NINETEENTH EUROPEAN ROTORCRAFT FORUM

Paper n° D4

" A NEW GENERATION OF FENESTRON FAN-IN-FIN TAIL ROTOR ON EC 135 "

by

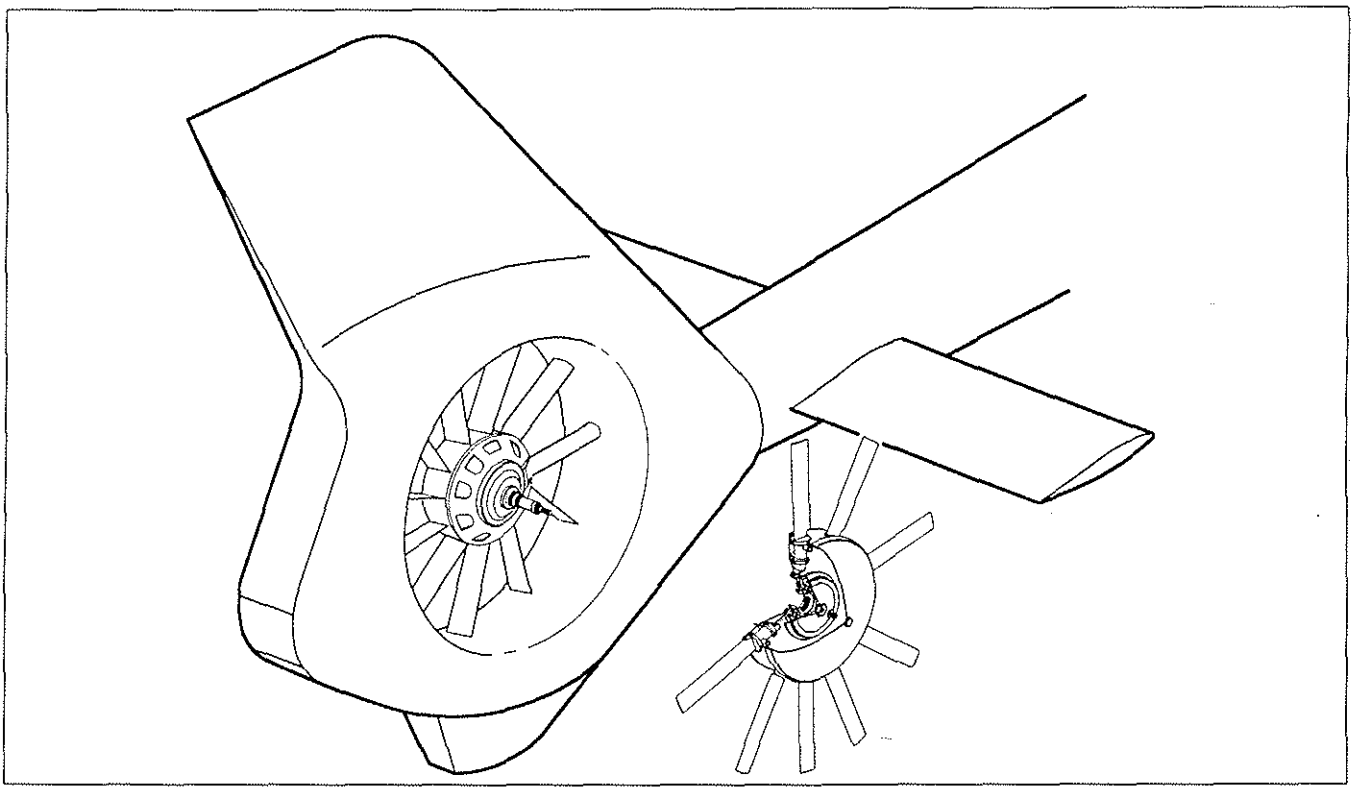
Michel VIALLE & Gilles ARNAUD
EUROCOPTER FRANCE

September 14-16, 1993
CERNOBBIO (Como)
ITALY

ASSOCIAZIONE INDUSTRIE AEROSPAZIALI
ASSOCIAZIONE ITALIANA AERONAUTICA ED ASTRONAUTICA

" A NEW GENERATION OF FENESTRON FAN-IN-FIN TAIL ROTOR ON EC 135 "

Michel VIALLE & Gilles ARNAUD
EUROCOPTER FRANCE



ABSTRACT

Since the first installation of a Fenestron tail rotor on an Aérospatiale Gazelle in 1968, a great experience has been acquired by Eurocopter on this concept thanks to the 4.9 million hours of flight logged by the Gazelles and Dauphins.

This has allowed to clearly define the main lines of R & D during the last ten years for improving this concept which, by nature, has greatly contributed reducing the number of accidents due to tail rotors.

These proceedings briefly remind the performance and the technologies used on the first Fenestron generations and specify the results of the Research and Development work conducted at Aérospatiale and then Eurocopter, ONERA and France Saclay's anechoic wind tunnel, in the aerodynamic and acoustic fields:

- *Effect of reduced Mach number at blade tip on performance, weight and noise level.*
- *Improvement of the figure of merit (a typical parameter of Fenestron efficiency) and maximum thrust owing to:*
  - *. the development jointly with ONERA of a new range of airfoils with a spanwise variable relative thickness,*
  - *. the use of a stator downstream of the rotor in order to straighten the outcoming flow and retain the airflow rotational energy,*
  - *. the optimisation of the air duct geometry in order to improve the diffusion ratio.*
- *Minimization of the overall dimensions of the items installed within Fenestron air duct in order to improve the aircraft noise level, performance and overall drag.*
- *Optimization of the rotor-to-stator distance, the*

number of blades (rotor and stator) and the blade angular position in order to drastically reduce the Fenestron-generated noise.

This new architecture so-called Phase-Modulation Fenestron allows to not only reduce the noise level emitted but also distribute the acoustic energy of the pure and shrill sound of the first generation Fenestrons over less audible lateral frequencies.

This work has been validated by wind tunnel and whirlstand test as well as flight tests aboard an experimental Ecureuil like aircraft.

The way the results have been applied to the Eurocopter's new range of light helicopters will then be presented. So, the EC 135 will be equipped with the latest generation of Fenestron, wich will provide it with outstanding performance in all flight cases. Moreover, these proceedings will present all the precautions taken for limiting the Fenestron-generated noise to the new regulatory requirements with margins (ICAO -6 dB) while reducing the acoustic nuisance of the first generation Fenestrons.

Lastly, all technological aspects specific to the EC 135 Fenestron will be dealt with. This Fenestron features an excellent reliability, a reduced maintenance and a low production cost with:

- *The optimization of the architecture of hubs, blades, stator and TGB/stator coupling*
- *Overall dimensioning (Control loads, service life limits, ...).*
- *Materials and processes used for the various components.*

In conclusion, thanks to the research work conducted during the last decade and the experience gained on the first generation of Fenestron, Eurocopter is now in a position to propose for the EC 135 an anti-torque rotor solution featuring the best compromise allowing to meet the various safety, reliability, performance and external noise requirements.

1. WHY A NEW GENERATION FENESTRON FAN-IN-FIN TAIL ROTOR ON EC 135 ?

The Fenestron is not a new helicopter tail rotor concept, in fact it has been used as a production item by Eurocopter since 1968.

From its very first introduction into service, the Fenestron has been recognized as significantly improving the safety level.

Moreover, the regulatory requirements together with customers' requirements on noise-generated troubles lead the manufacturers to look for still more silent concepts. These goals have early been taken into account in the design. So, the best compromise in terms of both safety and noise has led Eurocopter to select a new-generation Fenestron concept to fulfill the EC 135 aircraft anti-torque function.

