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Corresponding author: FORMIDABILE Martina
e-mail of corresponding author: martina.formidabile@gmail.com
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Effect of aeroelasticity on the acoustic imprint of TOP contoured nozzles in overexpanded conditions

Authors

Martina FORMIDABILE [1], Woutijn Baars [2], Ferry Schrijer [3]*

** Corresponding author*
[1] Faculty of Aerospace Engineering, Delft University of Technology, DELFT, The Netherlands, martina.formidabile@gmail.com
[2] Faculty of Aerospace Engineering, Delft University of Technology, DELFT, The Netherlands, w.j.baars@tudelft.nl
[3] Faculty of Aerospace Engineering, Delft University of Technology, DELFT, The Netherlands, f.f.j.schrijer@tudelft.nl

Abstract

Thrust Optimised Parabolic (TOP) contoured nozzles, with large area-ratios, are commonly employed in rocket propulsion systems as they feature an excellent thrust-to-weight ratio [1]. A significant shortcoming to this design, however, is that, during the startup and shutdown transients, the internal nozzle flow progresses through a series of overexpanded states - commonly referred to as Free Shock Separation (FSS) and Restricted Shock Separation (RSS) [2]. These have been documented to produce critical loads associated with asymmetric flow separation and shock wave boundary layer interactions (SWBLI) [3]. Nozzle wall deformations, and its aeroelastic coupling to the flow, have also been found to greatly contribute to critical loads [4]. Driven by the significance of this latter point, a study is conducted using the ASCENT nozzle test rig, situated in the High Speed Laboratory of the Delft University of Technology. Startup and shutdown cycles (cold gas) are performed on two different nozzle-specimens having an identical geometry: a rigid aluminium thick-walled nozzle is used as a baseline test case in which structural vibrations are absent; furthermore, a compliant thin-walled nozzle, made out of a urethane-based polymer, ensures the occurrence of fluid-structure interactions. A comparison of results between these two test articles aids the investigation on the effects that aeroelasticity has on vibroacoustic loading. Simultaneous measurements are performed and include (1) the nozzle-wall deformation, by means of stereoscopic tracking of markers on the nozzle lip, (2) the imprint of the near-field acoustic signature, by means of an azimuthal array of pressure-microphones, and (3) Schlieren imaging of the jet plume. Measurement data allows for a Fourier azimuthal decomposition of both the acoustic pressure and the nozzle lip displacement. Correlations of the structural and acoustic modes, together with a comparison between the stiff and compliant nozzle cases, quantitatively highlights the impact that aeroelasticity has on the noise directivity and spectral signature.

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