EXPERIMENTING A NEW COMPOSITE ROTOR ON AN AEROSPATIALE DAUPHIN HELICOPTER

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ABSTRACT:

AEROSPATIALE started in 1987 an experimental development carried out on a 365N DAUPHIN equipped with a new five bladed main rotor, intended to improve its performance, and to allow further studies of high speed conditions.

New technological concepts have been studied and flight tested in order to reduce aircraft drag.

Thanks to a composite (wound carbon epoxy) integrated mast hub, the main rotor has been set closer to the airframe.

Reduction of hub size has been allowed by new concepts such as fixing the mast on the M.G.B. by a single bearing, using interblade dampers, new swashplates.

Hub drag, one of the main part in aircraft drag, was reduced by decreasing its frontal area, and by designing a leakproof fairing, shaped with upper cowlings.

A large flight envelope has been tested, qualifying these new concepts.

Increasing the number of blades has reduced dynamics excitation. This has allowed to remove M.G.B. suspension while decreasing vibratory level

Compared with DAUPHIN, increasing the number of blades has also improved the maximum cruising speed at heavy gross weight, along with better handling qualities.

Flight tests results show that speed has been increased mainly due to new fairings design: fitted with current ARRIEL 1C engines, the maximum speed was increased by some 5 to 15 Kt, depending on aircraft weight.

Following this program, this experimental aircraft will be equipped with reinforced M.G.B. and uprated ARRIEL 1X engines, so as to perform high speed flight tests in helicopter conditions in the vicinity of 200 Kt.

1. Introduction

Helicopter has a recent history. It has been evolving for the last 40 years through main significant steps:

- A demonstration phase of feasibility and viability of this concept
- An improvement phase of its safety
- An improvement phase of cost reduction.

Along with continuous efforts in safety and cost improvements, Helicopter manufacturers have already started a new phase of performance improvement: going further and faster.

This experimentation of a new composite main rotor on a DAUPHIN is one of the major step in this performance improvement phase. It includes two phases:

- Phase A: Research of a significant reduction in the overall drag.
- Phase B: Evaluation of helicopter high speed behaviour in the vicinity of 200Kt.

This first phase was completed in early 1990. The second phase is currently in progress, and will be achieved on the same aircraft, with upgraded engines.

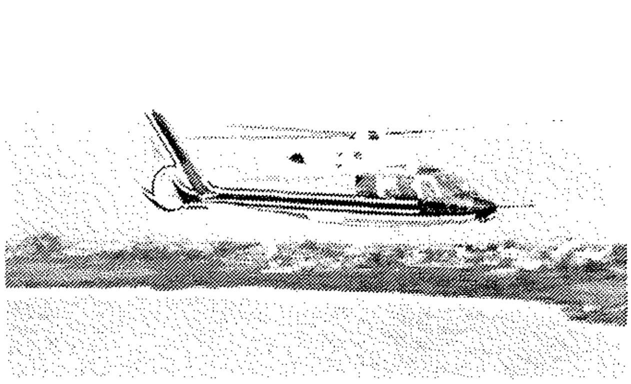

Fig. 1 : X380 IN FLIGHT

This paper deals with the first phase. The experimentation, partly founded by the French Government, has been carried out on a DAUPHIN, embodying the following modifications:

- A new main rotor, with a compact hub, fairing, equipped with five blades,
- New upper fairings, so as to reduce fuselage drag.

The schedule, the main goals of this program and the new technological concepts are presented below. The flight results are also presented, from the technological, dynamic, aerodynamic and handling points of view

2. Program Schedule

Figure 2 shows the program schedule for the two phases of this program:

- Phase A: 1987 -> 1990
- Phase B: 1990 -> 1991

Phase A started in 1987 by a first preliminary and feasibility phase for the study of the new concepts described below.

Studies and manufacturing were achieved during 1988, enabling tests to start at the beginning of 1989.

