ACOUSTIC LINERS INTEGRATION ON A TURBOSHAFT ENGINE

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1. Abstract

This article presents the study of acoustic liners integration on a turboshaft engine. It was conducted by Turbomeca in co-operation with Eurocopter and was funded by SPAè as part of the Silent Helicopter Project (DTP HS) from 1994 to 1999.

Both air intake and exhaust insulation are considered:

- On the air intake side, several plenums were devised, manufactured and tested. The liner is an Helmoltz resonator tuned to attenuate the blade passage frequency of the 1st stage compressor. The results are convincing and demonstrate that a significant noise reduction (up to 15 dBA) can be achieved.
- On the exhaust side, an innovative design was performed. A patent was submitted and accepted [2]. The concept is a multi-duct channel treated with a metallic felt over a cavity with non constant depth. This device allows to conjugate a good aerodynamic performance with a significant noise reduction (up to 10 dBA) in a reduced axial length.

The effects on performance and weight were studied and are discussed in the article. The solution achieved is a good compromise between noise reduction and performance penalty. Moreover, further optimisations (by improvement of aerodynamic and acoustic performance, use of cheaper and lighter materials) seem achievable and are currently being studied in FP5 on-going projects (HORTIA, SILENCER).

2. Introduction.

The noise sources of turboshaft engines, installed on helicopter, radiate essentially through the opening of the air intake and exhaust ducts.

- At the air intake, the major noise source is due to the first compressor stage (tone noise at the blade passage frequency and broad band noise in the range 1kHz to 6 kHz)
- At the exhaust, the noise is a combination of four noise sources:
  - A broadband noise generated by the combustion in the frequency range of 200 Hz to 630 Hz.
  - The core noise, a broadband noise in the medium frequency range from 1 kHz to 4 kHz generated by the air flow, turbulence and rotor/stator interactions in the global turbine flow path.
  - The turbine blade passage frequency which is a pure tone noise in the very high frequencies, above 18 kHz.
  - And finally, the jet noise, which is a negligible noise source in a turboshaft engine due to the low exhaust gas velocity.

The engine noise repartition between air intake and exhaust noise highly depends on the installation of the engine on the helicopter. When the compressor noise is shielded (cut-off effect of the inlet duct or mask effect of the engine compartment), the exhaust noise may even become dominant. It is therefore necessary to develop liners for both air intake and exhaust nozzle.

This article presents the work carried out by Turbomeca in co-operation with Eurocopter in a French research program (DTP HS), funded by SPAè from 1994 to 1999. In a first part, the article will present the noise reduction devices applied in this project for both air intake and exhaust nozzle. Then after a detailed presentation of the Turbomeca acoustic test bed, the results of measured engine noise reduction will be presented and discussed.

3. Air intake treatment

The air intake can be axial or annular depending on the compressor nature (axial or centrifugal). When the compressor is centrifugal, the annular air intake is included in a plenum. The easiest way to insulate the air intake is to then integrate a liner in the plenum in order to reduce the tone noise of the 1st stage compressor.

The liners presented in this research project are of Helmotz resonator type: a resistive layer of metallic felt over honeycomb cavities which thickness is tuned to attenuate the blade passage frequency noise. In order to maximise the treatment area, a liner is positioned on the walls of the plenum and on several winglets added in the inlet.

Three plenums were designed, manufactured and tested in this study (figure #1):

- The reference plenum is the non treated EC120 air intake plenum.

- The so called standard plenum has the same volume as the reference plenum. It includes wall and winglets liners.
- The so called acoustically optimised plenum. The volume of this plenum is bigger than the reference one in order to compensate the losses of aerodynamic section due to the obstruction of the winglets.

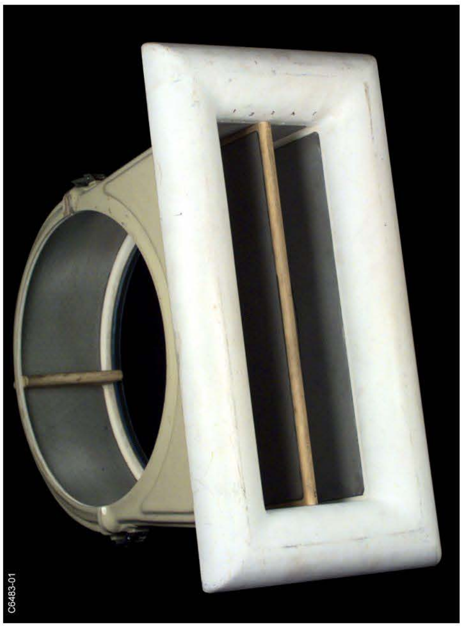

Figure #1: Acoustically treated plenums

4. Exhaust Nozzle treatment

The exhaust noise is a different problem to tackle. The main difficulties to address are the following:

- The noise attenuation must be carried out over a very wide frequency range from 1kHz to 4 kHz.
- The liner should be able to withstand the high temperature environment at the outlet of the engine.
- the aerodynamic performances of the treated nozzle should be good. A clean flow diffusion must be insured.

