Fan Stage Broadband Noise Benchmarking Programme

Specification of Fundamental Test Case 1 (FC1)

Version 1 : 17 February 2014

Test Case Coordinator

John Coupland

ISVR
University of Southampton
UK
E-mail : j.coupland@soton.ac.uk

Programme Website

The programme website is

http://www.oai.org/aeroacoustics/FBNWorkshop

Information on the programme organisation and all the test cases are available there.

Introduction

The purpose of this test case is to benchmark broadband noise calculation methods for the prediction of the far-field noise due to the interaction of homogeneous isotropic turbulence with an isolated airfoil.

Methods expected to be benchmarked for this test case include

- Analytic turbulence-plate interaction models
- CAA methods using stochastic source modelling
- Flow simulation methods such as LES or DNS

Submission of results using these or other relevant models will be welcomed.

Results submitted by contributors for this test case will initially be discussed and compared with the available experimental results during a Panel Session on Fan Broadband Noise Prediction to be held at the 20th AIAA/CEAS Aeroacoustics Conference in Atlanta, Georgia, USA, on 16-20 June 2014. Further details on the Panel Session will be available on the Programme Website.

Test Rig Description

This test case is based on data taken in the open jet facility at the ISVR, University of Southampton. UK. The open jet exhausts into an anechoic chamber. More details of the test rig are available in [1] – [2]. A turbulence grid is located in the exhaust nozzle upstream of the open jet. An airfoil is located within the potential core of the jet. The noise generated by the interaction of the grid-generated turbulence with the airfoil is measured by a polar array of far-field microphones.

Rig Geometry

The general layout of the rig is shown on Figure 1.

The nozzle outflow is of height 150mm and span 450mm.

The airfoil span is 450mm.

Here the spanwise direction is normal to the plane shown on Figure 1.