The High Speed DAUPHIN (HSD) program is now in progress so as to perform flight tests in 1991:

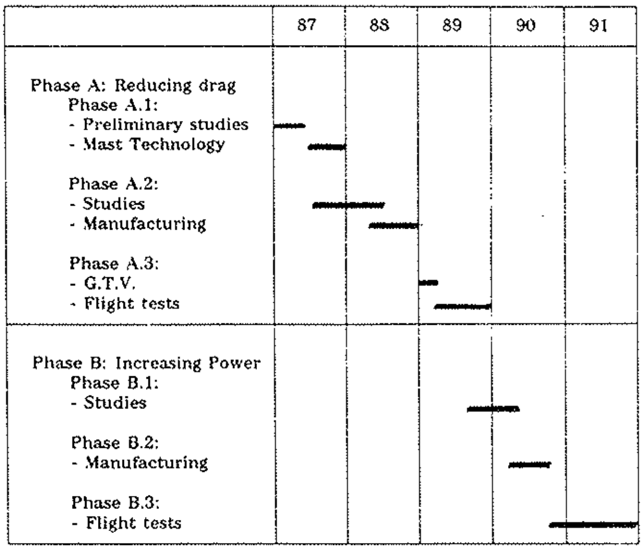

Fig. 2 : GENERAL SCHEDULE

3. Objectives

The main goal of this program is to reduce aircraft drag so as to increase speed, reduce fuel consumption and increase range.

Wind tunnel tests carried out in 86 on a clean mockup had shown that it should be possible to reduce the aircraft drag by 15 to 20%. Our goal was to get this improvement on the aircraft in a full scale flight test.

Along with this performance goal, the research program gave us an opportunity to test and validate new technological concepts. The main technological challenge of this program was to perform the flight tests with a new, integrated composite rotor mast.

So we had two main objectives:

- Decreasing drag
- Validating new concepts.

4. Technological Description

4.1 General Design Approach

As explained in paper [ref.: 1], wind tunnel tests showed that on a standard DAUPHIN, the equivalent surface area of the main rotor hub is about 40 % of the total drag.

Along with improvement of fuselage aerodynamic, it was obviously necessary to reduce drag due to the main rotor hub. The general design approach was conducted in order to reduce the main rotor hub dimensions (height and width) and to integrate the hub into rotating fairings.

New concepts have to be developed to meet this dimension reduction requirement. These new concepts are:

- Mounting of the main rotor mast on the main gearbox with a single ball bearing
- Short, conical, composite rotor mast,
- Mast-suited swashplates
- Interblade dampers on a SPHERIFLEX rotor hub.

In order to meet high speed program requirements, it was necessary to increase the blade surface area. In order to avoid high vibratory level at high speed, or to have to develop a new suspension, it was decided to use 5 DAUPHIN blades, with slight modifications.

4.2 Description and ground tests

4.2.1 Single ball bearing

In order to save vertical dimensions, instead of mounting the mast on the M.G.B with 2 bearings, it was decided to use a special single ball bearing, which counteracts:

- Lift
- Horizontal drag
- Bending loads

This new kind of ball bearing was developed jointly with S.N.R., a French ball bearing manufacturer, who developed adapted calculation tools for this kind of application.

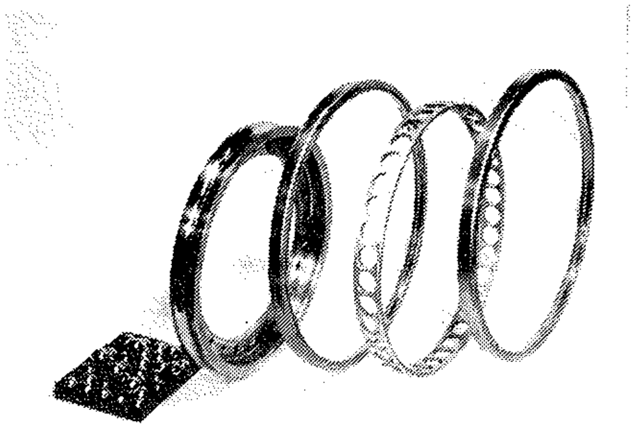

Fig. 3 : SINGLE BALL BEARING DISASSEMBLED

As a matter of fact, the ball rotational speed 1 around center of the ball, and rotation speed 2 around axis of the bearing, depend on the combination of thrust and bending, and so vary with location of the ball.

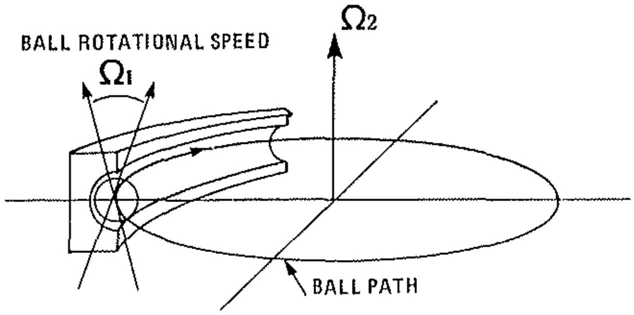

Fig. 4 : SINGLE BALL BEARING : THE 2 ROTATIONAL SPEEDS

Endurance ground tests were performed in 1986, demonstrating the concept validity.

