Project no. 516079

TURNEX

Turbomachinery Noise Radiation through the Engine Exhaust

Project funded by the European Community
SIXTH FRAMEWORK PROGRAMME
PRIORITY 4
AERONAUTICS AND SPACE

Project Deliverable Report

Deliverable D0-1-9a: Publishable Final Activity Report

B J Tester (ISVR), F Arnold (RRD), S Caro (FFT)

and

S Lidoine (AI-F)

Period covered: from 1 January 2005 to 30 June 2008
Date of preparation 12 December 2008
Start Date: 1 January 2005   Duration: 42 months

Project Coordinator: B J Tester
Project Coordinator Organisation: ISVR, Southampton University

Publishable Final Activity Report
1 January 2005 to 30 June 2008

TURNEX

Turbomachinery Noise Radiation through the Engine Exhaust

Report: Publishable Final Activity Report D0-1-9a

CONTRACT No: 516079

PROJECT COORDINATOR: B J Tester, ISVR

PARTNERS

Institute of Sound and Vibration Research	ISVR	GB
Airbus France	AI-F	FR
Dassault Aviation	DASSAV	FR
Rolls-Royce Deutschland	RRD	DE
Rolls-Royce	RRUK	GB
Free Field Technologies	FFT	BE
Deutsches Zentrum für Luft- und Raumfahrt	DLR	DE
European Aeronautic Defence and Space Company	EADS-CRC	DE
National Aerospace Laboratory	NLR	NL
Technische Universiteit Eindhoven	TUE	NL
AVIO	AVIO	IT
Middle East Technical University	METU	TR

Start Date:	1 January 2005
Duration:	42 Months
Issue Date:	15 August 2008

Project funded by the European Community
SIXTH FRAMEWORK PROGRAMME
PRIORITY 4
AERONAUTICS AND SPACE

Edited by B J Tester (ISVR), F Arnold (RRD), S Caro (FFT) and S Lidoine (AI-F)

Contents

Summary

TURNEX has delivered **validated industry-exploitable methods** for predicting turbomachinery noise radiation through exhaust nozzles, which will allow EU industry to compete effectively with NASA-funded technology developments in the US. It has also delivered a **technical assessment on the way forward for European fan noise testing facilities** and an assessment of exhaust nozzle concepts for **noise reduction at source**.

Strategic objectives addressed

TURNEX has addressed technical domain 2.f (External noise) of area 2 (Improving environmental impact with regard to emissions and noise) for Priority Thematic Area 4 (Aeronautics and Space) of the Specific Programme ‘Integrating and strengthening the European Research Area’. It supports the EU FP6 objective of reducing aircraft external noise by 4-5 dB and by 10 dB per operation in the short and long-term respectively

Background

Research is needed to develop innovative concepts and enabling technologies to reduce aero engine noise at source. Turbomachinery noise radiating from the bypass and core nozzles is becoming a dominant noise source on modern aircraft, but, while recent EU research programmes have made significant progress in reducing both the generation of turbomachinery noise and the radiation of noise from the intake, little work has been conducted on reducing the radiation of turbomachinery noise from exhaust nozzles. TURNEX has addressed this shortfall by delivering improved understanding and validated design methods, and by evaluating a number of low-noise exhaust nozzle configurations aimed at a source noise reduction of 2-3dB.

Project Objectives

The goal of TURNEX was to develop concepts and enabling technologies for ***reduction of engine noise at the source***, through an improved understanding, modelling and prediction of fan and turbine noise radiation from exhaust nozzles, and through the evaluation of a number of low-noise exhaust nozzle configurations. To achieve that goal, TURNEX had four focussed, ambitious objectives.

1. To test experimentally at model scale (a) innovative noise reduction concepts, including a scarfed exhaust nozzle, and (b) conventional engine exhaust configurations. The experiments will develop and utilise novel simulated turbomachinery noise sources and innovative measurement techniques in order to evaluate the noise reduction concepts and to provide a high quality validation database.

2. To improve models and prediction methods for turbomachinery noise radiation through the engine exhaust to a level comparable with that being achieved for intake radiation, to address specific shortcomings associated with such methods, and to validate those methods with the experimental data.

3. To conduct a parametric study of real geometry/flow effects (pylons, wings, flow-asymmetry) and noise reduction concepts (scarfed nozzles, acoustically lined after-

body and wing) as applied to current and future aircraft configurations of interest, aimed at achieving a 2-3dB source noise reduction.

4. To assess technically the relative merits of different methods of estimating far-field noise levels from in-duct and near-field noise measurements, using both models and the validation data, in order to enhance the capability of European fan noise test facilities to investigate and simulate fan noise radiation through the exhaust.

The consortium consisted of two leading airframe manufacturers, three leading engine manufacturers, an SME that specialises in computational aeroacoustics software, three leading research centres and three leading universities from France, Germany, Belgium, the Netherlands, Italy, Turkey and the UK, Fig. 1.1. This mix of partners has formed the basis for delivering the ambitious project objectives.

Objective 1: To test experimentally at model scale (a) innovative noise reduction concepts, including a scarfed exhaust nozzle, and (b) conventional engine exhaust configurations… in order to evaluate the noise reduction concepts and to provide a high quality validation database.

TURNEX Partners

ISVR) - Co-ordinator
Airbus France (AI-F)
Dassault Aviation (DASSAV)
Rolls-Royce Deutschland (RRD)
Rolls-Royce UK (RRUK)
Free Field Technologies (FFT)
DLR
EADS-CRC
National Aero Lab (NLR)
TU Eindhoven (TUE)
AVIO
Middle East TU (METU)

Figure 1.1: Bypass exhaust nozzle and the hot core exhaust nozzle of a Rolls-Royce Trent 500 on an Airbus A340 and TURNEX Consortium Partners

- **Small-scale experiments:** in support of the main experiment, small-scale experimental tests were conducted on simulated turbomachinery noise sources and advanced measurement techniques, including one with (a) the Mode Synthesiser for fan *tone* noise and (b) arrays of incoherent actuators for fan *broadband* noise, at jet Mach numbers up to 0.7. This test produced valuable information on the behaviour of the Mode Synthesiser under realistic conditions and also provided data that was used to validate a model that was being developed to support improved predictions of far-field broadband noise from in-duct measurements in support of Objective 4. In another small scale test, experimental data was obtained on the behaviour of the novel core duct noise sources, which had to function under extreme conditions of high temperature flow and within a very limited space.

- **Main experiment:** in the main experiment, two model scale exhaust nozzle configurations were tested in the QinetiQ Noise Test facility (NTF) under subcontract, using simulated fan and turbine noise sources and advanced measurement techniques. The rig included a rotating bypass duct section with wall mounted microphones for radial mode analysis (RMA); Fig. 1.2 shows a detailed schematic of the test rig with the ¾ cowl (short cowl) assembly.

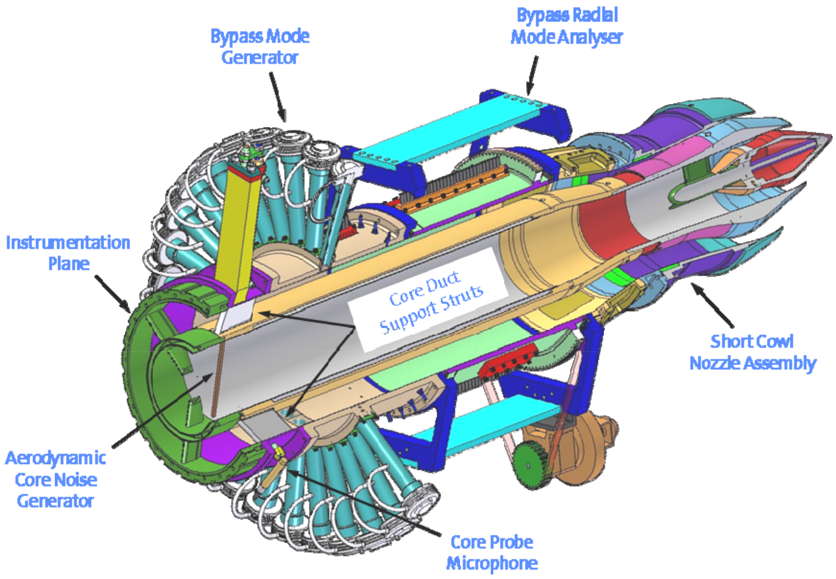


Figure 1.2: Test rig with short cowl bypass nozzle installed, without pylon, showing bypass duct sound sources ('Mode Synthesiser') and rotating microphone array (RMA) for azimuthal and radial mode measurement.

