of construction of the track.

A theoretical assessment of the air clearance required for a typical elevated track is shown in Fig A.4. If track constructional tolerances were reduced to produce a perfectly smooth track then only the dynamic component would be required. If, in addition, the track were continuously supported to prevent deflection then only a very small air clearance would be required. However, even if such a track were built, it is most unlikely that it would retain this perfection in service without incurring exceptional maintenance costs. The problem of fixing a minimum air clearance requirement is thus that of assessing the degree of accuracy to which a track can be economically built and maintained.



Sinusoidal track profile, 4 in crest to trough.

Fig. A.4. Theoretical assessment of required air clearance

POWER REQUIREMENTS

The total power required for lift by an air cushion is made up of two components:

(1) The fan power required to compress the air to form the curtain jets.

(2) The propulsive power required to overcome the drag (momentum drag) resulting from taking air on board the vehicle and thereby accelerating the vehicle from rest to vehicle speed.

Both of these powers are directly proportional to the quantity of air required to form the cushion, and this is directly proportional to the design air clearance.

The power required for compression at the jet nozzle is:

$$H_j = \frac{P_j Q}{550} \text{ hp}$$

where P_j is the total pressure at the nozzle (lb/ft² gauge), Q the air volume flow (ft³/s), and if P_D represents the pressure losses through the ducting between the fan and the nozzle then the power output required from the fan, H_F, is

$$H_F = \frac{P_F Q}{550} = \frac{(P_j + P_D)Q}{550} \text{ hp}$$

where P_F is the pressure rise across the fan.

The engine shaft power required to drive the fan is thus:

$$H_{FS} = \frac{(P_j + P_D)Q}{550\eta_F} \text{ hp}$$

where η_F is the fan efficiency.

The drag associated with air collection at speed, termed momentum drag, is

$$D_M = \frac{WV}{g} = \frac{wQV}{g} = \rho QV \text{ lb}$$

where W is the air mass flow (lb/s), Q the air volume flow (ft³/s), w the density of air (lb/ft³), ρ the density of air (slugs), and V the vehicle speed (ft/s).

Thus propulsive power required to overcome momentum drag

$$H_P = \frac{\rho QV^2}{550} \text{ hp} \quad \left(\text{i.e. hp} = \frac{D_M V}{550}\right)$$

and the engine shaft propulsion power required is

$$H_{PS} = \frac{\rho QV^2}{550\eta_p} \text{ hp}$$

where η_p is the propulsive efficiency.

If a perfect air intake is used the air-stream dynamic pressure rise due to the forward speed is available to reduce the pressure rise required across the fan and hence the power. Under these conditions $P_F = P + P_D - q$, where q is the air-stream dynamic pressure rise $= \frac{1}{2}\rho V^2$.

The power reduction is equal to

$$\frac{qQ}{550} = \frac{\frac{1}{2}\rho V^2 Q}{550}$$

which is half the ideal propulsive power required to overcome the momentum drag.

Thus, while momentum drag is a basic quantity and the power required to overcome it must be provided in full by the propulsive system, efficient air intakes can provide an alleviation in total power requirements up to a value of half the momentum drag power. The power reduction realised in practice will, of course, depend on the intake efficiency η_I. This beneficial effect from the air-stream dynamic pressure bears some resemblance to the ram-wing method of cushion generation previously discussed. However, the mechanism of pressure transmission is less direct with the ducted system in which air