With this concept, compared with dual bearing, it was therefore possible to save 20 cm in height:

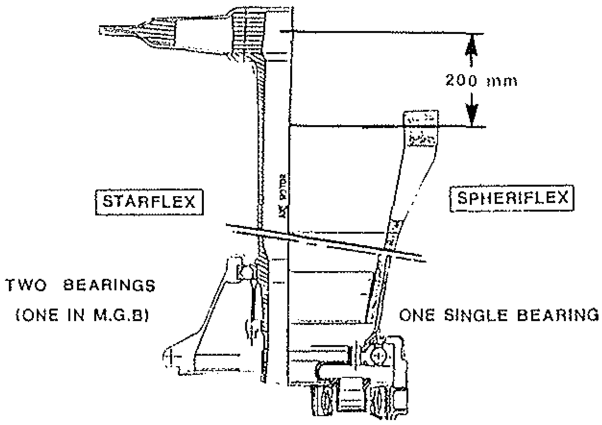

Fig. 5 : MOUNTING OF THE MAST ON THE MGB

4.2.2 Composite mast-hub

With the bottom part of the mast now mounted on a larger diameter, and with the use of a SPHERIFLEX hub (see par. 4.2.4), the idea sprang as to join the spherical bearing center straightly to the ball bearing.

This direct joining made use of composite material easier.

Meanwhile, we had to fullfill different requirements for this part:

- Counteract CF load in the upper part,
- Transmit torque and thrust,
- Attach the mast on the main gearbox.

Technology and material used for this part was filament-wound carbon epoxy. A special process, and tools developed for rocket application were adapted for the studies and allowed variation of the cross section along the axis of this part.

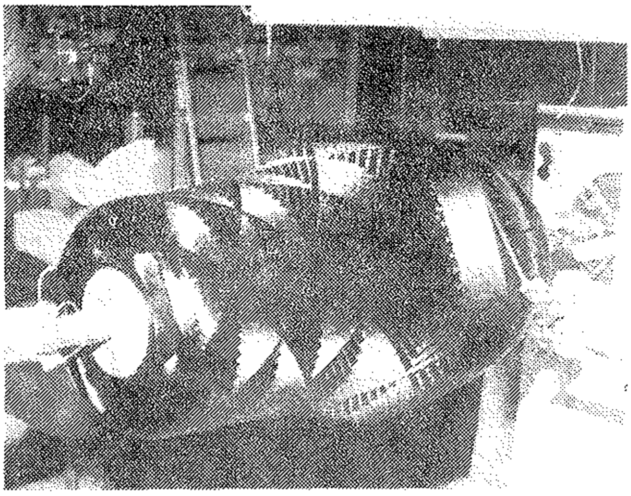

Fig. 6 : WINDING THE MAST

After the winding operation, the mast was then machined:

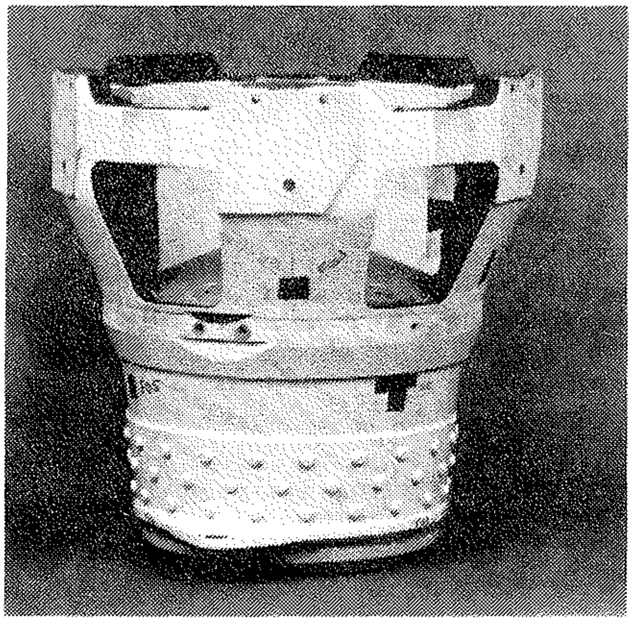

Fig. 7 : MACHINED WOUNDED MAST

Finite element calculations were checked by a fatigue test which allowed us to start the flight.

