Leonardo I4N research program – design of novel acoustic liners for aero engine nacelles

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Abstract. The minimisation of aircraft noise remains a major challenge for the aerospace industry. Noise certification limits continue to be driven lower over time to counter the impact of the steadily increasing number of noise events in the vicinity of airports, along with an increased sensitivity of the public to aircraft noise. This, in turn, ensures that considerable engineering time and effort is used to target all of the major contributors to aircraft noise. Aircraft noise sources include engine fan inlet, fan bypass, jet, and airframe noise, among others. Fan inlet, bypass, and core, ducts are typically lined with absorbing acoustic panels in order to minimise radiated fan noise. This paper is focussed on the latter, describing work to address the design and optimisation of novel acoustic liners.

Introduction

In recent years, the design and manufacture of more efficient aero engine duct acoustic panels has been receiving increased attention. However, the design process cannot be performed in isolation, as the requirement for ever lower aircraft noise levels may be impeded somewhat by the drive to reduce Specific Fuel Consumption (SFC). In particular, modern aero engine ducts have progressively larger fan diameters, and higher bypass ratios. They also have reduced duct lengths in order to minimise weight. While both of these modifications help to reduce fuel consumption, from a noise perspective the ensuing reduction in duct lined length-to-height ratio reduces the attenuation for a given liner design. Hence, for a fixed source level, liner efficiency must be improved just to maintain the status quo. Further challenges are also introduced as modern engine fans generally rotate less quickly, and have fewer blades, than their predecessors. This leads to a tonal content shifted towards lower frequencies, while higher frequencies remain important for broadband noise sources, thus broadening the target frequency range for the acoustic linings. This scenario is particularly challenging for traditional liner designs, as their maximum efficiency is realized over a relatively narrow bandwidth. Hence, if possible, novel designs must be introduced with larger attenuation bandwidths adapted to the source of modern engines.

The Leonardo Innovation for Nacelles (I4N) programme has a work stream dedicated to the design of novel aero engine duct liners. This paper summarises the progress realised to date in liner design. The studies have led to the development of a number of low weight novel liner configurations of varying complexity which are predicted to show improved broadband attenuation when compared to that realised for traditional designs. Work has included the development and validation of acoustic liner impedance models [1], liners with porous cell walls and cells which are considerably wider than traditional designs [2], and the design and manufacture of novel liners with complex cavities (replacing traditional straight cavities) [3,4]. The attenuation potential of the novel designs is improved further by increasing the integrity of duct liner attenuation modelling

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significantly, in particular by using a more representative source content and by including the influence of boundary layer refraction at the duct walls [5]. Each of the above subjects are now addressed.

Development and validation of a single degree of freedom perforate impedance model under high SPL and grazing flow

Normal incidence impedance, grazing flow in-situ impedance, and insertion loss testing of a range of Single Degree-Of-Freedom (SDOF) perforates was performed, along with insertion loss tests on a complex cavity panel with varying cell widths and path lengths [1]. Grazing flow measurements, performed in the Santa Catarina grazing flow facility in Brazil, acquired liner impedance and attenuation data at Mach numbers up to 0.6, and at SPLs up to 155dB. The semi-empirical impedance models developed were validated by employing them in calculations of lined duct insertion loss (Figure 1). The studies also confirmed the potential for complex cavity designs to provide improved broadband attenuation (Figure 1).

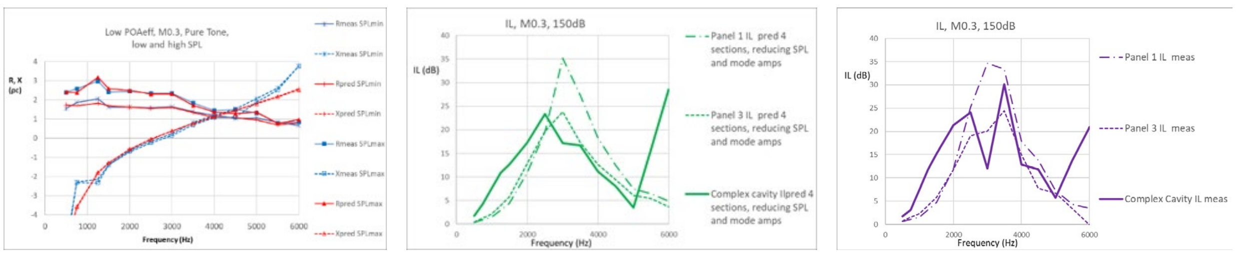

Figure 1. SDOF Perforate Impedance Prediction vs Measurement (left), plus predicted (centre) and measured (right) insertion loss showing bandwidth benefits of complex cavities

