INNOVATIVE FLIGHT TEST INSTRUMENTATION FOR IN-FLIGHT NOISE MEASUREMENT OF A DAUPHIN'S FENESTRON

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ABSTRACT

Shrouded tail rotors found on some helicopters are a french design called Fenestron. Although the rotors provide increased performance, acoustics emissions can be reduced in some in-flight configurations. The purpose of the Fenestron Noise Study program funded by the French Directorate for Civil Aeronautics Programs (DPAC) and based on earlier research contracts is to improve and validate the aerodynamic/acoustic numerical tools dedicated to the analysis and prediction of Fenestron generated noise. The Flight Test Center at Istres and the Eurocopter company are involved in this program that is led by the ONERA Department of Digital Flow Simulation and Aeroacoustics (DSNA).The program has planned for two flight test campaigns. Its purpose is to study the sources of the noise nuisance generated by the Fenestron rotor on the Dauphin 365N helicopter. A first test campaign has been carried out in 2008 but another complementary test campaign will be conducted to take acoustic measurements on the ground. The ONERA computation tools should enable industry to improve the definition of the rotor type Fenestron so that its noise emission is significantly reduced.

ACRONYMS

DGAC	French General Directorate for Civil Aviation
DPAC	French Directorate for Civil Aeronautics programs
CEV	French flight test Center
ONERA	Office National d'Etudes et de Recherches Aérospatiales
DSNA	ONERA Department of Digital Flow Simulation and Aeroacoustics
DAAP	ONERA Department of Applied Aerodynamics
DRIM	ONERA Department of Engineering and Scale Models
DCSD	ONERA Department of System Control and Flight Dynamics

1. INTRODUCTION

Implementation of a type shrouded Fenestron on tail rotors can bring to helicopter some benefits in terms of efficiency and safety. Although these tail rotor arrangements provide increased performance, acoustics emissions can be reduced in some in-flight configurations. To understand and analyze the aero-acoustics phenomenon involved in these configurations a Fenestron Noise Study program has been funded by the French Directorate for Civil Aeronautics Programs. It is based on earlier research and aims at developing and validating the aerodynamic/acoustic computational tools for the analysis and prediction of noise generated by Fenestron. A first flight test campaign started in 2008 to study the sources of the noise nuisance generated by the Fenestron rotor on the Dauphin 365N helicopter. The Flight Test Center (CEV) at Istres and Eurocopter were involved in this research program conducted by the Department of computational flow and aeroacoustics (DSNA) of ONERA.

As wind tunnel tests of an isolated Fenestron are not able to simulate in a realistic way the conditions on a real helicopter, flight tests of the helicopter Dauphin 6075 of the French Flight Test Center at Istres has been chosen as experimental means. In the framework of the program called "Fenestron Noise Study", the French Flight Test Center, Eurocopter and ONERA have been in charge of designing and building the rear structure which was then integrated and tested in flight on the helicopter.

The goal of the first campaign was to perform onboard aerodynamic and acoustic measurements to identify the flight conditions for which the Fenestron is more noisy. The resulting experimental database will contribute to understand the physical mechanisms responsible for Fenestron noise generation as well as to validate the aero-acoustic computation codes from ONERA (at DSNA and DAAP departments)

Later on another test campaign will be conducted to measure helicopter acoustic footprint on the ground and to

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identify correlations between onboard and ground measurements.
One of the final objectives is to provide to industry numerical prediction tools, validated by experiments. This will contribute to improve understanding of acoustics phenomena and to develop computation tools for the calculation of low noise optimized flight procedures as well as for the designing of future very low noise helicopters.

2. INSTRUMENTATION

This part of the paper deals with the development, integration and testing of the on-board instrumentation.
In order to perform onboard aerodynamic and acoustic measurements, a very innovative instrumentation and measurement chain architecture was achieved by Eurocopter, the CEV and the Department of System Controls and Flight Dynamics (DCSD) of ONERA.
The Fenestron blades, duct, fuselage sides and tail of the Dauphin 6075 helicopter (Figure 1) have been equipped with this advanced instrumentation. A complete description of the instrumentation installed on the fixed parts of the helicopter will be presented here after.

Figure 1: Dauphin 6075

2.1. Fixed instrumentation

2.1.1. Microphones

Acoustic measurements were performed by means of 4 microphones Brüel & Kjaer ¼" mounted on the empennage, 2 on each helicopter side (Figure 2).

Figure 2: Implementation of the microphones

A specific device was developed by the CEV to fix the microphones on the Dauphin's empennage. Originally composed in composite fibres, a part of the empennage has been replaced by a metal sheet to allow the fixation of the microphones supports (Figure 3).

Power supply of the microphones is installed in the cabin.

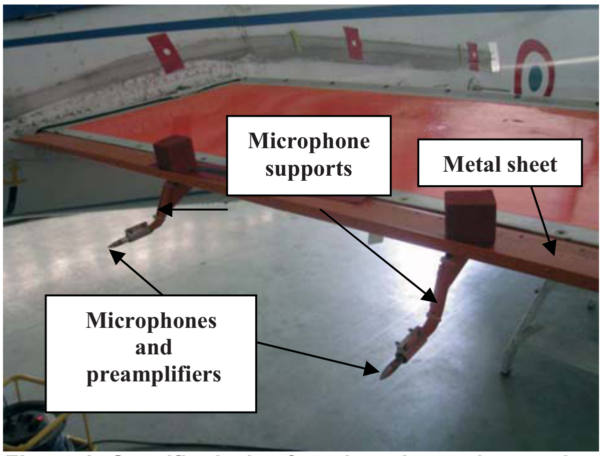

Figure 3: Specific device for microphones integration

2.1.2. Static pressure measurements

In order to measure the pressure around the rear part of the fuselage, flexible strips in silicon were elaborated by ONERA/DRIM and stuck along the tail boom and around the Fenestron as shown in figure 4.

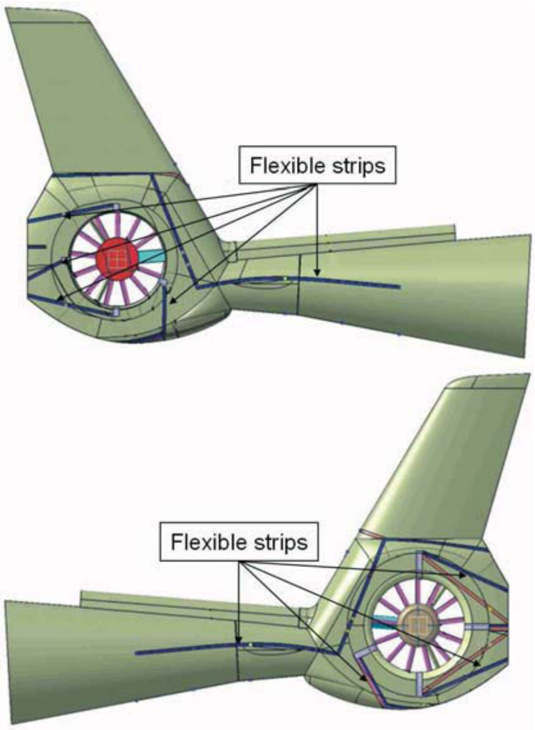

Figure 4: Flexible silicon strip on the tail boom

Each strip includes 8 ducts (figure 5). At different locations, these strips were perforated, providing 13 pressure holes on both sides of the helicopter tail boom.