The EC 135, a 2.5 tons range aircraft, has been developped by Eurocopter Deutschland with Eurocopter France participation for the tail unit.

In fact, this new Fenestron generation is different from the previous in that it takes advantage of the experience gained in service (4.9×10^6 flight hours) and the results from R & D efforts made during the last 20 years.

The following presentation very briefly states which is the Eurocopter's experience within the Fenestron field. Some of the R & D results obtained during the last two decades jointly with ONERA, CNRS, ... are given hereinafter.

This summary more specifically deals with the test results obtained on the Marignane's balance rig and at Saclay's CEPRA 19 anechoic wind tunnel. Lastly, the technology selected for the EC 135 Fenestron will be presented together with the aerodynamic thrust and noise performance.

2. EXPERIENCE GAINED ON PREVIOUS FENESTRONS

In 1968, Eurocopter was the first helicopter manufacturer in the World to assess and then introduce a Fenestron on the Gazelle aircraft to replace the conventional tail rotor. Ever since, the Gazelle has logged 3.6×10^6 flight hours and the Dauphin which also uses the Fenestron has logged 1.3×10^6 flight hours since 1972 (See Fig. 1).

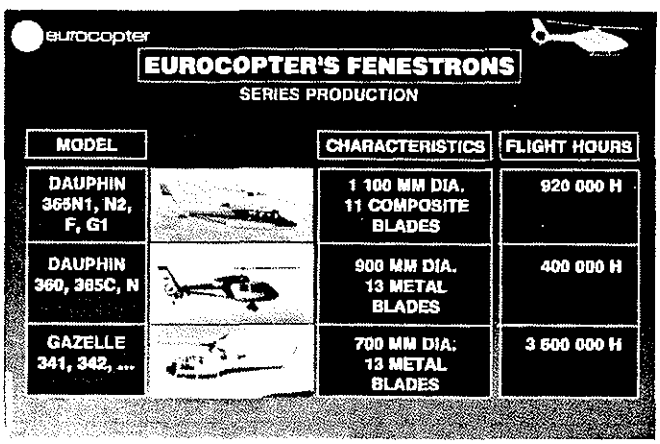


Figure 1

Such a significant number of flight hours has allowed

Such a significant number of flight hours has allowed to appraise the advantages and disadvantages of various technologies in terms of maintenance, reliability, cost, acoustics and operability in varied environment conditions (transport missions in the North Sea, military missions in Europe and Africa - Chad war, Desert Storm,... - Sea surveillance missions) and for 2- and 4- ton aircraft. This extensive experience allowed to precisely define which research orientations had to be followed (Fig.2: Demonstrators) to eliminate the previous drawbacks (shrill effect, reliability, power consumed,...) while retaining the concept advantages (safety, global noise, maneuverability, vulnerability,...).

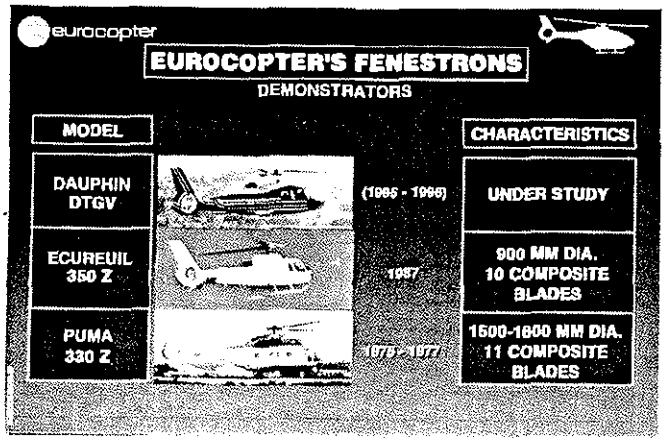


Figure 2

It should be reminded that thanks to the Fenestron concept, the operational safety has very highly been improved compared to those helicopters equipped with a conventional tail rotor. The Fenestron has proved its capability of allowing a safe landing after losing the anti-torque function due to the rupture of a component. No personnel's injury on ground due to the Fenestron has been recorded. The number of accidents involving impacts, trees, power lines, wires or obstacles in the vicinity of the helicopter working areas is considerably reduced.

When comparing the rate of accidents due to the tail rotor, according to Eurocopter's statistics, for 1.5 to 9 ton aircraft, since their first introduction into service (Alouette, Ecureuil, Puma, Super Puma) and according to the U.S. Army statistics (OH6, OH58, AH1, AH64, UH1, UH60 from 1968 to 1988), it can be noted that it is of the same order of magnitude, i.e. 7.5×10^{-6} and 7.4×10^{-6}/ flight hour, respectively (see Fig. 3).

For lightweight helicopters, the distributions of the causes for such accidents (Fig. 4) can be cancelled thanks to a shrouded tail rotor preventing impacts with ground or trees, contacts with personnels, impacts with foreign objects in flight and during aerial sling work. A great number of these accidents can obviously be prevented using a conventional tail rotor as fitted to the fin in a very high position. This is the configuration generally adopted for heavy-lift helicopters.

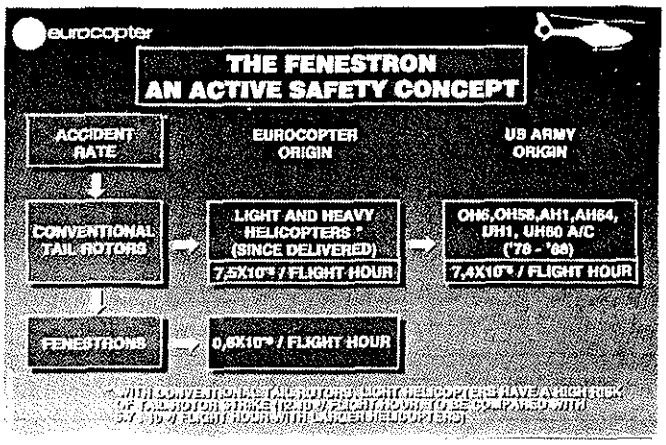


Figure 3

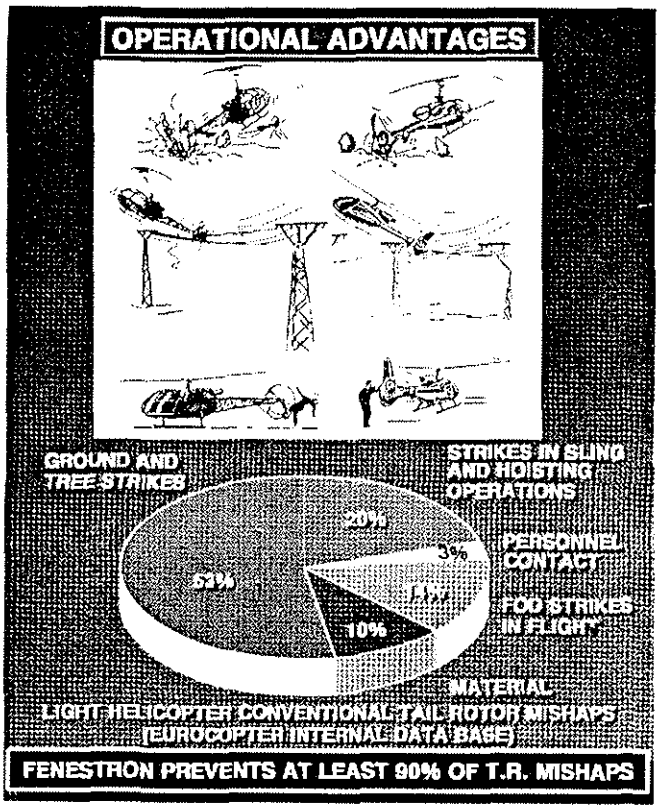


Figure 4

Eurocopter's own statistics show that the rate of accidents due to the tail rotor is approximately twice as low for heavy-lift helicopters as for lightweight.

