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The 260-Ton French Amphibious Hovercraft—Naviplane N 500

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The Naviplane N 500 is an amphibious hovercraft which transports 400 passengers and 65 cars in 2.5-m waves at speeds of between 40 and 70 knots. This craft, which was produced by SEDAM-BERTIN, includes recent developments with a view to providing economical exploitation. For instance, it is the first double-deck hovercraft and also the largest. Power is provided by five Avco-Lycoming TF-40 gas turbines at moderate fuel consumption.

Introduction

THE Naviplane N 500 is an amphibious hovercraft with a 260 ton full-load weight (Fig. 1), designed for use as a ferry on the English Channel.

The craft was built by SEDAM at the demand of the SNCF (French National Railway). The development was helped by a Ministry of Transport loan. It was assembled in the SEDAM factory at Pauillac (Gironde) and was successfully launched on November 26, 1977 to arrive at Boulogne-sur-Mer 750 n. mi. away. Tests were carried out at Boulogne and the craft is now in service across the Channel between Boulogne and Dover, where SRN 4 hovercraft are now in service. The N 500 is larger than the SRN 4; however, British Hovercraft Corp. has "jumboized" the SRN 4 in order to offer the same transport capacity as the N 500.

General Data

The Naviplane N 500, 50 meters long by 23 meters wide has a 105 ton payload and can carry 400 passengers, 65 cars, 5 coaches, and 24 tons of fuel (35 m^3). Its range is 300 n. mi. The speed of the craft is 45 knots in 1.5-2.5 m waves. It reached a speed of 72 knots with a full load (263 tons) in calm water during tests.

Technical Data

Main dimensions:

Overall length	164 ft (50 m)
Overall width	75 ft (23 m)
Overall height during flight	56 ft (17 m)
Cargo deck area	10,320 ft^2 (960^2 m)
Passenger deck area	3440 ft^2 (320^2 m)
Height of lateral and rear skirts	8 ft 2 in. (3 m)
Height of bow skirts	12 ft (3650 m)
Width of vehicle embarkment door	32 ft 10 in. (10 m)
Cleared height for vehicles	
Central	12 ft 6 in. (3.8 m)
Lateral	7 ft (2.13 m)
Height of passenger embarkment doors	6 ft 7 in. (2 m)
Volume	20,000 ft^3 (566 m^3)
Total gross weight	291 longtons (265 tons)

Cushions:

Cushion area	9,030 ft^2 (850 m^2)
Length of cushion	147 ft 6 in. (45 m)
Width of cushion	72 ft (22 m)
Average pressure of air cushion	64 lb/ft^2, i.e., 30 mmb. pressure
(for a total weight of 265 tons)	

Weight:

Empty craft ready for use but without carburent	163 tons
Commercial equipment and operating crew	5.4 tons
Payload (fuel included) possible freight load limited to 400 passengers + 65 vehicles	96.8 tons
Total weight	265 tons

Craft Description

Basic Characteristics

The N 500 is the first air cushion vehicle to have two decks, the lower one carrying the cars and the upper one for passengers (Fig. 2).

A longitudinal platform is used as parking space for five coaches. The two-deck construction was chosen to achieve a larger load area without increasing the craft's dimensions. The ratio of load capacity to total weight is 0.40.

A characteristic of the N 500 is the rear bridge carrying the three propulsion engines and the three propellers, each having a diameter of 6.4 m. The rear bridge has several functions:

1) The horizontal wing carries the turbines and provides aerodynamic lift which compensates for the vehicle bow lift at high speed. A lift of 8-10 tons is achieved.

2) The vertical supports act as stabilizing surfaces.

3) The supports and the wing are equipped with steering rudders located in the propeller airflow, which even at low speed provides lateral and vertical control.

4) The supports incorporate air passages for propeller engine air filters located in the vehicle body.

