Visualising and understanding jet noise

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Background

Aircraft today emit less than 1% of the noise than the first passenger jets. Further reductions in noise emission are a real challenge. With noise shielding and acoustic absorption techniques being substantially mature, the quest is to design aircraft engine jets that are intrinsically quieter at source. This requires enhanced modelling of the complex three-dimensional flow from the dual-flux jets of turbofan engines, in which shock waves interact with turbulent structures to generate shock-associated jet noise.

Shock cell noise in jets

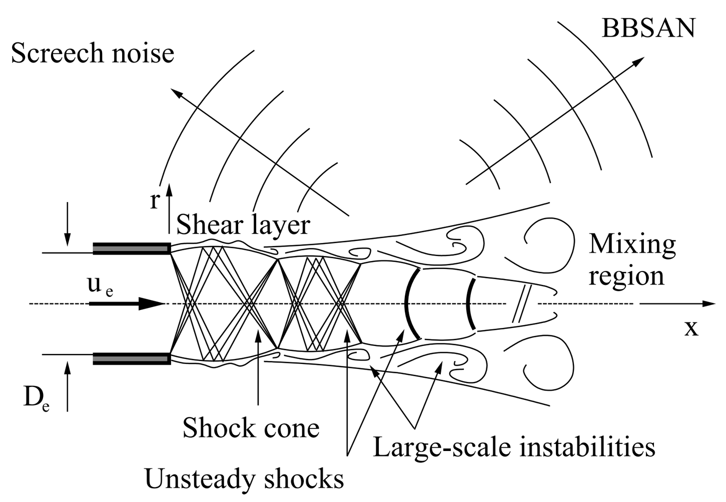


Fig. 1: Under-expanded jet

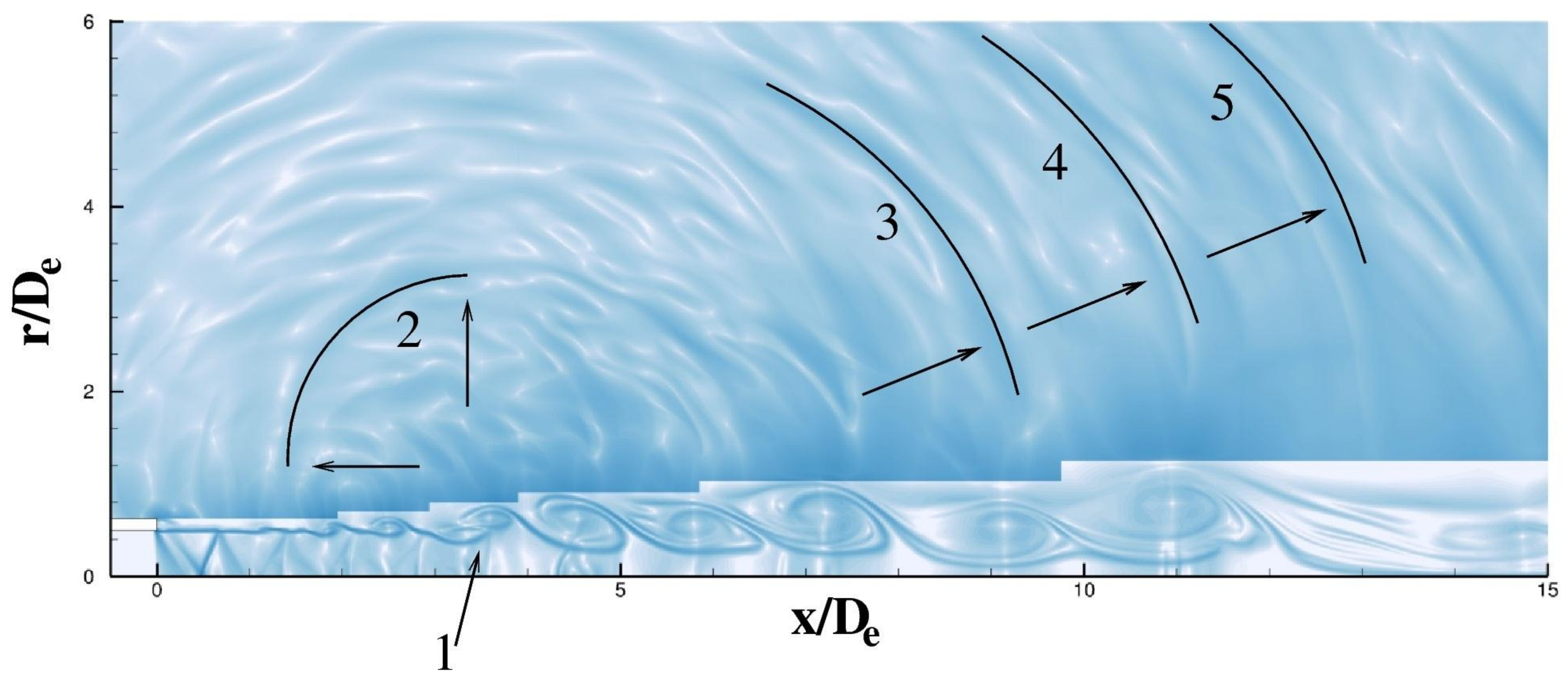
When the exit pressure of a jet does not match the ambient pressure, a series of shock and expansion waves are observed. These waves appear in the form of a characteristic diamond-shape and are termed shock cells. Fig. 1 shows that the structures developed inside the jet core are surrounded by the shear layer, a region of flow where the gradient between the velocity of the jet and of the ambient air is significant and instabilities are easily triggered. The interaction between full-scale eddies, developed from such instabilities, and the shock cells is responsible for the generation of intense noise in modern civil aircraft engines. Such shock cell noise can be divided between screech noise (a tonal component) and Broad Band Shock Associated Noise (BBSAN).

