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NUMERICAL MODELLING OF DIAPHRAGM-RUPTURE-ASSISTED STARTING OF PRANDTL-MEYER SUPERSONIC AIR INTAKES

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ABSTRACT

Air-breathing hypersonic propulsion systems, such as scramjet engines, offer an alternative to conventional rocket-based designs, with high potential for high-speed aerial vehicles and space transportation applications. The stable and efficient operation of the engine is possible only when its air intake is started, i.e., the flow throughout the intake is supersonic. The Kantrowitz theory based on conservation laws sets a severe limit on the maximum intake contraction for successful starting by quasi-steady acceleration. One of the potential ways to start a high-contraction intake is to seal it with a diaphragm and then rupture it, thus inducing a highly unsteady starting flow, which would presumably allow circumventing starting constraints dictated by the Kantrowitz theory. In the previous studies, this way of intake starting was demonstrated to be successful for fully enclosed (internal compression only) intakes, if their sealed interior was evacuated to sufficiently low pressure.

The present numerical research focuses on the application of diaphragm-rupture-assisted starting to Prandtl-Meyer (PM) supersonic intakes. PM intakes belong to mixed (external-internal) compression intakes often encountered in scramjet engines because their starting is facilitated by overboard flow spillage during the starting process. It is of interest to investigate to what degree the PM intake starting can be further assisted by the installation and rupture of a diaphragm.

The numerical simulations are performed using an in-house solution-adaptive unstructured Euler (inviscid) finite-volume flow solver. The gas is assumed to be an ideal gas with constant specific heats. A multi-block meshing strategy is applied, allowing finer background meshes at critical locations. Concerning computations, transient h-refinement of the grid is applied at shock wave fronts and other localized flow features. Grid convergence studies are performed for a representative case to determine how fine the grid should be to reliably establish the outcome of the starting process (start or unstart). The flow solver is additionally validated by the comparison of the simulated started flow with the analytical solution.

Parametric studies of diaphragm-rupture-assisted starting are then carried out for freestream Mach numbers from 2 to 6 and for intake contraction ratios between the Kantrowitz and isentropic limits. The massless diaphragm is placed across the intake entry and ruptured instantaneously. For each combination of freestream Mach number and contraction ratio, the maximum pressure inside the intake prior to diaphragm rupture that would still allow successful starting, is determined. The mechanism of unsteady intake starting is discussed based on the results of simulations.