DEVELOPMENT AND FLIGHT TESTING OF A NEW AMPHIBIAN TECHNOLOGY DEMONSTRATOR*

ICAS-84-5.2.2

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Abstract

The large number of flying boats still in service most of which are outdated, as well as new tasks such as the surveillance of the new Exclusive Economic Zone extending to 200 nm provide the basis for the prognosis that a future market potential for amphibian airplanes exists. However, one prerequisite for this forecast to be realized is the development of economical amphibian flying boats which are capable of operating under most weather conditions. On the basis of their specific missions and operational flexibility they must also be compatible with todays conventional landplanes with regard to performance and economy. This makes the application of modern technologies to this class of aircraft indispensable.

A new amphibian technology demonstrator which made its successful maiden flight on April 25, 1983 is described. This demonstrator was developed to investigate and flight test the effects of new technologies on the high sea capability, operational flexibility, performance and economy of amphibian airplanes.

The configuration of the technology demonstrator and the technologies which have been realized in the areas of aerodynamics, performance, flight mechanics, structures and weights are presented. During the design process of the wing computer aided design was used extensively. The wing planform is rectangular. This was achieved by supporting the wing by struts at 40% of the half span thus optimizing the wing bending moments. The rectangular wing design also permitted to use many idential components on the wing which reduced the manufacturing costs. The manufacturing of the wing, the fuselage and empennage characteristics and the installation of the new two men cockpit are described.

The results of the initial land and sea flight tests of the technology demonstrator over a period of about 12 months are presented and are compared with wind tunnel test and computed values. Finally, the possible uses for a new and modern amphibious aircraft are mentioned.

I. Introduction

The worldwide increasing importance of the oceans especially in connection with the recently internationally passed Law of the Sea enlarging the territorial waters to 12 nm and creating the new Exclusive Economic Zone (EEZ) which extends to 200 nm, as well as the traditional tasks of flying boats such as sea air rescue, fire fighting and various transport missions to places without infrastructure allows the prognosis that a future market for amphibious flying boats exists. The new Law of the Sea not only gives the countries concerned the rights of exploration and exploitation but also the duties to protect and supervise the maritime resources and environment. The availability of modern amphibious aircraft should, therefore, primarily be in the interest of the governments of countries with large coastal areas and which possess many islands.

One of the prerequisites for meeting the requirements of this market potential is the development of economical amphibious airplanes capable of operating under most weather conditions. This, however, makes the application of new technologies as they are applied to todays conventional airplanes to this class of aircraft indispensable.

Numerous project studies and wind tunnel tests related to amphibious aircraft have been carried out by Dornier over the past years. In 1980, these studies led to the definition of an amphibian technology demonstrator. The design and construction phase started later during the same year. Early in 1983, after a series of ground tests this technology testbed (ATT) performed its successful first flight on April 25, 1983 (Figure 1). Initial tests on water have been carried out during August of 1983 (Figure 2). Flight tests on the high seas are scheduled for May 1984.

The amphibian technology demonstrator is used for the following technical investigations:

- Testing and evaluating a modern technology wing incorporating advanced aerodynamics and which was designed for simplified manufacturing to cut production costs
- Demonstration of the testbed's increased high sea worthiness compared to other known amphibians
- Demonstration of its operational flexibility due to the amphibious configuration

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* This work is sponsored by the German Ministry of Research and Technology

- o Demonstration of its greater efficiency and economy compared to earlier amphibian flying boats
- o Testing of modern turboprop engines during high sea operations
- o Exploring the improved short take-off and landing (STOL) capabilities
- o Investigating the improved corrosion resistance by using advanced materials and anti-corrosion coatings
- o Testing of stiffened composite skin panels on the bottom side of the hull.

The goals of this technology program are to determine the effects of new technologies and the interaction with one another on the

- o high sea worthiness
- o operational flexibility
- o performance
- o economy

of amphibian flying boats during actual flight tests.

In addition, this technology demonstrator program is aimed at obtaining full scale test data for the design of modern amphibious aircraft thus reducing the technical and financial risks associated with any future engineering development.

The design and construction of the amphibian technology demonstrator included the following tasks:

- o Overhauling an existing hull and empennage from a former Do 24 T flying boat which had been in service as a search and rescue flying boat in Spain since 1944 and which was returned to Dornier in 1971.
- o Design and construction of a modern rectangular strutted wing with special emphasis on low design and manufacturing costs.
- o Installation of three Pratt and Whitney of Canada PT 6 - 45 B turboprop engines with 1125 shaft horsepower each and 5 bladed propellers from Hartzell.
- o Design and installation of a nose wheel type landing gear using the nose gear from the Fokker F 27 and the slightly modified main gear of the Do 31 VTOL transport.
- o Design and installation of all new aircraft equipment systems (e.g. electrical, hydraulic, avionics system etc.) including a new cockpit.
- o Final assembly and experimental certification of the amphibian.
- o Flight testing of the aircraft from land and water.

In the development of the ATT a design-to-cost approach was used as opposed to other criteria such as maximum performance or extreme service life. Based on earlier project studies performance goals were set but no detailed specifications. The flight test results are used to verify the analytical prediction techniques and thus allowing extrapolation to a wide range of flight conditions and similar amphibian configurations.

II. Amphibian Description

Configuration

The configuration of the amphibian technology demonstrator is shown in Figure 3. With the exception of the old Do 24 T hull and empennage it consists of new parts and new equipment systems.

The configuration is characterized by:

- o Canopylike, strut-mounted rectangular wing with triangular wing tips
- o Propulsion by three turboprop engines with five bladed propellers
- o Sponsons for stabilization on water
- o Nose wheel type landing gear
- o Flat bottom hull with two steps
- o Twin vertical tail

The main technical data of the ATT is summarized in Table 1.