Structure

The structure is made of light alloy offering resistance to sea-water corrosion and, except in forward and aft locations, features recurring elements. It comprises (Fig. 3):

1) A principal section composed of a box girder carrying longitudinal bending forces and a flat supported by transverse

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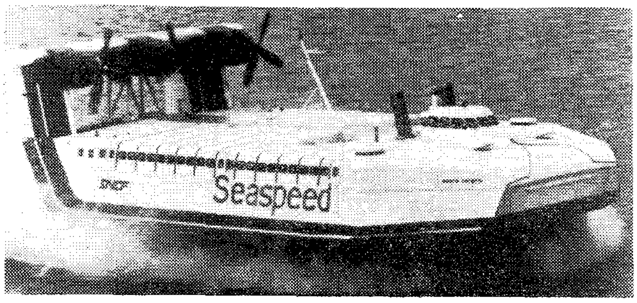

Fig. 1 The N 500 Naviplane at sea.

lattice girders. These are interconnected by longitudinal beams and rest at their extremities on floatation tanks. Such an arrangement accommodates five motor coaches. The flat comprises the car deck. This all-welded arrangement was engineered by Arsenal de Lorient.

2) Secondary lattice structures—passenger-compartment deckheads, plating, roof, and forward and after casing (Fig. 4).

3) Forward and aft doors that are 10 m wide, serving as ramps for vehicle access.

4) A stern gantry comprising two uprights and a box girder forming a horizontal tail assembly which carries propulsion installations.

The material selected for the load-bearing structure is 5083 aluminium alloy for the plating and 6082 for shaped work. It

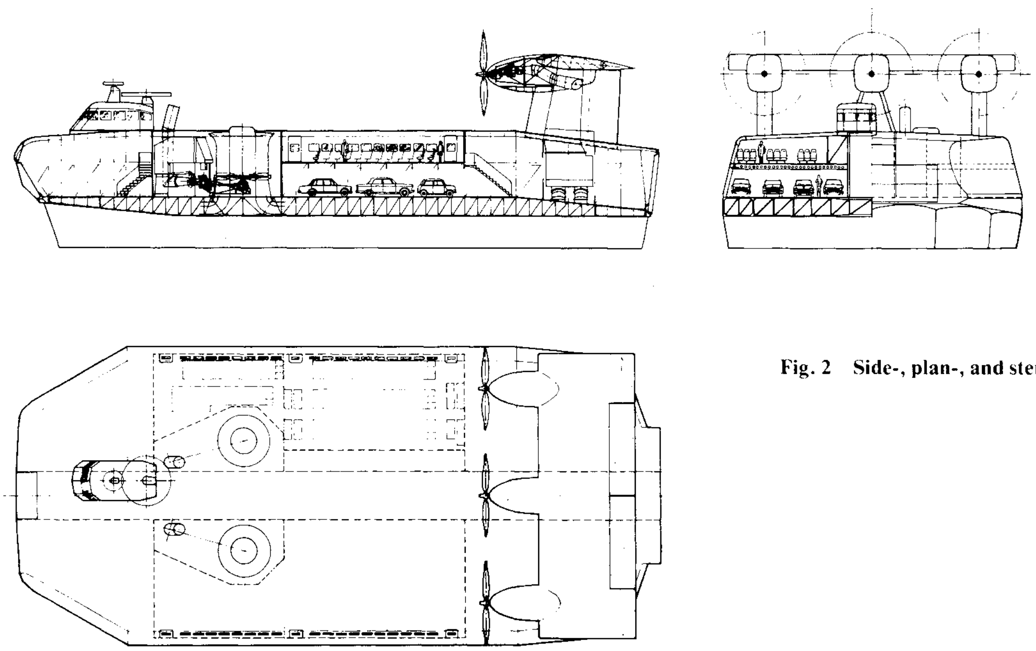

Fig. 2 Side-, plan-, and stern-views of the N 500 Naviplane.

