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TAIL ROTOR STUDIES FOR SATISFACTORY PERFORMANCE STRENGTH AND DYNAMIC BEHAVIOUR

by

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1 – ABSTRACT

During the last few years detailed studies have been conducted on several configurations of classical tail rotors in order to improve their general behaviour with reduced weight and production cost.

The paper presented will cover the conceptual design of several versions of two bladed and four bladed classical tail rotors. Flexbeam types, teetered, cantilevered or semi-rigid two bladed rotors have been studied, manufactured and tested. Flexbeams and soft in plane «Triflex» types have been studied for four bladed classical tail rotors.

After a brief review of the theoretical tools available for performance, loads, strength and dynamic behaviour predictions, the presentation covers the test conducted on whirl test stand and in flight.

Problems encountered are briefly analyzed and solutions are presented. Some noise measurements, made during the whirl stand test have been processed and their results are presented.

2– INTRODUCTION

The qualities requested for present and future helicopters, from an operator point of view, are essentially

- Better efficiency
- Improved Security and reliability
- and, last but not least, excellent cost effectiveness.

The civil operator, will normally, be well satisfied if the manufacturer could prove that his helicopter is indeed outstanding on the three above qualities. At the utmost, he may also request a high level of availability, but more or less this fourth request is imbedded in the previous three.

The military operators have their own special requests, depending on the type of missions that they have to fulfill and so they have to accept various types of trade-off. At least, they will request in addition, a low vulnerability and a good crashworthiness behaviour.

One question remains in mind, when one speaks of tail rotors in this general context :

- Is it worth to spend time and money on this «small item» of the helicopter, to improve its general behaviour ?

  A brief set of data can easily illustrate that the answer is yes :

- The number of helicopters crashed due to a failed or impacted (tail rotor) is about 0.15 per 10,000 hours of flight in the accident log book, as compared to a registered total number of .71 per 10,000 hours of flight.
- A tail rotor of improved design can, on a given aircraft (AS 332 for example) reduce, by 36 % the power needed for maximum tail rotor thrust, while improving the maximum thrust by 35 % and cutting the component weight to thrust ratio by 20 %. If no other constraints are encountered (power available, gear box limitation, structural strength of the aircraft), this tail rotor improvement can allow for a substantial increase of the helicopter payload.
- The tail rotor noise represents a significant part in the helicopter acoustic signature at least in one flight path retained by ICAO as a noise certification procedure : the take-off.

During the past five years, Aerospatiale has studied several types of «free» tail rotors which could be fitted on Aircraft of the two-ton and eight-ton categories while concurrently, research has been pursued on the «fan in fin» type tail rotor. This paper presents a limited survey of the work conducted on the «free» tail rotor type. In order to remain in the limited space and time allowed to this lecture the general trends are first of all specified in each chapter and then one or two examples are briefly developed under the following headings :

(a) Two-Bladed (Two-Ton Category) and Four/Five Bladed (Eight-Ton Category) **Concept Studies** for free type tail rotors.

(b) **Aerodynamics and Performance**

The five Bladed composite tail rotor for the AS 332 is taken as an example to illustrate the general trend followed by Aerospatiale in order to increase the figure of merit, and to make good use of the freedom that composite materials offer to the engineer in designing blades with tapered, variable airfoil sections and twist.

(c) **Dynamic behaviour**

The most important problems to be solved are : a **good positioning** of the natural frequencies over the complete pitch range, **acceptable stability margin** and **acceptable stress level** .

Prediction methods and ground test facilities have been developed to provide a tool to the designer. The examples shown deal with the AS 332 composite rotor blades for which a good compromise had to be obtained on pitch-flap coupling effect while taking into account the blade twist, the hub stiffness and the large pitch excursion. A second example is given for the two bladed flexbeam.

(d) **Tail Rotor strength - Material selection**

Three types of rotor are reviewed under this heading :

- The flexbeam four bladed rotor using glass fiber roving laminates for the spar of two opposite blades
- The Triflex hub made of glass filament thread embedded in an elastomeric matrix, which needed the development of special tool to predict its behaviour under flexural and torsional deformations
- The flexbeam two bladed rotor, for which several hub fixtures were studied in order to reduce the critical stress levels.

(e) **Control forces**

For the small size helicopter, the control forces must be low enough to guarantee an acceptable pilotability in case of failure of the single body servo-control unit. For large helicopters one tries also to achieve low control forces during the design phase in order to reduce weight. On the two bladed flexbeam tail rotor, shown as an example, hub tuning weights (Chinese Weights) have been used to reduce these control forces.

(f) **Design**

The six types of tail rotors are briefly reviewed as regards their main technological features. The philosophy followed is to reduce as much as possible the number of parts, to use (wherever possible on a cost effectiveness basis) composite materials and to obtain the best compromise on weight and cost with acceptable strength margin.

(g) **Noise**

Tail rotor noise is shown to be an important part of the overall helicopter noise radiated externally, specifically in the ICAO take-off flight procedure. A brief survey of the work undertaken to better understand the important parameters is given with some preliminary test results on the effect of fin and tail/rotor interaction.

(h) **Comparisons and Conclusions**

The several types of rotors surveyed, are compared in this final section which emphasized the progress also made concurrently, on «Fan in Fin» type tail rotor. There is some evidence that the «Fan in Fin» type may be preferable for medium size helicopters, let us say, up to a maximum take-off weight of about six tons.

3– CONCEPT STUDIES

The tail rotors which will be dealt with in this paper are presented on Figure 1. Studies of the two bladed flexbeam which could fit the «two tons» gross weight class were initiated in 1972. The three types of concept developed for this category differed only by the mode of attachment of the flexbeam on the rotor mast. One of them (teetered rotor) was developed for concrete application to the «Astar» helicopter, the two others for research purposes, using the same flexbeam and blades in order to reduce the research investment cost.

The most simple of them is the cantilever type, with no pitch hinge and no Chinese Weights. But as one can expect it may suffer three types of problems : High stress level in the beam (1P), stability (occurring out of harmonic frequencies) due to the very close coupling between the structure and the tail rotor and high control forces. A pitch hinge (laminated bearing) can relieve the stability problem, a teetered hinge with low spring effect (laminated bearing) can reduce the stress level. Tuning weights (Chinese Weights) as explained in ref. 1, can help decreasing the level of the control forces. If one wants to minimize the difficulties during the development of such a concept with a view to application to a production aircraft, these choices must be made from the beginning. This was the case for the AS 350 helicopter which needed only, during development, a correct adjustment of the pitch flap coupling, of the height of the teetering hinge and a reasonable selection for the two types of hinges (laminated bearings). A limited number of experiments was nevertheless made for research purposes with the two other types and they are briefly covered in the following chapters.

For the «eight tons» gross weight class helicopter, three types of rotor (**Fig. 1**) have also been studied from 1976.

	FLAPPING	LEAD-LAG	PITCH	DESIGN	
TWO-TON CATEGORY	SOFT	STIFF	SOFT	2, 1 CANTILEVER 3, 4 SEMI CANTILEVER 2 TEETERED	2 BLADES 1.86 m.dia C = 185 mm NACA 0012 NO TWIST
EIGHT-TON CATEGORY	HINGED	STIFF ($\omega_T > 1\ \Omega$)	HINGED		5 BLADES 3.04 m.dia C = 200 mm TWIST CAMBERED AIRFOILS
	SOFT	STIFF ($\omega_T > 1\ \Omega$)	STIFF	2 BEAM	4 BLADES 3.04 m.dia C = 227 mm TWIST CAMBERED AIRFOILS
	SOFT	SOFT ($\omega_T < 1\ \Omega$)	SOFT	3 TRIFLEX	

1 CHINESE WEIGHTS
2 ELASTOMERIC BEARING
3 DRY BEARING
4 FLEXIBLE COUPLING

Fig. 1 : FREE TYPES TAIL ROTORS

One of them, the five bladed composite tail rotor with conventional hub, has been selected from the start, to be production fitted on the AS 332 Super-Puma helicopter. The two others-four bladed flexbeam and four bladed Triflex - are research topics, one of them the Triflex still being in course of research.