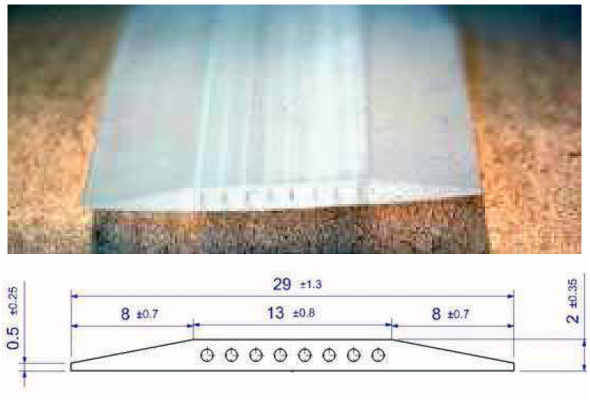

Figure 5: Side view of a silicon strip

In the next figure (Figure 6), red arrows show the positions of the pressure holes along the tail boom.

Figure 6: Position of the pressure measurements

Instrumentation was developed to provide also pressure measurements in the Fenestron duct. To perform these measurements, rigid strips were designed. The rigid strips were integrated inside and around the Fenestron as indicated in the following figure (Figure 7).
Mounted on both sides of the tail rotor hub, these strips were divided in two parts. One was mounted downstream of the Fenestron shaft, the other one upstream.

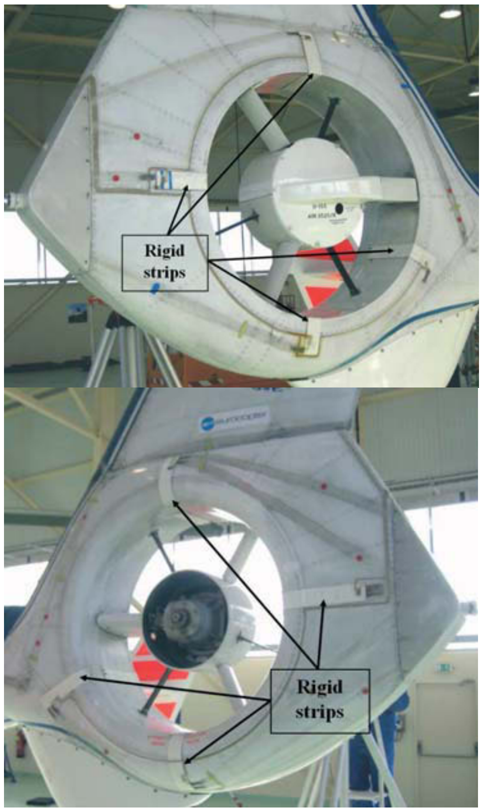

Figure 7: Position of the rigid strips around the Fenestron

The next figure (Figure 8) shows these rigid strips before assembly. It can be seen on the bottom of the figure an upstream part with 13 pipe connections for the pressure holes.

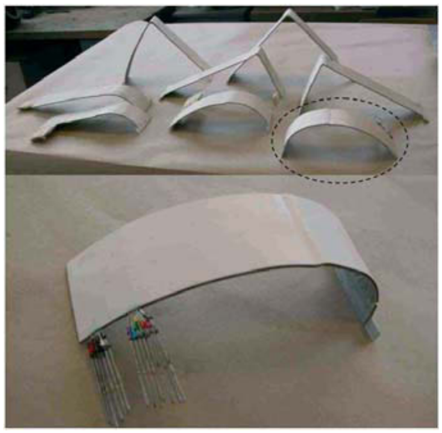

Figure 8: Rigid strips

With 13 small pressure holes on one side and 7 on the other side of each rigid strip, the set of rigid strips provide 80 static pressure measurements.

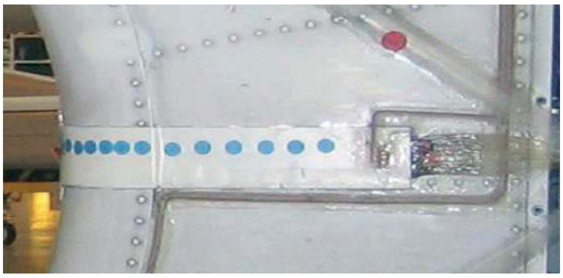

Figure 9: Location of the pressure holes on the rigid strips once mounted

As it will be described in a next chapter, the location of the static pressure taps was very precisely measured (Figure 9). This figure shows the high number of vinyl tubes getting out of the rigid strips and wired to the electronic pressure scanners installed in the rear part of the tail boom.

2.1.3. Unsteady pressure measurements

In addition, 8 unsteady pressure transducers (Kulite sensors) were mounted into the rigid strips and were positioned upstream and downstream the blade plane (Figure 11).

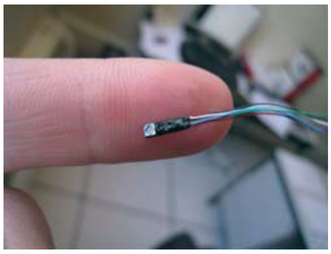

Figure 10: Unsteady pressure transducer Kulite

These LL-072 Kulites were chosen because of their small size, good resistance to vibration and shock, high frequency response and wide temperature range.
Due to the very high thinness of the connecting wires (Figure 10), the integration of these sensors was very delicate and some of the wires were broken when the rigid strips were stuck on the fuselage.
Repairs were necessary but in the end tests were carried out with only 4 Kulite sensors operational because repairing required the detachment of the rigid strips, a long and delicate work which was not done due to time constraints.