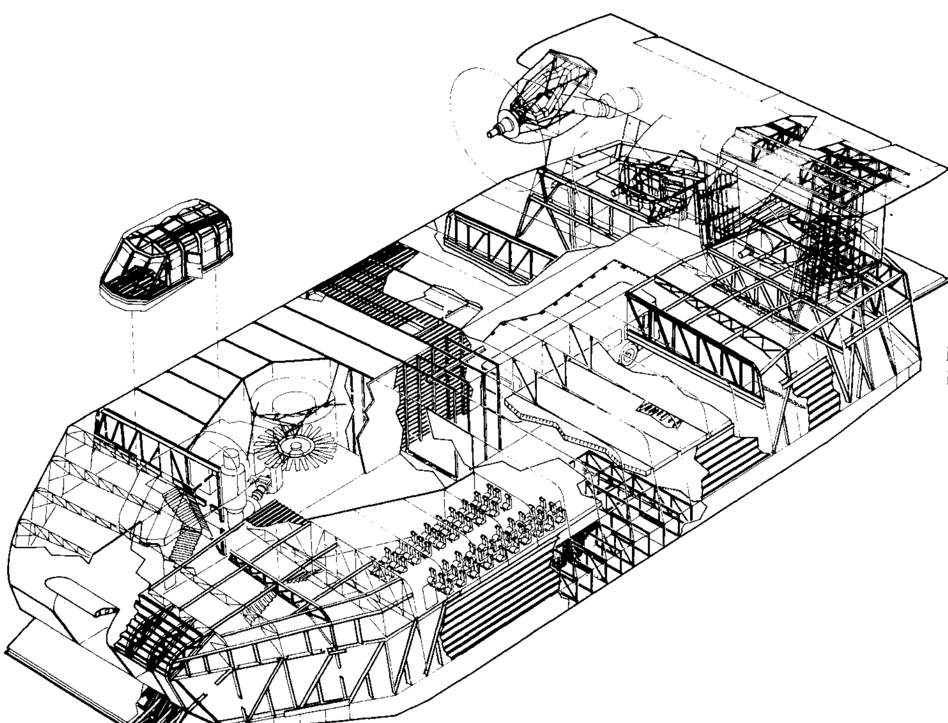

Fig. 3 Isometric view of the N 500 Naviplane.

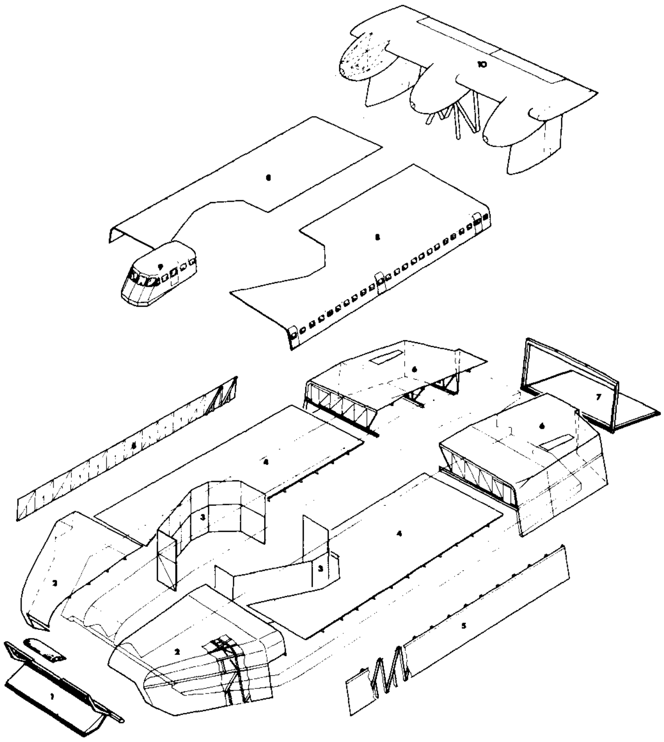

Fig. 4 View of secondary lattice structure.

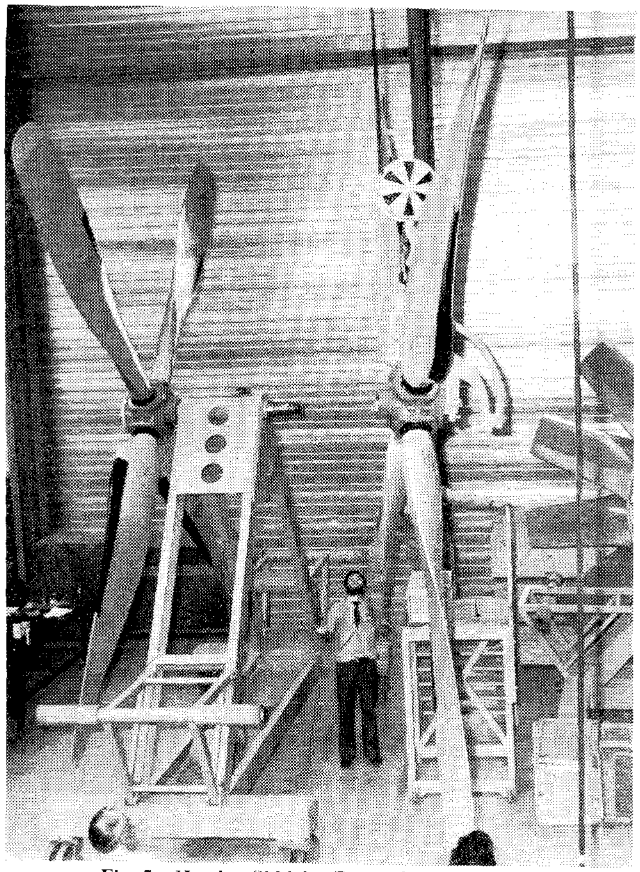

Fig. 5 Hawker Siddeley Dynamics propellers.

offers light weight and high mechanical strength, unresponsiveness to the marine environment and weldability.

