Investigations of a Generic Rocket Model with Plume in Hypersonic Flow

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Base buffeting is a major engineering design issue for space launchers during atmospheric ascend. Massively separated flow in the launcher's base region causes strong dynamic loads on the vehicle's nozzle. The present work makes both experimental and numerical investigations of a generic rocket model in hypersonic ambient flow to analyze and to enable predictions of these afterbody flow phenomena. Additionally, a cold plume is considered.

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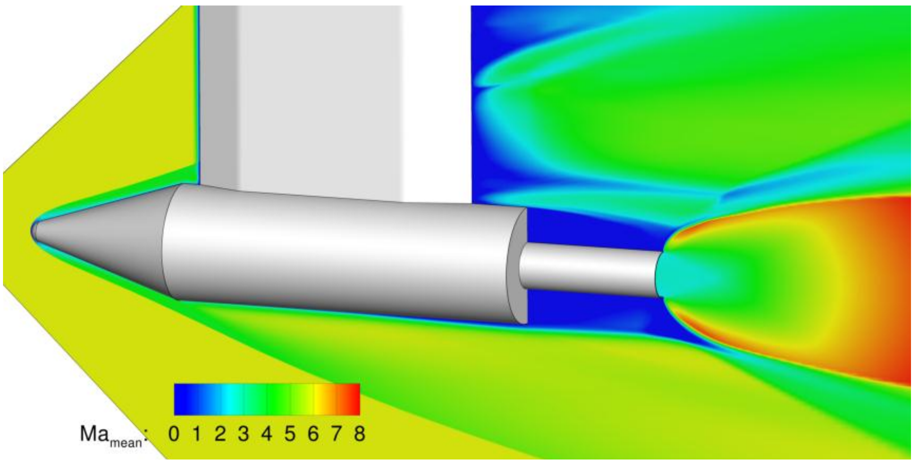


Figure 1: Geometry of the generic rocket model and mean Mach number distribution in the symmetry plane

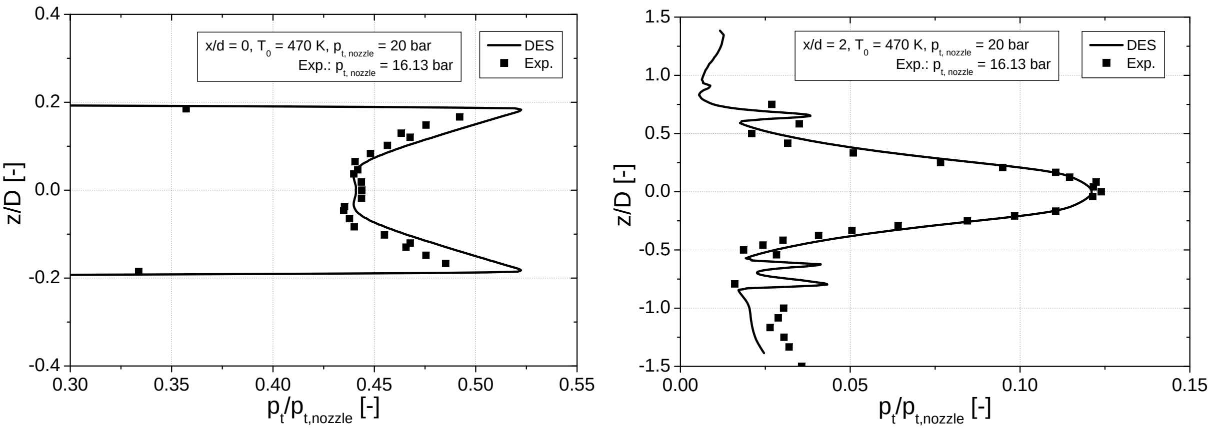
The main body of the generic rocket geometry consists of a conical top with a nose radius followed by a cylinder with diameter D. In the center of the rear part of the main body a TIC-nozzle (truncated ideally contour) is attached. The outer shape of the centered nozzle is a cylinder of diameter $0.4D$ and length $1.2D$. The scaling is inspired by the Ariane 5 launcher. A support on the main body keeps the model at a fixed position inside the wind tunnel and supplies test gases needed for the plume generation via internal pipes.

The ambient flowfield has a freestream Mach number of 6 and an unit Reynolds number of $16 \cdot 10^6 \mathrm{m}^{-1}$. The cold plume exhibits a strong expansion when leaving the nozzle due to the high pressure ratio between the nozzle flow and the freestream. The current investigation focuses on the base region. The flow separates at the base shoulder resulting in a large recirculation area between the base and the strongly expanding plume (Fig. 1).

Experiments are conducted at the Hypersonic Ludwieg Tube Braunschweig (HLB) of the Technische Universität Braunschweig and at the supersonic wind tunnel H2K of the DLR in Cologne. Schlieren images of the base region are taken to visualize the interaction between the ambient flow and the nozzle flow. Several pressure transducers are placed on the base in radial and azimuthal directions and also on the outer wall of the nozzle to record the pressure history. The unsteady pressure signal is analyzed with respect to its spectral information. Several characteristic modes are identified. Pitot pressure profiles at the nozzle exit and downstream are available from the experiments.

A numerical simulation of the stated configuration is carried out via the Detached Eddy Simulation (DES) technique using the DLR-TAU-code, a second order finite volume approach with the ability to produce time-accurate results. The one-equation Spalart-Allmaras (SA) turbulence model is used as a baseline model for the DES. All experimental data are compared to numerical results. The time averaged data shows a good agreement as can be seen in Fig. 2. Up to now, the number of samples generated by the numerical simulation is not sufficient for a comparison of the pressure spectra. Therefore, the simulation is still ongoing.

The grid sensitivity of the nozzle shear layer is analyzed in the numerical simulation. A region enclosing the nozzle shear layer near the nozzle exit is significantly refined, leading to a doubling of the overall grid points. The results computed with both spatial resolutions are compared with respect to the influence on the base flow.



(a) Nozzle exit

(b) Two nozzle diameters behind the nozzle exit

Figure 2: Pitot pressure profiles of the plume in the vertical direction: HLB measurements and DES results