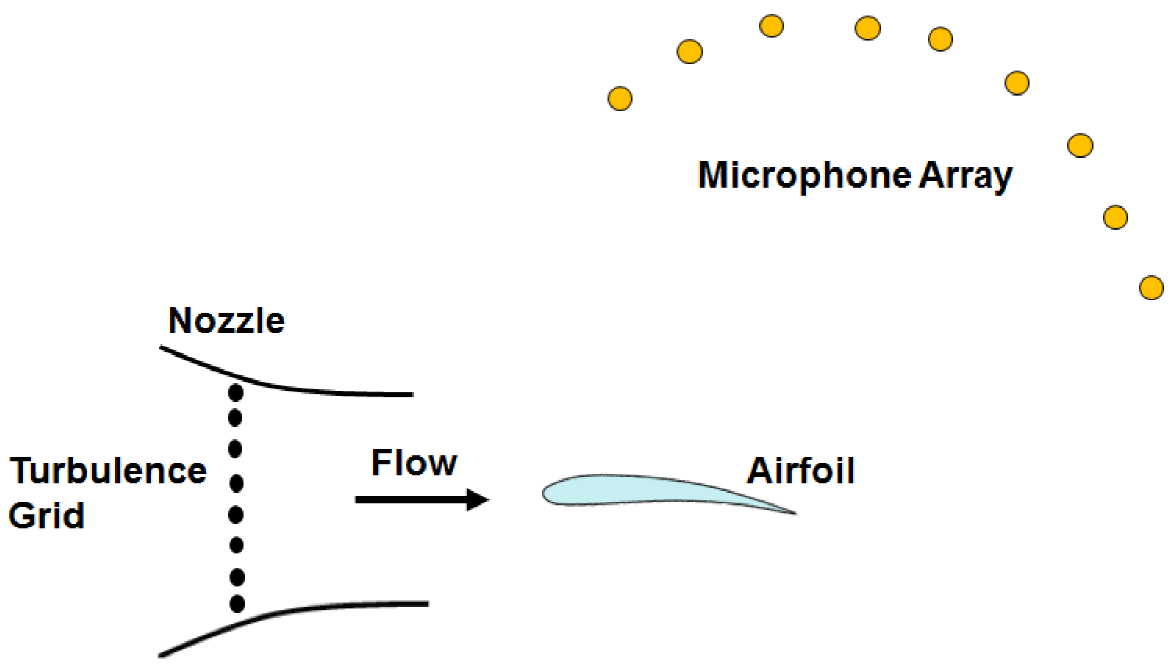

Figure 1 : General Arrangement (not to scale) of ISVR Open Jet Experiment

Airfoil Geometry

The airfoil is a NACA 65(12)-10 with a nominal chord of 150mm. The airfoil has been set at an angle of attack to create some positive incidence onto the airfoil leading edge.

The airfoil coordinates at this angle of attack are defined in a coordinate system where the X=0.0 and Y=0.0 coordinates correspond to the datum leading edge plane and the mid-height of the nozzle outflow, as shown on Figure 2. Note that the leading edge of the airfoil at the actual angle of attack used here does not lie exactly on the datum leading edge plane. In the same coordinate system the nozzle exit plane is at X=-150mm as shown on Figure 2.

A spreadsheet with the airfoil coordinates at the actual angle of attack used can be requested from the test case coordinator. No further changes to the airfoil coordinates are required.

The airfoil includes rougness strips to trip the surface boundary layers to turbulent on both surfaces of the airfoil, as indicated on Figure 2. The roughness strips start and finish at 10% chord and 20%

chord respectively on both airfoil surfaces, and cover the full span of the airfoil. The details of the roughness strips themselves are not available.

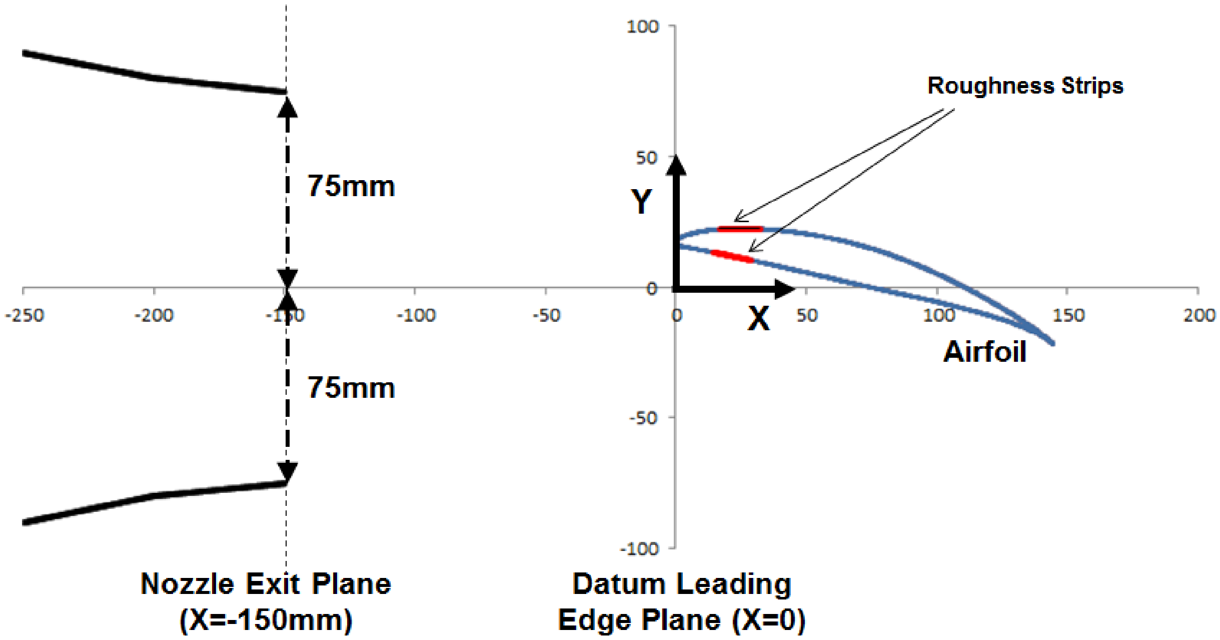

Figure 2 : Nozzle Outflow and Airfoil Geometry

<u>Jet Flow</u>

The velocity of the mean flow at the nozzle exit plane is 60 m/s. The mean flow should be taken to be uniform over the nozzle exit plane with zero lateral and spanwise components.