Aerodynamics

The aerodynamic profile DO A-5(1) which was recently development by Dornier for its Do 228 utility and commuter aircraft family is also used on the amphibian technology demonstrator wing. This wing is the major new component to be tested on the ATT.

The DO A-5 profile features

- o lower drag in cruise and climb
- o higher maximum lift with flaps retracted and extended for take-off and landing

compared to other aerodynamic profiles presently used on propeller driven aircraft.

The simple rectangular wing planform could be realized by supporting the wing at 40% half span resulting in very favourable spanwise bending moment characteristics. The triangular wing tips were chosen because wind tunnel tests showed

- o a 2% stability increase of the wing body combination

and

- o a 1.5% reduced computed zero lift drag of the aircraft because of the 5% smaller wing area

compared to a more conventional rectangular wing tip.

The landing flaps have a total span of 17.8 m and consist of three separate sections. They extend over the complete trailing edge of the wing between the ailerons (Figure 4) and are designed for a maximum deflection of 40 degrees. However, initial flight tests at these high flap deflections have verified the wind tunnel test results which indicated that the maximum deflection has to be limited to 30 degree because of flow separation on the unmodified horizontal tail of the former Do 24 T which is being used.

The DO A-5 profil is also used on the ailerons. It has a 16% thickness ratio. The ailerons can be drooped 10 degrees for increased lift during landing approach.

Flight Mechanics

The technology demonstrator's allowable center of gravity range for good longitudinal stability and control was determined from wind tunnel tests to range from 25% mean aerodynamic chord (m.a.c.) to 32% m.a.c. For optimum deflection the horizontal stabilizer may be varied on the ground from -4 to +4 degrees. For the initial tests the horizontal stabilizer was set to zero degrees.

Lateral control was designed in conformance with the Military Specification, Mil-F-8785 B.

Weights

The weights and center of gravity locations were determined by weighing the individual parts, components and the complete airplane. The weight breakdown is summarized in Table 2. It must, however, be emphazised that the technology demonstrator is not weight-optimized. For cost reasons a great number of components and equipment parts were taken from other airplanes (e.g. landing gear, engines including nacelles etc.). In addition the wing and struts are designed for a 16 ton take-off weight although the take-off weight of the testbed has been initially restricted to 14 tons from land and to 12 tons from water. These weight limitations were imposed due to the old hull and the landing gear used. However, recent calculations showed that the take-off weight from land could be increased to 15 tons without modifications to the amphibian.

Wing and Struts

The wing including all strut mountings were designed by computer aided design methods exclusively. A considerable amount of design time and costs could thus be saved.

The wing box is made up of ten 1.2 by 5.1 m similar panels (5 on top and 5 on bottom, respectively) with integrated rib, front and rear spar flanges and stringers (Figure 5). The panels are manufactured by numerically controlled milling. Following the milling process the panels are shaped to the airfoil contour by compressing the rib flanges, a newly contouring technique developed by Dornier(2). The front and rear spars are also numerically milled. The few ribs inside the wing box consist of simple identical or similar C-profile material (Figure 6). Because of these identical or very similar components which the wing consists of, a low cost wing box structure resulted. The wing tips are made out of composite material and are manufactured in two sections (Figure 7).

All 9 wing support struts are conventionally designed. The loads are carried by conventional tubes inside the symmetric, aerodynamically profiled aluminium covers. The equipment system wires, cables, hydraulic lines and hoses etc. which run inside these covers are mounted to a single panel attached to the load carrying tubes.

Composites

A considerable number of composite components have been incorporated into the wing as well as into the whole aircraft (Figure 8). Four different composite materials are used on the following parts of the airplane:

- o Carbon fiber reinforced plastics
  - at the wing tips
- o Kevlar (aramid fiber reinforced plastics)
  - at the integrated outboard section of the sponson noses and the front cap of the main landing gear pods
- o Glass reinforced plastics
  - at the engine cowlings and engine wing fairings
  - at the fuselage aft body fairing
  - at the raised cockpit fairing
  - at the main landing gear pod aft fairings
  - at all strut and underwing aileron and landing flap support fairings
- o Carbon fiber/Kevlar hybrid composites
  - at the complete rear section of the wing behind the rear spar.

For direct comparison of the structural behaviour of a composite panel and a conentional aluminium panel on the bottom of the boat, the right hand main landing gear door was covered with a carbon fiber/ Kevlar hybrid composite panel while the left hand door was covered with a conventional aluminium panel.

Hull and Empennage

The basic structure of the hull and empennage and the longitudinal and directional control systems are the only components from the former Do 24 T remaining on the amphibian technology demonstrator (Figure 9). The old hull is made up of ribs and stringers with aluminium sheet metal panels riveted to the outside which are part of the load bearing structure. Eight vertical bulkheads with watertight doors divide the boat in 9 separate compartments. This design guaranties that the boat floats with two adjacent compartments flooded.

During the modification of the former flying boat into an amphibian the following changes on the hull were made:

- Installation of the nose wheel door at the lower part of the bow
- Rebuilding of the sponsons and mounting of the main landing gear pods at the sponson tips
- Raising the cockpit top to improve the pilots visibility and head clearance.

Airplane Systems

All airplane equipment systems have been renewed and a complete new hydraulic system for powering the lateral controls, the landing gear and the brakes was retrofitted. The longitudinal and directional control systems which are used from the former Do 24 T have been thoroughly overhauled and six rods had to be replaced because their buckling lengths dit not meet todays certification requirements.

