ENITEP

Experimental and Numerical Investigation of Turbulent Boundary Layer Effects on Noise Propagation in High Speed Conditions

State of the art – Background

Future propulsion configurations such as Open Rotor or Ultra High Bypass Ratio engines offer reduced fuel consumption but subject an aircraft fuselage to significant tonal noise levels within a lower frequency range than current engines. In order to enable the efficient design of fuselage structure and acoustic treatment for a comfortable cabin, reduction of uncertainty requires acoustic predictive tools. More specifically, there is a need to capture the beneficial refraction effects of the fuselage boundary layer.

Objectives

The aim of ENITEP was to investigate acoustic refraction by the turbulent boundary layer on a simplified, three dimensional rear fuselage geometry, enabling validation and development of acoustic simulation methods. The two major objectives were:

- to conduct a high speed acoustic wind tunnel test in order to generate an extensive experimental database characterising the refraction phenomenon in terms of the boundary layer steady/unsteady aerodynamics and the fuselage surface acoustics and
- to simulate selected experimental test cases using computational aero-acoustic (CAA) tools followed by comparison with the experimental data in order to validate and develop those tools.

Description of work

The following tasks were conducted as part of the experimental work package:

- modification of an existing, 1/6-scale rear fuselage shell model (Figure 1) to accept traversed hot wire probes for investigation of the unsteady boundary layer (Figure 3)
- further modification of the fuselage, and design and manufacture of several pressure rakes for measurement of the mean boundary layer flow
- modification of the model support for minimum aerodynamic blockage
- integration of an existing, in-flow noise source (Figure 3) with the ARA Transonic Wind Tunnel (TWT)
- high speed acoustic wind tunnel tests in the range M = 0.2-0.8 to measure the boundary layer aerodynamics and the fuselage surface acoustics (Figure 4 and Figure 5) subject to broadband and tonal noise emissions introduced at a range of separation distances
- separate measurements with the noise source in the absence of the fuselage model in order to characterise output level and directivity as a function of Mach number and separation distance (Figure 6)
- computational fluid dynamics (CFD) simulation of the fuselage, using Euler and RANS approaches, of four experimental test cases (M = 0.4 & 0.75, noise source separation 17cm & 35cm) to provide flow field definition for input to the CAA task

The CAA work package comprised the following tasks:

- construction of a numerical noise source model based on a compact monopole group to match the results of the experimental characterisation (Figure 7)
- construction of a CAA geometry to acoustically represent the fuselage installation in the wind tunnel (Figure 8)
- Actran simulations of the fuselage acoustic field corresponding with the eight CFD test cases (Euler & RANS flow solutions, 2 Mach numbers, 2 separation distances)
- comparison of the Euler and RANS-based CAA solutions to highlight the influence of the boundary layer refraction on the directivity of the propagated noise (Figure 9 and Figure 10)
- comparison of the CAA-derived fuselage surface acoustic pressure distributions with those measured during test (Figure 10)

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Results

a) Timeline & main milestones

The project was originally launched with a 24mth timescale. However, extensive investigation of potential design solutions capable of adequately characterising the unsteady aerodynamics of the turbulent boundary layer required the project to be re-planned, both in terms of timescale and content in order to ensure a successful outcome from the wind tunnel experiment. The project was amended to extend the timescale to 42mth. The design and manufacture of two traverse mechanisms enabling constant temperature anemometry (CTA) hot wire measurements in the boundary layer were taken outside of the project. The scope of the boundary layer measurements was extended and an experimental characterisation of the noise source was added. Finally, the experimental and numerical comparisons and tools development originally planned for the CAA task were limited for application to the steady refraction phenomenon only, although the extensive experimental data set would support investigation of the unsteady refraction phenomenon beyond the close of the current project.

