Experimental study of the dominant modes and its contributions to detached internal flows in a TIC nozzle

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Abstract :

During the transient phases of start-up and shut-down, liquid engine nozzles operate under severe over-expanded conditions. Furthermore, these transient phases result in rocket nozzles exhibiting dynamic off-axis loads caused by asymmetric internal separation. There are two recognisable types of flow separation, Free-Shock Separation, FSS, and Restricted-Shock Separation, RSS. Nave and Coffey (1973) showed that the resultant separation type depends largely on nozzle geometry. Thus, affecting the load fluctuation frequency and magnitude during transition (Ödtlund, 2002).

Many studies have analysed these distinct separation patterns concluding that FSS topologies result in lower magnitude side forces than RSS ones (Ruf et al., 2010). Moreover, it has been shown that Truncated Ideal Contour, TIC, nozzles only experience FSS separation while TOP (Thrust-optimised parabola) and TOC (Thrust-optimised Contour) nozzles experience both regimes, RSS and FSS, having the largest side-loads at, or close to, the transition from FSS to RSS (Aghababaie and Theunissen, 2015; Frey and Hegemann, 1998, 1999; Terhardt and Hegemann, 1999). Besides, it should be noticed that the start-up side-loads are one of the main design factors of a rocket engine. Consequently, in order to attain improved designs a better understanding of the flow characteristics is required.

Thus, this work presents an experimental study of a TIC nozzle developed in a cold supersonic wind tunnel at PPrime Institute in Poitiers. The study consists of a series of pressure measurements for a range of pre-selected pressure ratios which permit the characterisation of the regime where the nozzle undergoes the most significant jet fluctuations as it is believed that they are strongly associated with the side-loads. The pressure sensors are located axially and azimuthally. The measurements are performed for four different configurations, acquiring twelve simultaneous pressure measurement at each time. Hence, both azimuthal modes in two different locations inside the nozzle and axial modes can be obtained.

Additionally, visualisation of the jet is carried out by means of Schlieren imagery as well as Particle Image Velocimetry, *PIV*. The latter permit to look for relations between the internal flow behaviour and the external jet topology.

Preliminary results have shown that whenever there exists a noticeable first azimuthal mode, believed to be the source of the side-loads, a marked low frequency beating is observed on the external jet. Moreover,

as the Nozzle Pressure Ratio, *NPR*, is increased the amplitude of this first azimuthal mode increases, and so does the amplitude of the external jet beating. Eventually, a maximum is reached beyond which the beating, as well as the amplitude of the first azimuthal mode, quickly decrease and stabilise.

Furthermore, preliminary analysis of continuous as well as spark Schlieren photography has qualitatively shown a distinct low frequency vibration in the external jet and demonstrated a considerable amplitude decay as the pressure ratio is increased. Hence, validating the results obtained with the other two experimental techniques.

Finally, it should be noticed that further analysis is still under way. Firstly, focusing on the correlation between the external jet topology and the internal wall pressure measurements. Correlations between the azimuthal modes in two nozzle locations are also being obtained. Finally, an extended temporal and spatial analysis of the jet mixing layers is carried out putting special emphasis on the correlations between the external and the internal jet mixing layers as well as on the shock mixing layer interaction.

Mots clefs : Turbulence, Boundary Layer, Shock Wave, SWBLI, Interaction, Rocket Nozzle, Over-Expanded, Side-Load, Jet, Mixing-Layer.

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