The pilot house is at the bow of the craft, arranged to house three persons—pilot, co-pilot, and navigator. Measuring 3 × 6 m, it is spacious and offers an excellent forward and lateral visibility. It accommodates an anticollision radar and long-range radar.

Passenger access is via two embarkation doors arranged aft with built-in stairs. Three auxiliary doors are also available in each passenger cabin.

Skirts

In terms of design and technology, N 500 craft skirts are derivatives of those on the N 300 Naviplane, a 30-ton hovercraft built by SEDAM in 1967.

Simple transposition was not possible in view of craft size. Moreover, the declared intent to provide easy maintenance (rapid replacement of worn or defective components) had to be recognized.

N 500 skirts are of independent contiguous design, each formed of three easily replaceable components. They are arranged in two concentric rings each of 24 skirts. This double barrier insures stability together with an output saving due to labyrinth effect. It also confers safety: the N 500 hovercraft can operate with one or several skirts torn off. These skirts have a diameter of 4 m. The skirt material is a neoprene-coated tergal fabric. Skirts are fed in groups, each group receiving an airflow regulated by shutters from the pilot house. This arrangement provides good control which enhances operational safety at high speed and waves. An elastic backing has reduced the drag of the rear skirts by almost entirely suppressing tuck-under, so that the rear skirts now have a long life. In view of their cardinal importance, the kind of skirts selected for the N 500 were tested first on a model N 300 (half the size of the full-scale craft) over short, high waves.

Propellers

For propulsion, Hawker Siddeley variable-pitch propellers (Fig. 5), which were developed especially for hovercrafts, are

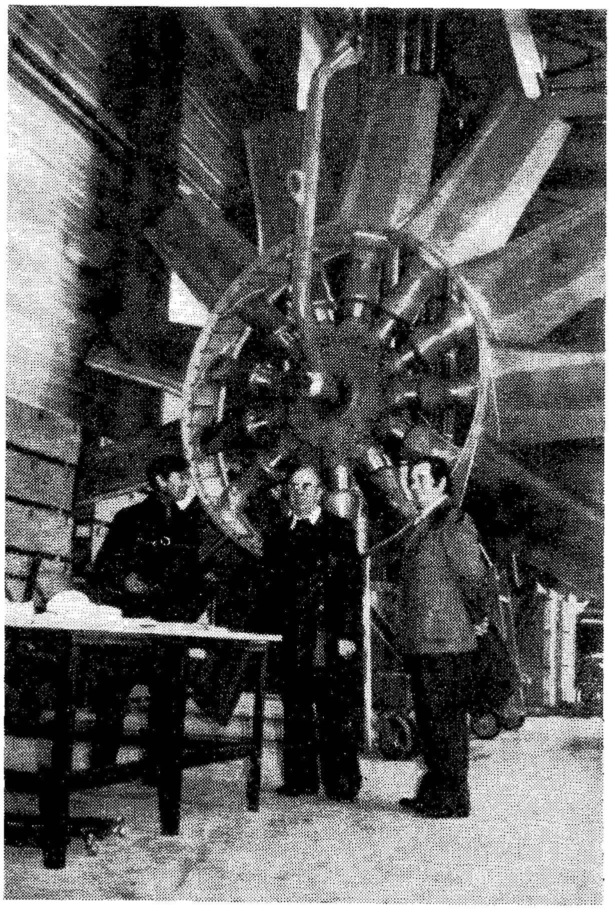

Fig. 6 The N 500 Ratier-Bertin lift fan.

