PROPOSITION DE STAGE – MASTER 2 DET

Dynamique des fluides, Energétique et transferts
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Title: Tripping in Large Eddy Simulations of supersonic air intakes

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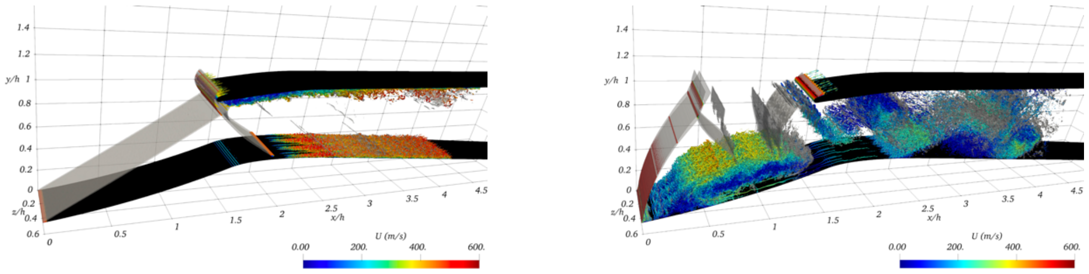
Background and motivations

Efficient design of supersonic air inlets is still a challenge today due to the occurrence of violent transitions between subcritical and supercritical regimes inherent to high-speed vehicles operating conditions. These different configurations are all very sensitive to shock wave / boundary layer interactions (SBLI): in all regimes, weak and attached shock waves, arising from the compression ramp (supersonic diffuser) or the cowl lip, impinge on the boundary layers developing on the opposite walls (see Fig. 1a). In the subcritical regime, a strong shock wave is positioned upstream of the inlet as a result of the blockage (see Fig. 1b), whereas in the supercritical regime, the shock wave is placed in the subsonic diffuser where the boundary layer is particularly sensitive to separation. A detailed analysis of these high-speed air inlets is thus necessary not only to predict their performance, but also to control the switching margins between the two previously mentioned flow regimes.

One major well-known problem of these configurations is the supersonic inlet buzz [1] 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 a terminal shock standing upstream of the inlet entrance (see Fig. 1b). 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 flow unsteadiness should thus be avoided as much as possible. In order to accurately capture the buzz phenomenon, the state of the boundary layer (laminar / transitional / turbulent) on the ramp is of major significance as it determines its sensitivity to separation, which in turn may affect the effective inlet area of the supersonic air intake.



(a) (b)

Figure 1: Isocontours of Q criterion colored by the magnitude of the velocity in a supersonic air intake not experiencing buzz (a); experiencing big buzz (b). Large Eddy Simulation results from [2].

The numerical simulation of such flow configurations is still a challenging task due to the unsteady turbulent nature of the problem and the presence of shocks and acoustic waves that interact with each other. During the past three years, several attempts have been conducted in our laboratory (see [2]): they allowed to perform LES simulations of the air intake geometry investigated by Chen et al. [3] in their experiments, see Fig. 1. However, due to a reduced Reynolds number in the simulations compared to the experiments, the boundary layer on the ramp surface was found to be laminar up to the throat for the cases that are not experiencing the buzz phenomenon (see Fig. 1b), which leads to significant differences compared to the experimental configuration regarding the occurrence of the different regimes.

The objective of the present work is thus to perform a tripped Large Eddy Simulations (LES) of this complex flow configuration using our in-house solver (IC3), in order to assess the influence of the boundary layer state on the ramp on the appearance of the buzz phenomenon and its associated frequencies. To this purpose, we will investigate numerically different tripping methods in order to obtain a fully turbulent boundary layer on the ramp.

Program of internship

Up to now, for all our Large Eddy Simulations, the boundary layer was not tripped on the ramp, leading to a laminar boundary layer up to the throat for the cases that are not experiencing the buzz phenomenon. In order to trigger turbulence on the ramp boundary-layer, a small geometric step will be added at the beginning of the ramp, as it is done in supersonic and subsonic jets [4,5]. The size, the exact position, and the shape of the geometric step will be changed in order to see what is the best tripping strategy for this flow configuration.

The research program will follow the different steps described below.

1. Getting started with IcemCFD (meshing software) in order to adapt the existing meshes to the tripped configurations;
2. Getting started with the IC3 code;
3. Carrying out of two-dimensional simulations of the chosen air inlet with the tripping methodology;
4. Analysis of the influence of the tripping on the boundary layer state on the ramp and the subsequent occurrence and intensity of the buzz;
5. Depending on the time available, preparation of three-dimensional configurations.

References:

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

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[3] H. Chen, H.-J. Tan, Y.-Z. Liu and Q.-F. Zhang. External-compression supersonic inlet free from violent buzz. *AIAA Journal*, vol. 57(6) :2513-2523, 2019.

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