ENTRY, DESCENT, AND LANDING ANALYSIS OF LOW MASS MARTIAN PROBE FOR SURFACE CLIMATE NETWORK. B. Maryatt[1], S. D'Souza[1], B. Tackett[1,2], V. Hawke[1,3], M. Herreras Martinez[1,4]. [1]NASA Ames Research Center, Moffett Field, CA, [2]Analytical Mechanics Associates, Hampton, VA, [3]Science and Technology Corporation, Hampton, VA, [4]Axient, Arlington, VA.

Introduction: Aeolus is a mission to provide the first direct measurements of Martian atmospheric wind speeds and correlate them with thermal and compositional data to bring together a complete systematic description for the global energy balance and climate cycles of Mars. Objective A of the Mars Exploration Program Analysis Group (MEPAG) Goal II cites a Science Investigation Area to develop a network of surface landers to provide global, diurnal and synoptic coverage of the near-surface environment to characterize present Mars climate [1]. Aeolus will characterize the present Martian global climate system via an orbiter element and a novel surface network element. A series of low mass, low power probes will be distributed across the Martian surface and measure pressure, sky opacity, temperature, wind speed, water vapor and other trace gases.

Low Mass Landed Probes: Low mass and power electrical systems designed to operate in extreme cold and daily thermal cycling for one Martian year could facilitate lower cost, Class-D science probes. Aeolus is targeting a total per-probe mass of <5 kg. Recent advances in nanofabrication of chip-scale sensors that are highly robust to temperature and shock, combined with a novel packaging concept (the deployable sensor probe [2]) originally developed by the Aerospace Corp., for the first time enables a Mars surface climate sensor network. These probes are folded flat during transit to Mars and automatically deploy into the final reentry configuration once released from the orbiter. The capability to fold for stowage significantly increases the probe quantity carried by the orbiter.

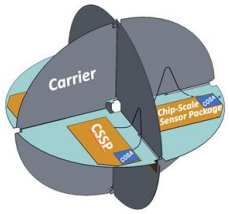

Fig. 1. Original folding/deployable probe concept.

EDL Analysis Technical Approach: Successful placement of the deployable sensor probe and survivability of the sensor package depends on an Entry, Descent, and Landing (EDL) concept that ensures survivability to entry heating and a mass efficient EDL system. The key performance parameters (KPPs) for this EDL system include peak heat rate, impact velocity, total mass, system complexity and the network footprint. Since the probe is very small, any EDL system needs to ensure sufficient deceleration for survivable impact velocity. Ensuring a mass efficient EDL architecture comes from reduced system complexity and minimized total mass. Two EDL system architectures were assessed:

EDL System 1. Probes are released individually from the orbiter at regular intervals to create a surface network of probes. Probe EDL heating was analyzed to determine thermal protection system (TPS) needs. A variety of probe shapes were assessed on their ability to slow their descent while protecting the sensor package from excessive heating and G forces.

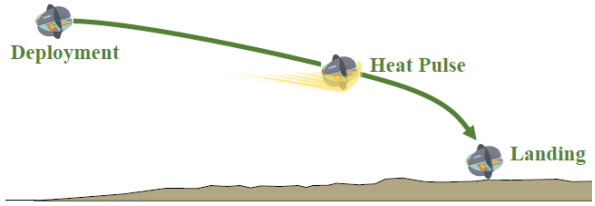

Fig. 2. EDL System 1 architecture.

EDL System 2. Carrier entry vehicles are deployed from the orbiter that take the probes through the high heating portion of the entry trajectory before deploying the probes at altitude. This architecture protects the probes from heat loads.

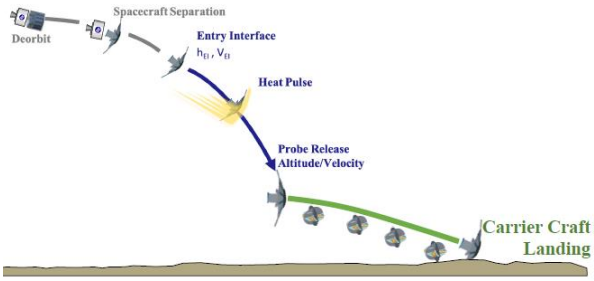

Fig. 3. EDL System 2 architecture.