The objectives set for the «8 tons» category were essentially :

- To improve the performance of the SA 330 tail rotor while keeping the same rotor diameter.
- To use wherever possible, on a cost effective, basis composite materials in order to increase life time.
- To look for a solution which could be fitted to the SA 330 tail structure with minimum parts change.

On the five bladed tail rotor, the main problems encountered from the design stage were linked to a good positioning of the blade natural frequencies and stability.

Natural frequencies are very sensitive to the hub stiffness, the large pitch excursion and the twist of the blade set up for performance purpose. A reduced pitch-flap coupling compatible with the stress level was found, together with a correct hub stiffness to solve the dynamic problems.

The research work on the four bladed flexbeam was aimed at simplifying the design (reduced number of parts), relieving the maintenance cost of the hub, and reducing the component weight. The problem encountered is mainly linked to the **stress level** in the beam.

Two types of beam were evaluated and flown : a simple, rectangular beam in R glass fiber roving with constant section, to provide through flight measurements the data needed for correlation with developed theories. An improved geometry for the beam was then developed and concurrently the influence of the resin impregnation percentage on the beam fatigue behaviour was studied. The stress level was significantly reduced in flight, while the optimized resin impregnation percentage found guarantees a better life time for the beam, but probably not an infinite service life.

The Triflex four bladed tail rotor is a **soft in plane rotor,** strikingly different from the two previous «8 tons category» tail rotors. The four Triflex «arms» integrated with the four blade spars through splicing of the spar rovings with the glass filament threads of the Triflex make a very simple component with a largely reduced number of parts. Strength of the arms and stability of the rotor were the main problems to be solved. A better understanding of the stresses developed through torsional and flexural motions of the Triflex arm was the main effort exercised. As a soft in plane rotor, it needed sufficient structural damping to guarantee a fair stability margin when the rotor is speeding up to its nominal R.P.M.

These problems are now solved and a full scale rotor is presently built for flight tests at the beginning of 1982.

As a summary, for these «8 tons class» tail rotors one can say that the main problems encountered are : stresses, stability, control forces.

They can be classified in the following decreasing order of importance :

5 Bladed classical Hub:
Stability, Strength, Control forces

4 Bladed flexbeam :
Strength, Control forces, Stability

4 Bladed Triflex :
Strength, Stability, Control forces.

4 – AERODYNAMICS AND PERFORMANCE

Aerodynamics and performance of tail rotors have been presented elsewhere in outstanding articles (see ref. 1, 2). We will underline here only a few features and illustrate how they were applied and with what success to the 5 bladed composite tail rotor of the AS 332.

In addition to its function of providing equilibrium in yaw of the main rotor maximum torque, the tail rotor has to counteract lateral wind speeds of 17 kts for civil application and up to 50 kts, on some requirement, for military applications. This demand for 30 % to sometimes 100 % more thrust than that just needed to equilibrate maximum main rotor torque. Reverse thrust is also needed for manoeuvre sometimes reaching up to 30 or 50 % of the maximum tail rotor thrust. In addition the tail rotor participates to the yaw stability of the aircraft, which would be very poor without this device.

Most of the manufacturers have used «Pushers» type rotor for many years, in order to prevent the accelerated airflow to blow on the tail fin. Once these specifications have been set up, it remains to design a rotor which will be as efficient and as light as possible. This means, for a given rotor diameter, a low solidity, a high mean lift coefficient in order to reduce the blade chord and to decrease blade weight. For external noise limitation, the tip speed must at the same time be limited to a maximum value of 200 to 220 m/sec. One understands, then, that all the effort will be exercised on the airfoil sections characteristics and on the blade twist in order to obtain a rotor figure of merit as high as possible.

Airfoil sections aerodynamic characteristics are presented on **Fig. 2**. As for the main rotor, it is of paramount importance to have a high C_L max for the inboard airfoil sections up to a Mach Number of 0.5 and a high drag divergence Mach Number for the outboard airfoil sections with a reduced relative thickness for noise control.

Fig. 2 shows that large increase on these two items have already been obtained by using a new airfoil family. Progress is still possible and new airfoils are being developed (see research goals - **Fig. 2**) at present with the C_L max and M_{DD} shown.

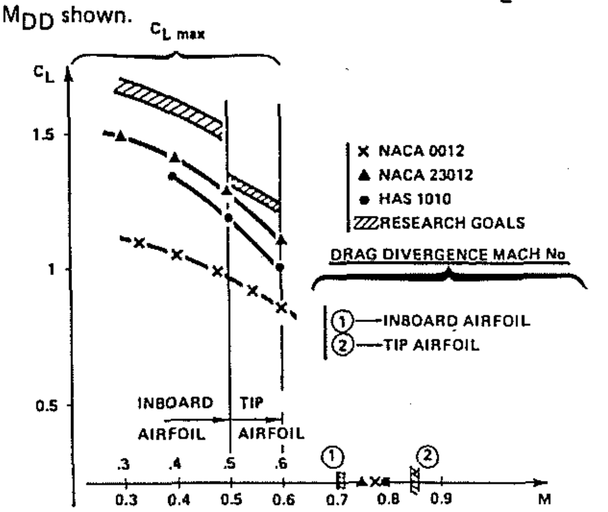

Fig. 2 : AIRFOIL SECTION AERODYNAMIC CHARACTERISTICS

Blade twist has a large influence on rotor performance as shown on **Fig. 3**. The maximum thrust has been increased by 3 % and the power needed decreased by 10 % with a – 10.9 degree twist. The combined effect of airfoil sections and twist introduced on the AS 332 provides a large increase in figure of merit as shown on **Fig. 4** which compares SA 330 and AS 332 tail rotors.

It should also be noted that the maximum value of the mean lift rotor coefficient has been largely increased, at the same time, with a much higher figure of merit. The general performance of the AS 332 Helicopter tail rotor is compared

GEOMETRICAL DEFINITION

	332 COMPOSITE BLADES
DIAMETER (m)	3.04
CHORD (m)	.2
U_T (m/s)	204
BLADES	5
AIRFOIL	NACA 23012 HAS 1010
TWIST (d°)	– 10.9

IMPROVEMENTS DUE TO TWIST

ON MAXIMUM THRUST → 3 %
ON POWER → 10 %
ON TAKE-OFF WEIGHT (S.L.) -50 Kg

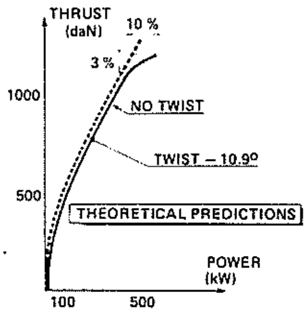

Fig. 3 : BLADE TWIST INFLUENCE ON PERFORMANCE

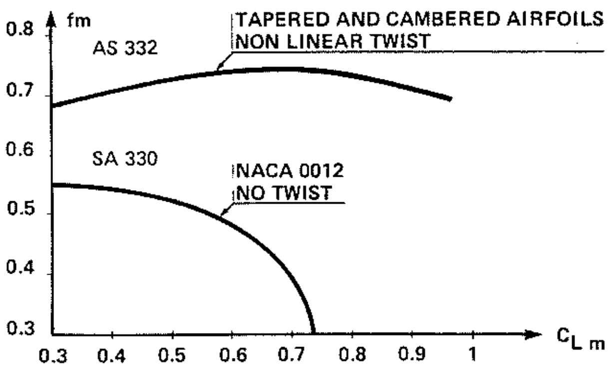

Fig. 4 : TAIL ROTOR FIGURE OF MERIT

on **Fig. 5** to the SA 330 performance. A very large improvement has been obtained both on maximum thrust and on needed power.