The critical scientific milestones reached during the current project were as follows:

- completion of modifications to the wind tunnel model, integration of the noise source and provision of the associated control and measurement systems for characterisation of the model aerodynamics and acoustics
- completion of wind tunnel testing; achieved in two tunnel entries following delays due to tunnel availability and plant failure
- completion of CFD solutions and provision of the experimental and CFD data sets and reporting
- completion of the CAA tasks with a report presenting comparisons between the experimental and numerical results for the steady refraction phenomenon

b) Environmental benefits

The immediate environmental benefit of the current project will be an improvement in passenger comfort. Improved accuracy in simulation of the steady acoustic refraction phenomenon will assist in future prediction of noise levels at the fuselage surface and estimation of noise treatments required. However, a more accurate definition of these treatments will also help to minimise the associated weight penalty and therefore the impact on aircraft structure, performance and fuel burn.

c) Dissemination / exploitation of results

The results of the ENITEP project have been disseminated internally by the consortium partners via the periodic and work package-related reporting throughout the duration of the project. Comparisons between the experimental and CAA results and an assessment of the steady refraction effect have also been presented at the 2016 *AeroTraNet* aerodynamics training network meeting. Presentation of these results at an aero-acoustics conference is also planned for 2016.

The experimental data set generated by the ENITEP project is ideally suited to support further investigation and CAA tools development in connection with the steady refraction effect. The current data set can also be applied to gain a better understanding of the unsteady refraction (scattering) phenomenon. The extensive CTA hot wire results generated within ENITEP may be applied to improve algorithms for the correction of hot wire data in compressible viscous flows.

d) Communication

A summary of the ENITEP project objectives and outcomes will be provided on the company websites of the consortium partners:

Aircraft Research Association Limited
www.ara.co.uk
Free Field Technologies, MSC Software Belgium
www.fft.be

