PREDICTION OF NOISE GENERATED BY A CABIN OUTFLOW VALVE USING THE STAR-CD CODE

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1.INTRODUCTION

Cabin comfort is a paramount concern for business aircraft design. To maintain cabin pressures at equivalent to 8000 feet above sea-level whilst flying at 45000 feet requires careful maintenance of the airflow exhausting from the cabin. This is normally achieved using a servo-controlled flap outflow valve, such as that shown in Figure 1. Unfortunately the air pressure ratio across the outflow valve can be as high as 7, so a lot of shock and screech noise can be generated as well as the jet noise from the highly separated flow behind the valve.

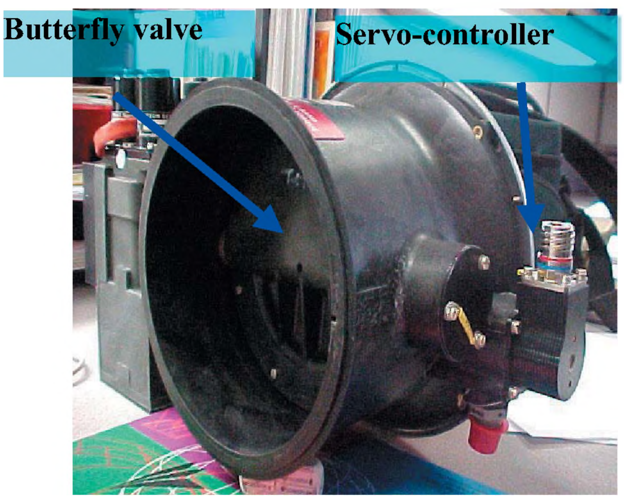

Fig. 1. Cabin outflow valve

As part of a noise reduction exercise on a business jet, noise measurements were made on a rig consisting of a full-scale outflow valve exhausting horizontally through a circular steel plate, with 4 microphones centered on the exhaust plane, as shown in Figure 2.

Commercial Navier-Stokes codes have been used for computational aero-acoustic (CAA) predictions for flows around bluff bodies, internal flows and fans. It was decided to use the STAR-CD code to predict the noise of the outflow valve at sub-critical pressure ratios. The flow is of the jet-type i.e. dominated by quadrupole noise sources due to the turbulent shear stresses. This would be a good validation case similar jet flows found in aircraft systems such as APU exhausts.

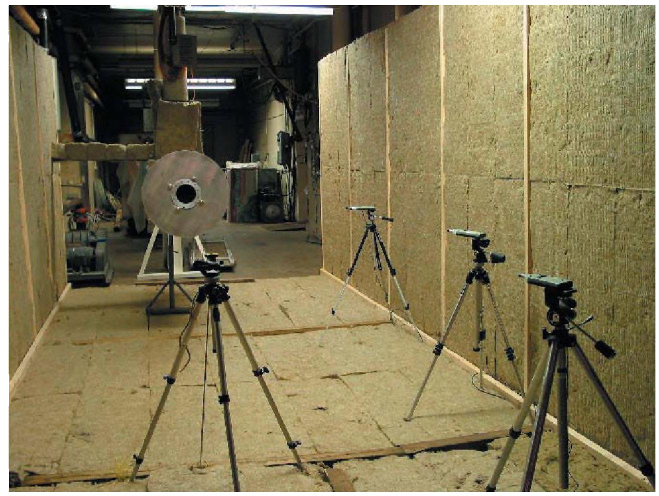

Figure 2. Cabin outflow valve noise measurement

2. STAR-CD Computation

STAR-CD is a commercially available thermofluids analysis system developed by the CD-adapco Group. The solver is an implicit finite-volume method, with pressure calculated from a pressure correction equation using the SIMPLE algorithm. The user can select either a high or low order spatial discretisation scheme and either a fully implicit or a second-order Crank-Nicholson temporal discretisation scheme. For the outflow valve case spatial discretisation used MARS (monotone advection and reconstruction scheme) and the Crank-Nicholson second-order time marching scheme. The solver used an AMG (algebraic multi-grid) method to solve the linear equations.

The unstructured grid used prism and tetrahedral cells, with a total of $4.98*10^6$ cells, with the majority of the cells clustered around the butterfly valve and downstream over the region of the jet as shown in Figure 3. An initial, steady state solution was run at a pressure ratio of 1.43. The turbulence was modeled using a detached eddy simulation (DES) based on a modified Spalarat-Allmaras turbulence model. The unsteady solution used a time-step of 1.0e-05 seconds, run for 6000 iterations.

