

**Presentation Abstracts for  
AARC Turbine Noise Workshop  
May 8-9, 2008**

**1. Eric Nesbitt (Boeing), "The Turbine Noise Challenge: Why is it so Difficult?"**

Low Pressure Turbine noise has long been portrayed as one of the “lesser” community noise components from turbofan engines. This has led us to a situation where there is no good semi-empirical or even empirical prediction of LPT noise. This and new developments in turbine design for low cost and high performance have coupled to mean that although LPT noise is typically still not a dominant component, it is one of the most miss-predicted. This has led to it being responsible for most of Boeing’s significant recent community noise prediction misses. This pitch will outline this situation and show how the data base renders “traditional” correlating parameters to be somewhat meaningless. It will also break up the database into different “Classes” of LPT’s and show some of the characteristics of each class.

**2. Alastair Moore (Rolls-Royce), "Turbine Noise in Context - a Rolls-Royce Perspective"**

Rolls-Royce's wide civil aerospace powerplant portfolio leads to a broad range of Low Pressure Turbine (LPT) designs and noise requirements. The presentation outlines the issues involved in designing low noise solutions into LPTs for engines rated from less than 10klb to above 90klb thrust. Examples of the relative importance of the LPT in various cases will be illustrated.

The assessment of LPT noise will also be discussed from the point of view of discerning its contribution from static engine noise measurements, and how during such a static test, frequency scattering (haystacking) makes this more challenging.

To illustrate more detailed diagnostic measurement capability, a recent comparison of spectra and circumferential mode detection from a cold full-scale noise rig test and equivalent results from an instrumented hot exhaust duct of a Trent derivative engine will be presented.

**3. Fritz Kennepohl (MTU), "Turbine Noise Reduction by Design: Numerical Studies on the Influence of Blade/Vane Numbers and Lean Angle"**

High speed LP turbines for future geared aero-engine applications will be designed ‘cut-on’ in many cases, as cut-off would require rather high vane-to-blade ratios and, on the other hand, the blade passing frequencies can rather easily be driven to high values where their contribution to the engine noise level is low. Also, the upstream stages of multi-stage LP turbines for large civil aero-engine applications, which contribute often significantly to the engine noise, are usually designed ‘cut-on’. This is the motivation to investigate measures to reduce the BPF tones by design within the ‘cut-on’ regime. To develop low noise design rules, parametric studies have been carried out with a linearised Euler method, studying systematically the influence of blade / vane numbers and lean angle on both the noise generation and transmission.

**4. Adolfo Serrano (ITP), "Linearized CFD Techniques Applied for Low Tonal Noise Designs in Turbines"**

Linearized CFD techniques has been successfully applied in fan tonal noise in the past and the added value for understanding on the physical mechanisms as well as the application for low noise designs has been demonstrated. The general purpose of this presentation is showing that this is also applicable for Turbine Tone Noise, exploring the particularities of this source when compared against fan tone noise and how this affect to the development of a methodology based on linearized CFD. General aspects that are briefly explored are:(a) Feasibility for predicting all the tones in the turbine multistage environment based on independent linearized calculations.(b) Linearized Euler vs RANS particularly applied on turbine representative geometries. (c) Generalized turbine cut-off concepts based on a gained physical understanding on the stator/rotor and rotor/stator interaction.(d) Different approach levels based on 2D and 3D runnings are shown as a feasible way of assessing different LPT design styles.(e) Discussion on the relevance of the different tone noise sources as potential, wake as well as the influence of the secondary flows.(f) Analysis on the complex transmission mechanisms involved in a multi-stage environment, as the appearance of combination tones or cut-off to cut-on transitions.

## **5. Dale Van Zante & Ed Envia (NASA GRC), “A Numerical Investigation of Turbine Noise Source Hierarchy and Its Acoustic Transmission Characteristics”**

Understanding the relative importance of the various turbine noise generation mechanisms and the characteristics of the turbine acoustic transmission loss are essential ingredients in developing robust reduced-order models for predicting the turbine noise signature. A computationally based investigation has been undertaken to help guide the development of a turbine noise prediction capability that does not rely on empiricism.

The investigation relies on highly detailed numerical simulations of the unsteady flowfield inside a modern high-pressure turbine (HPT). The simulations are developed using TURBO, which is an unsteady Reynolds-averaged Navier-Stokes (URANS) code capable of multi-stage simulations. The purpose of this study is twofold. First, to determine an estimate of the relative importance of the contributions to the coherent part of the acoustic signature of a turbine from the three potential sources of turbine noise generation, namely, blade-row viscous interaction, potential field interaction, and entropic source associated with the interaction of the blade rows with the temperature non-uniformities caused by the incomplete mixing of the hot fluid and the cooling flow. Second, to develop an understanding of the turbine acoustic transmission characteristics and to assess the applicability of existing empirical and analytical transmission loss models to realistic geometries and flow conditions for modern turbine designs.