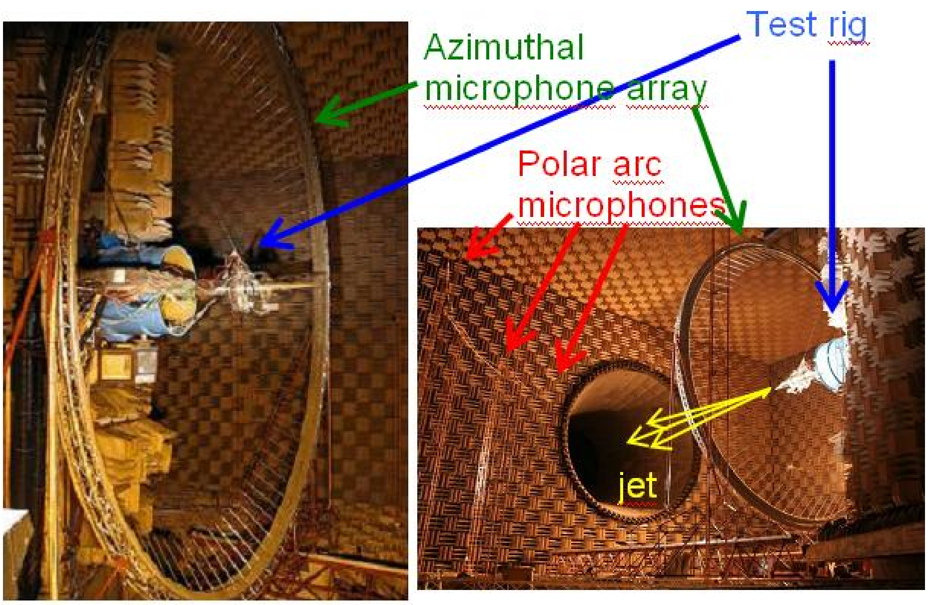


Figure 1.3: Large-scale test rig with short cowl (no pylon) installed in the QinetiQ NTF, showing the far-field polar microphone and azimuthal arrays

A far-field azimuthal far-field microphone array (FFA) was designed and installed in the QinetiQ NTF, which could be moved over a range of axial positions and hence polar angles, as shown in Fig. 1.3. This enabled 3D effects and the azimuthal mode content in the far field to be studied.

The objective of testing conventional, scaled, nozzle configurations was fully achieved. It was also possible to extend the number of different test configurations including short and long cowl nozzles, pylon, installed wing (Fig.

1.4) and external loudspeaker sources to obtain additional information on sound reflection and refraction or shielding.

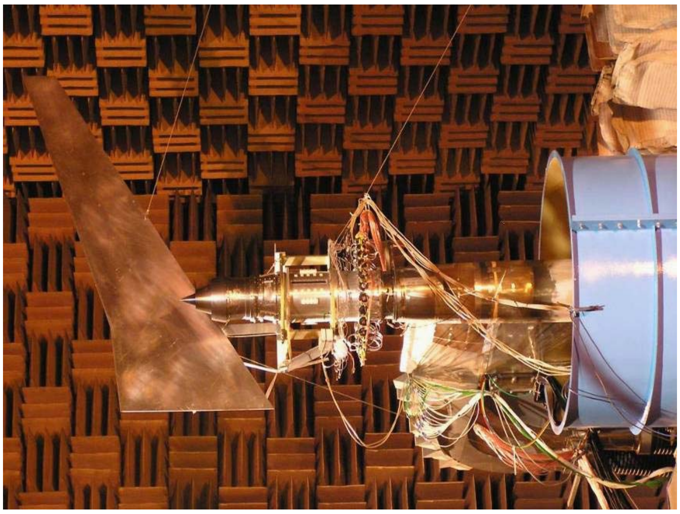


Figure 1.4: Large-scale test rig design with short cowl, without pylon showing bypass duct sound sources and rotating microphone array for mode detection.

- **Scarfed nozzle:** the scarfed nozzle as an advanced noise reduction technology has been numerically investigated under Objective 3, instead of an experimental evaluation, in order to understand the mechanisms involved.

- **Main experiment results:** the data has provided the means to validate existing and new methods developed within TURNEX (Objective 2) for realistic scaled geometries over a wide range of mean flow conditions, corresponding to the aircraft approach and take-off noise conditions. An example of results obtained from the duct RMA in Fig. 1.5 demonstrates that the Mode Synthesiser worked well and generated the target modes with high tone protrusion. Figure 1.6 shows modal spectrum results obtained with the FFA. In this example, the impact of the pylon is clearly visible as it strongly modifies the radiated modal structure of the sound field. Also the shielding and reflection effects of an installed wing can be clearly observed in Fig. 1.7.

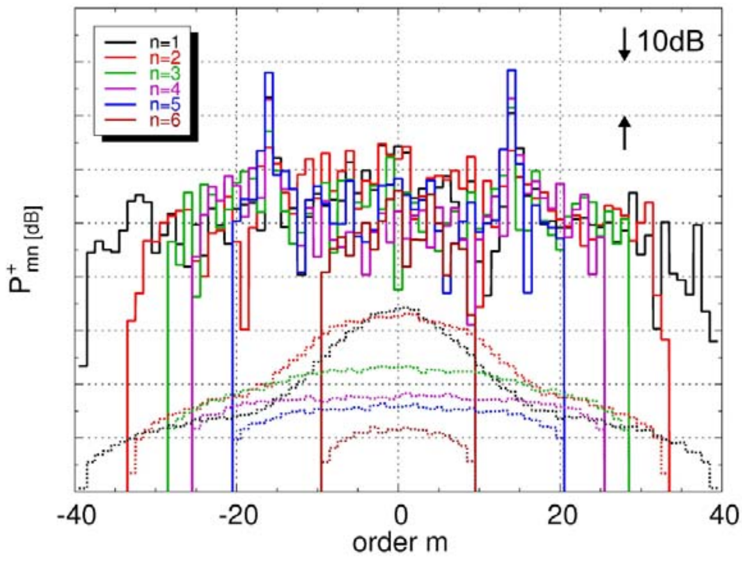


Figure 1.5: Sound power azimuthal spectrum of radial modes propagating downstream measured in RMA duct section for target mode m_t=14 with associated spill over mode m=-16 at 14.4 kHz at Approach. Solid lines: sound power P^+_{mn}; dotted lines: standard deviation.

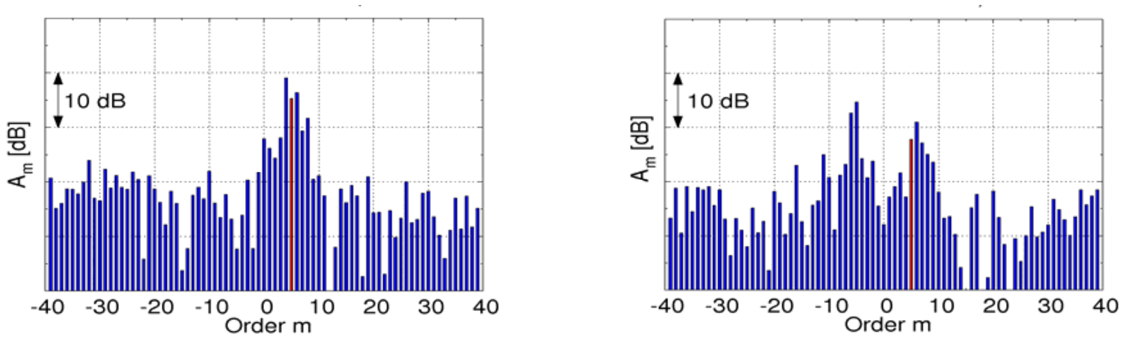


Figure 1.6: Impact of the pylon on far-field azimuthal mode spectrum. The left, right spectra were measured without and with installed pylon at peak polar angle 70°

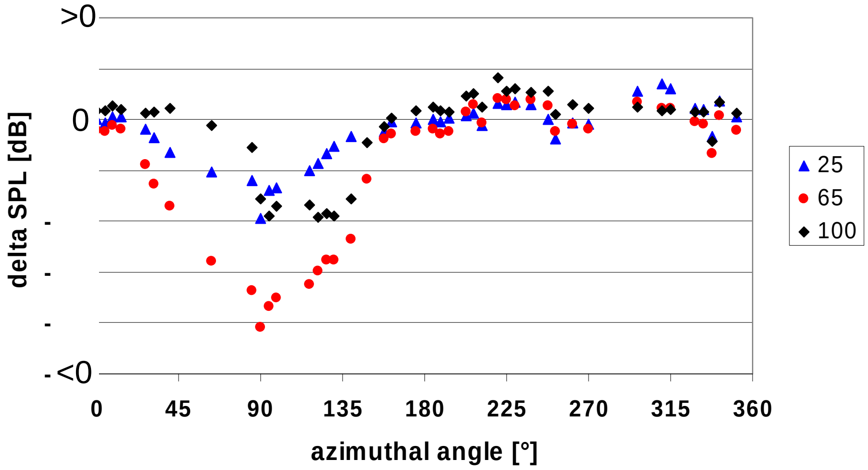


Figure 1.7: Influence of nozzle under-wing installation on far-field polar angles 25°, 65° & 100° as SPL difference in azimuthal directivity over 8 kHz 1/3-octave band, measured with FFA without and with installed wing. Simulated fan broadband noise was generated in bypass duct. Tests conducted on ¾ cowl short nacelle at Approach.