Such a difference can very probably be explained by the higher position of the tail rotor from ground.

Therefore, it can be noted that using a Fenestron is much more safety efficient than a tail rotor mounted at the top of fin since the rate of accidents (those which caused the aircraft total loss, people death or damage whose cost amounts to half the price of the helicopter) for Eurocopter's aircraft equipped with a Fenestron is 0.8×10^{-6}/flight hour. These values show that the Fenestron is a much safer concept than the conventional tail rotor.

However, it appeared that it was still possible to improve this concept in numerous fields such as performance, acoustics, safety, maintainability. A second research line has been defined in order to improve the aerodynamic performance of the Fenestron (selection of rotor blade airfoils, shroud geometry, ...) without increasing the power to be transmitted to the tail rotor system. It seemed also that the shrill noise emitted by the first generation of Fenestrons could be a nuisance to the human ear for those communities living close to heliports. Therefore, research activities have especially been conducted with a view to eliminating this ear nuisance while trying to reduce the overall noise generated by the Fenestron.

Aerodynamic improvements

In the early eighties, special effort was focused on the Fenestron's aerodynamics. The rotor, previously equipped with NACA63 type airfoils, was set with new advanced airfoils providing a higher lift both with less power consumption (ref 1 and Fig. 5). OAF airfoil blades, developed in cooperation with ONERA, have a spanwise variable relative thickness, and have essentially been designed with a view to increasing the load at blade tip, so as to produce the maximum depressure level on the shroud and delay the blade tip stall as far as possible.

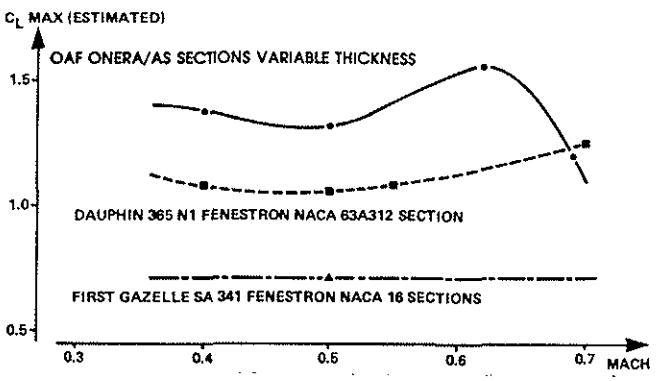


Figure 5: Fenestron airfoil C_L max improvement

Instead of blunt support arms, a stator was designed to get power from the swirl flow along with suppressing pure tone sounds emerging from the support arms. Fig. 6 below shows that the flow has been almost completely straightened with these stator blades, thus gaining from the flow rotational energy by creating an extra axial thrust, and recovering pressure.

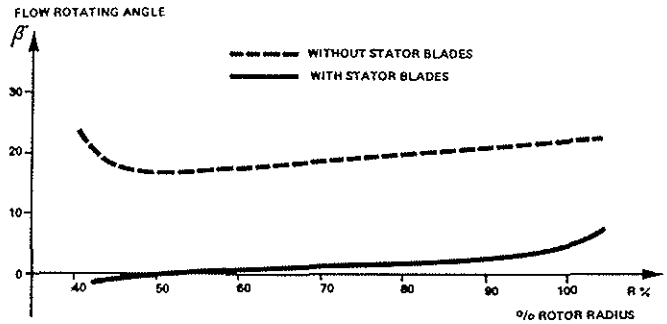


Figure 6: Influence of stator blades on flow rotating angle at the diffuser exit

The inlet and the exhaust were optimized to produce a maximum suction and a maximum diffusion while delaying separation, respectively. Although the optimal angle of diffusion was found to be 20° (as in current subsonic diffusers theory), the diffuser angle is actually limited to a practical angle of about 10° (Fig. 7).

Indeed, higher diffusion angles experienced flow instabilities in the presence of the main rotor wake in hover. This effect has been evidenced on early versions with the bottom aft fenestron direction of rotation which had been forsaken because of poor performance in tail wind in ground effect.

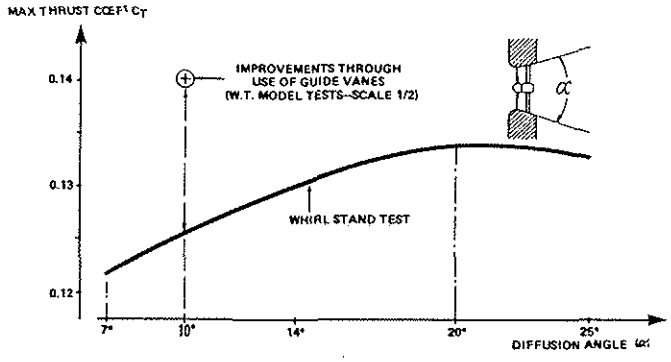


Figure 7: Influence of diffuser angle and stator blades on fenestron performance

As shown in fig. 8, these modifications led to a substantial gain : an increase of +7% in maximum

figure-of-merit and +37% in maximum mean blade load coefficient, as compared to the present 365N1 Dauphin's fenestron. Moreover, stall is delayed and the range at which the figure-of-merit remains at maximum is increased.

	CONFIGURATION	$(FM)_{max}$	$(C_{lm})_{max}$
①	365 N1 (REFERENCE)	0.71	0.825
②	WITH GUIDE VANES	+4.2%	+26%
③	WITH OAF AIRFOIL SECTIONS + G. VANES	+7.0%	+37%

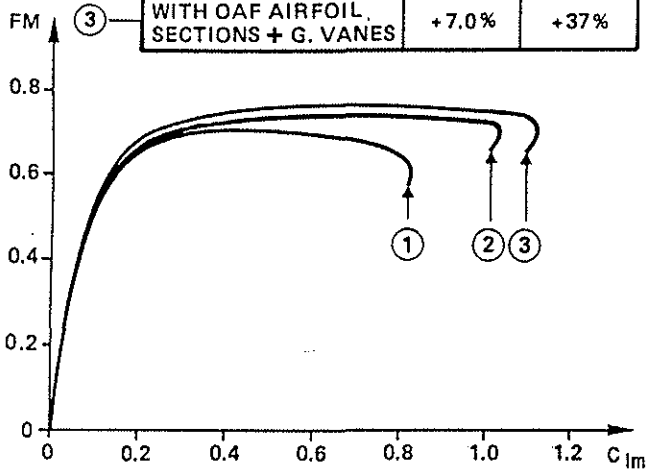


Figure 8: Fenestron performance improvements (full scale ground tests)

Acoustic improvements

In 1992, a set of experiments, aiming at investigating the effects of different devices on the emitted far field noise of a light helicopter fenestron, were performed by Eurocopter France, under the financial support of STPA (French Aeronautical Programs Department).

These investigations dealt with the practical study of the phase modulation concept, the quantification of the noise effect due to tip Mach number reduction with attention to performance, the effect of stator position on noise and performance compromise, the geometrical effects of foreign objects such as a transmission shaft placed in the exhaust, and piloting effects in forward flight such as yawing, speed, or loading compromise between the fin and the fenestron.

The program was divided into two parts : hover characterization in the open air, which represented 150 hours of experiments, and forward flight characterization (300 hours of experiments) for representative flight cases for the EC135 such as a fly-over at 0.9 Vm or an optimal climbing at Voc in the CEPRA19 anechoic wind tunnel, Saclay (France). The experiments described herein mainly refer to the hover case.