Aerodynamic conditions of the jet flow should be set using

- Static density 1.2 kg/m^3
- Static sound speed 340 m/s

<u>Incoming Turbulence</u>

The incoming turbulence was generated by a turbulence grid of square bars positioned inside the nozzle at 630mm upstream of the nozzle exit plane. The turbulence grid bar width was 8.5mm, with a spacing between bars of 22mm.

The generated turbulence downstream of the grid should be assumed to be homogeneous and isotropic.

The turbulence velocity spectrum has been measured on a plane matching the leading edge plane of the airfoil. The velocity PSD, as dB/Hz using a reference velocity of 1 m/s, to be used for the benchmark calculations has been derived from the measurements on the airfoil leading edge plane. The velocity spectrum is shown on Figure 3.

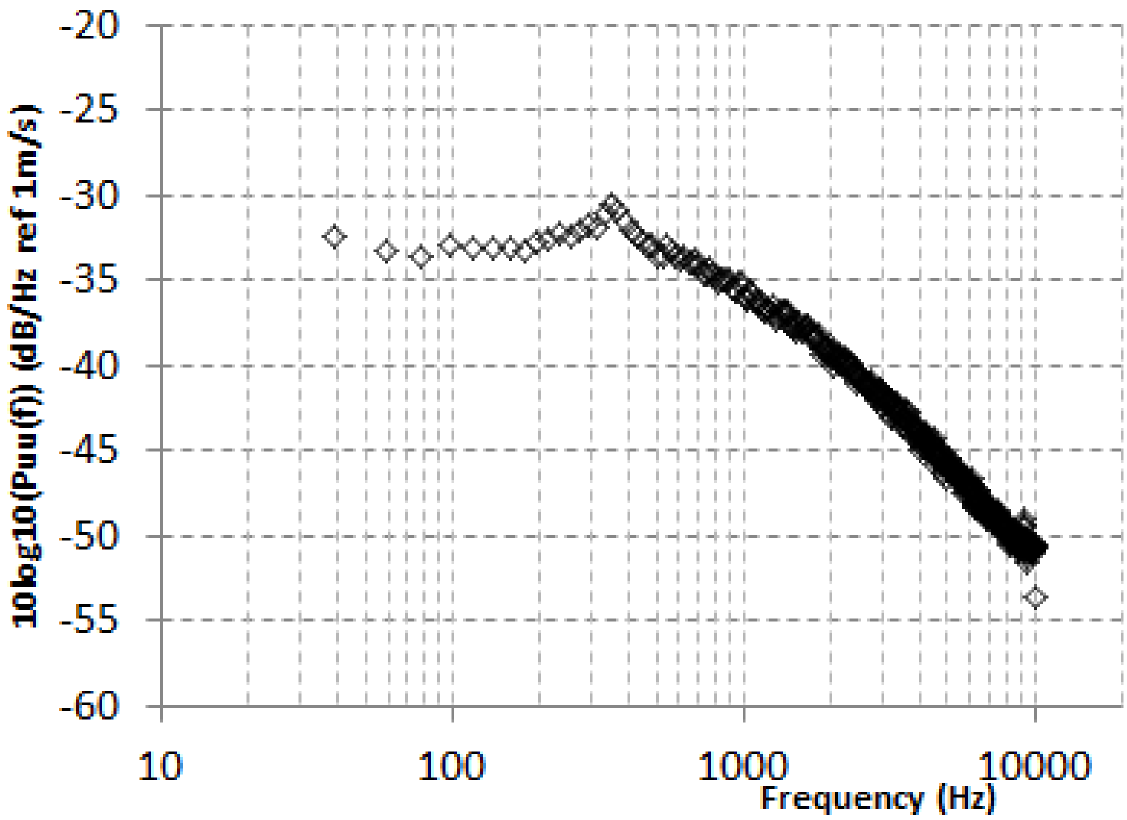

Figure 3 : Incoming Turbulence Velocity PSD (dB/Hz) at the Airfoil Leading Edge

A spreadsheet with the turbulent velocity spectrum should be requested from the test case coordinator.

