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Computational aeroacoustics of a cold aerospike nozzle at off-design conditions

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The fluid flow and the aeroacoustic signature of an aerospike nozzle configuration are analyzed for one cold over-expanded configuration (Nozzle Pressure Ratio NPR3) and non-rotating inlet boundary conditions. Implicit Large Eddy Simulations (ILES) are performed, which provide data for far-field acoustic computations based on Ffowcs Williams-Hawkings equation (FWH). Power spectral density estimates in the far-field allow to identify screech and oscillations modes of the annular shock-cell structure as the main sources of sound.

Introduction and Motivation

Rotating detonation combustion increases the specific impulse of engines. The air-propellant mixture burned by the rotating detonation wave in the annular chamber expands through a nozzle resulting in a supersonic jet, known to be a strong source of sound. Besides the well-known mixing noise in subsonic flows modelled by Lighthill's tensor, other noise generation mechanisms become relevant in supersonic configuration, leading to propagation of **Mach wave radiation**, **screech noise**, **broadband-shock associated noise (BBSAN)** and **crackle noise** for highly heated jets. Moreover, the noise generation in RDC might be influenced by the oblique shock wave emerging at the tip of the rotating detonation wave observed.

Aerospike nozzles are used to expand the flow at the exit of the combustion chamber and allow for a better thrust-vector control. They can be also implemented for RDC. Therefore, it is important to firstly analyze the acoustics of such a device at simple baseline conditions before tackling the rotating cases.

Setup

Implicit LES are used to simulate an aerospike nozzle jet and provide data to compute the far-field noise using FWH equation. The 3D domain expands from $70D_{eq}$ in the flow direction and $35D_{eq}$ in radial direction. The mesh shown below has 170 million cells. It is low-stretched in the near-field to properly resolve the most energetic fluid flow structures while it is stretched in the far-field to dissipate the acoustic waves. We consider an over-expanded cold case at NPR3, which corresponds to the EAP for RDC engines.

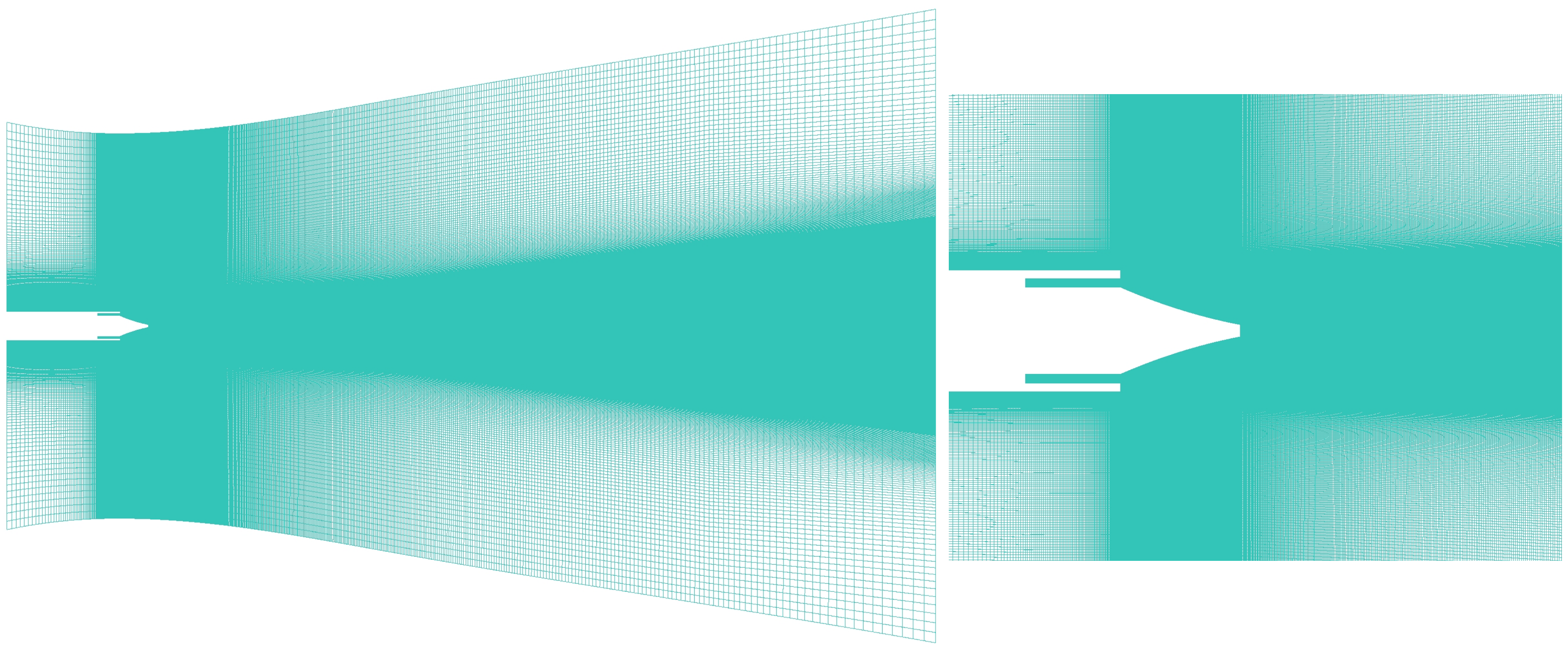

Fig. 1: complete mesh (left) and mesh around the aerospike nozzle (right)