Time-resolved Computational Fluid Dynamics

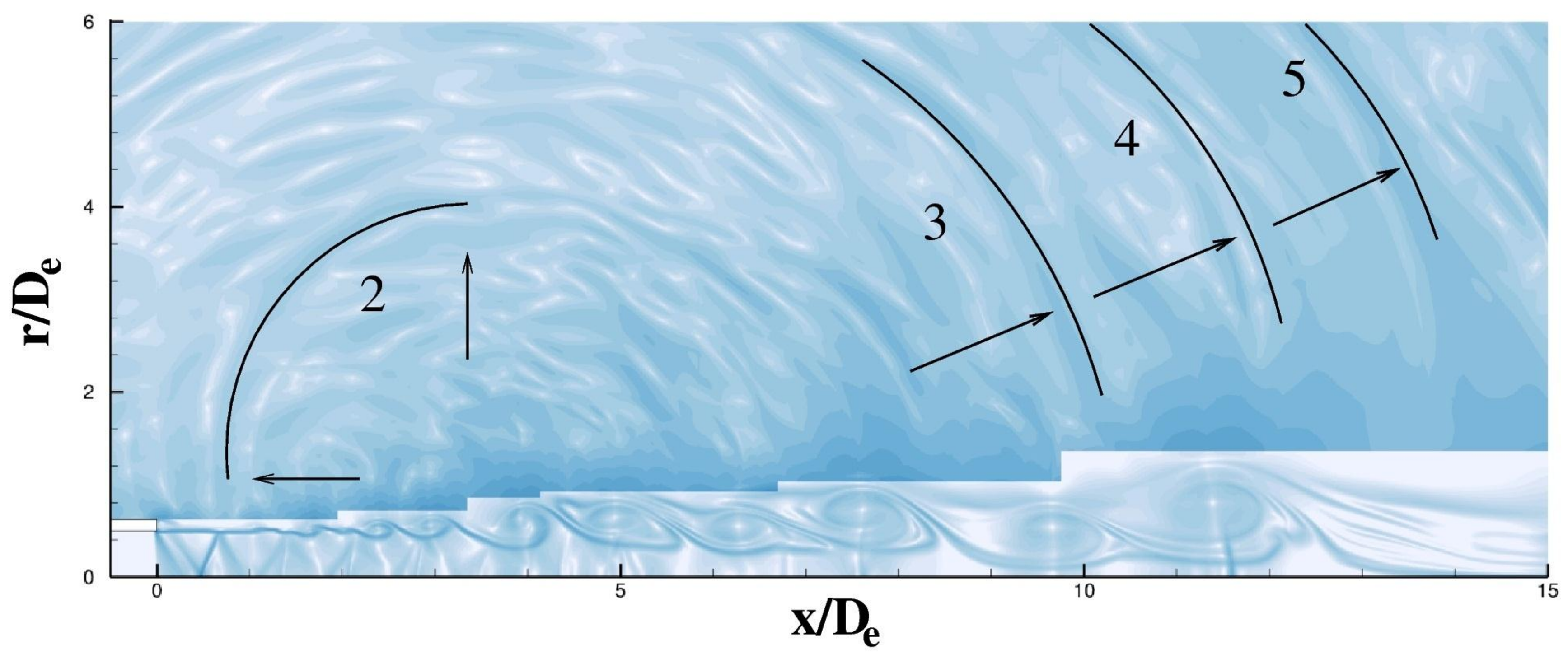
In Computational Fluid Dynamics (CFD), a numerical solution of the flow equations is obtained by means of dedicated methods and algorithms. In this study, three-dimensional Navier-Stokes equations are discretised over a finite volume and solved by means of Cosmic, an in-house code, implementing a 2nd order approximate Riemann solver by Roe [1], a two-step Runge-Kutta time integration by Hu et al. [2] and turbulence closure models by Yoshizawa [3] and Wilcox [4]. The obtained results are then post-processed with specific visualization techniques to highlight and analyse the physical phenomena of interest.

Impact

Advances in computer modelling of jets in this research aim to give unprecedented insight into the noise generated aerodynamically from aircraft engines. This knowledge will be used by the project industrial partner Airbus to design quieter and lighter airframes, making a positive impact on the health and wellbeing of passengers, operators, and airport communities.



