DESIGN CHOICE CONSIDERATIONS FOR VEHICLES UTILIZING SUPERSONIC RETROPROPULSION

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The entry, descent, and landing (EDL) systems for the United States' six successful landings on Mars and the 2011 Mars Science Laboratory (MSL) rely heavily on extensions of technology developed for the Viking missions of the mid 1970s.[i] To achieve NASA's long-term exploration goals at Mars, including human exploration, technologies are needed that enable substantial improvements in landed mass and landing accuracy as compared to the expected performance of MSL. Supersonic deceleration has been identified as a critical deficiency in extending Viking-heritage technologies to the high mass, high ballistic coefficient systems required to achieve these goals.[i,ii] As the development and qualification of significantly larger supersonic parachutes is not a viable path forward to increase landed mass capability to 10+ metric tons, alternative approaches must be developed.[i]

Supersonic retropropulsion (SRP), or the use of retropropulsive thrust while an entry vehicle is traveling at supersonic conditions, is one such alternative approach.[i,ii,iii] Work has been completed to define mission scales and relevant operating conditions for which SRP may be beneficial.[iv] As part of one study, the propulsion system was sized to simultaneously minimize the mass and volume of a generic multiple nozzle propulsion system in order to achieve a designated subsonic condition (altitude and velocity).[iv] In contrast, without accounting for the mass and volume of the propulsion system, NASA's EDL Systems Analysis study[ii] minimized the propellant mass required for propulsive deceleration with solutions resulting in a maximum vehicle thrust-to-weight three times greater than that derived from consideration of both propulsion system mass and volume. SRP aerodynamic effects were not considered in the definition of either configuration. Continued work is establishing a minimum fidelity requirement on SRP aerodynamics models for systems analysis in support of developing a capability to evaluate and compare a number of SRP concepts against one another and also against alternative decelerator concepts. How these SRP concepts are to be derived and how much consideration should be given to SRP aerodynamics in defining the configurations remain open questions.

Significant effort in the wind tunnel testing of small supersonic retropropulsion models took place in the 1960s and early 1970s, though the combined data is not of sufficient breadth to draw detailed conclusions on the effects of utilizing SRP within a full-scale EDL architecture. The aerodynamic-propulsive interaction arising from SRP significantly alters the static aerodynamic characteristics of the vehicle.[iii] However, no work has yet attempted to develop an SRP configuration targeting an advantageous relationship between the SRP aerodynamic-propulsive interaction and the system performance of the powered descent vehicle.

The planned outcome of the work to be presented is a point design of a flight-relevant SRP configuration that considers the sensitivities of parameters governing SRP aerodynamics to variation in physical quantities related to vehicle configuration and system performance. Momentum transfer within the flowfield governs the change in the surface pressure distribution of the vehicle, and accordingly, governs the integrated change in the vehicle's static aerodynamic characteristics. Parameters governing SRP aerodynamics can be identified using both experimental trends in the literature and analytical statements of momentum transfer within the SRP flowfield. These analytical statments are specific to highly under-expanded jet flows, contact surfaces, and blunted bodies in supersonic flows.

Experimental efforts have determined that the flowfield structure and the flowfield stability for SRP are highly dependent on the retropropulsion configuration and the strength of the retropropulsion exhaust flow, relative to the strength of the freestream flow. For a fixed set of freestream conditions, thrust coefficient is a force coefficient based directly on the ideal retropropulsive nozzle thrust. As a limited example of parameter identification, the expression of thrust coefficient based on ideal nozzle thrust can be translated into an expression that is dependent on the ratio the total pressure of the exhaust flow to the total pressure of the freestream flow, the freestream Mach number, the nozzle expansion ratio, composition of the freestream and exhaust flows, and the ratio of the nozzle exit area to the reference area of the vehicle. These parameters are directly related to the operating conditions, propulsion system composition, nozzle geometry, vehicle configuration, and required propulsion system performance, all of which can be considered to be design choices.

Investigation into the sensitivities of such parameters to variation in physical quantities related to vehicle configuration and system performance will allow for conclusions to be drawn about the impact of design choices related to system performance on the change in the vehicle's static aerodynamic characteristics. An initial understanding of the significance of powered descent vehicle configuration on the change in the vehicle's static aerodynamic characteristics arising from SRP and the relationship to other vehicle performance-based metrics that traditionally determine vehicle configuration is necessary for identification of the types of configurations to be prioritized for SRP concept development.

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[i] Braun, R. D., and Manning, R. M., "Mars Exploration Entry, Decent and Landing Challenges," *Journal of Spacecraft and Rockets,* Vol. 44, No. 2, 2007, pp. 310-323.
[ii] Zang, T. A., and Tahmasebi, F., "Entry, Descent and Landing Systems Analysis Study: Phase 1 Report," NASA TM 2010-216720, July 2010.
[iii] Korzun, A. M., Braun, R. D., and Cruz, J. R., "Survey of Supersonic Retropropulsion Technology for Mars Entry, Descent, and Landing," *Journal of Spacecraft and Rockets*, Vol. 46, No. 5, 2009, pp. 929-937.
[iv] Korzun, A. M., and Braun, R. D., "Performance Characterization of Supersonic Retropropulsion for High-Mass Mars Entry Systems," *Journal of Spacecraft and Rockets*, Vol. 47, No. 5, 2010, pp. 836-848.