Figure 1 - Existing Fuselage Model Previously Used for CROR Integration Studies

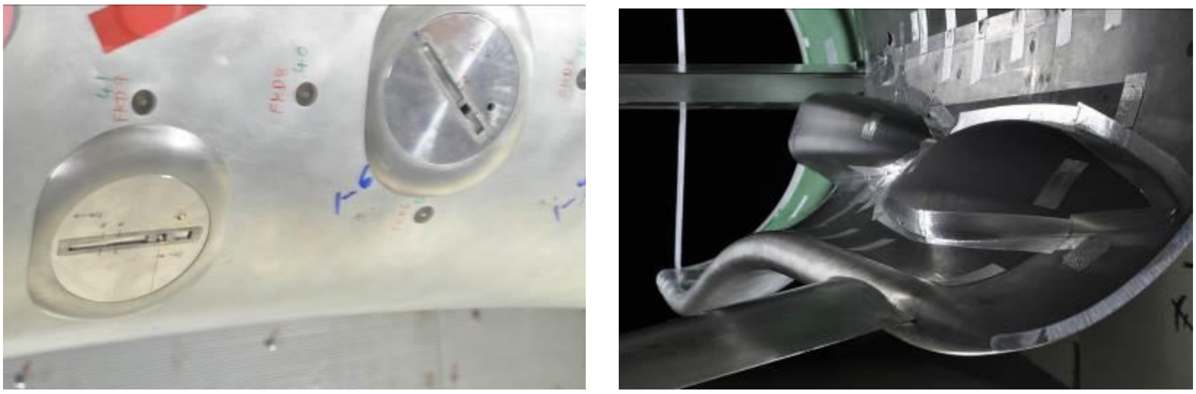

Figure 2 - Multiple Degree of Freedom CTA Probe Traverse Mechanisms & Fairings

Figure 3 - Modified Fuselage Model with Variable-Position, In-Flow Noise Source

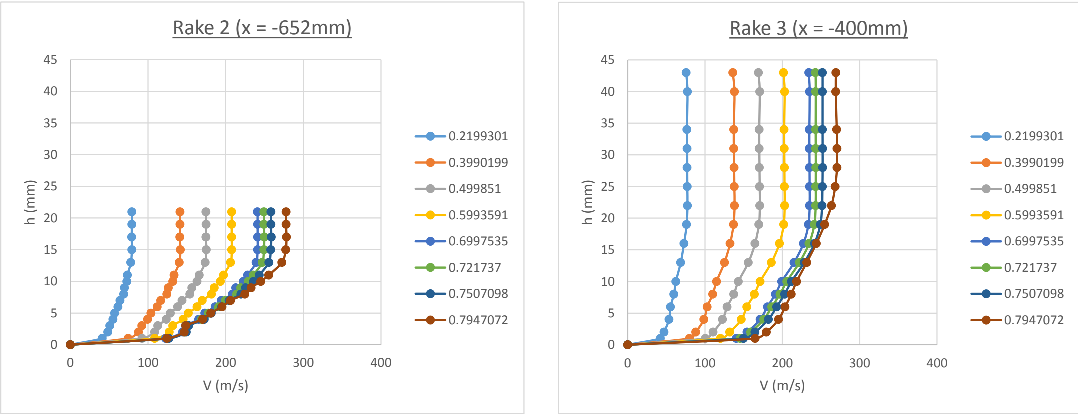

Figure 4 - Sample Fuselage Boundary Layer Velocity Profiles

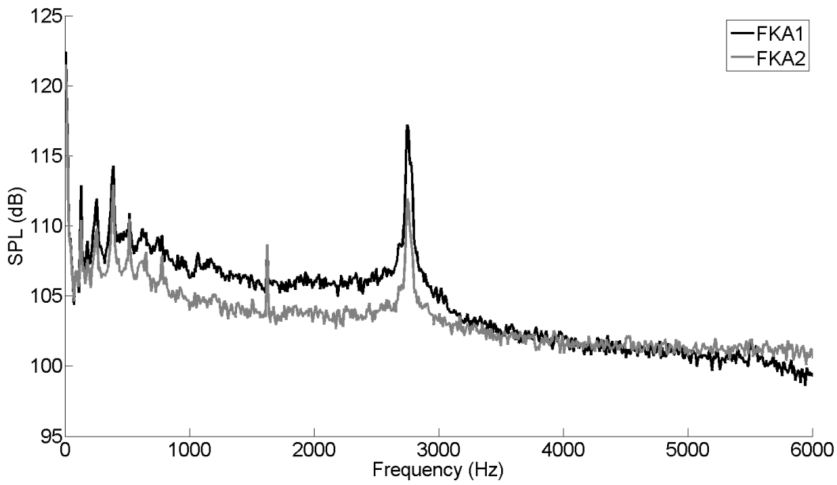

