PostDoc @ ISAE-SUPAERO, 12 months

High-fidelity simulation of supersonic air intakes

Project SIENA (Simulation numérique haute-fidélité d'entrées d'air supersoniques)

European applicants only

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Location: Aerodynamics, Energetics and Propulsion Department (DAEP), ISAE-SUPAERO, Toulouse
Funding: DGA
Scientific domain: Compressible fluid mechanics
Keywords: Supersonic flows, shock turbulence interaction, High performance Computing (HPC), Large Eddy Simulation (LES), Flow Instabilities

Summary:

The design of air inlets plays a key role in the performance of aeronautical propulsion systems. This is particularly true in the supersonic flight regime where the incoming flow must be decelerated before entering the core of the engine. Figure 1 displays a sketch of a canonical supersonic air inlet. The supersonic flight regime implies the presence of compressible phenomena: shock waves and expansions from the ramp compression devices (supersonic diffuser) or from the inlet cowl lips. The latter can impact the boundary layers developing on the opposite walls, causing shock wave/boundary layer interactions (SBLI) that have direct repercussions on the performance and operation of the supersonic air inlet, see Chen *et al.* (2018). Indeed, the strong adverse pressure gradient induced by a shock wave on a boundary layer may cause a separation of this low speed zone and leads to the creation of a separation bubble. The air flow rate is then reduced, which is detrimental to the propulsion system.

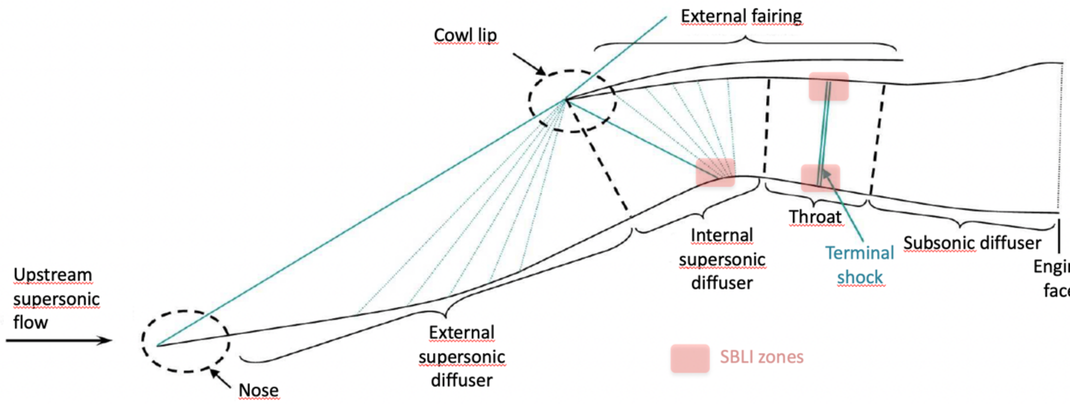

Fig 1: Sketch of a canonical supersonic air intake configuration.

One major well-known problem of these configurations is the supersonic inlet buzz, see Oswatitsch (1947), which can be a great threat to air-breathing supersonic vehicles. Usually, it is triggered by an accidental downstream pressure- or thermal-driven flow blockage, which can throw the inlet into the undesirable subcritical mode, featuring the expected terminal shock standing upstream of the inlet entrance (see figure 2). Once the buzz occurs, self-excited streamwise normal-shock oscillations are generated along with periodic duct pressure fluctuations, provoking a sharp drop in captured air flow and the consequent engine thrust penalty. Inlet buzz with intense fluid unsteadiness should thus be avoided as much as possible.

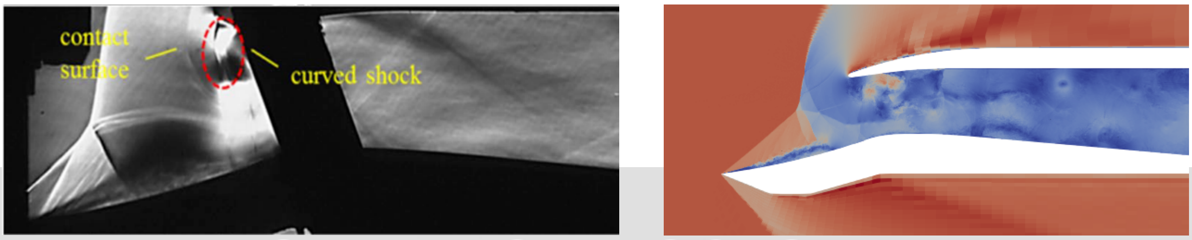

Fig. 2: Supersonic air intake experiencing “Buzz” – Left: Schlieren visualization [experiment by Chen et al. (2018)] ; Right: LES, magnitude of velocity.