The whole project has been conducted with those very restrictive constraints.

An innovative exhaust device was designed, manufactured and tested on the Turbomeca acoustic test bed. A patent has been submitted and was recently accepted [2]. The exhaust nozzle is made of a multi-duct channel. Two liners were tested:

- an Helmoltz resonator type with non constant cavity depth and a resistive layer made of metallic felt,
- the other made of glass fibres contained in perforate.

The multi-duct channel concept has been designed in order to achieve a high pressure recovery coefficient without increasing the axial length of the nozzle. Moreover, this solution makes available a large surface that can be treated leading to a very good acoustic attenuation. In the present case, the treatment area was more than doubled with respect to a standard single channel nozzle.

The liners that have been tested are of Helmoltz resonator types over a non constant cavity depth. This characteristic allows to tackle the problem of the wide frequency range of the noise

Both liners are able to withstand the high temperature environment at the outlet of the engine.

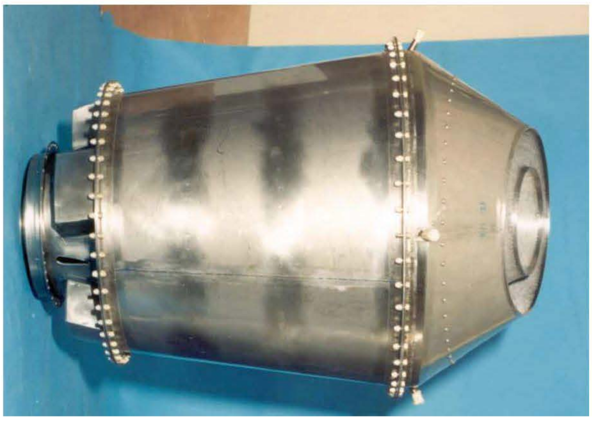

Figure #2 : Multi-duct exhaust device

5. Acoustic tests

Test bed description

The tests are carried out at the TURBOMECA acoustic test bed which is located near the PAU-UZEIN airport (figure #3). The test bed enables the acoustic emissions of the turboshaft engines up to a shaft power of 2000 kW to be measured.

The measurement area of the turboshaft engines is made up of a uniformly reflective concrete ground. The engine axis is 3 meters high and installed in the acoustic area center. Acoustic measurements are carried out in far field, at R=19.2 meters for 19 circular positions from 0 degree in front of the engine to 180 degrees behind, at 10 degree intervals.

The acoustic measurements are performed using 3 microphones. These microphones are located on a moving platform, which can be remotely controlled from the acquisition room. At each measured location, the platform is stopped for acoustic data acquisition.

A meteorological station, fitted 3 meters above the ground, enables complete recording of meteorological conditions (Temperature, relative humidity, atmospheric pressure, wind speed and wind direction).

Figure #3 : Aerial view of Uzein acousticTest Bed

This station enables to verify that the atmosferic conditions are within the following limits during the measurement and to record environmental data.

- Wind velocity < 5.2 m/s (10 knots)
- Relative humidity : 30% to 90%
- Ambient temperature : 2°C to 35°C
- Barometric pressure : 800 to 1100 hPa
- No precipitation present.

The control room and the acoustic acquisition room are located on the other side of the measurement area. The control room is for operating the engine and also for recording of thermodynamic parameters. Control of the movable platform, the acoustic measurement equipment, the meteorological recordings as well as the records and data processing are located in the other room.

The measurements are transposed into "free field" conditions and adjusted according meteorological conditions with respect of the standard SAE ARP 865.

The acoustic measurements are carried out using a movable platform equipped with three microphones:

- one on the ground at h = 7 mm high
- one 3 meters high above the ground
- one 6 meters high above the ground

Microphone/preamplifier couples comply with recommendations given by the International Electrotechnic Commission (IEC – publication 179) and are compatible with the frequency range studied (16 Hz to 20k Hz).

The recording and acoustic analysis equipment is based on :

- a digital third octave band real time analyser BK2131
- a two-channel narrow band digital real time analyser BK2032
- a eight-channel multiplexer BK2811

In order to separate air intake noise from exhaust noise, a muffler can be set up on either the plenum or the nozzle.

