EVALUATION OF JET NOISE PREDICTION CAPABILITIES OF STOCHASTIC AND STATISTICAL MODELS

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1. INTRODUCTION

With the progressive reduction of the maximal noise level acceptable for aircraft, the ability to predict the noise at a design stage is now required by the aeronautic industry. At take-off conditions, jet noise remains the main noise source and is considered here. The present study consists in developing and evaluating a quick methodology for the prediction of jet noise based on Reynolds-Averaged Navier-Stokes (RANS) simulations. Since these mean simulations only give the averaged solution and that the turbulence noise is produced by the velocity fluctuations, a model is required to compute acoustic data. Two statistical models, the Mani, Gliebe, Balsa and Khavaran (MGBK) [1] and Self [2] models are compared with a stochastic model, the Stochastic Noise Generation and Radiation (SNGR) [3].

2. TEST CASES & RANS SIMULATIONS

2.1 Experimental data base

Two 2 inch nozzles have been used in the present study: the Acoustic Reference Nozzle 2" (ARN2) and the Simple Metal Chevron 000 (SMC000) nozzle. For the operating conditions, multiple set-points of Tanna's test matrix [4] have been used. For the calibration of the models, two jet velocities (M_j=0.5 and 0.9) and two temperatures (T_j/T_∞=1 and 1.76) are considered.

2.2 RANS simulations

The RANS simulations were performed using the standard k-ε model of Fluent 6.3.26. A typical result of turbulent kinetic energy (k) is shown in figure 1 for a high-speed subsonic cold jet and the SMC000 nozzle. Various jet properties were validated using experimental data [5], including the axial velocity and the turbulent kinetic energy (K) on the jet centerline as shown in figure 2 for the lower Mach number case on the same nozzle.

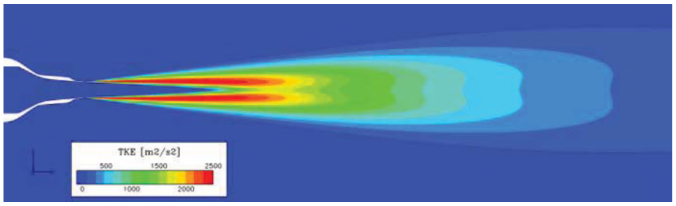

Figure 1. RANS turbulent kinetic energy contours (SMC000 nozzle, M_j=0.9 jet).

3. JET NOISE METHODS

Two methods have been selected to evaluate their capabilities in jet noise prediction, one stochastic, the SNGR method [3], and one statistical, the MGBK method [1] or a simplified model proposed by Self [2].

3.1 SNGR

The SNGR method is based on Kraichnan's turbulence model and expresses the turbulent velocity as a summation of Fourier modes for each turbulent scale. The von Karman spectrum is used to get the turbulent velocity of each scale and random functions following probabilistic laws determine the direction and phase. The summation of all turbulence scales at each point of the domain produces the turbulent velocity field for one time step. By repeating the process with a new random generation, the turbulent velocity time signal is given by Eq. (1), where u_n is the velocity amplitude, k_n the wave number, ψ_n the phase and σ_n the direction of the turbulence scale n [3]:

$$u'(\vec{x},t) = 2\sum_{n=1}^{N} u_n \cos(\vec{k}_n \cdot \vec{x} + \psi_n)\vec{\sigma}_n \qquad (1)$$

The various SNGR models are characterized by different time and space correlation introduced into Karweit's baseline model. Béchara's model [3] has been selected here, which uses a frequency domain Gaussian filter $f_0 = {}^{\varepsilon}\!/_{K}$, $\left|\tilde{H}(f)\right| = \exp\left[{}^{(f-f_0)^2}\!/_{af_0^2}\right]$ to regenerate the temporal correlation. The final step of the SNGR method is the propagation of the sources. Lighthill's acoustic analogy has been used to yield the far-field acoustic pressure.

