Air traffic doubles every 15 years and triples every 20 years. In this context, aircraft manufacturers will have to offer even quieter products so that acoustic environment around airports is protected. In close relation with engine manufacturers, Airbus have launched very ambitious research projects with the aim of developing silent technologies. These technologies are optimised and fine-tuned thanks to the high-performance know-how and tools that have been developed either internally or in close collaboration with highly skilled partners. By doing so, Airbus made the choice of improving their understanding of acoustic phenomena. This communication presents an overview of Airbus achievements in terms of noise reduction with a special focus on aero-engine noise reduction thanks to nacelle advanced acoustic designs.

1 Introduction

Noise concerns near airports are such that reducing noise emitted by aircraft is one of the priorities of aircraft manufacturers. In addition, air traffic is expected to grow significantly over the next years and low noise technology breakthroughs will be required to preserve the environment in the vicinity of airports. This paper first presents the industrial context with a description of acoustic regulations and aircraft noise features. Then, Airbus efforts in terms of aircraft low noise design and simulation are introduced. Finally, use of these tools is shown on fan noise reduction with a technological application on A380.

2 Industrial context

2.1 Aircraft acoustic regulations

Each new aircraft type has to be certified acoustically according to ICAO (International Civil Aeronautical Organisation) regulations. Certification is achieved through measurements made at three reference points (see Fig. 1).

At each point, noise is measured, integrated and corrected with annoyance weighting factors. Noise is then expressed in EPNL (Effective perceived noise levels) and compared to certification maximum levels. In all cases, aircraft noise has to be below the authorised levels that are defined with respect to aircraft weight. All Airbus aircraft comply with current certification levels (Chapter 3) and also comply with more stringent future levels (Chapter 4), which will be applied from January 2006.

2.2 Aircraft noise features

The noise of aircraft in flight is a complex mix of different noise sources. As shown in figure 2, noise at approach and take-off can be broken down into contributions coming from the engine (fan, jet, compressor, combustor, turbine) and from the airframe (wing slats and flaps, nose and main landing gears).
To summarise, for modern aircraft powered by modern engines, take-off noise is dominated by fan and jet noise and approach noise is dominated by airframe and fan noise. These features are common to all aircraft types but the noise spectra and directivities pattern of each source can be significantly different from one product to another.

3 Aircraft low noise design

3.1 Aircraft development

Airbus introduced noise constraints from the very beginning of overall aircraft development. The importance given to this parameter is such that noise appears in Airbus aircraft TLAR (Top Level Aircraft Requirements) that define the most significant definition drivers.

Preliminary noise breakdown of the aircraft in flight is built on the basis of a preliminary engine noise signature provided by the engine manufacturers. On these bases, an important step consists in defining the sensitivity of aircraft noise reduction to individual source reduction (see Fig. 3).

For example, figure 3 shows that sensitivity of aircraft noise reduction to forward fan noise reduction is 29% at take-off fly-over. This means that reducing forward fan noise by 1 EPNdB will reduce aircraft noise by 0.29 EPNdB.

The sensitivities lead to identifying the sources that need to be reduced. As said before, jet noise, fan noise and airframe noise, mainly landing gear noise, are the main contributors to aircraft noise in flight.

As aircraft integrator, Airbus is deeply involved in the low noise design of all aircraft components. Jet noise is addressed in close cooperation with the engine manufacturers since jet features are closely related to engine thrust. Fan noise reduction is considered in close collaboration with the engine manufacturers and the nacelle manufacturers, the former being asked to provide low noise rotors-stators systems and the latter being asked to provide efficient acoustic liners in order to reduce fan noise in the course of its propagation through air intakes and exhaust ducts.

Given that fan noise represents more or less half the noise at both approach and take-off, the remainder of this paper will be focused on this source and its reduction thanks to nacelle low noise designs.

3.2 Acoustic simulation tools

During the last decade, Airbus invested a lot in simulation tools development. The first application cases were fan noise propagation, reduction and radiation, and fan noise problems are still the main drivers for acoustic code development within Airbus France. The whole simulation of nacelle acoustics requires wall impedance, in-duct propagation and far field radiation to be computed. These computations have to take into account 3D geometries and flows, 3D distributions of wall boundary conditions (acoustic liners), various thermodynamic features, and noise source signatures representative of the fan, turbine, compressor, and combustor. In addition, codes must cover a wide range of frequencies from 0 to kR~100, referring to R, the outer radius of the duct.

An important effort is devoted to development of analytical codes in order to keep the control of physics. In this frame, various tools were developed to describe the influence of source modal contents, in-duct flows, varying geometries, varying wall impedances. In addition, these analytical codes serve as reference for more complex numerical tools.

The first numerical code validated and used by Airbus France is a BEM (Boundary Element Model) code able to simulate 3D geometries with or without acoustic liners in the low-medium frequency range. This code was originally developed for Electro-magnetic problems by EADS-CRC (European Aeronautic Defense and Space Company – Common Research Centre) and transposed to nacelle acoustics.

Once validated, this code constituted a reference for the validation of ACTRAN code, a FEM (Finite Element Model) code developed by FFT (Free Field Technology). This code was successfully applied to low frequency non-uniform lined intake problems with a close agreement with fan rig test results.

Airbus France also addressed high frequencies with the development and the validation of various numerical codes.