- **Afterbody Liner test**: in a separate test, a novel noise reduction technique called the Afterbody Liner (AL) was manufactured and tested on a no-flow rig excited with simulated fan broadband noise source and also with tone noise; the model AL is shown in Fig. 1.8. These no-flow results have show that the AL yields significant broadband noise attenuation at certain far-field angles, over and above that achieved by the bypass liner. A possible implementation of the AL is shown in Fig. 1.9, for which the benefits have been evaluated under Objective 3.

Figure 1.8: ISVR/RR No-flow rig with Inner & Outer Lined Bypass and Afterbody Liner Configuration

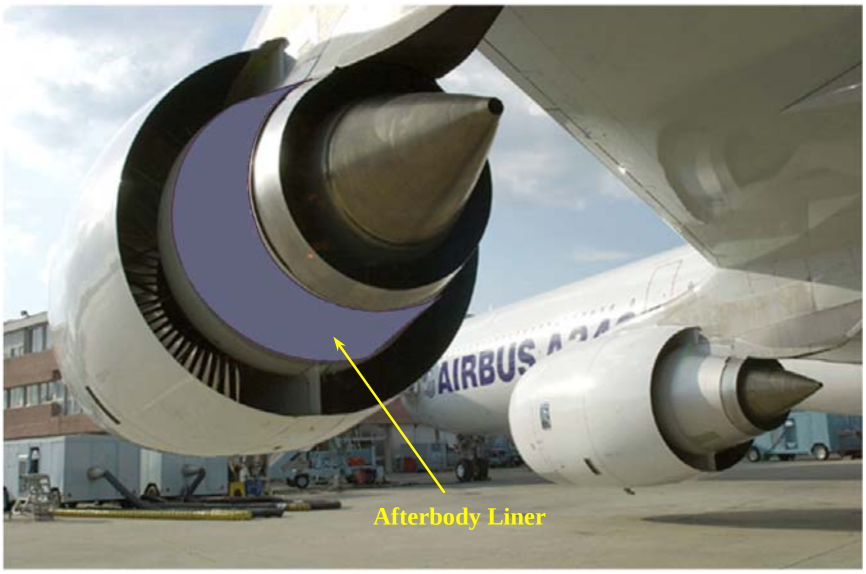


Figure 1.9: Possible application of Afterbody Liner acoustical treatment on a typical turbofan engine

Objective 2: To improve models and prediction methods for turbomachinery noise radiation through the engine exhaust…and to validate those methods with the experimental data.

- **Analytical models:** TURNEX has advanced the state of the art by developing a new analytical Munt-type solution for the radiation of annular duct modes through a vortex sheet model of an exhaust jet, for the effects of (a) an acoustic lining on the centrebody and (b) an acoustic lining on the afterbody only. These can be used in industry to further the understanding and verification of methods and CAA codes and in the development of models of the ‘afterbody liner’ the noise reduction concept evaluated experimentally under Objective 1. In addition new analytical solutions have been derived for annular ducts with dual stream flows and (1) the inner nozzle buried and (2) the co-planar nozzle thus fully emulating two of the most common aero-engine configurations, which will be useful to industry in the same way.

- **Intake CAA code enabled for exhaust:** an existing commercially available code for propagation through potential mean flows, Actran/TM, is already used as a computational prediction method for turbomachinery noise radiation through engine intakes. TURNEX has now shown that this same type of code can be used for the special case of radiation through vortex sheet jet models of the jet shear layer(s) with the aid of a new membrane finite element and can provide near and far-field results, which have been verified with analytic solutions. However this does require a simplified mean flow model to be used with vanishingly thin shear layers and if accurate results are required a full linearized Euler solver (LEE) has to be used. Nevertheless, when extensive parametric studies are required the more rapid computations of the intake code may be an acceptable trade-off for reduced accuracy.

- **CAA LEE time domain code Actran/DGM:** a new time domain CAA code developed under a previous EC-funded project MESSIAEN, called Actran/DGM, which has been designed to efficiently solve the linearised Euler equations (LEE) for 3D radiation problems, has been extended to axisymmetric geometries within TURNEX. Verification of Actran/DGM at the Approach condition has been achieved with analytic solutions for idealised geometries and with other CAA codes for realistic ¾-cowl and long cowl exhaust geometries.

  During the initial verification and validation of Actran/DGM, to achieve convergence a previously used technique of suppressing mean flow gradient terms in the LEE had to be employed. Termed ‘Gradient Term Suppression’ (GTS), this technique has now been fully understood with the aid of analytical Munt-type solutions. GTS can be used to suppress Kelvin-Helmholtz and other types of instability modes of the duct and exhaust shear layer(s) if required, but results obtained with another time code ‘ENFLOW’, have shown that this is not normally required because the developing shear layers lead to the neutralisation and decay of these modes It is recommended that when time domain codes such as Actran/DGM are used in future these instability modes should not be suppressed with GTS because real geometry and flow effects could lead to indirect radiation from instabilities driven by the internal turbomachinery noise sources. The time domain codes are also able to solve large industrial 3D problems such as radiation through the coaxial exhaust nozzle with the engine pylon present or when other 3D features are included, which are not feasible with current frequency domain CAA codes.

- **CAA LEE frequency domain code FLESTURN:** a new frequency domain code, FLESTURN, has been developed under TURNEX to enable solutions to be obtained for the same types of problems being addressed by Actran/DGM. Solving in the frequency domain automatically excludes Kelvin-Helmholtz instability modes but without the need to use GTS. In addition, FLESTURN is better suited to modelling configurations with acoustic linings than the CAA time domain codes. Thus the FLESTURN CAA code complements the time domain code and has a number of attractions within the industrial context, except at very high frequencies where computer memory becomes a limitation for axisymmetric geometries; for the same reason it is less suitable for 3D problems.

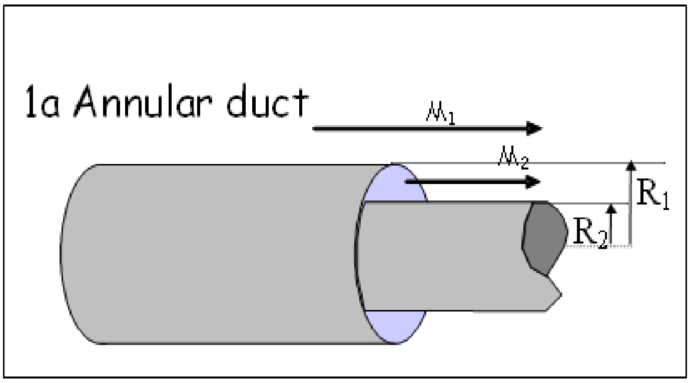


Fig 2.1a: Case 1a Munt-type flow/geometry

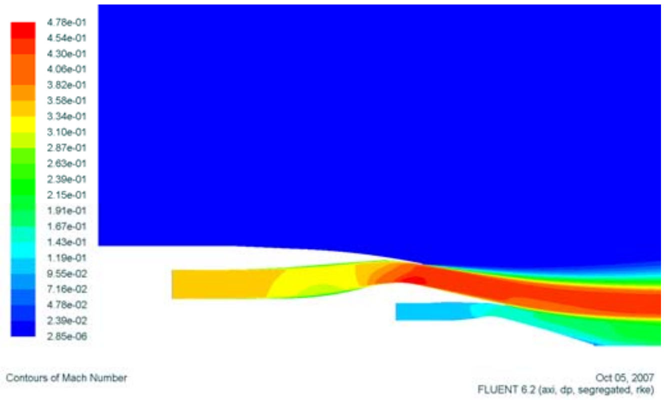


Fig 2.1b: Case 5 Coaxial ¾ cowl geometry with mean Mach number contours from FLUENT

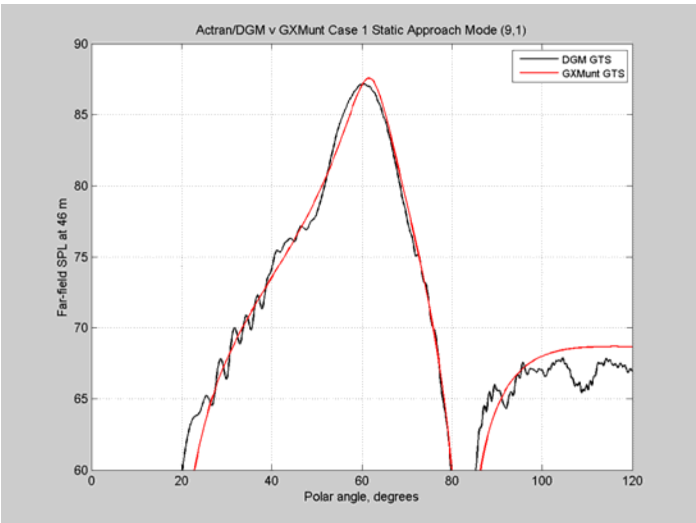


Fig 2.1c: Actran/DGM v GXMunt both GTS: Case 1a at Approach, fan 866 Hz m=9, n=1 at 46 m