A turbulence integral length scale has been derived by using the measured overall turbulence intensity and fitting a Von Karman spectrum to the measured turbulent spectrum

- Incoming turbulence intensity 1.7%
- Incoming turbulence integral scale 8 mm

Far-field Noise Measurement

The far-field noise due to the turbulence interaction with the airfoil is measured by a polar array of microphones centred around a point (X=150mm, Y=0mm in the airfoil coordinate system) close to the actual trailing edge of the airfoil. There are 18 microphones located on an arc of radius 1200 mm as shown on Figure 4.

The 18 microphones cover polar angles from 50° and 135° in steps of 5°. A polar angle of 0° corresponds to the location downstream of the airfoil.

Note that the microphones are located in zero flow outside of the open jet. For calculations of the far-field noise that do not include the jet shear layer then a correction to the polar angle range will need to be applied to account for acoustic refraction through the jet shear layer.

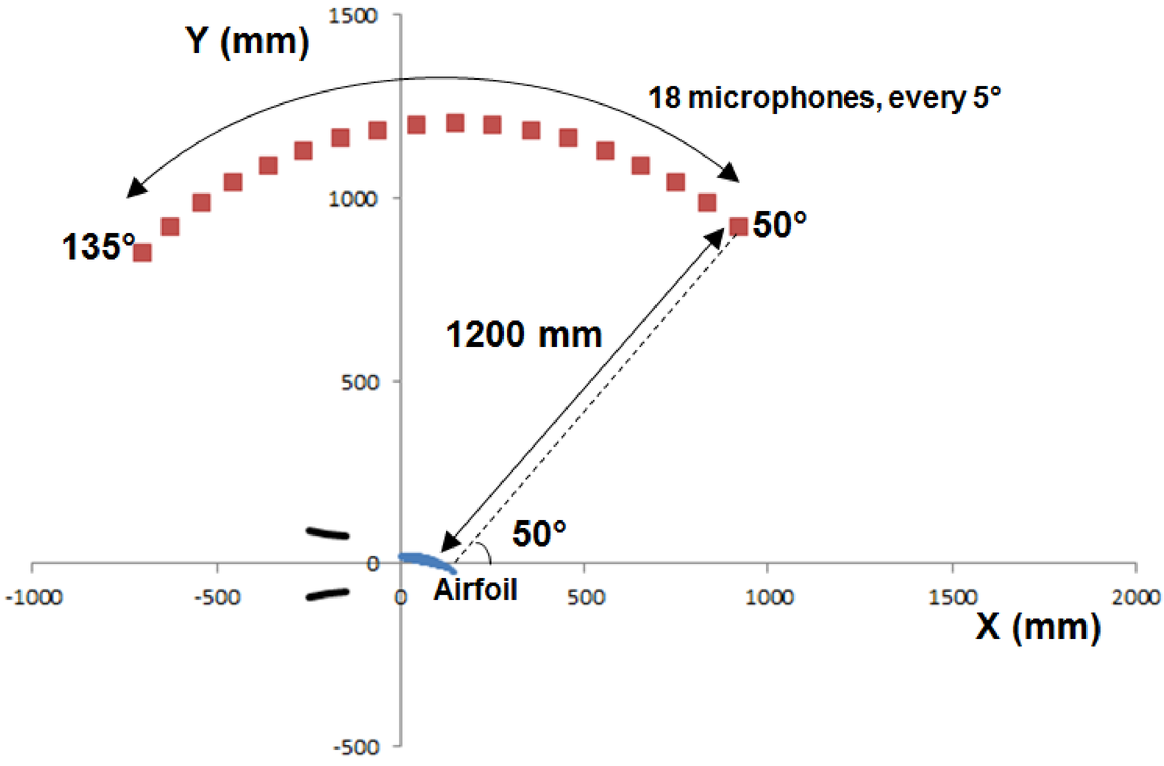

Figure 4 : Microphone Polar Array Arrangement

Measured Sound Power Calculation

The sound power, PWL, in dB/Hz, was calculated from the sound pressure at the microphone array by summation over the polar angle range of the microphone array, and assuming cylindrical radiation and source strength distributed uniformly over the airfoil span.