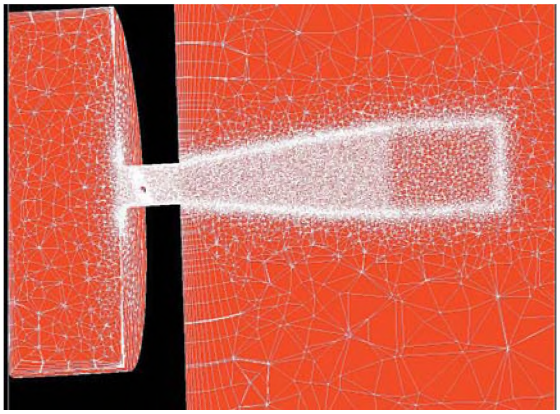

Figure 3 Outflow valve mesh

The unsteady velocities on a survey plane surrounding the exhausting jet were recorded at every time step. An integral acoustic code, based on the porous Ffowcs Williams-Hawkings method[1], was written to predict the far-field acoustic pressures at the microphone positions. The results at the closest microphone position are shown in Figure 4. The results for the first 0.02 seconds were assumed to be affected by the start up transients of the calculation and were discarded. The pressures were converted to the frequency domain using a Hanning window with a 64 Hz bandwidth, to match the experimental results.

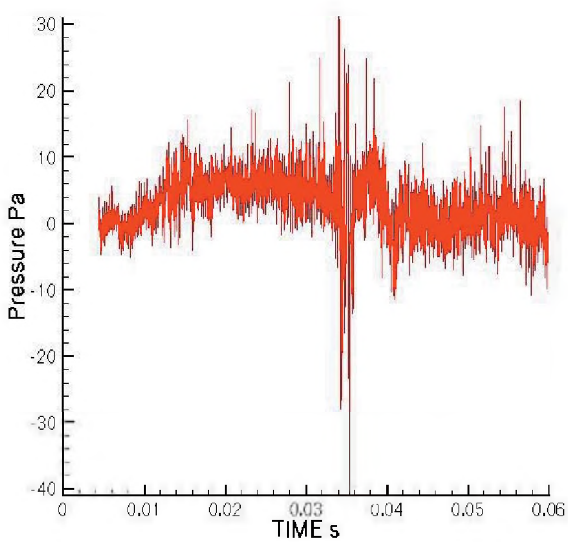

Figure 4 STAR-CD unsteady pressure prediction

3.RESULTS

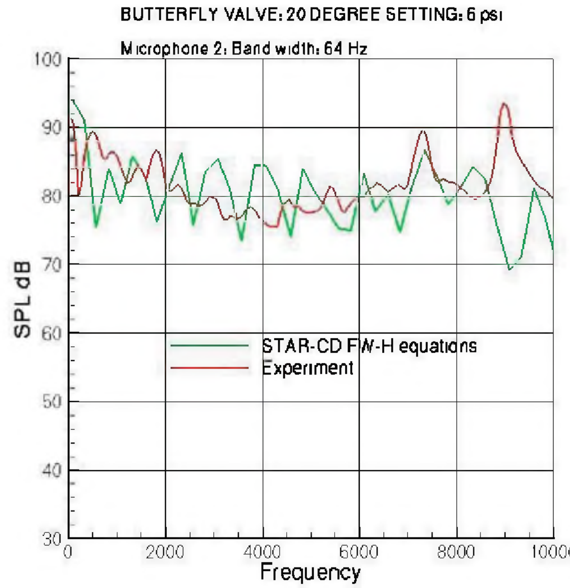

Figure 5 STAR-CD noise prediction at microphone 2

The predicted noise compared to the measured noise at the second microphone position, starting from the closest microphone to the valve as shown in Figure 2, is shown in Figure 5. The agreement is good up to all but the highest frequency, 9kHz, where STAR-CD does not capture a local peak. The results at higher pressure ratios showed this peak developing into a screech tone, so it is likely created by locally supersonic flow around the valve which is probably not resolved by STAR-CD.

4.DISCUSSION

The prediction of the noise generated by a cabin outflow valve operating at sub-critical pressure ratio by STAR-CD was very good. Unlike a conventional jet, which has the shear layer and mixing developing slowly with distance downstream, the flow here is dominated by highly separated flow with large-scale vertical structures. This flow is well adapted to the DES turbulence model in that the flow structures are large relative to the mesh size so that it will operate in it's Large Eddy Simulation mode.

REFERENCES

1. Lyrintzis, A.S., Uzun, A., (2001), 'Integral Techniques for Jet Aeroacoustics Calculations' AIAA Paper 2001-2253