TECHNICAL ASPECTS OF THE AEROBAC AB-7

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ABSTRACT

The AEROBAC AB-7 is an offroad transportation vehicle combining air cushion and conventional tracks. This vehicle is presently in the conceptual stage and a feasibility study conducted for the Transportation Development Center, Transport Canada, by the SNC Group with the collaboration of Bombardier Ltd., Valcourt, Québec and SEDAM, a division of Dubigeon-Normandie, S.A. Paris, France has confirmed that its realisation is technically possible.

This paper deals with the technical aspects of the AEROBAC AB-7 and attempts to describe its main components and their interrelations.

The AEROBAC AB-7 has a total weight of twenty one metric tonnes including a seven tonne payload and is able to travel at a maximum speed of thirty kilometers per hour over terrains virtually impassable with conventional offroad vehicles.

It is believed that the AEROBAC AB-7 would be a valuable asset for offroad transportation in the Northern regions of continental Canada, where the ground surface lacks sufficient strength with regard to trafficability.

INTRODUCTION

The AEROBAC AB-7 concept has evolved from studies and tests conducted by the Transport Development Center (TDC) aiming to provide economic transportation means for Canadians located in the Canadian North where distances, low population density and difficult terrain make it economically unjustifiable to provide a conventional surface transportation network.

The AB-7 is an amphibious vehicle integrating air cushion load relief with surface contacting traction provided by tracks. The need for the integration of the two systems derives from the fact that ground surfaces in the Canadian north greatly vary, some are well suited for air cushion, but not for traction equipment, others unsuitable for air cushions, but suitable for tractors, also on slopes full ground contact is needed to provide guidance and traction. Finally the presence of a a great number of streams and lakes, imposed the necessity that the vehicle be able to float should a malfunction of the air cushion occur while over water.

In the following sections, the AB-7's different components will be described as well as their interaction.

VEHICLE PERFORMANCES AND CHARACTERISTICS

The AB-7 expected performances are summarized as follows:

- hybrid vehicle able to move on tracks only, that can be fully or partially supported by its air cushion system;
- amphibious vehicle able to float over water;
- a payload of 7 metric tonnes, approximately;
- an average ground pressure of 35 kPa ± 3 kPa when fully supported by tracks only;
- an average ground pressure of 6 kPa ± 1 kPa when fully supported by air cushion only;
- maximum speed of 30 km/hr, when fully loaded, over flat surfaces and with support from the air cushion;
- ability to handle 40% slopes with tracks only, provided approach angle does not exceed 17°;
- outline dimensions of 11.5m length, 6.2m width and 3.37m height; tracks able to be dismantled from structure, thus reducing width to 4m for transportation by road or railway.

The technical characteristics of the AB-7's components are detailed in the specification sheets included in the Appendix. One point should be stressed here is that all mechanical components used are conventional equipment which has proved its reliability in similar applications.

AIR CUSHION

The air cushion system used for the AB-7 includes the fans, the distribution system and the skirts.

Two double inlet fans are used and are installed behind the cab. The fans' impellers are mounted on the same shaft and are driven by the engine through a multiple chain drive. Air is supplied to a diffusion chamber then to two ducts installed in the central portion of the structure. Openings in the bottom of the ducts direct the air to the skirts.

The type of skirts equipping the AB-7 consists of a multicellular type and includes 42 peripheral skirts and 32 inner skirts. The rear of the vehicle is equipped with offroad skirts, specially designed to permit movement of the vehicle over obstacles. The front and rear skirts are covered with antisplash skirts to minimize projection of water and other particles.

A multicellular type of skirt has been used because the compartimentation of the air cushion helps to avoid excessive air leakage when passing over obstacles or small ditches. In theory the air leakage is restricted to the skirts passing over the obstacle or ditch and the other skirts are able to support the vehicle. Biconical skirts are used in the front and rear in order to increase the air cushion area and to protect the vehicle structure.

On flat surfaces. the distribution of vehicle load between the air cushion and the skirts is function of the fans speed. This distribution is shown on Table 1. It can be noticed that, at the nominal fan speed of 2700 rpm and nominal flow of 20m 3/s, the air cushion supports 85% of the vehicle weight and the tracks 15%. When the fan speed is increased to 2950 rpm, the air cushion supports the total weight of the vehicle.

POWER SYSTEM

Power is supplied by a Detroil Diesel engine model 8V-92TA, of 310 kW capacity for a continuous service of 8 hours per day. The engine has two outlets, one in the front and the other at the rear. The front outlet is connected by a drive shaft to a hydraulic pump. The rear outlet drives the fans through a clutch and multiple drive chains.

Oil under pressure from the hydrostatic pump drives a hydrostatic motor, connected to the inlet shaft of a transmission with six gear ratios. Power from the transmission output shaft is transmitted to the tracks through a differential, drive shafts, gear reduction units and drive sprockets.

PROPULSION SYSTEM

Urethane covered sprockets located at the rear drive the tracks, each consisting of two rubber belts joined by bolted steel studs.

Similar sprockets located in the front tension the tracks, these sprockets are mounted on pivoted levers and grease filled cylinders act on each lever to maintain the required tension in the track.

In between the two sprockets, four wheels distribute the vehicle weight on each track. Each two wheels are mounted on a pivoted tandem to equalize loading between them.

The pivot of the tandem is mounted on a lever maintained in position by hydraulic cylinders. By varying the stroke of the hydraulic cylinders, the position of the tamdems' pivots is changed and the vehicle can be raised or lowered with respect to the ground.

Fan Speed rpm	% weight Supported by air cushion	% weight Supported by tracks	Fan Flow m3/s	Fan Power kW**
0	0	100.0	0	0
1 000	19.0	81.0	7.3	15.0
1 500	27.5	72.5	11.0	30.0
2 000	48.0	52.0	15.0	65.0
2 500	72.5	27.5	18.5	125.0
2 700*	85.0*	15.0*	20.0*	155.0*
3 000	100.0	0	22.0	215.0

*Nominal operating points **Excluding transmission losses

TABLE 1 LOAD DISTRIBUTION AS FUNCTION OF FAN SPEED

The tracks, wheels, hydraulic cylinders, sprockets and all related accessories can be dismantled from the structure in order to maintain it within shipping distances.

VEHICLE STRUCTURE AND CAB

The vehicle structure is constructed from welded aluminium alloy to decrease weight and consists of a set of interconnected Warren trusses which transmits the loads to the suspension system. The trusses are covered by stiffened aluminium alloy plates in order to form water tight compartments. The whole structure at the exception of the ducts is watertight and is able to float when fully loaded with a reserve floatation of around 20%.

Floatation stability is adequate due to the vehicle size and to the position of the center of gravity which is located close to the water surface.

The vehicle cab construction is similar to the type used in Bombardier's offroad vehicle and can accomodate the operator and two passengers.

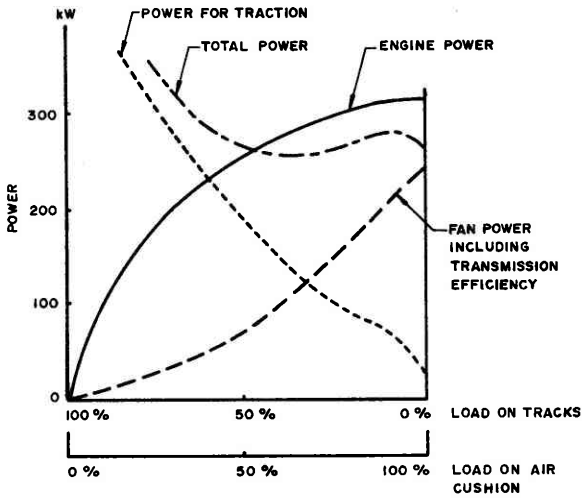
INTERACTION

The vehicle weight can be fully supported by either of the air cushion or the tracks. In principle, the portion of the weight transmitted to the tracks should be the one required to provide adherence to the ground for traction. On flat surfaces, this portion is quite small while on slopes, it is increased depending on the slope gradient.

In soft ground, track sinkage may exceed the air gap between the skirts and the ground, and cause flattening of the skirts. However, the adjustable height suspension provided permits raising of the vehicle in order to maintain the required air gap.