All these tools were validated thanks to cross comparison and comparison to internal or external test results. Figure 4 gives a status of the coverage of nacelle problems by available simulation codes. As illustrated, 3D flow problems with liners at high frequencies are still to be resolved.
Figure 4: Coverage of nacelle problems by codes

Figure 5 gives an illustration of the code validity in terms of far field noise levels. The reference data are results of indoor fan rig tests performed by Rolls Royce. As it is shown, A-F are able to predict the far-field SPL (Sound Pressure Levels) with a good level of accuracy provided right flows and intake geometry are available.

Figure 5: A-F computed far-field noise radiated from intake compared to Rolls Royce fan rig test results.

Such comparisons are in progress on exhaust and open test bed problems. We expect agreement between computations and measurements to be worse and discrepancies will be studied in order to assess potential improvement of both numerical codes or test beds.

Using these tools A-F have designed new nacelle low noise technologies. After an optimisation phase, candidate technologies have been assessed acoustically and proposed for integration on Airbus aircraft. The next section presents one of these technologies that has been successfully assessed through computations and experiments and which will be mounted on A380 engine intakes: the zero splice intake (ZSI) liner.

4 The zero splice nacelle liner

4.1 Principle of ZSI

The fan is a rotating machine working downstream of an intake that can be roughly assimilated to a cylindrical circular wave-guide. The noise is therefore propagated in the duct by circumferential spinning modes that carry acoustic energy from the fan (the source) to the duct exit (the lip).

At take-off, fan noise is mainly propagated by modes called fan-alone modes, which propagate the noise close to the duct wall (see Fig. 6). These modes are significantly attenuated by the liners since they propagate close to the wall.

Figure 6: Rotating fan and fan-alone mode field

In such cases, the liner will be really efficient. Unfortunately, reality is not so clear cut and in-duct noise scattering due to various effects can significantly alter the efficiency of liners. Figure 7 gives an illustration of the effect of assembly splices between acoustic treatment panels on the in-duct acoustic field. It becomes obvious in this case that liner efficiency will be reduced because incident mode has been scattered on other modes that propagate farther from the wall.

Figure 7: Scattering of in-duct field due to splices

On this basis, A-F performed simulations of the effects of splice number and width on noise radiated to the far field. As shown in fig. 8, significant benefits were obtained thanks to splice number reduction.

Figure 8: Radiated noise reduction thanks to splice number reduction
These promising results have been confirmed through different simulations or tests performed by other companies [ISVR, RR].

Thanks to these promising results, Airbus took the decision of incorporating this technology in intakes of the two motorisations of A380. This decision demanded to find new intake designs capable of sustaining loads with single peace intake barrels. In parallel, new materials and new assembly have been requested to provide the liner with the requested high rate of homogeneity. Finally, brand new manufacturing processes and tooling have been invented by A-F Nantes production plant in order to make compatible these high quality requirements with industrial constraints. Figure 9 illustrates the new facing sheet invented for the ZSI and the assembled ZSI ready for static tests.

**Figure 9: New facing sheet for ZSI and A380 ZSI ready for noise static tests.**

### 4.2 RAMSES concept

RAMSES is a direct extension of the zero splice concept. The acronym stands for Reduced Acoustic Mode Scattering Engine System duct.

Its principle is quite simple. The idea is to consider that any scattering due to liner or duct non-homogeneities, like splices, yield a negative snowball effect in the downstream propagation.

Indeed, let’s consider that a duct is lined with two sequential liners as for the intake where the small length fan case liner, installed close to the fan, is immediately followed by the main intake liner. The RAMSES principle is such that any scattering removal in the upstream liner will enhance the benefit of the liner itself but will also improve the efficiency of downstream liners by keeping the incident acoustic field undisturbed.

Effectively, this effect has been confirmed through tests and computations which showed that benefit of removing splices in the small length fan case liner can have the same magnitude than the benefit provided by the removal of splices in the longer main liner. Moreover, as illustrated in figure 10, it has been demonstrated that in some cases, it is better to keep the fan case untreated instead of lining it with a spliced acoustic treatment. This phenomenon was already measured during previous flight or static tests but never explained. This result underlines the fact that liner efficiency is not simply due to a treated area but also due to processes used for acoustic panel assembly.

**Figure 10: Acoustic radiation computed at Sideline in various fan case and intake treatment conditions.**

- : Intake (I) hard wall and Fan-case (FC) hard wall.
- : I hard wall and FC treated 3 spl.
- : I hard wall and FC treated 0 spl.
- : I treated 0 spl. - FC hard wall.
- : I treated 0 spl. - FC treated 0 spl.

The RAMSES and ZSI concepts were patented by A-F and will be considered for the next Airbus aircraft nacelles.

### 5 Conclusion

In this paper, we first present the need to reduce the noise around airports and then the way Airbus is tackling this problem by taking acoustics into account very upstream in the aircraft development. Next, efforts made by Airbus in simulation are reviewed and illustrated by successful comparison with test results. Finally, technological applications are discussed with an overview of the zero splice intake that allows improving the attenuation efficiency of nacelle liners. The splice improvement campaign has been launched by Airbus with the A340-500/600 equipped with twin thin splices intake acoustic liner and is now speeded up with the A380 equipped with a zero splice intake liner. Airbus are now working on the RAMSES concept, an extension of the ZSI concept, to the complete nacelle ducts.

The ZSI and RAMSES technologies have been patented by Airbus and are now considered as standards for future nacelle liners.
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