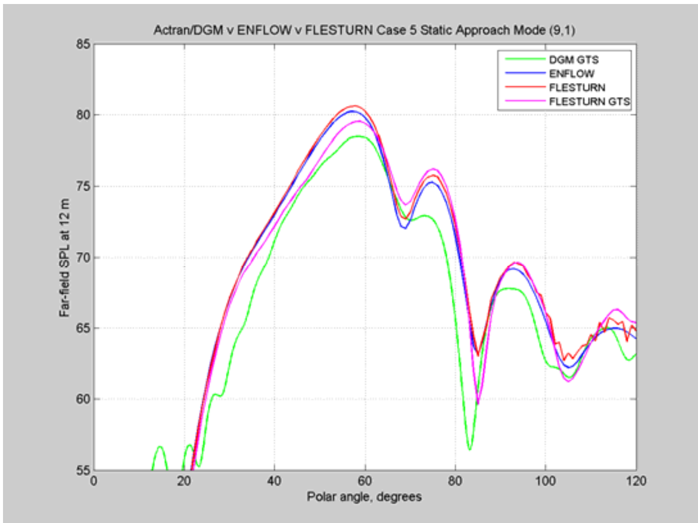


Fig 2.1d: DGM, ENFLOW & FLESTURN: Case 5 at Approach, fan 7497 Hz m=9, n=1 at 12 m

- **Verification of CAA codes:** verification of the above CAA codes with analytical Munt-type codes, for simple geometry/mean flow configurations such as that shown in Fig. 2.1a, have proved invaluable in the development and testing of both the time domain and frequency domain codes; here verification is shown in Fig. 2.1c.

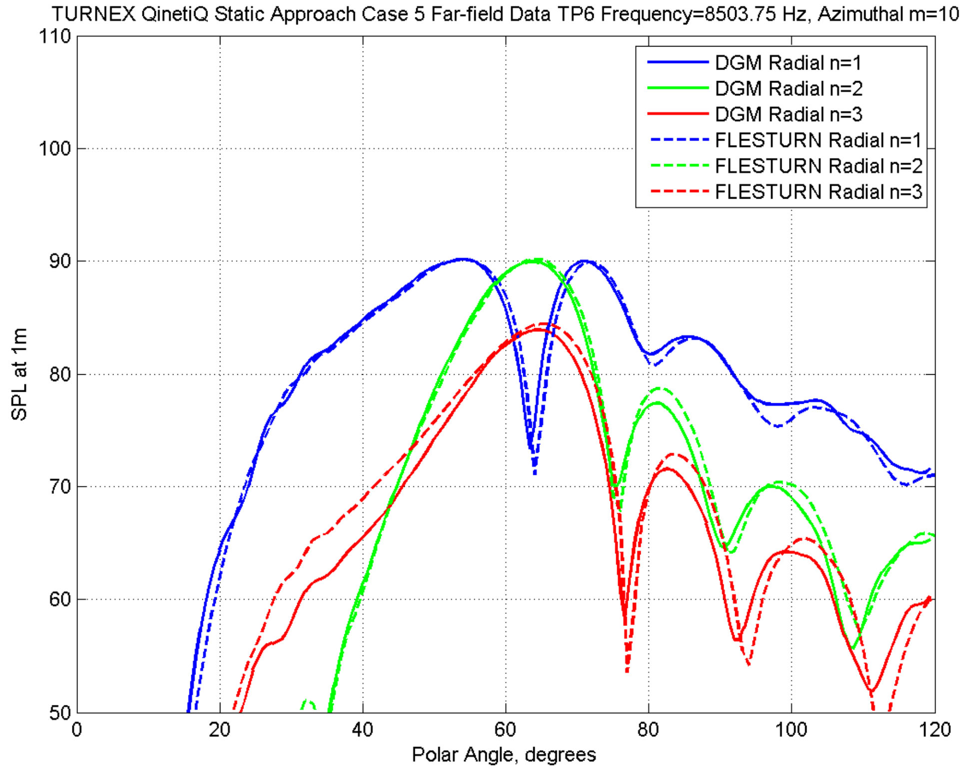


Fig 2.2a: Cross-verification of CAA codes Actran/DGM & FLESTURN: ¾ cowl at Approach simulated fan BPF 8500 Hz m=10

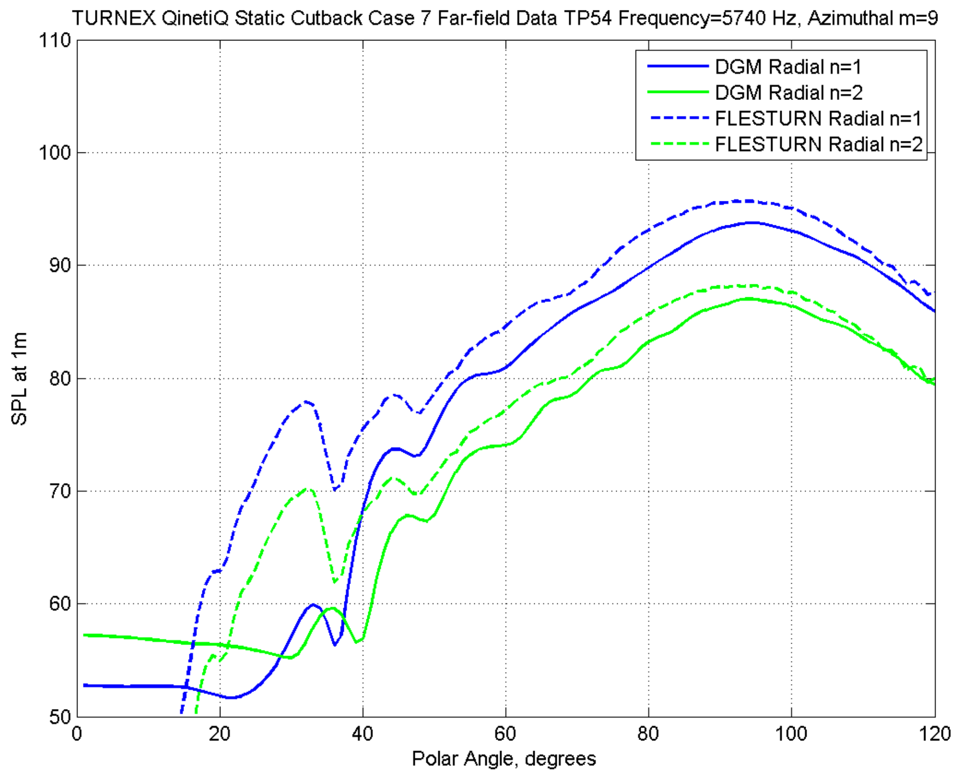


Fig 2.2b: Cross-verification of CAA codes Actran/DGM & FLESTURN (GTS): Long cowl at Cutback simulated fan 1/2BPF 5740 Hz m=9

Similarly 'cross-verification' of the different codes for more realistic geometries and mean flows, such as that in Fig.2.1b, has been invaluable; cross-verification is shown in Fig. 2.1d for the first radial mode. Similarly cross-verification results for higher order radial modes are shown in Fig. 2.2.

- **Validation of CAA codes:** a key part of this second objective is the validation of the above codes with the experimental data acquired under Objective 1. A typical result is shown in Fig. 2.3 which shows measured noise levels from the two different far-field arrays ('Polar' and 'Azimuthal') compared to predictions from the Actran/DGM and FLESTURN codes, using as the source input the mode amplitudes measured with the RMA. This is validation in both far-field *level and directivity shape*, which is unusual in the context of aircraft noise prediction methods where normally the level is based on a semi-empirical 'calibration' and only the directivity or field shape, is normally validated.

