Mars Entry, Descent, and Landing (EDL): Considerations for Crewed Landing. R. R. Sostaric[1], C. C. Campbell[2]; [1]NASA Johnson Space Center, Mailcode: EG5, 2101 NASA Parkway, Houston, TX 77058, ronald.r.sostaric@nasa.gov, [2]NASA Johnson Space Center, Mailcode: EG3, 2101 NASA Parkway, Houston, TX 77058, charles.c.campbell@nasa.gov.

Introduction: Human missions to Mars require landing multiple spacecraft carrying usable payload masses on the order of 20-40 metric tons (MT).[1] Previous studies have shown that in order to land 40 MT of payload, masses of 80-110 MT are required in Mars orbit prior to Entry, Descent, and Landing (EDL).[2] Precision landing is critical, as multiple mission elements will be required for mission success. The thin Martian atmosphere creates additional challenges, requiring a large drag area during entry. Additionally, aerocapture has been shown to be of mass benefit over chemical propulsive capture. This requires thermal protection which is capable of enduring two large heat pulses (aerocapture and entry) which may have a long time interval in between (possibly on the order of months in the event of dust storms).

Human EDL on Mars has additional challenges which may be unique or of lower priority for Mars robotic landings. These constraints, in addition to those above, will likely drive the choice of EDL architecture for human missions. The constraints include transition from entry to descent and landing, load magnitude and direction, reliability, timing of large attitude maneuvers (such as bank reversals or pitch-up during descent), and hazard detection and avoidance (HDA) related maneuvering.

Considerations for Human Mars EDL: The following discusses some of these considerations for human Mars EDL architecture design that may be considered unique from robotic missions.

Loads. Mission concepts show that the crew will be significantly de-conditioned due to being in zero-G during a six month Earth-to-Mars transfer.[1] Total G-limits under the “Limit for Return to Earth” heading is 4 G’s in the “eyeballs in” and “eyeballs out” directions for extended periods (about 100 sec and longer).[3] Though the exact crew loads limit criteria is not defined for Mars EDL this is a reasonable place holder due to similar length ISS missions and subsequent crew return. Short durations allow for exceedance of the sustained 4 G limit. In other axes, the sustained crewed load limit is much more restrictive—1 G in the “eyeballs down” and side directions, and 0.5 G in the “eyeballs up” direction.

Significant loading during EDL is encountered both during entry and powered descent. The preferred orientation is through the chest. However, depending on the orientation of the crew in the entry vehicle and the thrust axis of the descent stage, it may be required to re-orient the crew during the transition from entry to powered descent in order to meet load constraints. If required, a re-orientation would be a significant design driver for the internal volume of the vehicle. An additional consideration is crew disorientation that may occur as a result of the vehicle transition to the landing configuration. Since this re-orientation occurs prior to or at the start of powered descent, significant attention to the design will be necessary to avoid excessive disorientation right before this critical phase of flight.

Transition. Current concepts show that separating a large (~50 MT) descent system from an 10 m x 30 m rigid aeroshell, or 23 m hypersonic inflatable aerodynamic decelerator (HIAD) at supersonic conditions is required.[2] This critical flight phase occurs at an altitude of a few kilometers (km). Transition concepts are not sufficiently mature and work is being undertaken to develop them in greater detail. What is clear is that the transition design may, or is even likely to, drive the choice of EDL architecture.

Reliability. Reliability and safety for human missions can drive architecture selection and have a large impact on total implementation costs. Complex capabilities with multi-faceted failure modes or systems needing lengthy and costly flight test programs to demonstrate failure mode robustness and design qualification should be less favored in efforts advertising an ultimate human mission. Emphasis on system complexity characterization and forward-leaning planning for reliability evaluation should be included as part of technology developments efforts. Areas of particular focus along these lines could include vehicle transitions, as mentioned earlier, as well as identification of full scale entry vehicle systems that are unlikely to be sufficiently qualified and certified in ground based testing. Failing to address this question adequately can lead to a mature design for non-human systems that is untenable for human missions due to implementation cost and schedule requirements for a human system.

Precision Landing. Mission scenarios show that a cargo mission will be placed on the surface prior to the crewed landing. Precision landing is an important consideration for any multiple asset mission design. The crew will have to be able to land near the pre-placed asset(s), so mobility capability must be equal to or greater than the expected landing precision. Active entry guidance with sufficient trajectory control capability will be necessary to reduce propellant usage during terminal descent to achieve the precise landings.

Local precision is needed as well to avoid hitting the pre-placed assets as well as any natural hazards such as rocks, slopes, or craters. Approach trajectories must be designed to minimize risk to pre-placed assets or crews in the event of failure during EDL. The predicted impact location of any aeroshell or stage intended to be jettisoned must also be well away from ground assets.

