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TURBOMACHINERY NOISE RADIATION THROUGH THE ENGINE EXHAUST (TURNEX)

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Abstract

TURNEX (Turbomachinery Noise Radiation through the Engine Exhaust) is a 6th Framework European-funded project comprising a consortium of 12 partners, coordinated by the ISVR, and is aimed at an improved understanding and a reduction of turbomachinery noise radiation through the jet exhaust. The project spans three years (2005-2007). Turbomachinery noise radiating from the bypass and core nozzles is becoming the 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 will address 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 2–3 dB. The main achievements at the end of the second year are described here, which include experimental test results and verification of CAA solutions with analytical solutions for radiation of duct modes through different types of exhaust jet flows.

1. INTRODUCTION

When an aircraft is taking off the main components of turbomachinery noise are buzz-saw noise radiated from the intake and fan broadband noise and tones from the bypass exhaust. In addition there may be higher frequency turbine tones radiated through the core exhaust. Fig.1 shows the bypass exhaust nozzle and the hot core exhaust nozzle of a Rolls-Royce Trent 500 on an Airbus A340. TURNEX is concerned with the turbomachinery noise that is radiated from these two nozzles. The reason we are concentrating on ‘turbomachinery noise radiation through the jet exhaust’ is that this is becoming the dominant source on modern aircraft. Research is therefore needed to develop innovative concepts and enabling technologies to reduce aero engine noise at source. Fig. 1 also lists the partners in TURNEX.

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

Fig. 2 shows the Workpackage structure and scope of TURNEX.

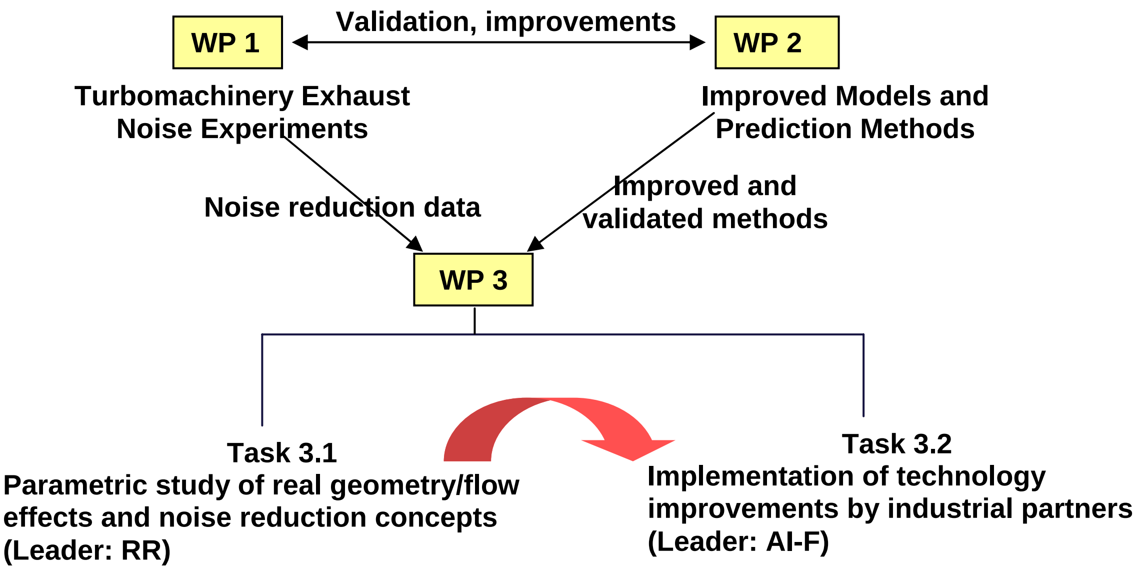


Figure 2: TURNEX Workpackage structure

The overall objective of TURNEX is ‘Improved understanding & validated design methods and evaluation of low-noise exhaust nozzle configurations aimed at a source noise reduction of 2-3dB.’

