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

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: PROPHY / NEWSPA / CFDMPS / *(3 maximum from the list of topics)*
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Type: Oral
Status of corresponding author: Student

Title

Cooling system analysis of a clustered module aerospike for upper-stage applications

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Abstract

The increasing competitiveness in the development of space transportation systems demands reduced launch costs and high reliability and efficiency for present and future launchers. In recent years [1], aerospike nozzles underwent an increasing renewed interest, especially because of their self-adaptive behavior with altitude [2, 3]. Moreover, possible advantages can result from the compactness of the aerospike compared to conventional bell nozzles in high altitude operations [4]. In either case, aerospike characteristics can lead to increased engine specific impulse and thus improved payload mass fractions. Different engineering solutions and design approaches have been proposed over the years, which typically feature an internal expansion followed by an external expansion over the spike. These solutions include annular or linear plug nozzles, whose internal expansion can be achieved by a cluster of nozzle modules either with a conventional bell-type geometry [5], rectangular or round to square nozzle module [6].

Even though such systems are characterized by many advantages, there are yet no applications on operational launchers. One of the main reasons is the management of thermal loads. As a matter of fact, being the throat located at the maximum radial distance from the axis, the heat flux peaks insist on a rather large surface compared to a conventional bell nozzle, leading to a higher thermal power to be extracted by the cooling system. However, such a criticality could turn into an advantage for expander cycle engines, where turbopumps are driven thanks to the power gained by the coolant.

The understanding and prediction of heat transfer characteristics and wall temperature distributions in the thrust chamber are key features of the present work. To this goal, hot gas side heat flux management of an annular clustered plug nozzle is numerically investigated to evaluate the technical challenges that this kind of nozzle poses and the possible solutions. The analyses are conducted on a 10-tons class LOX/CH4 reference liquid rocket engine for upper-stage applications for which CFD simulations of the hot gas flow are available and can be used as input for the cooling system analysis [4]. In the present study, conjugate heat transfer simulations are carried out to assess the solid walls and the coolant behaviors. Different cooling system designs are proposed and tested to find a possible solution able to limit the modules and spike wall temperature in a range that allows feasible engine operations. The analysis is carried out with a validated approach developed by the Authors. Among the different design strategies, the module shape, propellant distribution in the different cooling segments, as well as channels cross-section, aspect-ratio and helix angle will be explored to find an optimal theoretical solution.

References

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