PostDoc @ ISAE-SUPAERO, 18 months

High-fidelity simulation of control devices for supersonic air intakes

Project SIENA2 (Simulation numérique haute-fidélité de dispositifs de contrôle au sein 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, Flow control

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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 that leads to the creation of a separation bubble. The air flow rate is then reduced, which is detrimental to the propulsion system.

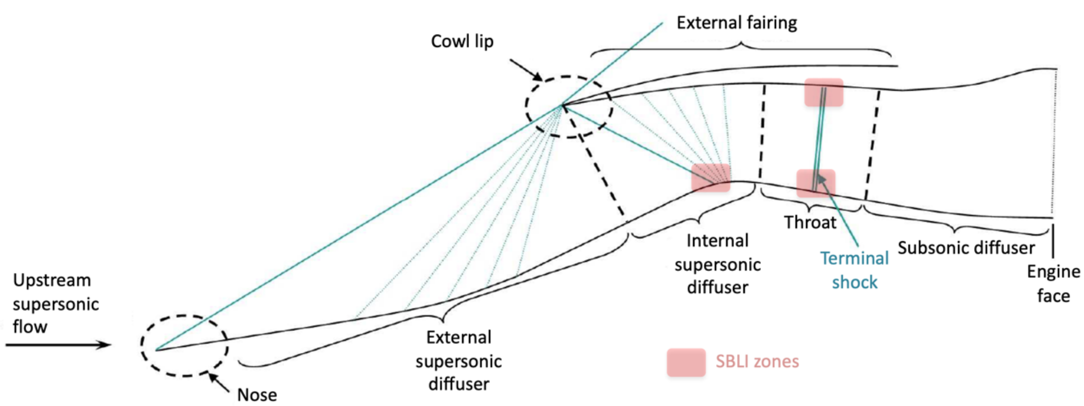

Fig 1: Sketch of a canonical supersonic air intake configuration.

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, right image). 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.

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. In an attempt to cope with the above-mentioned phenomena a first numerical campaign has been conducted at ISAE/DAEP using Large Eddy Simulations (LES), in the frame of the first phase of the so-called SIENA project (see figure 2). This work allowed a detailed characterization of the buzz phenomenon which appears in off-design conditions for the air inlet geometry used in the experiments conducted by Chen et al. (2018).

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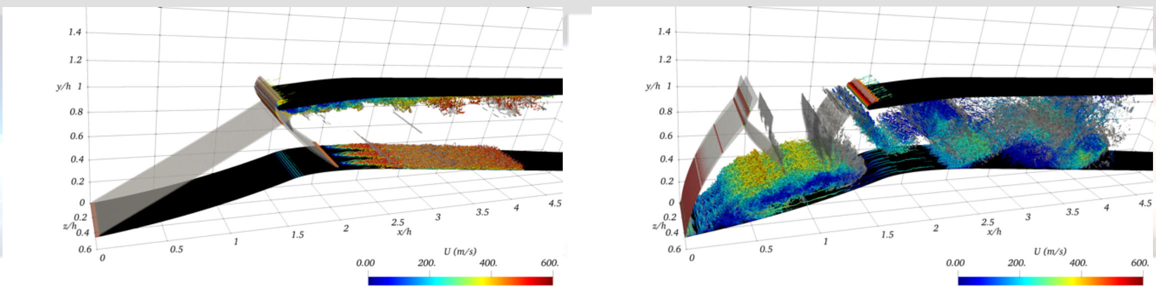

Fig. 2: Overview of the results obtained by LES of the supersonic air inlet configuration studied at ISAE/DAEP in the first phase of the SIENA project. Iso-contours of Q criterion. (left) low back-pressure downstream; (right) high back-pressure downstream (triggering the "buzz" phenomenon).

The first objective of the present work is to deepen the analysis of the produced LES results using up-to-date signal processing techniques such as Fourier Analysis, Spectral Proper-Orthogonal Decomposition (SPOD), etc. Then, an evaluation of control devices allowing the mitigation of the strong undesirable unsteady effects encountered in these off-design operating regimes will be conducted.

Work agenda:

The 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. The simulations will be conducted 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.

The present Postdoc position will be dedicated to extend the previously mentioned LES of the baseline geometry to controlled cases. Several types of passive control devices will be tested and compared, the first of which will be the one proposed by Chen et al. (2019) which is based on a bleed system incorporated in the external compression ramp (see figure 3). Preliminary simulations of this configuration have already started recently and must be continued. The next step will be to test other control devices such as boundary layer traps, micro vortex generators or wall bumps. As was done in the uncontrolled situation, the effectiveness of the control devices in mitigating the effects of the buzz phenomenon will be evaluated using advanced post-processing methods such as SPOD.

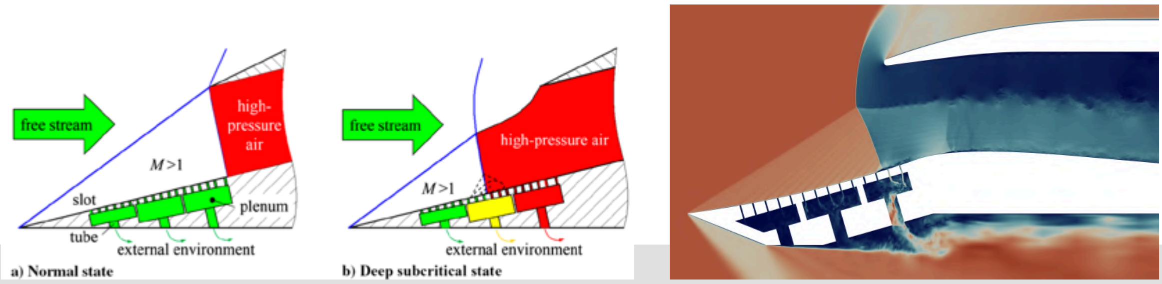

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Fig. 3: Illustration of the control device used in the experiments of Chen et al (2019). (left) sketch of the device; (right) Preliminary simulation of this device at ISAE/DAEP, longitudinal velocity.

Expected skills:

- Compressible flows
- Computational Fluid Dynamics (CFD)
- Aeroacoustics
- Signal processing, Modal analysis methods
- HPC, Python, Paraview

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.

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