The Autonomous Landing and Hazard Avoidance Technology Project (ALHAT) is developing a suite of sensors and algorithms, along with integrated GN&C and avionics, to perform the precision landing and the hazard detection and avoidance function.[6]

Powered Descent. Previous studies have shown that supersonic engine start-up will be required to support supersonic retropropulsion.[2] Maximum descent loads may be as high as 3 G's. Apollo lunar landings utilized a significantly different descent and landing approach than expected for Mars landing. The timeline for Mars is very compressed, as shown in Fig 1.[245]

In Apollo, the high gate marked a switch in guidance mode to account for the crew actively receiving visual information about the landing area and making frequent adjustments to the landing target. This phase began with about 205 sec remaining to touchdown. Mars simulation results show powered descent beginning with only about 60 sec to touchdown remaining, at a supersonic flow condition. The compressed timeline means that critical events and decisions will have to be made more quickly, and high quality information about the landing area will be even more critical.

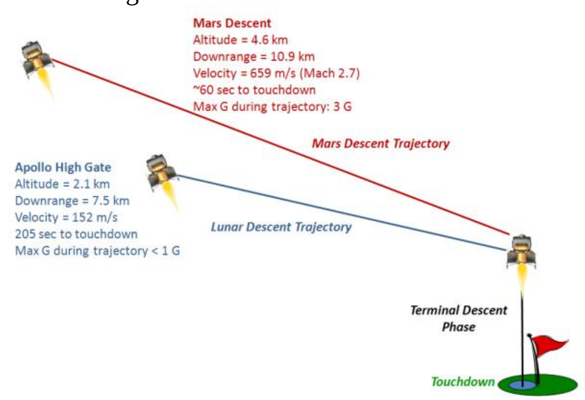

Figure 1. Descent Trajectory Comparison

Hazard Detection and Avoidance. The hazard detection function can be partially or totally completed prior to the mission, via remote sensing, landing site selection, or landing area modification. Real time hazard detection may be needed for additional risk mitigation. During Apollo, crew members performed the real-time hazard detection function by looking out a window with a down range view of the landing area. The ALHAT project has developed a flash lidar suitable for mapping 3-D hazard fields for real-time hazard detection. The flash lidar is designed to be capable of detecting 30 cm hazards at a distance of 1 km.[6]

Hazard avoidance requires a redesignation decision with enough time, altitude, and propellant for a divert maneuver, as well as adequate knowledge of the landing area. The redesignation location is limited to the size of the landing area, which is defined as the area about which adequate hazard information is known. Figure 2 depicts the hazard avoidance strategy. Enough divert capability must be budgeted to respond to updated hazard information when it is expected to become available. As the vehicle approaches the landing site, at some point it will no longer have enough divert capability to reach all points in the divert area. The divert capability will continue to decrease as the vehicle gets closer to landing. A final, constant vertical velocity phase with minimal or zero horizontal velocity is employed just prior to touchdown.

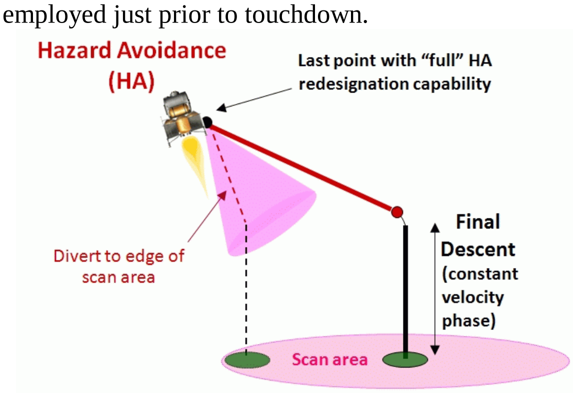

Figure 2. Hazard Avoidance Strategy

Summary: Human missions to Mars will require EDL technologies and capabilities beyond those required for heavy robotic missions. Developing and testing these new approaches while pursuing robotic missions will prevent future delays and inadequacies when eventual human Mars designs become reality.

References: [1] Human Exploration of Mars Design Reference Architecture 5.0, NASA-SP-2009-566 (2009). [2] Entry, Descent, and Landing Systems Analysis Study: Phase 1 Report, NASA/TM-2010-216720 (2010). [3] Constellation Program Human-Systems Integration Requirements, CxP 70024, Baseline (2006). [4] Bennett, F.V. (1970) Lunar Descent and Ascent Trajectories, MSC Internal Note No 70-FM-80. [5] Apollo 12 Mission Report, MSC-01855 (1970). [6] Epp, C.D., Robertson, E.A., Brady, T., Autonomous Landing and Hazard Avoidance Technology (ALHAT), *IEEE* (2008). [7] Braun, R.D., Manning, R.M., Mars Exploration Entry, Descent, and Landing Challenges, *AIAA* (2006).