National Aeronautics and Space Administration

NASA Engineering and Safety Center Technical Bulletin No. 14-02

Aerodynamic Reaction Control System (RCS) Orientation and Jet Interaction (JI) Model Validation

Careful consideration should be given to placement and orientation of RCS jet thrusters on hypersonic entry vehicles in order to minimize adverse RCS JI. Modern state-of-the-art computational fluid dynamics (CFD) tools should be able to predict the RCS effectiveness and JI accurately when coupled with verification and validation studies, including the use of appropriately designed experimental wind tunnel testing.

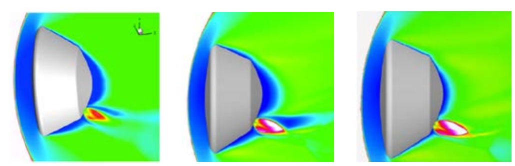
Applicability

Development of experimental techniques and CFD predictive capabilities to determine proper placement and orientation of RCS jet thrusters on hypersonic entry vehicles to minimize adverse RCS JI.

Historical JI Prediction Issues

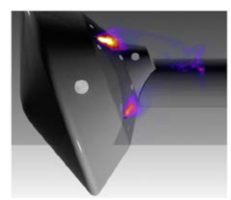
Historically, the prediction of hypersonic entry RCS effectiveness and associated JIs with surrounding flowfields has been a challenging CFD problem. For example, during the bank maneuvers of the first space shuttle orbiter reentry, the rolling moment that occurred when the forward yaw thrusters were fired was less than expected, resulting in greater RCS fuel usage than anticipated. The cause of this discrepancy was attributed to improper scaling of wind tunnel derived RCS interaction correlations to the flight condition.[1] In a more recent example, CFD analyses of the RCS JI on the Mars Phoenix entry vehicle indicated the possibility of uncontrollable adverse JI, enough so that the project chose to not use the RCS during portions of the entry phase, increasing the landing footprint and the overall mission risk.[2]

The Mars Science Laboratory (MSL) mission was plagued by similar issues in the early design phases. The entry vehicle aerodynamics was based on a combination of experimental results, CFD calculations, and comparisons with estimates of flight aerodynamics from previous Mars missions. Estimates of the RCS effectiveness and RCS JI with the aftbody flow-field were originally developed based primarily on CFD calculations, indicating the potential for large, undesirable RCS JI. Recommendations were made to change the RCS jet locations and orientations in an attempt to reduce plume impingement on the spacecraft, jet-to-jet plume interactions, and to minimize undesirable interaction torques. Given the uncertainties associated with the wake flow predictive capabilities of current CFD codes, a wind tunnel test was designed and executed in the Langley Research Center 31-Inch Mach 10 Wind Tunnel to provide experimental data for the new MSL RCS thruster configuration design.[3] This data served to provide validation results specific to MSL and, at the same time, the experimental test techniques developed would potentially be of benefit to other projects and programs employing blunt body entry aeroshell designs with aftbody RCS jet thrusters (e.g., Orion/Multi-Purpose Crew Vehicle or commercial crew vehicle designs). Additional CFD calculations were made on the new thruster configuration to assess effects of the aerodynamics and RCS interactions.[4] Results indicated generally good agreement between the experimental data and CFD predictions of the RCS JI. This, along with recommended conservative uncertainty values for RCS JI, provided an appropriate degree of confidence to the MSL Project on the adequacy of the new thruster configuration and overall robustness of the entry flight control system.



Comparison of MSL Aero/RCS interaction using 3 different CFD codes.

MSL model in LaRC 31-Inch Mach 10 Wind Tunnel.



Experimental flow image of MSL RCS jets.

Conclusions and Guidance

Appropriate consideration must be given to RCS thruster locations and orientations to minimize impingements and interactions. Modern CFD tools should be used in conjunction with well-designed experimental testing early in development to accurately predict the RCS JI and overall control effectiveness.

References

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2. Dyakonov, A. A., Glass, C. E., Desai, P. N., and Van Norman, J. W.: "Analysis of Effectiveness of Phoenix Reaction Control System," AIAA Paper 2008-7220.

3. NASA/TM-2013-218023, NESC-RP-10-00613 Mars Science Laboratory (MSL) Reaction Control System (RCS) Jet Interactions (JI) Testing and Analysis, July 2013

4. Schoenenberger, M., Van Norman, J. V., Rhode, M., and Paulson, J.: "Characterization of Aerodynamic Interactions with the Mars Science Laboratory Reaction Control System Using Computation and Experiment," AIAA Paper 2013-097.

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