The technology demonstrator was also equipped with a new two men cockpit. A comparison of the new and old cockpit is shown on Figure 10. While the old Do 24 T had to be flown by 4 crew members (pilot, co-pilot, mechanic and navigator) because most airplane systems were operated by the mechanic in the mechanics compartment and the navigation equipment was installed in the navigators compartment, aft of the cockpit of the flying boat the new technology demonstrator can be flown by two pilots (in emergency the airplane can even be flown by one pilot) because all system controls and instruments are now integrated in the cockpit.

III. Flight Tests from Land

The flight test results presented here are those from the initial flight tests of the technology demonstrator from land and water. These tests were aimed at checking the correct functioning of all airplane systems and no attempts have been made as yet of testing the demonstrator at all of the limits of its operational flight envelope. In addition, the correlation between flight tests and the computed and wind tunnel test results was to be established.

Already during the maiden flight the correct functioning of most airplane systems including the airplane primary control systems, the landing gear and the engine control system was checked out. Subsequent test flights were performed to test all other systems (e.g. landing flaps, avionics etc.) and to calibrate the pitot static system.

Aerodynamic Characteristics

The airplane exhibits very harmless and gentle stalling characteristics. Slight buffeting indicates the approaching stall which is followed by a symmetrical post-stall nosedown pitching in most flight configurations. Recovery is normal by slightly pulling back on the control wheel. The stall speeds which were measured at altitudes between 10 000 and 13 000 ft are presented in Figure 11.

The airflow on many parts of the airplane was visualized and photographed by attaching tufts to these parts. Especially the flow observations behind the 5 center struts in the propeller slip stream indicated an area of high turbulence and flow separation. The results of these observations clearly indicate that improvements to the flow characteristics in this area of the airplane are certainly possible.

Take-off and Landing

The technology demonstrator's take-off and landing performance is governed by the rather high minimum control speed (V_{MC}) which was fixed at 77 kcas in order to meet FAR 25 requirements. This speed is the result of the rather high control forces of the directional control system of the old Do 24 T. The take-off roll distances measured are shown on Figure 12 as a function of the energy height at lift-off (square of the lift-off speed divided by 2 g). Also shown on this diagram are the computed lift-off distances for the minimum control speed V_{MC} = 77 kcas and a minimum control speed of 66 kcas which was calculated from the geometrical limits of the directional control surfaces. The computed lift-off and take-off-distance-to-50 ft capabilities with all engines operating and the accelerate-stop-distance with one engine failed for the reduced minimum control speed of 66 kcas are shown in Figure 13.

The landing performance of the technology demonstrator is shown on Figure 14. No attempts have been made as yet to slow down the airplane within a minimum distance. According to Figure 14, deceleration values reached during slowdown have been about -0.064 g. However, the airplane has a deceleration capability (by breaking and reverse thrust) of about -0.23 g leading to landing roll distances on the order of 200 to 300 m for the landing weights tested.

Horizontal Flight

Due to the old Do 24 T hull and empennage used the maximum horizontal speed tested so far has been limited to a safe 185 kcas because of the 200 kts maximum speed of the old Do 24 T and the changed loading characteristics on the horizontal tail. Increasing the maximum speed should be possible after additional static and dynamic load tests on the empennage.

As mentioned before, the amphibian technology demonstrator has not been optimized for maximum performance. Cruise performance test data is, therefore, not representative of a modern amphibian which could be derived from this testbed. The main reasons for this are the rather unfavourable drag characteristics of the former hull, empennage and strut configuration used. A modern amphibian would incorporate the new wing, a similar propulsion system but would have a complete new hull and empennage and a new wing support structure. Initial wind tunnel tests on such a new hull have just been completed as part of this program.

Stability and Control

The center of gravity range as predicted from wind tunnel tests and verified from flight tests extends from 25 to 32% of the wing mean aerodynamic chord. Already from the wind tunnel tests it was apparent that the airplane's neutral point is strongly dependent upon flap deflection and thrust setting. This was essentially confirmed from flight tests as is shown on Figure 15.

The critical longitudinal trim characteristics are presented on Figure 16. As can be seen from this figure the trim changes due to thrust changes are rather small. However, at flap angle settings of 30 degrees trim changes become extremely large with reduction of speed. In order to avoid mistrimming the airplane the trim limits have been set at trim tap settings of +5° (nose up trim) and -5,5° (nose down trim).

The airplane exhibits very good roll control even at low speeds. The bank angle which is reached in 1.8 sec is compared with the Military Specification in Figure 17 for different forward speeds and flap settings. The corresponding rolling velocities are given in Figure 18.

As mentioned before the airplane directional control is characterized by very high pedal forces of the old directional control system used. Reduction of these high control forces is of prime importance for any future amphibian design based on this demonstrator aircraft (e.g. by hydraulically powered controls).

IV. Flight Tests from Water

The aims of the initial water tests were

- to demonstrate the correct functioning of the technology demonstrator as an amphibian
- to determine the best take-off and landing configurations
- to critically judge the present configuration and to generate test data which can be used in the design of modern amphibian airplanes.

Handling Characteristics

The amphibian was launched down a ramp with a 1 : 10 slope under its own power without any problems (Figure 19). Reverse thrust and/or brakes were used for controlling forward speed and heading. Brakes are applied only before the main wheels enter the water. With 90 to 95% of the available reverse thrust the amphibian can be held on the ramp. With 50 to 60% reverse thrust it smoothly rolls into the water.

