DEVELOPMENT OF SUPERSONIC RETROPROPULSION FOR A MARS PRECURSOR MISSION.

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Introduction: NASA's goal of landing humans on Mars will require new entry, descent, and landing (EDL) technologies that address a well-known challenge: a thin atmosphere that provides less aerodynamic deceleration than Earth's atmosphere. The state of the art EDL system, Mars Science Laboratory (MSL), has nearly the largest ballistic coefficient for which aerodynamic drag is sufficient to decelerate to supersonic parachute conditions near Mach 2. Recent studies[1,2] have concluded that supersonic aerodynamic decelerators by themselves, such as advanced parachutes and inflatable aerodynamic decelerators (IADs), are less effective or insufficient to decelerate larger robotic (2-5 metric tons) and human scale payloads (10s of mt).

Supersonic Retropropulsion (SRP), or the use of retrorockets at supersonic conditions to augment deceleration, is a promising EDL technology for future Mars missions[1-4]. However, open issues still exist related to entry vehicle stability and controllability, engine ignition and operation against a supersonic freestream, and analytical tools to predict SRP performance. This paper, in response to Challenge Area 2 (Safe and Accurate Landing Capabilities), summarizes the current state of SRP and recommends tasks to prepare for a Mars robotic precursor mission in the 2018-2024 timeframe prior to human missions.

State of the Art and Recent Work: Initial development of SRP as an EDL technology was completed through exploratory investigations in the 1960s and 1970s. This early work focused on subscale wind tunnel testing for the development of an all-propulsive Mars lander configuration[3]. The selection and further development of a supersonic parachute for the Viking landers (and all subsequent robotic Mars missions) ended SRP development efforts at the time.

The knowledge base for SRP has recently expanded since interest in high-mass missions to Mars resurfaced in the mid-2000s[3]. The potential for SRP to substantially increase Mars payload capability resulted in SRP investment through NASA's EDL Systems Analysis[1,2] team (EDL-SA) and EDL Technology Development Project[4] (EDL-TDP). Both projects advanced the state-of-the-art for SRP in systems analysis, computational fluid dynamics (CFD), and experimental testing. Achievements in these areas represent a preliminary step in addressing the challenges faced in maturing SRP from its current status to a technology with sufficient performance and acceptable risk for Mars EDL.

EDL-SA architecture level studies[1,2] showed the advantages of SRP for both robotic and human scale missions. The primary advantages of SRP are: (1) a decrease in complexity by reducing the number of aerodynamic decelerators and vehicle transitions, (2) the use of smaller aerodynamic decelerators which eases packaging, deployment, and separation constraints, and (3) increases in timeline and control authority for descent and precision landing with hazard detection and avoidance.

Two EDL-SA architectures[2] were developed for a precursor mission with a 7-mt arrival mass, the maximum for a Delta IV Heavy launch vehicle (Figure 1). The concepts included an 8-m diameter hypersonic IAD (HIAD) and SRP to deliver a 3.5 mt payload to 0 km elevation. When modified to use SubRP (Mach = 0.8), the required HIAD diameter is 16 m and the payload capability dropped by almost 1 mt for the same landing elevation. Also, the descent time decreased from 52 s with SRP to 32 s with SubRP. The arguments for SRP are even more compelling for human scale missions[1]. Mars precursor missions that pair a HIAD and SRP are proposed for 2018-2024 in preparation for scaling up to human payloads.[5]

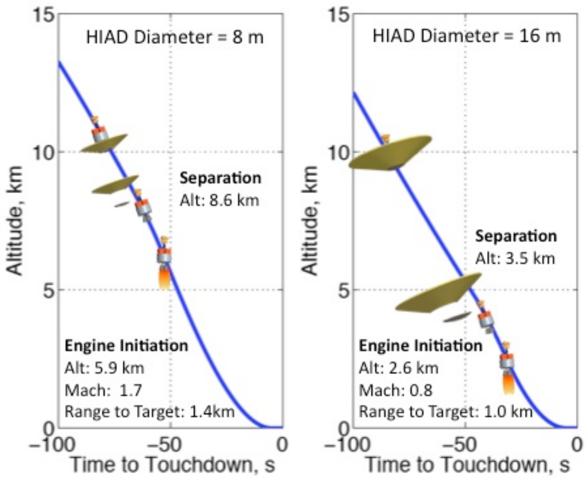

Figure 1. Altitude vs. time to touchdown for HIAD+SRP (left) and HIAD+SubRP (right)

Technical Challenges: A number of technical areas should be addressed with testing and analysis to show that SRP is viable for a Mars robotic precursor mission in 2018-2024.

