NNA16DATAACQSYSL-ALM, Attachment 1

Nominal Specifications for the Engineering Science Investigation Data Acquisition System

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1 ESI Background and Sensor Suite

1.1 Mission Background

The Planetary Science Division of the Science Mission Directorate in NASA has two categories of competed missions, Discovery and New Frontiers. The prioritized list of planetary missions for New Frontiers is determined by the Planetary Science Decadal Survey (PSDS), *Vision and Voyages*. Four out of 5 of the mission concepts require entry, descent, and landing (EDL) into a planetary atmosphere, including Earth. Venus, Comet Surface Sample Return, Saturn Probe, and South Pole Aiken Lunar Sample Return are the concepts that require EDL for New Frontiers-4. Discovery mission destinations are open ended and proposers may design mission concepts that address the science themes in the PSDS.

The Announcement of Opportunity for New Frontiers-4 is expected to be released in September 2016. It is anticipated that an Engineering Science Investigation (ESI) requirement, similar to that for Discovery-13, will be part of the proposal call. Details of the ESI requirement can be found in the *Discovery 2014 Announcement of Opportunity*, as well as in the document *EDL Instrumentation ESI Proposal Details and Programmatic Structure*.

NASA would like to offer an "off the shelf" ESI sensor suite to mission proposers that addresses the goals and objectives as outlined in the document *EDL Instrumentation ESI Goals and Objectives* for Discovery-13. Following a NASA EDL instrumentation workshop held in August 2015, the prioritized sensors for SMD competed missions would be embedded thermocouples in thermal plugs in the thermal protection system (TPS), similar to the instrumentation suite MEDLI. (A summary of the workshop will be published in an upcoming NASA Technical Memorandum.) Expanded capability would entail recession, heat flux (radiative and/or combined radiative and convective), and/or pressure measurements to the baseline suite. The data acquisition system (DAS) would acquire and process all ESI data, with a possibility of storing and/or communicating the data back to Earth.

1.2 Example Concept of Operations

For planetary missions involving EDL instrumentation, typically a parent spacecraft transports the entry probe. The DAS for the EDL instrumentation is launched while in the non-operational mode (powered off) and remains so throughout most of the cruise phase enroute to the target planet. One or more times during cruise the DAS is powered on to confirm survival of the unit as well as the sensors, and to obtain readings, such as temperatures from the TCs, that are used for later analysis. The probe is then released on an atmospheric-intercept trajectory and its heatshield protects the payload during the rapid deceleration and intense heating associated with aerodynamic drag during entry. After the probe has slowed significantly and heating has diminished to tolerable levels, most missions deploy a parachute to slow the vehicle even more, as shown in Figure 1 from the Galileo mission to Jupiter. The heatshield is generally ejected from the vehicle to further reduce the descent rate, and also to protect the payload from the heat absorbed by the shield during entry. The probe then descends slowly until it either deploys another flight

system, reaches the surface of the planet, or (at a gas giant) gets crushed under the increasing pressure.

Throughout this process, on-board sensors are used to monitor the probe's performance and flight environment. Some measurements are used in real time to trigger mission events at the appropriate point in the trajectory, or transmitted to the parent spacecraft in a status update. Other measurements are stored for later transmission to the parent spacecraft or directly back to Earth. The time available for data transmission before end of mission varies greatly with the mission architecture and environment; some vehicles must transmit rapidly before end of life, while others have more time available.