Figure 5 - Sample Fuselage Surface Pressure Spectra

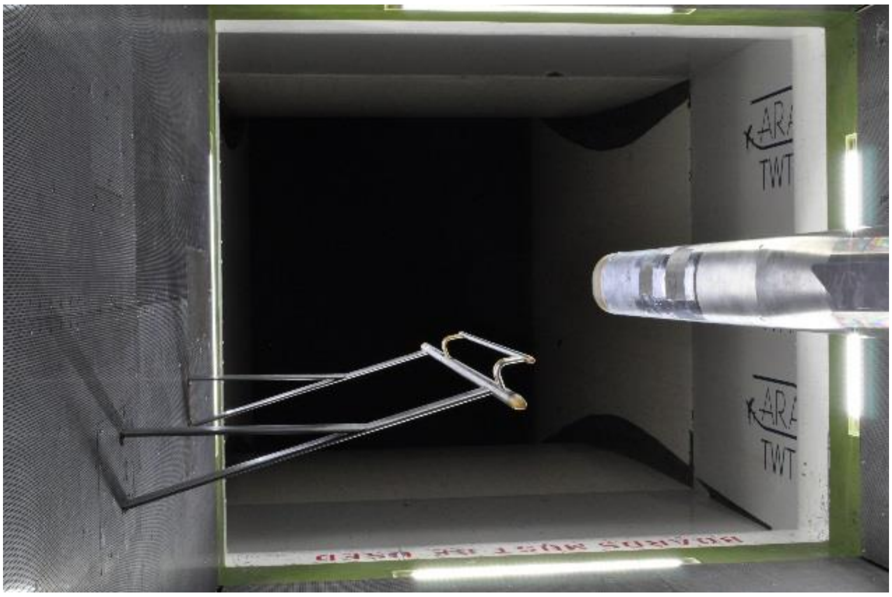

Figure 6 - Noise Source Characterisation Exercise

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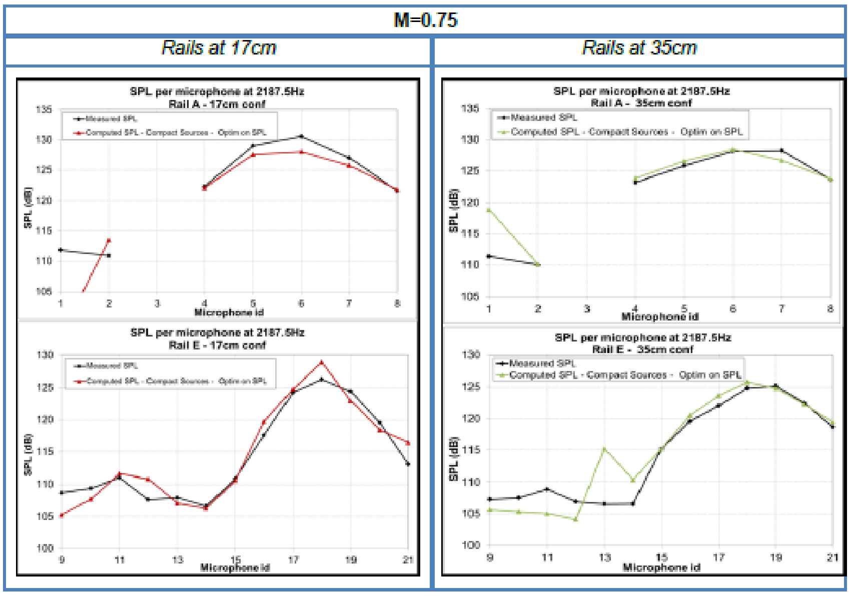


Figure 7 - Comparison of Measured and Simulated Source Directivities

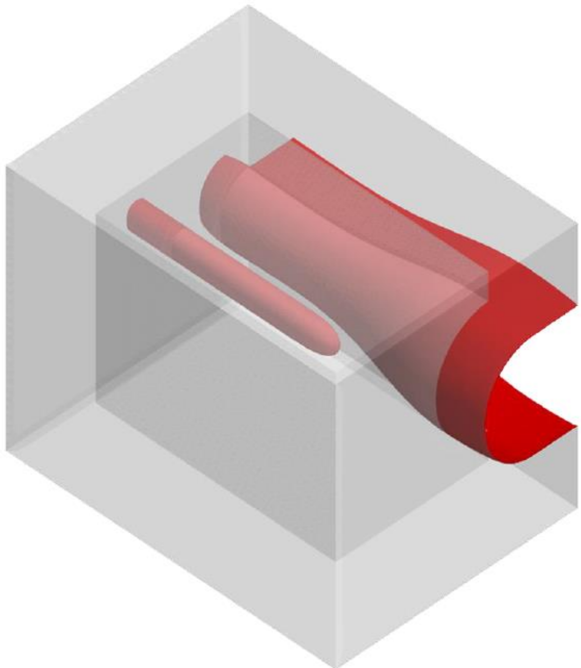
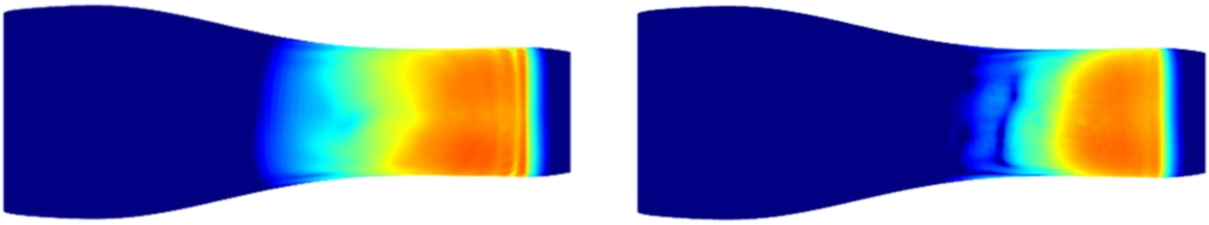


