NASA SBIR 2020 Phase I Solicitation

Z7.01 Entry Descent & Landing Sensors for Environment Characterization, Vehicle Performance, and Guidance, Navigation and Control

Lead Center: ARC

Participating Center(s): JPL, JSC, LaRC

Technology Area: TA9 Entry, Descent and Landing Systems

Scope Description

NASA human and robotic missions to the surface of planetary or airless bodies require Entry, Descent, and Landing (EDL). For many of these missions, EDL represents one of the riskiest phases of the mission. Despite the criticality of the EDL phase, NASA has historically gathered limited engineering data from such missions, and use of the data for real-time Guidance, Navigation and Control (GN&C) during EDL for precise landing (aside from Earth) has also been limited. Recent notable exceptions are the Orion EFT-1 flight test, Mars Entry, Descent, & Landing Instrument (MEDLI) sensor suite, and the planned sensor capabilities for Mars 2020 (MEDLI2 and map-relative navigation). NASA requires EDL sensors to: a) understand the in-situ entry environment b) characterize the performance of entry vehicles, and c) make autonomous and real-time onboard GN&C decisions to ensure a precise landing.

This subtopic describes three related technology areas where innovative sensor technologies would enable or enhance future NASA EDL missions. Proposers may submit solutions to any of these scope areas:

1) High Accuracy, Light Weight, Low Power Fiber Optic or Recession Sensing System for Thermal Protection Systems.

2) Miniaturized Spectrometers for Vacuum Ultraviolet & Mid-wave Infrared In-Situ Radiation Measurements during Atmospheric Entry.

3) Novel Sensing Technologies for EDL GN&C and Small-Body Proximity Operations.

NASA seeks innovative sensor technologies to enable and characterize entry, descent and landing operations on missions to planetary and airless bodies. This subtopic describes three related technology areas where innovative sensor technologies would enable or enhance future NASA EDL missions. Candidate solutions are sought that can be made compatible with the environmental conditions of deep spaceflight, and the rigors of landing on planetary bodies both with and without atmospheres. Proposers may submit to scope areas 1, 2 or 3 below.

1) HIGH ACCURACY, LIGHT WEIGHT, LOW POWER FIBER OPTIC OR RECESSION SENSING SYSTEM FOR THERMAL PROTECTION SYSTEMS.

Current NASA state-of-the-art EDL sensing systems are very expensive to design and incorporate on planetary missions. Commercial fiber optic systems offer an alternative that could result in a lower overall cost and weight, while actually increasing the number of measurements. Fiber optic systems are also immune to Electro-magnetic Interference (EMI) which reduces design and qualification efforts. This would be highly beneficial to future planetary missions requiring Thermal Protection Systems (TPS). In addition, as NASA looks to the future of science missions to the Outer Planets, extreme entry environments will require the new, 3-D woven Heatshield for Extreme Entry Environment Technology (HEEET) TPS recently matured within the Agency. Gathering flight performance data on this new material will be key, particularly the measurement of recession, which was so very important on the Galileo probe mission to Jupiter. Minimizing the sensor intrusion of the outer mold line is critical in this case, because the extreme environment dictates that the TPS be as aerothermally monolithic as possible. In applications to planetary entry vehicles greater than about 1 m diameter, however, the HEEET TPS is expected to contain seams that might be used for accommodating instrumentation. Recession measurements in carbon fiber/phenolic TPS systems like Phenolic Impregnated Carbon Ablator (PICA) and AVCOAT are also of interest. When ablation is not severe and/or rapid, accurate measurements have proven difficult with the historic Galileo-type sensor, which was based on the differential resistance resulting from sensor materials that have charred.

The upcoming Mars 2020 mission will fly the Mars Entry, Descent, and Landing Instrumentation II (MEDLI2) sensor suite consisting of a total of 24 thermocouples, 8 pressure transducers, 2 heat flux sensors, and a radiometer embedded in the TPS. This set of instrumentation will directly inform the large performance uncertainties that contribute to the design and validation of a Mars entry system. A better understanding of the entry environment and TPS performance could lead to reduced design margins enabling a greater payload mass fraction and smaller landing ellipses. Fiber optic sensing systems can offer benefits over traditional sensing system like MEDLI and MEDLI2, and can be used for both rigid and flexible TPS. Fiber optic sensing benefits include, but are not limited to; sensor immunity to EMI, the ability to have thousands of measurements per fiber using Fiber Bragg Grating (FBG), multiple types of measurements per fiber (i.e. temperature, strain, and pressure), and resistance to metallic corrosion.