GEOMETRICAL DEFINITION

	330	332 COMPOSITE BLADES
DIAMETER (m)	3.04	3.04
CHORD (m)	.186	.2
U_T (m/s)	204	204
BLADES	5	5
AIRFOIL	NACA 0012	NACA 23012 HAS 1010
TWIST (d°)	0	– 10.9

ROTOR PERFORMANCE

	330	332	IMPROVEMENTS 332 / 330
MAX THRUST (daN)	900	1220	35 %
MAX POWER (kW)	625	460	36 %
Czm MAX	.75	.93	24 %
FIG. OF MERIT	.55	.765	39 %

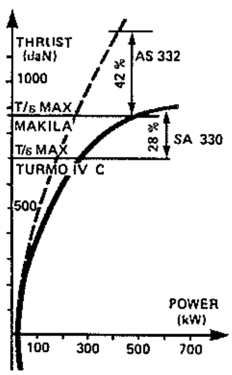

Fig. 5 : TAIL ROTOR PERFORMANCE SA 330 / AS 332

5– DYNAMIC BEHAVIOUR

The dynamic behaviour of rotors has been studied theoretically and experimentally for many years at Aerospatiale. General methods have been developed to predict coupled natural frequencies and mode shapes taking into account all the technological details of the blades, control system and hub characteristics.

Quasi steady Aerodynamic forces have also been introduced in order to take into account the modal aerodynamic damping. The steady state blade and hub deformations are computed by a **non linearized** theory which can cope with large deformations. The natural modes, shapes and frequencies are computed by a linear theory, where the variables (deflections, forces and moments ...) are only linearized around their steady state values.

Paper No 8 presented at this forum gives a broad outline of the general approach to solve the complete set of partial differential equations which governs the rotor behaviour. The method is of sufficient general nature to address the three types of problems : Natural frequencies and mode shapes, stability in hover conditions, rotor responses to airloads.

In order to compare these theoretical results with experimental data, whirltest stands have been especially equipped with hydraulic exciters (**Fig. 6**) to shake the rotor blades at the correct phase, with a numerical data processing and control unit which allows for real time data processing using «Fast Fourier Transformations» of the strain gauges located on the blades. Blades coupled natural frequencies and even mode shapes if the blades are correctly equipped, can be obtained from this procedure. Micro-sweeping the excitation frequency around a natural frequency, can also provide a fair idea of the mode damping. Reference 3 provides much deeper information on this general experimental approach.

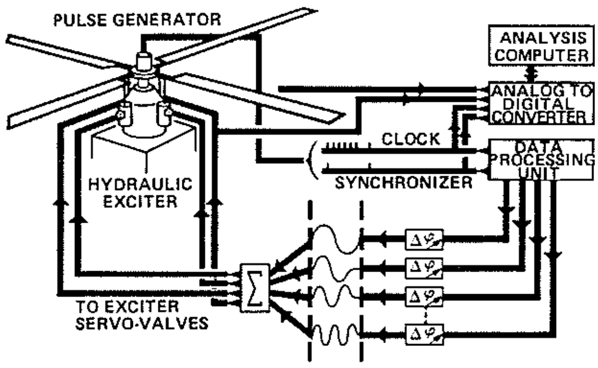

Fig. 6 : DYNAMIC TESTS ON WHIRL TEST STAND

To illustrate the applications of theory and experiments to the tail rotor problems, two examples are given hereunder for the AS 332 tail rotor. **Fig. 7** presents the evolution of blade natural frequencies versus pitch, and hub stiffness. One can see that large variations of mode frequencies are experienced both as a function of pitch and hub stiffness. This can easily place a natural mode frequency coincident on a rotor R.P.M. harmonic or very close to an other mode frequency thus creating a difficult situation. **Fig. 8** shows the influence of twist and pitch flap coupling on the second mode natural frequency and damping. The twist and the coupling effect both have a tendency to destabilize the blade.

The AS 332 tail rotor solution was found by decreasing the coupling effect K from 1 to about 0.7, while keeping the same twist set up for performance purposes. **Fig. 9** shows the final solution retained. A good correlation is obtained between measurements and computations (better than

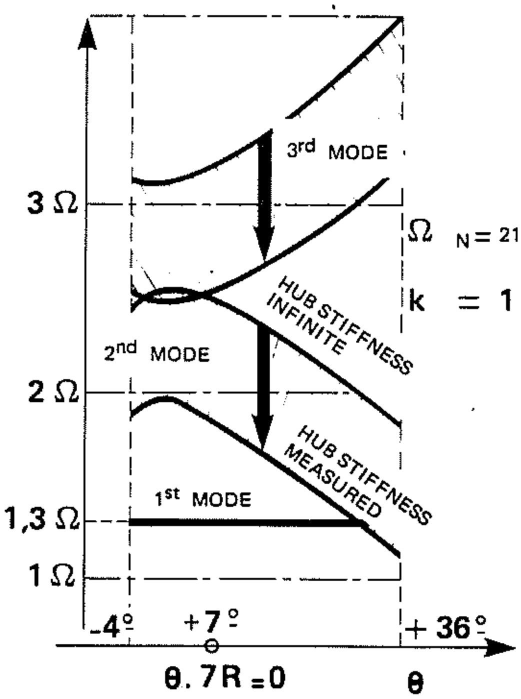

Fig. 7 : INFLUENCE OF PITCH AND HUB STIFFNESS ON NATURAL FREQUENCIES

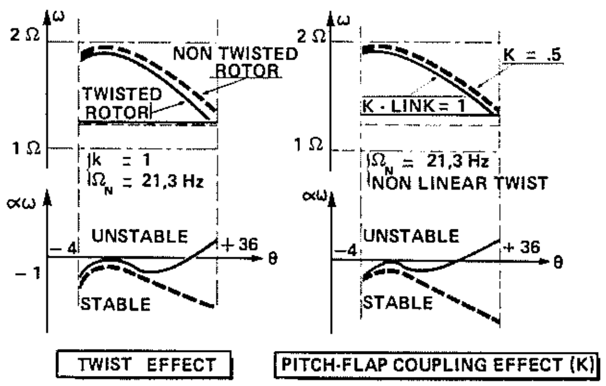

Fig. 8 : INFLUENCE OF TWIST AND PITCH-FLAP COUPLING ON NATURAL FREQUENCIES AND DAMPING

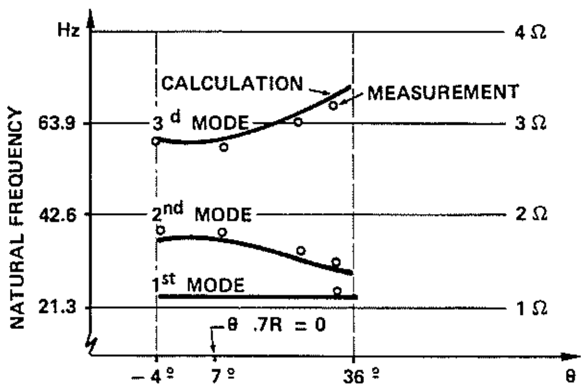

Fig. 9 : FIVE BLADED ROTOR NATURAL FREQUENCIES. COMPUTATION/TEST

2 Hz). The second mode (lead lag type) has a measured critical damping of 12 %o, about the same as for the SA 330 metal blades. The third mode which cut through the 3 Ω frequency at reduced pitch has sufficient damping not to raise any problem.