The efficient design of supersonic air inlets is still a challenge today and performing numerical simulation of such flow configurations is a difficult task due to the unsteady turbulent nature of the problem and the presence of turbulence, shocks and acoustic waves that interact with each other. One possible approach is to perform Large Eddy Simulations (LES) of this complex flow, since it can cope with the above-mentioned flow features at an affordable numerical cost.

Work agenda:

The objective of the present work is to use the LES approach to characterize the unsteady features of supersonic air inlets and the underlying mechanisms driving the flow when a backpressure occurs and triggers the buzz phenomenon.These LES will be conducted using an in-house solver: IC3. The latter solves the 3-D compressible Navier-Stokes equations on unstructured grids. Thanks to its high scalability, it can be run in parallel on thousands of processors and is applicable to state-of-the-art simulations of turbulent supersonic flows.

Preliminary simulations have already been made on a 2D air intake geometry (same as the one studied by Chen *et al.* (2018)), or thin 3D-extruded domains. These allowed to demonstrate the ability of the code to properly reproduce the unsteadiness of this flow configuration, as illustrated in figure 3 where one cycle of the “little buzz” phenomenon is displayed.

The present PostDoc position will be dedicated to extend these preliminary simulations to full 3D configurations, making use of the High-Performance Computing resources of the laboratory and of national computing centers. A comprehensive analysis of the flow will then be expected from these LES results, using up-to-date signal processing techniques such as Fourier Analysis, Spectral Proper-Orthogonal Decomposition, etc.

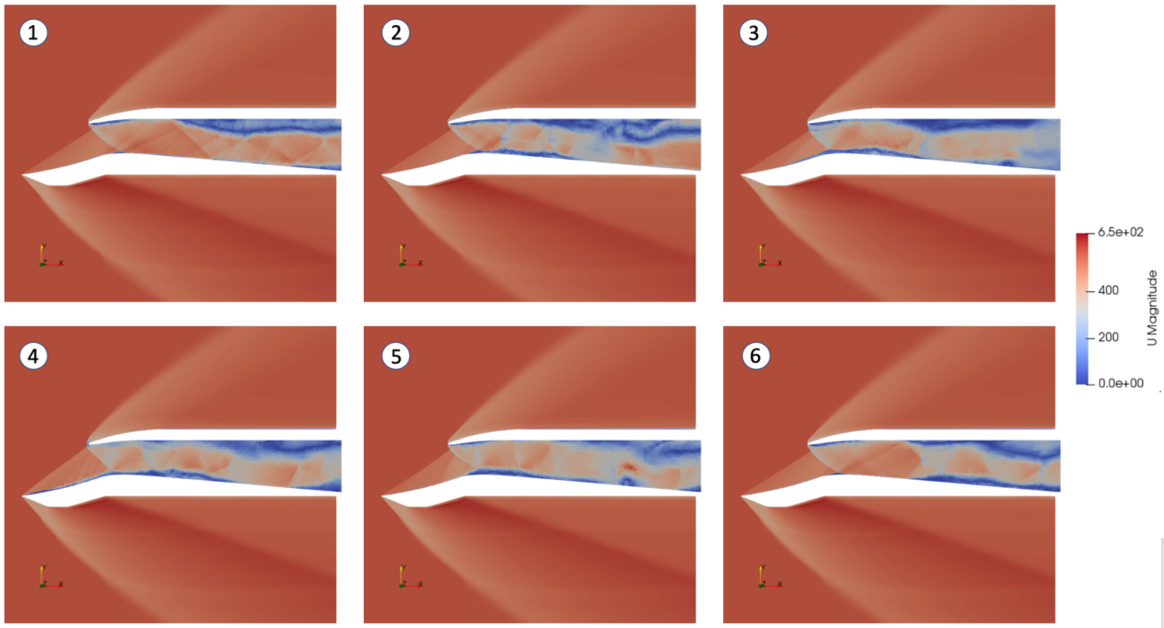

Fig. 3: Snapshots of velocity magnitude from LES at six consecutive instants during a little buzz cycle.

Expected skills:

- Compressible flows
- Computational Fluid Dynamics (CFD)
- Aeroacoustics
- High Order schemes
- C++ programming, MPI, HPC, Python, Signal processing

References

H. Chen, H.-J. Tan, Q.-F. Zhang and Y. Zhang. Throttling process and buzz mechanism of a supersonic inlet at overspeed mode. *AIAA Journal*, vol. 56(5): 1953-1964, 2018.

K. Oswatitsch. Pressure Recovery for Missiles with Reaction Propulsion at High Supersonic Speeds. NACA TM-1140, 1947.