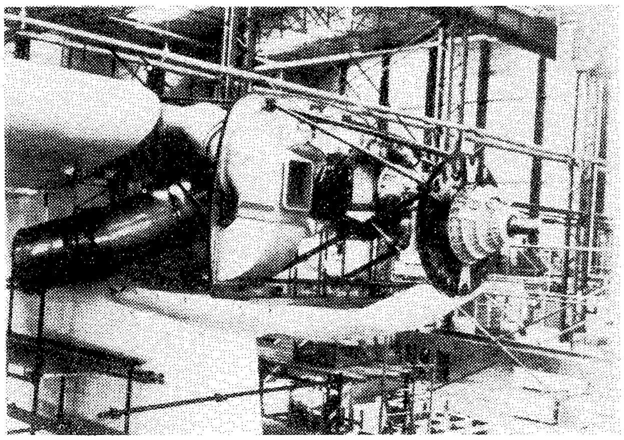

Fig. 7 The N 500 propulsion transmission.

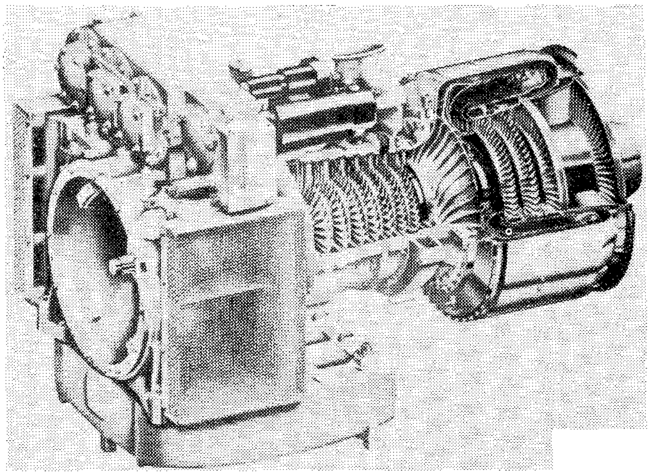

Fig. 8 Avco Lycoming TF 40 gas turbine.

used. They have a diameter of 6.4 m and a maximum blade width of 0.8 m. Their peripheral speed is low, 208 m/s at 620 rpm to keep the noise level as low as possible. They differ from aircraft propellers in that they were especially developed for large thrust and good efficiency at low speeds and they are resistant to salt-laden environment.

The propellers are located in the stern of the N 500 in order to maximize efficiency. There are only three propellers. No larger number is needed for the N 500 whose aerodynamic and hydrodynamic drags have been reduced to a very low level. The propeller thrust is 16 long tons at standstill and 11.5 long tons when cruising.

The propellers are mounted on a gantry consisting of two faired uprights and a 6×20 m horizontal airfoil, the latter having been assigned the additional function of balancing the aerodynamic forces which may be imposed forward at high speed of providing a lift bonus. The airfoil and uprights are fitted with cambered flaps located in propeller airflows to accomplish trim and directional control of the craft.

Lift Fans

Power is provided by two 4 m diam Ratier/Bertin axial fans turning at 915 rpm and having a circumferential speed of 193 m/s. Efficiency is 87% of potential power. Thirteen glass-fiber blades are attached to a steel hub which assures the stand-still position of the blades (Fig. 6). Transmissions between engines and propellers and fans were developed by Fiat, especially for the N 500 (Fig. 7).

Engines

Five identical Avco Lycoming TF 40 gas turbines (Fig. 8) are installed to drive the three propellers and two lift fans. Auxiliary power is generated by two additional Klöckner Humboldt-Deutz T 216 turbines coupled with 400 cps generators.

The propeller turbines are speed-controlled to a speed of 15,400 rpm for continuous power and 15,800 rpm for maximum power. The lift-fan engines are power controlled; the gas generator speed remains constant except in extreme cases. Only the power turbine speed is variable.

The use of three individual turbines for the propeller drives and two individual turbines for the lift fans provides independent control for each unit. Fuel saving becomes possible and above all the connecting shafts and gears, which would nearly double the weight of the propulsion system, are omitted.

Engine Air Supply

In using gas turbines at sea, the salt content of the intake air must be kept within certain limits. The salt forms deposits on the compressor blades causing power losses which can be eliminated by washing the compressor. However, on the hotter parts of the combustion chamber and turbine, the salt causes permanent damage by corrosion. Therefore, the salt content of the intake air must be reduced to a value, which for TF 40 turbines is up to 0.005 ppm during continuous operation and may be exceeded temporarily up to 0.03 ppm.