The second example concerns the two bladed flexbeam rotor. **Fig. 10** illustrates the effect of the fixture spring constant between beam and rotor mast on the natural mode frequencies (symmetrical and anti symmetrical modes). Pitch effect introduces large variations in natural frequencies especially on the symmetrical lead lag mode which can be strongly excited by the 1P loading.

One must set this mode as far away as possible to the one per rev. excitation frequency, which is the case for the three type of beam-to-mast attachment. The torsion mode and the second flap (symmetrical and anti symmetrical) are located between 2 and 3 per rev and create no problem.

Many studies have been conducted on the dynamic behaviour of the Triflex tail rotor. They are given as examples in paper No 8, presented at this forum (ref. 4).

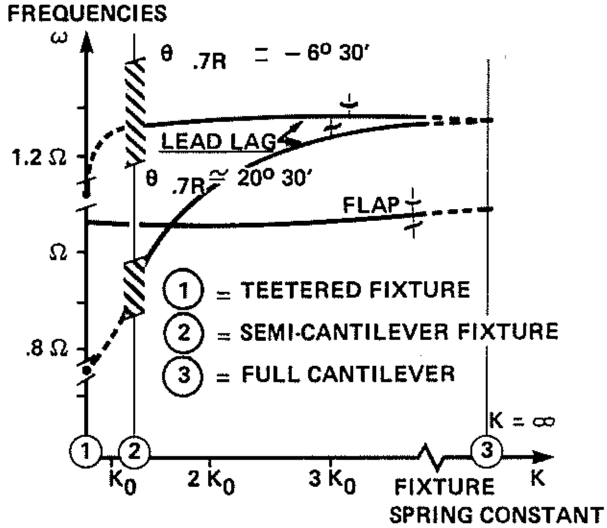

Fig. 10 : FIXTURE SPRING EFFECT ON TWO BLADED FLEXBEAM N.F.

6– TAIL ROTOR STRENGTH – MATERIAL SELECTION

The life time of the tail rotor component is very important from the operational point of view, since it has direct impact on the maintenance cost and on the availability of the helicopter for the operator. Aerospatiale tries to design for infinite life time in order to decrease the maintenance burden and cost of operations of its helicopters. The effort made on tail rotor will be illustrated by the research studies conducted on the four bladed flexbeam and Triflex and on the two bladed flexbeam tail rotor.

6.1 – Four bladed flexbeam

On the four bladed flexbeam rotor, the most important item as regards strength is the **beam**. After a few flight tests of a rotor fitted with a constant, rectangular section R glass Roving beam, conducted in order to get the loading data and to adapt theoretical prediction methods to this particular concept, Aerospatiale engaged a research study to design a beam which could withstand the flexural and torsional moment distributions with an **improved stress distribution** and an improved **fatigue behaviour of the flexbeam material**.

The constraints set were essentially :

. Ease of production (simple design)
. Flexural stiffness (in flap and lead lag) set by a good positioning of the mode natural frequencies
. Maximum level of dynamic stresses set between one half and one third of the mean fatigue limit for the material
. Fibers continuity to be ensured from beam to blade which imposes geometrical limitations on the beam section size.
. Length of torsible beam element limited to .37R to provide a sufficient aerodynamic efficiency.
. Low torsion stiffness to reduce rotor control forces.

The parametric studies engaged showed that a rectangular cross-section beam of constant width, with local reinforcement in flap toward the rotor axis as shown in **Fig. 11**, achieved the best compromise. Laboratory tests conducted on a full size beam loaded in flexion with centrifugal forces applied showed that the normal stress distribution in the reinforcement area was approximately uniform.

From the point of view of the **material** choice, three criteria are to be used :

– High fatigue resistance characteristics
– High $\frac{E}{G}$ to reduce the rotor control forces
– Correct choice of E and f (mean material fatigue life) to obtain the best life time.

A brief study showed that the weight and torsional stiffness of the beam have negligible effect on the dynamic characteristics of the blade in flexion and on the loads. Therefore the normal stresses on the beam are to a first order independant of both the torsional characteristics and the weight of the beam. «Equivalent» beams can then be defined, with different materials, providing the same flexural rigidities in flap and lead lag and they can be compared on the basis of fatigue life time. It turns out that this approach leads to defining a criterion for the beam material choice : The $\frac{E^{3/4}}{f}$ value must be **as low as possible** in order to obtain the best fatigue behaviour.

Fig. 11 shows the variation of $\frac{E^{3/4}}{f}$ as a function of the unidirectional composite material type and of the % of resin impregnation for the test coupon. The choice made for the second beam production was «R glass» material with a larger impregnation rate than currently used. About, 15 % improvement in the $\frac{E^{3/4}}{f}$ has been obtained by this procedure, most of this gain resulting from the elasticity modulus drop.

The stresses reduction obtained in flight by this new beam are presented on figure 12. A 30 % stress level reduction was obtained in the flight envelope tested up to 240 km/h.

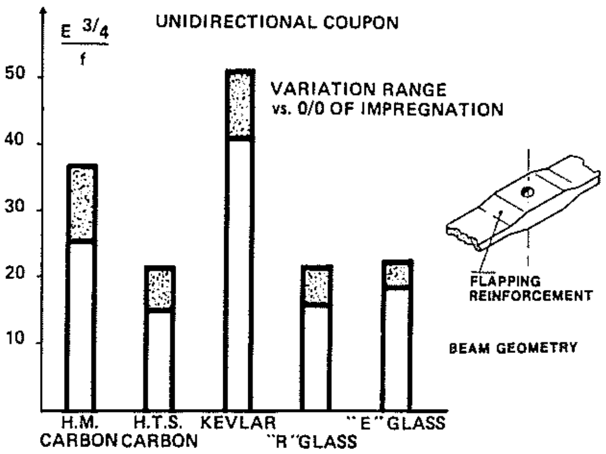

Fig. 11 : FLEXBEAM STRENGTH CHARACTERISTICS $\frac{E^{3/4}}{f}$, BLADE SHAPE

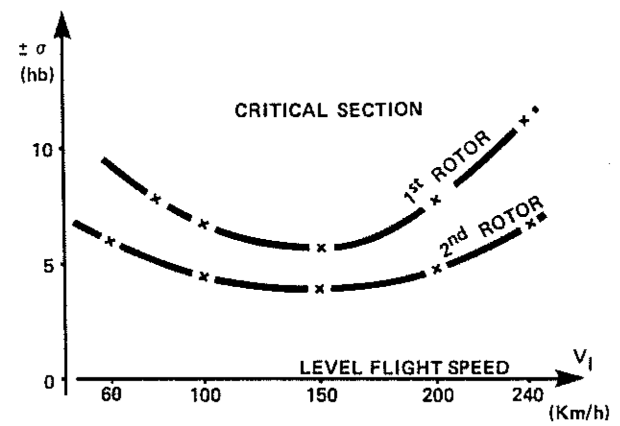

Fig. 12 : FOUR BLADED FLEXBEAM : CRITICAL STRESSES VERSUS FLIGHT SPEED

6.2 – Triflex tail rotor

The rotor arms are made of deformable elements which allow to fix the blades on the hub and to provide motion of the blade in flap, lead lag and pitch. The deformable element is made of a bundle of roving threads, in R glass and epoxy resin, of small cross-section (**Fig. 13**), with a cantilever attachment on hub side and a spliced attachment, with the blade spar on the outer part. To provide damping the roving thread bundle is embedded in an elastomeric matrix which can be cast in a mold, after fabrication of the R roving threads structure.