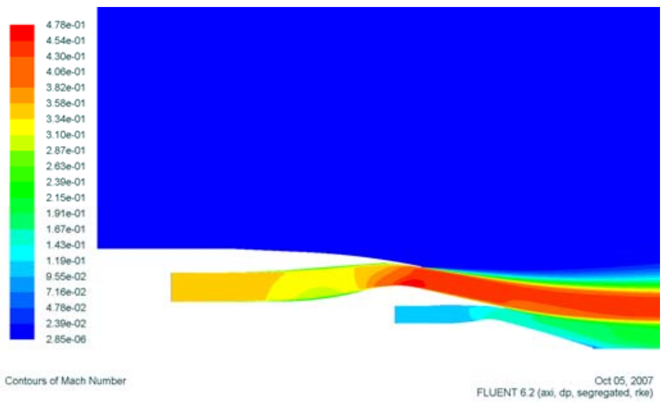


Fig 2.3a: Coaxial ¾ cowl geometry: Mach number contours from FLUENT at Approach

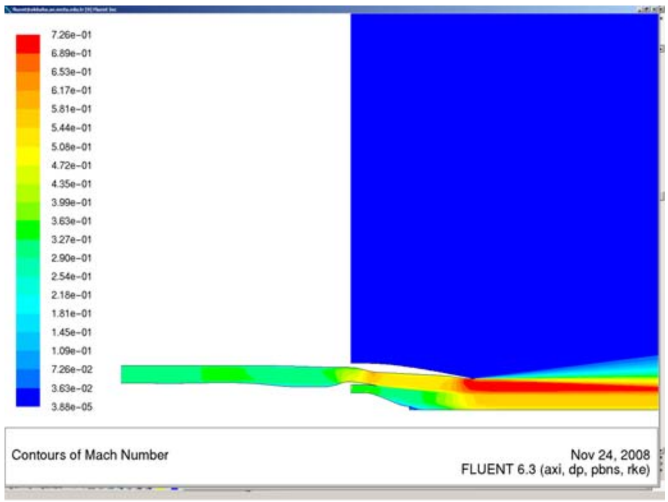


Fig 2.3b: Long cowl geometry: Mach number contours from FLUENT at Cutback

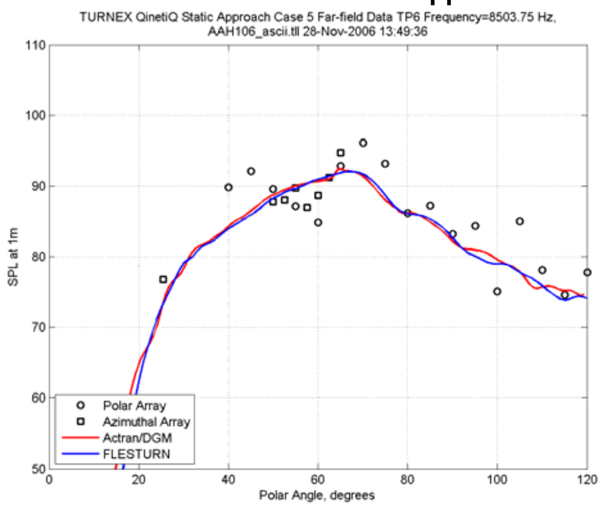


Fig 2.3c: Validation of Actran/DGM & FLESTURN with data from Objective 1: ¾ cowl at Approach, simulated fan BPF 8500 Hz m=10 (TP6)

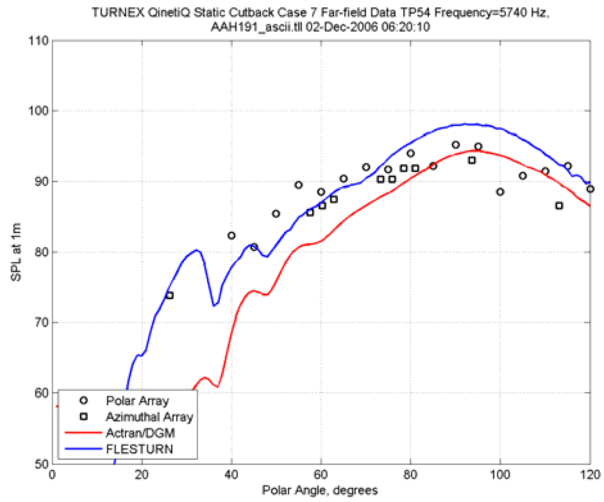


Fig 2.3d: Validation of Actran/DGM (GTS) & FLESTURN with data from Objective 1: Long cowl at Cutback, simulated fan 1/2BPF 5740 Hz m=9 (TP54)

- **Tone Haystacking:** the above methods and codes all address propagation through the steady component of the exhaust jet flow(s). However, industry also requires methods for predicting the effects of scattering by the turbulent components within the jet shear layer(s), which leads to broadening or 'haystacking' of high frequency turbine tones and also spatial scattering into azimuthal modes other than those excited initially by the turbine tone generation processes.

  TURNEX has made significant advances in this subject by (1) evaluating an analytic, asymptotic solution based on the Cargill 'weak' scattering method, which appears to be robust and can be rapidly computed and (2) developing and evaluating the application of a time domain CAA code, PIANO, without the limitation of weak scattering. Both methods have been initially tested against published experimental data by Candel. The analytic model is compared to that data in Figs. 2.4 and 2.5, where the measured trends with frequency and jet velocity are essentially reproduced by the analytic method. Fig. 2.6 shows a comparison of PIANO CAA results at different frequencies and with the experimentally measured haystack for one frequency and again good agreement is achieved. Measured data acquired under TURNEX is available for validation of these and other methods for more realistic jet flow conditions.

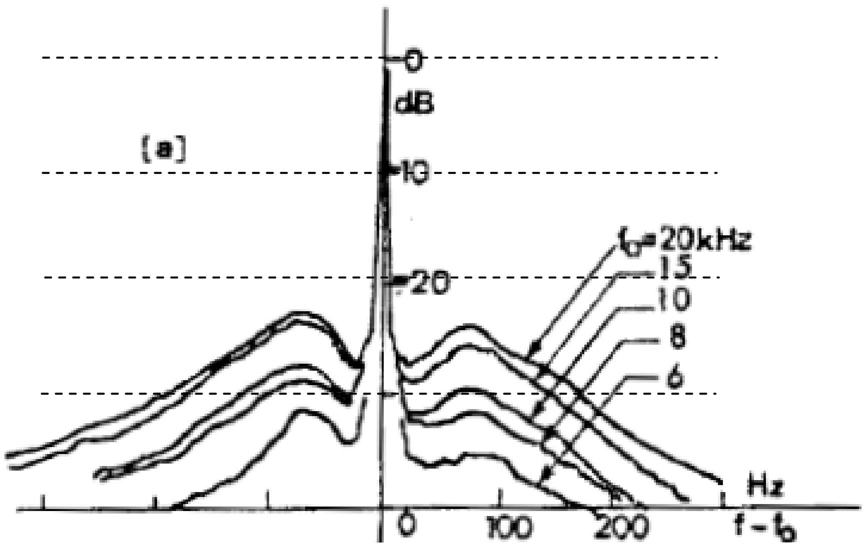


Figure 2.4a: Measured haystack spectra from Candel (Fig. 25a)

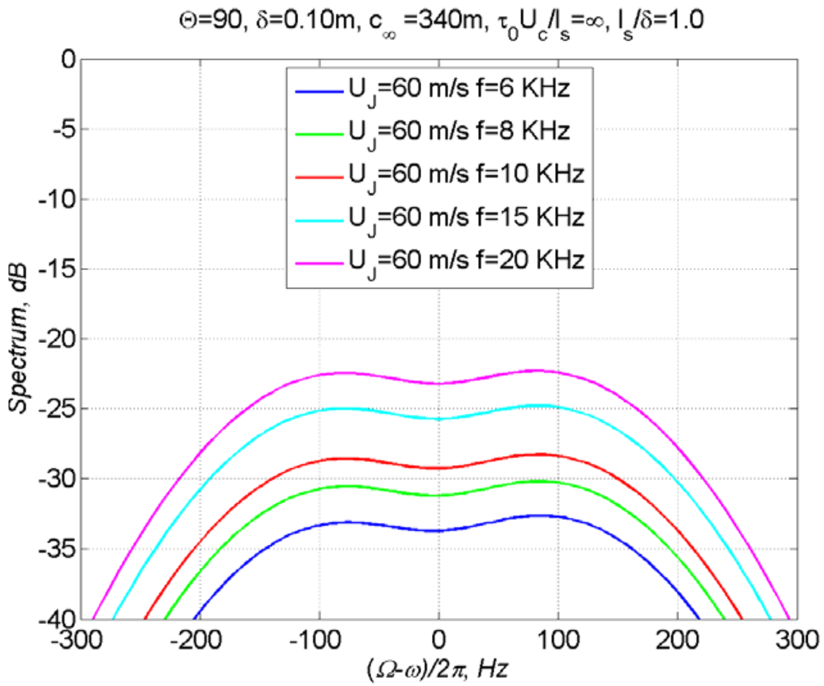


Figure 2.4b: Predicted haystack spectra based on Cargill weak scattering method with frozen turbulence model