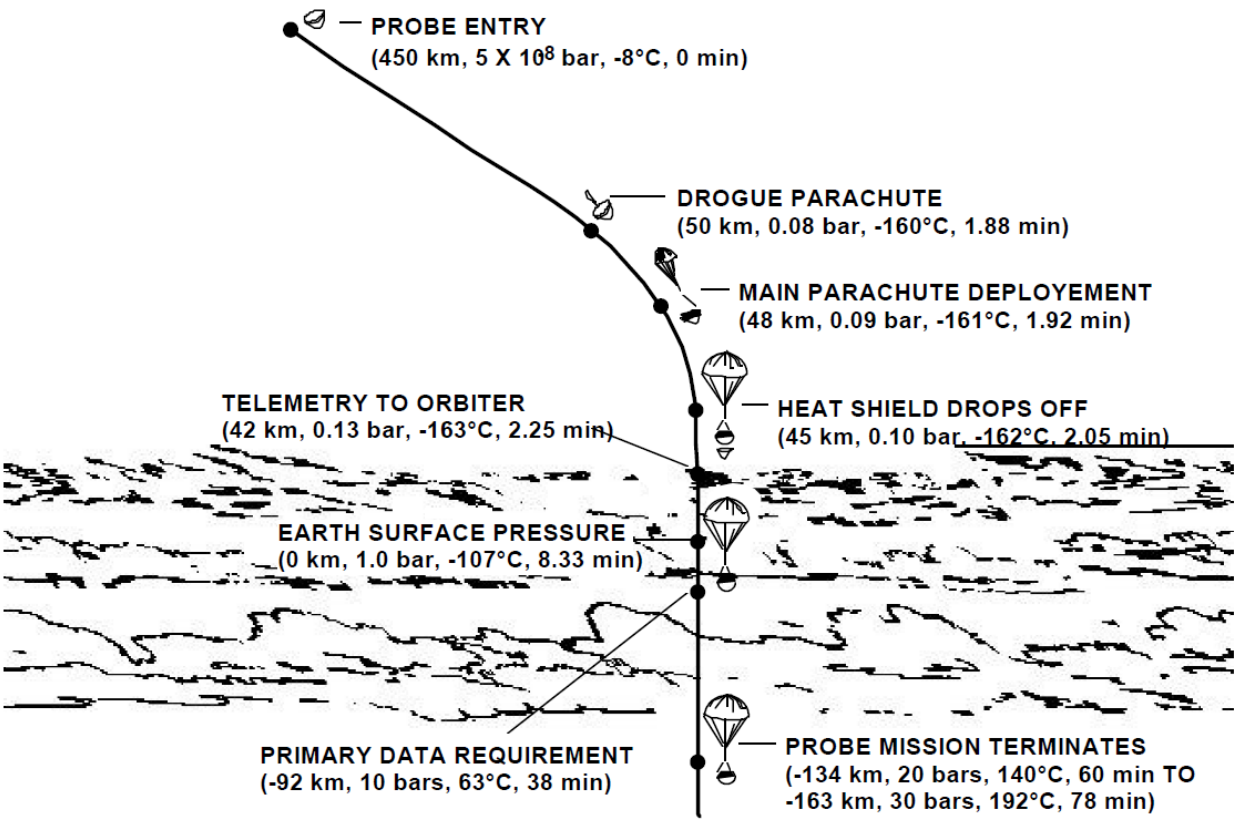

Figure 1 Galileo Probe Entry Timeline

1.3 Example Sensor Suite

For the Mars Science Laboratory mission, the heatshield was instrumented with 7 thermal plugs, each with 4 embedded TCs and one Hollow aErothermal Ablation Temperature (HEAT) sensor, as shown below. The heatshield also had 7 pressure transducers. Data acquisition was handled by the Sensor Support Electronics (SSE) which was designed specifically for the sensor suite. NASA is looking to employ a similar type of sensor suite (thermal plugs) in Discovery and New Frontiers class missions, but substituting a commercially supplied DAS for the NASA-designed SSE. Further details on the MEDLI hardware can be found in *Mars Science Laboratory (MSL) Entry, Descent and Landing Instrumentation (MEDLI): Complete Flight Data Set*.