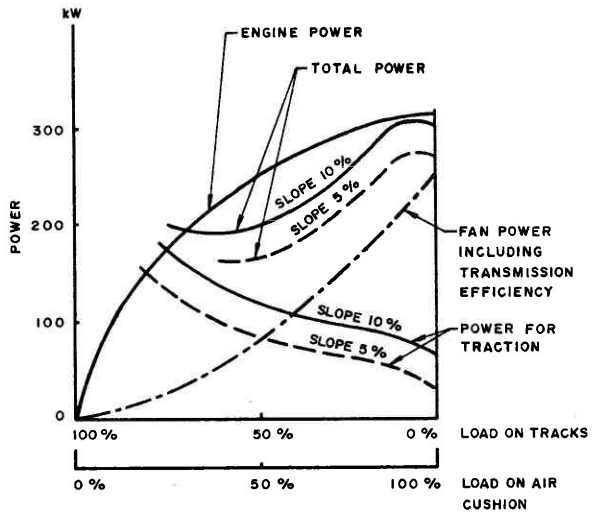
Figure 1 and 2 give an indication about the distribution of vehicle weight between the air cushion and the tracks as well as power requirements for operation on soft ground at different gradients. Load distribution is done by varying the fans' speed and accordingly the engine speed. At lower engine speeds the power available is decreased. However in the expected operational range the reserve capacity of the engine permits its continuous operation without stalling even in case of momentary overload.

The operational range is sufficiently wide to permit the movement of the vehicle over varied terrain with minimal control of the engine speed. This is possible because vehicle speed can be varied by direct control of the hydrostatic transmission independantly of the engine speed.



POWER REQUIREMENT FOR MOVING AT 30 km/H ON FLAT SOFT SURFACES "MUSKEG"

FIG. 1



POWER REQUIREMENT FOR MOVING AT 10 km/H ON SLOPES

FIG. 2

In principle a certain engine speed could be selected for a certain terrain condition and kept constant while vehicle speed is changed to suit the terrain configuration.

Should slippage of the tracks occur loading of the tracks could be increased by decreasing the engine speed while vehicle speed is unaffected, provided engine speed is decreased within certain limits.

Although the adoption of variable speed drive between the engine and the fans would have permitted the full availability of power from the engine when fan speed is decreased. This solution was not adopted because of the higher costs and the lower efficiency of such drives which would have necessitated the use of a larger engine.

STABILITY

One point of concern was the dynamic stability of the vehicle when both air cushions and tracks are in operation. However, a stability analysis conducted with a simplified model indicated that the distribution of vehicle weight between the air cushion and the auxiliary suspension does not affect the fundamental stability of the air cushion.

The static stability of the air cushion is very good, and the maximum admissible unbalance is around 9% in roll. This stability is provided by the skirts geometry and the multicell cushion.

CONCLUSION

It can be concluded that the realisation of the AEROBAC AB-7 is technically feasible since both technologies, air cushion and track propulsion are well known, well experimented in the case of the former and widely used in the case of the latter, finally all the vehicle components are conventional equipment which has proved its reliability in numerous applications.

However some doubts may remain due to the fact that the integration of air cushion to track propulsion has not been yet experimented. Although the feasibility study has managed to solve most of the unknowns only field tests of a prototype could confirm that the expected performances will be attained.

ACKNOWLEDGEMENT

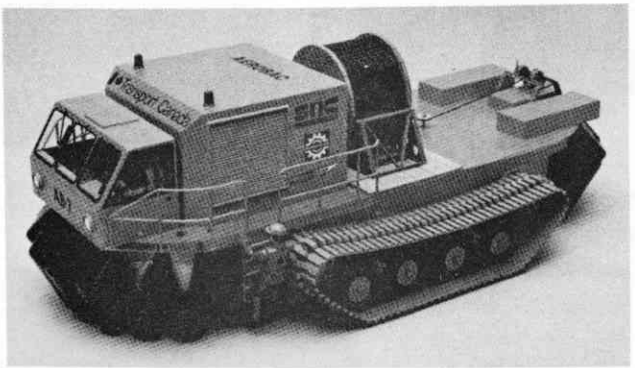
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AEROBAC AB-7



The AEROBAC AB-7 is a hybrid, off-road and amphibious vehicle presently under development. This new vehicle integrates caterpillar traction with air cushion lift technology.

The AEROBAC AB-7 is a concept of the Transportation Development Centre, Transport Canada.

CHARACTERISTICS

Dimensions

Overall length	11,5 m
Overall width	6,2 m
Overall height	3,37 m
Chassis structure length	10,60 m
Chassis structure height	1,00 m
Skirt height	0,60 m
No-load weight	14 000 kg
Full load weight	21 000 kg
Loading platform area	12 m²
Fuel	810 l

Performances

Pay load	7 000 kg
Maximum speed	30 km/h
Running time between fuelings	13 h
Pressure on ground	
— air cushion only	6,3 kPa
— tracks only	35,6 kPa
Maximum performance on slope tracks only	40%
Approach angle	17°
Amphibious vehicle	

Engine

Manufacturer	Detroit Diesel
Model	8V-92TA
Number of cylinders	V8
Kilowatts (brake horsepower)	310 kW (415 HP) @ 2100 RPM

Drivetrain

Transmission type	CLARK "Power Shift"
Model	28661

	Gear ratio	
	Hi-speed	Lo-speed
1st	4,84	13,91
2nd	2,29	6,58
3rd	0,84	2,41

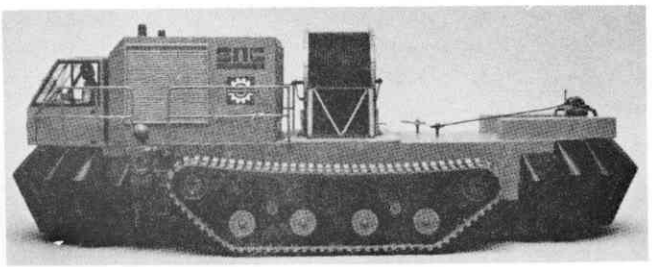
Differential	LEVY M-24
— Gear ratio	2,62 @ 1
Final reduction	FRANKLIN E-230
—Gear ratio	4,6 @ 1
Sprockets	0,58 m dia.
— Location	back

Brakes

— Service: Multi-discs mounted directly on sprockets driving shafts, foot pedal operation.

— Parking: A brake on main driving shaft actuated by hand lever.





3,37 m

6,2 m

11,5 m

AEROBAC AB-7 *

Air cushion system
Fans
— Quantity 2
— Manufacturer ..... VIM
— Model HCHB-040
— Total flow ..... 20 m³/s
Clutch
— Manufacturer ..... FUNK
— Model 2861
Transmission ..... Chain
Skirts ..... SEDAM multicell system (peripheric adjacent cells) Biconical front skirts and off-road biconical in the back.
Air distribution ..... Left and right cells supplied separately by two ducts with individual opening per cell.

Hydrostatic system
Motor
— Manufacturer ..... SUNDSTRAND
— Model MF-36
Pump
— Manufacturer ..... SUNDSTRAND
— Model PV-24

Electric system
Voltage ..... 12 V

Suspension
Type ..... Independent, adjustable height through hydraulic cylinders

Wheels
Quantity 8
Tires ..... solid rubber
Dimension ..... 825 x 15

Tracks
Type ..... Rubber belting and steel struts
Width ..... 1,00 m

Chassis Structure
Type ..... Welded aluminum structure with waterproof compartments to provide floatation

Cabin
Type ..... 3-seater, steel, installed on rubber pads, thermal insulation, heater and defroster, adjustable driver's seat, emergency hatch in roof.

* The model above presents the AEROBAC AB-7 transporting a transmission cable reel weighing 5 tonnes and a 6-tonne capacity hoist for handling.

March 1982

"LARUS" AND "VP-1" TESTED IN WINTER 1982

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ABSTRACT

Two air-cushion vehicles, "Larus" and "VP-1", were tested in the south-western archipelago of Finland. The tests were carried out in March 1982, when the sea was frozen and covered with 50 mm of snow. During the tests "Larus" operated independently and also towed "VP-1". Measurements were made of the speed, resistance and manoeuvrability of the two craft.

INTRODUCTION

In air cushion technology the main emphasis has been on developing craft that can operate in open-water conditions. In recent years, efforts have also been directed to expanding the technology to include air-cushion vehicles operating on other surfaces, especially ice and snow. Among the first air-cushion vehicles designed for winter traffic in subarctic and arctic areas are "Larus" and "VP-1".

"LARUS", AIR-CUSHION FERRY FOR THE FINNISH GOVERNMENT

This car/passenger air-cushion ferry is designed for service under winter conditions in the Finnish archipelago. The craft has a capacity of 22 tonnes and can carry 16 light vehicles or two buses and 50 passengers.

The inhabitants of the islands have always had difficulties during periods when the ice is not strong enough to bear car traffic. Another problem has been how to cross channels kept open all through the winter season on the sea lanes, mainly by big ferries.