Beaching also does not present any problems. Cross winds of up to 15 kts could be compensated by asymmetric thrust an appropriately heading the aircraft into the wind. About 20 to 25% thrust is required for rolling up the ramp within 15 to 20 seconds. The aircraft can be turned around on a 20 by 20 m platform within about 30 seconds and be readied for passenger and/or cargo loading and unloading.

On the water the amphibian can be maneuvered easily and precisely by asymmetric thrust. At zero forward velocity the following heading changes were demonstrated:

- landing gear retracted : 13° / sec.
- landing gear extended : 7° / sec.

Obtaining maximum values was not attempted.

At zero and slow forward velocities cross winds above 12 kts cause the windward wing to raise. However, roll angles remained smaller than 6° at cross wind velocities of up to 15 to 20 kts due to the lateral stabilization effect of the sponsons. Rolling may be reduced by reducing flap angle settings.

With increasing forward velocity the amphibian pitch angle increase while the directional stability decreases. The pitch angles reached during transitioning onto the step are dependent upon the flap angle settings. After reaching a velocity of about 20 to 25 kts the amphibian is driven onto its step and into a planing pitch attitude which is considerably lower than before (Figure 20).

Important parameters which significantly influence the transition from floating to planing and the subsequent planing are:

- flap deflection
- rate of power increase
- elevator deflection
- wind velocity and direction
- water surface conditions

Directional control during take-off from water can be achieved by rolling the amphibian by means of the very effective ailerons into the desired direction such that the corresponding sponson dips into the water thus generating a yawing moment and/or by differential thrust. Differential thrust, however, was found to be best for directional control.

For high sea operation minimum lift-off and landing speeds are prerequisites in order to minimize the structural loads on the hull. As expected flap settings influenced lift-off and landing velocities of the technology demonstrator most significantly. From the initial water tests a flap angle of 20° was found to be the best compromise between controllability, forward velocity and water handling characteristics for both, take-off and landing.

Engine failures were simulated with a ciritcal outboard or the center engine thrust suddenly reduced to idle. All single engine failures were found to be uncritical because of the three engine configuration.

Any porpoising tendencies were investigated on the amphibian technology demonstrator also. Porpoising is characterized by a rythmic pitch and heave motion of the amphibian during the planing phase of the take-off and landing runs. Porpoising could only be excited during take-off and landing within the small velocity range from 30 to 50 kts and thrust settings below 65% torque (Figure 20). It can easily be stopped by the pilot by appropriate thrust changes.

Take-off and Landing

No attempts have been made to minimize the take-off land landing speeds and distances during the initial water trials. The flight test results for the lift-off speeds and distances are compared with the computed values in Figure 21. The corresponding values for the landings are presented in Figure 21. As is seen from these figures the pilot maintained a safe velocity margin during take-off and landing. The latter figure also shows that a significant reduction in landing distance can be obtained by reverse thrust.

V. Concluding Remarks

A renewed need for amphibious aircraft is seen based on new governmental and public tasks for this kind of aircraft. As a prerequisite new technologies as they are used on modern land planes have to be applied to the amphibians in order for them to be compatible with conventional aircraft on the basis of their special missions. Sponsored by the German Ministry of Research and Technology Dornier has developed and built an amphibian technology demonstrator which is used for testing some of these new technologies in flight. The flight test results are used extensively in conjunction with analytical and model test results in order to extend their applicability to a wide range of amphibian configurations.

Because of its high sea capability, operational flexibility, performance and economy a future amphibious aircraft can be used for the following missions:

- Maritime surveillance
- Fire fighting (e.g. wild fire control)
- Environmental control (e.g. oil pollution control)
- Sea air rescue
- Passenger and cargo transport
- Ambulance and medical services
- Earth and maritime research

This new amphibious aircraft has yet to be developed. Its realization has to be seen to be in the public interest and, therefore, it has to be commisioned by the governmental agencies concerned.

References

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"Wing Design for Light Transport Aircraft with Improved Fuel Economy"
12th ICAS-Congress, Munich
October 12 - 17, 1980

(2) M. Flemming
"Structures Technology for General Aviation Aircraft at Dornier"
SJAC-Conference, Tkyo
April 1983

Main Data	
Length	21.95 m
Span	30.00 m
Overall Height	6.68
Height to Keel	5.65 m
Wing Area	100.0 m^2
Aspect Ratio	9.00
Wing Cord	3.60 m
Width incl. Sponsons	8.00 m

Propulsion Data	
Engines	3 x Pratt & Whitney, PT6A-45B
Max. Shaft Horse Power	839 KW (1125 shp)
Propeller	Hartzell Variable Pitch, HC-B5 MP-3 – 10282 B + 6
Diameter	2.86 m
Number of Blades	5

Weights	
Max. Take-off Weight from Land	14000 kg
Max. Take-off Weight from Water	12000 kg
Max. Landing Weight on Land	12000 kg
Max. Landing Weight on Water	12000 kg
Operat. Weight Empty	10635 kg

Landing Gear Data	
Gear Track	6.90 m
Wheel Base	6.55 m

Table 1 Technical Data

	kg
Structures Propulsion System Standard Equipment Systems	7 028 1 274 1 939
Standard Weight Empty	10 241
Special Systems Flight Crew	224 170
Operational Weight Empty	10 635
Payload: Flight Data Recording and Transmission System	365
Empty Fuel Weight	11 000
Fuel (to 12 ton/14 ton)	1000/3000
Take-off Weight from Water	12 000
Take-off Weight from Land	14 000