Engine ignition and flow establishment in a supersonic counter-flow begins the SRP phase. No known tests have been conducted to show engine start-up and operation against a supersonic flow, however small the atmospheric pressure, as is the case at Mars. Ground tests with appropriate engines in an opposing freestream are recommended to retire concerns about engine performance during start-up. Possible test platforms will be examined for their ability to deliver the proper engine initiation conditions.

Aerodynamics and control during SRP can be affected by engine plume interaction with the external flow and the entry vehicle. EDL-TDP recently completed wind tunnel and CFD[6] modeling efforts to understand the accuracy of CFD modeling of these interactions (Figure 2). Further ground testing with realistic vehicle configurations is recommended to determine plume interaction for an eventual flight vehicle. NASA's existing wind tunnels and CFD codes can be used to accomplish this goal.

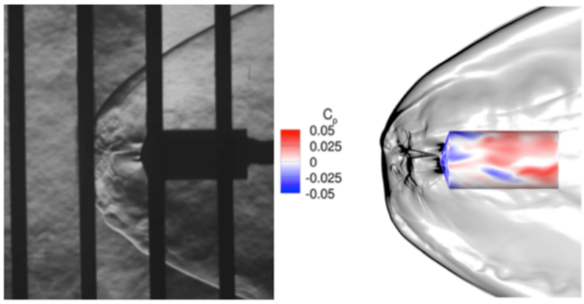

Figure 2. SRP Wind Tunnel Test (left) and CFD (right) for a Single Jet Configuration[6]

Convective and radiative heating due to SRP engine plume exhaust is expected during deceleration and landing. Techniques appropriate for analysis of ascent vehicles can be applied here. A wind tunnel test of base heating is recommended, as is a test for radiative heating from a live fire engine.

Landing site alteration is a challenge for a retrorocket on an unprepared surface. This aspect is not specific to SRP, nor is it specific to Mars. Landing strategies and SRP design choices will be evaluated to determine a low risk approach to landing.

Flight demonstration of SRP at Earth is recommended to demonstrate maturity of the technology. Several levels of demonstration, in order of increasing complexity, are recommended[4] that range from a passively stabilized sounding rocket flight to a closed-loop controlled system, scaled to simulate flight at Mars. Several test platforms will be evaluated.

Recommendations: In order to prepare SRP for a Mars robotic demonstration mission in the 2018-2024 timeframe, the following tasks are recommended and will be further defined in the paper:

1. Develop the SRP requirements and constraints for a robotic Mars precursor mission using an aerodynamic decelerator[5] paired with SRP.
2. Demonstrate engine startup and operation in a supersonic or suitable environment using prototype SRP engines. The engines should be capable of throttling and scalable to a robotic Mars precursor mission.
3. Test sub-scale models of Mars SRP configurations in supersonic wind tunnels to characterize the aerodynamics at relevant thrust levels. The test data will be used to anchor and validate CFD models to be used for flight predictions.
4. Demonstrate the ability of CFD to predict SRP aerodynamics through comparison to wind tunnel data. These exercises will build confidence in extending CFD to flight conditions.
5. Develop all required SRP models, including uncertainties, to support EDL analyses of an Earth flight test and a Mars precursor mission.
6. Conduct instrumented Earth-atmosphere tests demonstrating SRP with a representative configuration, and show as-predicted performance. Analytical predictions will be compared to in-flight measurements. These tests will reduce risks associated with scaling SRP systems for Mars.

References:

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