Lift and propulsion

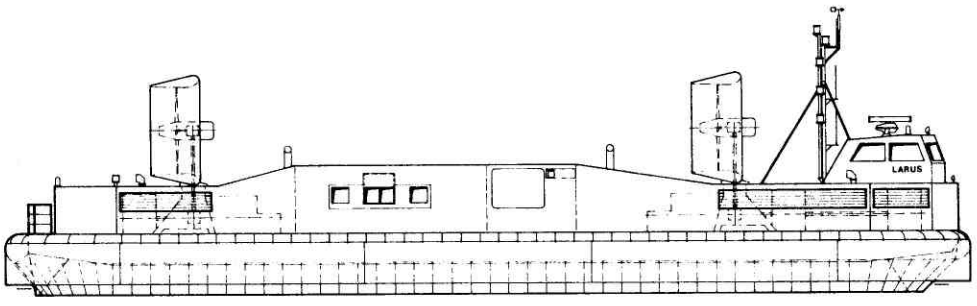
Four integrated lift and propulsion machinery units, each consisting of a 650 kW diesel engine, a centrifugal fan and a four-bladed pylon-mounted ducted c.p. propeller.

Hull

Built in marine-grade aluminium. Raft-type structure with longitudinal superstructures on each side containing two engine rooms and passenger spaces midships. All controls are located in a raised bridge well forward on the starboard superstructure.

Main data

Length overall	33.0 m
Beam, max.	14.7 m
Height overall	8.2 m
Payload	22 t
Speed (over water)	12 m/s
Power output (total)	2600 kW



"Larus", car/passenger air-cushion ferry

"VP-1", AIR-CUSHION VEHICLE
FOR ARCTIC CARGO HAULAGE

The vessel is designed to operate together with 20 000 tdw arctic multipurpose cargo ships delivering cargoes to arctic shores that lack port facilities.

Design criteria for "VP-1"

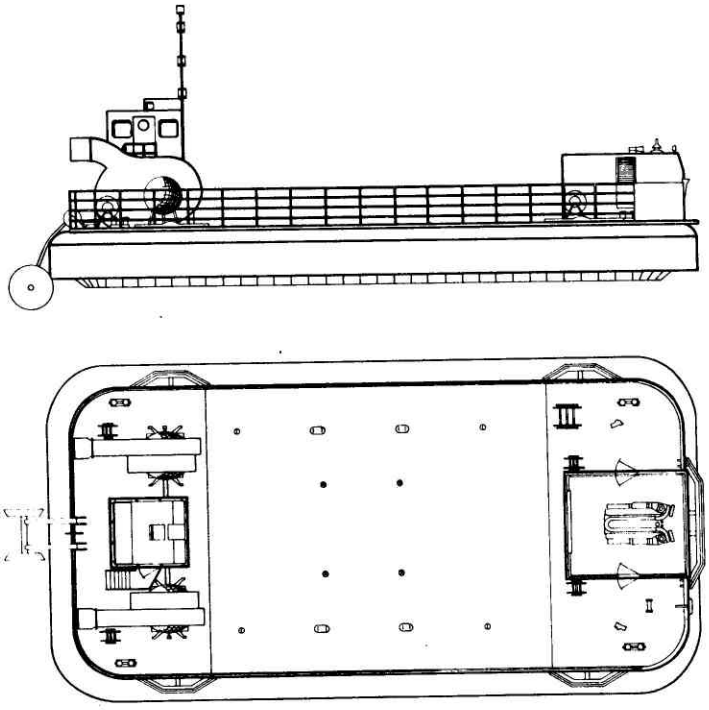
- Operation in arctic conditions in temperatures down to -40°C. Storage in a temperature of - 50°C.

- Operation in coastal waters, on ice and snow, and on hard or swampy ground. Capacity to negotiate obstacles.

- Possibility to load and transport cargo of all sorts, including containers, wheeled vehicles, pipes and general cargo.

Main data

Length, max.	20.7 m
Breadth, max.	9.9 m
Hovering height	0.7 m
Machinery, diesel engine	625 kW
Payload	40 tons
Lightweight	35 tons
Building material	steel
Crew	3



"VP-1", towable arctic air-cushion ferry

SKIRT

The skirt system used in both vehicles is the normal finger and loop type. Some special features are added to accommodate the shocks caused by big ice blocks. Special attention has also been paid to rapid replacement of fingers in case of damage.

WINTER TESTS

The winter test programme for "Larus" and "VP-1" was designed for the purpose of:

1. Studying the behaviour of the skirt on level ice and in channels.

2. Determining drag and air consumption in different ice conditions.

3. Studying the icebreaking capabilities of the air-cushion vehicles.

4. Determining manoeuvring characteristics.

The tests were carried out in March 1982 in south-western Finland. During the tests the ice thickness varied between 300 and 400 mm, the snow cover being about 50 mm.

In the first part of the tests "Larus" towed "VP-1". Speed, cushion pressure and air flow were varied during repeated passes over level and floe ice, in broken and frozen channels.

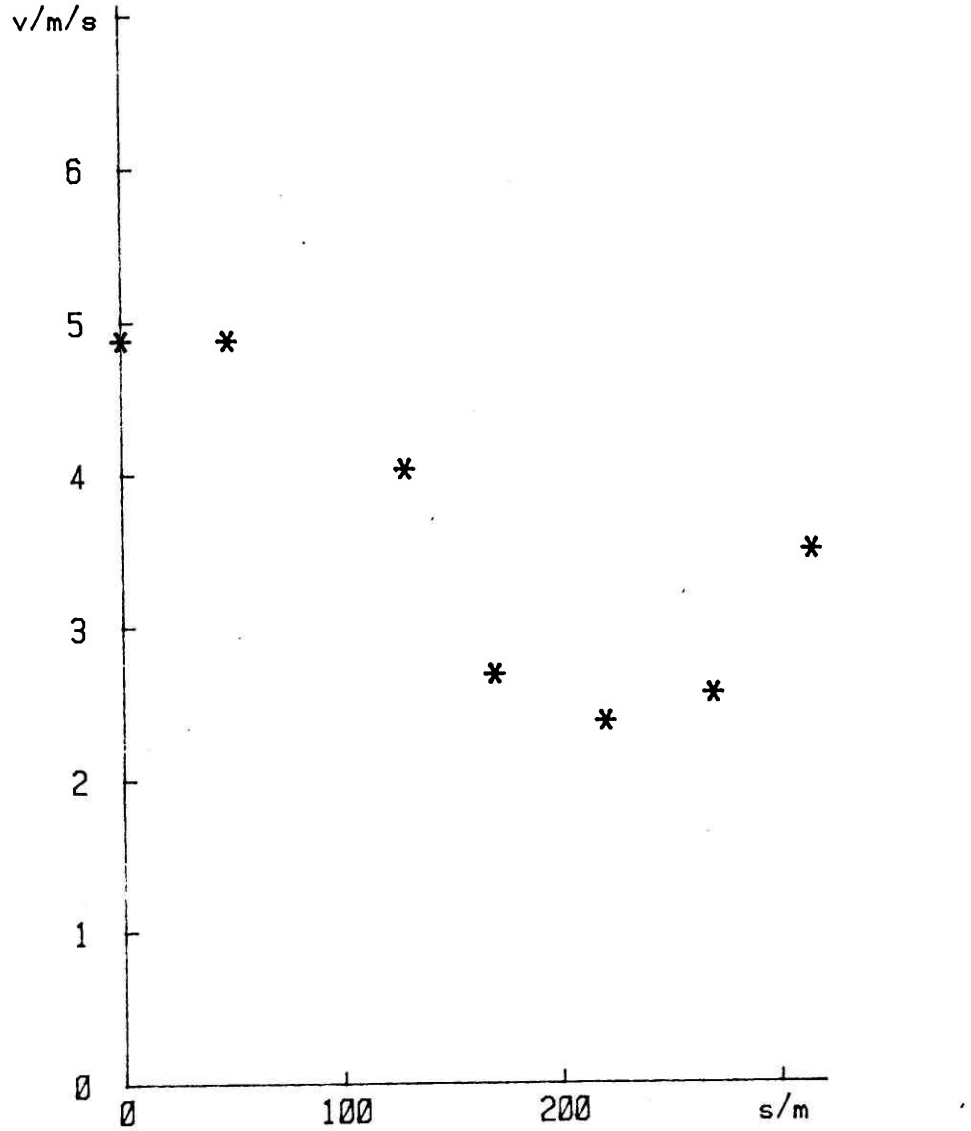
In the second part of the tests "Larus" operated independently in different ice conditions. Measurements of resistance, speed and manoeuvrability were made.

A typical result of the tests is shown in Figure 1.

CONCLUSIONS

The tests showed that "Larus" and "VP-1" can operate successfully in the ice conditions described. The skirts withstood the severe tests without breaking and only minimal wear was detected.

WADAM	LARUS	FIG. 1
	SPEED WHEN CROSSING TURKU CHANNEL. ENGINE SPEED 1900 RPM.	EMM 18. 5. 82



NEW CONCEPT IN HOVERCRAFT DESIGN DIESEL VERSUS GAS TURBINES

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INTRODUCTION

The concept of using diesel engines in hovercraft was brought about by the fact that large increases in fuel charges which occurred during the nineteen seventies had necessitated the need to design a more cost effective vessel.