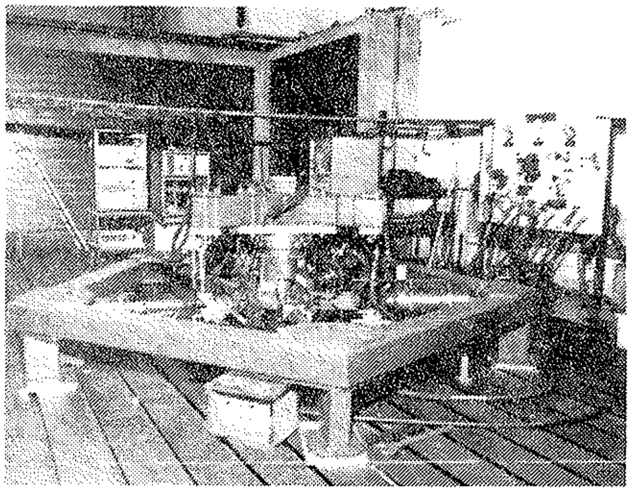

Fig. 8 : FATIGUE TEST

4.2.3 Mast suited swashplates

The direct joining of spherical bearing center to the ball bearing is interesting for composite stresses but leads to a larger diameter mast in the swashplate area.

Classical swashplates with a spherical bearing would have been very large, and were therefore prohibited, regarding size reduction goal.

A new concept was then imagined, and ground tested:

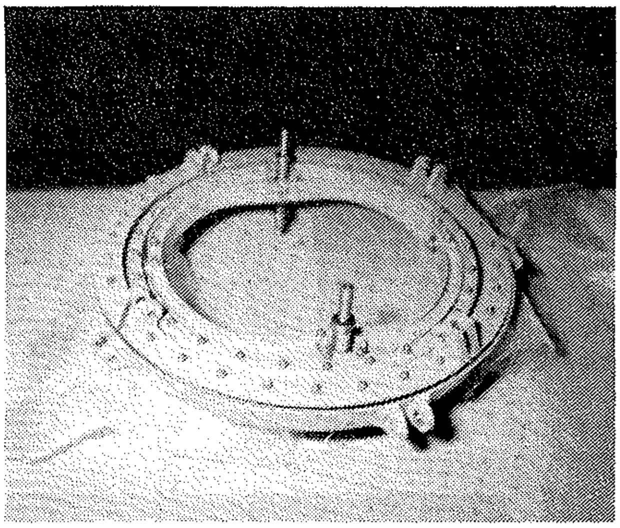

Fig. 9 : SWASHPLATES

This concept allows axial displacement (i.e. collective pitch) with 2 small columns, rotating with the mast.

The cyclic pitch is provided by angular displacement of the swashplates around a cardan joint.

This system has been endurance tested to check that any jamming was possible.

4.2.4 SPHERIFLEX hub with interblade visco-elastic dampers

Along with height reduction, it was also necessary to reduce width so that the hub can be faired.

Compared with the STARFLEX hub, this was enabled by SPHERIFLEX hub which allows an horizontal diameter reduction of 280 mm.

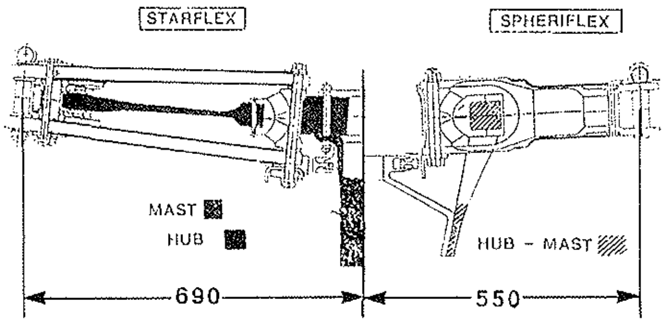

Fig. 10 : HORIZONTAL SIZE REDUCTION

This new and smaller size, combined with 5 blades instead of 4 leads to a very small available area to install the lead-lag dampers.

Fortunately, a new damper concept was developed and first tested on a four bladed DAUPHIN (see ref. [3]). Conventional dampers, attached between hub and blade were replaced by interblade dampers, mounted between the blades.