The work in this project was partly inspired by the results of Zhang e.a. [1] obtained in a previous EC-funded project called TurboNoiseCFD. Their LEE solutions have been especially useful, for example Fig. 3 shows how complex the radiation of sound waves is from the bypass of a realistic engine exhaust. The sound is mainly diffracted around the bypass nozzle lip but another significant radiation path is through inward waves propagating almost parallel with the afterbody and then being diffracted or scattered off the core nozzle lip, to form a separate lobe radiating to the far field. This later inspired the idea that if we could find some means of absorbing these inbound waves it might bring about a significant reduction in the far-field noise level.

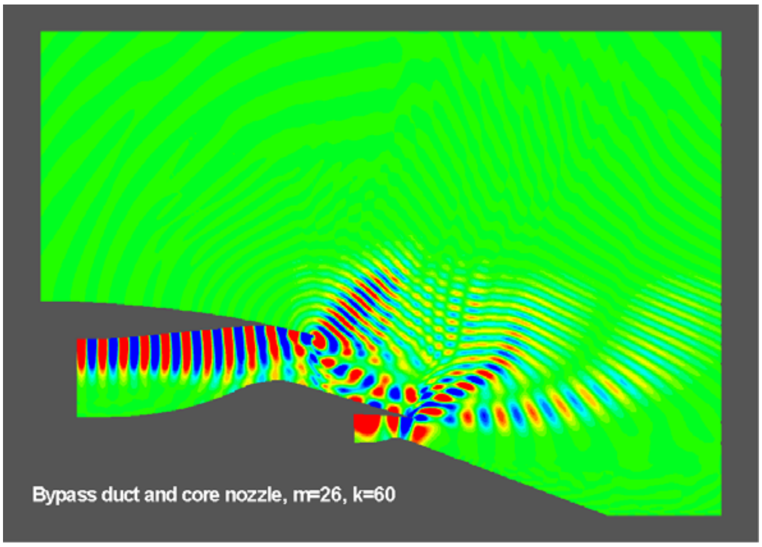


Figure 3: Radiation of fan tone mode from typical high bypass exhaust, LEE solution [1]

2. TURBOMACHINERY EXHAUST NOISE EXPERIMENTS (WP 1)

The objectives of this part of TURNEX are (1) to acquire high quality experimental validation data on scaled exhaust models for exhaust fan tones and broadband noise, utilising simulated turbomachinery noise sources and innovative measurement techniques and (2) to test experimentally at model scale innovative noise reduction concepts. The main experiment tests were conducted late last year at a subcontractor test facility at QinetiQ, Farnborough, England, which were organised and lead by RRD. This comprised a 1/10-scale model with realistic, geometry and mean flow and temperature and is providing much of the validation data in TURNEX, which is still being analysed.

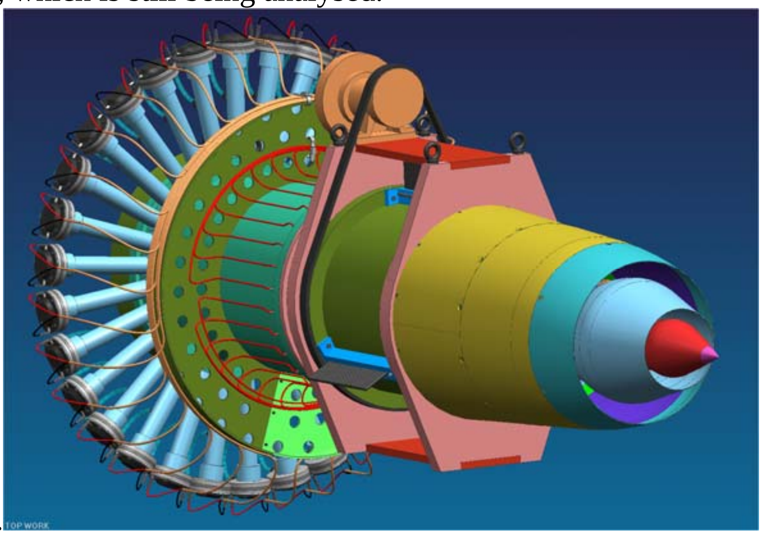


Figure 4: Large-scale test rig design with short cowl, bypass duct sound sources and rotating microphone array for mode detection.