(a) Non-dimensional time τ = 586.



(b) Non-dimensional time τ = 587.

Fig. 2: Pseudo-schlieren visualisation of an axisymmetric simulation of a jet at non-dimensional times (a) τ = 586 and (b) τ = 587.

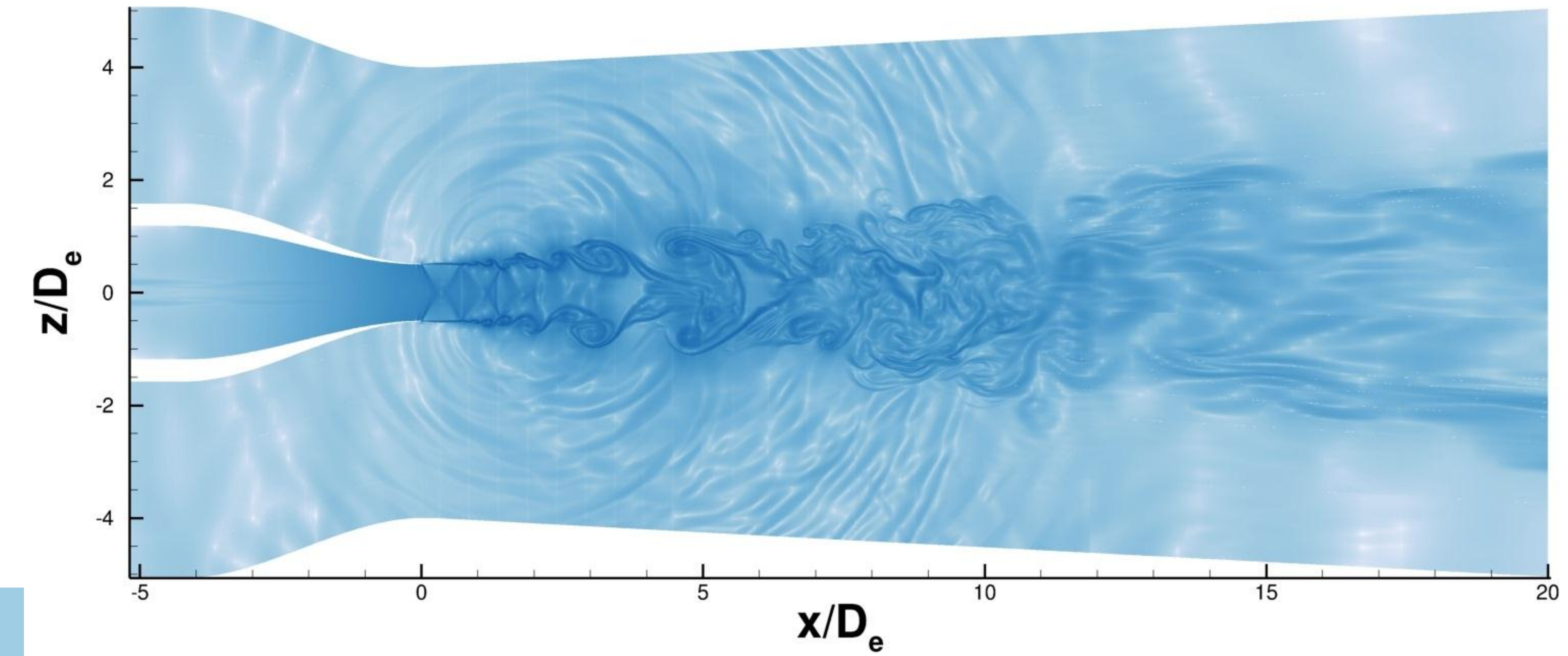


Fig. 3: Pseudo-schlieren visualisation of a 3D jet simulation

Discussion

Fig. 2 and 3 have been produced using a post-processing technique which reproduces the effect of a circular schlieren image. By computing the density gradient of the flow in both x and y directions, it is possible to highlight travelling waves, shocks and expansions inside the jet domain. In Fig. 2 the wave front labelled as 2 is due to screech noise emission, while fronts 3, 4 and 5 are related to BBSAN. A rolled-up shear-layer structure is indicated by arrow 1 in Fig. 2(a). By means of this visualisation technique, it is possible to identify the origin of the pressure waves and to understand the underlying physical mechanisms that produce them. Fig. 2 is obtained from an axisymmetric simulation of an under-expanded jet. The same jet has then been studied via a 3D simulation, shown in Fig. 3. Comparing the images it is possible to appreciate the greater complexity of the flow topology expressed in the 3D test case. The eddies developed in a jet have complex 3D structures that can be correctly captured by fully 3D simulations. The evolution of these vortices is of key importance for noise production and its correct prediction by computational aeroacoustics.

Conclusions

The results clearly show that the extra expense required by a 3D simulation reveals additional flow structures which are fundamental to understanding noise generation in a jet. Once validated against ongoing experimental research at Von Karman Institute, the technique discussed will be used to test designs for quieter engines.

References

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