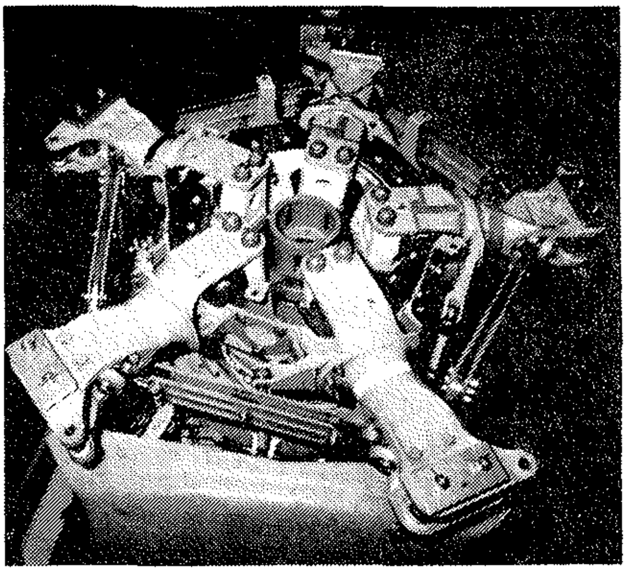

Fig. 11 : INTERBLADED SPHERIFLEX HUB

Next figure shows the complete hub mast mounted on the aircraft:

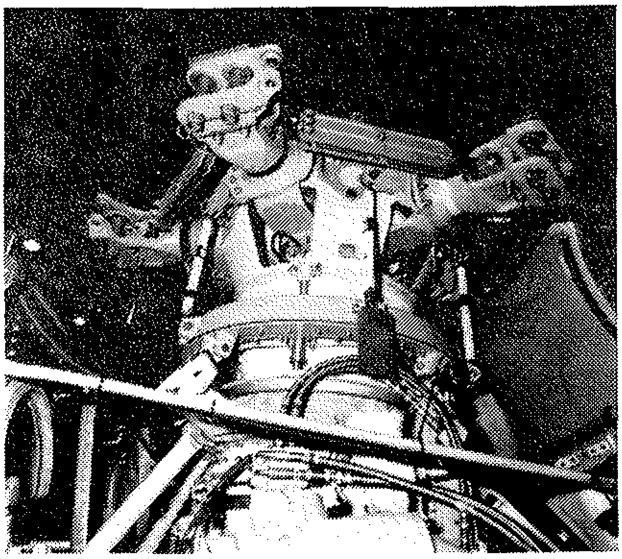

Fig. 12 : HUB MAST INSTALLED

4.2.5 Blades

Five DAUPHIN blades were used instead of 4. The modifications made to the blades were minor:

- Stretched tip cap, in order to keep current rotor diameter (attachment diameter reduced)

- Removal of the tuning weight (for frequency adaptation), which is no more necessary on a five bladed main rotor.

In order to avoid major modification to the blade, a longer tip was designed, instead of increasing current blade length. This choice leads to an increase of blade tip weight, for tip cap attachment reason.

The consequence on the flapping natural frequency of blade tip weight and removal of the tuning weight were:

	4 blades	5 blades
2 nd 3 rd	2.4 4.7	2.8 4.8

The new longer tip, was designed with the latest state-of-the-art technology , i.e. swept tip.

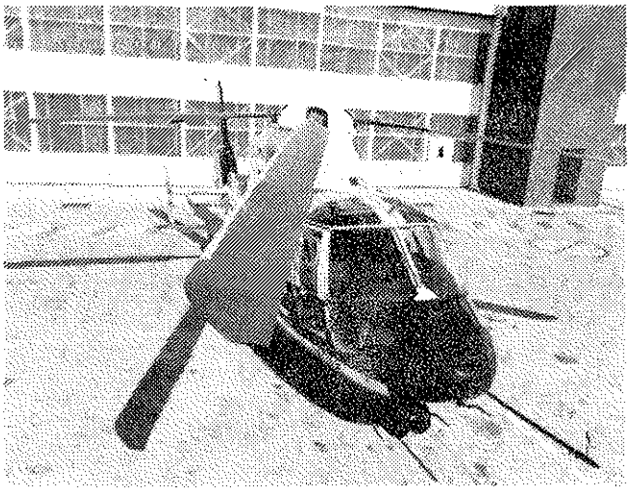

Fig. 13 : SWEPT TIP

4.2.6 Hub Fairing

The main rotor hub with reduced vertical and horizontal dimensions was faired with a shape properly adapted with upper cowlings (see ref. [1]):

From the different configurations flight tested, it was obvious that the fairing efficiency was closely dependent on the absence of internal air circulation.

