

Single-Phase Internal Flowfield Validation with an Experimental Solid Rocket Motor Model

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Incorporating a submerged nozzle for solid propellant rocket motors, the resulting cavity formed in the vicinity of the nozzle integration part enhances the entrapment of liquid residues of the combustion and leads to the accumulation of slag with a considerable mass. As a first step for the slag accumulation assessment, an experimental and numerical investigation of the single-phase internal flowfield is performed and the numerical tool is validated. The measurements are carried out in a cold-gas simplified model in which the flow is injected from the forward end (no wall injection). Simultaneously, the experimental configuration is simulated numerically with the help of a commercial solver (CFD-ACE+). The experimental results allowed the full characterization of the complex recirculation zone downstream of the inhibitor model and in the cavity. It was also demonstrated that the airflow in the cavity is slightly altered in case the gas–slag interface is represented either as a rigid or a liquid. The time-averaged statistical results of the three-dimensional simulation in the midspan plane compare very well to the experimental database, ensuring a satisfactory validation. The mean streamlines close to the walls, plotted from the computational fluid dynamics field, allow better understanding of the flow structures. The analysis reveals a two-dimensional flowfield for the studied geometry with locally some three-dimensional behaviors, especially along the main recirculation bubble interface.

Nomenclature

H	=	height of the channel
h	=	height of the inhibitor
Re_h	=	Reynolds number based on h
rms_U	=	root mean square of the U velocity component
rms_V	=	root mean square of the V velocity component
rms_W	=	root mean square of the W velocity component
U	=	streamwise velocity component
U_0	=	freestream velocity
V	=	transversal velocity component
W	=	out-of-plane velocity component
x, y, z	=	Cartesian body axes
Δt	=	particle image velocimetry separation time

Introduction

THE first stage of launch vehicles (e.g., Ariane 5, Vega, Shuttle, Ares, H-II) generally incorporates solid propellant rocket motors (SRM). These are typically operating during the first part of the liftoff, providing most of the thrust to accelerate the vehicle. To

shorten the overall length, the nozzle is submerged in the last segment of solid propellant. That means that the convergent, the sonic throat, and part of the divergent are surrounded by solid propellant. This integration allows orientation of the nozzle to provide adaptation of the rocket trajectory during the launch. During the combustion (please see Fig. 1), the regression of the solid propellant surrounding the nozzle integration part leads to the formation of a cavity around the nozzle lip. The aluminum, being part of the propellant grain composition, is oxidized during the combustion. This process goes along with the generation of alumina droplets, which are then carried by the hot core flow toward the nozzle. Meanwhile, the droplets interact with the vortices formed by the internal flow and thus may modify their structure. As a consequence, some of the droplets are entrapped in the cavity instead of being exhausted through the throat. The amount of entrapped droplets in the cavity depends most probably on their interaction with the vortices. The accumulation of these droplets in the cavity generates an alumina puddle, also called slag. This slag reduces the performance of the solid propellant motor due to its dead weight and absence of impulse generation. In the case of the Ariane 5 solid rocket motors (MPS P230) the total mass of the accumulated particles can reach up to 2 tons in each motor by the end of the launch [1].

Background and Objectives

The present section describes the previous works carried out to assess the problem and the objectives of the current investigation.

Previous Studies Related to Slag Accumulation

Slag accumulation in aluminized SRMs has already been studied directly or indirectly through numerous projects pointing out various consecutive mechanisms driving the entrapment of alumina droplets. The first obvious steps in this process are the aluminum combustion, the alumina formation, and the generated droplet size distribution, which have been studied by several authors [2–5].

The entrainment and transport once the droplets are flowborne have been investigated first through quasi-steady numerical simulations [6–8]. However, the unsteady nature of the internal flowfield has proven to be important [9,10]. Also, the slag accumulation was

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