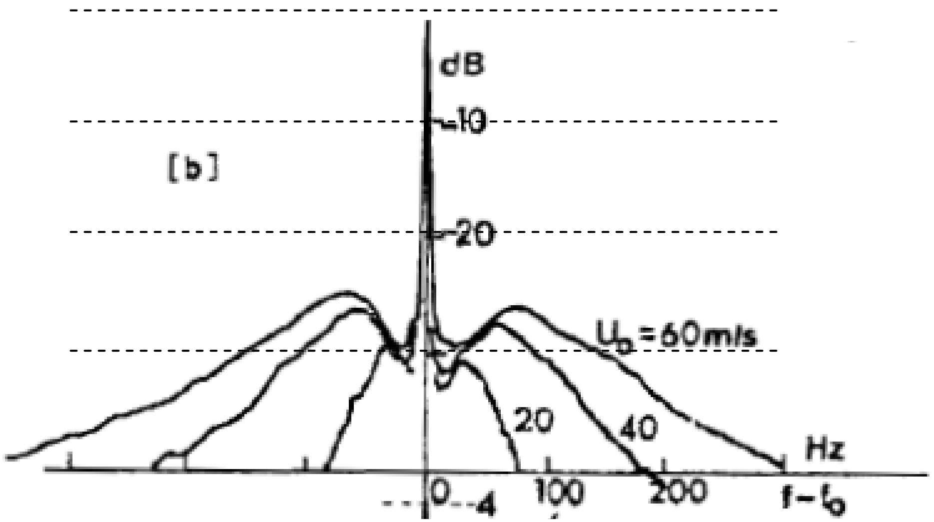


Figure 2.5a: Measured haystack spectra from Candel (Fig. 25b)

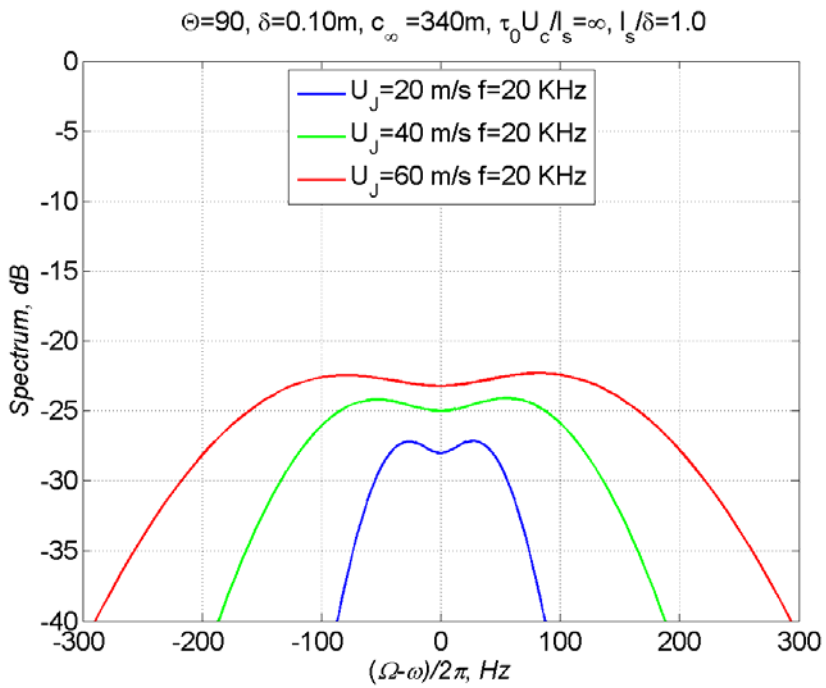


Figure 2.5b: Predicted haystack spectra based on weak scattering Cargill method with frozen turbulence model

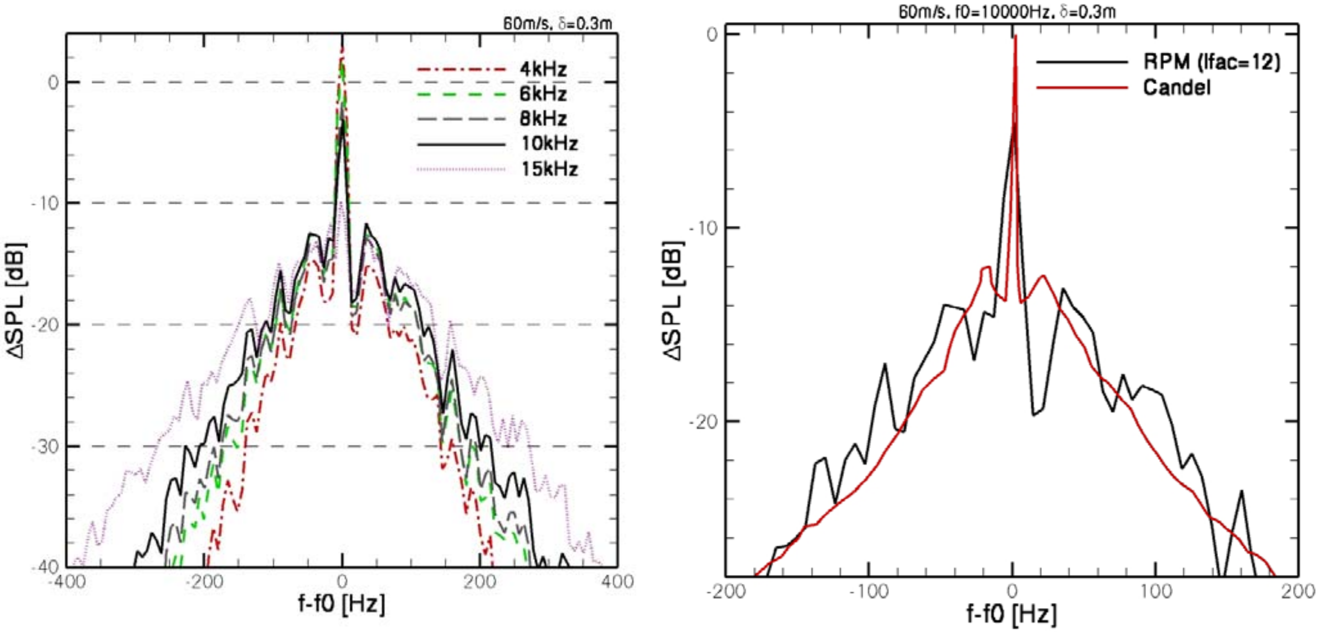
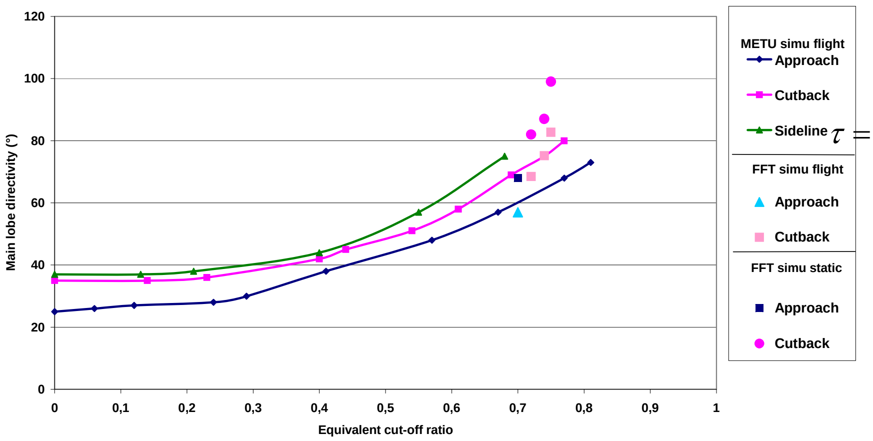


Figure 2.6: Computed haystacks for different frequencies from PIANO code (left) and comparison with the experiment of Candel at 10 KHz (right)

Objective 3: To conduct a parametric study of real geometry/flow effects (pylons, wings, flow-asymmetry) and noise reduction concepts (scarfed nozzles, acoustically lined after-body and wing) as applied to current and future aircraft configurations of interest, aimed at achieving a 2-3dB source noise reduction.

- **Parametric Study**: a parametric study on a typical full-scale engine with short cowl, called LRAS, has been conducted. Both axisymmetric and 3D configurations with pylon have been addressed and two novel noise reduction noise concepts have been evaluated (Afterbody Liner and Scarfed Exhaust). Except for the Scarfed Exhaust concept, the computational matrix has been successfully completed. The main obtained results are as follows.