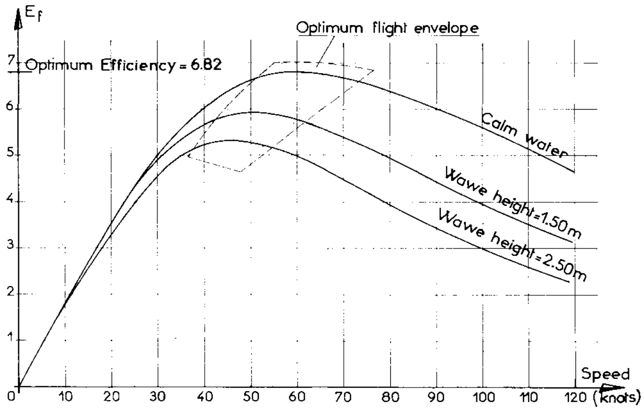

Fig. 9 Generalized efficiency of the N 500.

Dependent on the wind velocity, sea air contains up to 0.2 ppm salt (wind velocity 9 beaufort). Around a hovercraft at sea, air contains up to 0.4 ppm due to the atomizing effect of the air escaping from the air cushion.

To keep the salt content of the intake air within the specified limits, air is withdrawn from the plenum between the fans and air cushion and conducted through a moisture separator and filter, the lift fan already acting as preseparator of atomized seawater and larger salt particles. At the same time, the pressure of the air cushion compensates approximately the pressure losses in the filters and in the relatively long air channels.

Development

Preliminary Study

The Naviplane N 500 design was conceived to provide the required service with maximum economy. One of the main features is the good ratio of weight to total power.

Evaluation of the Power Demand

The transport effectiveness for an air cushion vehicle is defined as $E = WV/P$ where W is the total weight, V is the speed, and P is the total power, and as function of the non-dimensional speed:

$$\nu = V/\sqrt{2Pc/\delta}$$

where δ is the air density and Pc is the air cushion pressure. In this case ν is the ratio between the craft speed and the (isentropic) air discharge speed from the gap between skirt and ground. The function of $E = f(\nu)$ depends upon the geometrical dimensions of the ship, upon the size and characteristics of the resistance coefficient (wave height), and upon the chosen air escape gap. Figure 9 shows the characteristics of this function for the Naviplane N 500.

The chosen maximum in calm waters is approximately 70 knots. In this case, the optimal air cushion pressure is approximately 0.03 bar (64 psf).

The optimum speed (V opt), with transport effectiveness not deviating more than 3% from the optimum value, is as follows:

Calm sea	V opt = 50-73 knots
Wave height, 1.5 m	= 42-61 knots
Wave height, 2.5 m	= 37-53 knots

The required power (at 70 knots) is 12,500 kW or approximately 52 kW/ton.

Weight-Price Ratio

Objectives pursued were to facilitate lift-off onto cushion even when overloaded or with one engine disabled, to reduce aerodynamic drag without complicating construction, to provide good seaworthiness and capacity for safe operation in waves of up to 4 m in height, and to insure good commercial speed in waves of a frequently encountered height.

In the course of these studies, the criterion adopted for evaluation of each improvement was the reduction in the direct operational cost it provided compared with the cost of the reduction. Thus, the acceptable cost increment for a weight reduction of 1 ton or a fan output increase of 1% was determined to be about one hundred thousand dollars.

Aerodynamics

A commercially feasible hovercraft requires a refined aerodynamic design in order to provide regular service in any wind conditions. This is difficult to reconcile with elementary forms. Moreover, the intention was to develop a wide craft. There were several reasons for this, one being the possibility of subsequent "jumboizing."

Special studies and associated wind-tunnel tests resulted in elaboration of easily producible low-drag forms. The mid-body-section draft coefficient is only 0.30, a figure not attainable by racing cars. This result allows not only maintenance of commercial speed in head winds, but also a saving in fuel at all times.

Technical Studies and Model Tests

The intention here is to give only a brief review of test results, which are discussed in greater detail in Ref. 3.

Tests were run with two models in a wind tunnel, two bench-tested skirt models, three models tested at the basin used for testing model ships, two operational manned models tested on Lake Berre over a two-year period, an N 300 Naviplane (production tests), production tests of materials and assemblies, and 1/4th and 1/7th scale tests of fan models.

Aerodynamic investigations were run on static and motorized models in a wind tunnel. From these studies a Cx (C_D) of 0.30, a tail-assembly life of 5 tons at 70 knots, and a good yaw stability were obtained.

