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NASA SBIR 2021 Phase I Solicitation

Z7.01 Entry, Descent, and Landing Flight Sensors and Instrumentation

Lead Center: JSC

Participating Center(s): ARC, GSFC, JPL, LaRC

Scope Title:

High-Accuracy, Lightweight, Low-Power Fiber-Optic or Recession Sensing System for Thermal Protection Systems and Low-Cost Data Acquisition System

Scope Description:

Current NASA state-of-the-art entry, descent, and landing (EDL) instrumentation and associated data acquisition are very expensive to design and incorporate on planetary missions because they must meet functional and performance requirements during and after exposure to loads and environments associated with spaceflight and atmospheric entry.

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Commercial fiber-optic systems offer an alternative to traditional sensors that could result in a lower overall cost and weight reduction while actually increasing the number of measurements. Fiber-optic systems are also immune to electromagnetic interference (EMI), which reduces design and qualification efforts. This would be highly beneficial to future planetary missions requiring thermal protection systems (TPSs). In addition, as NASA looks to the future of science missions to the outer planets, extreme entry environments will require the new,Â 3D-woven Heatshield for Extreme Entry Environment Technology (HEEET) TPS recently matured within the Agency. Gathering flight performance data on this new material will be keyâ€”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 in diameter, however, the HEEET TPS is expected to contain seams that might be used for accommodating instrumentation.

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Recession measurements in carbon fiber/phenolic TPSs such as 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.

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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, and quantity) and associated data acquisition system mass, size,Â power, and cost. Therefore, NASA is looking for a fiber-optic system that can meet the following requirements:

- TPS Temperature
  - Measurement Range: -200 to 1,250 ÂºC (up to 2,000 ÂºC is preferred).
  - Accuracy: +/-5 ÂºC desired.
- Surface Pressure
  - Measurement Range: 0 to 15 psi.
  - Accuracy: < +/-0.5%.

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Destinations such as Mars, Venus, and Titan pose many challenges for EDL data acquisition systems, including radiation, g-loading, and volume constraints. Recent notable examples of such systems are the Mars Entry, Descent, and Landing Instrument (MEDLI) sensor suite, which successfully acquired EDL data in 2012, and the upcoming MEDLI2 system, which will gather data during EDL at Mars in February of 2021. The NASA MEDLI and MEDLI2 data systems are very well designed and robust to the extreme environments of space transit and EDL, but this comes at a great financial burden to these missions. The high cost prohibits smaller mission classes such as Discovery and New Frontiers from using MEDLI-like systems, therefore limiting the EDL science that can be conducted by NASA. In an effort to bring EDL instrumentation to all missions, NASA is seeking a low-cost, robust, high-accuracy data acquisition system that can meet the following requirements:

- Performs instrument signal conditioning and analog-to-digital conversion, and includes a spacecraft bus serial interface.
- Weight: 5 kg or less.
- Size: Modularity encouraged; maximum module size 10 cm^3; 4 modules maximum.
- Power: 16 W or less.
- Measurement Resolution: 12-bit or higher.
- Accuracy: +/-0.5% of full-scale output.
- Acquisition Rate per Measurement: 8 Hz or higher.
- Radiation Tolerant by Design: Minimum of 10 kRad (30 kRad or better desired).
- Axial Loading Capability: Minimum 15g (Venus missions could require 100g to 400g).
- Operating Temperature Capability: -40 Â°C to 85 Â°C.
- Cost: Fully qualified target of ~$1M (recurring).
- Sensor Compatibility.
  - Minimum 15 thermocouples with at least 2 Type R and 8 Type K.
  - Minimum 8 pressure transducers (120 or 350 ohm bridge).

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

- Up to 5,000 W/cm^{2}Â total heat flux (convective plus radiative).
- Up to 5 atmospheres of pressure on the vehicle surface.

- Minimum recession measurement accuracy within +/-1 mm.