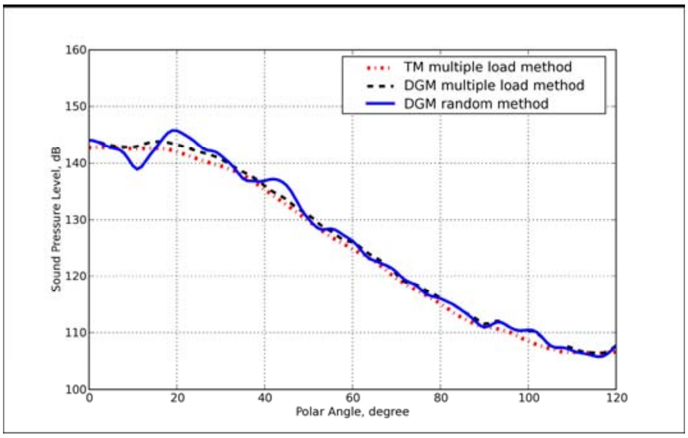
  1. A successful application of Actran/DGM (Axisymmetric) to real engine configurations has lead to a better understanding of the influence of shear layer refraction, through the development of an approximate model for the peak radiation angle as shown in Fig. 3.1.



$$\tau = \sqrt{\frac{k_{r_{mn}}^2}{k^2 + M^2 k_{r_{mn}}^2}}$$

Figure 3.1: Influence of flow conditions on the main lobe position for different equivalent cut-off ratios (characterising the propagation angle in the duct)

2. Actran/DGM (Axisymmetric) has been successfully applied to the multimodal excitation situation for broadband noise and found to agree well with Actran/TM (the intake code); an example is given in Fig. 3.2.



$$p_{bb} = \sqrt{\sum_{m,n} \left| p_{mn} \right|^2} \approx \sqrt{\sum_{m} \left| \sum_{n} p_{mn} e^{i\#_{mn}} \right|^2}$$

Figure 3.2: Validation of Multimodal excitation in Actran/DGM

3. Evaluation of the Afterbody Liner concept, including the effects of mean flow has been conducted with the FLESTURN code (both broadband and tonal source). Up to 4-5 dB additional attenuation has been demonstrated at high angles (refraction effects) on broadband noise (Fig. 3.3) but the impact on tonal noise is relatively weak.

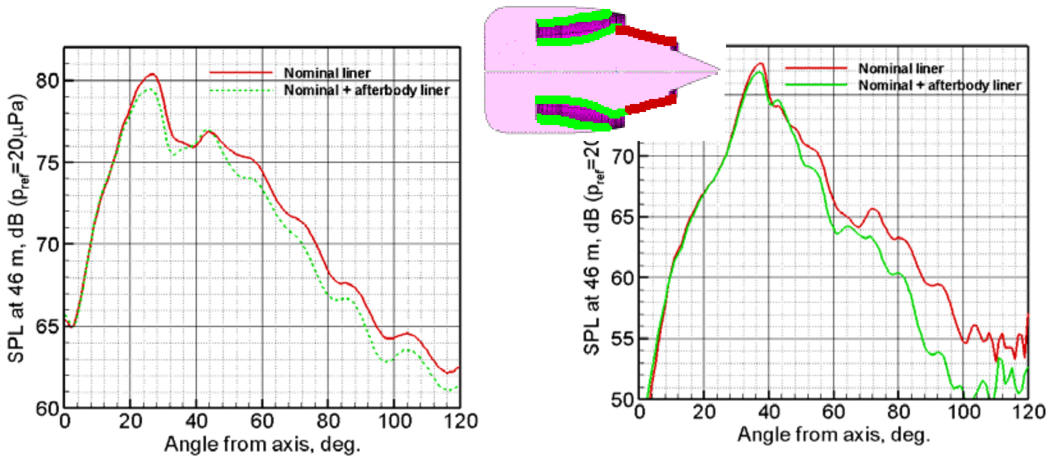


Figure 3.3: Additional noise reduction due to Afterbody Liner for broadband noise (Left: Approach, 866Hz. Right: Sideline 1215 Hz).

4. The effects of the pylon and the bifurcation for unlined bypass (hardwall) cases have been studied with the ENFLOW code. An incident azimuthal mode was found to be significantly reflected into the opposite order mode by the pylon and bifurcation and radiates to far field, Fig. 3.4, which has been confirmed by the experimental results from Objective 1.

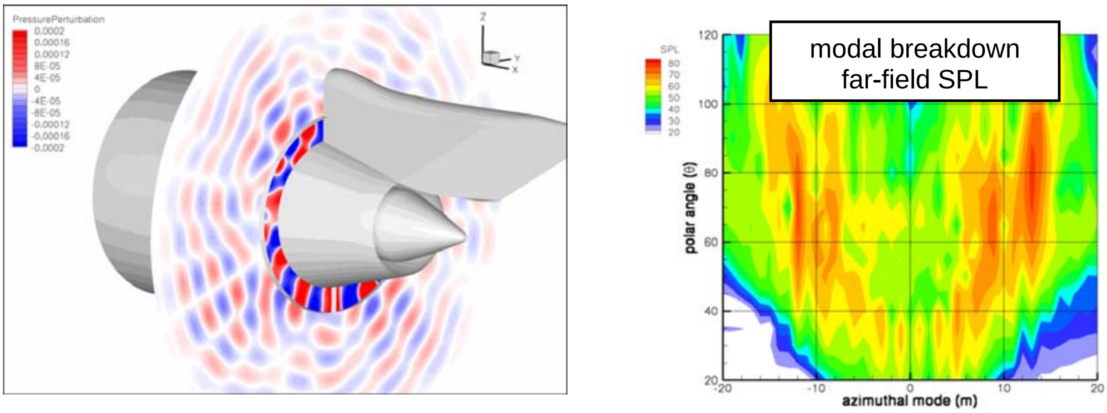


Figure 3.4: ENFLOW near-field acoustic pressure on LRAS engine with pylon (Cutback condition, 715Hz; incident mode (13,1) reflected into mode (-13,1)

- **Jet Shielding**: turbomachinery and other noise sources radiated from engines installed under the aircraft wing are partially reflected by the wing and then partially shielded by the coaxial jet exhaust flow before arriving at the observer position on the ground, Fig. 3.5. TURNEX has addressed the industrial need for improved methods for predicting installation effects by studying the shielding of noise by coaxial heated jets with the aid of both asymptotic and numerical solutions (NLS) to the Lilley equation for steady refraction or shielding of sources outside the jet. Comparisons between models and experimental data from the test conducted under Objective 1 have shown the theories agree well with experiment, as illustrated in Fig. 3.6.

  From this study, it is recommended that, in general, NLS should be used if accurate shielding predictions are required at particular frequencies but if predictions are required at many frequencies, e.g. for broadband sources, a combination of the asymptotic methods offers a means to compute this quickly and with acceptable accuracy. At high frequencies the effects outside the cone of silence appear to be well predicted by the application of simple ray theory with a plug flow model of the jet. Inside the cone of silence *the shielding becomes independent of the centreline Mach number and temperature and can be accurately predicted by modeling the shielding as if it were caused by the reflection and diffraction by a 'solid' body of radius equal to the jet nozzle, with a pressure release boundary*. This is a key result and offers a means of implementing the shielding effect inside the cone of silence (where rays cannot penetrate) within the framework of industrial ray-acoustics models for installations effects.

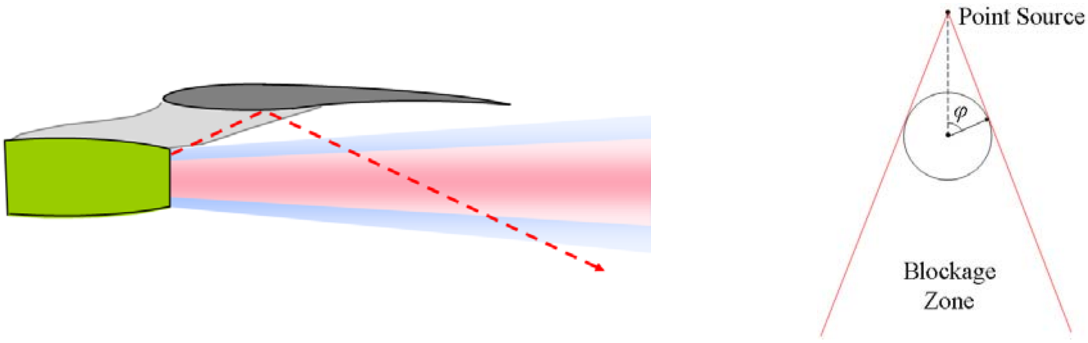


Figure 3.5: Large-scale test rig design with short cowl, without pylon showing bypass duct sound sources and rotating microphone array for mode detection.