The investigation so far has concentrated on two simulations: (1) a single-stage HPT and (2) a two-stage HPT and the associated inter-turbine duct/strut segment. The simulations are designed to resolve up to the second harmonic of the blade passing frequency tone in accordance with accepted rules for second order solvers like TURBO. The calculations include blade and vane cooling flows and a radial profile of pressure and temperature at the turbine inlet. The calculation can be modified later to include the combustor pattern factor at the turbine inlet to include that contribution to turbine noise.

We shall present preliminary analysis of the results obtained so far in order to assess the validity of such an approach and to seek feedback on improving the approach. This work addresses both Area 1 (Turbine Tone Noise) and Area 5 (Influence of the Turbine on Combustor Noise) topics.

## **6. Don Weir (Honeywell), “Turbine Noise Evaluations from the NASA EVNERT Program”**

The Engine Validation of Noise and Emissions Reduction Technology (EVNERT) was a NASA funded test program to validate integrated technologies that reduce aircraft engine noise. A number of noise source diagnostic measurements were used to isolate noise components in a Honeywell TECH977 engine. The effort concluded with a measurement of engine noise with the fan replaced with a water brake dynamometer. Measurement results from the test will be presented with emphasis on the identification of turbine noise. Predictions with the NASA Aircraft Noise Prediction Program (ANOPP) were made to compare with measured data.

## **7. Chuck Royalty & Dan Brown (Honeywell), “The Importance of Turbine Noise for Auxiliary Power Units”**

Auxiliary power units (APUs) are gas turbine engines installed on jet aircraft, helicopters, and tanks to provide electrical and pneumatic power. They are configured with either axial or radial turbines. Noise requirements are dictated by the OEMs, but generally follow the guidelines of ICAO Annex 16. The properties of APU turbine noise as well as their contribution to the overall engine signature are explored in this presentation. General turbine noise characteristics are described in terms of broadband and tonal sources, directivity patterns, and the effects of the engine performance cycle. Design practices for rotor and stator blade count selection are described. Insight for the relationship between turbine work extraction and combustor noise propagation through the turbine is provided. Noise penalties from flow separation in the turbine diffuser are described. Finally, the extrapolation of turbine noise sources to installed noise levels is detailed.

## **8. Bruce Morin & Oliver Atassi (Pratt & Whitney), “Empirical Models for Predicting Turbine Noise”**

This presentation will describe empirical models that are used at P&W to predict turbine noise. The models are based on correlations of measured turbine noise versus meanline aerodynamic and geometric parameters for a variety of engines. The models also include the effect of tone scattering by shear layer turbulence.

## **9. Brian Tester, Christopher J Powles, and Alan McAlpine (ISVR), “A Weak Scattering Model for Turbine Tone Haystacking Outside the Cone of Silence”**

We consider the scattering of turbine tones by turbulence in a jet shear layer. The turbulent, time-varying inhomogeneities in the jet flow scatter sound fields in such a way as to give spectral broadening, which decreases the level of any incident tone, but increases the broadband level. Spatial scattering can also occur. The process of turbulent scattering is modelled using an approximate form of the Lilley equation originally developed by Cargill at Rolls-Royce. The source terms of this equation are expressed in terms of the turbulence and the incident acoustic field. Using high-frequency approximations valid outside the cone of silence, the incident field and the Green’s function are modelled, and the scattered is then calculated using a Green’s function integral. After appropriate manipulations, and using an assumption of small turbulence length scale, the directivity of the scattered spectral density function can be expressed as a sum over all the scattered azimuthal modes, with each mode given by a triple integral over the polar radiation angle, the radial coordinate, and the incident frequencies, of

the product of a scattering function and the incident field directivity. Comparisons will be presented between model predictions and the measurements of Candel and also with the predictions from a CAA code currently being produced by the DLR.

