École Doctorale SCIENCES ET INGÉNIERIE DES MATÉRIAUX, MÉCANIQUE, ÉNERGÉTIQUE

2018 Doctoral research projects for PhD recruitment
Institut P'

EXPERIMENTAL STUDY OF AN AXISYMMETRIC SHOCK WAVE BOUNDARY LAYER INTERACTION

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1 Context and Objectives

Shock wave / boundary layer interaction (SWBLI) is encountered in a wide variety of supersonic flows [9]. For example, when the launchers engines operate in over-expanded condition, a shock wave forms inside the divergent to adapt the flow pressure to the atmospheric pressure. This shock wave is perceived as a strong adverse pressure gradient for the upstream boundary layer and forces its separation from the wall. A sketch of this flow is given in Figure 1 (left). The SWBLI is also encountered on the wall of supersonic aircraft, especially in the presence of sudden changes in cross-section area. This flow is shown schematically in Figure 1 (right). In these configurations, the shock wave oscillates around its mean position, causing unstable forces on the motor or apparatus structure [11, 9].

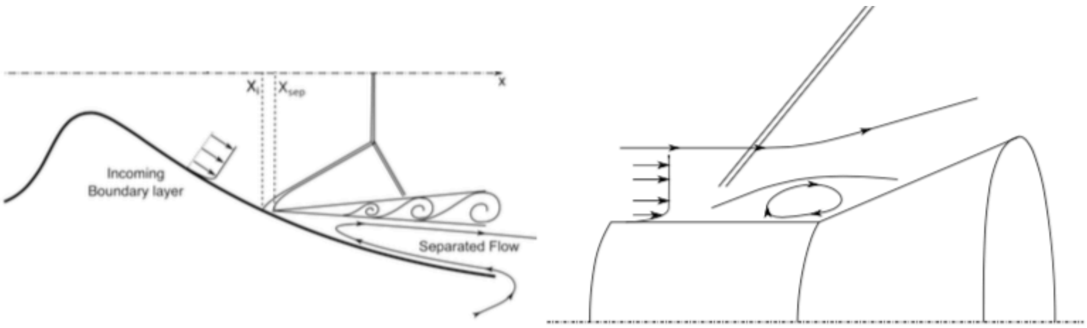

Figure 1 : Flow separation inside a nozzle (left) and on an axisymetric corner flow (right).

These shock oscillations are often referred to as the main cause of the appearance of forces in the radial direction of the object of interest [12]. These off-axis forces, called "side-loads", are the main reason why such a major research effort has been made to understand this type of flow. For practical reasons, the supersonic SWBLI has nevertheless been more widely studied in a planar configuration, although the engines and real machines have most of the time an axisymmetric geometry. Therefore, the shock oscillation mechanism remains largely unexplored in the axisymmetric configuration. The objective of this thesis is to study the effect of axisymmetric geometry on the unsteadiness of the interaction.

The collected data will be used as reference for the realization of numerical models of the interaction, allowing a finer analysis of these phenomena. Finally, these data will be used to put in place simplified, representative and sizing models of these side-load phenomena.

2 Thesis workflow

Symmetry considerations show that the lateral charges on the wall are entirely due to the first Fourier mode of pressure in the azimuth direction (m = 1) (see Jaunet et al [10] for example). However, previous studies have rarely focused on the contribution of this mode and the interaction has often been studied in plane geometry which prohibits any possibility of extraction of this mode of Fourier.
Since the pioneering work of Schmucker [12], studies have mainly focused on the description of oscillations of the shock wave. It is understood, in fact, that small asymmetries of the position of the shock in azimuth can generate lateral forces. However, the pressure measurement in the nozzles is carried out at fixed positions [8]. This has the consequence of i) making very complex any attempt to put in similarity of the pressure fluctuations according to the operating condition of the nozzle [7]; and ii) to give only a partial image of the dynamics of the movement of the shock in wall (one only measures the passage of the shock to the vertical of the sensor).
In other words, the data experimentally available so far lacks spatial and / or temporal resolution to fully address the problem. It is therefore proposed in this study to develop and use modern means for measuring wall pressure (via PSP pressure-sensitive paint) to meet the previously discussed questions.
We will first focus in this study on open geometries which, unlike nozzle detachments, will decouple the effects due to axisymmetry from those due to longitudinal pressure gradients. This geometry also ensures the necessary optical access on the entire circumference of the model. We will therefore be interested in a supersonic flow on a geometry of revolution as shown in Figure 1 (right). Different ramp angles will be considered in order to characterize the influence of the intensity of the interaction on the spatio-temporal structure of the loads.