Results:

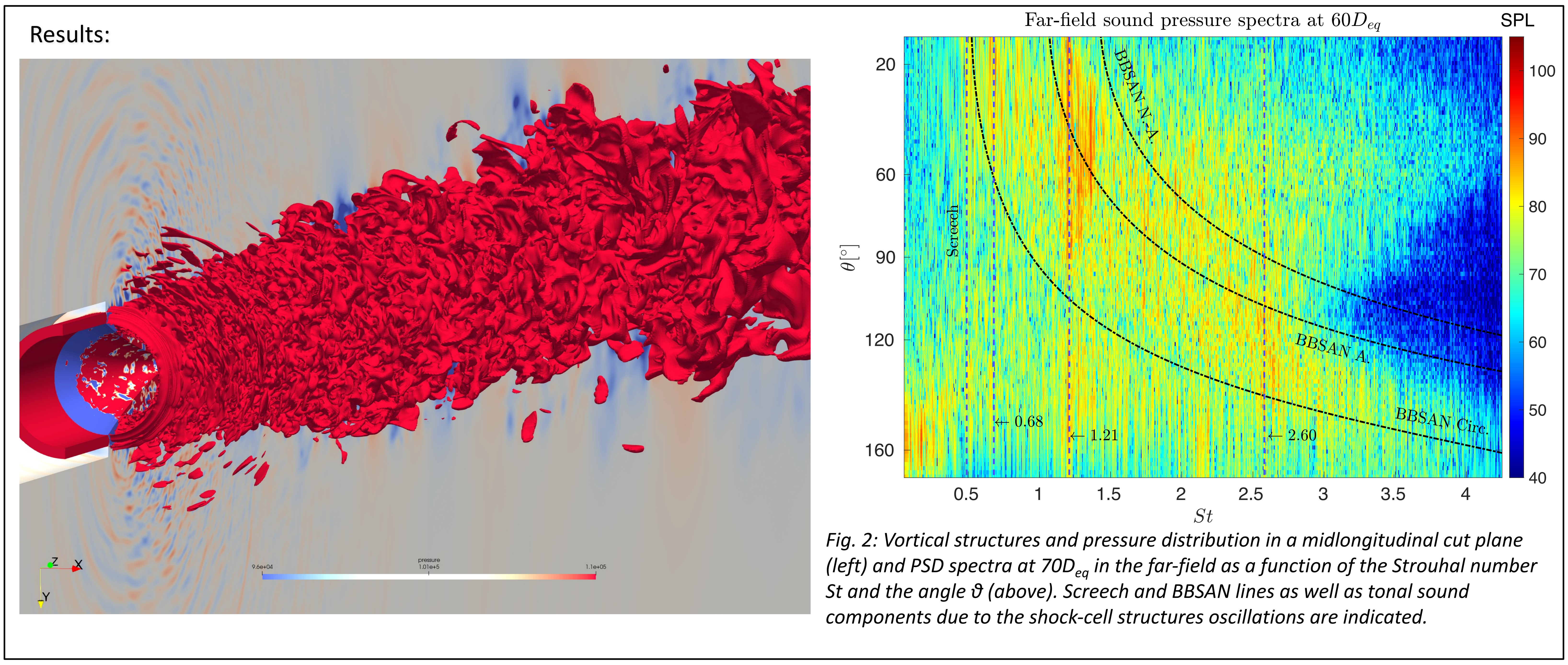

Fig. 2: Vortical structures and pressure distribution in a midlongitudinal cut plane (left) and PSD spectra at $70D_{eq}$ in the far-field as a function of the Strouhal number St and the angle ϑ (above). Screech and BBSAN lines as well as tonal sound components due to the shock-cell structures oscillations are indicated.

Summary and Conclusion

This baseline study lays the foundation for assessing the aeroacoustic method used for the more complex rotating detonation cases. It also provides a comparison point for SPL for non-rotating configurations at the same Equivalent Available Pressure (EAP) as in RDE for the aerospike nozzle. As a first next step, the effects of a higher NPR as well as a higher temperature should be analyzed. Subsequently, swirling rotating conditions should be imposed at the inlet of the nozzle.

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