Apart from modifications to basic design, certain hovercraft designers undertook an investigation into the cost advantages of using lightweight diesel engines over the favoured gas turbines, which although having a considerable power weight advantage, also had considerably higher fuel consumption.

Through this investigation, which considered both aircooled and watercooled diesel engines, it was decided that the aircooled diesel, with its many advantages over its watercooled counterpart was the most suitable substitute for the gas turbine, and hence the AP1-88 hovercraft was born.

While the first half of this paper deals with a general comparison of the two main types of power source, by necessity, the second part, dealing with installation considerations has had to relate to experiences gained with AP1-88.

Although the need to reduce fuel consumption has been paramount, care had to be taken to ensure that engine weights were kept to a minimum, and therefore the engines chosen for this project were both turbocharged, being the BF10L413F for lift, and BF12L413FC, both turbo charged and intercooled, for propulsion.

It was considered that for the AP1-88 application, intermittent ratings would suffice, but obviously this will be reconsidered in the light of experience.

A REASONS FOR CONSIDERING DIESEL ENGINES

(i) Fuel

Based on the initial route of the AP1-88 hovercraft from Southsea to Isle of Wight, a trip of some ten minutes, it was estimated that a percentage saving in fuel could be obtained by using diesel engines. This represents a substantial cost saving per day, based on present fuel costs and on fuel with a calorific value of 10,000 Kcal/kg.

The following chart lists the fuel consumptions for each type of diesel engine compared with its equivalent turbine, together with a comparison of the power weight ratios.

Although these fuel consumption figures are based on gas oil, research is continuing into the use of blended fuels which of course will result in further saving in fuel costs.

Fuel Consumption - Cost Comparison

Machinery type	BF10L413F	BF12L413FC
Full load cons galls/hr	18.0	22.68
Fuel cost per gal sterling	£0.90	£0.90
Percentage saving	65%	65%
Weight/Horsepower loss	0.85	0.95

This added advantage of fuel saving will to some extent be offset by the necessity to use different materials in the construction of the engine, but in the long term it is felt that the change will be worthwhile.

(ii) Power-Weight

It was recognised from the outset of the investigation that the advantage of power-weight with the gas turbines would have to be sacrificed. The chart shows the considerable difference in this ratio between the different types of machinery.

However, this disadvantage has been kept to a minimum by the utilisation of turbo-charging in the engine design, and in the case of the propulsion engine, by inter-cooling the turbocharged air.

(iii) Aircooling

The main advantage of using aircooling instead of watercooling is the considerable saving in weight of coolant to be carried. In the context of four engines per vessel, this saving is considerable. However, in addition to this obvious advantage, there are several other advantages in using aircooled engines, and these are listed on the following chart.

Advantages of Aircooling

a) No cooling water with its associated problems of freezing and boiling.
b) No sealing elements required.
c) No radiator or water circulating pump.
d) No water hoses with associated hose clamps.
e) No damage due to corrosion or cavitation.
f) Engine reaches running temperature quicker, therefore less wear caused by cold corrosion.

(iv) Spare Parts

A major advantage when using a particular engine series with outputs covering a relatively large range is that all the major components are interchangeable, resulting in a significant reduction in both the cost and quantity of parts to be carried by the operator.

This particular advantage is highlighted with the AP1-88 hovercraft in that both engine types installed are of the same engine family, so that items such as liners, pistons, con rods, cylinder heads, etc are usable for both configurations of engine. The advantage of this is obvious.

In addition to less sophisticated materials used in the diesel engine ensure that the capital cost and cost of replacement parts is significantly less than with the turbine.

(v) Maintenance

The simpler construction of the diesel engine ensures that routine maintenance and hence downtime for maintenance is considerably easier than for turbines.

In addition, the choice of aircooling in itself represents a saving in downtime over watercooled engines, in that it is estimated that approximately forty percent of breakdowns on watercooled engines are caused by the watercooling system.

Accessibility, particularly for routine maintenance is made considerably easier by the relatively simple design of the diesel. In the case of the FL413F engine series, removal of the top engine cover gives access to a considerable number of the components requiring routine maintenance, for example injection pump, cooling fan. In addition of course, this reduced downtime leads to a reduction in overall maintenance costs.

Machinery wear with the slower speed diesel is less than with the higher speed turbine, and this in itself contributes to the longer maintenance times and

anticipated service life of the main wearing components of the diesel, compared with the gas turbines.

Again, all these facts are considerable when considering the annual running costs of the installation.

Service Intervals

Service	Intervals (hrs)
Oil change	100
Fuel pre filter	100
Lubricating oil filters	200
Cooling blower coupling bowl	200
Valve clearance check	300
Fuel filter check	1200
Dynamo	600
Gauges	600
Starter motor	1200
Crankcase breather	2000
Fuel injectors	3000

(vi) Capital Costs

As already stated, the less sophisticated materials used in the diesel results in lower replacement parts costs, and ease of supply of replacement parts, but in addition, represents a considerable saving in initial capital cost.

The following chart gives a comparison, based on approximate values, between initial cost of diesels and gas turbines, both on total and price per horsepower basis.

Capital Cost Comparison

Machinery type	BF10L413F	BF12L413FC
Capital cost	£15,000.00	£18,000.00
Capital cost per HP	£40.00	£36.00

These values were based on costs at mid 1981.

B INSTALLATION

(i) Design Modification

The larger physical dimensions of the diesel engines meant that the available physical space on the hovercraft had to be fully utilised, and it was considered that modifications to the basic engine assembly should be made to accommodate this.

Whilst the engines themselves had been designed with ease of maintenance in mind, accessibility to the engines themselves in situ had to be considered, and with this in mind, it was decided to modify the physical design of the engines themselves on a number of points.

a) Filtration

Both fuel oil and lubricating oil filters, which are obviously the most frequent recipients of routine maintenance, and which are normally engine mounted, were supplied loose, to be mounted on a bulkhead in a position most convenient to the engine operator, as far as accessibility is concerned.

b) Alternators

The battery changing alternator, again engine mounted in the original engine design,

was supplied loose and driven from the power take off pulley via vee belts. This ensured that one of the commonest causes of engine breakdown, the broken vee belt, would cause a minimum of delay to replace.

c) Waterwash Facility

Whilst these aircooled diesels with full approval of classification societies are extensively used worldwide on marine applications both as propulsion and electrical generation units, experience of the effect of the fine spray thrown up by hovercraft operation is minimal. It has been recommended, therefore, that the cooling fins of the cylinders be washed with pressurised fresh water daily, in order to minimise the effect of any salt which may habe passed the filtration system and adhered to the cylinder walls.

To ensure that this cleaning is done with a minimum of inconvenience, consideration is being given to installing a water gallery between the cylinders, with jets directed to the fins. The idea would then be for the engineer to open a remotely located valve to admit the pressurised water to the gallery and hence to the fins.

d) Top Cover Accessibility

As previously mentioned, a considerable number of points concerned in routine maintenance are located below the top cover of these engines, and while in everyday marine applications this does not constitute a problem, the confines of a hovercraft machinery space meant that accessibility to this top cover had to be made from above the engines.

This was easily achieved, and quick release fastenings were incorporated into the cylinder cover to ensure ease of removal.

e) Starter Motor Carrier

It was thought that the one point where a physical design modification could be carried out would be in the area of the starter motor carrier, and this was done by reducing the relatively sophisticated carrier to a simple plate form.

This also resulted in a weight saving per engine of approximately 15 kg, which is considerable when considered in terms of are carrying passengers.

f) Cooling Air Ducts

The cooling air duct is probably the single most important factor in the successful running of aircooled engines, but it will be appreciated that accessibility to the engine cylinders is hindered by these ducts.

A method of quickly releasing these ducts from their frames in the case of the outlet ducting has been incorporated.

(ii) Cooling Air Filtration

It was considered that the amount of spray put up by the hovercraft might cause a problem, and although various tests were carried out it was difficult to simulate the actual environment and form of spray which would be encountered.

The decision was taken, therefore, to incorporate a cooling air filter at the entrance to the air duct intake, and this, with its integral water separator will make the cooling air virtually salt free.

With this in mind, it was decided to locate the combustion air filter behind the cooling air filter, thus ensuring double filtration of the combustion air resulting in reduced cylinder wear.

Obviously, calculations had to be undertaken, and these proved that the pressure drop in the system became too great when combining this additional cooling air filter with the tight run of ducting, and therefore it became necessary for an additional cooling fan to be incorporated into the system. This fan was located immediately behind the air filter, and has also been driven from the engine crankshaft power take off pulley.

(iii) Vibration and Noise

With passenger carrying vessels, special consideration had to be given to the keeping of noise and vibration levels to a minimum. To assist in this, considerable investigation into engine noise transmission was carried out, and finally the hardness of the flexible mountings was decided upon.