Optimisation of non-locally reacting liners for improved duct attenuation

Traditional aero engine liner configurations have narrow cells (approx. 10mm wide) which allow only a plane wave to propagate within them at the frequencies of interest for community noise. The liner response is then independent of the angle of incidence of the impinging sound, and it is considered “locally reacting”. As such, the acoustic response may be characterized uniquely by an impedance, defined as the complex ratio of the acoustic pressure and velocity at the liner surface. Should the cell width increase, additional modes may propagate within the cells, and the liner response becomes a function of the incident mode content.

It is well known that non-locally reacting porous materials show good broadband behaviour. However, they may not be used in aero engines given their propensity to retain fluids. In this work [2], a set of parametric studies were also performed to look at the acoustic attenuation of non-locally reacting liners which are also suitable to fly within aero engine ducts.

The COMSOL Multiphysics® simulation software was used to model the lined propagation for a number of designs under uniform flow. The FEM model was validated initially against insertion loss measurements performed for traditional liners in the NLR rectangular Flow Duct Facility (FDF) in Holland. Thereafter, a parametric study was performed to look at the impact of adjusting these designs to incorporate varying cell widths and varying cell wall resistances. The study demonstrated potential gains in insertion loss for the non-locally reacting designs over that predicted for traditional designs (Figure 2).

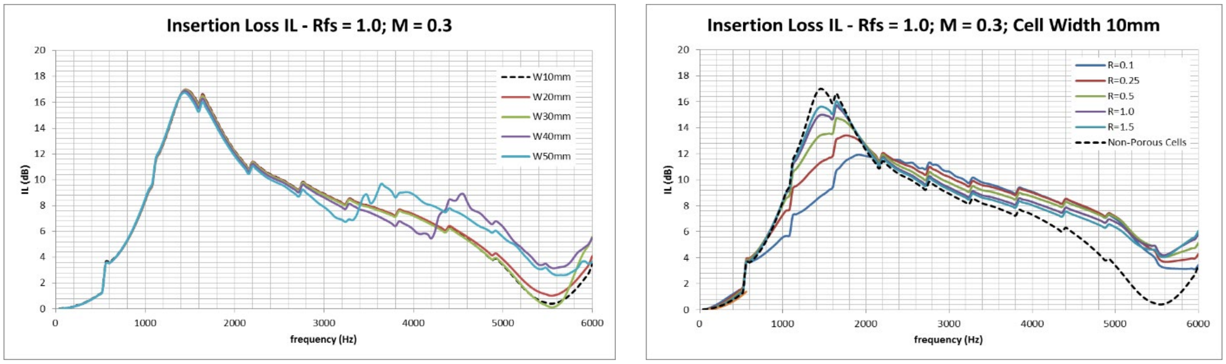

Figure 2. Downstream propagation at Mach 0.3 – Wide cell performance (left) and porous cell wall performance (right)

Improved aero engine inlet attenuation from novel broadband liners

The work presented in [4] continues the research activity initiated in [3], where a novel broadband liner, which uses a core of complex cavities, was designed and optimised to maximise the normal incidence sound absorption over a wide frequency range, including low frequencies. In [4], the novel broadband liner concept was optimised to improve the AneCom inlet attenuation over a wide bandwidth. The liner optimisation incorporated the measured AneCom fan noise circumferential modal content and it also included the impact of wall boundary layer refraction. The geometry of the broadband liner was optimised for two different overall panel depths, 24mm and 40mm, with the deeper panel allowing lower frequencies to be targeted via the inclusion of longer folded cavities. The predicted performance (Figure 3) of the two broadband liner geometries was compared with that predicted for the traditional liners tested by Leonardo previously at AneCom, along with their re-optimised designs, which also account for the impact of the measured source and the wall boundary layer refraction. The novel designs were able to provide significant improvements in attenuation across the frequency range where the AneCom source was loudest in the far-field.