The separation of the strength element in multiple threads of small cross-section provides a low torsional rigidity which allows using conventional servo control unit for pitch control of the blade. The flexural rigidity in flap places the Triflex rotor in the category of articulated rotor with spring constant in flap (first flapping mode between 1.06 and 1.1Ω) The natural frequency in lead lag characterizes a stiff but subcritical rotor (ω_T > 0.5 Ω). Taking into account the coupling effects, the lead lag damping is sufficient to provide a good behaviour when running up the rotor to its nominal R.P.M.

The following phenomena characterizes the sizing of the Triflex deformable elements :

– Static strength when the rotor is at stop (The critical part is the elastomeric matrix)

- Fatigue strength of the roving threads subjected to variations of the axial loads and of the flexural and torsional loads.

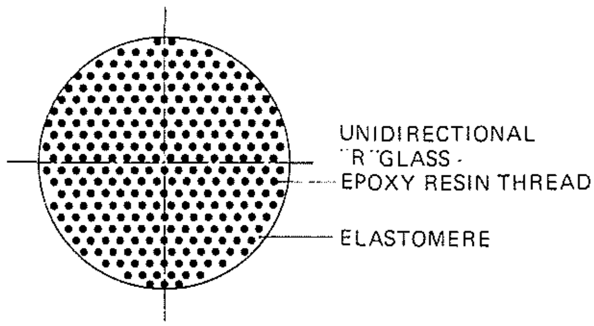

Fig. 13 : TRIFLEX ELEMENT

The stress computations under load, when one neglects the elastomer , can be made exactly by classical material strength theory. When the flexural loads are large, these computations show that some of the threads are under crushing (compression) loads and the thread deformations, similar to buckling deformations, can be important.

The elastomere is then strongly strained. Sizing must be made to withstand this type of loading. In order to correlate theory with experiment a Triflex has been equipped with strain gauges located on the threads, before applying the elastomere casting process.

The type of correlation obtained is illustrated in **Fig. 14** which shows axial stresses under application of a flexural moment and the centrifugal force on a cantilever circular cross-section Triflex arm, where roving threads are equipped with three gauges per thread in order to provide the axial stress and the flexural stress. A fair correlation is obtained in axial stresses when the flexural moment applied (M_0) is not too high. Under the 3 M_0 loading the tension part of the beam is slightly under predicted by the theory and compression stresses appear. In the computation, the

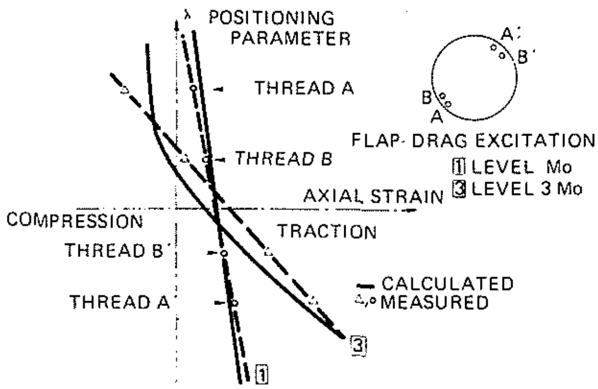

Fig. 14 : NORMAL STRESSES GENERATED BY FLEXURE

elastomere strength is neglected in this theory so that the thread are supposed to buckle when a small compression load is applied. The experiment shows, that it is not the case when the elastomere is taken into account so that the element behaves better than the theory predicts. **Fig. 15** provides the correlation in both normal and flexural stresses on the thread when the element is subjected to a torsional deformation.

To conclude on this Triflex element strength chapter, one has to point out that the philosophy of running fatigue test on this type of component had to be reviewed. When a part is designed to withstand the loading from the blade at rest and the dynamic loading in flight, with the necessary safety margins, it is not possible to run the fatigue test at much higher loading to obtain fatigue data within a short time because these out-of-design loadings can damage the component. The fatigue test will then have to last longer.

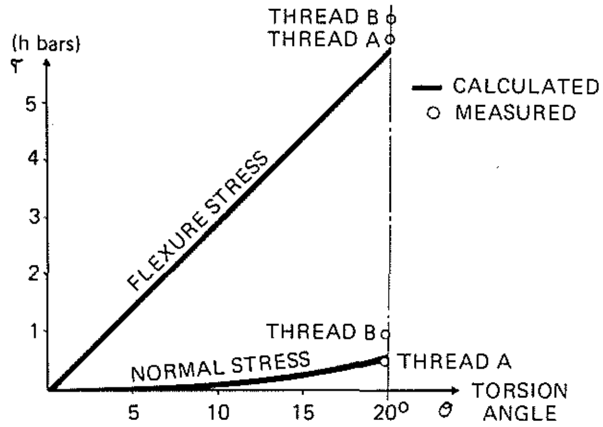

Fig. 15 : NORMAL STRESSES GENERATED BY TORSION

6.3 — Two bladed flexbeam strength

As pointed out previously, three types of beam attachment to the rotor mast have been evaluated. Flight tests have been conducted on the three types in order to evaluate the relief that can be obtained from the cantilever type to the semi-cantilever type and finally to the teetered rotor with low spring constant (laminated bearing). **Fig. 16** presents the data obtained in flight for flapping flexural moments on the beam at the critical section, as a function of test speeds.

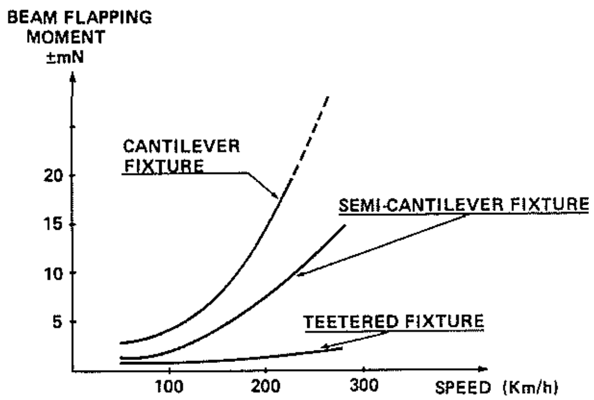

Fig. 16 : TWO BLADED-FLEXBEAM FLAPPING MOMENT.

Stresses experienced by the beam lead to an infinite life time on the teetered version to a limited life time on the semi cantilever type and to limit severely the flight envelope on the cantilever version.

7– CONTROL FORCES

The control forces problem is illustrated on **Fig. 17** for the two bladed flexbeam rotor.