Table 2 Weight Summary

Figures

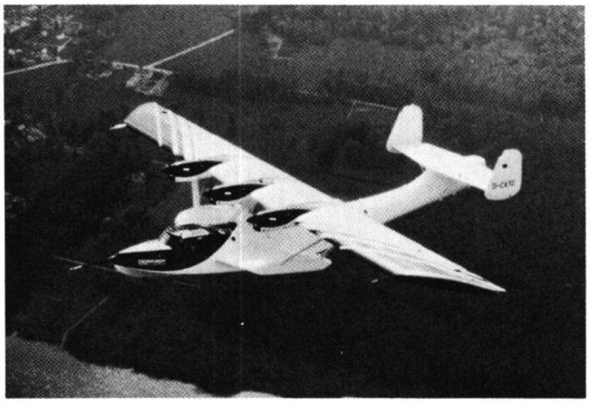

Figure 1 Amphibian Technology Demonstrator (ATT) in Flight

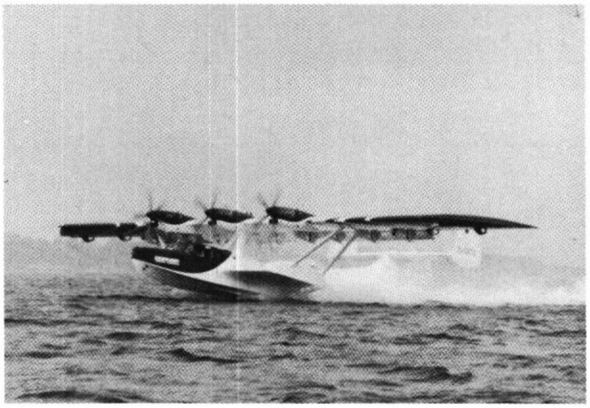

Figure 2 Amphibian Technology Demonstrator During Water Tests

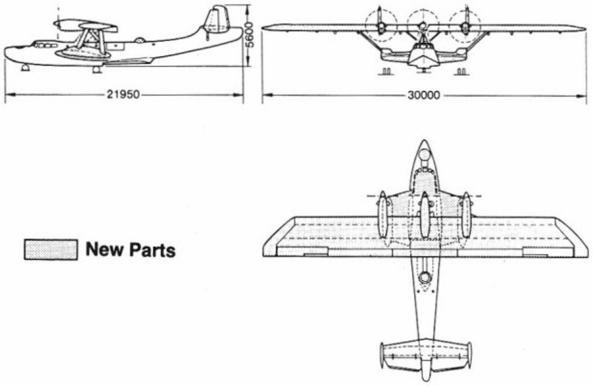

Figure 3 **Amphibian Technology Demonstrator Configuration**

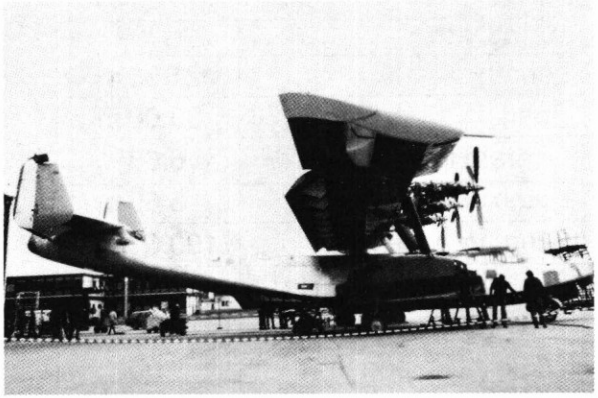

Figure 4 Landing Flaps

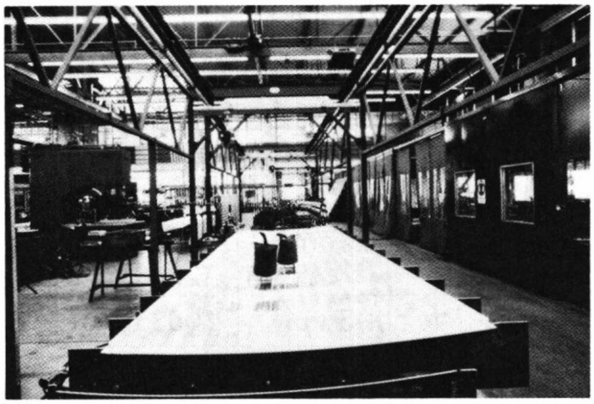