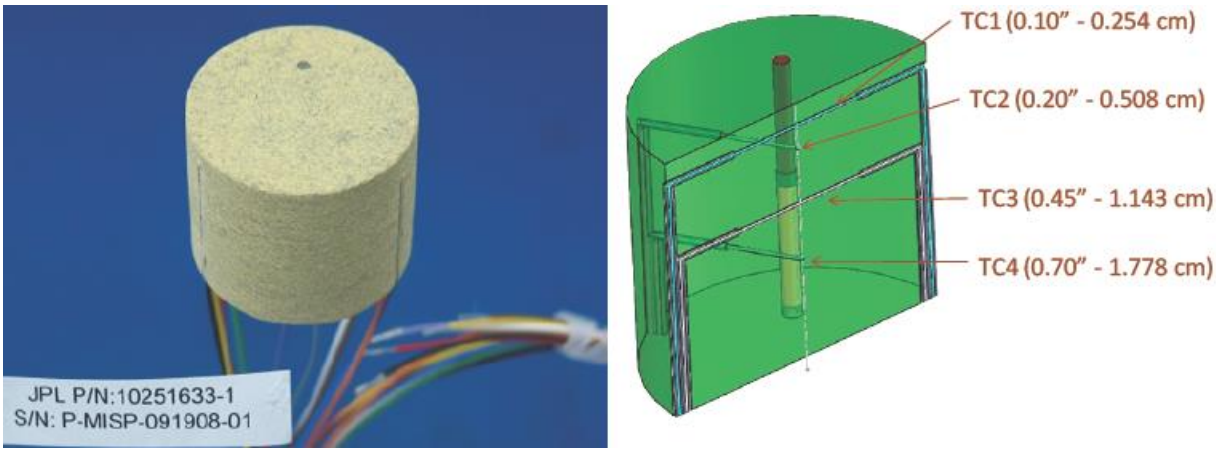

Figure 2 MEDLI Thermal Plugs with Embedded Thermocouples

2 Functionality and Performance

Please provide capability of the DAS with respect to the following items.

2.1 Measurement Resolution

A measurement resolution of 0.25 °C or better is desired for thermocouple (TC) measurements. Please provide the bit rate of the DAS.

2.2 Range of Measurements

The full measurement range for each thermocouple is desired for thermocouple measurements, per Table 1.

TC type	Desired Temperature Measurement Range
K	−270 to 1372°C
R	−50 to 1768°C
S	−50 to 1768°C
B	0 to 1820°C

Table 1 Desired Maximum Thermocouple Range (per ASTM E230, 7.1.2)

2.3 End-to-End Accuracy

A total end-to-end accuracy of 1% full-scale output or better is desired for thermocouples.

2.4 Measurement Rate, per type of sensor

A data rate of 10 Hz per channel or faster is desired for thermocouple measurements. A DAS that can also support sampling at multiple data rates is also desired (e.g. 3 TCs at 10 Hz and 3 TCs at 5 Hz). Ability to switch the data rate for a given thermocouple based on an input signal is desired. An

example application is lowering the data rate based on the output of an acceleration switch or a timer.

2.5 Number of Channels, per type of measurement

A DAS that can support at a minimum of 14 thermocouples (of up to two types shown in Section 2.2) is desired.

2.6 Data Storage Capability

A DAS that can store, at a minimum, 0.5 MB of data in non-volatile memoryg is desired. Additional information on scalability of storage solutions is also requested.

2.7 Concept of Operations

Details of the expected DAS concept of operations is desired; specifically, the necessary sequence and timing of events prior to streaming or storing of EDL data. Also, any external triggering that is required or optional is desired—for instance, triggering recording or streaming of data from an external g-switch.

3 Environments and Survivability

3.1 Operational Temperature Range

A DAS that can function across a wide temperature range is desired. Pre-launch tests include thermal cycling to 10°C beyond the expected maximum and minimum flight temperatures, per NASA Technical Standard "Payload Test Requirements", NASA-STD-7002A. Please specify what range the DAS can tolerate. Typical ranges:

-55°C to +125°C (Military)

-10°C to +125°C (Industrial)

0°C to +70°C (Commercial)

3.2 Non-Operational Temperature Range

A DAS that can survive across a wide temperature range is desired. Please specify what range the DAS can tolerate in a low-power or power-off state. Typical values:

-65°C to +150 (Military)

3.3 Dry Heat Microbial Reduction for Planetary Protection

The DAS shall survive (power off) a Dry Heat Microbial Reduction (DHMR) bake-out to meet Planetary Protection requirements for interplanetary flight per NASA Procedural Requirements "Planetary Protection Provisions for Robotic Extraterrestrial Missions", NPR 8020.12D. Typical DHMR treatment involves heating the assembled vehicle until all internal components reach 125°C for 25 hours.

3.4 Cold Soak Exposure

The DAS shall survive deep space / cold soak conditions for a duration stretching from hours (Earth orbit tests) to years (interplanetary flights). Please specify the coldest temperature the unit can withstand for long duration in a space environment, both during operation and non-operation. (This range may be the same as the ones listed in 3.1 and 3.2, but should be indicated as valid for a space environment for long duration.)