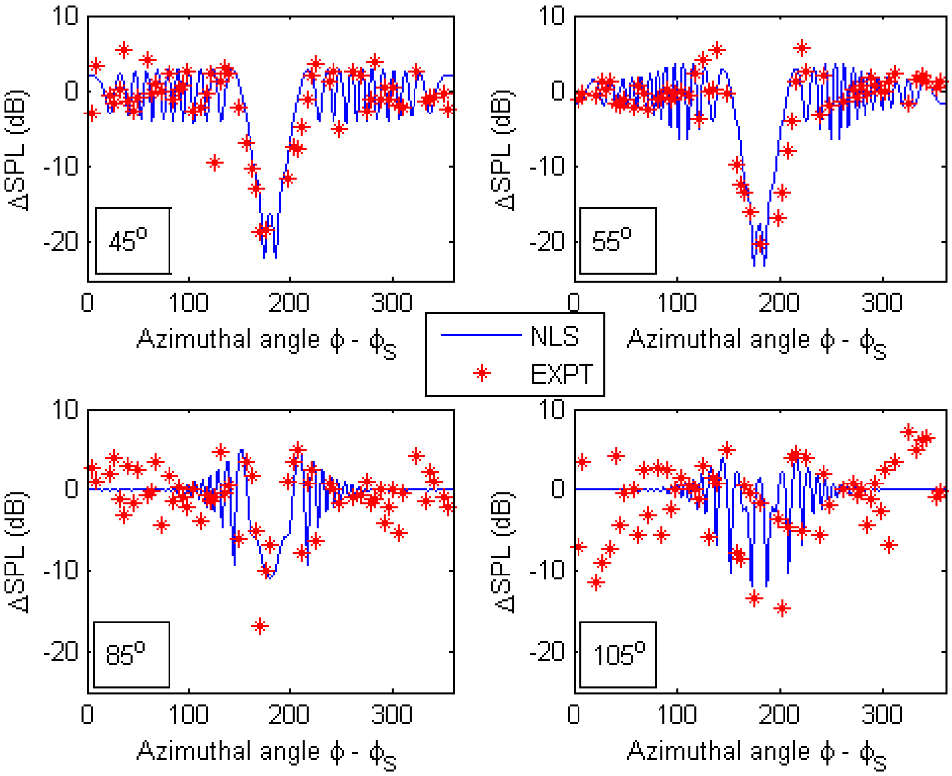


Figure 3.6: Comparison of numerical (blue) results (NLS) with experimental (red) from TURNEX model coaxial jet test under Objective 1, at Approach. Polar angle *θ* is shown in the bottom left of each frame

- **Jet shielding in industrial installation predictions:** an industrial code for installation effects, PUREFLO (based on asymptotic methods), has been evaluated on the experimental configurations with a simple flat plate wing from the TURNEX tests under Objective 1 and both experimental and numerical results has highlighted *the importance of jet blockage/shielding.*

Figure 3.7 shows the measured and predicted reflection effect of installing the flat plate wing above the experiment nozzle rig as an installation delta (installed minus isolated far field levels). The right hand plot shows the PUREFLO code ray-tracing prediction in which the wing planform leading and trailing edge sweep can be seen in the reflected sound field. The horizontal band of reduced level corresponds to the simple attenuation of the reflection due to the existing hot jet blockage model. The left hand plot in Figure 3.7 shows the equivalent measured installation reflection delta from the TURNEX experiment using a bypass duct broadband source level. The wing planform reflection and its hot jet blockage can clearly be seen in the results. However the red areas show that a significant amount of reflected energy is *not simply blocked but re-directed to azimuthal angles either side of the blockage region*. This corresponds well with the results from the isolated test cases and with the jet shielding model described above.

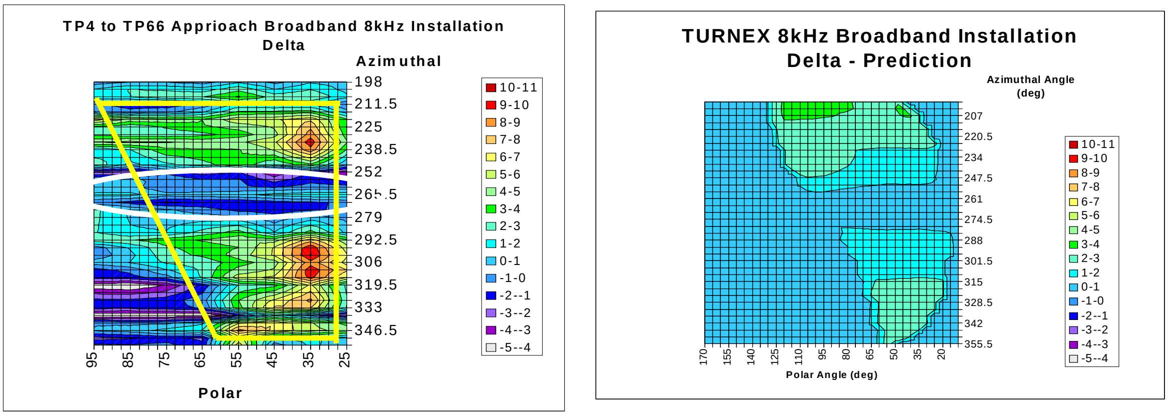


Figure 3.7: Comparisons TURNEX experiments with PUREFLO predictions for the installed case at Approach, 8000Hz Broadband (plate wing, no flap, jet blockage included)

- **Aircraft noise assessment:** based on the numerical results from the LRAS engine study, a specific installation effect study has been conducted in order to assess the effect of the wing on the numerical results obtained on rearward fan noise. A correction has been applied on the results in order to take the jet blockage effect into account, based on the TURNEX experimental results. LRAS results have been interpolated / extrapolated in order to provide third-band octave attenuation matrix for Aircraft noise predictions. The differences have been applied to the VP2-LR2 Aircraft-Engine (Virtual platform designed in SILENCE® project) which corresponds to the LRAS Engine. The main results (EPNL) are given below. Positive difference or 'delta' means a noise increase.

Lined after body	approach	flyover	sideline
aft fan	0.0	-0.4	-0.5
engine	-0.1	-0.1	-0.1
total aircraft	0.0	-0.1	0.0

IFX axi BB + EO no jet blockage	approach	flyover	sideline
aft fan	2.3	1.7	2.1
engine	1.0	0.6	0.6
aircraft noise	0.5	0.5	0.6

IFX axi BB + EO with jet blockage	approach	flyover	sideline
aft fan	0.5	0.5	n/a
engine	0.2	0.2	n/a
aircraft noise	0.1	0.1	n/a

Objective 4: To assess technically the relative merits of different methods of estimating far-field noise levels from in-duct and near-field noise measurements, using both models and the validation data, in order to enhance the capability of European fan noise test facilities to investigate and simulate fan noise radiation through the exhaust.

- **In-duct to far-field beamformer method for broadband noise:** a method for estimating far-field broadband noise levels from in-duct measurements in the form of a beamformer technique has been evaluated with the aid of data acquired under Objective 1. This is based on cross-spectrum measurements taken with a simple flush-mounted, in-duct axial array of microphones. In effect, an in-duct directivity is measured and a computed transfer function is used to project that directivity into the far-field, which should be insensitive to the source model assumed and this does appear to be the case, provided any influence on the directivity is taken into account, such as a change in duct area or refraction by the jet exhaust flow. The estimated far-field results with an angle correction included for the area change between the beamformer array and the bypass nozzle are compared with measured data in Fig. 4.1.

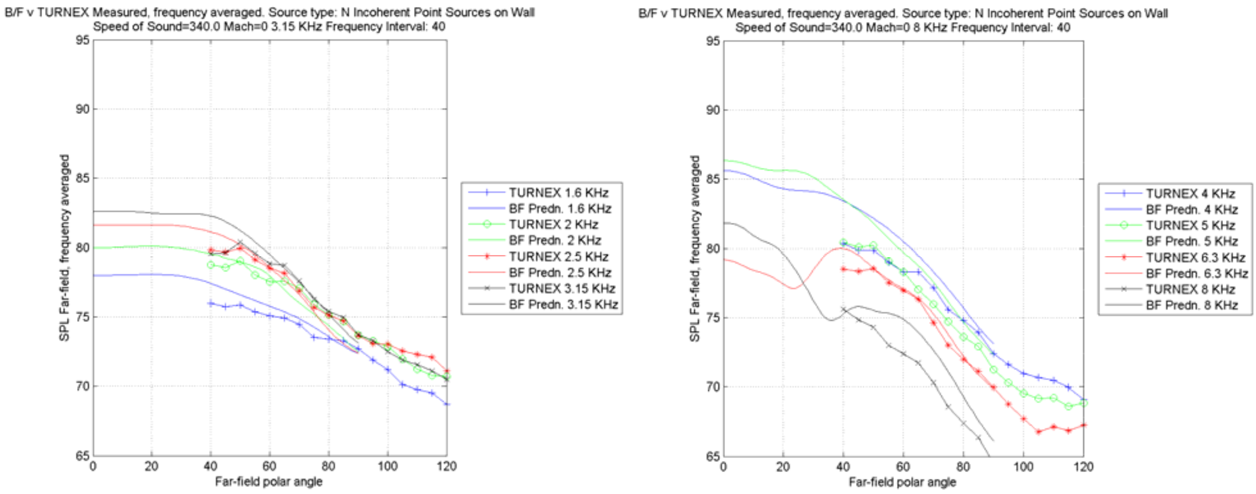


Figure 4.1 Axial beamformer far-field broadband noise predictions compared to measured data, based on TURNEX rig data acquired at QinetiQ: left - low frequency, right mid-frequency 1/3 octaves

- **Application of beamformer technique:** fan models or rigs that are tested in the Anecom facility are designed to model the main bypass duct but not the final bypass nozzle. Therefore when the Anecom in-duct beamformer data is projected to the far-field (for subsequent comparison with engine data etc), it will be necessary to take into account propagation from the axial measurement section through the bypass nozzle, which would normally involve a flow acceleration and an area change.

Last page