We present in the following the expected progress of the thesis:

2-1. Facilities preparation (12 months)
During this phase, the PhD student will work on the preparation of the S150 wind tunnel, with the help of the Promété platform's technical staff, in order to obtain a flow allowing the development of a supersonic boundary layer on a cylinder. Special attention will be given to the instrumentation of the model to be able to decompose the pressure field in azimuthal Fourier modes.
In parallel, tests will be conducted to refine the knowledge of the capabilities of the time-resolved PSP measurement system, currently in development in the laboratory. These crucial results will allow us to refine the approach we will use during the test campaigns.

2-2. Nozzle and wind tunnel qualification (6 mois)
Averaged and instantaneous strioscopic visualizations will be used to determine the spatial organization of the flow: average positions of shock, separation and attachment.
A fine measurement of the average and turbulent quantities of the boundary layer will be performed using a laser Doppler anemometer. It will be verified that the upstream boundary

layer is turbulent and homogeneous in azimuth. If conditions permit, a frequency analysis of the velocity signals will be carried out along the interaction.
The bench will then be instrumented to measure the average and fluctuating pressure profile along the interaction.
The comparison of these data with the results of the literature will validate the experimental setup.

2-3. Dynamics eduction of the antisymmetric pressure mode (6 months)
In the following of these works we will try to extract the dynamics of the anti-symmetric mode of Fourier in azimuth. The model will therefore be instrumented with unsteady pressure sensors in both azimuthal and axial directions. The PSP seems appropriate for this approach and a synchronous measurement campaign PSP - unsteady sensors will be conducted. The PSP will at least indicate the instantaneous position of the shock foot. If it proves to be sufficiently sensitive, it will allow us to obtain a spatial mapping of the power spectral density of this Fourier mode. If not, the approach will be conducted using conventional sensors.

2-4. Analysis and modelling (12 mois)
This last part of the thesis will be dedicated to the capitalization of the collected information. In particular, we will try to model the antisymmetric movements of the shock and estimate the lateral forces induced by these movements.
We will also discuss the relevance of the approach taken in this work with regard to the interactions observed inside nozzles.

3 Context

The thesis will take place at the PPRIME institute (UPR 3346) in Poitiers within the 2AT team (Aerodynamic Acoustics Turbulence) in the compressible aerodynamic activity of the group. The experiments will be carried out on the S150 wind tunnel of the new Prométée platform on the Futuroscope site.

4 Candidate Profile

The candidate must have a Master degree (or equivalent degree) in fluid mechanics with, if possible, a laboratory experience. Knowledge in compressible aerodynamics and gas dynamic will be appreciated.
The candidate should be comfortable with the inevitable technical aspects of experimental research, and should demonstrate a good practical spirit. A good open-mindedness, a great tenacity to overcome the problems encountered and a team spirit to integrate the research team will be additional assets to carry out this thesis and this project.

Recent publications on the subject

[1] Eric Goncalves, Guillaume Lehnasch, and Julien Herpe. Hybrid rans/les simulation of shock-induced separated flow in truncated ideal contour nozzle. In International Symposium on Shock Waves, 2017.

[2] V Jaunet, S Arbos, G Lehnasch, and S Girard. Wall pressure and external velocity field relation in overexpanded supersonic jets. AIAA Journal, pages 1–13, 2017.

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