The test models included conventional exhaust nozzle configurations as shown in Fig. 4 with turbomachinery noise simulation arrays and extensive in-duct microphone arrays for mode detection by DLR. Fig. 5 shows the rig mounted in the QinetiQ Noise Test Facility, along with the far-field azimuthal microphone array, which was required to measure azimuthal directivity of 3D configurations, e.g. the engine pylon. These tests in the QinetiQ facility were preceded by a pilot test at NLR to test the Mode Synthesiser - supplied by EADS - and the tone and broadband noise simulation techniques, the results being reported in [2]. That test also provided data that is being used to validate a model being developed to support improved predictions of far-field broadband noise from in-duct measurements [3].

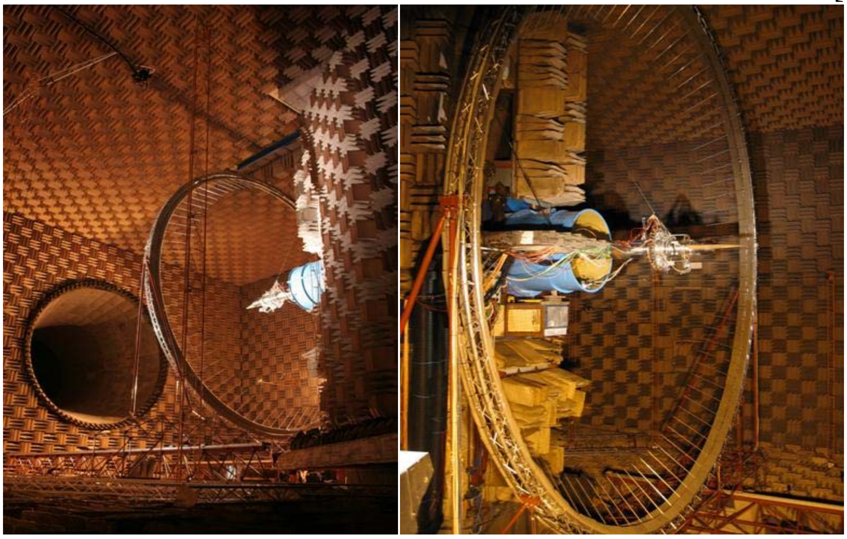


Figure 5: Large-scale test rig design with short cowl, without pylon showing bypass duct sound sources and rotating microphone array for mode detection.

One of the innovative noise reduction ideas we have investigated is the concept of using acoustic linings on *external* parts of the aero-engine nacelle, such as the afterbody and plug nozzle. It is emphasised that conventional acoustic liners are normally used in the *interior* of the duct such as bypass liners, which are especially effective in attenuating aft fan noise. The 'afterbody liner' (AL) concept applies the liner to an exterior surface.

Figure 6: ISVR/RR No-flow rig with Inner & Outer Lined Bypass and Lined Afterbody Configuration

To assess this concept, we have conducted tests on a ‘No-flow’ rig with a broadband noise source, using scaled, linear SDOF acoustic linings to simulate the conventional, internal bypass liners and also the new external Afterbody Liner (AL), see Fig. 6.