$$PWL(f) = 10\log_{10}\left(\frac{Lr\Delta\theta}{\rho c W_0}\sum_{i=1}^{i=N_{mic}} S_{pp,i}(f)\right) \qquad (1)$$

where

- f is the frequency, Hz
- L is the airfoil span (0.45 m)
- r is the microphone polar array radius (1.2 m)
- $\Delta\theta$ is the microphone angular spacing (5°) in radians
- ρ is the fluid density (1.2 kg/m^3)
- c is the fluid sound speed (340 m/s)
- W_0 is the reference power, $1.0{*}10^{-12}$ Watts
- $S_{pp,i}$ is the mean square sound pressure fluctuation (Pa^2/Hz) at the ith microphone
- N_{mic} is the number of microphones (18)

Time Mean Aerodynamic Measurements

The time mean surface static pressure was measured at a number of locations along the airfoil chord on both pressure and suction sides of the airfoil. Figure 5 shows the measured normalised surface pressure coefficient, Cp, for the operating condition of the benchmark, where Cp is defined by

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho U_0^2} \tag{2}$$

where

- p is the surface static pressure, Pa
- p_∞ is the far-field static pressure, Pa
- ρ is the fluid density, kg/m^3
- U_0 is the jet outflow velocity (60 m/s)

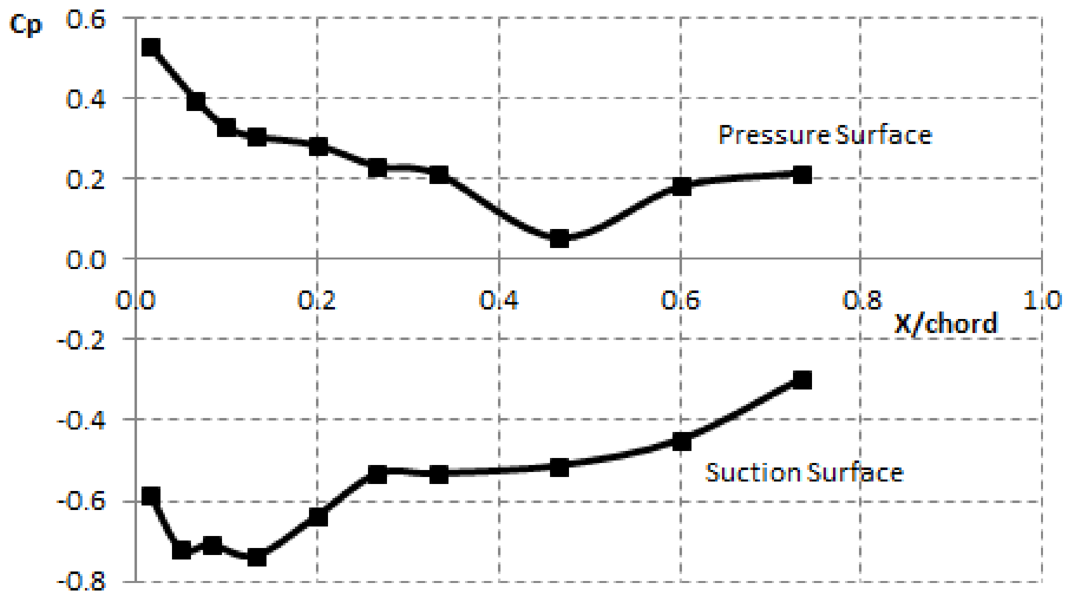

Figure 5 : Measured normalised surface pressure coefficient, Cp, along the blade chord