3.2 MGBK

The MGB method originally developed by Mani et al. [1] was further developed by Khavaran to become the MGBK model, which consists in modeling the two point correlation tensor and propagate the noise to the far field using RANS data. Eq. (2) shows the averaged square acoustic pressure as a function of ψ_{self}, the self noise intensity of the source propagated to the observer, and a_{ij}, the quadrupôle-directivity tensor.

$$\overline{p'^2}(R,\theta,\omega) = \int_v \Psi_{self}\left(a_{11} + 2a_{22} + 4a_{12} + 2a_{23}\right) d\vec{r} \qquad (2)$$

In this study, Frendi's formulation [6] was used to determine the empirical constants required in Eq. (2).

4. RESULTS

4.1 SNGR Aerodynamics Results

For the SNGR methods, both the one point spectral analysis and the r.m.s. statistics of the velocity field were verified. From the one point spectral analysis, a constant a=25 was determined for Béchara's filter. Figure 2 (right) shows the turbulent kinetic energy of the SNGR models and is compared with the RANS results and experimental data [5]. Béchara's filter greatly reduces the turbulent kinetic energy levels and over-corrects Karweit's model. An additional correction was therefore developed to force the turbulent kinetic energy of the SNGR velocity signal to be at the same level than the RANS data and therefore to preserve turbulent kinetic energy.

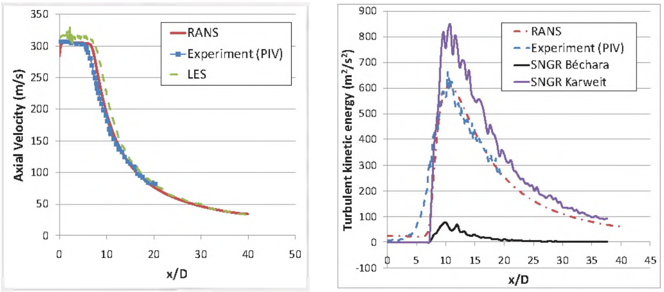

Figure 2. Axial velocity profile (left), Turbulent Kinetic energy (right) along the axis (SMC000, M_j=0.5, T_j/T_∞=1)

4.2 Acoustic results

Figure 3 compares the Sound Pressure Level (SPL) in 1/3 octave for several set-points predicted by both MGBK and Self methods, with SHJAR experimental acoustic data [7].

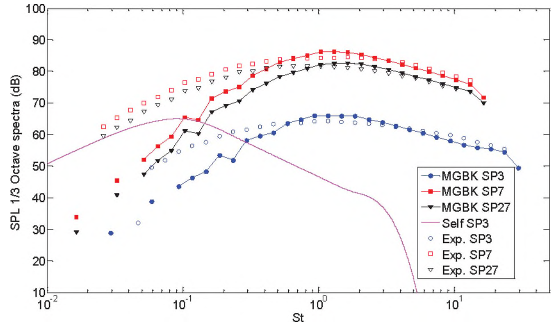

Figure 3. Sound Pressure Level 1/3 octave spectra, (SMC000 nozzle, M_j=0.9, T_j/T_∞=1 and 1.76)

For all cases, the MGBK results follow the experimental data with a difference less than 3dB for Strouhal numbers larger than 0.7. Below this limit, the SPL is under estimated by MGBK. The low frequency divergence is actually a known weakness of MGBK model because the geometric parameters are disregarded, which can significantly influence the low frequency part of the spectrum. Self's simplified model is found to predict the peak radiation at much lower frequency and to have a much quicker roll-off at higher frequencies.

Béchara's SNGR model presently yields too large levels, which is traced to the derivation of the Lighthill tensor in the acoustical analogy. In the future, some regularization of the flow field will be required to obtain reliable derivatives.

5. DISCUSSION AND CONCLUSIONS

Two different methods based on RANS flow fields have been implemented and tested to predict jet noise. For the MGBK method, the results are in good agreement with the experimental data around 90° for all jet conditions tested, and for Strouhal numbers beyond 0.7. Yet, a more elaborate form of the directivity that includes shielding coefficients is required to predict noise over a wider range of angles. Self's simplified model was not found to yield the proper peak efficiency and correct roll-off at high frequencies. For the SNGR method, since the aerodynamic properties of the turbulent field have been validated and corrected to conserve energy, the noise over-prediction seen in the use of the Lighthill analogy is traced to the lack of differentiability of the stochastic field that will require some future regularization.

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