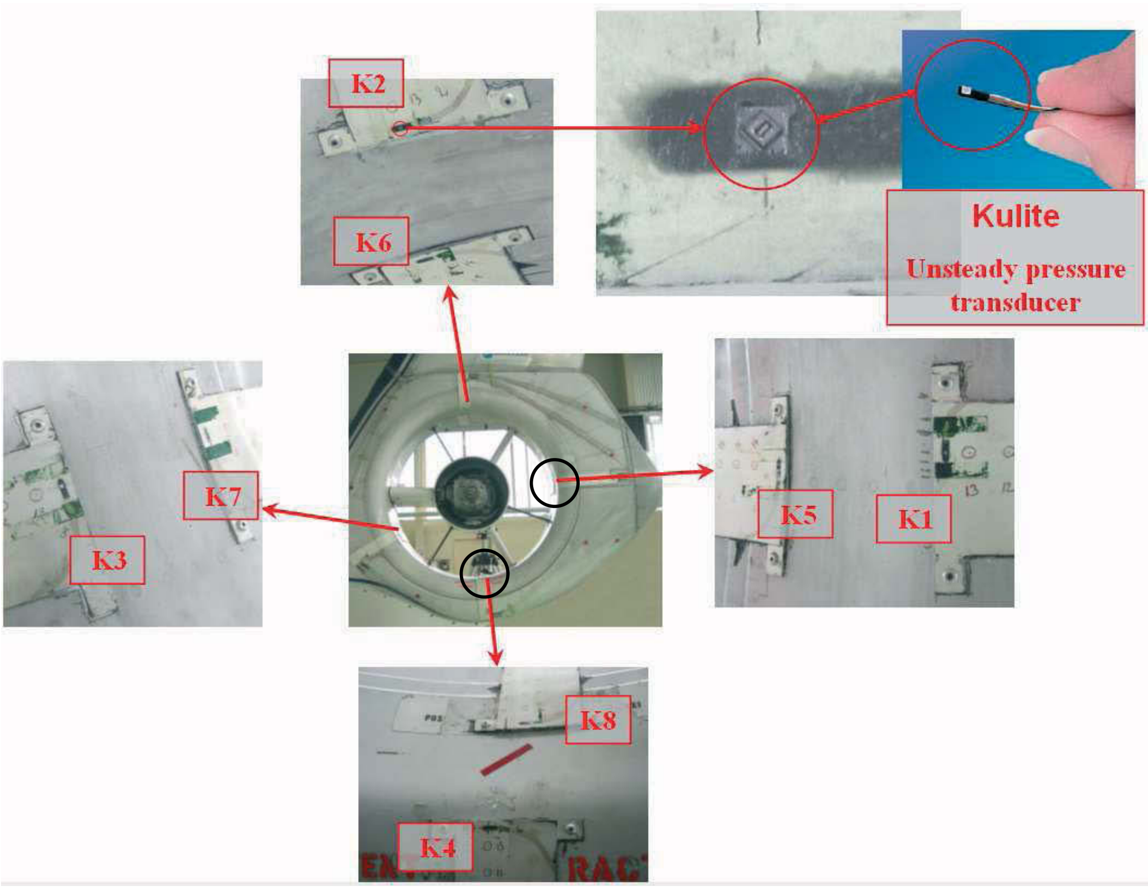

Figure 11: Unsteady pressure transducers in the Fenestron duct

2.1.4. Aerodynamic measurements

Another objective was to measure the speed profile in the Fenestron duct by means of 3 measurement combs radially placed in the Fenestron.
Each of them was supporting 5 pitot tubes providing the local kinetic pressure and one 5-holes probe providing in addition the measurement of the local incidence and sideslip angles.
The Pitot tubes and of the 5 holes probe were positioned respectively as follows: at 20% 35% 50% 65% 75%(5 holes probe) 85% of the radius
These positions are provided in percentage of the height in the Fenestron duct (0% corresponding to the centre of the rotor hub).
Calibration functions of the measurements in incidence, sideslip and speed were carried out in the subsonic wind tunnel S45 at ONERA Lille (Figure 12).
The calibration was made at three speeds of 20m/s, 40m/s and 60 m/s and for an angular domain of ± 40° for the incidence and ± 60° for the sideslip.

Figure 12: Calibration in wind tunnel

Attachment of the combs in the Fenestron duct has been achieved by Eurocopter.
The following figure (Figure 13) shows the position of the 3 combs in the Fenestron. 16 vinyl tubes came out from each comb and had to be guided and connected to the mini electronic pressure scanners installed in the rear part of the tail boom.

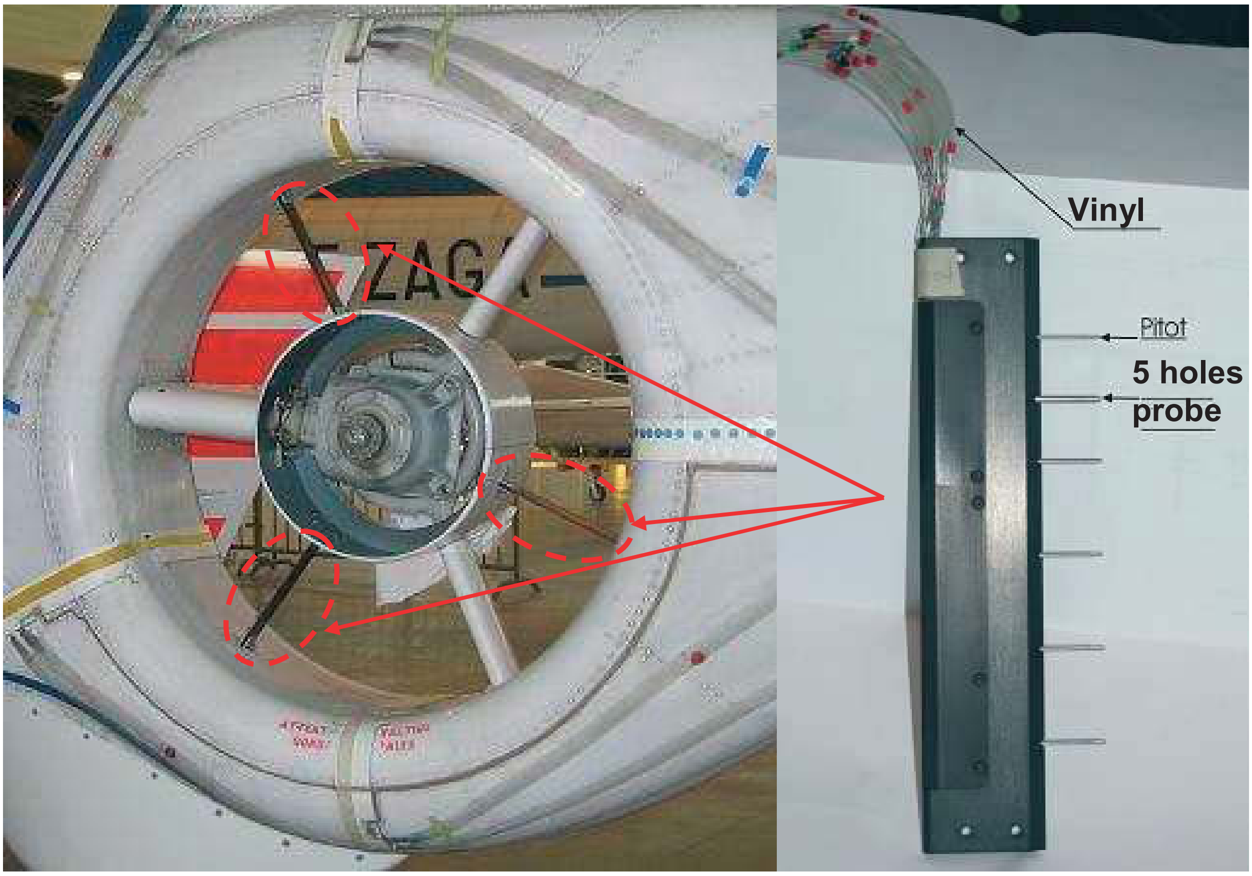

Figure 13: Aerodynamic measurements

2.1.5. Signal synchronization

As it will be explained later, sensors were also installed on the blades of the rear rotor rotating at a speed close to 5,000 RPM.

A specific device was elaborated to synchronise the signals emitted from two sets of instruments: the inboard instrumentation which is fixed to the helicopter and the rotating instrumentation which is fixed to the rear rotor.

One LED (Light-Emitting Diode) was fixed near the tail rotor hub (in the fixed instrumentation reference system), one other was mounted on the rotor (in the rotating instrumentation reference system) and two photoreceptors diametrically positioned to the LEDs which detected their signal passing in front of them.

To be installed around the hub and the rotor, specific supports were built by Eurocopter and installed on the tail rotor hub by the CEV (Figure 14).

Figure 14: LED and photoreceptor supports

The following figure shows the LED and the photoreceptor mounted around the rotor hub (fixed instrumentation).

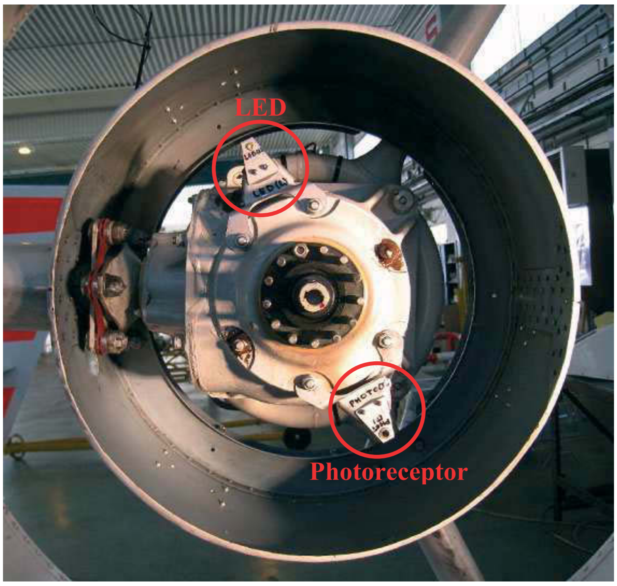

Figure 15: synchronizing signals

The hub is in the centre of the figure, the LED is in the upper part of the hub and the photoreceptor at the right bottom.