#### **10. Roland Ewert (DLR), “CAA Simulation of Engine Tone Broadening”**

It is well known that the far-field noise spectra of jet engines show for certain jet configurations and turbine tones a characteristic spectral broadening effect, causing a reduction of the tone peak in favor of a more distributed spectral hump around the tone frequency. This haystacking effect likely occurs due to the interaction of acoustic waves with the unsteady turbulent jet shear layers. The modified tonal noise components influence the perceived noise levels considerably such that a better understanding of this effect may help to utilize it for noise reduction purposes. A non-empirical approach to predict this effect as a function of Reynolds number / jet shear layer characteristics is currently missing. This talk presents a Computational Aeroacoustics (CAA) approach. Two different generic problems are used in this study. CAA simulations are carried out for the round jet configuration, which was studied in previous experimental work of Candel et al. In this experimental study a sound source was embedded in the jet, such that the tone is scattered in a single shear layer. Finally, as a benchmark a more realistic problem is computed, which is based on the scattering of a spinning mode in a coaxial jet. The CAA computations are carried out in the time domain. The turbulent fluctuations in the jet shear layers appear as additional time dependent coefficients in the governing linearized equations. The jet mean-flow is represented by a steady RANS solution, whereas the superposed turbulent jet fluctuations are modeled with a stochastic method that utilizes the turbulence characteristics as provided by the RANS solution. The CAA simulations resolve the scattering of the acoustic waves in the turbulent jet and as such allow to study the haystacking effect numerically. In this approach both the incident and scattered field are simulated simultaneously, allowing for a direct estimation of the peak reduction. The unsteady turbulent fluctuations are generated with a highly efficient method, which was previously already with great success to broadband noise problems such as high-lift noise, the modeling of fine and large scale turbulent jet noise, as well as a generic combustion noise problem.

#### **11. Lars Enghardt (DLR), Antoine Moreau (DLR), and Fritz Kennepohl (MTU), “Experimental Radial Mode Decomposition in the Outlet of a LP Turbine”**

In the frame of the EU research project SILENCE(R), DLR performed in co-operation with MTU in-duct acoustic measurements using 75 wall-flush-mounted microphones in the outlet of a three-stage LP turbine (compare the schematic drawing in fig. 1). The acquired data consist of fluctuating pressure time series, which, after being post-processed, allow for a radial mode analysis, the calculation of the duct mode distribution at the tones of interest, and the computation of the tonal sound power propagating in and against flow direction.

The sensor array consists of 3 axial lines of 25 wall-mounted high-quality microphones, staggered by 120° in the circumferential direction. These are integrated in a rotating duct section, allowing for measurements at different azimuthal positions. During the tests, the duct was rotated by steps of 2°. As a consequence, each measurement was taken at 180 circumferential positions and 25 axial positions, corresponding to a total amount of 4500 positions. The measurement data was acquired with 50 kHz sampling frequency. The sampling time was 14 sec in order to measure at least 550 rotor rotations at the low regimes.

A radial mode analysis was performed at each of the three blade passing frequency (BPF) tones for different operating points. As the microphone array is situated directly downstream of the turbine stage replacing the exit guide vanes, the flow in the cylindrical measurement section has a swirling component. In the acoustic analysis, the swirl was taken into account by means of an analytic rigid body model. Mode spectra as well as the evolution of the modal content as a function of the operating point will be presented for the three BPF tones. Finally, for the operating point approach, the sound power of the tonal components will be compared with an estimation of the broadband sound power.

## **12. Claudia Schipani (Avio), "Turbine Noise Research at Avio"**

The presentation will give an overview of Avio running research activities on turbine noise, covering both experimental and numerical investigation. These activities are mainly focussed on turbine tones, being tones the most relevant and known noise source in the turbine.

The specificities of the turbine environment, that distinguish the turbine from the fan and represent the *fil rouge* of the work, will be discussed; among them multistage environment, hence multiple rows interaction and modes scattering, and non uniform swirling flows, requiring more sophisticated numerical modelling.

Numerical models developed at Avio to address noise generation by rows interaction and noise propagation will be presented, and examples of application will be given. Moreover, Avio experimental rigs (acoustic cold flow, cascades, etc.), covering different aspects of models validation, will be described, and test results will be provided.

## **13. Maxime Lebrun (Snecma), "Snecma Overview of Turbine Tone Noise Issues"**

When preparing new generation of engines for a completely new aircraft fleet, the engine manufacturers have to rethink their well-known noise sources distribution. For instance, when fan noise is strongly reduced, some emergent sources rise like low-pressure turbine tones. The very high-frequency characteristic of this source is no more realistic when reducing the turbine blade numbers. With fewer stages of high loaded turbine blades, the tones emerge more and more. Moreover it's crucial to work now on a multi-disciplinary optimization; acoustics needs to be studied at the same time than aerodynamic performance. Consequently, the discussion will deal with these different aspects: after presenting the far-field noise "symptoms", we will present an analysis of the different acoustic mechanisms and the feasible cures concerning blade numbers, blade shape, hot or warm passive liners that are the challenge for the next decade for an engine manufacturer. We will focus particularly on the generation of tones and their modal content. The propagation effect through turbine stages will be addressed. Comments on cut-off and clocking effects as an illustration of a multi-disciplinary optimization will be also proposed.