Figure 5 NC - Milled Wing Box Panel

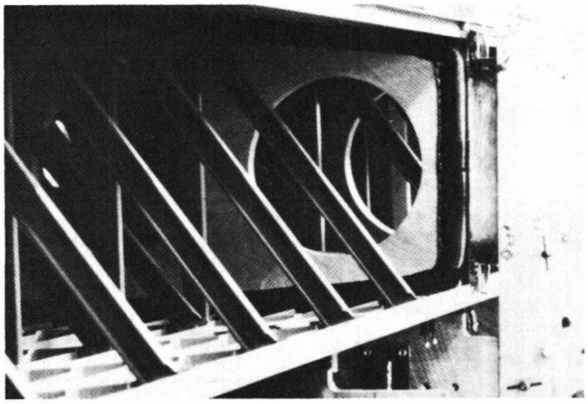

Figure 6 Wing Ribs

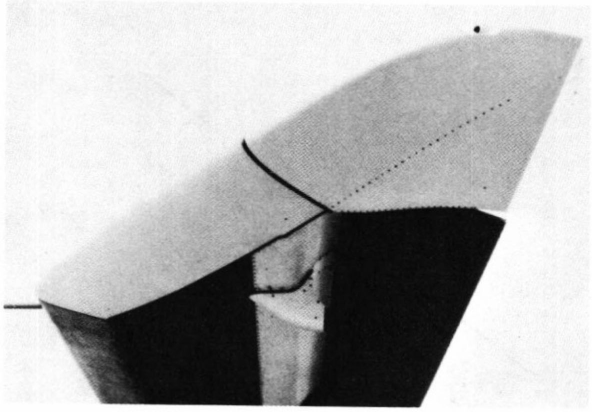

Figure 7 Wing Tip

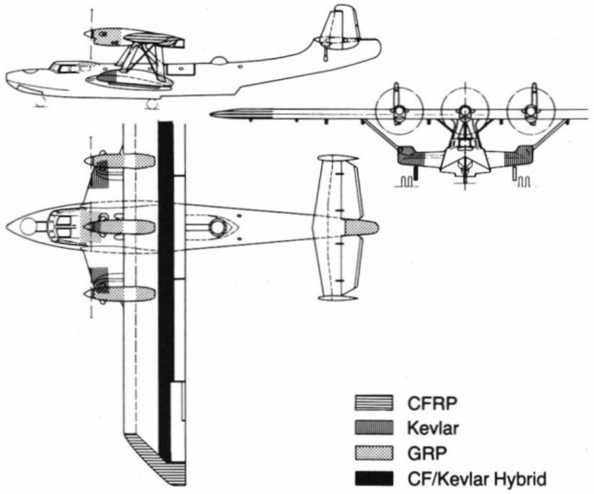

Figure 8 **Composite Parts on the Amphibian Technology Demonstrator**

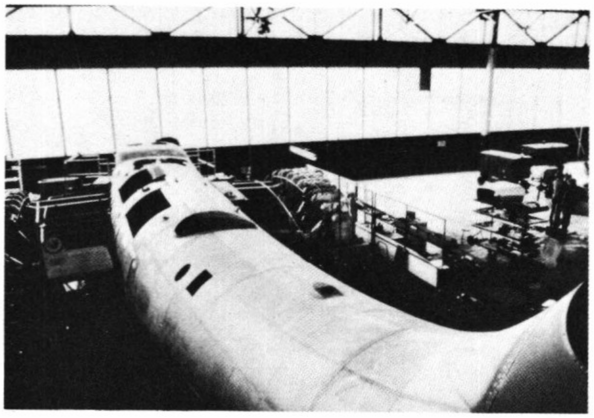

Figure 9 Hull and New Sponsons

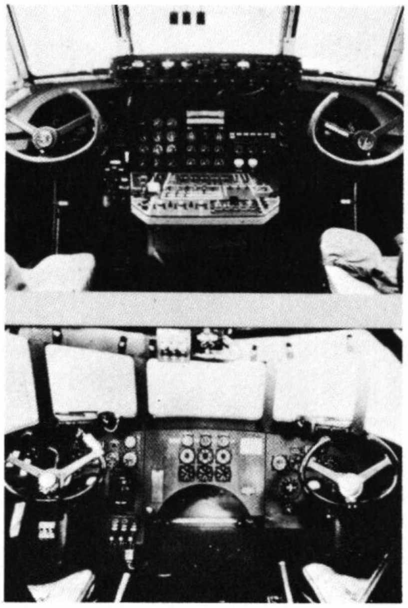

Figure 10 Cockpit Comparison of ATT and Former DO24T

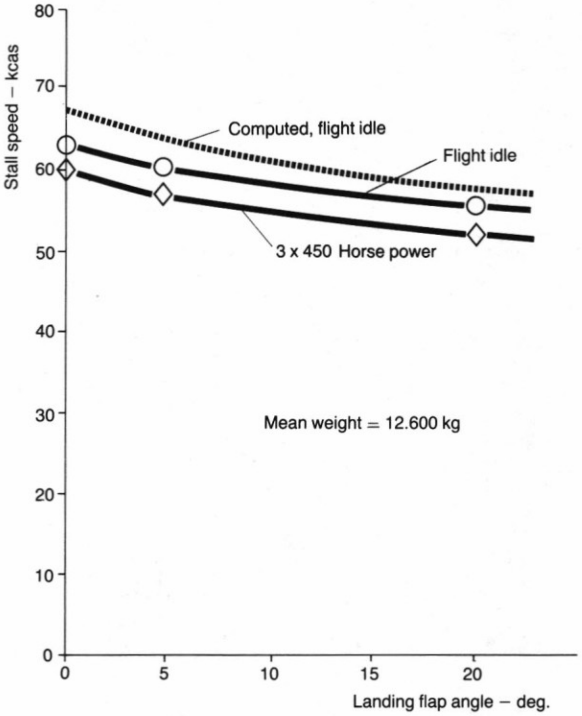

