APPLICATION OF THE MEDLI SUITE TO FUTURE MARS ENTRY VEHICLES. M. M. Munk, NASA Langley Research Center (1 N Dryden Street, M/S 489, Hampton, VA; michelle.m.munk@nasa.gov)

Challenge Area Summary: Mars atmospheric models currently carry large uncertainties on density. This lack of knowledge affects system design trades and technology choices for future missions. This abstract addresses Challenge Area 1; in particular, ***Concepts for measurements of lower atmosphere winds and densities***, but in the near term. The presentation will explain the scientific and engineering value of the Mars Science Laboratory (MSL) Entry, Descent and Landing (EDL) Instrumentation (MEDLI) suite and its application to future Mars entry vehicles.

Introduction: MEDLI is an instrumentation suite currently en route to Mars, attached to the MSL heatshield. MEDLI includes 7 pressure transducers mounted in a cross-shaped configuration, as a flush air data system (Fig. 1); they comprise the Mars Entry Atmospheric Data System (MEADS). MEDLI also includes 7 plugs of the acreage PICA (phenolic impregnated carbon ablator) thermal protection system (TPS), each with a stack of 4 Type K thermocouples (Fig. 2) and a hollow aerothermal ablation temperature detector (HEAT sensor). The thermal plugs comprise the MSL Integrated Sensor Plug (MISP) subsystem of MEDLI. Together, MEADS and MISP provide critical information on MSL's entry performance, as well as provide valuable scientific and engineering information about the Mars entry environment.

The MEDLI project has been a very successful cooperative effort between HEOMD, SMD, and ARMD, with HEOMD (and in FY2012, OCT) funding the hardware development, SMD accommodating the instrument and supporting the flight integration, and ARMD and OCT funding the data reconstruction work. Since its inception in 2006, the project has been managed by NASA-Langley, with NASA-Ames support. Of all recent Mars landing missions since Mars Pathfinder, only MSL has been instrumented to such an extent. NASA expects MEDLI to return an order of magnitude more, higher-quality data then ever before, from a Mars entry. MSL is larger than any lander to date, so it produces high shear and will likely transition to turbulent flow on the forebody; it is hypersonically guided; and it has a segmented PICA tile TPS never before flown at Mars. These features made it extremely important to instrument the MSL entry vehicle.

MEDLI Objectives: MEDLI collects data from about 10 minutes before Mars entry until a few seconds after parachute deploy to satisfy both engineering and scientific objectives as detailed below.

MEADS: Since MEADS provides an independent measure of pressure on the heatshield during entry, the atmospheric density can be determined. Usually the vehicle aerodynamics need to be assumed in the density calculation, which introduces significant uncertainty. With the MEADS determination of the dynamic pressure to within 2%[1], the density profile from the top of the atmosphere to ~20 km above the surface can be calculated unambiguously for the specific time and location of the MSL entry. Although one profile (or even a few) does not provide enough data to close the strategic knowledge gaps in atmospheric models, it does provide an anchor point for model comparison and validation. Engineers are hopeful that an atmospheric wind component will also be discernable in the MEADS data.

In terms of engineering and vehicle performance data, MEADS will provide an important, independent measure of the angle of attack and angle of sideslip (within 0.5° 3-sigma) as MSL guides itself through the atmosphere. Providing a measurement independent from the inertial measurement unit (IMU) improves the observability of the flight system parameters and significantly aids in resolving conflicting data. Predicted aerodynamic and guidance system performance can then be compared with actual flight data, facilitating model validation. Model validation is especially important since NASA plans to use the MSL EDL system on future missions. In addition, the potential for margin reduction exists once models are validated, saving mass and cost for subsequent missions.

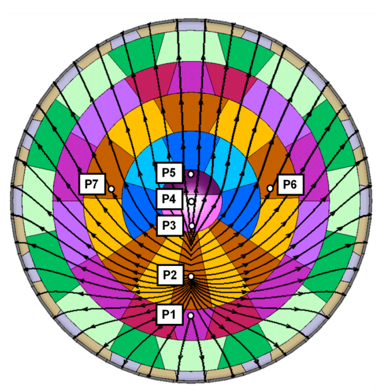

Fig. 1 MEADS pressure port layout on MSL heatshield

MISP: The MISP thermocouple (TC) stacks will inform engineers about MSL's heating environment and the response of its TPS material, PICA.[2] Currently, the TPS thickness on a given entry vehicle has 30-50% margins added to it, to account for aeroheating uncertainties, manufacturing variabilities, recession rate unknowns, and other factors. Some previous vehicles have included thermocouples, but none have been as close to the surface as in the MISP plugs, and there have been problems obtaining meaningful data from them. The approach of using a stack of thermocouples through the PICA thickness will enable temperature readings at various TPS depths at different locations. From this information, engineers can determine the heating distribution on the vehicle forebody, detect turbulent transition in time and space, and compare material thermal response to that predicted in models and observed in ground test facilities. Reconstruction of the forebody heating may give new insights into atmospheric chemistry as it influences catalycity.

