Numerical and experimental evaluation of the performance of a cavitating valve for the control of oxidizer flow in a hybrid rocket engine

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Abstract

Numerical simulation of cavitating flow inside a control valve was successfully performed by the Institute of Aerospace Engineering, Brno University of Technology in support of a valve development program by Moog Bradford. These activities are performed in course of the FP7 European Commission funded project SPARTAN (SPAce exploration Research for Throttleable Advanced eNgine). The objective of the project is to develop crucial technology for extra-terrestrial planet exploration: deeply-throttleable rocket engine enabling planetary soft and precision landing. The SPARTAN project exploits hybrid rocket engine technology for this purpose. The project is coordinated by Thales Alenia Space Italia S.p.A. and incorporates both commercial and academic partners from seven European countries.

The valve of interest is used to control liquid oxidizer flow to a hybrid rocket engine. Not only does it have to deal with a broad range of operating conditions, but the key challenge is to achieve prompt and accurate mass flow control in the presence of rapidly changing conditions downstream of the valve imposed by operation of the rocket engine. The valve is therefore deliberately designed to feature cavitation, preventing combustion-induced pressure oscillations from propagating upstream. Consequently, the mass flow response of the valve in cavitating mode is independent of downstream conditions – a highly desirable characteristic for the given application.

Based on literature review the cavitating venturi was identified as the most promising valve design and was promoted into test phase. A breadboard model featuring a modular nozzle section and exchangeable pintle was developed. A test rig enabling evaluation of the valve with water as a reference medium was designed specifically for this project. The test rig can subject the valve to the full operating pressure and generate the full scale mass flow. It allows pressure, mass flow, and valve actuation force to be measured directly. This enables full characterization of the valve in terms of pressure drop needed for the valve to operate in fully cavitating mode. Furthermore the required force to be generated by the valve actuator is assessed. Two different nozzles and two different pintles have been manufactured and tested based on theoretical and practical considerations.

Following the initial development tests, the two original nozzle designs were found to provide unsatisfactory performance with respect to pressure drop needed for the valve operation in fully cavitating mode. To facilitate the redesign process, extensive numerical parametric study was performed to explore the available design space, optimizing the geometric design of the valve within the constraints imposed by an acceptable valve envelope. Forces acting on the pintle are extracted to assist in the selection of an appropriate actuator. Quantitative and qualitative assessment and

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comparison of performance of the original and optimized valve design is performed in the scope of this paper, both by numerical as well as experimental means.

The numerical simulation is based on Ansys Fluent 14 solver and Ansys ICEM mesh-generation tool. The flow is modelled inside an axi-symmetrical domain to enable rapid evaluation of numerous geometrical variants. Schnerr-Sauer cavitation formulation is deployed in combination with k-epsilon turbulence modelling. Numerical code setup is validated against acquired experimental data and other published experimental results. Good agreement is found between the numerical data and experiment. The present results have been confirmed by independent study at University of Padova, Italy.