3.5 Launch Environment

The DAS shall survive the specified launch environments:

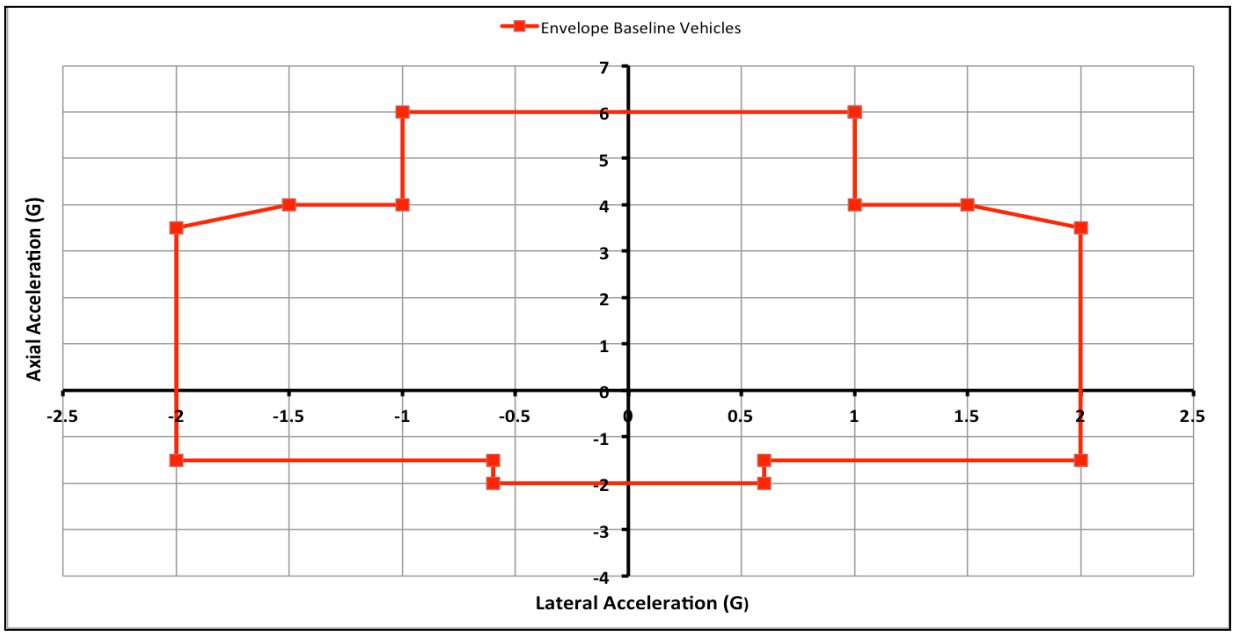

Figure 3 Design Load Factors, per Discovery 2014 AO (envelopes Delta II & Atlas V / New Frontiers loads)