2.1.6. Fixed instrumentation chain

For the fixed instrumentation chain, a data acquisition subsystem (DAS), on the shelf, named ACRA Control KAM-500 has been used.

The basic unit of the DAS is referred to as a chassis. This chassis includes one power supply and a data encoder module. The encoder module controls the chassis and outputs the acquired data in a pulse-code modulated (PCM) digital data stream. The KAM-500 chassis consists of a power supply and individual slots for the various modules (DAM: Data Acquisition Module) to interface with the sensors.

Coming from the static pressure measurements (combs, rigid and flexible strips), the vinyl ducts are dispatched in 5 mini electronic pressure scanners of 32 channels each. These pressure scanners are measuring a differential pressure which is referenced to the helicopter static pressure. They are implemented in the rear part of the helicopter in the tail fairing as shown in the next figure (Figure 16).

There are totally 154 channels of pressure measures, that is a high density of vinyl ducts and a complex arrangement.

The pressure ranges of these scanners are:
± 0.7225 psi; ± 0.7225 psi; ± 0.7225 psi; ± 1 psi and ± 2.5 psi

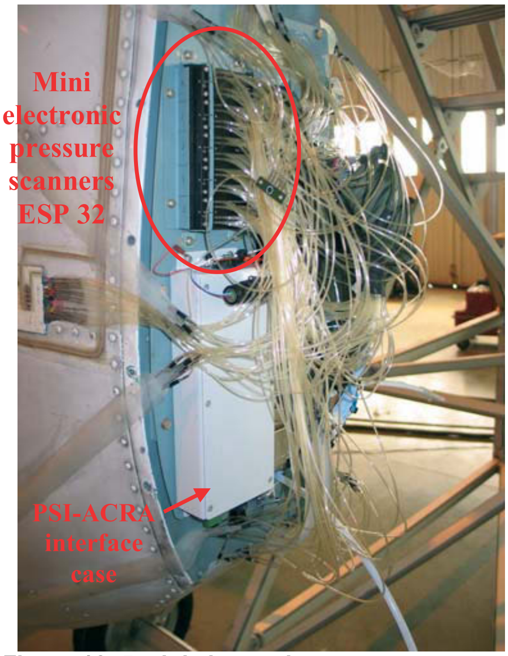

Figure 16: 5 mini electronic pressure scanners

The three different types of pressure sensors are controlled by the electronic pressure scanners, themselves controlled by the ACRA module KAD/MDC/001. The power supply, not provided by the ACRA module, is then furnished by means of a specific electronic interface receiving the 28V from the helicopter and connecting all pressure sensors to the ACRA modules

Pressure measurements are connected to the ACRA module KAD/MDC/001 and the different temperature measurements (from Kulites and pressure scanners), the synchronization signal and the helicopter static pressure are linked to the ACRA module KAD/ADC/014.
Others ACRA modules were used for the unsteady pressure transducers, the microphones and the Dauphin IRIG time code.

In order to provide the bandwidths, the acquisition frequencies and the cut off frequencies of the signal filtering as shown in table 1 for the different types of sensors, a complex PCM stream was coded. In this PCM stream, data words are 12 bits in length.

Sensor	Bandwidth	Acquisition frequency	Cut off Frequency	ACRA Module
Microphone	20 kHz	80 kHz	Fs/4	ADC/010/B
Unsteady pressure	5 kHz	20 kHz	Fs/4	ADC/109/S1
Synchronisation signal	100 Hz	10 kHz	Fs/4	ADC/014/C/10V
Temperature et Static pressure	100 Hz	312.5 Hz	Fs/4	ADC/014/C/10V
ESP 32	100 Hz	208.33 Hz	Fs	MDC/001

Table 1: Sensor specifications

2.1.7. Topographical mapping of the sensors

The location of the different sensors was very precisely determined by the CEV by means of a laser measurement system. These data will allow performing accurate comparisons between CFD calculations and in-flight measurements. 132 measures were performed with a precision of ±0.5mm.
Figure 17 shows the helicopter installed on hydraulic jacks (to reproduce a level flight) and the laser device.

Figure 17: Positioning of the sensors in the helicopter frame

2.2. Rotating instrumentation

One of the main challenges of this instrumentation was to be able to get measurements from sensors installed in a rotor turning at a rotation speed close to 5,000 RPM.
The sensors are installed on four blades of the tail rotor to deliver the following measurements:

- Pressure
- Temperature
- Strain gauges

The challenge was especially tough because the instrumentation and the batteries were submitted to high centrifugal strains.
The instrumentation had to be perfectly sized and computed to comply with the geometry of the Fenestron hub. A fast-rate telemetry was designed and built to transmit all the measurements performed in the rotating rotor to a high-capacity recorder installed in the helicopter cabin.

2.2.1. Blades instrumentation

Unsteady pressure measurements on the blades are important features to explain the particular noise which can be encountered in flight with the Fenestron. For this purpose unsteady pressure transducers Kulites LL-072 were also installed on 5 blades of the rotor.
One blade was equipped with 4 Kulites (2 on the extrados, 2 on the intrados) at different radius (0.7R and 0.9R). Figure 18 shows this blade.

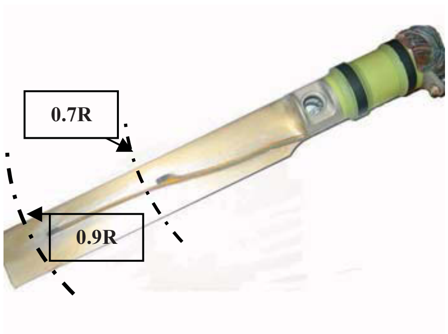

Figure 18: Blade instrumented with 4 Kulites

Moreover 3 blades were equipped with 2 Kulite sensors on the extrados and intrados at 0.7R as represented in the following figure (Figure 19).

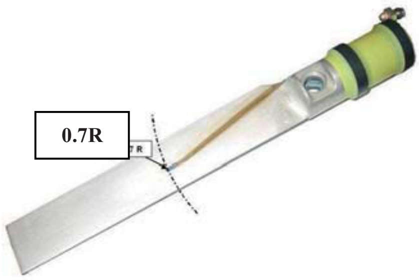

Figure 19: Blade instrumented with 2 Kulites

In order to avoid as much as possible any undesirable aerodynamic disturbances, the unsteady pressure transducers were flushed mounted on the blades. However this structural modification of the blades conducted to a slight structural weakening of these elements which consequently required to use specific procedures and equipments in flight to limit occurrence of high loads, to visualize loads on blade and guarantee safety.
Hence in flight to monitor in real time the structural efforts on the blades, 3 strain gauges were mounted on one blade at different radius as shown in the next figure (Figure 20). This conventional blade, not weakened by the integration of any pressure transducers, was used as standard reference.

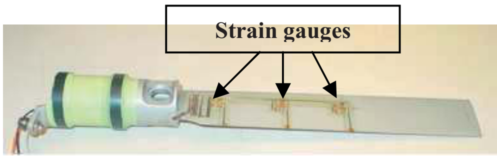

Figure 20: Blade instrumented with strain gauges

Eurocopter provided the constraint limits to consider statically as well as in dynamically.