The pitch link force needed to balance the blade in pitch is broken down into four terms :

1 Blade zero-pitch return

2 Beam torsional stiffness and centrifugal return

3 Aerodynamic moment

4 Laminated bearing spring effect.

In order to reduce the individual contribution of these moments to the pitch link force, the following design steps were taken :

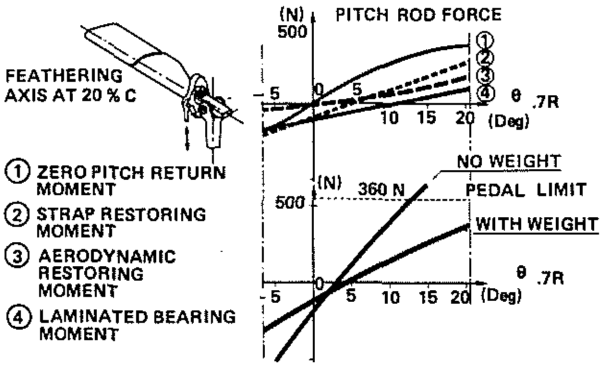

Fig. 17 : CONTROL FORCES ON THE TWO BLADED FLEXBEAM ROTOR

- The beam has a built-in linear twist of about 10° between mast attachment and .29 R.
- The laminated pitch bearing is set at a 10 degree pitch.
- The pitch axis was located at 20 % of the blade chord which represented the best compromise between aerodynamic moment, inertia moment (CG at ≃ 30 %) and technological constraints.

The resulting pitch link force as a function of pitch setting is presented on the bottom of **Fig. 17.** In spite of the previous design choices, the certification requirement of maximum control force on the pedal of 360 Newtons (case of single body servo-control failure) could not be met in the full pitch range of the flexbeam rotor.

«Chinese Weights» located at the pitch link rod level, were then used to provide through their centrifugal forces a torque component in pitch which decreased the pitch link forces as shown on **Fig. 17.** The localisation and weight adjustment of these «Chinese Weights» were optimized in flight, in such a way that a sufficient margin would be provided for pedal force. In addition they were set to nullify the pedal force in fly over at the refuge speed.

8– TECHNOLOGY

The technological objectives set for the «two-tons» and for the «eight tons» tail rotor categories tail rotors (are essentially different : Economy for the first category and high overall performance for the second.

The «eight tons» category tail rotors (Fig. 18 - 19 - 20) make use of the most recent technology for the three types of rotors :

(1) The skins are made of high modulus carbon and high tensile strength carbon where needed, using ± 45° and 0° oriented plies. The outer skin is made of glass fiber to improve impact resistance.

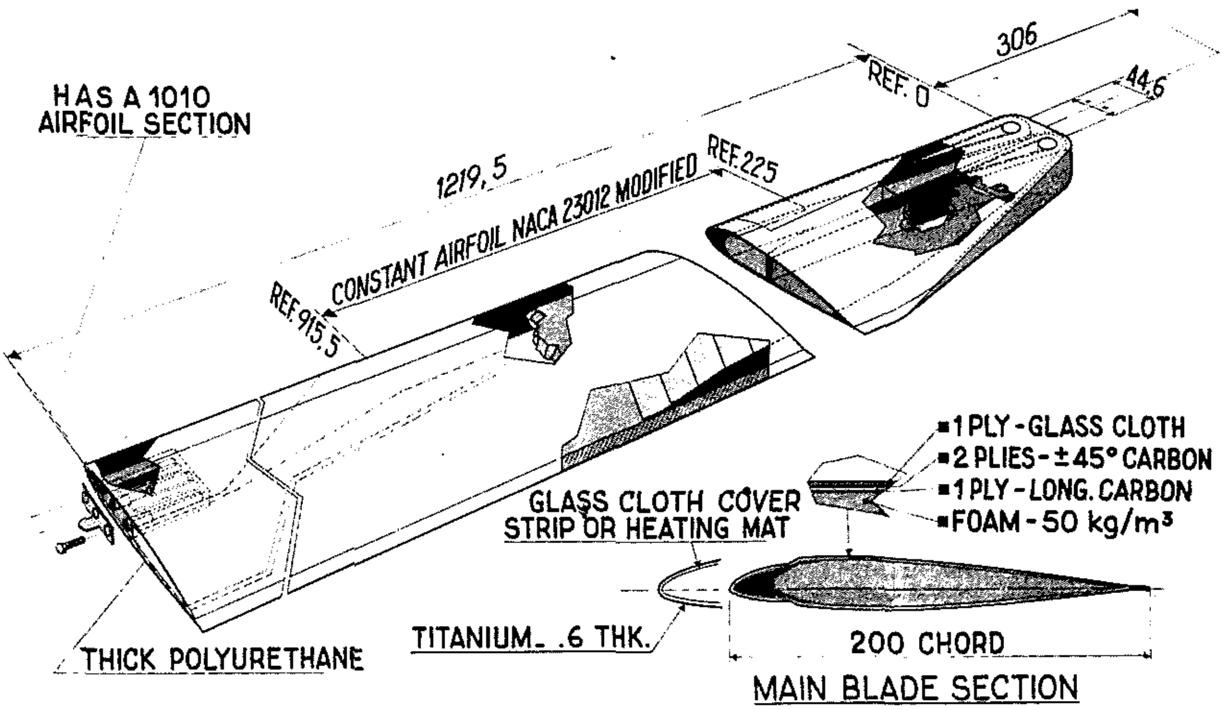

Fig. 18 : AS 332 COMPOSITE BLADE TECHNOLOGY

(2) The spar is in R fiber glass roving.

(3) The filling consists of low density foams of 50 to 80 kg/m3.

This technology provides a correct dynamic behaviour, reduced pitch control forces and good strength characteristics because it leads to very good stiffness to weight ratio.

Particular features of the three types of blades are essentially :

(1) A titanium erosion strip on the five composite blade rotor (**Fig. 18**) with an additional polyurethane treatment on the blade lower surface at the tip.

The leading edge erosion strip is connected to the metallic hub in order to provide good electrical bonding to prevent static charges build-up.

(2) The cuff, which is attached to the pitch rod and imparts the pitch motion to the blade, is a stiff structure integrally linked to the blade skin on the flexbeam four bladed rotor (**Fig. 19**) and on the Triflex rotor (**Fig. 20**).

(3) The spar of the flexbeam rotor is made integral with the beam (**Fig. 19**).

For the Triflex rotor the junction between the arm and the beam is provided by a spliced attachment (**Fig. 20**).

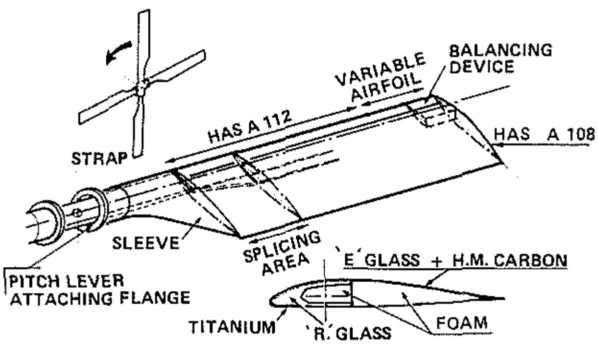

Fig. 19 : FOUR BLADED FLEXBEAM ROTOR TECHNOLOGY

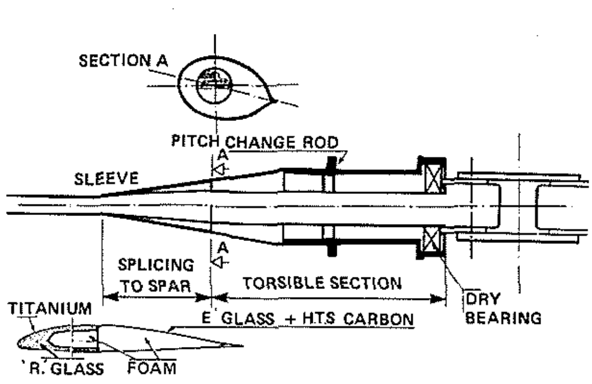

Fig. 20 : TRIFLEX ROTOR TECHNOLOGY

In the «two tons» **category** tail rotors, the materials used are essentially R glass rovings for the beam and spar and E glass fabric for the skins, with a low density foam filler.