The KPPs for each system stem from the entry probe/vehicle design, aerodynamics analysis, and a 3-DOF trajectory analysis. The aerodynamics analysis are also important for EDL System 1, considering the very low probe mass, drag area, and Martian atmosphere resulting in reduced vehicle deceleration. The

trajectory analysis, consisting of parametric sweeps of relevant entry conditions (mass, flight path angle, and lift to drag (L/D) ratio), provide the heating environments and landing locations for each probe module/entry system. The results from this trajectory analysis provides the landing speeds, heating environments, and network footprints for several entry condition combinations, establishing probe module survivability and mass efficient systems.

Study Results: The EDL System 2 architecture was rejected due to insufficient spread of the probes across the Martian surface. At the earliest opportunity after passing through the high heating portion of reentry, the carrier vehicle's horizontal velocity was too low to achieve the required surface probe distribution. The EDL System 2 architecture was determined to be acceptable with sufficiently large drag to slow the probes' descent to acceptable impact velocities, and the heat load experienced by the probes is sufficiently low that only minor amounts of TPS is needed.

Several probe concept shapes were investigated, including a deployed flap version of the original probe design, a Maple seed design, a tri-wing autorotator design, and a Tree of Heaven seed design. The seed designs were rejected due to aerodynamic unpredictability and uncertain orientation during key stages of flight. The tri-wing autorotator design was rejected due to excessively high rotational velocities which put too much strain on the sensor package. The deployed flap design was found to be the most favorable of all the options considered due to its self-orienting nature, geometry that protects the sensor package from entry heating, and small stowage footprint.

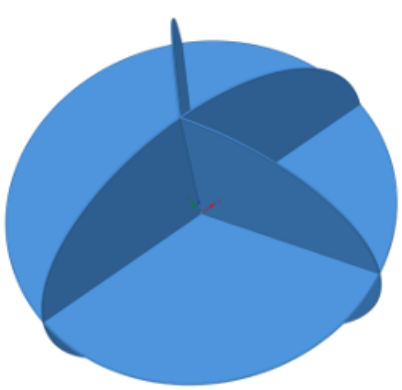

Fig. 4. Deployed flap (60° angle) design

The swept flaps add stability to the probe to prevent tumbling during reentry and, alongside additional weighting on the leading edge, give the shape a preferred flight orientation. This sweep angle also adds sufficient drag to slow the probe to acceptably-slow impact velocities.

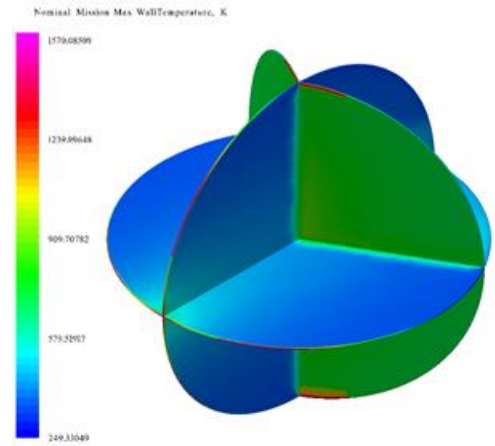

Fig. 5. Maximum wall temperatures through nominal mission.

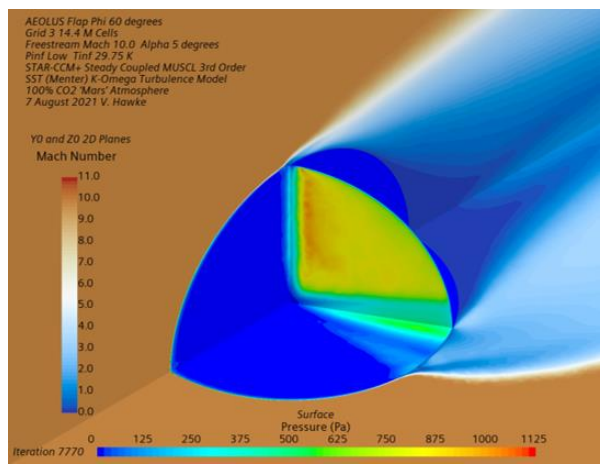

Fig. 6. Sample aerodynamic flow.

Forward Work: This probe shape has been assessed to be viable for reentry from Mars orbit and remain intact after impact with the surface. The design continues to be refined to further reduce the impact velocity and improve the shape's geometry to accommodate the sensor package, solar cells, and antenna. Prototypes of new iterations will be fabricated and subjected to environmental testing to increase the TRL of the design.

References: [1] MEPAG: Mars Science Goals, Objectives, Investigations, and Priorities: 2020, https://mepag.jpl.nasa.gov/reports/MEPAGGoals_2020_MainText_Final.pdf, [2] Fuller, J. Atmospheric Probe and Dispenser Mechanism, The Aerospace Corp. Private Communication.