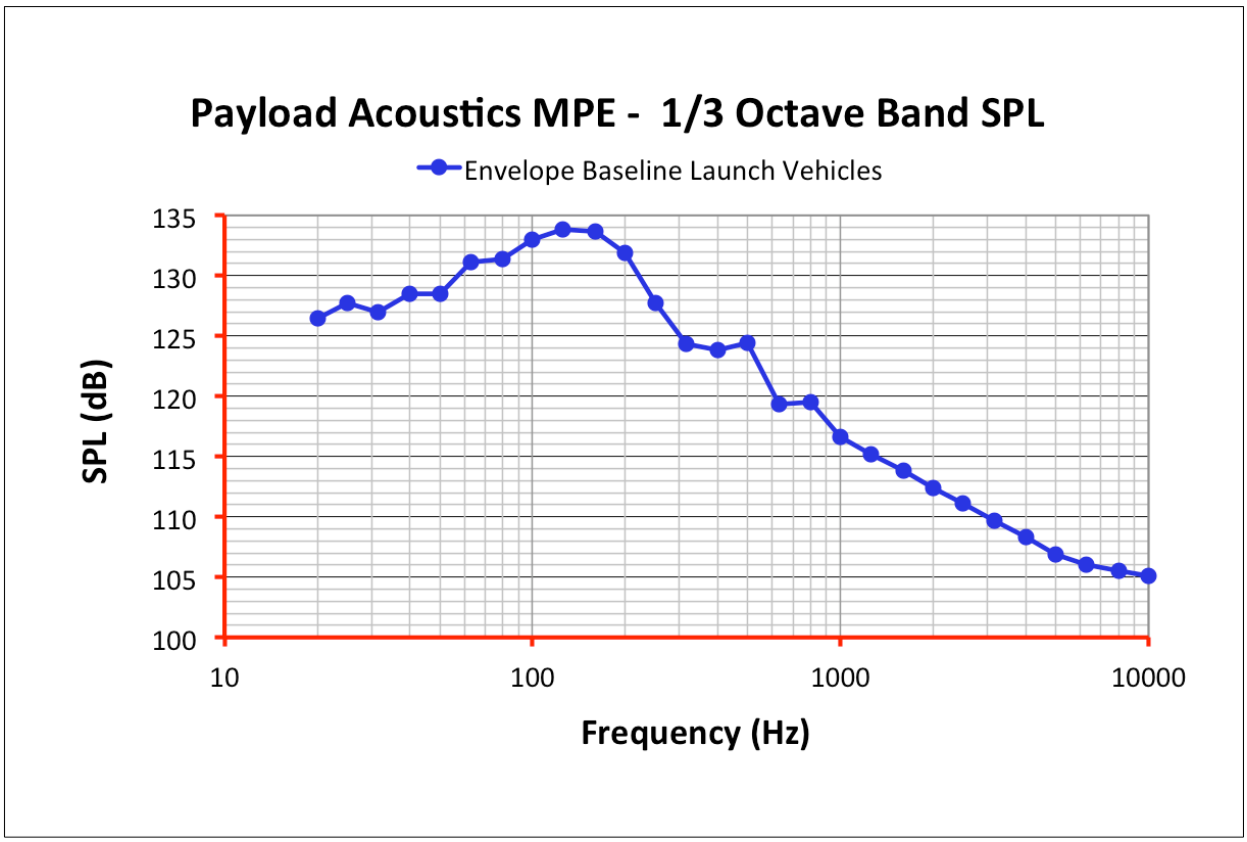

Figure 4 Design Payload Acoustics: Maximum Predicted Environment (MPE) for sound pressure level (SPL), per Discovery 2014 AO (envelopes Delta II & Atlas V / New Frontiers loads)

3.6 Entry, Descent, & Landing Environment

Vehicle loads during atmospheric entry, descent, and landing are highly mission specific. Peak loads generally occur during initial atmospheric deceleration of the vehicle, before parachute deployment. Previous mission deceleration loads have exceeded 200 G's for the Pioneer Venus mission and the Galileo probe at Jupiter. Please specify the acceleration load tolerance of the DAS.

3.7 Pyrotechnic and Mechanical Shock Loads

Launch vehicle staging, payload separation, entry vehicle release, and mission-specific hardware deployments will induce a range of pyrotechnic and mechanical shock loads. (Example below.) Please specify the shock-tolerance levels of the DAS, to permit evaluation of isolation needs.