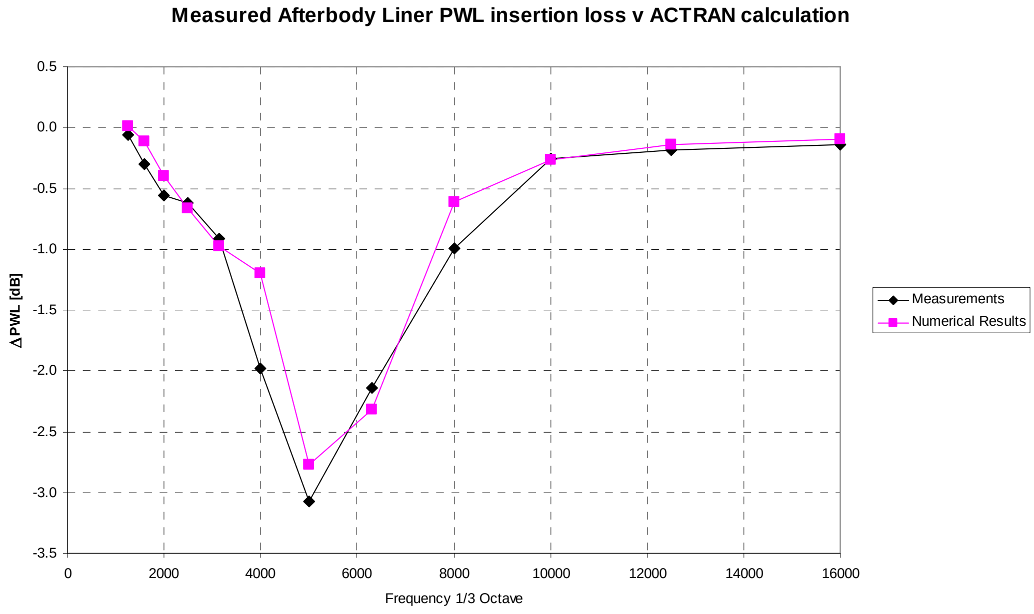


Figure 7: ISVR Measured Afterbody Liner PWL insertion loss v ACTRAN calculation

The results show that when the afterbody is acoustically lined it can reduce the far field sound power of broadband noise by up to 3 dB, a result which we have confirmed with calculations using a commercially available CAA code [4], see Fig. 7. In a companion paper here at this conference [5], we describe an extension of these broadband tests to include tone noise, using an EADS array of loudspeakers to excite specific modes in the same No-flow rig. The results confirm our expectations that the AL could also provide significant reductions in aft fan *tonal* fan noise levels. However, it should be emphasised that the results obtained so far are without mean flow and have to be confirmed by numerical simulations and tests with flow.

3. IMPROVED MODELS AND PREDICTION METHODS (WP 2)

The objective of this part of TURNEX is to verify and validate a limited number of computational models and prediction methods that can be implemented and evaluated by the industrial partners in WP 3. Verification of CAA methods with analytical solutions is based on simple idealized geometries, like these shown as configurations 1-5 in Fig. 8.