Figure #4: muffler on the air intake (exhaust noise)

6. Air Intake Results

The acoustic tests were performed at two operating points corresponding to fly-over and take-off for ICAO certification [1].

The air intake tests were conducted with the muffler on the nozzle so that the air intake noise only could be measured. The EC120 non treated plenum was tested as a reference configuration to evaluate accurately the noise attenuation.

All results are presented in two different units :

- Delta dB(A) corresponding to the difference between maximum levels measured at 19,2m from the engine with the reference configuration.
- Delta TPNdB corresponding to the difference between maximum levels calculated at 150m sideline with the reference configuration. The maximum TPNdB level is representative for the engine at the certification points of noise annoyance following the chapter 8 of the ICAO recommendations [1]. This intermediate unit corresponds to the EPNdB unit without the duration correction of the helicopter flight.

Directivity:

The measured levels versus angle are presented in the following chart:

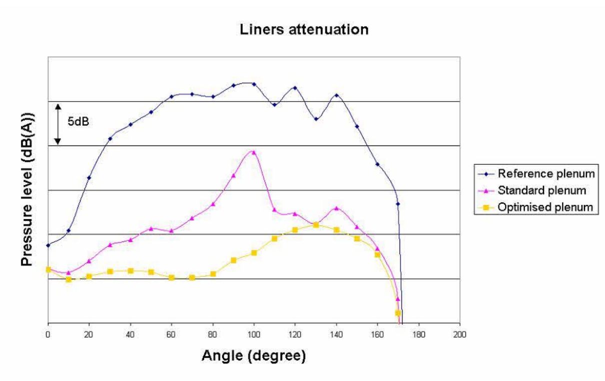

Chart #1 : Air intake noise level at 19.2m

The efficiency of the liner depends directly on the surface of treatment: on the acoustically optimised plenum, the surface treatment is higher so that the attenuation is higher as well.

The directivity is classical for a plenum and is not strongly modified by the liners.

Spectral behaviour:

The noise spectrum is presented on the following chart. Due to the nature of the resistive layer employed, we obtained a good attenuation not only at the blade passage frequency but over a large frequency range as well.

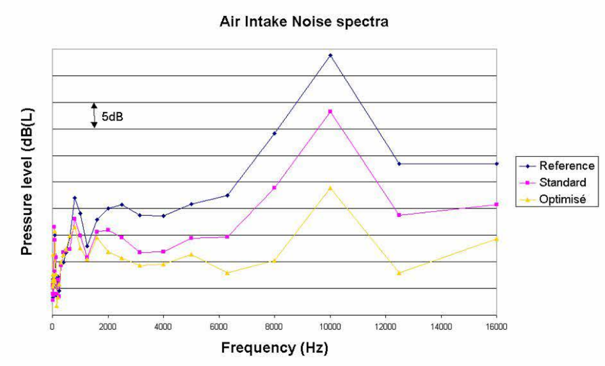

Chart #2 : Air Intake Noise Spectra

Results summary and analysis:

The global results obtained are summarised in the following table:

Configuration	Standard plenum	Acoustically optimised plenum
ΔdB(A) fly-over ΔdB(A) take-off	-10.3 -7.5	-16.6 -15.7
ΔTPNdB fly-over ΔTPNdB take-off	-8.5 -6.8	-13.9 -14.8
Δ Power (%)	-0.9%	0.5%
Δ weight (kg)	+4.7	+9.1

Table #1: Air intake noise reduction

The noise reduction obtained is very significant and the efficiency of the liners is demonstrated. Discrepancies observed between near (dB(A)) and far field (TPNdB) are small. The attenuation does not depend on the unit and will be valid even if the certification rules change.

The noise reduction is almost constant with the operating point.

The weight penalty presented here is only a status. No weight reduction study was performed. All the manufactured parts are mock-up.

From a performance point of view, the presence of winglets reduced the aerodynamic section leading to an increase of the pressure losses in the plenum. The acoustically optimised plenum took that constraint into account and the loss of power was already divided by two with respect to the standard plenum.

Additional comment:

Airworthiness aspects were not studied in the project. In particular, Icing behaviour of the liners should be studied in the future.

7. Exhaust results

The exhaust tests were conducted with the muffler on the air intake so that the exhaust noise only could be measured. The EC120 non treated nozzle was tested as a reference configuration to evaluate accurately the noise reduction.