2.2.2. Fast rate telemetry

The fast rate telemetry, installed on the rotor, has three major functions:

- Sensors conditioning (power supply, amplification, filtering);
- Acquisition of numerical signals (sampling, digitalizing and multiplexing) ;
- Radio transmission of the signals to the cabin receiver

The mechanical integration, the volume of the telemetry system and the environmental constraints were defined by Eurocopter. This innovative telemetry system was manufactured by DeKerac Company.
The telemetry was mechanically fixed at the tip of the rotation axis of the rotor. Eurocopter designed and built the mechanical support of the telemetry system. This support was manufactured to receive the electronic parts of the telemetry as well as its power supply, and its batteries located in its centre (Figure 21).

Figure 21: Telemetry support

The dimensions of this support on the tail rotor hub needed to redefine a specific rotor hub cover, larger than the conventional one (Figure 22).

Figure 22: New rotor hub cover

The transmission of the data was ensured by an antenna fixed in the centre of the telemetry support. The part containing this antenna is shown in the next figure (Figure 23). The antenna is located inside the black part in plastic. The metallic piece below closes the batteries container.

Figure 23: Rotating antenna

For safety reason the telemetry was operated during the whole flights in order to record the loads the blade was submitted to. This specification reduced the autonomy of the telemetry to 1h20min.
A telemetry receiver installed in the cabin was in charge of the telemetry reception.
Electromagnetic compatibility was verified and the frequencies of the telemetry and the receiver were carefully chosen to avoid any disturbances with other frequencies used on-board as IFF (Indicator Friend Foe) or radios. To

get the best transmission efficiency, the location of the fixed antenna was finally chosen behind the port side door as illustrated in Figure 24.

Figure 24: Fixed antenna

As mentioned before, the telemetry power supply consisted in batteries which were mounted on the telemetry support at the tip of the rotor axis and radially centred. At this place, due to the thermal radiation of the oil in the rotor transmission system, and due to the possible ingestion of warm engine exhaust flow in the rear rotor hub, it was suspected that the temperature in the rotor hub could increase significantly in some cases. To avoid any failure or damage of the batteries caused by an excessive temperature, thermo sensitive papers were preliminary placed near the rotor hub to measure the highest temperatures which were reached in flight.

Hereafter, a picture of the three different electronic parts of the in-rotor telemetry system (Figure 25).

One part is dedicated to the signals conditioning, one another to the acquisition of data and the third one to the radio transmission.

One main problem was to build electronic cards on a circular support.

Another important aspect was the very high centrifugal efforts to which the electronic components were submitted during flights since they were turning at the nominal RPM of around 4700. In the figure 25, are mentioned the centrifugal forces as induced by the rotor rotation speed at two different locations in radius. In these conditions, the centrifugal acceleration increase which respect to its radial location at a rate of 247g/cm. Of course, these constraints were taken into account and the heavier electronic components were, as much as possible, placed near the centre of rotation.

To connect the Kulite sensors and the strain gauge wires to the telemetry, it was decided to use OMNETICS miniature connectors as shown in figure 26.

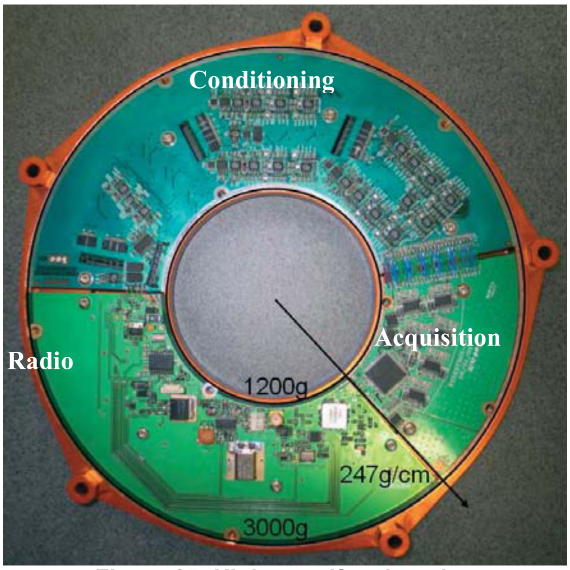

Figure 25: High centrifugal strains

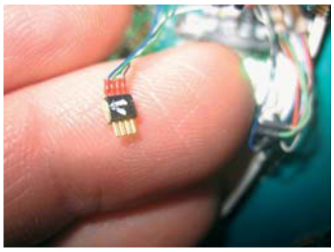

Figure 26: OMNETICS miniature connector

The wires and the OMNETICS connectors are linked to 15 slots (10 Kulites, 3 strains gauges, 1 synchronising signal, 1 frame counter) of the conditioning part of the telemetry (Figure 27). This type of connection allows an easier disassembly of the rotor instrumentation, that is very appreciable in case of failure or maintenance.

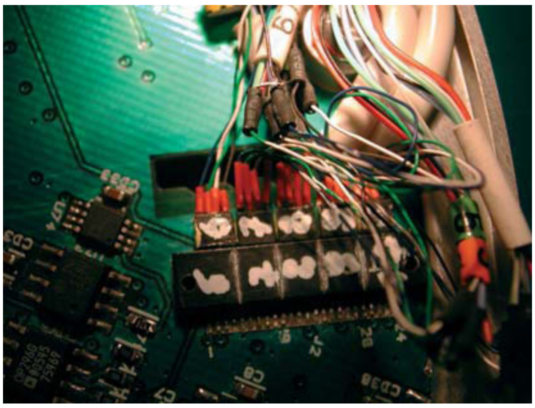

Figure 27: OMNETICS connectors linked to the conditioning part of the telemetry

In order to verify the good behaviour of the rotor equipped with the instrumentation with regards to vibrations, vibratory tests were performed (figure 28). The complete rotor was excited on two axes at different frequencies.
Moreover, as mentioned before, the nominal RPM of the tail rotor is 4700 rev/min with a transient maximal value of 5650 rev/min. In those conditions, a very precise dynamical balancing of the rotating system was required. A maximal unbalancing of 40 millimetre- grams was specified by Eurocopter.

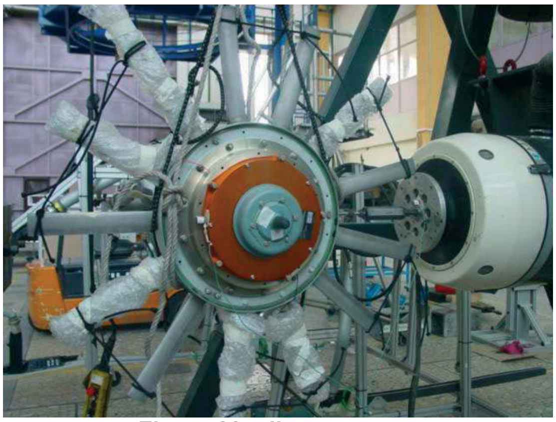

Figure 28: vibratory tests

The instrumented rotor was then balanced and a good functioning of the telemetry was first demonstrated in rotating conditions (Figure 29).
This first test performed in conditions close to flight conditions revealed that the centrifugal forces applied on the OMNETIC connectors could tear away and disconnect some of them from the telemetry slots.
For that reason, an aluminium ring was designed and mounted on the electronic cards of the telemetry to maintain them (Figure 30).