A 850mm diameter wide fenestron equipped with 8 advanced airfoiled blades and a stator was mounted on top of a massive bench (see fig. 9), blowing downwards, 3.60m above the ground in order to avoid recirculations and ground noise reflections.

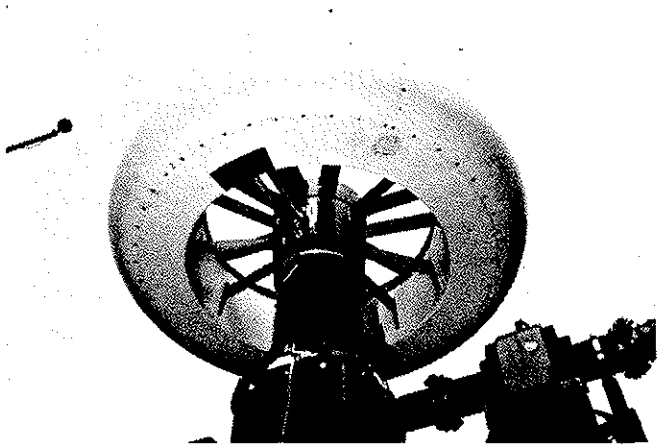
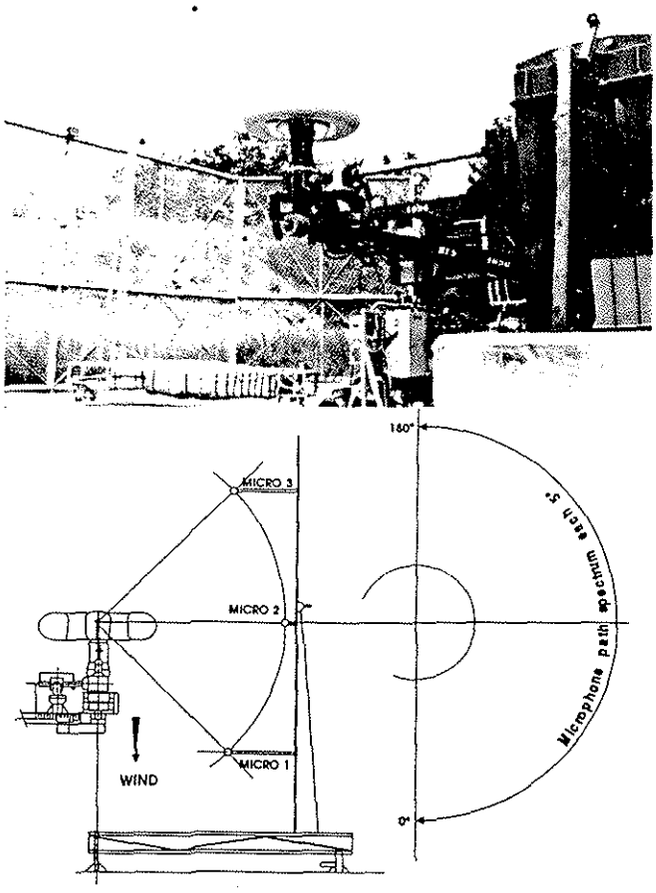


Figure 9: The fenestron on the whirl tower, Marignane, Sept. 92

The stator was equipped with 10 blades, the transmission shaft playing the role of the 11th one in order to avoid major interference with rotating blade passing. Stator blades were placed in such away that they minimized interaction. Two different rotor heads were available : the former with equally spaced blades and the latter with an uneven setting of blades to generate phase modulation. The stator blades were equally spaced and the distance from the rotor could vary by 1 chord. The shaft position could also vary in the same range and shells were built up to artificially increase the shaft diameter by a factor of 2, when adapting them around it.

A pole equipped with 3 microphones, one 45° above the fenestron plane (3), one in the fenestron plane (2) and one 45° below, was rotating from 0° to 180° azimuth around the fenestron, at a distance of 3m from the center head. The portion of space covered corresponded to a half-sphere below the fenestron, as in certification conditions (see picture below). Acoustic signals were recorded continuously and a real time treatment was done for a sample

of 6496 points in the 0 - 6.5KHz frequency range, each 5° in azimut.



Figures 10 and 11: The fenestron on the whirl tower, and the acoustic setup

At Cepra 19, 25 microphones were placed to cover a portion of sphere from azimuth 45° to 135° and side angle from -45° to +45°.

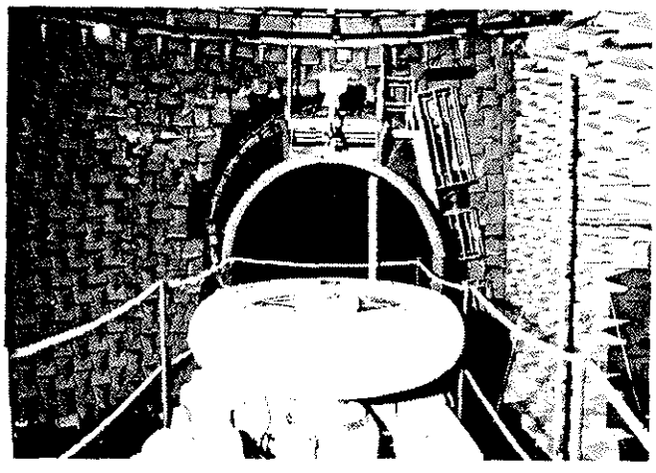


Figure 12: The fenestron in the Cepra 19 anechoic wind tunnel, Saclay, Jan. 93

Nominal conditions referred to hereafter cover the tip Mach number M_O=0.565, fundamental frequency f_O=72 Hz

PHASE MODULATION EFFECT

Breaking the symmetry of rotating systems to reduce noise is a rather old idea (ref 2-3-4-5). Recently, Lévy (ref 6) theoretically established that the overall sound level (in Sound Pressure Level) is independent of blade spacing, providing the spectrum generated by a single blade is flat enough. Mainly, the acoustic energy, initially concentrated on several pure tones (among them the blade passing frequency B*omega), is spread out over multiple tones, according to the modulation chosen.

Consequently, the strong blade passing frequency pure tone, responsible for the characteristic «shrill noise» of the fenestron, which emerges in the range of frequencies where the ear sensitivity is at maximum, transfers a part of its acoustic energy towards other frequencies, most of them lower. A subjective effective noise reduction may appear since the «shrill noise» is replaced by a more distributed noise. Therefore, more harmonics are less significant since their frequencies or emergence are low enough to benefit from a de-emphasis in A-weighted noise level (dBA) and mainly perceived noise level (PNLT units).

Figure 13 illustrates the effect of phase modulation on the fenestron for nominal conditions at the hover corresponding thrust.

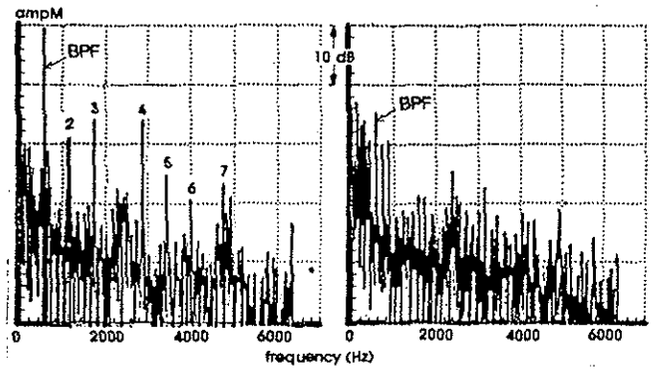


Figure 13: Spectra comparison between the moduled fenestron (right) and the conventional one (left)

The conventional fenestron spectrum is dominated by those pure tones emerging high above the broadband noise, at frequencies multiple of the BPF (Blade Passing Frequency). Moreover, the BPF tone is dominant (between 10dB and 15dB higher). On the contrary, the modulated fenestron exhibits a

much richer spectrum, particularly in the low frequency range.