To be considered against NASA state-of-the-art TPS sensing systems for future flight missions, fiber optic systems must be competitive in sensing capability (measurement type, accuracy, quantity), and Sensor Support Electronics (SSE) mass, size and power. Therefore NASA is looking for a fiber optic system that can meet the following requirements:

Sensing Requirements

- TPS Temperature: Measurement Range: -200 to 1250C (up to 2000C preferred), Accuracy: +/- 5C desired.
- Surface Pressure: Measurement Range: 0-15 psi, Accuracy: < +/-0.5%

Sensor Support Electronics Requirements (including enclosure):

- Weight: 12 lbs or less,
- Size: 240 cubic inches or smaller,
- Power: 15W or less,
- Measurement Resolution: 14-bit or Higher,
- Acquisition Rate per Measurement: 16 Hz or Higher.
- Compatibility with all sensors types, e.g., Temperature, Pressure, Heat Flux, Strain, Radiometer, TPS recession.

For recession measurements in extreme entry environments requiring 3-D woven TPS, NASA is seeking novel concepts that fit into the sensor/electronics architecture described above, and meet the following requirements:

- Up to 5000 W/cm2 heat flux,
- Up to 5 atmospheres of pressure on the vehicle surface,
- Recession measurement accuracy within +/- 1 mm.

For recession measurements in moderate entry environments requiring carbon fiber/phenolic TPS systems, NASA is seeking novel concepts that fit into the sensor/electronics architecture described above, and meet the following requirements:

- Up to 150-2000 W/cm2 heat flux,
- Up to 1 atmosphere of pressure on the vehicle surface,
- Recession measurement accuracy within +/- 1 mm.

2) MINIATURIZED SPECTROMETERS FOR VACUUM ULTRAVIOLET & MID-WAVE INFRARED RADIATION IN-SITU MEASUREMENTS DURING ATMOSPHERIC ENTRY

The current state-of-the-art for flight radiation measurements includes radiometers and spectrometers. Radiometers can measure heating integrated over a wide wavelength range (e.g. MEDLI2 Radiometer), or over narrow-wavelength bands (COMARS+ ICOTOM at 2900 nm and 4500 nm). Spectrometers gather spectrally resolved signal and have been developed for Orion EM-2 (combined Ocean Optics STS units with a range of 190-1100 nm). A spectrometer provides the gold standard for improving predictive models and improving future entry vehicle designs.

For NASA missions through CO2 atmospheres (Venus and Mars), a majority of the radiative heating occurs in the Midwave Infrared range (MWIR: 1500 nm - 6000 nm) [Brandis]. Similarly, for entries to Earth, the radiation is dominated by the Vacuum Ultraviolet (VUV) range (VUV: 100 - 190 nm) [Cruden]. Both of these ranges are outside of those detectable by available miniaturized spectrometers. While laboratory-scale spectrometers and detectors are available to measure these spectral ranges, there are no versions of these spectrometers which would be suitable for integration into a flight vehicle due to lack of miniaturization. This SBIR calls for miniaturization of VUV and Mid-Wave Infrared (MWIR) spectrometers to extend the current state of the art for flight diagnostics.

Advancements in either VUV or MWIR measurements are sought, preferably for sensors with:

- Self-contained with a maximum dimension of ~10 cm or less,
- No active liquid cooling,
- Simple interfaces compatible with spacecraft electronics, such as RS232, RS422, or Spacewire,
- Survival to military spec temperature ranges [-55 to 125C],
- Power usage of order 5W or less.

3) NOVEL SENSING TECHNOLOGIES FOR EDL GN&C AND SMALL BODY PROXIMITY OPERATIONS

NASA seeks innovative sensor technologies to enhance success for EDL operations on missions to other planetary bodies (including Earth's Moon, Mars, Venus, Titan, and Europa). Sensor technologies are also desired to enhance proximity operations (including sampling and landing) on small bodies such as asteroids and comets.

Sensing technologies are desired that determine any number of the following:

- Terrain relative translational state (altimetry/3-axis velocimetry).
- Spacecraft absolute state in planetary/small-body frame (either attitude, translation, or both).
- Terrain characterization (e.g., 3D point cloud) for hazard detection, absolute and/or relative state estimation, landing/sampling site selection, and/or body shape characterization.
- Wind-relative vehicle state and environment during atmospheric entry (e.g., velocity, density, surface pressure, temperature).

Successful candidate sensor technologies can address this call by:

- Extending the dynamic range over which such measurements are collected (e.g., providing a single surface topology sensor that works over a large altitude range such as 1m to >10km, and high attitude rates such as greater than 45° /sec).
- Improving the state-of-the-art in measurement accuracy/precision/resolution for the above sensor needs.
  * Substantially reducing the amount of external processing needed by the host vehicle to calculate the measurements.
- Significantly reducing the impact of incorporating such sensors on the spacecraft in terms of Size, Weight, and Power (SWaP), spacecraft accommodation complexity, and/or cost.
- Providing sensors that are robust to environmental dust/sand/illumination effects.