Apart from this, the engine builder has little influence over the transmission of noise, but advice, gained from experience in the use of various types of insulating materials has been utilised.

This particular problem is more the problem of the naval architect.

CONCLUSION

As we have already stated, the use of diesel engines in hovercraft, seen by Deutz as a method of getting away from the expensive aero engine designs at present in use, is a new concept and therefore while it is possible to evaluate the theoretical running conditions, the actual results will only be obtained from running experience.

With this in mind, the engine settings, for example are flexible and will be set only following trials.

It is confidently considered that as long as the engine manufacturers maintenance instructions are adhered to, the maintenance times as previously given in this paper will be prolonged with a resulting further reduction in costs.

The running and trials of the prototype vessels will determine whether further overall economic gains in terms of engine modifications, running costs and maintenance costs can be made, but as a manufacturer we consider that the use of diesel engines in hovercraft will assist in making this proven versatile means of transport more cost effective.

DESIGN ASPECTS AND TRIALS OF THE HM5 PROTOTYPE

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ABSTRACT

The HM5 project has taken some eight years from initial concept to prototype trials and has evolved through several internal configuration changes the last of which was at the request of the first customer.

The overall craft proportions are not far removed from HM2 but details of sidewall geometry are considerably different and will accommodate the future development that is envisaged for this series of craft.

As for HM2 a number of variants on the basic design are likely to be produced and because of its greater sea-capacity will be applied to more offshore applications.

The trials of the prototype are still underway. In general the craft has performed as expected and predicted from model tests. It has considerable stability reserves which was established by means of radio controlled model testing.

The paper will be augmented by the latest VHL film which includes some shots of the HM5 prototype during its recent trials programme.

ACV LIFT AIR SYSTEMS - MORE PUFF FOR LESS POWER

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ABSTRACT

The lift air supply of an ACV must be viewed as an aerodynamic system, not simply as a fan in isolation. It consists of an intake, whose performance affects and is affected by the external aerodynamics of the vehicle and its relative wind and spray environment. The air then enters the impeller, usually centrifugal, whose characteristics (steady-state and dynamic) are vital to the performance and stability of the vehicle. Air from the impeller is then led to the cushion and skirt of the vehicle, and the ducting used to do this presents many difficult problems. The orthodox fan scroll is not necessarily appropriate to this situation, and various alternatives possible under the constraints of vehicle design are discussed. Finally, the overall stability and efficiency of the air system are discussed.

Half an egg is better than no egg, but the only way you can cook half an egg is to scramble it. This is why some lift systems turn out "scrambled"; the designer only looked at half an egg! The fan is only half the system, the ducting is at least as critical as the fan, and both must be considered to design a good lift system!

First to consider the requirements of the lift system in an ACV. The steady-state running requirements are simple. The ACV needs a supply of air of x m^3/s at y kPa to hover, and these numbers are obtained from standard design data[1, 2]. It is also clear that this design point must fall on the negative slope side (A) of the operating curve of the blower (Fig. 1), and that the slope should not be too flat. This assures that if the craft momentarily falls, and reduces the escape-gap under the skirt hem and hence the airflow, the cushion pressure will rise and lift the craft back up to normal hover-height. If the blower were operating on the positive slope, this reduced flow would reduce the cushion pressure and the craft would fall further and collapse. In any case, the positive slope is a somewhat unstable region, and potentially prone to blower surge.

The steady-state operating characteristics of blower and craft have therefore to be matched accurately at the design point.

Further, since the craft will operate at anything from empty weight to maximum overload, a range of cushion pressures is required. Also, since it will run over terrain varying from flat non-porous concrete or ice to uneven porous pebble beaches or muskeg, the airflow needed will cover quite a large range.

Thus we have not one operating point, but an envelope, which will probably be obtained by varying fan speed. The efficiency lines therefore have to be added to the fan curves, and the characteristics of the engine driving the fan examined, to see that the power available over the required speed range is adequate.

The remaining quasi-steady state condition to be satisfied occurs at lift-off, when the machine is rising off the ground. Initially the skirt will be folded under the hull, and form an almost perfect seal with the ground. Thus, apart from the small flow to fill the plenum, the fan will be running at practically zero flow, but still required to generate full pressure to lift the craft. This means that either the fan must not surge, or that the surge must be so mild as to be tolerable. The writer recalls one machine which never took off because the lift fan stalled and could not generate cushion pressure, and several which rose onto cushion, but surged so violently that the driver's vision was blurred and structural damage was caused to the craft.

Since the ACV is now used in temperatures varying from arctic to tropical, and from sea level to the high Andes and Himalayas, it seems most advantageous to plot blower and engine characteristics in completely non-dimensional form, and check the performance over the required range of inlet air temperature and pressure.

The second component of the lift-air system is the ducting, both before and after the blower, and in this is included the blower casing itself.

The inlet to the impeller has to collect air (preferably free from dust, spray and débris) and deliver it, uniformly distributed over the impeller eye. The idea that the inlet should face forward to take advantage of ram-air is a mistaken one. At most ACV forward speeds the ram effect is small, the ram direction due to cross-winds and craft yaw is often not on the craft's axis, and the intake of ram air causes aerodynamic drag which often exceeds the power saved in the lift blower. It may well be possible to reduce drag and overall power by using a side or rearward facing intake to control boundary layer detachment, although aerodynamic drag is small at the speed of many ACVs.

A much more important factor in inlet positioning is to choose a location as free from spray, dust, etc., to reduce fan blade erosion.

It is also important to avoid interference between lift and thrust airstreams. Because of drive-train considerations, the lift fan intake has often been placed below and in front of the thrust fan, which has been known to lose over 20% of its thrust due to lift-intake interference.

The layout of the vehicle and its components is, of course, a compromise between many conflicting requirements, and it is never possible to place each item in its ideal position, but at least the intake requirements of the inlet should be defined, so that the effects of any compromise can be assessed.

While a centrifugal blower is usually quite a robust device, its aerodynamics can easily be upset by poor inlet distribution. If the blower has several delivery ducts, one of them may be completely starved due to inlet maldistribution persisting through the blower.

The main inlet problem however is usually radial distribution. If the inlet does not have a sufficiently large "bellmouth" radius, inertia will funnel the flow into the centre of the eye, causing too high an axial velocity there, and leaving a dead zone at the eye outer diameter which will lead to trouble in the impeller. A minimum bellmouth radius of at least 0.16 x throat diameter, and preferably 0.25 x throat diameter, is desirable.

The joint between the stationary inlet bellmouth and the rotating impeller shroud also needs careful attention. The impeller often rotates in a large volute, part of whose wall forms the inlet bellmouth. Since the static pressure in the bellmouth is likely to be above that at the bellmouth throat, where it meets the impeller shroud, if there is not a proper arrangement there then a jet of air leaking from the volute can trip the flow from the bellmouth and cause just the kind of maldistribution into the impeller discussed above (Fig. 2).

Therefore either a good seal has to be provided at this point, or else the leakage has to be directed inwards, parallel to the wall, so that it can actually add energy to the boundary layer and help stick it to the impeller shroud. This latter is the solution usually adopted.

The design of the impeller itself is sometimes extremely poor. In order to avoid inefficient conversion of energy between kinetic and static pressures, the radial air velocity should be kept constant through the impeller. The inlet-eye area should therefore be maintained throughout the rotor. The thickness of the channel, between disc and shroud must therefore be adjusted to achieve this, and as the diagram shows, this implies something approaching a conical shroud (Fig. 2).

If this important point is neglected and the disc and shroud are parallel flat discs, as is often the case, then the air will break away from the shroud and hug the disc, leaving a mass of eddies under the shroud with an exit velocity profile as shown.

It is also essential to make the leading edge of the impeller vanes line up with the inlet airflow at the design condition, which is usually reasonably well achieved by the normal back-swept vanes.

The blower delivery presents a far more difficult problem.

In some cushion systems the air is dumped directly from the blower into the cushion, and a fairly normal snailshell volute is used. However, in other skirt types the lift air is blown into the "peripheral bag" at many points, thence through orifices into the "fingers", from which it flows into the main cushion area. This means that quite an appreciable pressure loss is suffered on the way, and also that the impeller often runs in a large empty hull compartment with various exits to the peripheral bag, rather than in a normal snailshell.

The design of the fan exit duct is a subject which has not received sufficient attention in the past. It is at least clear that most snailshell volutes are aerodynamic disasters[3]. The fact that their geometry encloses a constant rate of area increase is no guarantee that the airstream will fully occupy it, or that it will flow without developing violent energy-wasting vortices. The optimum design must be related to each particular application, and the collector feeding a ventilating system duct will not be at all suitable for dumping the impeller output into a plenum with minimum loss.