Figure 11 **Stall Speed**

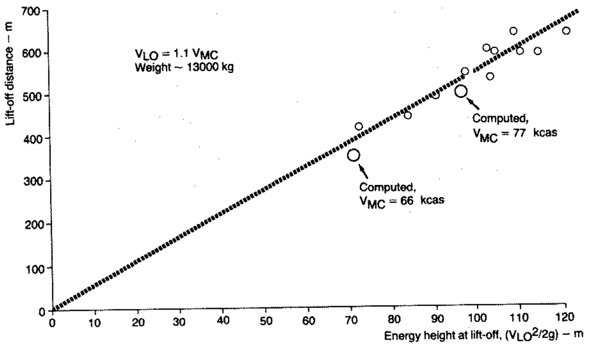

Figure 12 **Take-off Roll Distance**

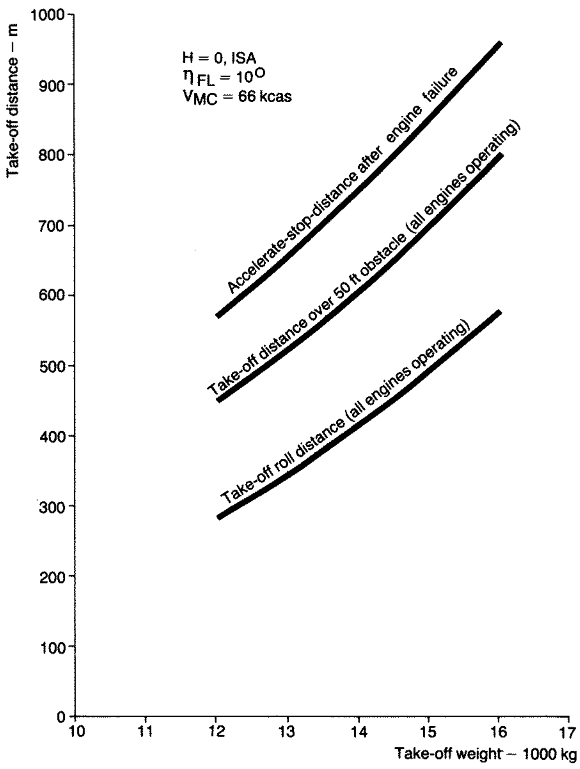

Figure 13 **Take-off Distance Capability**

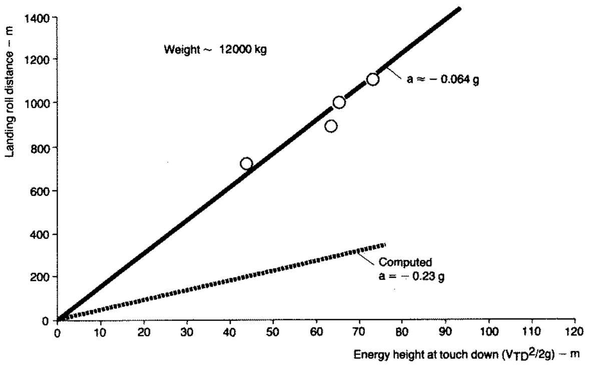

Figure 14 **Landing Roll Distance**

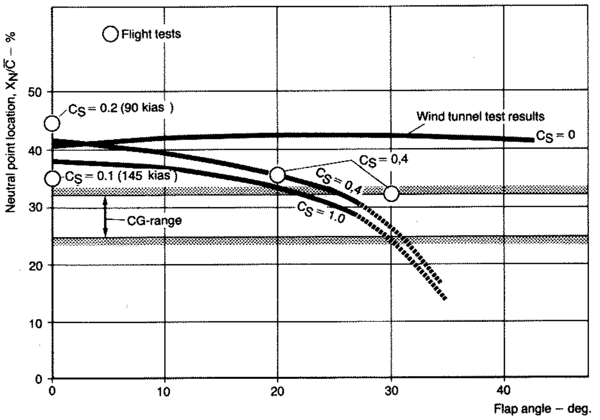

Figure 15 **Neutral Point and Center of Gravity Location**

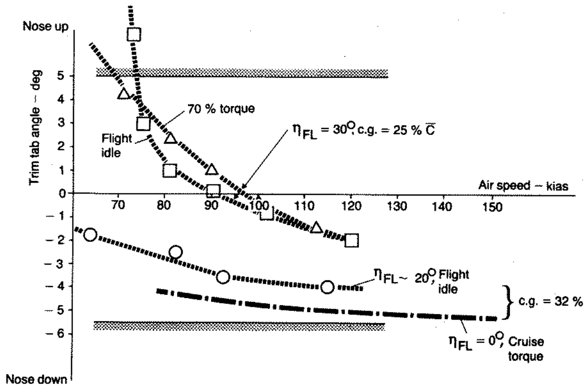

Figure 16 **Trim Curves**