Good maneuverability is provided when cruising by movable rudders sited aft on the uprights within the airstream of the side propellers. At a fixed location, variation in the differential pitch of these propellers allows easy maneuvering of the craft in wind speed as high as 40 knots.

Transfer to cushion-borne mode and drag in waves were initially investigated at 1/20th scale in an indoor testing basin and then subsequently on operational models of 1/9th and 1/7th scale. These tests resulted in the concept of skirts which offer low drag at lift-off, seaworthiness, and comfort.

Indoor basin tests were necessarily supplemented by tests outdoors. In fact, the behavior of a model traveling at a constant speed can be radically altered in relation to trim, drag, and course by the intervention of random disturbances. Outdoor manned models were tested for several hundred hours on Lake Berre.

Results were confirmed in tests on the Naviplane N 300. These tests, aimed principally at defining production problems, extended to strength testing of skirts and their attachments. As previously noted, their performance has been highly satisfactory.

A 1/9th scale model (5.5 m in length) was designed to evaluate the skirt system during operation in waves on Lake Berre. Another 7-m model was used to evaluate maneuverability and seaworthiness. This is an exact replica of the N 500 in terms of dynamics, weight distribution, and machinery installation. The two fans and three propellers have the same characteristics as their full-scale counterparts and are arranged in the same manner.

This similarity was necessary in the interest of accurate behavior prediction. In fact, the model served to validate a method of parameter identification which established the influence of a variety of parameters on the basis of analyses of complex test results. A film shows this model, with a slow-motion N 500 sequence, reproducing the time response of the N 500 full-scale in 2.50-m waves.

It should be pointed out that this is an overload test equivalent to a weight of 290 tons. Numerous tests were conducted at a weight largely exceeding the weight envisaged. They have demonstrated that the craft's capacities may be increased when required, as will be seen later.

Test results showing the influence of a variety of parameters are set out in Ref. 3. Finally, model tests at different scales allowed scale effects to be identified and measured, which, in turn, facilitated safe extrapolation on the full-scale N 500.

Production Tests

Partial tests were performed to determine the behavior of welded joints, skirt connections, straps, skirt attachments, etc.

Reliability and maintainability tests were run on all craft components involving any kind of novel concept. But wherever possible, recourse was made to proven components having current applications in aircraft engineering and marine technology, thus minimizing failure.

Re-evaluations

Another feature of the economy of any mode of transportation is its capacity for improvement and amenability to being enlarged and the payload capacity being increased as requirements evolve.

Composed centrally of 2-m spans, the N 500 structure may be "jumboized" by the addition of one or several more spans without affecting machinery located forward and aft. Capacity may thus be substantially increased without changing performance. Because of this, the rather large width of 23 m was adopted. On the basis of tests just described, it was established that an increase in weight would not appreciably affect craft performance.

Craft Trials

The N 500 was tested on the Channel before entering service. Although the tests are not completed, some results are available. The machine has reached 72 knots on calm water, without wind, with full load 0f 263 tons. It has proven to have good performance on waves up to 2.00 m. As far as speed is concerned, the seaworthiness, for instance, is good in ac-

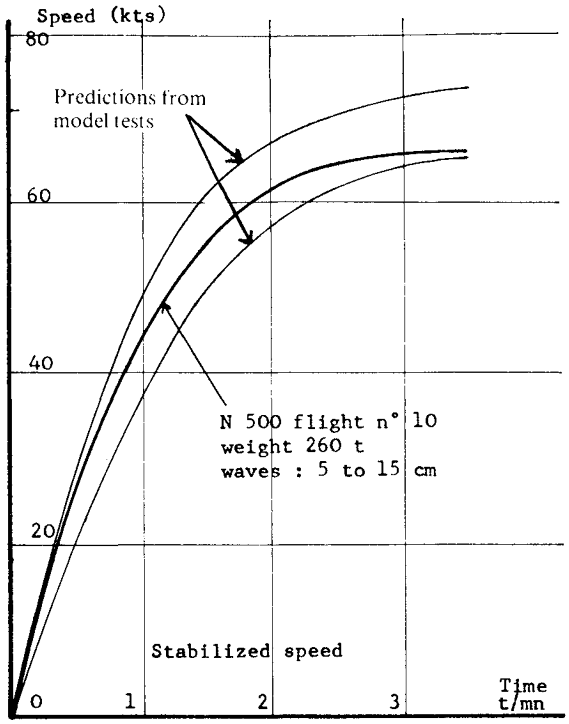

Fig. 10 Comparison of N 500 predictions and test results.