Fig. 21 shows the principles of two types of beam to mast attachment. The see-saw version (teetered version) presented on the right hand side has four laminated bearings : two conical for the teetering hinge and two cylindrical or spherical (most recent version) for the pitch hinges of the blades. The life time of these bearings being still limited, some research is presently made to improve their fatigue behaviour.

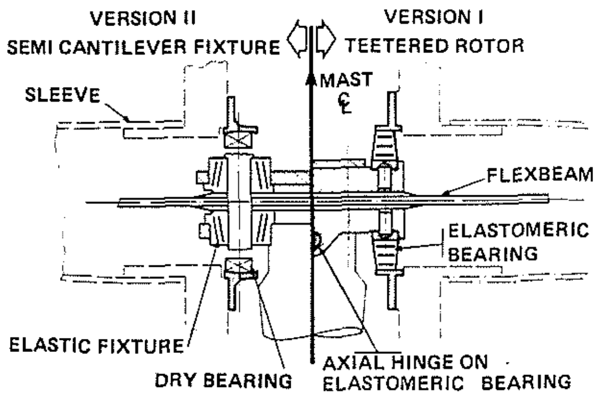

Fig. 21 : TWO BLADED FLEXBEAM. HUB PRINCIPLES

The semi cantilever version which was a research topic presented on the left hand side of **Fig. 21**, uses four conical laminated bearings and two dry bearings for the pitch hinges.

Fig. 22 illustrates the technology used for the blades and beam. The cuff, integral part with the blade skin, is stabilized by composite stiffeners and low density foam. The beam which is integrally produced with the blade spar is coupled to the blade skin by a glass fabric packer and a wrapping of E glass fabric. Two devices have been developed for tuning the blades chordwise and spanwise. One on the center part of the hub and the second (span) on the tip of the blades.

9 - NOISE

This topic has been a specific subject for several conferences on tail rotors (ref. 5, 6). The authors would only like to underline that careful choices should be made at the design stage of a tail rotor, bearing the external noise problem in mind.

Shown on **Fig. 23** is a narrow band analysis of a helicopter external noise recording taken during a take-off which follow the ICAO recommended procedure (Annex 16 - Chapter 9). It does show that tail rotor noise has a significant influence on the overall noise of the helicopter. Let us say, to be specific, that if one wants to reduce the overall noise by two or three decibels, this would be possible only if the **tail rotor noise** is first decreased.

Aerospatiale has recently built a simple and low cost free field test facility to obtain some data on interaction effects of the tail unit on the tail rotor noise. Calibration of this

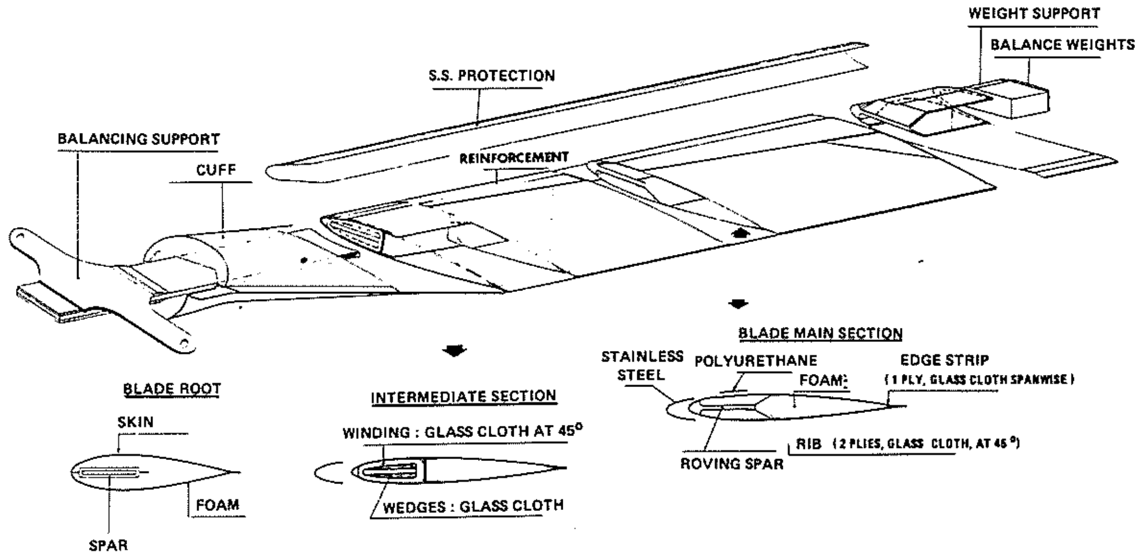

Fig. 22 : TWO BLADED FLEXBEAM TECHNOLOGY

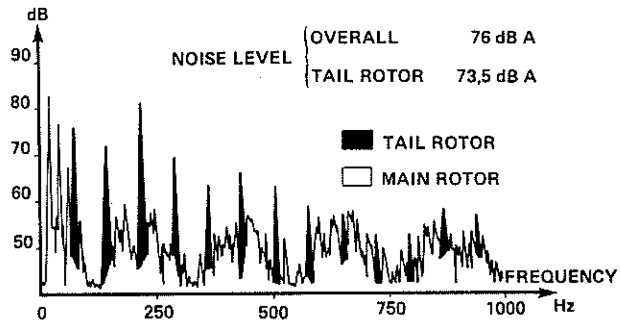

Fig. 23 : IMPORTANCE OF TAIL ROTOR NOISE IN HELICOPTER RADIATION

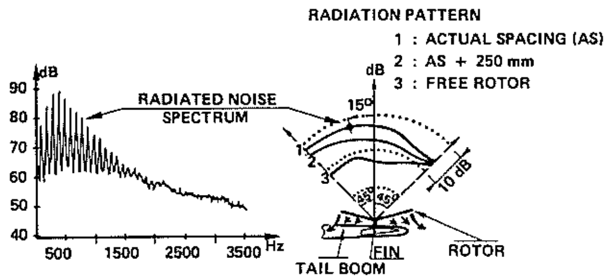

Fig. 25 : TAIL BOOM AND FIN INTERACTION EFFECT ON NOISE

test facility has been completed (ground effects as shown on **Fig. 24**). Preliminary results are presented on **Fig. 25**, where the spacing between rotor and tail unit has been varied. One can notice that significant improvements can be obtained if noise is indeed taken into account from the start of the design.