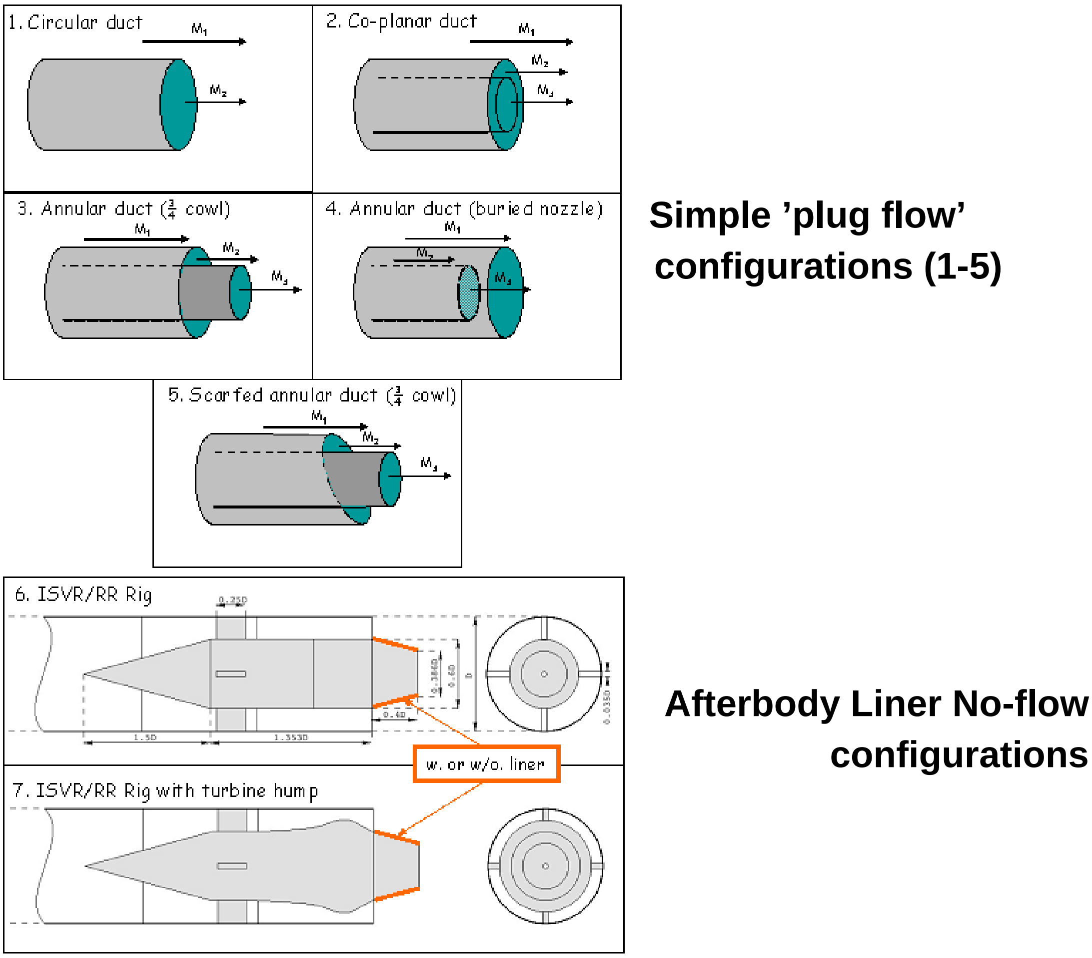
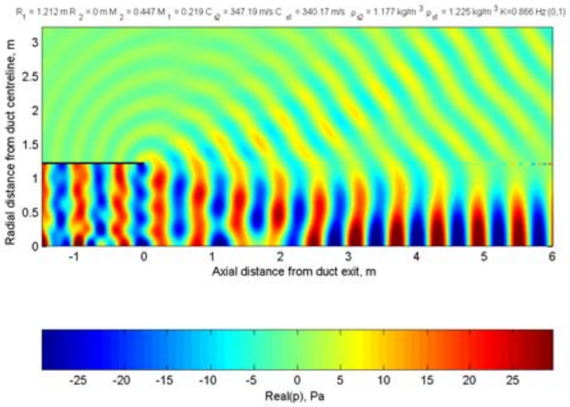


Figure 8: Simple 'plug flow' configurations (1-5), analytic solutions now available for 1-4

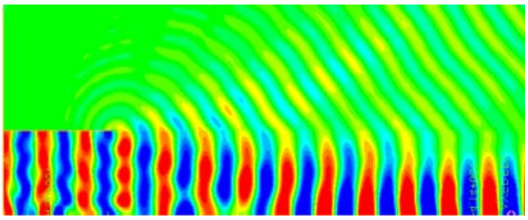
At the beginning of TURNEX, analytic Munt-type [6] solutions for configuration 1 were available at ISVR through a code 'GXMunt' developed by Gabard & Astley [7]; in addition GXMunt provides solutions for configuration 1a (not shown) with an infinite, hard centrebody. These have been invaluable as a means of verifying the CAA codes, as illustrated in Fig. 9, taken from the work of FFT & ISVR and reported in [8].