To return to the simplest "snailshell" volute, this design is certainly compact, but aerodynamically it is less than admirable. And the primary purpose of a fan volute is aerodynamic.

A detailed look at the flow in such a volute may suggest ways of designing an improved configuration (Fig. 3).

The trouble starts as soon as the flow leaves the impeller, heads outwards on a spiral path, and hits the volute outer wall.

In general it moves on round the volute, but an appreciable part of the flow is deflected upwards. This process keeps on, all round the volute, with the highest energy just leaving the impeller always pushing outwards, displacing the existing stream upwards and inwards.

Ultimately this leads to a stable flow state which has very little resemblance to the designer's original intentions, with a high speed jet of swirling air shooting out of perhaps one third of the snailshell exit, and the rest of the duct full of a mass of stagnant eddies, vortices, or even reverse flow. Naturally any flow calculated on a basis of the duct running full at mean velocity will not be realized.

This exact state of affairs has been clearly seen and measured with wool tufts, smoke, and pressure probes on numerous occasions. How then can it be avoided? If it is essential to use a snailshell type of volute, at least the worst faults described above can be avoided.

In the first place, while retaining the structural simplicity of the large box volute, the parts filled with useless eddies can be blanked off. The first part for this treatment is the volume within the impeller tip radius.

A cylindrical baffle A will eliminate this volume (a), which the designer may have included in his calculations, but which the air never used.

Next, a false roof "B" can be put into the box, climbing from b_1 at the start of the snailshell to b_4 at the exit. These two devices between them should reduce the eddying greatly. The flow will still tend to fling to the outside of the volute, but even this tendency should be minimized in this design.

However, if a snailshell can be avoided, a much better system can be adopted. The impeller of a centrifugal blower adds energy to the airflow in the form of increased whirl velocity, and unless the velocity (dynamic) head of the air leaving the impeller can be converted efficiently to pressure energy, a large proportion of the work put in will be lost. If the air leaving the impeller is allowed to expand suddenly the efficiency of diffusion will be very low, and therefore some sort of organized diffuser should follow the impeller.

The most efficient diffuser in a given space around the impeller is the vaned type often seen in centrifugal superchargers, but the vanes require quite a restricted range of inlet air angles (and hence flows) to avoid stalling, so in the present case a vaneless space is to be preferred. If the lift fan can be sunk into the hull, it is therefore often possible to take advantage of a flat layer of hull-space to form just such a vaneless diffuser, to convert as much as possible of the velocity head to static pressure before allowing a final abrupt area change (Fig. 4).

Assume for example that a flow of 7.5 m^3/s enters an impeller eye of 0.5 m^2 area at 15 m/s. Maintaining constant axial/radial speed through the impeller it emerges at the 0.2 m high tip, having required an additional whirl velocity of 100 m/s from the impeller's rotation. It is clear that unless the resultant velocity of 105 m/s can be diffused efficiently down to about half this value, too much kinetic energy will be lost and the fan efficiency will be unacceptably low.

The immediate sudden expansion into a large plenum must therefore be replaced by a controlled diffusion in a constant height annulus. If this is done, then the dynamic head of 6.7 kPa at the impeller exit is reduced to 1.4 kPa at the diffuser exit, with the 5.3 kPa difference being converted efficiently into useful static pressure. The exit ducting can then guide the air at this speed into the cushion, so that the total system losses are minimized, with consequent reduction of blower power.

In this case at least, a configuration can be incorporated which will greatly reduce the waste of power in the lift system. However, enough has been said to indicate that centrifugal blower exit volute design is a very difficult problem, and that model experiments on this component before finalizing a design will prove worth their weight in dollar bills. It is also obvious that a volute cannot easily be squeezed into a small volume and hidden, to improve the sleek outline of the vehicle.

Once the air has left the blower and "diffuser space", it has to be delivered to the skirt and the cushion area beneath the hull. In this transition there is usually some compromise between air distribution and craft roll and pitch stability on the one hand and pressure loss and resulting power loss on the other.

In order to distribute the air to all elements of the inflated structure which forms the skirt, the air is often fed through restricting orifices. These same orifices also reduce back-flow if one section of the skirt is hit by a wave or an obstacle, thus "stiffening" the skirt against local collapse. This is well illustrated in the BHC skirt (Fig. 5) where the peripheral bag is stiffened by many such orifices and diaphragms, particularly in the "antiplough bags" which are further stiffened by one-way valves.

Again, in the Bertin "jupe" system, roll stability is obtained by many orifices, sometimes with valves controlled by pilot or servo systems, feeding the many inflated quasi-conical structures of the skirt.

The HDL system in its simplest form dispenses with such devices, and merely dumps the air from the blower into the plenum under the hull. However, the more developed forms inject the air into the individual segments from a peripheral gallery, to improve the stability of the inflated segments, and here again the price is paid in pressure loss.

Since the fixed pressure in the system is the pressure needed in the cushion to support the craft's weight, the blower delivery pressure has to be raised above the cushion pressure by the sum of all these losses. This can easily represent a 50 increase in blower power as the price of stability. Every attempt must therefore be made to duct the air from the blower to the skirt in constant low velocity ducting with cascades of corner vanes, while the number and severity of orifices must be kept to the minimum consistent with skirt structure and craft stability[4].

The ducts can also act as resonators, and contribute to the vertical instability of the whole craft[5, 6]. The air in the cushion and ducts acts as a spring suspension, and if it is wrongly tuned to the craft's inertia, it can set the whole

vehicle bouncing. A recent example was a 150 tonne craft that could bounce with a 15 cm amplitude at about 1 Hertz. This is personally intolerable, and it can smash up the craft and terrain.

The heave stability of the craft is obviously also critically dependent on the blower characteristic. This is particularly vital in marine craft, where the progression of sea waves through the cushion alters its contained volume in a cyclic manner[7]. If the blower cannot cope with this cyclic demand, the vertical stability may be seriously compromised, and the craft can enter a violent heave oscillation.

The severity of the heave oscillation depends partly on the form of the skirt, and the rate at which the escape area under its hem varies as the craft rises and falls. The original Bertin jupes had a simple straight hemline, which gave a very abrupt valve cut-off characteristic, and correspondingly severe heave behaviour. Later versions with many peripheral jupes, having oblique hemplanes, had a geometry and heave sensitivity closely comparable to the BHC form.

In any of these forms, it is noticed that as the skirt deteriorates and the leakage between fingers increases, the tendency to heave diminishes. Amyot has shown[8] that if the lift system is run with an appreciable mean leakage rate that can be varied about the mean in an appropriately controlled manner, the craft can be stabilized considerably (Fig. 6).

Thus, schemes to defeat this instability include deliberate leaks between skirt fingers, blow-off valves, variable-geometry flapped-vane impellers, and inlet-guide vanes with aerodynamic boundary layer control to alter impeller incidence angle, all controlled by servo systems driven off a signal from the cushion pressure.

However, the blow-off or leakage schemes involve an airflow through the blower higher than the mean lift-air requirement, which clearly wastes power. If the same result can be achieved by a variable geometry blower capable of quickly varied flow at constant rotational speed, a considerable saving of power will result.

This phenomenon also raises the question of the dynamic characteristic of the blower. The steady state characteristic of the centrifugal blower is well known, but it is less well known that if a rapid cycling of either flow or pressure is applied to the machine, the response at constant speed lies in a loop.

Studies by Moran, Jennings and Bullock[9], have shown that the shape of this loop appears to depend on the frequency and amplitude of the applied disturbance. Much more work has to be done on this phenomenon, which is difficult to measure, but it is very important in understanding the unsteady behaviour of blowers in general.

In summary, it has been pointed out that while the lift-air supply system of an ACV is basically simple, there are many points at which good design can result in greatly improved efficiency. Many of these points are well exemplified in the better vehicles at present in service, but many other vehicles provide glaring examples of power wasted through lack of understanding of elementary aerodynamics.

It is also clear that with increasing vehicle size and performance, efficiency and stability are becoming much more important, and that great saving of fuel and installed power is possible by more sophisticated skirt design for craft and skirt structural stability, and by the use of variable-flow, constant-speed blowers.