Figure 29: rotor balancing

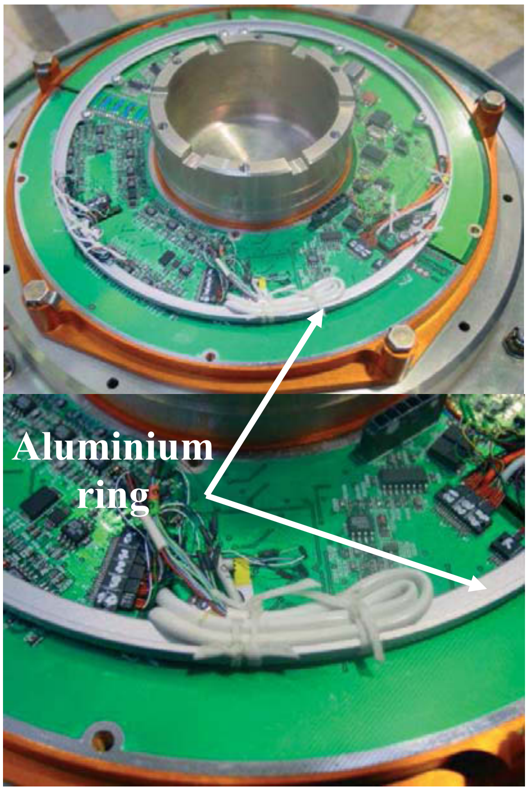

Figure 30: Aluminium ring

Due to the precision requirements of the measurements, the signals were coded on 16 bits.

A LED and a photoreceptor were fixed on the rotor to provide synchronising signals in the fixed and rotating measurement chains. One channel in the telemetry PCM stream was then dedicated to the rotating photoreceptor signal.

2.3. On-board data acquisition system

Three PCM are generated by the on board system:

- 1 PCM from the ACRA System, delivering a bite rate of 7.680.000 (bit/s) for the fixed instrumentation.

- 1 PCM from the telemetry system, with a bite rate of 5.376.000 (bit/s) for the rotating instrumentation

- 1 PCM from the basic instrumentation of the helicopter, with a bit rate of 106.496 (bit/s) incorporating the helicopter flight parameters.

These three PCM are stored on a numeric hard disk data recorder MESSIE DS2100 (from Enertec company).

3. FLIGHT TESTS

Flight tests were conducted in taking into account the very specific constraints due to this unique instrumentation.
As mentioned before, in order to avoid as much as possible any undesirable aerodynamic disturbances, unsteady pressure sensors were embedded in the blade profile. This structural modification of the blades conducted to a slight weakening of these elements which consequently required to use specific procedures and equipments in flight to prevent high load on blades and to visualize loads in real time to guarantee safety. During preliminary flights, conventional take-off procedures were used and hovers at different headings were carried out to evaluate the static and dynamic loads reached on the blades. It turned out that conventional take-off procedures (especially hover) had to be abandoned in favour of a rolling take-off.
Strain gauges were analysed by the CEV after each flight to verify if the tolerance relative to the blade loads in terms of dynamic constraints were respected. This was a request from Eurocopter which also specified that the strain gauges had to be monitored in real time during the flights.
This specification led to the development of a specific device installed in the helicopter cabin to monitor the blades loads (Figure 31). Hence, static and dynamic constraints (respectively left and right columns) on the gauges (jauge in the figure) were visualized by the flight engineer on a dedicated display as shown here after.

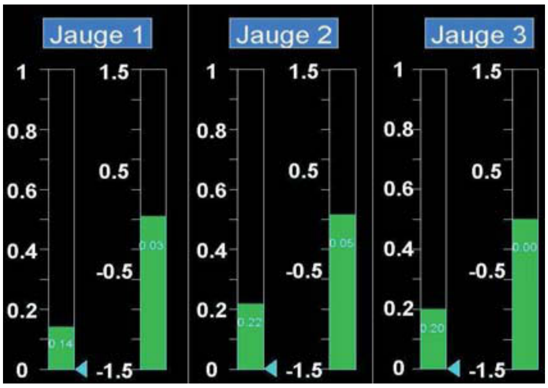

Figure 31: Blade strains monitoring in real time

Indeed, the main risk in flight was the break up of one of the instrumented blades which could generate a rotor unbalance. In this situation, the loss of all blades has been considered as being highly probable and the loss of yaw control as a result. For airspeeds higher than 55 kts, the fin can maintain the helicopter in straight line flight with sideslip. Below 50 kts, Eurocopter estimated that the yaw control is not ensured. Taking into account these recommendations, the lower airspeed in flight was fixed to 50 kts and conventional take-off and landing procedures have been abandoned in favour of a rolling take-off between 0 and 50 kts.
Moreover, in case of loss of the telemetry monitoring, specific instructions were established in order to allow the crew to minimise the blade loads (safe flight domain) and to land in the best conditions of safety.
Based on the recommendations of the CEV, a flight test program was defined by ONERA and Eurocopter (Figure 32) in order to identify the flight conditions when the Fenestron is noisy.

Take off

	55 kt	75 kt	90 kt
+500 ft/mn	P3	P3	P3
+750 ft/mn	P3	P3	P3
+1000 ft/mn	P3	P3	P3
Vz max	P2	P1	P2

approaches

	50 kt	60 kt	75 kt	90 kt	105 kt	120 kt
+250 ft/mn	P3	P3	P3	P3	P3	P3
-250 ft/mn	P3	P3	P3	P3	P3	P3
-500 ft/mn	P2	P3	P3	P3	P3	P3
-800 ft/mn	P3	P3	P1	P3	P3	P3
-1000 ft/mn	P2	P3	P3	P2	P3	P3
-1250 ft/mn	P3	P1	P2	P3	P3	P3
-1500 ft/mn	P3	P3	P1	P3	P3	P3

Level flights

	50 kt	60 kt	75 kt	90 kt	105 kt	120 kt	135 kt	150 kt
0 ft/mn	P2	P2	P2	P2	P2	P2	P1	P1

Level flights with sideslip

	75 kt / +15°	75 kt / -15°
0 ft/mn	P2	P2

Figure 32: Flight test program

The test program was compounded of different flight phases: take-off, approach phase, level flight, sideslip flight. For each flight phase different flight cases corresponding to various horizontal and vertical speeds were carried out.

Selected flight cases were repeated in order to validate the good agreement of the results between different flights.
Thus, the flight case 75 kts and -800 ft/min was repeated at each flight as a reference case.
The flight cases noted P1 and P2 (Priority 1 and 2) in the flight test program were flown three times in the entire flight test campaign.

In the beginning of the campaign, it was established that the on-board radio could disturb the telemetry signals so that the radio messages were then limited as much as possible during the measurement flight cases.

The in-rotor batteries needed for the telemetry system had 1h20min of autonomy, this feature had obviously an impact on the duration of the flights. Nevertheless, after a training phase the pilots could achieve around 20 flight cases in one flight which helped to finish the flight test program in time.
Due to the large number of sensors recorded and the high acquisition frequency of some of them, a huge amount of data was acquired and the time needed by the CEV to provide them in an appropriate format was around three days. Adding the time needed to analyse the loads obtained

in flight on the blades and the time needed to obtain the next flight authorization, only one flight per week was possible during this campaign.

For all flight tests, the actual atmospheric conditions were very important characteristics which sized the duration of the test campaign. Requirements for the flight cases were very precisely fixed, atmospheric perturbations, wind and gusts had to be low as much as possible. But during this campaign, specific meteorological constraints had also to be taken into account: humidity and moreover, rains, had to be avoided to protect the microphones. And finally, the outside temperature had to be lower than 30° to avoid any detachment of the flexible strips caused by the degradation of the silicon glue. But flying from October to January prevented us from high temperatures.