During the course of TURNEX, Demir & Rienstra [9] at TUE have developed the Gabard/Astley model to include the effects of a *lined* centrebody. Demir & Rienstra [10] are also presenting new analytic solutions at this conference for configurations 2 & 4, a significant contribution and also invaluable for code verification.

Turning to more realistic sheared mean flows, we had learned from the linearised Euler solutions (LEE) of Zhang [1] that when the sheared mean flow is included in the calculation, 'time domain' solutions for tone-excited jets can contain the unstable linear modes of the shear layer and one of the most important findings in TURNEX is that the mean shear profile, if modelled realistically as a *spreading* shear layer, will normally control the instability growth rates as shown in Fig. 10, taken from a recent paper by Kok [11] at NLR.

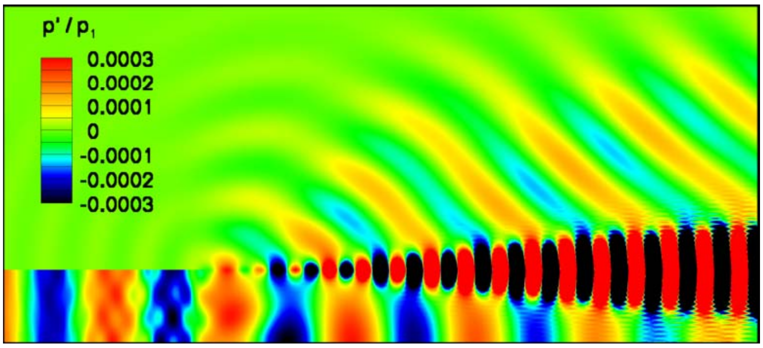


Analytic solution for near-field plane wave radiation from a circular duct (Munt model)

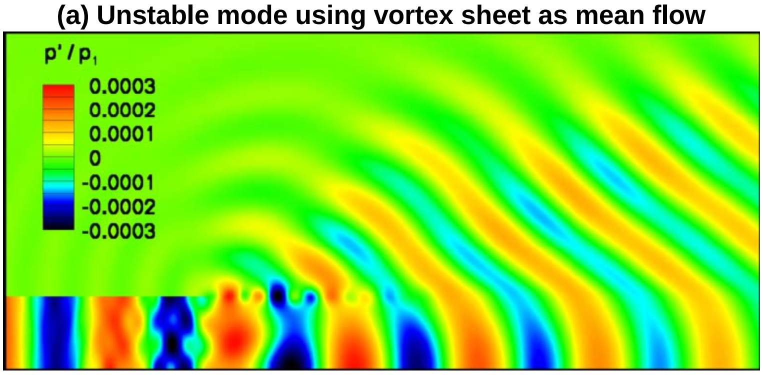


CAA solution for same case (Actran/AE - frequency domain)

Figure 9: Verification example (frequency domain) in near field, circular duct, plane wave [8]



(a) Unstable mode using vortex sheet as mean flow



(b) Stabilized solution using numerical shear layer as mean flow

Figure 10: Near-field pressure perturbation (dimensionless) for unstable and stabilized computations (annular duct, cutback condition, plane wave mode) [11]

It now seems likely that provided the initial tone amplitude is not too high, (to avoid non-linear effects), then the LEE solutions, with instabilities present, can be used with confidence in both the near and far-field. The development of the main time domain code to be validated, ACTRAN/DGM, is nearing completion at FFT [12], and a fuller understanding of the physical instabilities is close to being achieved. These only appear to arise in the time domain LEE solutions, not in those that solve the LEE equations in the frequency domain. Two frequency domain codes are being used in TURNEX, a pre-existing FFT code Actran/AE for propagation in potential mean flows [8] - adequate for some simple models of exhaust mean flow - and another more general code called FLESTURN being developed by Ozyoruk at METU [13] for purposes of comparing results with the time domain solutions.

5. CONCLUSIONS

The TURNEX project is making good progress and is on track to achieve all its objectives.

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