DEMONSTRATION OF HUMAN-SCALABLE EDL SYSTEMS WITH MARS SURFACE MEASUREMENTS.

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Challenge Area Summary: Solving the critical Entry, Descent, and Landing (EDL) problem for human-scale Mars missions [1] requires an extensive, long-duration approach to reconcile the many areas of concern ranging from performance, through safety and reliability, while also considering the ability to test and demonstrate these technologies. Mars presents a unique EDL challenge with its atmosphere – too much to ignore, and not enough to allow reasonable sized aerodynamic decelerators [2]. Through a blend of an inflatable aeroshell transitioning to supersonic retropropulsion followed by subsonic terminal descent and landing, our mission concept provides a strategy for safely delivering high mass surface payloads to Mars (responds to Challenge Area 2, Topic 8). The essential concept definition efforts have been completed through the NASA Office of Chief Engineer sponsored high fidelity systems analysis and concept design efforts for a human-scale feed forward demonstration mission [3].

Demonstrated Technologies: Large-scale hypersonic inflatable aerodynamic decelerators (HIADs) and supersonic retropropulsion (SRP) are the primary technologies demonstrated in our mission concept. By increasing the size of the entry aerodynamic decelerator beyond the limitations imposed by launch vehicle fairings, a sufficiently large amount of drag can be generated to allow deceleration high enough in the atmosphere of Mars to allow for reduced environmental loads along with the ability to access higher elevations and/or increase the landed mass. Previous studies have shown that aerodynamic decelerators with subsonic retropropulsion provide an inadequate EDL solution for human-scale [1] or human precursor scale [3] payloads, to access areas of interest. For human-scale missions [4], HIADs coupled with SRP provided the lowest entry mass solution (by more than 20 metric tons). Our mission provides an opportunity to demonstrate the two technologies deemed most critical for human-scale missions – HIADs and SRP.

Extensibility to Human-Scale Missions: Technologies selected for demonstration via our mission concept have relevance across a wide spectrum of EDL mission sets. Analyses have shown relevance at human and robotic mission scales. Current and past technology investments have illustrated the relevance and performance capabilities of these technologies. Further, analytical tools have been matured to allow for assessment across all mission classes [3], [4].

HIADs have been manufactured, tested, and demonstrated at a scale consistent with the majority of NASA's Science Mission Directorate (SMD) Mars missions (e. g., Pathfinder, MER, Phoenix, etc.) The demonstrated capabilities include the inflatable structure and its ability to withstand the aerodynamic loading, and the Thermal Protection System (TPS) suitable for heat rates up to 25 W/cm^2 [5]. Development results indicate there is a realistic path to fabrication of human-scale decelerators.

SRP has been previously investigated, most recently within NASA's EDL Project [6]. Ground testing of simplified entry vehicle shapes with cold-gas jets coupled with Computational Fluid Dynamics (CFD) models to analytically predict the fluid dynamic interactions and effect on entry vehicle aerodynamics were recently concluded. Future ground testing will improve and extend the analytical approaches enabling high fidelity predictions of SRP performance. Packaging and integration assessments have been completed illustrating how thrusters of sufficient performance could be incorporated into a lander configuration [3]. Development results indicate there is a realistic path to fabrication of human-scale SRP.

Mission Implementation: Launching on an Atlas V-401 on 15 May 2018 with a maximum C3 of 12.5 km^2/s^2, the 1750 kg launch mass provides a 30% mass margin. A 7.5 month cruise with a Type I trajectory allows for a direct entry over a wide range of latitudes of interest. By using a 6 m diameter HIAD, with an entry mass of 1500 kg, low entry environmental levels are experienced with a maximum peak heat rate of about 15 W/cm^2 (well within the capabilities of the current family of flexible insulating TPS) and a maximum deceleration of 6 g's. Transition to SRP initiates at Mach 2.5 at an altitude of about 5 km, with ejection of the rigid nose portion of the entry aeroshell followed by extraction and engine ignition. The difference in effective ballistic coefficients (defined as a ratio of decelerations) allows the decelerating thrusting lander to separate axially from the rest of the entry system. The lander continues its deceleration incorporating a gravity turn to achieve the final landing conditions. A traditional terminal descent is envisioned. Additional EDL demonstrations can be incorporated as desired (including use of a MEDLI type instrumentation suite, Range Trigger Guidance approach, flying the hypersonic vehicle at angle of attack to generate lift and control the entry trajectory, inclusion of Autonomous Landing and Hazard Avoidance technologies, etc.).