Another benefit from this modulation is to concentrate the acoustic noise level towards low frequencies : in the presence of a main rotor, these tones will be embedded in the main rotor spectrum and will not therefore emerge any more, thus being de-emphasized thanks to A-weighted noise levels or perceived noise levels.

The effect of modulation on signal directivity is shown on fig. 14.

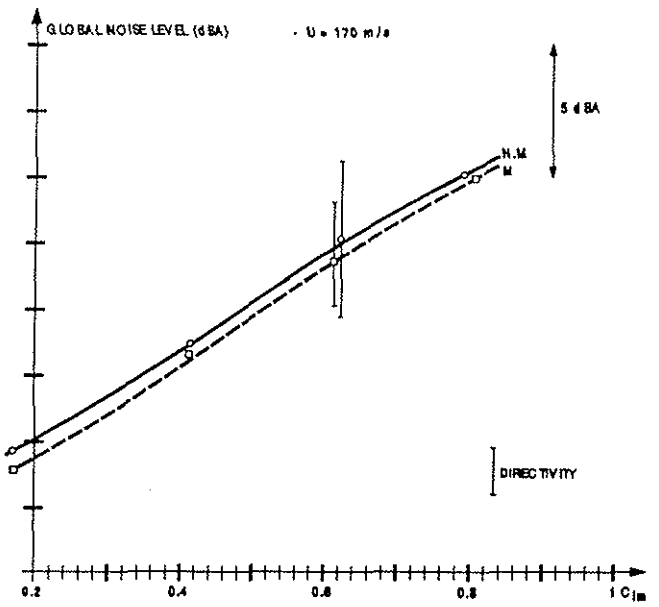


Figure 14: Modulation effect on global noise level

The conventional fenestron radiates noise in different selected directions with a gap of 5.5 dB to 6 dB between the lowest recorded level and the highest one. On the contrary, the modulated fenestron radiates noise with a gap of 3 dB to 3.5 dB according to the direction. This results in a reduced subjective noise annoyance : people are more sensitive to variable noise levels than to monotonous ones.

Lastly, this figure shows that the overall noise level is even reduced : though modulation effect mainly acts on subjective noise and not on overall noise, 1 dBa could anyway be saved.

These trends have been checked in forward flight, too ; modulation effect acts in the same way on spectrum, exhibiting a 1 dBa reduction at low speed essentially.

EFFECT OF TIP MACH NUMBER

So far the compromise between noise level and performance is acceptable for a given helicopter, an easy way to reduce the overall noise level is to reduce the tip Mach number. This could be realistic without much performance penalties, thanks to aerodynamic improvements performed on a previous study (ref. 1 and § 1).

From a nominal configuration, three different tip Mach numbers were selected on the modulated fenestron :

Mto = 0.565
Mt1 = 0.5 (- 11 %)
Mt2 = 0.441 (- 22 %)

Results are shown below:

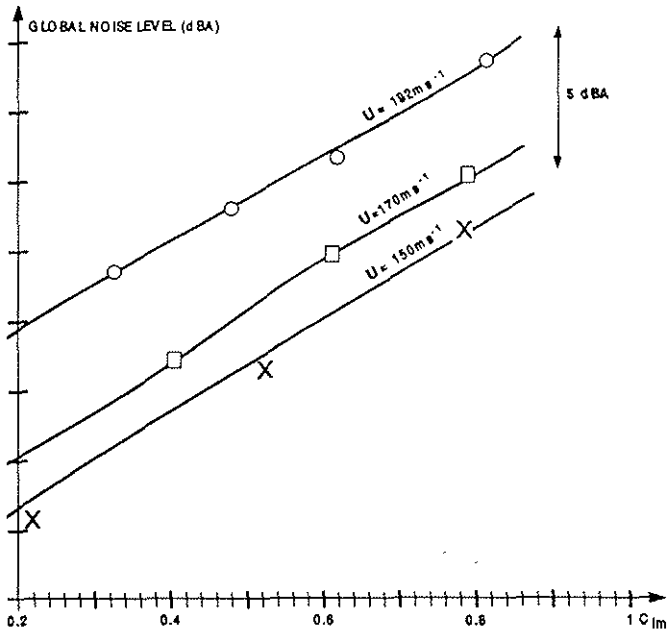


Figure 15: Tip speed effect on golbal noise level

For a given mean blade load coefficient (C_{lm}), the A-weighted noise level is reduced by approximately 3.5 dBa for a reduction of 11% M_t and 6.5 dBa for a reduction of 22% M_t (average values on repetitive experiments). This is in agreement with the commonly used approximation of the loading noise varying like $60\log M_t$, dominant noise source for a fenestron.

In forward flight, it has been stated that the effect of Mach number reduction, though important, is less impressive : instead of a 60log(dMt/Mt) law, it follows

a 45log(dMt/Mt) law approximately, which gives approximately a 2.3 dBa reduction for 11% reduction on tip Mach number.

STATOR POSITION

To reduce noise due to wake interaction between the stator and the rotor, the stator was positioned about one chord downstream from its nominal position. Fig 16 below compares noise levels (in dBa) between both configurations versus thrust.

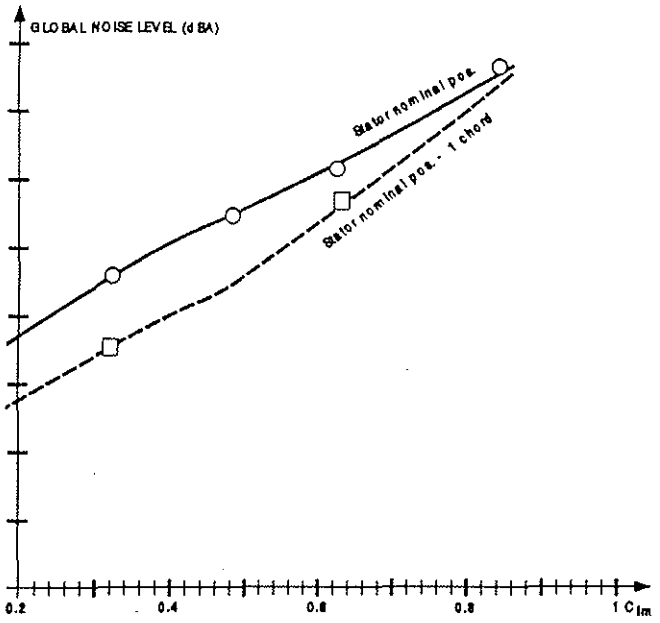


Figure 16: Stator position effect on global noise level

For a wide range of thrust, experiments show a 2 dB decrease of noise level. Performance was measured at the same time : no change was observed.

A position of the stator far downstream could lead to an impossibility to set the stator inside the exhaust while keeping advantage of the diffusive guide vane, with a short optimized exhaust (cf §1) to minimize drag SCd.

Again, in forward flight, the reduction in noise level is reduced compared with hover : it goes down to 1.5 dBa.

SHAFT POSITION

Usually, the transmission shaft is a rather big cylindric element producing a major potential noise, since it is embedded in the rotor wake, close to the rotor, due to mechanical constraints.

Diameter and position from the rotor were investigated. Doubling the shaft diameter has a major negative effect for hover (+ 1.5 dB at low thrust), while the effect of setting the shaft one chord downstream of its nominal position is not obvious, may be because this shaft is already thin enough.