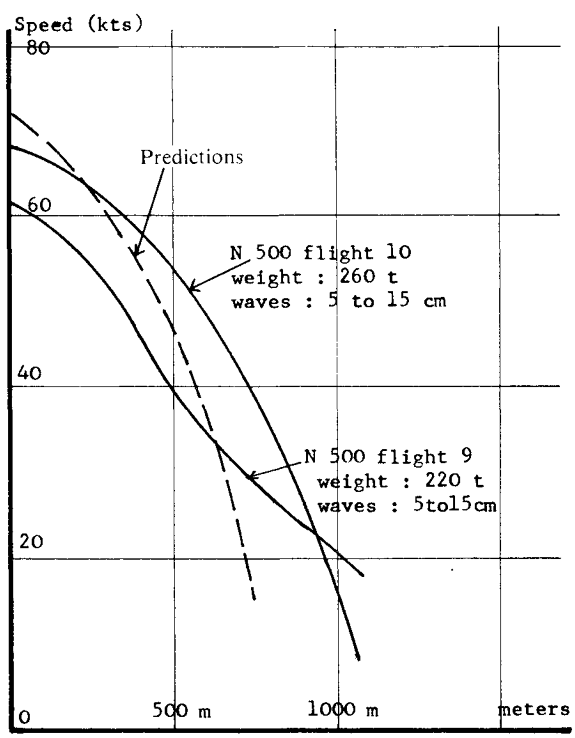

Fig. 11 N 500 deceleration.

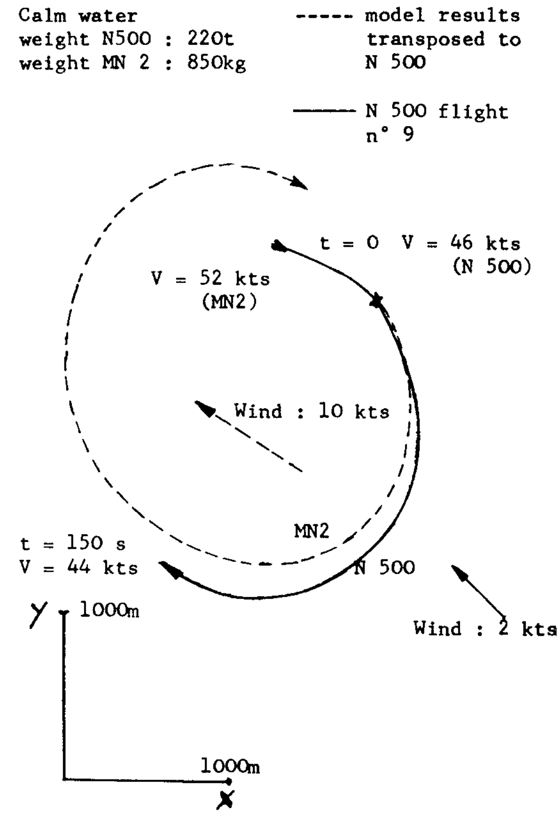

Fig. 12 Rudder tuning comparison between model MN2 and N 500.

cordance with predictions derived from model tests. Figure 10 shows acceleration curves in the tenth test, compared with predictions derived from calculations based on test models and theoretical propeller thrust. The calculations cover a large range, resulting from numerous tests in slightly different conditions. On the right, are the maximum values reached on the N 500 in flight at stabilized speed.

We have the same results concerning maneuverability: 1) acceleration up to 72 knots is shown on Fig. 10 (speed/min), 2) stop distance at 61 and 68 knots is shown on Fig. 11, and 3) turning radius (20 times the length of the craft).

On Fig. 12, this measured full-scale radius is compared with that predicted in model tests.

From tests, it appears that the N 500 is comfortable and very quiet, less that 79 dB (same as in a jet airplane) in the passenger cabins.

Further Developments

Craft with higher tonnage for long-range or military applications are being discussed. With the assistance of the CPE (Ministry of Defence, Center for Prospecting and Evaluating), projects with boats of some 100 tons with side keels have already been carried out. These high-speed craft are expected to be demanded by the French navy in the near future.

The SEDAM-BERTIN skirt system is advantageous for these applications as it gives great stability. Craft with a load capacity of 1000-2000 tons and speed of 80-100 knots are being considered.

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