Paper ID: 8898

MATERIALS AND STRUCTURES SYMPOSIUM (C2)
Space Structures I - Development and Verification (Space Vehicles and Components) (1)

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ADVANCED STRUCTURAL ANALYSIS OF FLEX NOZZLE FOR SOLID ROCKET BOOSTER

Abstract

Most world class Solid Rocket Boosters use flexible nozzle employing flex bearing, for controlling the thrust vector. This vectoring technology is essential to meet the control demand during the initial phase of the trajectory of advanced launch vehicles with higher payload capability. The major challenge in the structural design of the flex nozzle is to design the flex bearing to meet the high vectoring capability with minimal envelope and actuator load requirement. The Nozzle throat opening required for the strap-on Solid rocket Boosters for gsLVM3 based on ballistic studies is 4.5 times bigger than any flex nozzle developed by ISRO. Additionally, considering high vectoring requirement (8 deg.) for this stage, this flex nozzle design cannot take advantage of the flex nozzles previously developed in-house.

The design formulas employed for the configuration of flex bearing were found to have inherent limitations and cannot be used for the design of flex bearings with high vectoring capability. This puts a huge responsibility and challenge on the structural analysis. Conventionally, an axisymmetric element with non-axisymmetric loading is the approach used to analyse the flex nozzle using finite elements both in-house and elsewhere. However, this procedure gives highly inaccurate results while used for large vectoring conditions. When 3D models are used with hyperelastic material property (for simulating the elastomer pads in the flex bearing) the problem becomes hard to converge.

An elaborate study was carried to frame the modeling methodology that would follow the recommended features, yet is free from convergence related issues. As a result, a novel set of modeling features were tailored and incorporated to solve the 3D problem with geometric, material and contact non-linearities. An unprecedented analytical approach to interpret the nodal solutions from finite elements in terms of parameters of interest (for flex nozzle) was developed. Using this, the angle of vectoring (both in the actuator and resultant planes), inclination of the actuators and location of the effective pivot point are estimated. To reduce the complete dependence on FEA, a mathematical model was developed to estimate the compressive hoop strains in the shims, which is more critical for the design of flex bearing. This mathematical model was generated using regression analysis (linear least squares using Q-R decomposition) of the data extracted from flex seal testing. Both the output data from FE analysis and mathematical model is found to have reasonably good match with the test results.