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

- 150 to 2,000 W/cm^{2}Â total heat flux (convective plus radiative).
- Up to 1 atmosphere of pressure on the vehicle surface.
- Minimum recession measurement accuracy within +/-1 mm.

Expected TRL or TRL Range at completion of the Project:Â 3 to 5Â
Primary Technology Taxonomy:Â
Level 1: TX 09 Entry, Descent, and LandingÂ
Level 2: TX 09.X Other Entry, Descent, and Landing**Â**
Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I Goals: Design and proof of concept, including the production approach to achieve the cost goals.

Phase II Goals: Prototype/breadboard validation in laboratory environment.

State of the Art and Critical Gaps:

NASA now requires instrumentation on all EDL missions, includingÂ competed science missions, and these cost- and mass-constrained missions cannot use the state-of-the-art instrumentation.

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.Â

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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 a limited wavelength range; past interpretation of such flight data [Ref. 3, 4] shows 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 vacuum ultraviolet (VUV), which NASA currently has no capability to measure. For Mars and Venus, the aftbody radiation is dominated by midwave infrared (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 Science Mission

Directorate (SMD) planetary missions. Such spectrometers may also inform what ablation species are emitted from the heat shield and backshell during entry.Â

References:

1. M. Munk, A. Little, C. Kuhl, D. Bose, and J. Santos, "The Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI) Hardware," Proc. AAS/AIAA Space Flight Mechanics Conference, AAS 13-310, Kauai, HI, 2013.
2. F. Milos, "Galileo Probe Heat Shield Ablation Experiment,"Â Journal of Spacecraft and Rockets, Vol. 34, No. 6, Nov-Dec 1997.
3. B. A. Cruden and C. O. Johnston, "Characterization of EFT-1 Radiative Heating and Radiometer Data," 46th AIAA Thermophysics Conference, Washington, D.C., June 2016.
4. A. Brandis, C. O. Johnston, B. A. Cruden, D. Prabhu, and D. Bose, "Uncertainty Analysis and Validation of Radiation Measurements for Earth Reentry," Journal of Thermophysics and Heat Transfer, Vol. 29, No. 2, 2015, pp. 209-221.

Scope Title:

Novel Lidar Component Technologies Applicable to Guidance, Navigation, and Control (GN&C) for Precise Safe Landing

Scope Description:

NASA is seeking the development of component technologies for advanced lidar sensors that will be utilized within Entry, Descent, and Landing (EDL) and Deorbit, Descent, and Landing (DDL) Guidance, Navigation, and Control (GN&C) systems for precise safe landing on solid solar system bodies, including planets, moons, and small celestial bodies (e.g., asteroids and comets).Â The EDL phase applies to landings on bodies with atmospheres, whereas DDL applies to landings on airless bodies.Â For many of these missions, EDL/DDL represents one of the riskiest flight phases.Â NASA has been developing technologies for precision landing and hazard avoidance (PL&HA) to minimize the risk of the EDL/DDL phase of a mission and to increase the accessibility of surface science targets through precise and safe landing capabilities.Â One flight instrumentation focus of PL&HA technology has been in the development of lidar technologies that either provide terrain mapping (range point cloud) capability or direct velocity measurement.Â The continued maturation of these technologies is targeting (1) further size, mass, and power reductions of components; (2) multicomponent integration; and (3) multimodal operation (i.e., combing mapping and velocimetry functions).Â

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This solicitation is requesting specific lidar system components and not complete lidar solutions. To be considered, all component technologies proposed must show a development path to operation within the applicable EDL/DDL spaceflight environment (radiation, thermal, vacuum, vibration, etc.).Â The specific lidar component technologies desired include the following:

- Dense focal plane arrays for simultaneous ranging and Doppler velocimetry, plus associated signal processing approaches including photonic integrated circuits (PICs), with the following characteristics:
    - Simultaneous measurements from each pixel or from subsets of pixels.
    - Functionality (when integrated into a lidar system) that would operate up to 8 km range.
    - Functionality (when integrated into a lidar system) for measuring velocity from 0 m/sec along the line of sight (LOS) up to 200 m/sec or greater.