The mean velocity and rms turbulence profiles at 2 locations downstream of the airfoil were measured using hot-wire anemometry, by traversing a single hot-wire probe. The profiles were taken at locations X=149.5mm and X=167.5mm, defined using the airfoil coordinate system shown on Figure 2. Figure 6 shows the measured profiles of mean velocity and the rms turbulence velocity, each normalised by the maximum velocity across the full jet width at that axial location.

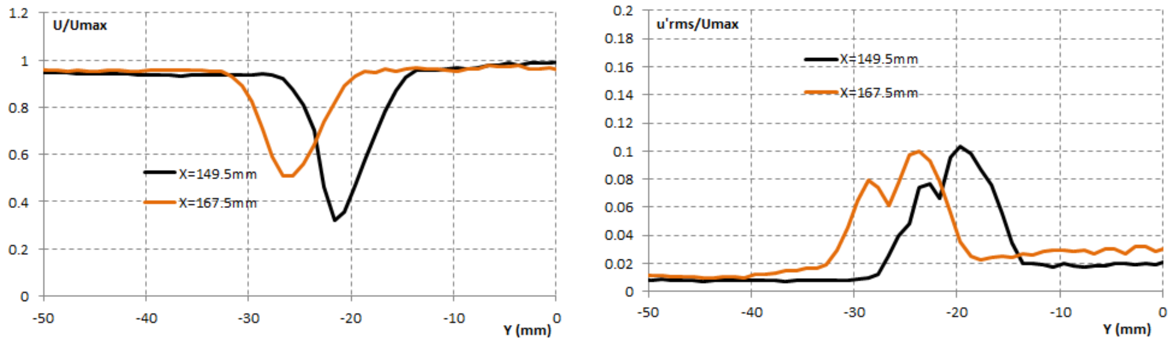

Figure 6 : Measured Normalised Mean Velocity and RMS Turbulence downstream of the airfoil

Measured Data Limitations

i) Incoming turbulence spectrum

The measured incoming turbulence spectrum shows a small bump around a frequency of 350 Hz which is believed to be a residual effect of the vortex shedding behind the bars of the turbulence grid. This effect is most evident in the very outer regions of the span of the jet flow and does not significantly contribute to the generation of the measured far-field noise spectrum.

ii) Far-field noise

The far-field noise spectrum is believed to be influenced by the noise of the open jet itself at low frequencies below around 300 Hz. Above this frequency, up to 10000 Hz, the experimental studies with the turbulence grid in place in the wind tunnel show the dominance of the turbulence - leading edge interaction as the dominant source. Despite the limitation of the low frequency measurement, far-field noise spectra are still requested from contributors over the frequency range of 100–10000 Hz in order to compare the behaviour of broadband noise models at low as well as at high frequency.

Required Data to be Submitted to the Test Case Coordinator

The following data must be submitted to the test case coordinator for the specified test case input :

- Sound power PSD (PWL) spectrum in dB/Hz, calculated as described above in equation (1), over the frequency range 100-10000 Hz (use a reference power of $1.0*10^{-12}$ Watts for the PWL dB calculation). The data should be provided to the test case coordinator as a table of frequency versus PWL, either as a text file or in a spreadsheet. Data file names should be of the form '*FC1_"Contributer Name"_Far_Field_PWL_.......*'.