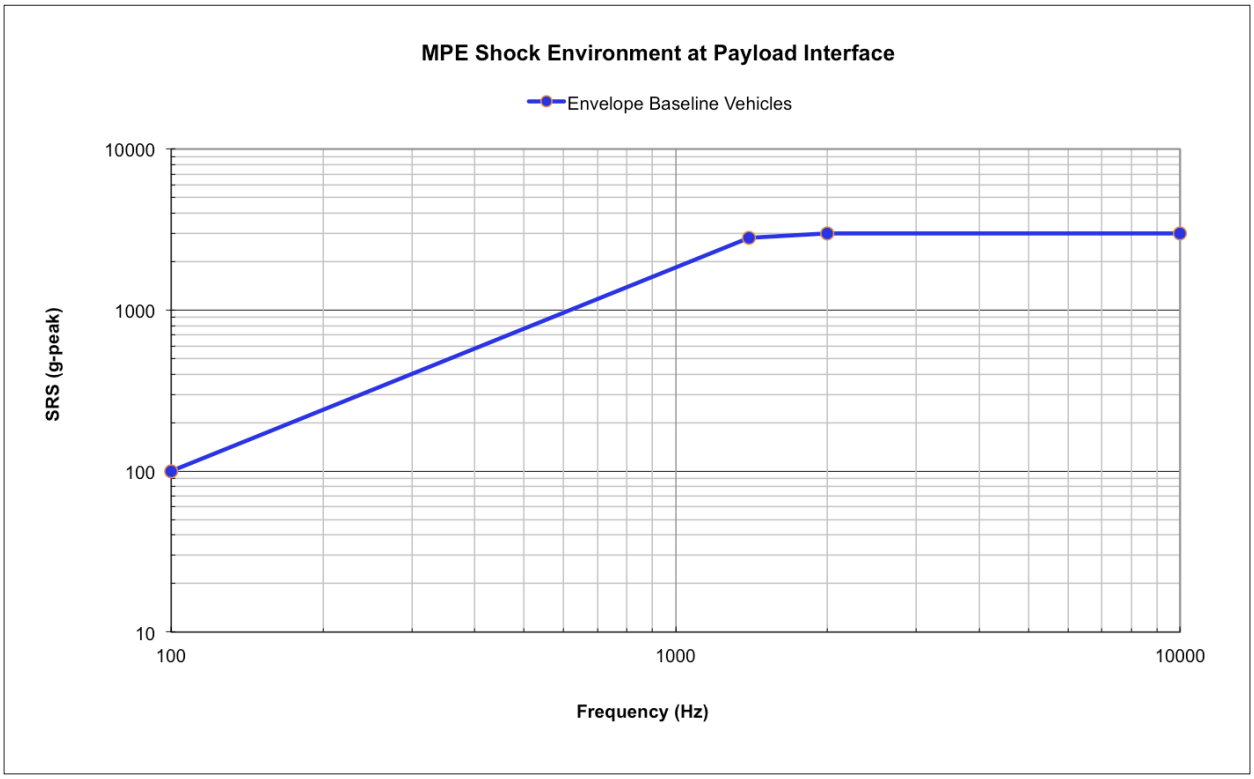

Figure 5 Design Shock Load: MPE Shock Response Spectrum (SPS), per Discovery 2014 AO (envelopes Delta II & Atlas V / New Frontiers loads)

3.8 Radiation / Single Event Effects / Error Correction

The space radiation environment varies greatly with location and mission architecture. Systems must typically tolerate unpredictable solar particle events and galactic cosmic rays, as well as mission-specific conditions such as the high-energy electrons (up to 500MeV, per 2007's *Extreme Environments Technologies for Future Space Missions*) trapped in Jupiter's magnetic field. Please describe the radiation-tolerance of your system and its approach to handling single event effects and related errors.

3.9 Space Environment Heritage

There are many unusual hazards associated with the space environment, from electrical shorts caused by solder whisker growth to the contamination of optics by cadmium plating on nearby mechanical fasteners. Please describe your company's experience with developing equipment for the space environment, and the flight heritage of the DAS.

4 Configuration and Mechanical Interface

For Discovery and New Frontiers class missions, mass and volume in the spacecraft are typically at a premium. A DAS that is small and lightweight is preferred.

4.1 Unit Shape and Size

List unit dimensions. If the unit is modular, list the minimum size achievable, and the increased size if additional modules are installed.

4.2 Total Mass and Mass Properties

List total mass of unit for configurations listed in 4.1. If known, list mass properties.

4.3 Mounting Hardware and Attachments

Depending on the mission concept, various spacecraft designs may need to mount the DAS in different locations depending on volume and payload constraints. Submit a drawing or provide a description of a preferred DAS mounting scheme, as well as any orientation restrictions (if any).

4.4 Modularity and Optional Modules

List optional modules that may be added to the DAS, along with the corresponding mass, size, and ROM cost increases.

4.5 Mating Connector Type

List mating connector type.

5 Electrical Connectivity

5.1 Nominal Power Consumption

Resource constraints for planetary missions require that electronic systems be extremely efficient in performing their tasks. This generates the requirement for the DAS to be as low power as possible when active. For reference the MEDLI 2 DAS that will fly on Mars 2020 will have a nominal power consumption of 10W. This is for a total of ~90 measurements. The DAS for this RFI will likely have less resources available and therefore there will be fewer measurements. 10W should be considered the maximum allowable power consumption, but much lower is desired.