4. RESULTS

4.1. Flight test campaign

The first campaign has been carried out from November 2008 to January 2009.
The entire flight test program was successfully achieved in eight flights and 11 flight hours.
Some sensors failed during the flights but the overall instrumentation gave very satisfactory results.
Actually, the unique and innovative features implemented on the Dauphin and the successful achievement of the first flight campaign provided a fairly complete aerodynamic and acoustic database relative to the flow and noise mechanisms in which the Dauphin Fenestron is involved.

4.2. Instrumentation

The fixed instrumentation worked perfectly during all flights. Only a few pressure sensors or taps turned out to be unserviceable and one pitot tube mounted on an aerodynamic measurement comb came to be obstructed.
Comparisons between flight test measurements and aeroacoustic computation code results will be provided by aerodynamics and aero-acoustics departments of ONERA in other papers to be published.
Regarding the instrumentation installed on the rotating parts, the outcome has to be tempered. The fast rate telemetry perfectly worked but due to the very high centrifugal constraints, some problems occurred with different connecting wires.
Indeed, in the first flights dedicated to the determination of the flight test envelope, the synchronizing signal mounted on the rotor was lost. It was rapidly discovered that the wire between the telemetry and the photoreceptor was broken.
The loss of this signal in rotating instrumentation chain unfortunately prevented the possibility of synchronising the two measurement chains. As discussed after, another way to count the tail rotor RPM was observed but it was not sufficiently precise to be used to precisely synchronise fixed and rotating measurement chains.

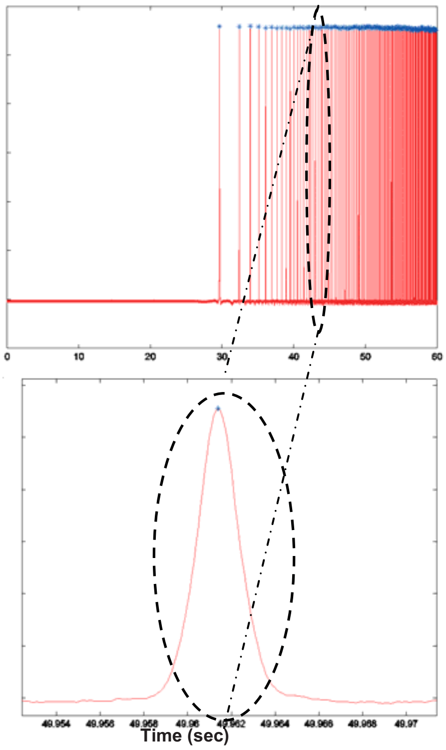

Figure 33: Synchronising signal at the engines start

In fixed parts, the synchronizing signal worked during all the flight test campaign. The previous figure represents the synchronizing signal recorded at the engines start (Figure 33). Blue stars identify the precise time of the passage of the LED in front of the photoreceptor (a zoom is presented in the lower part of the figure).
But when the rotor was dismantled, it appears that the LED was almost teared out (Figure 34).
The glue used was not adapted to such high centrifugal loads.

Figure 34: LED in rotating part

Some measurements on the blades were also progressively lost during the campaign, connecting wires being teared out by the centrifugal forces. Due to time constraints repairing was impossible, and finally only four Kulite sensors situated on two blades were still correctly working at the end of the flight tests.
The aluminium ring was very efficient and the mini OMNECTICS connectors remained attached to the slots.

4.3. Flight data

4.3.1. Microphones

Acoustic results will be deeply analysed by DSNA but some measurements from the microphones can already be shown. In the next figure (Figure 35), a Fast Fourier Transform reveals the fundamental frequency and harmonics of the main rotor captured by the first microphone. As expected, fundamental frequency of a four bladed rotor turning at around 352rev/min is well measured and equal to 23.46 Hz.

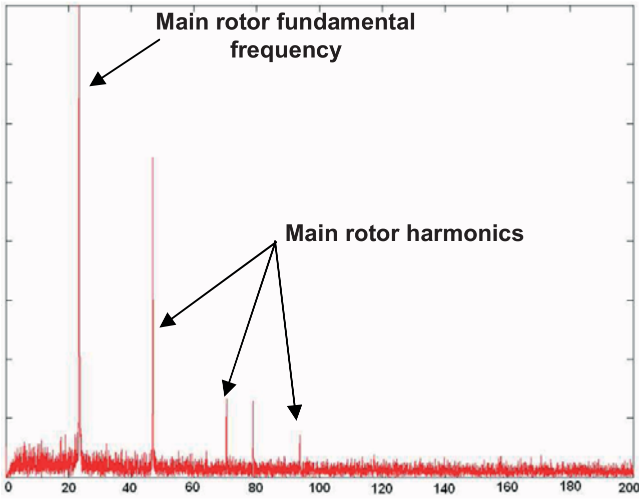

Figure 35: Main rotor frequencies

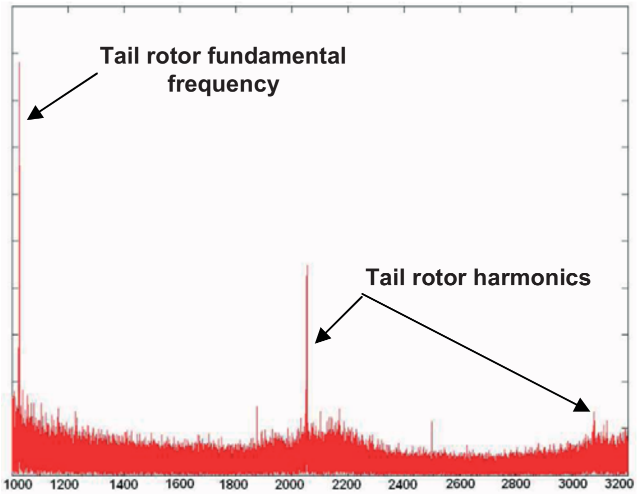

Figure 36: Tail rotor frequencies

During this stabilised flight case, the tail rotor turned at around 4734rev/min. Figure 36 shows the fundamental frequency and harmonics of this 13 bladed tail rotor. In these conditions, its first harmonic is equal to 1025.7 Hz.

4.3.2. RPM counter

As mentioned before, a “physical” way to count the tail rotor RPM was observed on the strains gauges. Indeed, analysing the recorded data from the blade gauges revealed periodic peaks on the strains as shown in the next figure (Figure 37). The period between each peak corresponds to the rotor RPM.

In this example, the time between two peaks is around 12.91 ms, corresponding to a rotor RPM of about 4645. This phenomenon was observed in all flight cases independently of the loads applied on the rotor. This led us to the conclusion that this rather high level of dynamic loads is certainly due to the passage of the blade in front of the tail rotor drive. The tail rotor drive careenage is a rather large metal piece placed in the Fenestron duct as it can be seen in figure 38. It probably creates locally a very disturbed airflow which causes blade flapping and then, alternated strains.

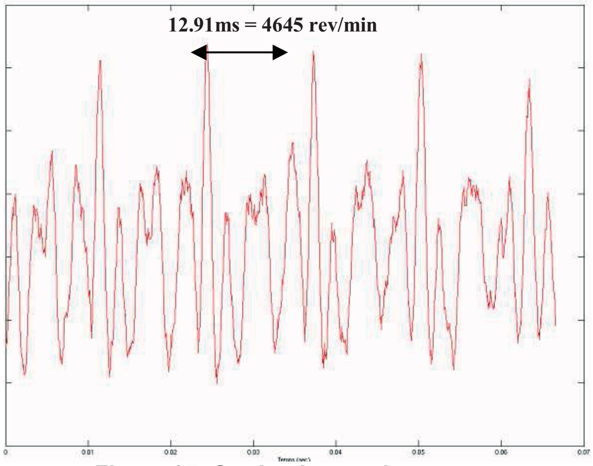

Figure 37: Strain observed on gauge

Figure 38: Tail rotor drive in Fenestron duct

Certainly based on aerodynamic disturbances due to the presence of the tail rotor drive, the accurate position of the blade when the peak occurs is not known.