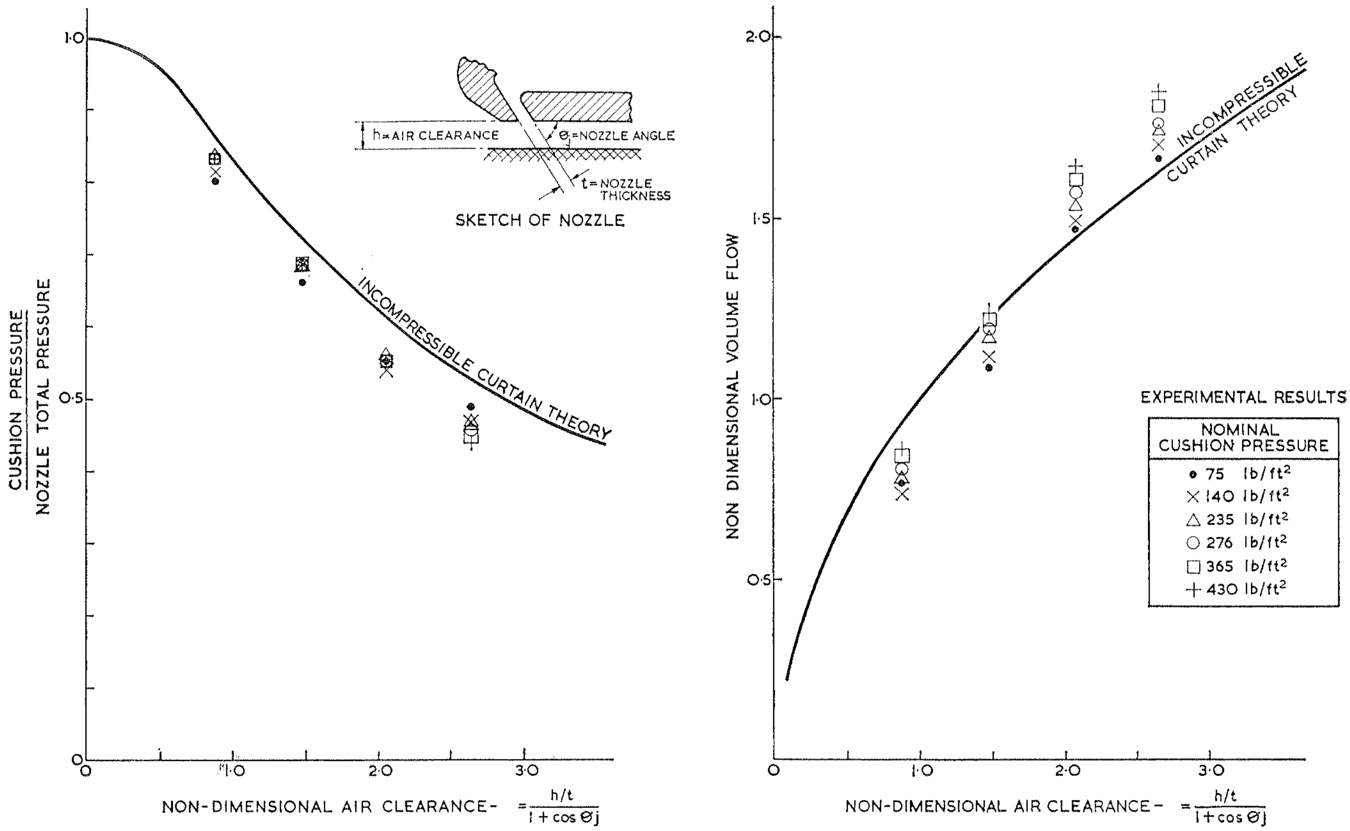


Fig. A.5. Air-cushion performance data

passes through the vehicle incurring a momentum drag and a pressure loss. Clearly, a condition is theoretically possible where the air-stream dynamic pressure, less the ducting system losses, exceeds the cushion pressure so that power to the lift fan is no longer required.

From the preceding it can be seen that the total power required for the air cushion can be written as

$$H_{\text{tot}} = \frac{(P_j + P_D - \eta_I q)Q}{550\eta_F} + \frac{\rho Q V^2}{550\eta_p} \text{ hp}$$

This shows that the power requirements of an air cushion at speed can be estimated using data which are, in the main, obtainable from stationary tests; the notable exception is propulsive efficiency which affects part of the total power requirement.

The two air-curtain performance parameters required to evaluate power requirements (jet total pressure P and air volume flow Q) can both be expressed in non-dimensional quantities, which are functions of a non-dimensional air clearance.

These non-dimensional quantities are:

$$\frac{P_c}{P_j} \quad \text{(pressure relationship)}$$

where P_c is the cushion pressure (gauge);

$$\frac{Q\sqrt{\rho}}{A_N\sqrt{P_c}} \quad \text{(air volume flow)}$$

$$\frac{h/t}{1+\cos\theta_j} \quad \text{(air clearance)}$$

where A_N is the nozzle exit area, h the air clearance, and θ_j the angle of inclination of the curtain jet, see Fig A.5.