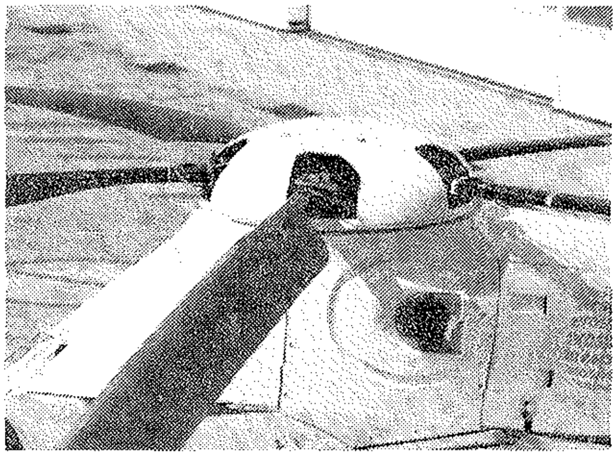

Fig. 14 : HUB FAIRING

The best efficiency was obtained with a perfectly closed fairing.

Since the reliability of an elastic boot is very poor, some relative tightness has been obtained with internal walls, leading to very similar results, for a quite improved reliability.

5. Flight tests

The flight tests started in March 89, after 20 hours of ground test. The purpose of this ground test was to check the behaviour of the new rotor system, from mechanical and dynamic points of view.

This ground test confirmed preliminary tests made on the four bladed rotor: with interbladed damper, ground resonance behaviour was improved, and stability of the drive chain was sufficient, provided a special tuning of the engine governors be made.

The flight tests was first intended to open the flight envelope, and to evaluate the general behaviour of the aircraft from

- Stresses
- Dynamic
- Handling
- Performance

points of view, in order to validate the new concepts, and determine the effect of the new five bladed rotor and of the new upper fairings.

Since no problem arose, a large flight envelope was quickly opened, allowing us to continue flight tests for handling, dynamic (vibration), and aerodynamic measurements.

The next figure shows this flight envelope. It corresponds to the maximum load allowable on the control units.

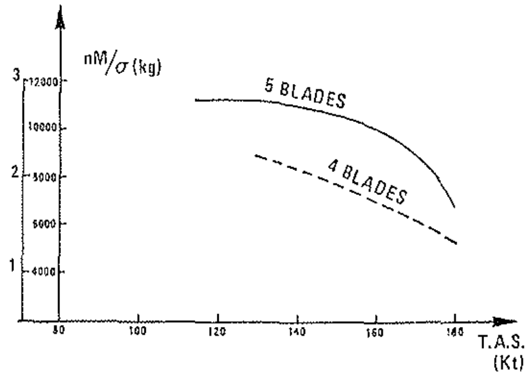

Fig. 15 : FLIGHT ENVELOPE

Next paragraphs will summarize flight results from performance, dynamic and handling points of view.

5.1 Aerodynamic results

The HSD features 2 main differences, compared with standard DAUPHIN:

- The upper fairing, with improved streamline
- The main rotor, now 5 bladed instead of 4

The method used to determine the effect of fairing and 5 blades on performance was based on a theoretical analysis of the forward flight polar with calculation tools formerly validated on other rotors.

A preliminary test, carried out on a standard DAUPHIN before transforming it into HSD, allowed us to establish an accurate reference for the fuselage drag.

Fig. 16 : REFERENCE FLIGHT (4 BLADES)

5.1.1 Fuselage Drag:

With the same method, DGV drag was determined in different configurations.

Since the wind tunnel tests showed that fuselage drag reduction was depending on hub fairing tightness, it was then decided to test the effect of different kinds of fairing on drag.

These tests gave the following drag area:

Standard DAUPHIN	100%
HSD without hub fairing	100%
HSD with fairing	85%

5.1.2 Rotor Performance

At 160 Kt, 3450 Kg, the effect of this 15% drag reduction combined with the effect of the five bladed rotor is a 12 % power saving.

Measurements at different gross weights show that the effect of the fifth blade was depending on the disk loading. Combined with the fuselage drag reduction, the effect on the speed at maximum torque is:

at 3200 Kg: 5 Kt
at 5500 kg: 15 Kt

5.1.3 High Speed DAUPHIN: Maximum speed

This program is now in progress with modification of engines and main gearbox: The aircraft will be equipped with ARRIEL 1X engines allowing a maximum power increased by some 40%. The main gearbox output will be modified in order to withstand this power augmentation.

Taking into account the first flight results, and power available, it will be possible to flight test the rotor in the vicinity of 200 Kt in a real helicopter operating condition (no additional horizontal thrust).