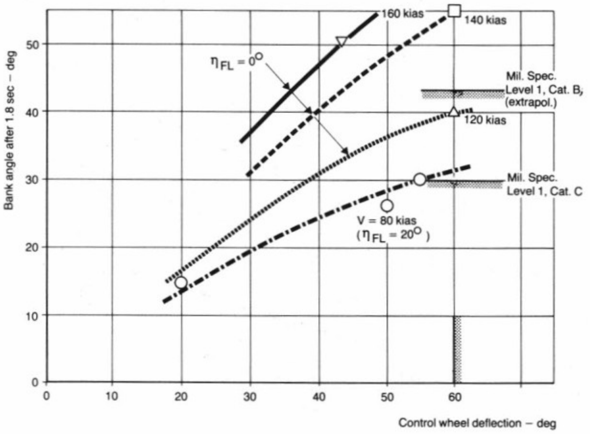

Figure 17 Roll Control Response

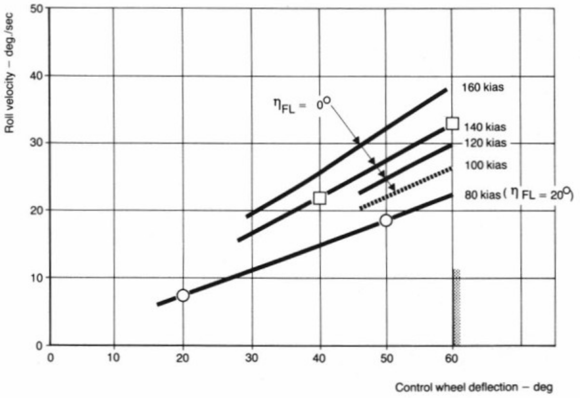

Figure 18 Roll Velocity

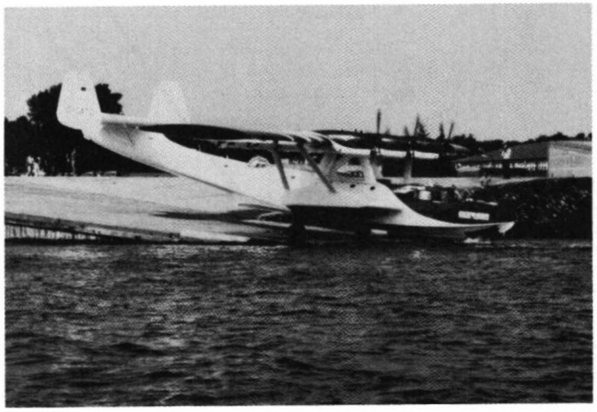

Figure 19 Launching the Technology Demonstrator

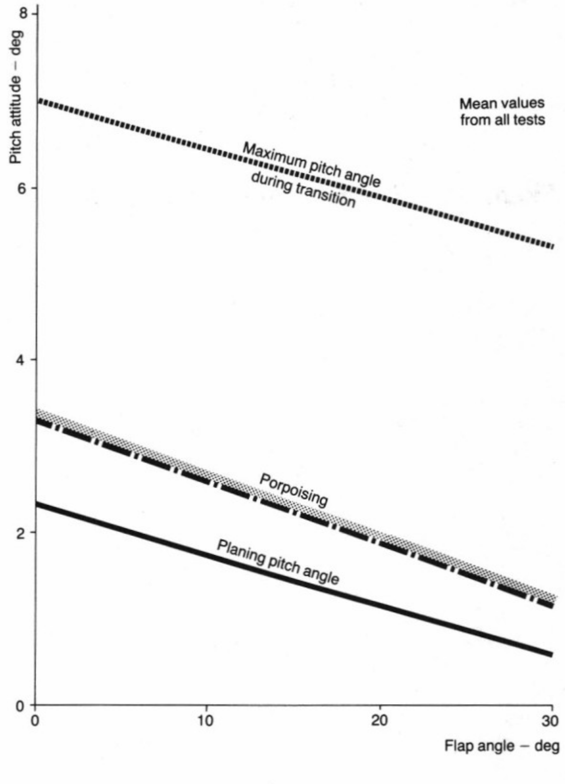

Figure 20 Airplane Attitude on Water

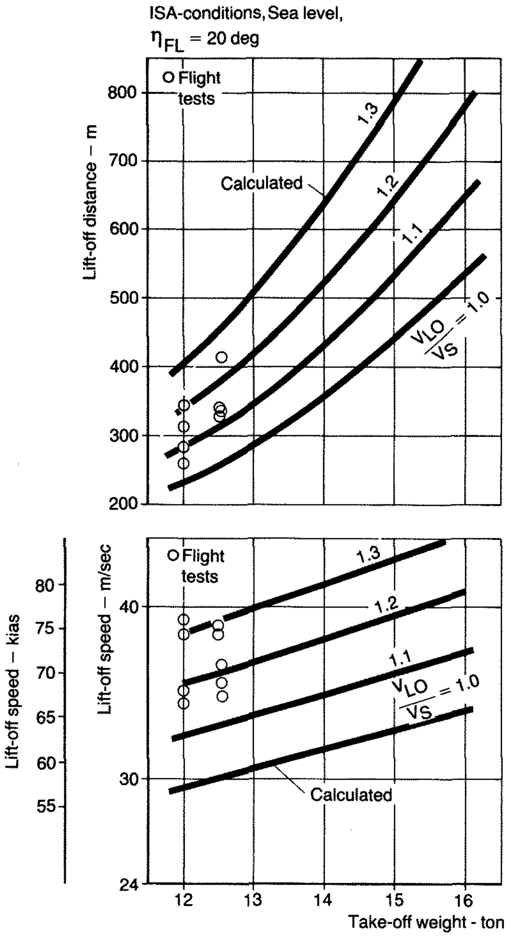

Figure 21 Take-off Performance on Water

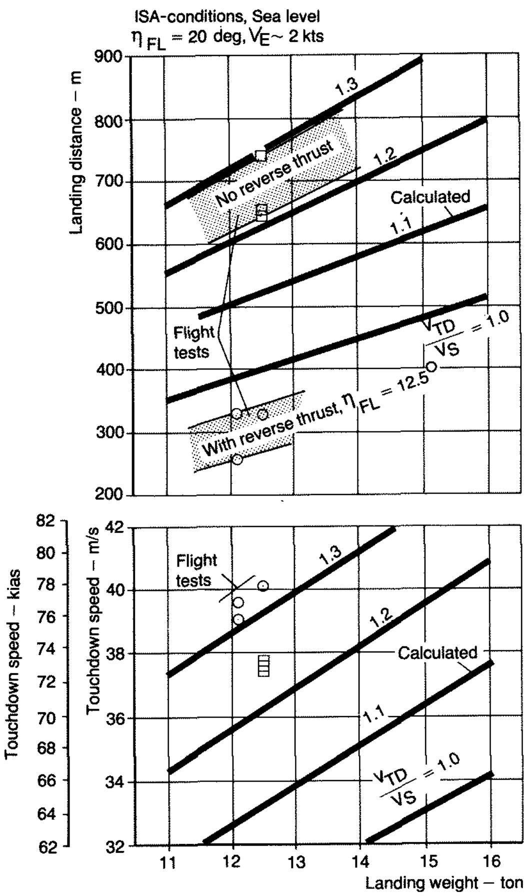

Figure 22 Landing Performance on Water