    - PICs approaches that integrate multiple components into a single device or provide a single component in a miniaturized robust package (e.g., master laser, modulator, and detectors).
    - Ability to reject false locks on dust plumes due to exhaust.
    - Implementation for low power, mass, and size.
    - Optical losses comparable with fiber-optic or bulk optical components.
- High-speed (5 MHz) wavelength tuning laser modules with low power driving electronics, which have random wavelength access or predefined wavelength-lookup-table tuning, and meet the following requirements:
    - Semiconductor laser module.
    - Tuning range: 1550 nm with tuning range of C-band.
    - Tuning speed:Â 5 MHz, and less than 100 ns settling time.
    - Wavelength grid: 10,000 evenly distributed over the whole tuning range.
    - Tuning fashion: Random wavelength grid access, or sequential predefined wavelength lookup table tuning.
    - High wavelength and power repeatability.
    - Low temperature or environmental dependency.

Expected TRL or TRL Range at completion of the Project:Â 4 to 6Â
Primary Technology Taxonomy:Â
Level 1: TX 09 Entry, Descent, and LandingÂ
Level 2: TX 09.X Other Entry, Descent, and Landing**Â**
Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

The following deliverablesÂ are desired for Phase I: (1) Hardware demonstrations of sensor componentsÂ and applicable support hardware and/or (2) Analysis and software simulations of componentÂ proofs of concept within simulated environments.Â Responses must show a path for the proposed capabilities to be compatible with the environmental conditions of spaceflight.

The following deliverables are desired for Phase II:Â (1) Hardware demonstrations of sensor components and applicable support hardware and (2) Analysis of components in laboratory or relevant environment (depending on TRL).Â Phase II products will need to demonstrateÂ a path for the capabilities to be compatible with the environmental conditions of spaceflight.

State of the Art and Critical Gaps:

The EDL GN&C and sensors community has been developing for more than a decade the technologies to enable precise safe landing. Infusion of these capabilities into spaceflight missions and spinoff into the commercial sector remains the critical gap.Â Bridging this gap requires additional component technology advancements for specific lidar sensors that enhance operational performance, increase dynamic envelope, reduce size/mass/power/cost, and enable spaceflight qualification.

Relevance / Science Traceability:

GN&C/PL&HA technologies for precise safe landing are critical for future robotic science and human exploration missions to locations with hazardous terrain and/or pre-positioned surface assets (e.g., cached samples or cargo) that pose significant risks to successful spacecraft touchdown and mission surface operations.Â The PL&HA technologies enable spacecraft to land with minimum position error from targeted surface locations, and they implement hazard-avoidance diverts to land at locations safe from lander-sized or larger terrain hazards (e.g., craters, rocks, boulders, sharp slopes, etc.).Â PL&HA has maintained consistent prioritization within the NASA and National Research Council (NRC) space technology roadmaps for more than a decade, and multiple near-term science missions, such as Mars 2020, are starting to infuse some of the PL&HA capabilities.

References:

1. *A. MartinÂ et al., "Photonic integrated circuit-based FMCW coherent LiDAR," inÂ Journal of Lightwave Technology, vol. 36, no. 19, 4640-4645, Oct.1, 2018, doi: 10.1109/JLT.2018.2840223.*
2. *C.V. Poulton, A. Yaacobi, D.B. Cole, M.J. Byrd, M. Raval, D. Vermeulen, and M.R. Watts, "Coherent solid-state LIDAR with silicon photonic optical phased arrays," Opt. Lett.Â 42, 4091-4094 (2017).*
3. *F. Amzajerdian, G.D. Hines, D.F. Pierrottet, B.W. Barnes, L.B. Petway, and J.M. Carson, â€œDemonstration of coherent Doppler lidar for navigation in GPS-denied environments,â€ Proc. SPIE 10191, Laser Radar Technology and Applications XXII, 1019102 (2017).*

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