5.2 Dynamic behaviour

Increasing the number of blade is interesting for the engineer from a dynamic standpoint: this leads to a decrease of the rotor dynamic excitation and to an increase of the airframe vibration frequency.

Experimenting a new five bladed rotor on the DAUPHIN fuselage was therefore very interesting since it allowed us to determine 5th blade effect on:

- Rotor excitation
- Suspension behaviour
- Fuselage transmissibility.

5.2.1 Rotor Excitation

On a five bladed rotor, the main dynamic load generating the vibratory level is at 4/rev (in rotating axis). Calculations and tests show that the airloads on the rotor decrease with the number of harmonics.

This has been flight demonstrated. Figure below gives the dynamic moment in 3/rev (365N 4 blades) and in 4/rev (HSD 5 blades):

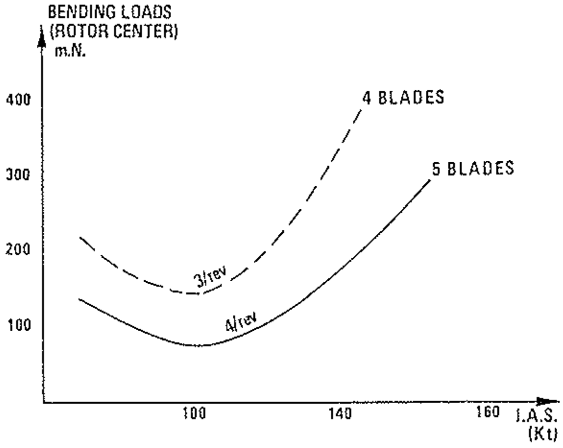

Fig. 17 : DYNAMIC LOADS 4 AND 5 BLADES

5.2.2 Suspension behaviour

On DAUPHIN, the main gearbox suspension is achieved by longitudinal and lateral springs set between the M.G.B. and the fuselage. This sytem operates by dynamic rotation around focus point attachment of the struts.

Reducing the height of the main rotor has reduced the efficiency of the M.G.B. suspension since it has reduced the length between CG of dynamic component and the bottom of M.G.B.:

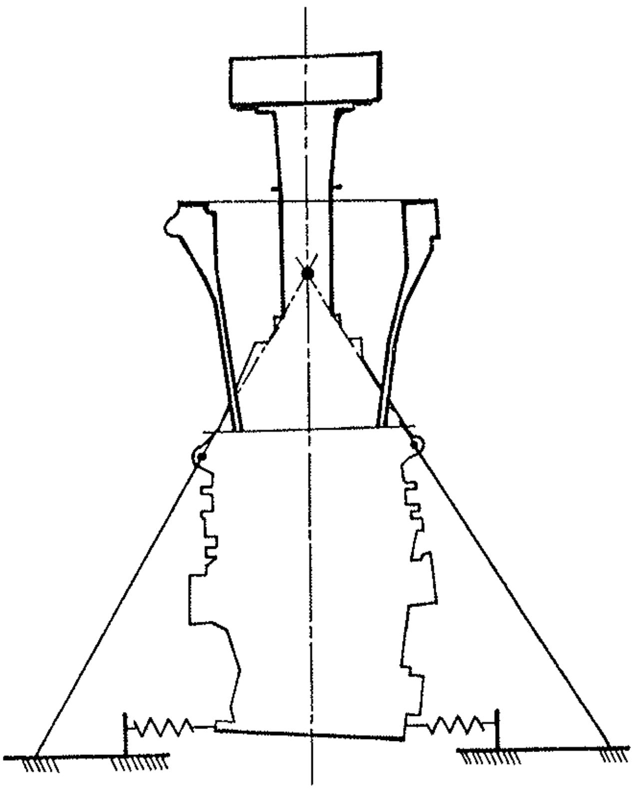

Fig. 18 : SUSPENSION

Furthermore, increasing the number of blades has increased the excitation frequency transmitted to the airframe from 4/rev to 5/rev.

As a consequence the tuning of the suspension was no more adapted to this new rotor.

It was therefore decided to make the flight tests without any suspension (in fact with rigid component instead of the longitudinal and lateral springs).

5.2.3 Fuselage behaviour

Calculation of the fuselage response is more and more difficult when frequency increases. A ground test was carried out in order to determine the effect of higher frequency on the fuselage transmissibility, and effect of the different loads (shear, moment, vertical).