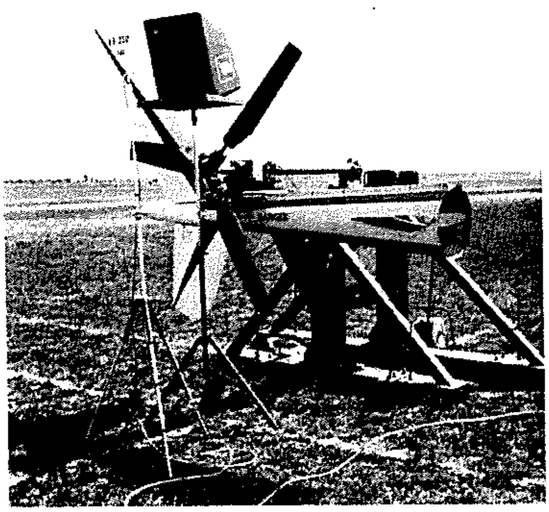

Fig. 24 : TAIL ROTOR TEST FACILITY

10– COMPARISONS AND CONCLUDING REMARKS

Fig. 26 and **27** provides comparisons between several types of conventional tail rotors surveyed in the «two tons» and «eight tons» helicopter categories. In the «two tons class», the Alouette type tail rotor, fully articulated in flap and pitch and fitted with metallic blades, has been selected for comparison. The new technology rotors are able to reduce, the number of parts to a large extent. The see-saw type of attachment allows for an infinite life span for blades and beam, a highly reduced manufacturing cost , it also cuts the maintenance burden by more than a factor of two.

TAIL ROTOR (2 BLADES)	BLADE LIFE TIME Hr	NUMBER OF PARTS (%)	WEIGHT (%)	MANUFACTURING COST (%)	MAINTENANCE (%)
CONVENTIONAL – ALOUETTE TYPE	2500	100	100	100	100
NEW TECHNOLOGY – TEETERED ATTACHMENT (AS 350)	∞	35	75	30	45
– CANTILEVER ATTACHMENT	LIMITED*	30	75	TO BE DEFINED	
– SEMI CANTILEVER	LIMITED*	38	75		

* WITH SAME ROTOR AS FOR AS 350

Fig. 26 : COMPARISON FLEXBEAM T.R. / ARTICULATED TAIL ROTOR

The cantilever and semi cantilever attachment types, which had to use, for research cost limitation reasons, the same beam and blades as in the see-saw version, have a limited life time on the beam. If new beam and blades were to be defined for the semi cantilever attachment type there are good chances that an infinite life time could be obtained at the expense of a slight weight increase. The cantilever attachment type presented problems of high flexural stresses on the beam which did not allow coverage of the AS 350 entire flight envelope. A better design would allow for some improvement, taking into account the work already done on the four-blade flexbeam, but with smaller chances to reach an infinite life time for the blades and beam assembly, unless larger weight penalities are accepted.

TAIL ROTOR	BLADE LIFE TIME (H)	PUSH ROD FORCE (%)	NUMBER OF PARTS (%)	WEIGHT / MAX. THRUST (%)	MANUFACTURING COST (%)	MAINTENANCE (%)
CONVENTIONAL (5 BLADES)						
- SA 330	6600	100	100	100	100	100
- AS 332	∞	125	100	80	100	90
NEW TECHNOLOGY (4 BLADES)						
- FLEXBEAM	LIMITED	440	40	55	40	50
- TRIFLEX	AIMED AT ∞	190	40	55	40	50

INCLUDING BLADES, HUB, SHAFT ...

Fig. 27 : «8 TON CLASS» HELICOPTER TAIL ROTOR COMPARISON

The comparisons for the «eight tons» helicopter category tail rotors (**Fig. 27**) show the large improvements achieved on the AS 332 composite blades concerning life time, weight to maximum thrust and maintenance. The new technology hub and blades present larger improvements in reduction of the number of parts, weight to maximum thrust and manufacturing costs.

But these improvements are at the expense of larger control forces and limited life time for the flexbeam. They remain to be test proved in flight for the Triflex rotor.

Before closing this paper on tail rotors, it is important to underline that progress has also been made on the «fan in fin» tail rotor version, as pointed out in a recent paper given *in May 1981 at the AHS manufacturer's panel (ref. 7).* The use of better airfoil sections, improved duct geometry new technology based upon extensive application of composite materials, allowed for improvements in rotor efficiency, weight and cost. This makes the above concept particularly attractive for small or medium size helicopters, let ut say up to 6 tons gross weight.

When one adds other operational advantages as :

- reduced accident rate resulting from protection of the rotor by the fin.
- better availability.
- less vulnerability resulting from a larger number of blades.
- reduced external noise (**Fig. 28** and **29**) compared to the classical tail rotors, one thinks that this particular concept of the «fan in fin» tail rotor has again a very good future.

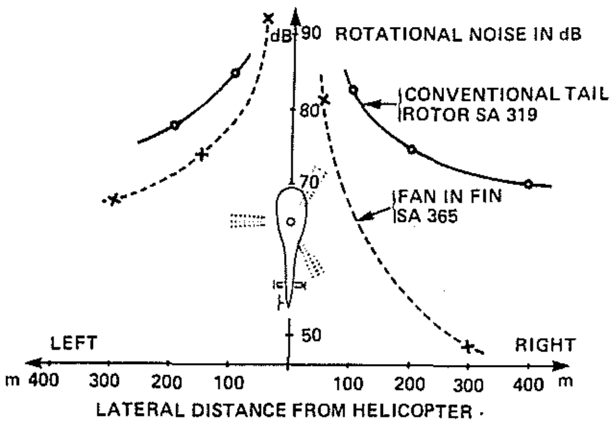

Fig. 28 : EXTERNAL NOISE COMPARISON : TAIL ROTOR / FAN-IN-FIN

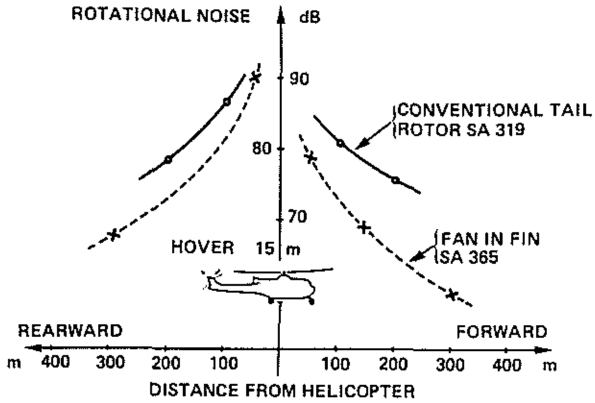

Fig. 29 : EXTERNAL NOISE COMPARISON

LIST OF REFERENCES

Ref. 1 C.V. COOK. «*A review of tail rotor design and performance*» - Vertica vol. 2 - p.p. 163 - 181. Pergamon Press

Ref. 2 R.R. Lynn and other. «Tail Rotor Design. Part 1 - Aerodynamics» - 25th AHS Forum. May 1969

Ref. 3 J.P. COSTON. «Methods of digital signal analysis applied to the study of dynamic systems in helicopters». Paper 48. Fifth European Rotorcraft and Powered Lift Aircraft Forum.

Ref. 4 J.P. LEFRANCQ - B. MASURE. «A complete method for computation of blade mode characteristics and responses in forward flight». Seventh European Rotorcraft and Powered Lift Aircraft Forum.

Ref. 5 John LEVERTON - J.S. POLLARD - C.R. WILLS «Main Rotor WAKE/TAIL ROTOR Interaction». Sixth European Rotorcraft and Powered Lift Aircraft Forum

Ref. 6 M. LAUDIEN. «Main and Tail Rotor Interaction Noise during Hover and Low Speed Conditions» (Paper 18) - Second European Rotorcraft and Powered Lift Aircraft Forum

Ref. 7 R. MOUILLE. «Futur Helicopters and New Technologies». Paper presented at the Manufacturers' Panel. New Orleans, May 1981.