This result points out that minimizing obstacles downstream of the rotor needs to be taken into account early in the development phase to avoid noise and mechanical conflicts.

Forward flight measurements showed that the effect of obstacles in the duct decreases as forward speed increases, which is rather logical since, in forward flight the fenestron acts as a «hole» as speed increases.

To sum up, experiments proved that a reduction of at least 6 dB along with an improved subjective noise can reasonably be targeted on an already advanced fenestron without performance penalty for hover. However, for forward flight, these gains are slightly reduced: they fall down to 4.5 dB approximately.

To gain even more in dB for forward flight, effects of loading according to speed and yaw were investigated. They showed that they could give a large potential of noise variation for all speeds in a certain range of thrust.

Finally, noise measurements of the Cepra19 fenestron in forward flight showed a potential gain of about -6 dB compared to the conventional fenestron used during those experiments.

3. THE EC 135's FENESTRON

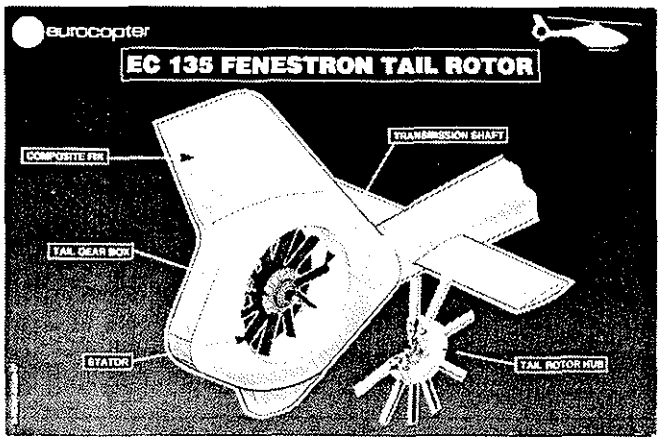


Figure 17

The EC135 fenestron will benefit from most recent advances achieved in the aerodynamic and acoustic fields, to propose remarkable performance while paying a special attention to environmental constraints. In that sense, this is the very first fenestron to be developed under such stringent specifications.

Aerodynamic Improvements

To match those specifications, the OAF advanced airfoil family has been chosen. Also, a stator has been placed in the exhaust, and special care was put on minimizing necessary obstacles size in the duct. The diffusion angle has been defined for the best compromise between performance and side wind manoeuvrability, according to the results obtained during the research phase (ref. 1).

These improvements lead to a 7% increase of the figure-of-merit in the positive range of thrust, while delaying stall. Indeed, the maximum mean blade load coefficient has been increased by 37% compared with the NACA63 airfoil family used on the Dauphin fenestron, as stated in § 2. Moreover, compared to an advanced conventional tail rotor, .this fenestron exhibits a much better performance.

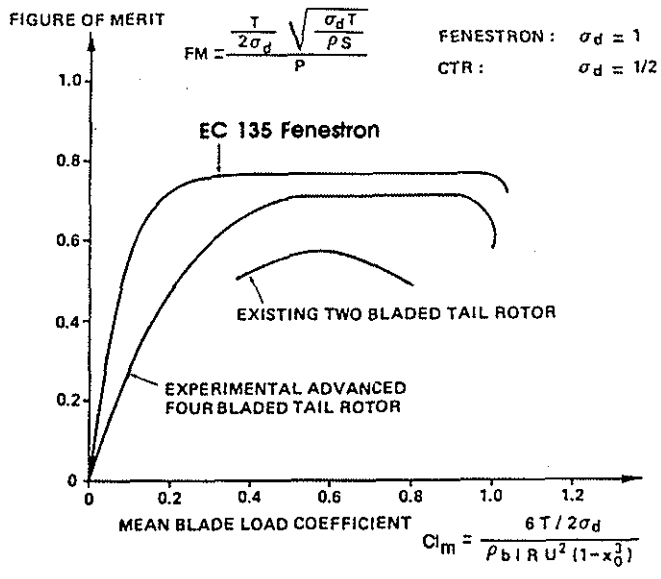


Figure 18: Isolated tail rotor efficiency

Also, the OAF airfoiled blade provides a very low Cm_0, thus contributing to almost eliminate static control loads.

Acoustic Improvements

Results obtained during the investigating phase and presented above can be applied to compare the estimated emitted noise (in dBa) for the EC135 fenestron with that measured on an Ecureuil demonstrator (350Z) advanced fenestron during an in-flight noise campaign performed in 1992.

The procedure of evaluation accounts for:

- geometrical differences : diameter, chord, stator position, shaft diameter, airfoil, modulation
- kinematic differences : BPF position, blade tip speed
- performance differences : reduced mean-load coefficient (Clm) for each flight case, fly-over and take-off speeds

This Ecureuil fenestron is close to the EC135 fenestron in its overall description, though a little bit smaller. The rotor is equipped with 10 evenly-spaced blades (advanced airfoils), a stator and a thin transmission shaft placed a little bit closer to the rotor than on the EC135. The main difference comes from the tip speed : 200m/s on the Ecureuil and only 187 m/s on the EC135.

On the other side, the EC135 fenestron, 1000mm diameter wide, is equipped with 10 modulated blades and a stator specially designed and placed to minimize noise interactions, while optimizing performance and mass balance.

Moreover, its BPF is lower than that of the Ecureuil fenestron, which can bring it some advantage in noise units when in presence of Doppler effect in forward flight (no 1/3 octave slip) or for pure sound corrections in the presence of the main rotor.

Compared to the Ecureuil demonstrator (which is a lighter aircraft), predictive results obtained for the EC135 fenestron speak for themselves: for hover, noise (expressed in dBa for an isolated fenestron) should be reduced by 2 dBa, while in fly-over, it should be 1 dBa less, and comparable for take-off. This could lead to a dramatic increase in operators' possibilities, as it is recalled in figure 19a below : reducing noise level by 1.5 dBa means a 40% increase in the number of flights and a 60% reduction of noise contour area
(see Figure 19b).

Besides, improvements introduced by the modulation effect on subjective noise should be greatly appreciated by the human ear : people around will not any more be affected by an aggressive «shrill noise».

Figure 20 gives comparative emitted noise levels (in dBa) for isolated tail rotors equipping different helicopters.

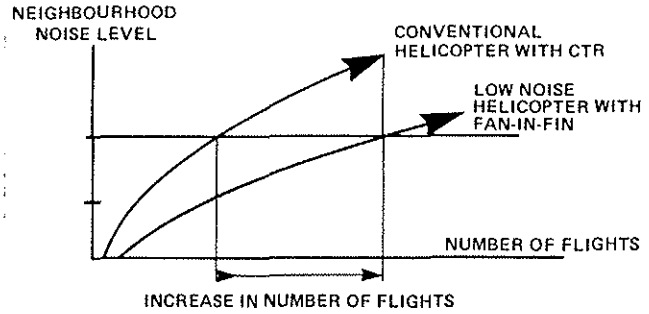


Figure 19a: Increase in number of flights

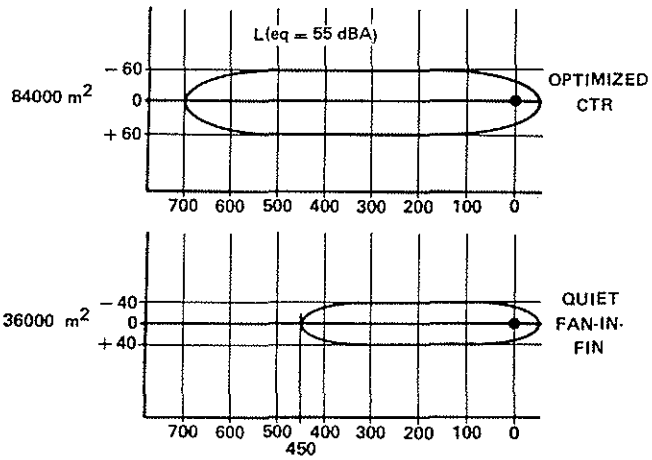


Figure 19b: Neighbourhood noise contours: 1 take off/hour

As shown on Fig. 20a and 20b, the EC135 fenestron, as far as the total gross weight is concerned, is a very quiet fenestron, compatible with the ICAO -6 dB certification requirements, as targeted during its development, and in the noise level range of the NOTAR system. Moreover, as stated on Fig. 20a, the fan-in-fin concept leads to a reduction of the overall noise compared to a conventional tail rotor.