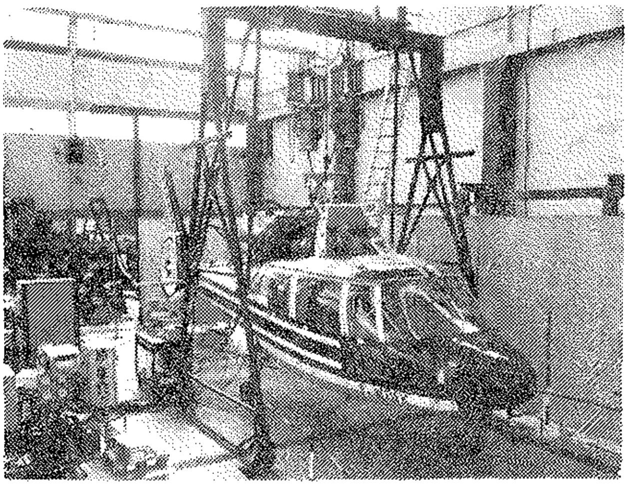

Fig. 19 : VIBRATION TEST

Dynamic loads were introduced at rotor center. The dynamic loads introduced in the fuselage were measured, allowing us to determine the ratio between input (loads) and output (vibratory level).

This test indicates that the main contribution to the vibratory level was due to vertical loads at rotor center.

According to blade frequency calculations, this is explained by 3rd flapping mode proximity (4.8) with 5/rev. With a shorter tip cap, and a longer blade, calculations indicate a lower frequency (4.5): it should be therefore possible to further reduce the vibratory level.

5.2.4 Vibratory level

In accordance with MIL 1427, the effect of increasing frequency from 4/rev to 5/rev is equivalent to a 30% reduction of physiological feeling.

The table below gives a comparison of the vibratory level in forward flight between 365N DAUPHIN and HSD. To take into account the frequency effect, the vibratory level for HSD has been reduced by 30% according to MIL 1427.

(g)	365N (150Kt)	HSD (160Kt)
Suspension	With	Without
Pilot feet	0.25	0.1
Forward seat	0.2 à 0.3	0.2
Rearward seat	0.2 à 0.25	0.15

This table shows that adding a blade has allowed to suppress main gearbox suspension, along with an increased speed, and lower vibration. This should be further improved with an adapted blade tuning.

5.3 Handling qualities

From pilots' point of view (AEROSPATIALE, French C.E.V., M.B.B.), this new rotor shows very good handling qualities. This is characterized by:

- A good manoeuvering stability (the stick moves back when the load factor increases)
- Easy flight conditions at high speed and high load factor (2.2g, 160Kt, 3600Kg)
- It's possible to fly at the maximum speed with autopilot off, and with hands off during several tens of seconds.

The following chart shows an example of longitudinal stability after a longitudinal cyclic input in forward flight. Uncoupling is quite good between the various axes:

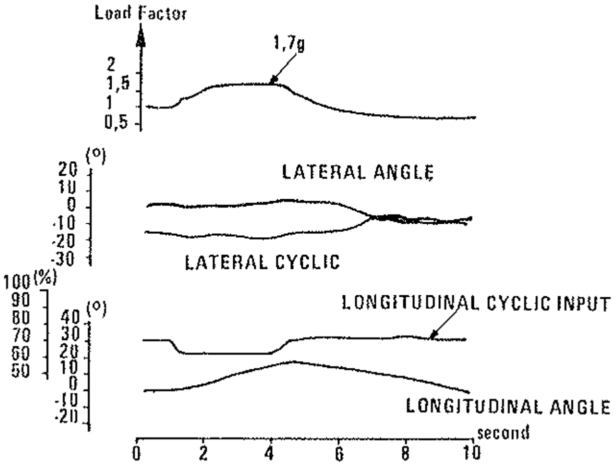

Fig. 20 : UNCOUPLING OF CONTROLS

6 Conclusion

This development of a new compact and lowered main rotor, on a DAUPHIN, is a major step in the research for improved performance.

With the same engines, this new rotor has provided significant improvements regarding:

- Speed or fuel consumption, with a drag area reduced by 15 %
- Vibration, with no more suspension system required
- Handling qualities

Furthermore, this development has given the opportunity to validate new technologies and new concepts such as carbon epoxy-wounded mast.

The next step, now in progress, will allow studies of high speed by increasing the installed power in pure helicopter mode.

References:

[1] - High Speed DAUPHIN Aerodynamics A.CLER 15th European rotorcraft Forum

[2] - A comparison of 4 versus 5 blades K.AMER AHS 89

[3] - Design, Test of Interblade Damper B.GUIMBAL 14th European Rotorcraft Forum