Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: CFDMPS / PROPHY
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Type: Oral
Status of corresponding author: Regular

Title

Effect of nozzle seal rupture on internal motor dynamics

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Abstract

Solid rocket motors are usually protected from the outer atmosphere via the use of a nozzle seal, which is designed to break once the chamber pressure reaches a sufficiently large value. This ensures a non-polluted internal gas composition, as well as the initial containment of the igniter gases and a rapid pressure rise, favouring ignition. When the seal breaks, the flow quickly accelerates through the nozzle and an expansion wave travels through the combustion chamber. Depending on its design, the seal may break in chunks of various sizes, and the debris may be ejected more or less quickly through the nozzle. A characteristic seal rupture time can be associated with these phenomena, and it may impact the establishment of a sonic flow at the nozzle throat, as well as the system of pressure waves inside the chamber. In particular, it may have an important effect on the intensity of the initial expansion wave, and thus the structural solicitation of the motor. All ignition simulations reported in the literature assume that the nozzle seal instantaneously disappears once its breaking pressure is reached, and no study has been reported on the effect of this nozzle seal rupture.

In this paper, we focus on the analysis of this phenomenon. We present two approaches to model and simulate the effect of seal rupture. The first one assumes that the seal is ejected as a single panel and uses a 3D moving and overlapping meshes technique to capture its interaction with the nozzle flow. The second one simplifies the problem by assuming a quasi-one-dimensional flow (Q1D) in the motor and representing the nozzle seal rupture as a gradual opening of the nozzle. We show that both approaches yield nearly identical dynamics on a small-scale test motor, thus validating the use of the cheaper Q1D approach. Parametric studies in Q1D show that there exists a threshold value of the characteristic rupture time, below which the internal dynamics is identical to that obtained when assuming an instantaneous opening of the seal. For longer rupture times, the intensity of the expansion wave may be greatly reduced. Eventually, a small experimental inert motor is presented, where the internal pressure evolution is prescribed by an external air tank. Results obtained with a variety of nozzle seal configurations are confronted to our numerical findings.