- Mitigation technologies for dust/particle contamination of optical surfaces such as sensor optics, with possible extensibility to solar panels and thermal surfaces for Lunar, asteroid, and comet missions.
- Sensing for wind-relative vehicle velocity, local atmospheric density, and vehicle aerodynamics (e.g. surface pressures and temperatures).

NASA is also looking for high-fidelity real-time simulation and stimulation of passive and active optical sensors for computer vision at update rates greater than 2 Hz to be used for signal injection in terrestrial spacecraft system test beds. These solutions are to be focused on improving system-level performance Verification and Validation during spacecraft assembly and test.

References

Brandis, A., Cruden, B., White, T., Saunders, D., and Johnston, C. Radiative Heating on the After-Body of Martian Entry Vehicles, AIAA 2015-3111, 45th AIAA Thermophysics Conference, Dallas, TX, 22-26 June 2015.

Cruden, B., Martinez, R., Grinstead, J., and Olejniczak, J. Simultaneous Vacuum-Ultraviolet Through Near-IR Absolute Radiation Measurement with Spatiotemporal Resolution in An Electric Arc Shock Tube, AIAA 2009-4240, 41st AIAA Thermophysics Conference, San Antonio, TX, 22-25 June 2009.

Johnston, C. and Brandis, A. Features of Afterbody Radiative Heating for Earth Entry, Journal of Spacecraft and Rockets, Vol. 52, Issue 1, 15 December 2014.

Expected TRL or TRL range at completion of the project: 3 to 5

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

Desired Deliverables Description

Depending on the type of technology submissions, hardware demonstrations of sensors or applicable support hardware (e.g. EDL sensors), or software simulations/analysis of simulated environments (simulation environments for passive and active optical sensors) are acceptable.

State of the Art and Critical Gaps

Active and passive GN&C EDL sensor technologies have been in development over the past decade. Infusion of these capabilities into spaceflight missions requires additional technology advancements to enhance operational performance and dynamic envelop, reduce size, mass, and power, and to address the process of space qualification.

The EDL community has a need to understand the specific contributors to aftbody radiation (especially in CO2 and air); a spectrometer is the next logical step beyond the current state-of-the-art radiometers for EFT-1 and MEDLI2. NASA now requires instrumentation on SMD competed missions involving EDL, and these cost- and mass-constrained missions cannot use the SOA instrumentation. The specific need is for miniaturized spectrometers for in-situ measurements with sensitivity in the VUV or MWIR regions where NASA predicts significant radiation for Earth, Venus, and Mars entries. VUV spectrometers require window operation under vacuum conditions with UV-grade windows for detection of the vacuum ultraviolet. The window materials become increasingly exotic as lower wavelengths are sought. The dispersion of wavelength becomes reduced as spectrometers shrink, which may become an issue for closely spaced features at lower wavelength. Extending the range of miniaturized spectrometers into the MWIR may be limited by the need for extensive cooling and as long wavelengths approach the diffraction limit.

Relevance / Science Traceability

EDL instrumentation directly informs and addresses the large performance uncertainties that drive the design, validation and in-flight performance of planetary entry systems. Improved understanding of entry environments and TPS performance could lead to reduced design margins enabling a greater payload mass-fraction and smaller landing ellipses. Improved real-time measurement knowledge during entry could also minimize the landing dispersions for placing advanced payloads onto the surface of atmospheric and airless bodies.

NASA Science missions are frequently proposed, that include high-speed Earth return (New Frontiers, Discovery, and Mars Sample Return) and Venus and Mars entry. Capsules used for these missions must withstand both convective and radiative aeroheating, and NASA now requires EDL instrumentation for these missions. Current radiative measurement techniques (radiometers) provide only an integrated heating over limited wavelength range; past interpretation of such flight data [Johnston] show the need for spectrally resolved measurements from spectrometers. For Earth and Venus, the radiative component may be the dominant source of heating, and emission comes from the VUV, that NASA currently has no capability to measure. For Mars and Venus, the aftbody radiation is dominated by MWIR. Again, NASA does not have a method to measure MWIR radiation in flight; the current radiometers integrate across several band systems. Miniaturized spectrometers that can measure in VUV and MWIR would have immediate application to SMD planetary missions. Such spectrometers may also inform what ablation species are emitted from the heatshield and backshell during entry.