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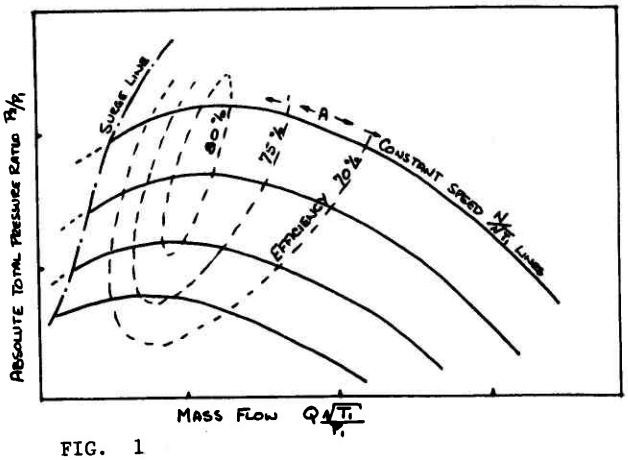


FIG. 1

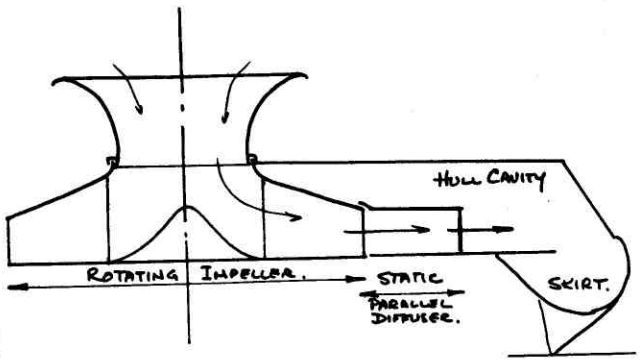
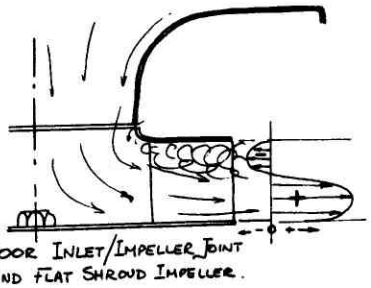


FIG. 4



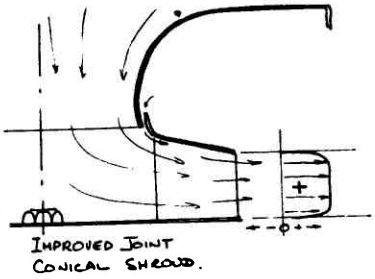


FIG. 2

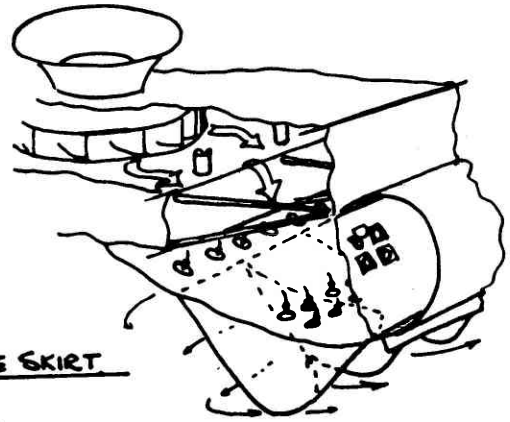
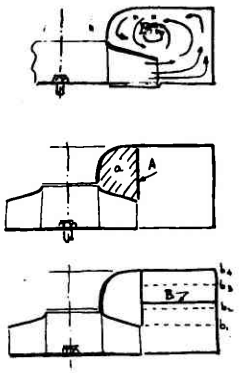


FIG. 5



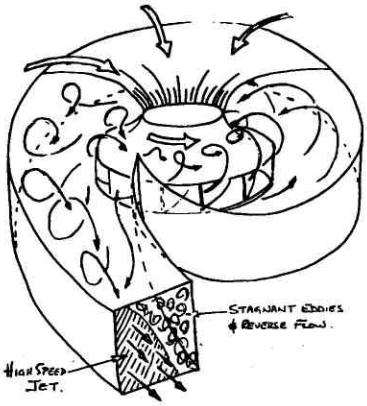


FIG. 3

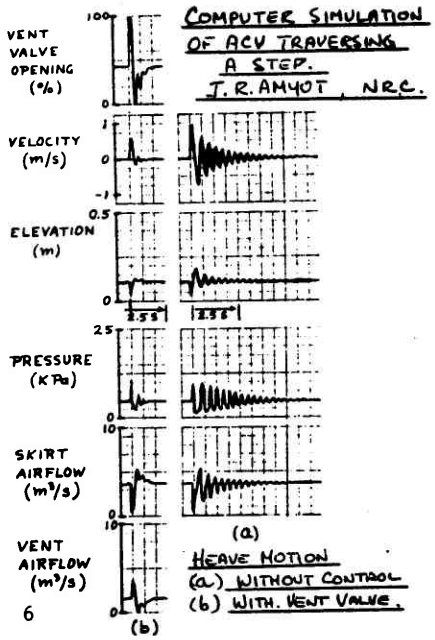


FIG. 6

AP.1-88 CRAFT 001
PROTOTYPE CLEARANCE TRIALS

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INTRODUCTION

AP.1-88 001 is the first of two 80 passenger 'prototype' craft designed by the British Hovercraft Corporation (BHC) for operation by Hovertravel Ltd., on their cross-Solent route, from Ryde to Southsea. Relative to the SR.N6 type craft, which have serviced this route since 1965, AP.1-88 is a radically new design. Its many novel features include a welded aluminium hull, four air-cooled diesel engines and twin ducted propulsors.

The craft concept has resulted from recent major improvements in hovercraft technology, first demonstrated in the SR.N4 development to the successful Super-4 configuration. A significant factor in this success was the use of a responsive, low pressure ratio skirt - permitting reduced propulsion and lift power levels relative to weight and improving ride comfort. This feature has been incorporated in the AP.1-88 together with the provision of reduced internal and external noise levels. The relatively high values of the latter, on SR.N6 craft in particular, have been a major source of criticism.

The basic hull for 001 was manufactured by Fairey Allday Marine at Gosport and towed across to the Isle of Wight on 21st December 1981 for final assembly at Hovertravel Limited's works in Bembridge Harbour. As a 'first-of-type' the programme of trials developed for AP.1-88 001 will obviously be fairly exhaustive, probably lasting up to 2 months. Broadly, these trials will cover:-

a) The clearance of all the systems to standards defined in a series of Acceptance Test Requirements (A.T.R.s).

b) Demonstration of the craft's capability in terms of safe handling and performance to satisfy the customer's specification and to obtain C.A.A. certification.

BASIC DESIGN CONCEPT

The sudden rise in fuel costs in the latter half of the 1970s dealt a heavy blow to hovercraft operators, as it did many other transport systems. For instance, what was a profitable operation on the cross-Channel routes became very marginal. The potential market for hovercraft thus reduced to specialist areas in the Middle East where fuel costs were not a problem.

It became evident that if hovercraft were to become really successful, it was necessary to drastically reduce both the initial and operating costs. As an initial phase, therefore, BHC set themselves a target of producing a replacement craft for the now ageing SR.N6 series operating on the Solent, of one half cost and at the same time to produce a craft which could be maintained cheaply and by skills locally available.

In terms of initial cost, two areas were rapidly identified as expensive. Firstly, the structure, traditionally of aircraft type due to the sensitivity to weight of the earlier craft, was extremely labour consuming. Secondly, the cost of gas turbines was becoming extremely high and some cheaper form of prime mover was indicated.

Since aircraft structures and gas turbines have both been developed

specifically to save weight, departure from these forms implied a reduced payload to all-up-weight ratio unless recovery could be obtained in terms of greater efficiency and, therefore, reduced power requirements.

The break-through came with the introduction of the 'fully responsive' skirt. This is a deep fingered low pressure ratio, low drag skirt which has been developed to the the point where the specific power requirements of the earlier craft are almost halved. The principle was first applied to two British Rail (now Hoverspeed) SR.N4s, enabling them to be 'stretched' by 50%, increasing the all-up-weight from 200 to 300 tons with a corresponding 80% increase in payload all without increasing significantly the power requirements.

To summarise:-

The new skirt allows the designer the options of:-

1) Increased operational payload/ range.

2) Cheaper but heavier structures.

3) Alternative forms of power plant.

After considerable study, BHC opted for a craft which:-

a) Uses a welded aluminium construction.

b) Is powered by diesel engines.

Both these features give a considerable increase in specific weight over the earlier designs but greatly reduce the cost of the craft.

Two further features which influenced the designer were:-

i) The use of fixed pitch propellers.

ii) The need to reduce noise levels.

Fixed pitch propellers were chosen because of the cost of variable pitch propellers and the complexity of the control system required. While this saves cost, it also reduces the contribution which propeller thrust can make to the craft control.

A major complaint against hovercraft has been the high levels of noise generated by the air propellers. Since noise is largely a function of tip speed, slow speed propellers running in ducts to enhance the thrust are indicated. Some additional attenuation is produced by the duct itself.

PRE-PRODUCTION CRAFT

Figure 1 shows the arrangement of the pre-production craft.

The structure consists of a central buoyancy tank constructed from standard extruded aluminium alloy planks and beams and surmounted by a passenger cabin and propulsion engine bay constructed by welding standard plate and extrusions. The side structure is also of welded aluminium alloy using tubular stringers.

Air-cooled diesel engines on either side of the passenger cabins drive a series of coaxial, horizontal axis, centrifugal fans which supply the cushion air directly to the skirt.