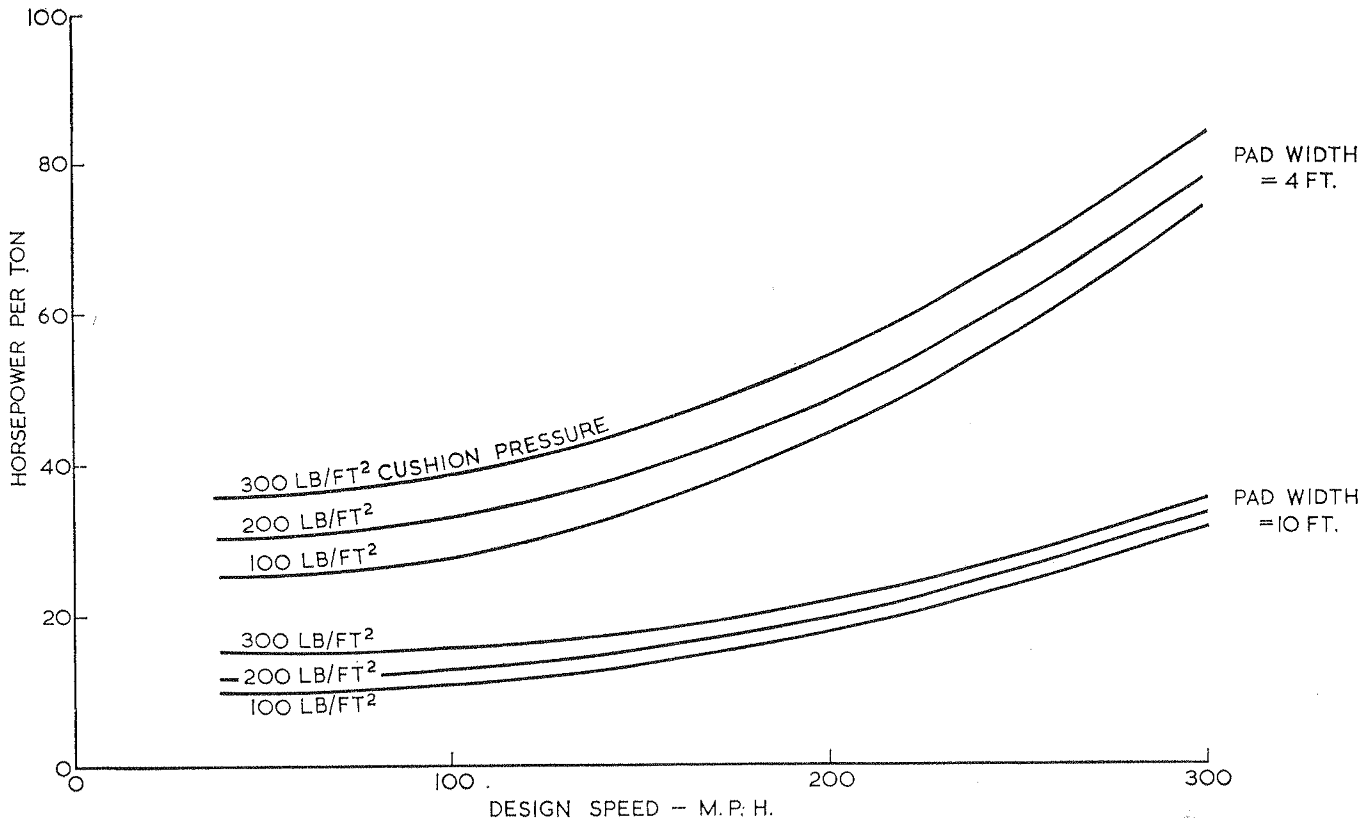
The relationship between these quantities as given by a simple inviscid incompressible flow theory is shown in Fig A.5, together with experimental points from tests conducted up to cushion pressures of about 450 lb/ft².

Using the air cushion data from Fig A.5, the air clearance required from Fig A.4, and practical values of efficiencies and losses, the power requirements of typical Hoverpads can be calculated. An example of this is shown in Fig A.6 as horsepower per ton supported plotted against vehicle speed for a range of pad widths and cushion pressures. In this particular case the overall effect of the efficiency factors included has been to approximately double the ideal power requirements. A marked reduction in power per ton with increased pad width is seen and in the assessment of the economics of the complete transport system this would be considered with the effect of track size on initial costs.

FUTURE DEVELOPMENT PROGRAMME

At the present time, the technology of air-cushion suspension for high-speed tracked vehicles is at an early stage of development. Experience gained in the development of marine Hovercraft is of some relevance. An insight into some of the likely problems can be gained from experiments carried out on static rigs designed for the purpose. Real progress, however, calls for a manned experimental vehicle capable of operating on a test track at a speed of at least 200 mile/hr. For this purpose a test track site at least six to seven miles in length with lateral curves not less than 12,000 ft is required. The development programme using the manned vehicle would include investigations of dynamic problems of the suspension system and vehicle, methods of stopping in normal operation and emergencies, track design features and means of propulsion suitable for use at high speed.

