PROJECT

PROBAND

Improvement of Fan Broadband Noise Prediction: Experimental Investigation and Computational Modelling

Funding: European (6th RTD Framework Programme)
Duration: Apr 2005 - Dec 2008
Status: Complete with results
Total project cost: €4,825,914
EU contribution: €3,000,000

Call for proposal: FP6-2003-AERO-1
CORDIS RCN: 74828

Background & policy context:

Fan broadband noise is a major aircraft noise challenge currently and will be even more important in the future. Novel low-noise engine architectures, such as ultra-high-bypass-ratio engines and lower-speed fans, can help address jet noise and fan tone noise, but they are unlikely to reduce fan broadband noise significantly. The accurate prediction and control of fan broadband noise is therefore essential if aircraft noise is to be reduced.

The most significant broadband noise sources are believed to be generated by the different interaction mechanisms between:

- the blade tip vortex of the rotor fan and the turbulent boundary layer on the inlet-duct (rotor boundary layer interaction noise)
- turbulent eddies convected in the rotor boundary layer past the rotor trailing edge (rotor self noise)
- the impingement of the rotor wake onto the downstream outlet guide vanes (OGV interaction noise), and
- turbulent eddies convected in the vane boundary layer and the vane trailing edge (OGV self noise)

These four mechanisms each generate a whole spectrum of frequencies, making it difficult to use conventional noise measurements to isolate the contribution of each mechanism. Furthermore, the broadband noise generation process is very complex to model, requiring representation of the fine length scales involved in turbulence generation and propagation.

Consequently, current methods for industrial broadband noise prediction are almost exclusively semi-analytic in nature. They rely largely on correlating measured noise levels to a few relevant aerodynamic and geometric parameters but are unable to predict the effects of different blade geometries. The advances in purely numerical methods, which have revolutionised tone noise prediction, have yet to make an equivalent impact on broadband noise prediction.

Objectives:

The objective of PROBAND was to develop methods to allow the design of a fan system that will generate sufficiently low broadband noise to meet the EU noise level targets.

This was achieved by:

- developing a better understanding of broadband noise generation mechanisms using advanced experimental and computational techniques
- developing and validating improved prediction methods using conventional computational fluid dynamics, and integrating them into industrial codes
- exploring new prediction strategies using advanced computational techniques, and
- developing low broadband fan noise concepts.
Methodology:

The main goals of the PROBAND research programme were achieved by:

- developing coupled RANS/semi-analytic models for fan stage broadband noise sources and validating these models against representative fan rig measurements
- developing and evaluating the application of advanced CFD methods based on LES and DES and demonstrating their potential application for industrial fan stage noise assessment
- promoting an increased understanding of turbulence-driven, broadband noise generation in aero-engine fan stages through detailed measurement of turbulence structure and noise on representative configurations, and
- developing concepts for low-broadband noise fan stage configurations by exploiting the project numerical and experimental results.

Parent Programmes:

FP6-AERO-1.2 - Improving environmental impact with regard to emissions and noise

Institute type: Public institution
Institute name: European Commission
Funding type: Public (EU)

Lead Organisation:

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Technologies:
Computer-aided design and engineering
Reduced fan noise

Development phase: Research/Invention

Key Results:

WP2 intense activity led to a number and variety of new results:

- Tip clearance noise was measured, and its sources physically characterised in an experimental approach.
- Self noise was measured in the same experiment thus the two sources could be quantitatively compared.
- New post-processing tools (based wavelet analysis) helped to shed a new light onto the flow physics.
- A new tip clearance noise model was developed.
- For the first time a tip clearance noise model was successfully applied to experimental flow data.
- An existing self noise model was considerably improved to be applicable in flow configurations that are relevant for real flight conditions.
- An additional model was developed and validated in order to apply the trailing edge noise model to RANS outputs.
- An existing interaction noise model was modified in order to be applied to fan-OGV geometries in WP3 and WP4.
- A new statistic model was developed that can predict the density variance in CFD codes that are not fully unsteady.
- A non-rotating single airfoil Trailing Edge configuration was computed by LES. Mean and RMS flow as well as velocity, wall pressure and far field pressure spectra could be compared to experimental data.
- All CFD codes used in PROBAND were tested on a common test case that consists of a symmetric non lifted airfoil in the far wake of a rod. The ability of the codes to predicting broadband noise could be quantitatively evaluated. Moreover, this test case allowed many partners to improve their CFD codes and in particular their turbulence models. It helped them to define the optimal conditions for broadband noise predictions in the turbomachinery context.

WP3 was to provide a parametric study on broadband noise sources in a laboratory-scale fan rig. Advanced measurement and analysis techniques to achieve this were to be developed on this fan rig. The predictions of the broadband noise of the laboratory fan rig were to be evaluated numerically using RANS/semi-analytic methods and validated LES/DES models.

Extensive acoustic and aerodynamic data were collected according to a test matrix defined previously. The second test campaign has also been completed. This test has focussed on the effect o
Technical Implications

The highlights of the RANS / semi-analytic model validation work are:

- steady and unsteady RANS predictions of the fan stage were demonstrated to give good prediction of the overall fan stage performance;
- use of RANS predicted wake turbulence intensity and length scale in the semi-analytic broad model, developed and validated in WP2 and WP3, has given good prediction of the trends of broadband noise variation with fan speed and working line variation;
- application of the fan-tip noise model developed in WP2 to the industrial fan stage rig was not successful due to the extent of transonic flow on the blade;
- the wake-OGV interaction model has been demonstrated as ready for industrial use.

LES simulation methods have been applied to the industrial fan stage using thin section models of the blades and also full annulus height fan and fan-OGV/ESS models. The simulations have been compared where possible to the fan rig test data but the lack of the hot wire data meant that no comparison of turbulence level was possible. Model developments have also been studied for use in turbomachinery LES simulation:

- URANS-LES matching technique;
- turbulence forcing techniques for LES;
- special periodic boundary conditions.

The overall conclusions of the LES simulations are:

- the calculations demonstrate the potential capability of LES and DES to predict fan stage turbulence and broadband noise;
- computing resource requirement is still very substantial for application of LES and DES to industrial configurations (initialisation run times, mesh requirement at high Reynolds number);
- LES and DES capability has though been demonstrated for application to model geometries (supported by WP2 and WP3 work) for studies of noise generation flow physics and noise reduction measures.

Readiness

The data acquisition task was done successfully, covering aerodynamics, forward and rear arc noise data, noise data for beamforming analysis, OGV surface pressure, and hot-wire traverses. Noise, aerodynamics and OGV surface pressure data have been made available to partners and used for comparison with noise models and CFD analysis. The hot-wire data is not available though, due to a problem in the data recording.

The rig test provided the opportunity to obtain a consistent set of aerodynamic and noise data on an industrial fan rig over range of fan speeds and working lines.

Using the beamforming techniques applied to the intake microphone ring, it was shown that broadband noise sources were present on both rotor and stator. By means of the azimuthal mode spectra, it was made plausible that the dominant sources of broadband noise were on the stator. Further application of the beamforming method is required to refine the technique.

Documents:
- PROBAND_Summary_Final_Results_Web.pdf (Other relevant documents)
- Final Report Summary - PROBAND (Improvement of Fan Broadband Noise Prediction: Experimental investigation and computational modelling)

STRIA Roadmaps: Vehicle design and manufacturing

Transport mode: Air transport

Transport sectors: Passenger transport, Freight transport
Societal/Economic issues, Environmental/Emissions

Transport policies: aspects

Geo-spatial type: Other