A 500 kg (dry) surface element is planned as the primary payload delivered to the surface of Mars. Conceptual studies have concluded this legged lander can accommodate a wide range of sensors and measurements applicable to human exploration. Key measurements included as part of the lander concept study were meteorological, dust toxicity, atmospheric conductivity (e-fields), electrical conductivity of surface including charge on dust, surface radiation, neutrons including directionality, and local mineral and ice resource. If desired, a more capable lander including surface ISRU or surface fission power demonstrations could be integrated with only minor adjustments to the HIAD and SRP EDL system [3]. Landed surface life is dependent on the planned surface measurements.

Mission Flexibility: Flexibility provided by this mission concept extends across the entire mission space, including Mars opportunities (can be accommodated in the 2020 or 2022 opportunites without a launch vehicle change). Payload/lander mass increases can be accommodated by increasing the HIAD inflated diameter, while not compromising the overall design maturity of the concept. The throttleable SRP system can also accommodate payload/lander mass increases, however, the limit does exist as a function of the number of retro engines. In addition, the payload has complete flexibility, whether it is a legged lander, a rover, or an airplane, the basic EDL capabilities of this mission can still be demonstrated. A final area of flexibility available is orbit insertion. If it is deemed desirable to first demonstrate an orbital insertion followed by an entry from orbit, then that can be easily accommodated using multiple HIADs with the first HIAD demonstrating an Aerocapture maneuver and the second HIAD demonstrating the EDL (including SRP) capabilities.

Technology Maturity: HIADs and SRP are the primary technologies demonstrated in this mission.

HIADs: HIADs have undergone extensive development through the Aeronautics Research Mission Directorate and from the Office of Chief Technologist. Inflatable Reentry Vehicle Experiment II (IRVE-II) flew in August 2009 demonstrating the critical exo-atmospheric inflation followed by stable decelerating flight during the suborbital flight test. IRVE-3 is in the final Integration and Testing phase with its launch slated for summer 2012. IRVE-3 will demonstrate a doubling of the ballistic coefficient with an order of magnitude increase in heat rate (~18 to 20 W/cm^2) with a higher deceleration. Additional developmental efforts include manufacturing of, and successful static load testing of, a 6 m diameter HIAD (Figure 1). Aero load testing at the ARC National Full-scale Aerodynamics Complex (NFAC) will occur in June 2012. Extensive developmental testing of flexible insulating TPS has been performed over the previous 4 years [5]. Testing includes multiple arcjet tests to investigate stagnation, shear, and age effects. Multiple material systems have been investigated with the Nextel/Pyrogel material system being baselined. HIADs have been demonstrated to be a relatively mature technology ready for mission infusion.

Figure 1: 6-m HIAD being readied for load and model correlation testing-ARC-NFAC (May/June 2012)

SRP: Extensive wind tunnel testing with computational assessments of SRP have been made [6]. Testing has been performed to investigate the sensitivity of jet strength, placement, quantity, and Mach number. Computational results have been blended with trajectory simulations to illustrate the overall performance and capabilities. Finally, concerns regarding engine ignition and operation against a supersonic flow will be addressed with ground testing.

Concluding Remarks: Early flight demonstration for the critical human-scale EDL technologies, is an essential step. Our mission concept provides a straightforward approach to satisfying this need.

References:

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