MARS SAMPLE RETURN EARTH ENTRY VEHICLE: CONTINUING EFFORTS. M. M. Munk and L. Glaab, NASA Langley Research Center (1 N Dryden Street, M/S 489, Hampton, VA; michelle.m.munk@nasa.gov)

Challenge Area Summary: Returning samples from Mars presents many challenges and will require several technology developments. One of these developments has been underway at NASA-Langley for over a decade—the Mars Sample Return (MSR) Earth Entry Vehicle (EEV). This abstract addresses Challenge Area 2; in particular, ***High-reliability sample return capsules suitable for Earth entry, with special attention on assured containment of returned samples, and preservation of sample integrity***. The focus here is on the readiness of the MSR EEV, recent and ongoing development efforts, and future maturation activities.

Introduction: Vehicles that are designed to transport extra-terrestrial samples through the atmosphere to the surface of the Earth can take several forms. Much of the vehicle's function and design are driven by the requirements of the payload, or sample, such as impact and heating tolerance. Other requirements directly influencing the design are based on the trajectory and acceptable mission risk. Mission risk becomes a significant design driver for the Mars Sample Return entry vehicle due to Earth planetary protection requirements. Unlike other Earth Entry Vehicles where loss of the EEV during entry would imply the loss of that particular mission, Mars EEVs have considerably greater risk involved. Due to the concern with possible release of Martian microbes into Earth's biosphere, assuring containment of the samples during a Mars sample return mission is a critical design driver. The current requirement for probability of loss of Mars sample containment is $1x10^{-6}$; this could be revised in the future.

High-Reliability Design: Designs of EEVs for Mars sample return have evolved into a passive, stable, single-stage entry, descent and landing concept.[1] This concept has the advantage of very high reliability due to the lack of systems that can fail during entry, such as parachutes and reaction control systems (RCS). Impact loads are attenuated through advanced energy-absorption materials. The ability to effectively ground test and verify impact attenuation systems is also a major advantage.

In 1998, NASA-Langley submitted an unsolicited proposal to the Mars Program to provide the MSR EEV for the MSR mission, then targeted for the 2003/2005 launch opportunities. The proposal was accepted for planning purposes, and the specific Langley vehicle design (Fig. 1) has been the baseline used for Mars Sample Return mission studies and technology maturation planning ever since. Design, development, and testing efforts followed, which included sample containment vessel prototyping, impact testing on realistic surfaces, wind tunnel testing, and terrain and soil surveys of the proposed landing site. That work greatly matured the concept, and forms the basis of efforts now funded through the In-Space Propulsion Technology (ISPT) program within SMD.

During the development of the EEV concept several risks were identified. One critical risk involves the ability of the EEV to appropriately orient itself during the initial atmospheric entry segment, particularly if moments are induced during release from the Earth return spacecraft or if the vehicle is struck by a micrometeoroid after release. Another risk is the vehicle's ability to provide adequate impact attenuation, protection of the sample from thermal soak, and ultimate sample containment. Development efforts in the 1999-2003 timeframe, and those presently funded at a low level, are focused on addressing these specific risks.

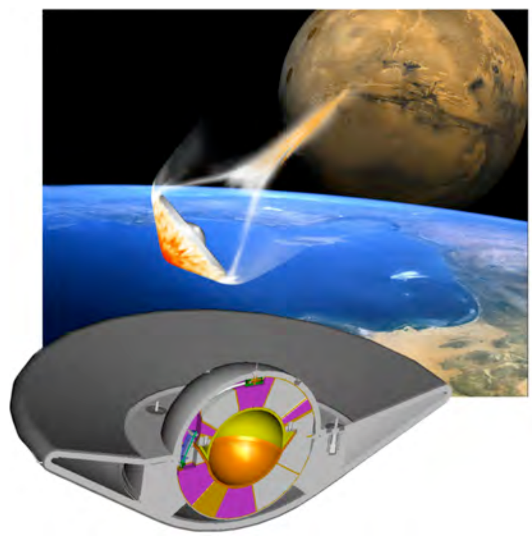

Figure 1. NASA-Langley concept for MSR EEV

In addition, the thermal protection system (TPS) material is an important consideration for EEVs. Based on predicted heat rates and heat loads alone, the mission can likely be accomplished with existing ablative materials such as phenolic impregnated carbon ablator (PICA). However, from a reliability perspective, the prevalent historical thinking has been that carbon phenolic will be required, since it is supported by an extensive database of testing and performance for military applications. The use of carbon phenolic brings a host of challenges, including a disappearing industrial base for the materials and manufacturing processes. NASA has held two workshops and sponsored tasks at Ames Research Center since 2010 to determine the best path for carbon phenolic revival or replacement, but the solution ultimately depends on available funding, the relative timing of all missions that might require the materials, and the cost and maturity of alternate solutions at the time the MSR project is formally underway.