Air-cushion suspension does not involve contact with the track: therefore, it is considered essential that the method of propulsion used should also be one which does not depend upon contact. Propulsion using airscrews is highly developed for use on aircraft, but this has disadvantages when applied to land transport. A possible alternative is the electric linear induction motor, but this has not yet been developed for transport. As the combination of air-cushion support and



Data used:
Lift fan efficiency, 75 per cent.
Inlet efficiency, 90 per cent.
Propulsive efficiency, 60 per cent.
Duct losses, assumed 5 per cent absolute pressure.
Air clearance (see Fig. A.4), Hoverpad weight = 5 per cent total weight.

Fig. A.6. Air-cushion power requirement

linear-motor propulsion offers an elegant solution for high-speed land transport these should be developed in parallel as part of the programme.

The overall objective of the manned vehicle development programme is to accumulate sufficient design data and experience to enable a pilot commercial scheme to be planned with confidence.

CONCLUSIONS

In conclusion, the advantages of air-cushion suspension which result from the elimination of contact between vehicle and track and an inertialess first stage of suspension may be summarised as follows.

Wear of both the track and vehicle are reduced and a relaxation of track surface accuracy dispenses with the requirement for steel rails. As a result of the low bearing pressures employed, the use of a relatively soft track surface layer which may be trimmed or filled to allow for settlement becomes possible.

The suspension of the vehicle is simplified because the first stage is inertialess and the weight of the second stage can be very small. Consequently it is possible to design relatively simple, compact suspension systems with the characteristics necessary for passenger comfort at high speed. Large vehicles will not require a multiplicity of Hoverpads and thus the size of the vehicle does not increase the complexity of the system. Taking a long term view, it appears probable that the air cushion will reduce the physiological effects of travel to a minimum and thus provide the ultimate in passenger comfort for high-speed land transport.

ACKNOWLEDGMENTS

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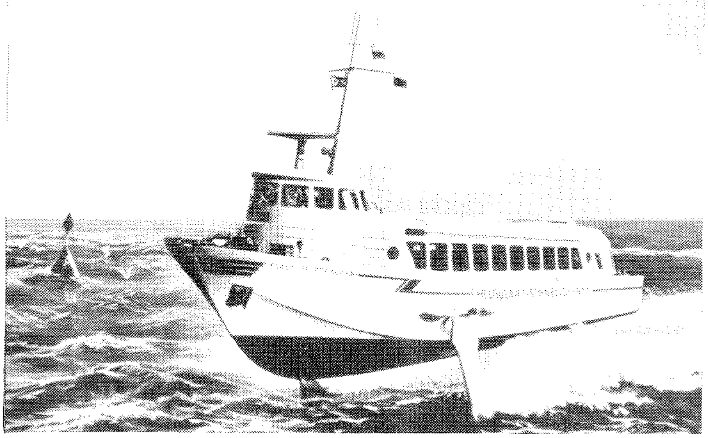
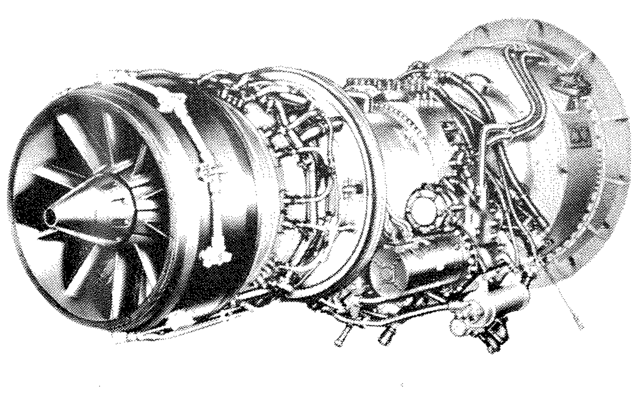
This paper was presented to the Institution of Mechanical Engineers' Convention on Guided Land Transport held in London on October 27th-28th, 1966.

1966
THE QUEEN'S AWARD
TO INDUSTRY

Rolls-Royce turbine power for hydrofoils and hovercraft



Grumman Dolphin hydrofoil craft to be powered by a Rolls-Royce Tyne turbine engine



The Rolls-Royce Marine Tyne Mk. 621 turbine engine

The gas turbine matches in terms of power the new marine developments as exemplified in hydrofoils and hovercraft.

In the Rolls-Royce Tyne gas turbine, lightness and compactness coupled with very high power output give this engine great advantages in these particular applications. Here, the influence of the aircraft engineer, with his dual demands of great power and minimum weight, react very favourably to the benefit of the marine engineer.

The Tyne with a variable pitch propeller is a reliable and economical source of marine power, offering considerable flexibility of operation. An outstanding characteristic of this engine is its low fuel consumption, which results in a lower operating cost over a very wide area of speed and gives a range of operation unobtainable with any other similar engine.

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