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Corresponding author: T. Jeremy P. Karpowski
e-mail of corresponding author: karpowski@stfs.tu-darmstadt.de

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Title

A numerical study of resonance ignition for space propulsion systems

Authors

T. Jeremy P. Karpowski [1], Federica Ferraro[1], Katharina Henn[1], Christian Bauer[2], Christian Hasse [1]*

** Corresponding author: karpowski@stfs.tu-darmstadt.de*
[1] Simulation of reactive Thermo-Fluid Systems, Technische Universität Darmstadt, Darmstadt, Germany
[2] Chair of Space Propulsion and Mobility, Technische Universität München, Munich, Germany

Abstract

With the increase in satellites in orbit, the importance of de-orbit burns increases, necessitating a reliable restart of the propulsion system years after the first start. Similar requirements are also encountered for deep space probes and reusable launch vehicles, although the latter with smaller time intervals but potentially numerous restarts. Currently, hypergolic fuels are employed as either primary or separate igniter fuel. However, their handling is complicated, and in the case of separate igniter fuel, it entails additional system mass.

A promising alternative is the resonance ignition concept based on a Hartmann-Sprenger tube. A resonance igniter consists of an underexpanded jet directed into a cavity. The resulting shock system in front of and in the cavity yields a temperature increase at the cavity tip. Two different modes are known in the literature. The jet regurgitant mode (JRM) is characterized by periodic inflow and outflow into the cavity. In contrast, the jet screech mode (JSM) is accompanied by much higher frequency noise caused by the oscillation of the shock structure in front of the cavity. However, the correct prediction of both phenomena, especially the transition from one operating mode to the other, is not yet reliably achieved by most numerical tools.
Therefore, this works aims to validate an open-source solver based on the OpenFoam framework in conjunction with the Blastfoam extension against experimental findings of a resonance igniter recently published by Bauer [1].

First, the solver and models are validated against the nozzle cavity spacing with the highest recorded temperature. A thin wall model is used for the heat losses at cavity walls. The parameters are chosen to ensure a good agreement between the simulation and the experiment. With these parameters, the simulation's frequency response and temperature increase agree with the experimental data. Further simulations covering different nozzle cavity spacings were also consistent with the experimental results. With an increase in the nozzle cavity spacing, a transition from the JRM to the JSM mode is observed. The transition is equally observable in the experimental frequency responses. The observed shock structures differentiating both modes are discussed. Lastly, variations of the original geometry are performed, and their effect on the temperature increase is discussed. The change in cavity shape from conical to cylindrical results in reduced tip temperatures. These are the result of a weakened incoming shock.

References

[1] Christian Bauer, Design and Test of Resonance Ignition Systems for Methan/Oxygen In-Space Propulsion Systems, Dissertation, TU München (2020)