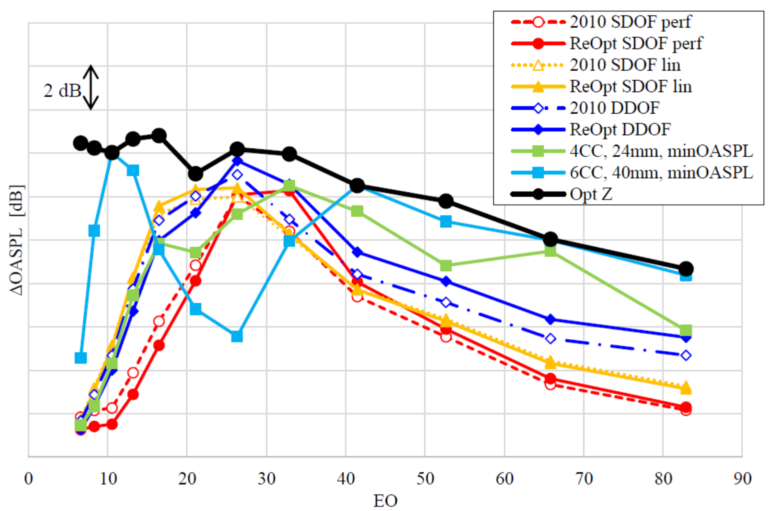

Figure 3. Predicted far-field attenuation at 18.5m from the AneCom inlet, between 40° and 90°, using the measured fan noise source and assuming shear flow in the inlet duct.

Impact of the engine fan source and wall boundary layer on inlet liner design

This work [5] sought to validate far-field predictions of engine liner attenuation. An improved version of the Leonardo cylindrical duct propagation and radiation code (NextGen Liner Multiphysics Code, NLMC) was developed to allow the inclusion of the measured modal source content along with the impact of refraction when sound propagates through the shear layer at the inlet wall. These aspects are generally not included by the industry. Application of the NLMC code was shown to provide excellent agreement with in-duct and far-field measurements, providing confidence in the acceptability of the assumed simplifications in the modelling. The predictions for an equal energy per mode source and no boundary layer were also found to be significantly different from those using a more representative source (measured circumferential amplitudes and equal energy per associated radial modes) and including boundary layer refraction (Figure 4).

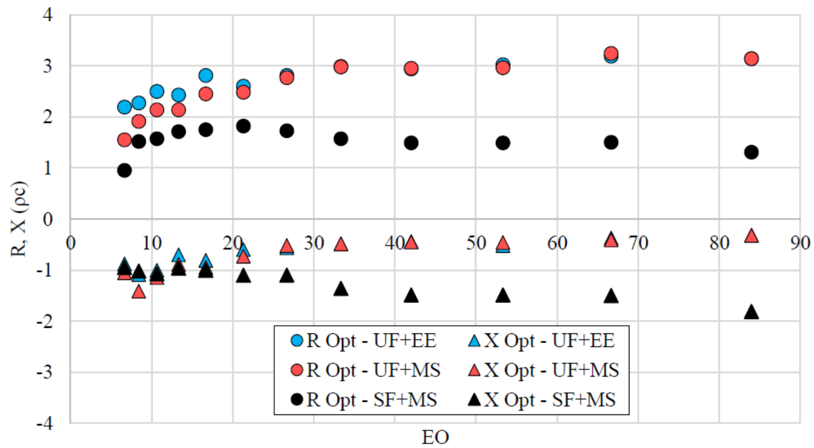

Figure 4. Impact of modelling integrity on the engine inlet optimum resistance (R) and reactance (X) at Approach. Uniform flow with equal energy per mode (NoBL+EE) or measured source (NoBL+MS), and shear flow measured source (BL+MS)

Conclusion

This paper has provided a brief overview of the aero engine acoustic design studies performed by Leonardo under the auspices of the I4N research programme. A series of coordinated activities has led to a significantly improved understanding and capability in the design of advanced aero engine nacelle liners. The novel designs can provide improved attenuation levels, accompanied by an increased bandwidth of attenuation, when compared to that of traditional designs currently flying. The design activity has led to the manufacture of four novel inlet liners which were tested successfully in the AneCom facility in May 2023.

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