Recent Development Efforts: NASA has been conducting research, design and development work for Earth entry vehicles as part of the Entry Vehicle Technologies (EVT) project within the In-Space Propulsion Technology (ISPT) program, since 2007. This has been a cooperative effort between NASA-Langley and NASA-Ames. ISPT's charter is to mature technologies for use on all SMD missions, so its purview is broader than only Mars. Given that, a key component of the ISPT approach to maturing the EEV is to demonstrate the key features, or better still, the actual EEV flight design, on other sample return missions leading to MSR. Use on other relevant flight missions will help raise the system reliability for the MSR application. In preparation for mission infusion, several technology development tasks are underway; some of these efforts are highlighted in the remainder of this section.

Analysis Tools: A major effort between the two centers has been the development of the Multi-mission Systems Analysis for Planetary Entry (M-SAPE) software program. M-SAPE provides rapid preliminary design of EEVs and trade space visualization and evaluation early in the design process, yet also contains high-fidelity trajectory, structural, thermal soak, impact, and material response models for detailed engineering. The availability of suitable computational tools is critical to MSR in particular, since testing alone will be inadequate (due to cost and schedule constraints) to achieve the statistics required for reliability.

TPS Testing: In 2011, ISPT funded an assessment of the micrometeoroid and orbital debris environment for the MSR EEV on a conjunction-class (baseline) mission. Results showed that the vehicle backshell is actually most vulnerable to impacts, since the forebody is protected by the Earth Return Vehicle for much of the mission. ISPT has exposed both candidate forebody and backshell TPS materials to galactic cosmic radiation, cold temperatures, high-speed simulated micrometeoroid impact, and finally, arcjet test at conditions relevant for the MSR EEV return trajectory. Results thus far are very favorable and show that there are several good-performing backshell materials from which to choose. Forebody materials will be arcjet tested in late FY12.

Foam testing: An important component of the EEV design is the impact attenuation foam that is present between the structural members of the impact sphere. Understanding its behavior is key to the integrated vehicle model. Both static and dynamic foam impact tests have been conducted at Langley over the past year, to understand the stress/strain curves and how the material will behave upon impact. Impacted and pristine samples are being tested for material properties that will then be inputs to the M-SAPE structural and impact models. The next step in FY13 is to conduct foam impact testing at temperature and then update the thermal soak model.

Future Work: In the likelihood that the MSR EEV design will not be demonstrated in another mission prior to MSR, a coordinated computational, wind tunnel, and flight-test effort should be performed to appropriately address the issue of EEV reorientation and other significant risks. Computational Fluid Dynamics (CFD) analysis tools have made positive advances since the initial analyses were conducted in the late 1990s. CFD provides an ability to observe the characteristics of the flow field in great detail, provides data for conditions beyond what are testable in wind tunnels (such as non-continuum aerodynamic conditions), and provides information for vehicle design and stability analysis. However, limitations still resident within CFD require wind-tunnel testing to appropriately anchor the results, provide an independent source of data, and provide engineers with appropriate insight into the vehicle's aerodynamics. Due to the level of mission reliability required for the MSR mission, a flight test that demonstrates the ability to re-orient from an off-nominal attitude is essential to adequately understand the vehicle dynamics in this extreme flight regime and provide adequate sample containment assurance. Secondary objectives of the flight test would address impact attenuation system design verification[2,3] as well as validate thermal soak rates.

Concluding Remarks: NASA-Langley's MSR EEV is designed to be highly reliable, to meet stringent planetary protection requirements. Leadership of current entry vehicle technology maturation activities, as well as LaRC's historical expertise and relevant experience in the aerosciences and flight testing, provide confidence that the MSR EEV can be produced reliably to support the MSR mission. Langley's experience in CFD, wind-tunnel testing, simulation, structural design, impact attenuation design and full-scale testing, and integrated flight testing; coupled with NASA-Ames' experience in providing thermal protection systems, provides the ability to retire critical risks for the MSR EEV and other EEV applications.

References: [1] Mitcheltree, R. A., Kellas, S. (1999). *NASA 99 ISAVRS. A Passive Earth-Entry Capsule for Mars Sample Return*. [2] Mitcheltree, R. A., et al (2001). *AAAF Paper ARVS-102; An Earth Entry Vehicle for Returning Samples from Mars*. [3] Kellas, S., Mitcheltree, R. A. (2002). *AIAA 2002-1224; Energy Absorber Design, Fabrication and Testing for a Passive Earth Entry Vehicle.*