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ADVANCED NOZZLE CONCEPTS IN RETRO-PROPULSION APPLICATIONS FOR REUSABLE LAUNCH VEHICLE RECOVERY: A CASE STUDY

Abstract

The bell-shaped nozzle deserves its role in modern rocket science as the key technology that contributed to making space accessible. Nevertheless, recent achievements in the main stage recovery of the current class of Reusable Launch Vehicles (RLVs) force the community to question the effectiveness of bell nozzles design for this scenario. Indeed, bell nozzles face difficulties during re-ignition in Supersonic Retro-propulsion Phases (SRPs), because of the counterflow that enters the thrust chamber and forces the exhaust gasses to push against it. Moreover, the recirculation areas near the baseplate tend to increase the temperature levels dramatically along re-entry.

These and many other critical physical phenomena arising during SRPs (i.e plume-plume, plume-shock and shock-shock interactions, flow separation and side-loads, thermal loads at side-walls, etc.) are addressed within this paper, in order to offer a clear picture of the limitations inherited from bell nozzles when applied in retro-propulsion scenarios for RLV recovery. Advanced Nozzle Concepts (ANCs) such as Aerospike, Dual-bell or Expansion-Deflection nozzles, might solve these drawbacks. Moreover, these concepts offer performance gains up to 15% thanks to their intrinsic altitude-compensation. Despite this, the only applications ANCs have found so far are experimental vehicles, resulting in a relatively low technology-readiness-level w.r.t. the well-established and reliable bell-shaped nozzle. Today's search for feasible solutions to these new challenges may offer ANCs a chance to find their role in the upcoming class of fully reusable launchers.

This paper opens a roadmap to both numerical and experimental studies on ANCs, by identifying the most relevant limitations of current bell-nozzle configurations and improvements expected by an adoption of ANCs for the main stage propulsion system. The chosen approach is an in-depth review of the available studies on both retro-propulsion applications and ANCs. This paper finds out common points of interest between the two topics, even though the reference publications were originally carried out with different purposes. The critical phenomena identified within this paper determine inputs for future numerical simulations and experimental campaigns, with purpose to test if ANCs could constitute a desirable solution for the main propulsion system of the upcoming class of RLVs.

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