Two further air-cooled diesels drive separate fixed pitch propellers in ducts at the aft end of the craft, using toothed belt drives.

Control of the craft is provided by:-

a) Rudders mounted at the rear of the ducts.

b) Rotating bow thrusters at the forward end of the cabin. These are supplied by fans driven from the lift system and rotate 90^{o} either side of the fore and aft position, to provide a side

force. A second mode rotates the duct through 180° while still allowing variation about the fore and aft line, thus providing a braking force.

c) Differential control of the propulsion engines to provide a turning moment.

d) Differential control of the lift engines to give some degree of roll control.

e) A fuel ballast system and elevators in the propeller ducts to establish craft fore and aft trim.

The full interaction between the various control devices has yet to be fully explored.

The craft carries 80 passengers and a crew of 3.

TRIALS PROGRAMME

The programme consists of the following main parts:-

1) Pre-engine running, initial systems clearance and static hover clearance tests.

2) Launch and initial sea trials.

3) Final static hover tests and sea trials.

Sufficient testing was conducted under part 1) to permit a satisfactory transfer from the Bembridge Harbour site to the BHC test facilites at East Cowes, some 12 miles to the west, around the Island's Solent coast, calling in at the Hovertravel terminal at Ryde on the way.

The initial systems clearance, mentioned in 1) above, is an item of work common to all craft covered by the BHC design authority. In this work all machinery and systems (engines, transmission, hydraulics, electrics, skirts, etc.) are tested for compliance with their respective Acceptance Test Requirements (A.T.R.s) specified by the designers responsible for each system on the craft. On AP.1-88 this work covers the following items:-

a) Engines and Transmissions

Ground running to full power, bearing and drive belt temperature checks, electrical generation clearance, transmission coupling setting, initial noise/vibration surveys and propeller/duct interference.

b) Controls

Control functioning checks, rudder hydraulic system pressure/temperature monitoring and tests with 'failed' system.

c) Fuel System

General integrity and ballast transfer capability.

d) Engine Air Filtration

Bay pressure, temperature and volume flow tests.

e) Skirt Clearance

Static hover, hemline level C.P. position, pitch and roll stiffness using fuel ballast transfer, skirt and cushion pressures, craft buoyancy tank clearance checks - all arranged to allow comparison with dynamic model tests.

f) Electronic Monitoring of Structure

At this stage restricted to simple accelerometer monitoring of one duct and associated propeller hub bearing casing, all recorded on F.M. tape.

This part 1) work was completed to schedule in the period 19th July to 23rd July 1982, the craft being removed from the hangar on 21st July. Following initial "running in" checks on bearings, belts,

powder couplings, etc., and skirt pressure checks, the craft was launched at 12.40 p.m. on 23rd July, approximately 1 hour behind original estimates.

Departure from the apron at Bembridge was achieved in the hover. A workboat was used to restrain the forward motion of the craft into the moorings of the harbour. The craft was towed by workboat through the confined harbour and then proceeded under its own power to the Hovertravel terminal at Ryde. Some practice manoeuvring was completed satisfactorily en route. Wind speeds were estimated as 5 - 10 knots with sea state 9 in. to 1 ft. significant height.

The craft achieved 40 knots IAS downwind. First appraisals of ride comfort, pitch attitude, stability and general handling were very favourable. Arrival at the Hovertravel base was well controlled and observers noted the relatively low noise levels. The craft subsequently continued to Cowes without incident, exploring the fuel ballast and elevator control en route. Trim down and plough-in recovery characteristics were very acceptable and elevator control proved very useful (of order $\frac{1}{2}^{o}$ trim change capability). The craft made a successful ascent of the 1 : 10 slipway at the BHC Columbine Works and demonstrated good low speed manoeuvrability, including a 180^{o} turn on the apron. Finally, the craft was taken to Falcon Yard where further slow manoeuvring practice was completed. The pilot's initial reactions with regard to control and handling were very encouraging and external observers commented most favourably on the low noise levels.

Subsequent to the delivery trip, the craft continued its initial engineering checking and several sea sorties were made, leading to a satisfactory demonstration to the members of the Board of Directors of Westland plc on 28th July - the date which had been scheduled during the earlier planning stage back in April.

The craft has subsequently continued with its initial clearance work to part 2) of the schedule and during August/September will complete the final part 3) stage. This work will consist of:-

a) Final clearance of the engineering systems, (including noise, vibration, alternating stress measurements and propeller strain measurements) and skirts during static hover and non-hover ground running tests.

b) Final sea trials leading to C.A.A. certification and customer acceptance. These trials will cover engineering systems clearance at sea, together with craft handling and performance assessment.

The overall object of the sea trials will be to check the handling and safety characteristics of the craft at various points in the operational envelope.

The following basic handling items will be checked for acceptability with realistic LCG conditions:-

a) The ability to manoeuvre over land in confined areas and general controllability when manoeuvring in high wind conditions.

b) Handling at low speed and control effectiveness and manoeuvrability in the boating mode.

c) Low speed manoeuvrability in calm and high wind conditions.

d) Handling during approach and departure from commercial operational bases, with particular reference to downwind approaches.

e) Handling during into wind, cross wind and down wind accelerations to speed, noting directional control, trim and general behaviour during the acceleration.

f) Handling during turning manoeuvres to determine yaw/speed limitations.

g) Handling and response to ships' wakes and sea states.

h) Handling during normal and emergency stopping.

i) General handling when operating at the extremes of LCG in calm and rough seas.

j) Handling during transition from land to water and vice versa, including ascent and descent of gradients in calm and high wind conditions.

k) Craft behaviour whilst drifting and wallowing in high wind conditons.

l) Handling during simulated failure cases.

1) Lift engine.

2) Thrust engine.

3) Bow thruster control.

4) Throttle control.

It is proposed that craft basic performance will be determined in conjunction with the craft handling trials and data on the following items will be recorded.

a) Time to speed.

b) Steady speed performance at cruise and maximum engine rpm in calm and rough seas.

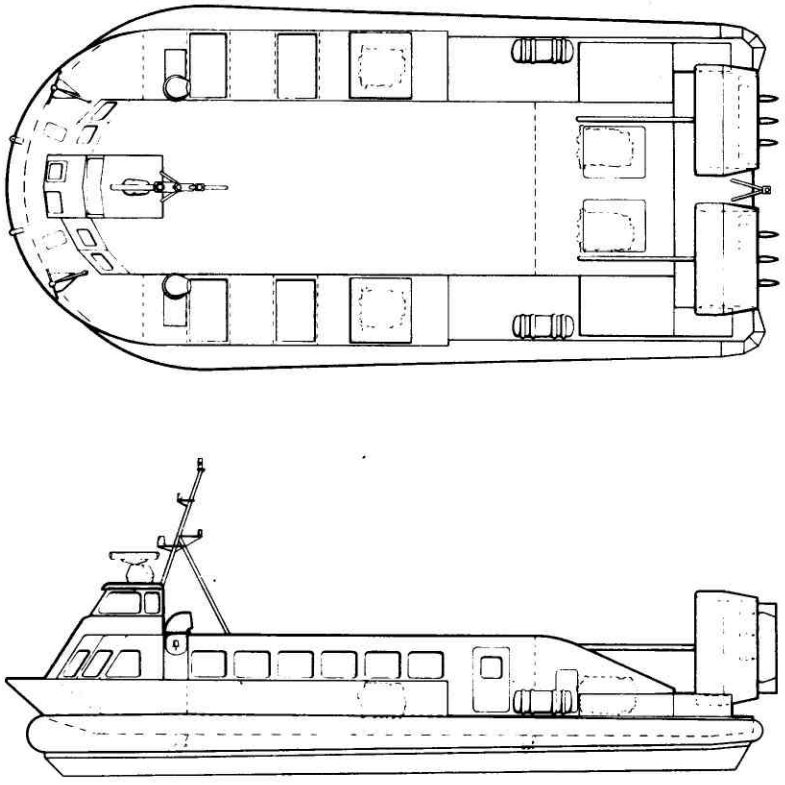
c) Stopping distances.

d) Radius of turn.

It is proposed that representatives of the C.A.A. should witness a limited number of the contractor's handling trials for familiarisation purposes prior to carrying out C.A.A. acceptance/certification sorties, one at low all-up-weight, one at maximum all-up-weight and a night sortie.

C.A.A. certification is expected to be obtained by October 1982 and AP.1-88 001 is scheduled to enter passenger service with Hovertravel between Ryde and Southsea in November 1982.

Overall Length		69 ft
A.U.W.		30 tons
Passenger Capacity		80
Engine	Lift	2 x 324 hp Deutz
	propulsion	2 x 428 hp Deutz
Maximum Endurance		5½ hrs



General Arrangement of the AP.1-88 Pre-Production Hovercraft

FIGURE 1