Technologic improvements

The technology retained for the EC 135's Fenestron has already been proven in operational conditions. Though this Fenestron involves no new technologies, it features numerous improvements resulting from an extensive experience in service so as to obtain an excellent reliability from the very early productionization of the EC 135. The best cost-weight-reliability compromise for this Fenestron size leads to select light alloy blades whose leading edge is protected against erosion by sand-laden atmosphere. As a matter of fact, while the resistance to erosion in Europe proves satisfactory, it appeared too low during CHAD's war.

Compared to the resistance of the Gazelle's blade, the sand erosion tests show that the skin selected for the EC 135's blade provides at least a 30% greater

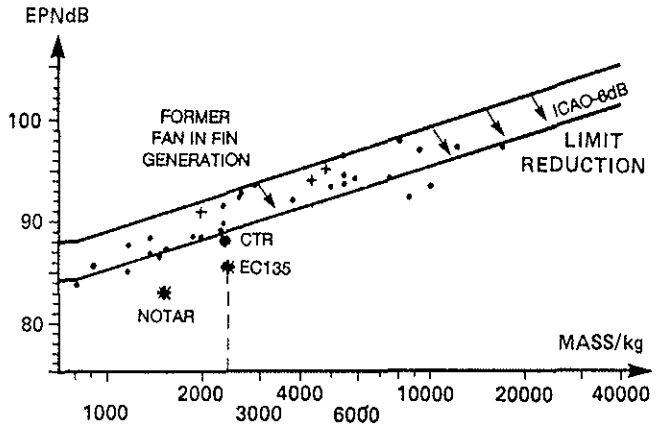


Figure 20a: Comparative noise levels (EPNdB) for different tail rotor generations

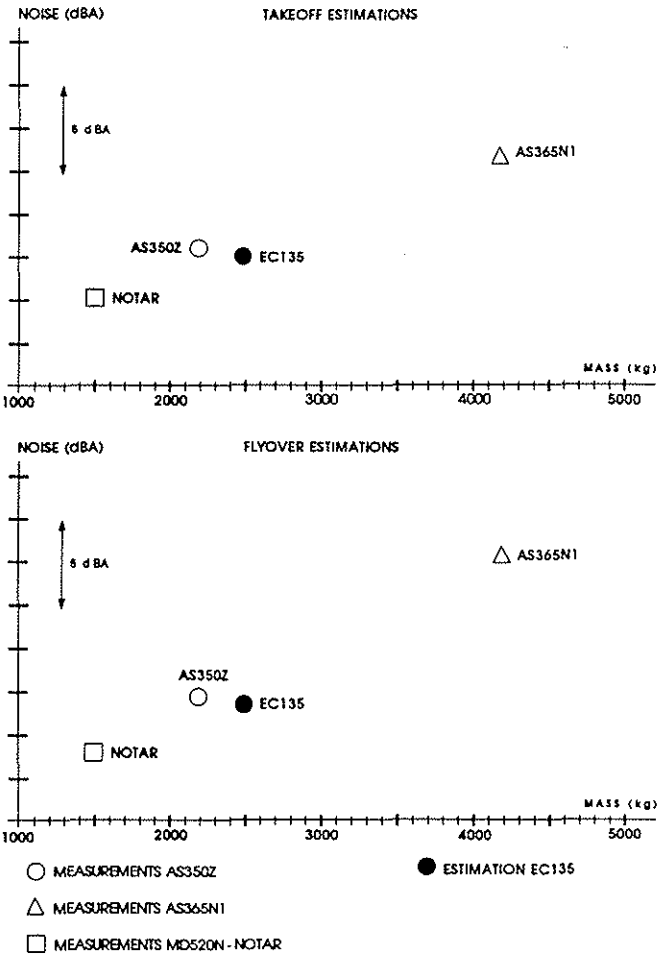


Figure 20b: Comparative global rotational noise levels (dBA) for different tail rotors helicopters

resistance. Since the EC 135's blade chord is larger than the Gazelle (40 mm against 50 mm respectively), the blade stall margin for the same size of defect is more important on the EC 135's blade. Moreover thanks also to the RPM reduction, an improvement ratio exceeding 2 is expected.

Furthermore, a very special effort was made to reduce the control loads and associated reactions on blade bearings, which of course results in weight

saving but also increases the reliability of items such as blade pitch horn spherical bearings and Torlon journal bearings that make the blade turn about the pitch axis. This was achieved with blades featuring not only better aerodynamic characteristics but also, an advantageous low Cm_o coefficient and an optimized setting, which contributes to reduce the control loads. Then, the position of the blade pitch horn on the leading edge very significantly contributes to decrease the control loads.

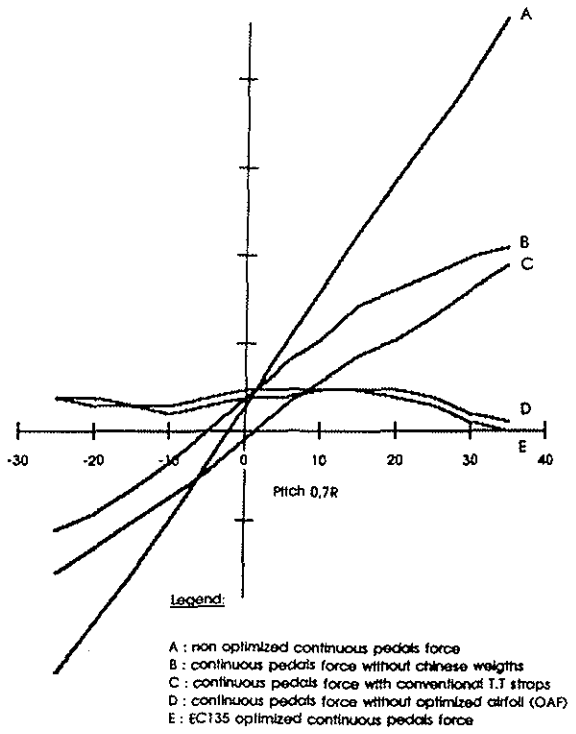


Figure 21: EC 135-Continuous pedals forces

In addition, chineese weights were optimized in order to obtain static control loads close to 0 daN within the current pitch ranges. Lastly, in order to reduce the transient control loads the feedback at the journal bearings was reduced compared to the Gazelle or Dauphin by increasing as much as possible the embedment between both bearings whose selected technology is that of the Dauphin. This transient control loads reduction is all the more great the pitch bearings diameters are small.

So, the friction loads are reduced, which therefore decreases the dynamic loads.

The technology used for the tension-torsion straps is derived from the Gazelle which has largely been proved and has shown no failures in 3.6×10^6 flight hours. In order to facilitate the maintenance and in so far as the Fenestron inside diameter allows, one metal tension-torsion strap per blade consisting of several strips with a small thickness and different widths so as to reduce the torsion stiffness as far as possible is used.

