A RANS-based reduced-order model for jet-surface interaction noise

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Introduction

As the bypass ratio of modern turbofan engines continues to increase, the proximity between the wing and the engine in underwing installations tends to aggravate the noise generation due to jet-surface interactions (JSI). To ensure that increasingly strict legislation requirements will be met with minimal aircraft performance penalty, the capacity to predict the JSI noise is crucial. Although advanced techniques such as LES can effectively tackle this problem, they are still computationally expensive for optimization or design, especially at preliminary stages. Thus, there exists a demand for fast, yet reliable, predictive methods that can be used to estimate the impacts of the engine relative position. This is especially true at preliminary design stages, when the decision timescales are in the order of hours. Another restriction is their use in Multidisciplinary Optimization (MDO), which is now commonplace in aircraft design and demands quick turnaround times. In this work, the authors propose a simple RANS-based reduced order model whose parameters can be calibrated based on either model-scale experiments or Large Eddy Simulations of the installed jet. Once the optimal model parameters are adjusted, the only necessary input is obtained from a RANS simulation of the installed jet. Ultimately this yields a model for JSI that is fast and relies on minimal input.

Results and discussion

As a first step to establish a relationship between RANS simulation results and JSI noise, use was made of experimental data from [1], who investigated more canonical configurations, namely a round nozzle installed under a flat plate. The respective RANS simulations were carried out and results suggested that a strong correlation exists between the sound pressure level at a polar angle of 90 degrees and the spanwise component of vorticity integrated over the flat plate. All analyses were carried out under static conditions, i.e., without the influence of the flight Mach number.

In order to develop a correlation applicable to more realistic installation configurations, the plate was replaced by a 2-D NACA4415 aerofoil, whose horizontal and vertical positions relative to a 40 mm-diameter, axisymmetric nozzle are indicated in Table 1. The aerofoil span and chord are 600 mm and 150 mm, respectively.

Regarding the operating conditions, the acoustic jet Mach number was set at 0.75 and the free-stream Mach number was set at 0.25, which represent typical take-off UHBPR conditions. The RANS simulations were carried out on hybrid meshes whose resolution was approximately 18.9 million cells. The Shear-Stress Transport (SST) turbulence model was chosen because of its better accuracy in the calculation of near-wall variables, e.g., vorticity.

After a thorough analysis of the numerical results, it was confirmed that the spanwise vorticity, area-averaged over the aerofoil, correlated well with the respective maximum SPL of each position (obtained via a combination of experimental near-field data and Lyu and Dowling's model [2]) via the equation below:

$$SPL = 42.46 + 4.32\overline{\varpi}_y^{0.2} \tag{1}$$

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Table 1 Relative positions of the NACA4415 aerofoil trailing edge in relation to the nozzle exit.

Position	L/D	H/D
1	1	1
2	2	1
3	3	1
4	1	0.6
5	2	0.6
6	3	0.6

The quality of the model fit is illustrated in Figure 1.

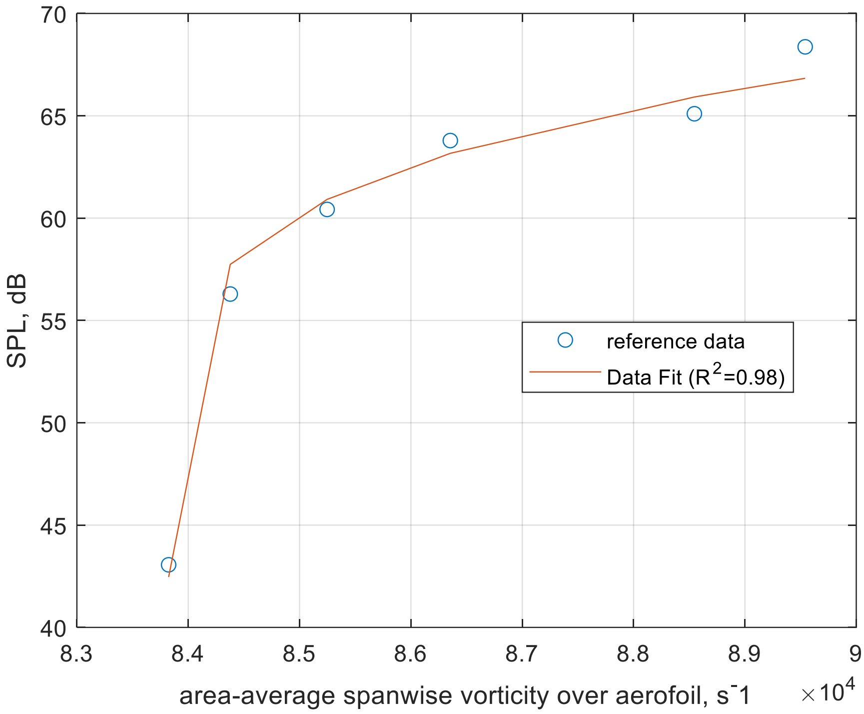

Figure 1 Correlation between jet-surface interaction noise and the spanwise component of the vorticity vector integrated over the aerofoil (Jet Mach number=0.75, free-stream Mach number=0.25).

Although other variables, for instance the area-averaged static pressure over the aerofoil, were also seen to correlate with the far-field noise, the spanwise vorticity provides the best fit. Large turbulent structures emanating from the jet, containing high vorticity, especially in the jet radial direction, can be seen to cause a “fingerprint” on the wing. Such explanation is more easily visualized under static conditions, as only the jet flow generates vorticity over the wing/surface. Indeed, the vorticity modulus correlates just as well with the far-field sound pressure level in this situation. In the presence of a free stream, however, a considerable amount of vorticity can be generated by a lifting surface, such that it is unclear how to separate the vorticity created by the jet alone from the overall value. Nevertheless, the results are very promising but must be confirmed by further experiments to be conducted at the Doak Lab in the near future.

References

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