For contributors who also calculate the detailed airfoil aerodynamics the following data must be submitted to the test case coordinator for the specified test case input :

- Time mean surface pressure coefficient, Cp, calculated as described above, on both airfoil surfaces tabulated against the X-coordinate of the airfoil coordinate system shown on Figure

2. The exact distribution of the tabulated points along the airfoil surface should be chosen by the contributor (and may well depend on a grid distribution used in the analysis), but should be fine enough to show the details of the leading edge and the chordwise *Cp* behaviour. The data should be provided to the test case coordinator as tables of X-coordinate versus *Cp*, either as text files for the two airfoil surfaces or in a spreadsheet. Data file names should be of the form '*FC1_"Contributer Name"_Airfoil_Cp_.......'*.

- The mean total velocity and rms turbulence, normalised by the maximum velocity across the full jet width at that axial location, along lines at X=149.5mm and X=167.5mm, and tabulated between Y=-100mm and Y=50mm, in the airfoil coordinate system shown on Figure 2. The exact distribution of the tabulated points along each axial location should be chosen by the contributor (and may well depend on a grid distribution used in the analysis), but should be fine enough to show the details of the airfoil wake. The data should be provided to the test case coordinator as tables of Y-coordinate versus velocity and rms turbulence, either as text files for the two axial locations or in a spreadsheet. Data file names should be of the form '*FC1_"Contributer Name"_Wake_.......',* or as '*FC1_"Contributer Name"_Wake_Velocity_.......'* and '*FC1_"Contributer Name"_Wake_Turbulence_.......'* if the data is in separate files.

Along with their results, contributors are requested to submit to the test case coordinator a 1 Slide overview of their method used for this test case, including key assumptions and limitations, and providing information on numerical methods and grids used where appropriate. The data file name for the summary slides should be of the form '*FC1_"Contributer_Name"_Overview_.......'*

<u>Optional Data to be Submitted to the Test Case Coordinator</u>

If generated by the calculation method the following data may be optionally submitted to the test case coordinator for the specified test case input :

- Sound pressure PSD (SPL), in dB/Hz, at the 18 microphone positions between 50° and 135° polar angle over the frequency range 100-10000 Hz (use a reference pressure of $2.0*10^{-5}$ Pa for the SPL dB calculation). The data should be provided to the test case coordinator as tables of frequency versus SPL, either as text files for each polar angle or in a spreadsheet. Data file names should be of the form '*FC1_"Contributer Name"_Far_Field_SPL_.......',* or as '*FC1_"Contributer Name"_Far_Field_SPL_Angle_nn_.......'* if in separate files.

- Sound pressure PSD (SPL), in dB/Hz, of the unsteady surface pressure on the airfoil over the frequency range 100-10000 Hz (use a reference pressure of $2.0*10^{-5}$ Pa for the SPL dB calculation) at the following chordwise locations on both the suction and pressure surfaces of the airfoil
    - 1% chord
    - 5% chord
    - 20% chord
    - 50% chord

  The data should be provided to the test case coordinator as tables of frequency versus SPL, either as text files for each chordwise position on the two surfaces, or in a spreadsheet. Data file names should be of the form '*FC1_"Contributer Name"_Airfoil_SPL_.......',* or as '*FC1_"Contributer Name"_Airfoil_SPL_pcChord_nn_.......'* if in separate files.

Measurements are not available for comparison with these calculated data, but comparison of the data between different calculation methods may shed light on the effectiveness of the methods.

Acknowledgements

The support of Dr. Mat Gruber, Snecma (formerly of ISVR), and Prof. Phil Joseph, ISVR, in setting up this test case for the broadband noise benchmark programme is gratefully acknowledged.

References

1. Chong, T.P., Joseph, P.J. & Davies, P., "Design and Performance of an Open jet Wind Tunnel for Aeroacoustic Measurement", Applied Acoustics, 70(4), 605-614, 2009
2. Gruber,M., Joseph,P.J. & Chong,T.P., "On the Mechanisms of Serrated Airfoil Trailing Edge Noise Reduction, 17th AIAA/CEAS Aeroacoustics Conference, AIAA 2011-2781, 2011