All five actions, i.e. low blade Cm_o, optimized chineese weights, large embedment between both blade journal bearings, geometry of tension-torsion straps and optimized position of the blade pitch horn, result in quasi null control static loads and as low dynamic loads as possible within the current pitch ranges (see Fig. 21). The calculations have shown that with all these optimisations the static control loads level is reduced by 90% in comparison with a non-optimized Fenestron. Concerning the transient loads, we have a reduction of 50%. The flight tests will allow to decide on the usefulness of a servo-unit.

These low control loads have allowed to oversize largely the control bearing which is located inside the tail gearbox and lubricated with the TGB oil. The lubrication of this bearing and the flowing of any chips to the magnetic plug, which was made very easy, were especially taken care of.

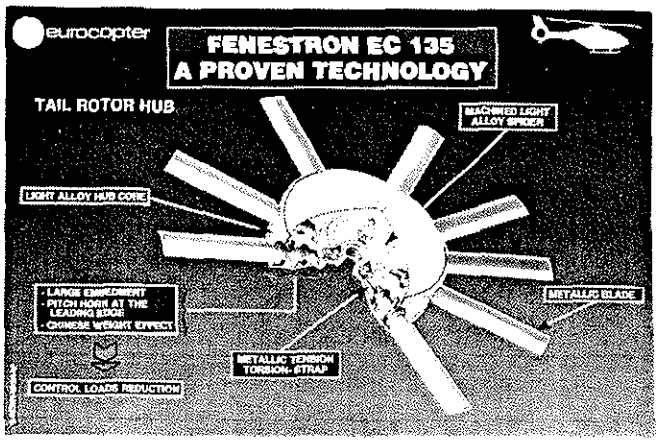


Figure 22

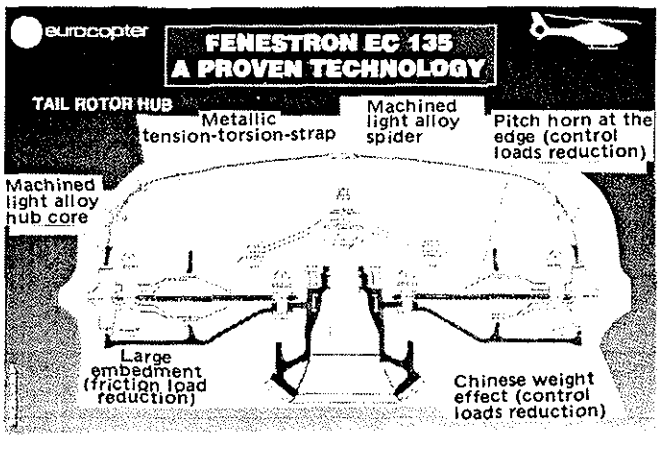


Figure 23

The hub and the spider are machined from a drop forging, which provides it a good low-cycle fatigue strength under centrifugal loads. This technology is derived from the Dauphin which proved the reliability of such a concept compared to a stamping which caused problems on the first Dauphin versions (Fig. 22 and 23).

Nitrided and ground tooth gears as combined with the use of a mineral oil give the tail gearbox a very high reliability. A very special care has been taken on TGB maintainability by cancelling any adjustments when replacing spiral-bevel gears. Since the effects of variable casing dimensions on tooth contact patterns and the accuracy of tooth surfaces have perfectly been controlled, it has been possible to eliminate the spiral-bevel pair setting shims and any possible replacement of a pinion does not require returning the gearbox to the factory, which considerably reduces the maintenance cost.

In order to make easier the operational maintenance procedures, the main components of the mechanical set are interchangeable without balancing or setting. So the blades are individually balanced and the length of the tail gearbox control rod is calibrated, which allows to replace either the tail rotor or the tail gearbox without adjusting the control channel.

The Fenestron airframe assembly (shroud, duct and fin) is in compound sandwich (Nomex honeycomb, glass/carbon hybrid cloth, high temperature (180°C) and non toxic resin). This is composed of four parts (see figure 24). So it avoids the intergranular and atmospheric corrosion and the fatigue cracks in comparison with the metallic Fenestron. The damage tolerance is improved (10 pick-up points provided by the stator blades, slow cracks propagation speed (less shapes to inspect, increased sensitivity and repair damages criteria (20 mm)). At last, the mean time between inspections is greater.

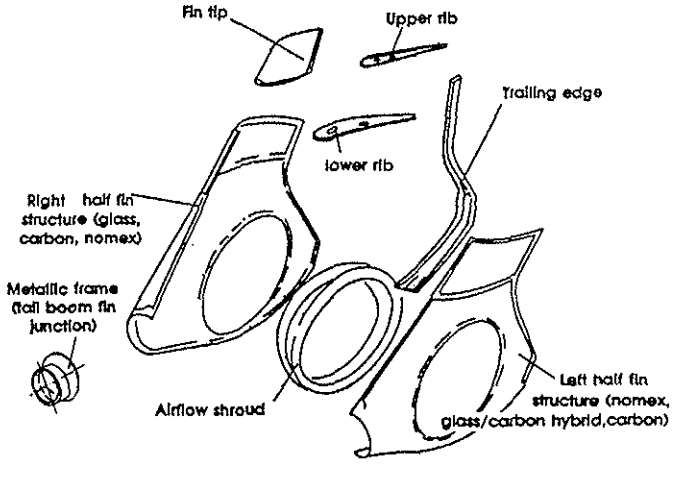


Figure 24: Composite fin

CONCLUSION

The EC 135's Fenestron is today's best solution to ensure the anti-torque function of this helicopter. It takes advantage of the very extensive experience gained on the Gazelles and Dauphins and the R & D activities (OAF blade airfoils, stator, shroud geometry, phase modulation, rotation speed optimization, ...) carried out during the last twenty years which give the EC 135's Fenestron remarkable, so far unmatched, aerodynamic performances while cancelling the ear nuisance generated by the shrill noise from former generation Fenestrons. Moreover, the technologies retained for the various components of this Fenestron allow to reach very high reliability levels, which cuts down the maintenance costs that are all the more reduced as special efforts were made to facilitate the maintenance operations.
So, the EC 135's Fenestron is a major step into the tail rotor field which materializes all the experience acquired from 5×10^6 flight hours and R & D results.

REFERENCES

1. A. Vuillet and F. Morelli, New aerodynamic design of the fenestron for improved performance, AGARD CP n° 423

2. W Behrmann, German Patent n° 669126, 23 June 1934

3. R.C. Mellin and G. Sovran, Controlling the tonal characteristics of the aerodynamic noise generated by fan rotors, Trans. ASME, J. Basic Eng. 92, 1, pp 143-154, 1970

4. P.E. Duncan and B. Dawson, Reduction of interaction tones from axial flow fans by suitable design of rotor configuration, J. Sound Vib.33, 2, pp 143-154, 1974

5. S. Fujii, Acoustics and performance of high speed, unequally spaced fan rotors, ASME Paper n° 79-GT-4, 1979

6. S. Lewy, Theoretical study of the acoustic benefit of an open rotor with uneven blade spacings, J. Acoust. Soc. Am. 92, 4, Pt1, 0001-4966/92/102181, pp 2181-2185, Oct. 1992,

7. P. Roesch, The fenestron antitorque concept, Royal Aeronautical Society Conference on Helicopter yaw control concepts, London, March 1990.

8. M. G. Clemmons, Antitorque safety and the RAH-66 fantail, AHS 48th Annual Forum, Washington D.C., June 92.

9. R.D. Janakiram, J.M. Currier, Noise charasteristics of helicopters with the NOTAR anti-torque system. THE QUIET HELICOPTER. London U.K., March 92.