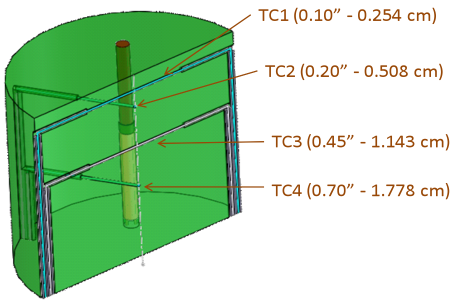

Figure 2. MISP TC depths and tubular HEAT sensor

The MISPs also include a HEAT sensor, which is an isotherm follower; a hollow thin-film tube that chars at approximately 700˚C and returns an electrical signal to indicate its length. The HEAT is based on Galileo instrumentation technology and acts as a recession sensor in steady-state ablation environments. Extensive ground testing is being conducted to calibrate the HEAT sensor to the expected PICA response using arcjet tests at flight-like conditions. Understanding recession is a key component in reducing future TPS mass margins without increasing risk.

Operations: It should be noted that about 10% of the MEDLI dataset will be returned real-time during entry, and MEDLI data is used to generate 8 of the sequence tones that inform Earth about the vehicle status during EDL. Some are catastrophic tones, signaling a very off-nominal vehicle attitude or indicating a very high temperature at an in-depth thermocouple. Nominally, the full MEDLI dataset (20 minutes at 8 Hz) is stored in the Rover Compute Element and returned to Earth within a few days of Curiosity’s successful landing.

Future Mars Missions: When we consider that there are only 10 Mars opportunities between now and the mid-2030’s (starting with 2018), and that in the last 8 opportunities since 1995 we have learned little more than whether a lander was a failure or a success, it is clearly *critical* that we learn as much as possible from each flight. As the sizes and masses of vehicles traveling through Mars’ atmosphere increase along the path to human exploration, while at the same time our tolerance to risk will decrease, our ability to model the complex vehicle performance must improve dramatically. Model validation from flight data is the means by which we will be able to realistically predict larger vehicle performance.

MEDLI is a very minimal system in terms of the number and types of sensors included. The originally-proposed system included backshell pressure and heat flux sensors, aimed at trying to improve the 300% margins currently used in computation. An upward-looking camera was also desired, focused on the opening dynamics of the bigger-than-ever parachute that MSL will use. The MSL schedule at the time (supporting a 2009 launch) eliminated these other sensor types and locations, but obtaining these data is still of utmost importance and additional sensors must be considered for future missions.

Programmatic Considerations: Since instrumentation such as MEDLI does not improve the design of the current mission but rather aids subsequent missions, the accommodation requirement must come from above the mission level. Project and mission managers may support the intent of feed-forward data gathering, but if there is no Level 0 requirement, instrumentation will not be included. Post-flight data reduction must also be considered from the project inception, budgeted and executed in order to maximize the returned data’s usefulness. Futhermore, there is currently no Agency investment in this type of instrumentation development. MEDLI utilizes well-established and off-the-shelf technology, but its cost, mass, and volume could be significantly reduced with technology investment.

Concluding Remarks: Instrumentation such as MEDLI provides value in both science and engineering arenas. As we prepare for sending larger and more complex vehicles to Mars, we must better understand both the operational environments and the system behaviors of the spacecraft. To that end, every vehicle that enters the atmosphere must have instruments at least as sophisticated as the MEDLI suite. This premise must be supported by a top-level requirement for instrumentation. Furthermore, sustained investments are needed to reduce the cost and mass impact of the instrumentation and to improve its accuracy.

References: [1] Karlgaard, C. et al (2009). *AIAA 2009-3916; MEADS Modeling and Algorithm Development.* [2] Santos, J. et al (2008). *AIAA 2008-4134; Thermal Modeling of In-Depth Thermocouple Response in Ablative Heat Shield Materials.*