This “physical” RPM counter couldn’t be used to synchronise the fixed and rotating measurement chains with the required precision but allowed us to verify the lack of transmission delays on the telemetry stream.

4.3.3. Aerodynamic measurements in the Fenestron duct

Aerodynamic measurements were performed very close to the tail rotor plane. As represented in figure 39, the 5-holes probes mounted on the combs provide the measurement of the local incidence and side slip angles.

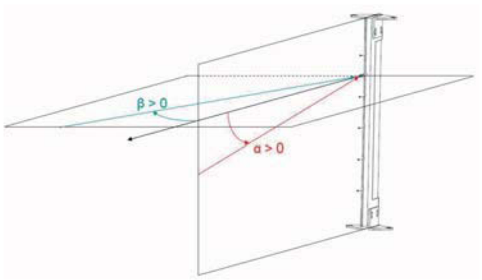

Figure 39: Incidence and sideslip provided by the 5 holes probes

In the next figure (Figure 40) is presented an example of aerodynamic measurements provided by one 5-holes probe. The flight case was a level flight at 60 kts.
During these 20 seconds, the airflow was relatively steady. The airflow velocity is around 60 m/s with small values of incidence and side slip, indicating a flow nearly parallel to the Fenestron duct.
But flight phases during which such measurements are available are not numerous. Available data were mainly observed at low forward speeds and in climb, when the loads on the rotor are high.
At high forward speeds, very few measurements were available, indicating that the probes were badly positioned and/or that the speed of the flow was too small to be measured. This low level of speed in the flow can be explained by the fact that at high airspeeds, the fin becomes more and more efficient and the loads on the tail rotor, such as the induced velocities, are highly reduced.

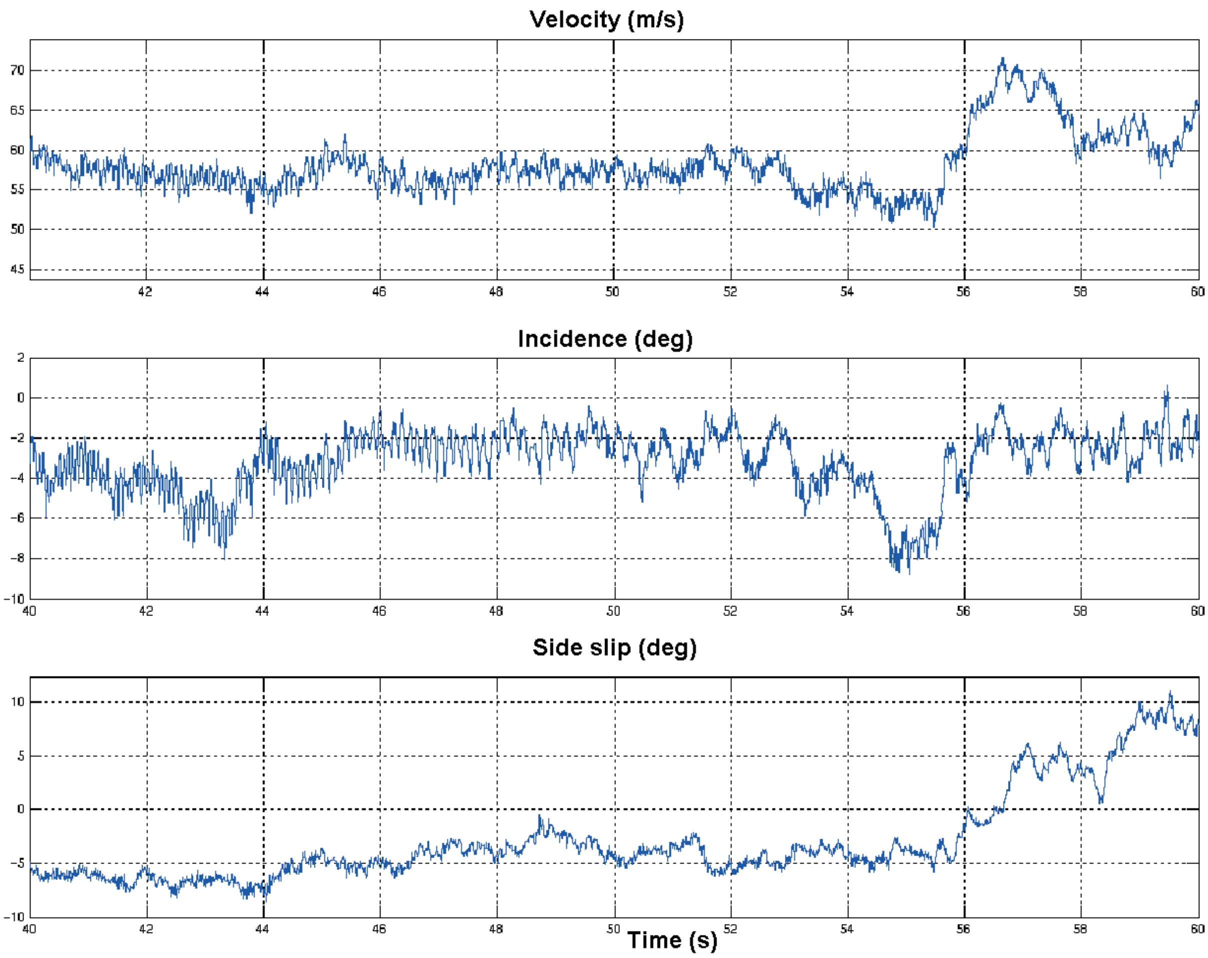

Figure 40: Airflow measurement provided by the 5 holes probes

Analysis and comparisons between airflow measurements and flight mechanics codes will be performed, allowing possible improvements of the current Fenestron models.

5. NEXT STEPS

Another test campaign, planned to begin in September 2009, will be conducted to provide acoustic footprint measurements on the ground in the most noisy flight conditions as identified in the course of the first campaign.
In this campaign, the aerodynamic measurements in the Fenestron will not be performed and the combs have been dismantled from the Fenestron duct. As these combs were fitted into the rotor airflow, a flight will be carried out in order to compare the noise levels with and without these intrusive sensors.

6. CONCLUSIONS

- A very innovative instrumentation and measurement chain architecture was designed, achieved and tested by the Department of System Controls and Flight Dynamics (DCSD) of ONERA, Eurocopter and the CEV
- The entire flight test program was successfully performed in eight flights from October 2008 to January 2009
- The successful achievement of the first flight campaign, which is the result of a five years' work, provided a fairly complete aerodynamic and acoustic database relative to the flow and noise mechanisms in the Fenestron of the Dauphin.
- This complete database should enable to improve the current Fenestron models in flight mechanics codes.
- Analysis and comparisons between flight test measurements and aeroacoustic computation code results are in progress and will be provided by aerodynamics and aero-acoustics departments of ONERA in further papers

7. ACKNOWLEDGEMENTS

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Finally, we all have a very special thought to Franck Descatoire from DCSD who worked from the very beginning of this program in the design, the development, the integration and the testing of the entire instrumentation and who passed away after a long disease just two days before the first flight.