5.2 Input Voltage

Spacecraft power buses commonly operate at 28VDC. Therefore the ESI DAS would ideally accept 28VDC within the input voltage range. Lower input voltage ranges would also be acceptable, but not preferred, as additional power regulation would be required.

5.3 Over-Voltage Protection

Given the extreme environments this DAS and parent spacecraft would be subjected to, it is important to include additional protection in case of a voltage bus drift or spike. Over-voltage protection should be considered at 35VDC or better. This is not a hard requirement since additional protection can be applied external to the DAS, but it would greatly simplify the system if this protection is built-in.

5.4 Start-Up Time

In the case of a power cycling event it is important that the data system be able to resume operations as quickly as possible. Please provide the required start-up time for the DAS to be powered-on and operational.

5.5 Data System Serial Interface

To communicate with the spacecraft computer or data transmission system a common serial interface is required. RS422 standard spacecraft serial protocol and is the desired interface. Other serial protocols such as RS232, RS485, CAN, SpaceWire, and Ethernet are also acceptable, and depending on the mission hardware may even be advantageous. Flexibility between multiple serial protocols would be highly desirable.

5.6 Thermocouple Measurements

The baseline sensors for use with the DAS are thermocouples. These sensors will be used to measure the thermal response of the spacecraft's heatshield (forebody or afterbody) during atmospheric entry. The following items are specific to TC functionality.

5.6.1 Open Circuit Detection

By design, an in-depth TC in the TPS material may burn out during EDL due to material recession. It is desired that the DAS provide open circuit detection so that if a sensor becomes disabled that channel can be easily distinguished from a working channel. If the open circuit is left floating it can be difficult to differentiate the two scenarios.

5.6.2 Cold Junction Correction

Please specify how the DAS will perform cold junction correction for the TC signals.

5.6.3 Transient Voltage Protection

Used commonly on aircraft electronics to mitigate lightning strikes, transient voltage suppression (TVS) technology was also used on MEDLI to protect against any electrical phenomena that might have propagated from the outside of the vehicle down through the thermocouple wires. 1500W is the upper bound of what is required for lightning TVS and is therefore the desired amount for the DAS.

5.7 Pressure and Thermopile Sensor Measurements

Pressure sensors, heat flux sensors and radiometers are of interest in addition to TCs. The following section lists items specific to these sensors.

5.7.1 Signal Input Range/Gain

The DAS is required to have a selectable gain or programmable input range of ±10mV to ±10V. Programmable input range will allow us to change the gain or amplification of the sensor signal providing better resolution of the signal. ±10mV is based on some candidate heat flux sensors and full bridge pressure sensors (0-10mV). However some sensors have higher outputs and even sometimes built-in amplification. Having a programmable range

or gain allows the freedom to use different sensors with different output ranges to maximum measurement resolution.

5.7.2 Open Circuit Detection

It is desired that the DAS provide open circuit detection to determine if a sensor becomes damaged or disabled. If the open circuit channel is left floating it can be hard to tell the difference between an active channel and a disabled sensor.

5.7.3 Signal Excitation

It is desired that the DAS have programmable sensor excitation ranging from 3.3V to 10V. If excitation is provided by the data system for sensors such as full-bridge pressure sensors then the team will not to have utilize a separate power source to excite the sensor.

5.7.4 Offset and Tare Capability

Please provide any information on the DAS ability to perform signal tares (channel zeroing) and signal offsets.

5.8 Recession Sensor Measurements

In addition to thermocouples, thermopiles, and pressure transducers, NASA is also interested in TPS recession sensors. Recession sensors typically have two different kinds of electrical interfaces. The first of these, the ARAD and HEAT sensors that have flown on past missions, utilize a milli-Amp (mA) source to excite a variable resistance, thus producing a voltage that could be measured. Data from these types of sensors could be acquired by the requirements in section 5.7 with the addition of a mA source. The second type of recession sensor (which is currently under development) utilizes photo-electric sensing. Functionally this looks similar to a pressure sensor (i.e. voltage excitation induces a voltage sensor response). This type of recession sensor would be encompassed by the requirements in section 5.7. Please specify the ability of the DAS to acquire data for these 2 types of recession sensors.