Directivity:

The measured levels versus angle are presented in the following chart :

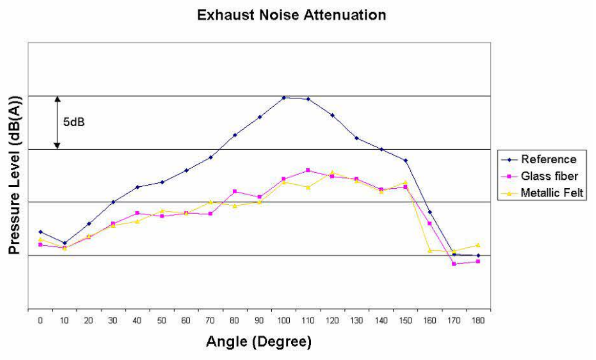

Chart #3 : Exhaust noise level at 19,2m

The two liners have a very similar behaviour. The directivity of the noise is not modified by the addition of liners.

Spectral behaviour :

The noise spectra of the three exhaust nozzles are presented on the following chart.

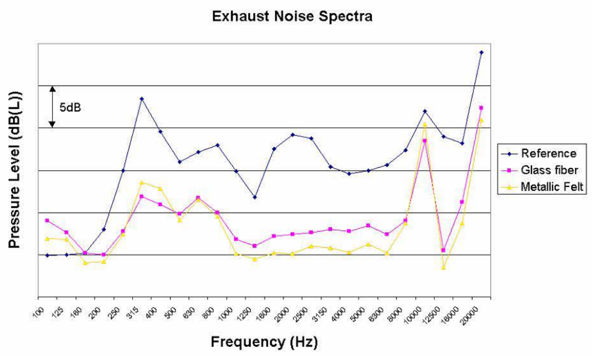

Chart #4 : Exhaust Noise Spectra

The liners were designed to attenuate the core noise which frequency range is 1 kHz to 4 kHz. The efficiency of the liners is high even at the low frequency of the combustion noise.

Results summary and analysis

The results obtained are summarised in the following table:

Configuration	Nozzle with metallic felt	Nozzle with glass fibers
ΔdB(A)	-7.8 to -9.6	-6.8 to -6.9
ΔTPNdB	-10.0 to -10.7	-8.0 to -8.9
Δ Power (%)	-1%	-1%
Δ weight (kg)	+30.5	+27.5

Table #2: Exhaust noise reduction

The noise reduction is significant with such a device: up to 9 dB(A) at 19.2m for the fly-over and take-off certification points. The multi-channel concept allows to double the treatment area leading to such good results.

The two type of liners have a similar efficiency and the noise reduction is almost constant with the operating point.

From a performance point of view, the pressure recovery coefficient is close from the coefficient of the reference nozzle and the power penalty is limited.

The main drawback of this concept is the weight penalty that makes it not suitable for a serial helicopter. The objective of the project was to demonstrate the feasibility of exhaust noise reduction. No weight reduction study was performed and all the manufactured parts are mock-up that were design without serial constraints.

Weight penalty associated with acoustic treatment being a major issue, Turbomeca has a strong research activity on that topic. Actions are currently on-going (FP5 HORTIA project) to reduce drastically the nozzle weight by using light materials such asTitanium alloys.

8. Conclusion - Future prospects

Conclusion

This article presented a research project (DTP HS) on acoustic liners integration. Insulations were designed, manufactured and tested in order to reduce the turboshaft engine noise.

It has been demonstrated that a really significant engine noise reduction is achievable by adding acoustic treatment at the inlet and exhaust of a turboshaft engine. The following noise reductions were achieved:

- Up to -15 TPNdB by treatment of the plenum.
- Up to –10 TPNdB with an innovative multi-channel nozzle.

The effects on performance and weight were studied and were discussed in the article. Nevertheless, weight and costs still have to be improved.

Future prospects

EU funded FP5 programs are currently in progress and should, next year, result in:

- SILENCER to improve exhaust liners (cost and attenuation)
- HORTIA to decrease significantly the weight of nozzles

EU FP6 Integrated Project FRIENDCOPTER has just started. The work package 3 on engine noise reduction will synthesise 1O years of active research by applying the main results of all those projects (DTP HS, SILENCER, HORTIA) on a real helicopter in flight.

9. References

[1] Environmental Protection, Annex 16 to the Convention on International Civil Aviation, volume 1, Aircraft noise

[2] Acoustically treated turbomachinary multi-duct exhaust device
Application US Patent n°09/461330

[3] Aerodynamic, acoustic and icing aspects of engine-helicopter integration.
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10. Acknowledgement

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