Figure 8 - Fuselage Configuration for CAA Simulations Comprising Physical Geometry (Inner) Extended into Far Field Buffer Zone (Outer)



Acoustic pressure (based on Euler CFD, no boundary layer refraction)

Acoustic pressure (based on RANS CFD, boundary layer refraction)

Figure 9 - Raw CAA SPL Maps Indicating Steady Refraction Effect, M = 0.75, Source at 35cm

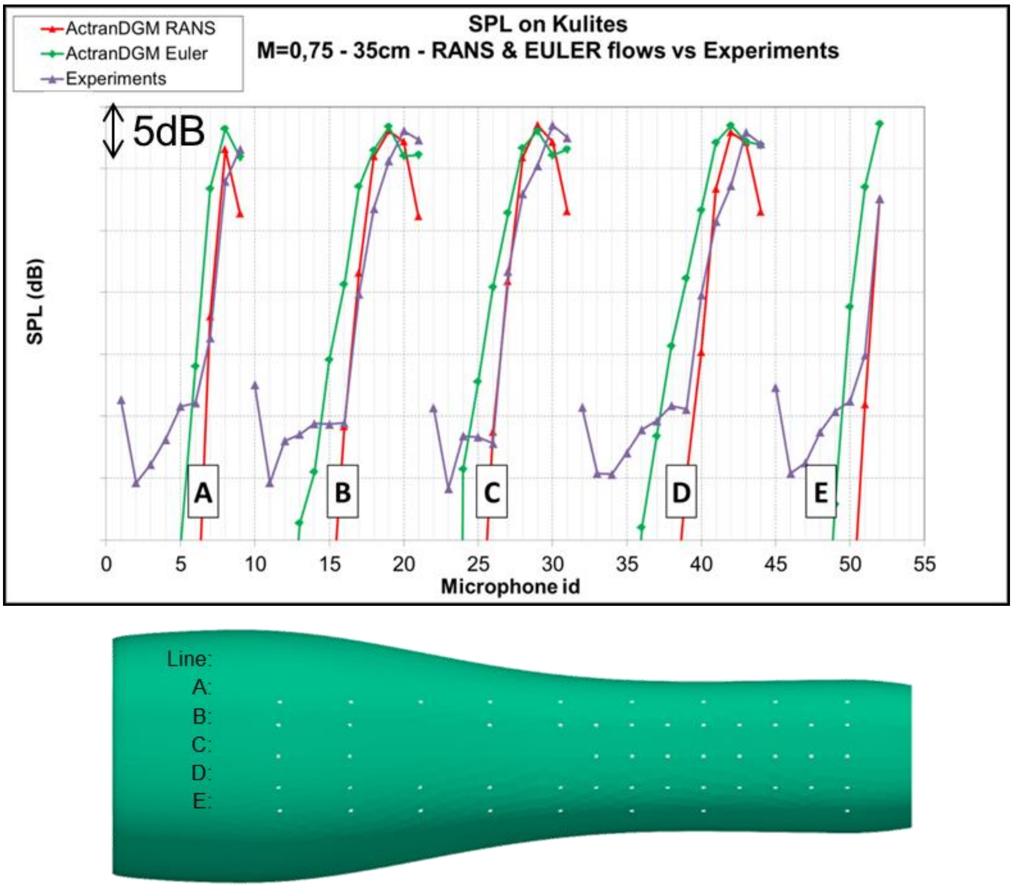


Figure 10 - Post-Processed SPL Comparisons, Experiment & CAA, M = 0.75, Source at 35cm

Project Summary

Acronym:	ENITEP
Name of proposal:	Experimental and Numerical Investigation of Turbulent Boundary Layer Effects on Noise Propagation in High Speed Conditions
Involved ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement:	323412
Instrument:	Clean Sky
Total Cost:	€750,000
Clean Sky contribution:	€512,450
Call:	JTI-CS-2012-01-SFWA-02-026
Starting date:	01.12.12
Ending date:	31.05.16
Duration:	42 months

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b) Free Field Technologies, MSC Software Belgium, partner

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