Low Cost Entry, Descent, and Landing (EDL) Instrumentation for Planetary Missions

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Outline

- Background and Motivation
- Workshop Recap
- Commercial Data Acquisition Systems
- Drivers for Cost and Mitigation Methods
- Current Status and Future Work

EDL Instrumentation Overview

Flight Instrumentation

Reduce system risk
- Better definition of entry environment
- Characterize system performance
- Identify "unknown-unknowns"

Increase system performance
- Reduce TPS mass/margins
- Increase landing accuracy

Identify capability limit of build-to-print systems
- Reduce predicted environment
- Identify excess margin

Reduce development costs
- Reduce testing and analysis
- Open design space by reducing predicted environments

Obtain in-situ system and atmosphere data
- In-situ atmosphere density, winds, and trajectory reconstruction

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- Mission opportunities are limited, and most are unique; every lost opportunity is a setback
- Types of flight instrumentation/measurements: thermocouples, pressure sensors, heat flux gages, recession sensors, radiometers, spectrometers, etc.

EDL Instrumentation on Missions

Year	Mission	Planet	Forebody TPS	Afterbody TPS	TCs	Pressure	Heat Flux	Calorimeter	Radiometer/ Spectrometer	Recession/ Isotherm
1965	FIRE II	Earth	Beryllium	Fiberglass	X	X	X	X	X	
1966	Apollo AS-201	Earth	Avcoat	Avcoat	X	X	X	X		
1966	Apollo AS-202	Earth	Avcoat	Avcoat	X	X	X	X		
1967	Apollo 4	Earth	Avcoat	Avcoat	X	X		X	X	
1968	REENTRY-F	Earth	Beryllium	Glass-Phenolic	X	X	X			
1968	Apollo 6	Earth	Avcoat	Avcoat	X	X		X	X	
1971	PAET	Earth	Beryllium & Silicon Ealstomer	Silicon Elastomer	X	X	X		X	
1975	Viking	Mars	SLA-561	None	X	X				
1978	Pioneer Venus Large	Venus	Carbon-Phenolic	Phenolic-nylon	X					
1978	Pioneer Venus Small	Venus	Carbon-Phenolic	Phenolic-nylon	X					
1981	Shuttle	Earth	Reuseable	Reuseable	X	X	X			
1995	Galileo	Jupiter	Carbon-Phenolic	Phenolic-nylon	X			X		X
1997	Mars Pathfinder	Mars	SLA-561V	SLA-561S/SIRCA	X					
2012	IRVE-3	Earth	Rigid nose & Flexible Insulator	None	X	X	X			
2012	MSL-MEDLI	Mars	PICA	SLA-561V	X	X				X
2014	Orion EFT-1	Earth	Avcoat	Tiles	X	X			X	X
2015	LDSD-SIAD	Earth	Kevlar Attached	None	X	X				
2018	Orion EM-1	Earth	Avcoat	Tiles	X	X			X	
2020	Mars2020-MEDLI2	Mars	PICA	SLA-561V	X	X	X		X	

Compiled from B. A. Woollard, R. D. Braun, and D. Bose, “Aerodynamic and Aerothermal TPS Instrumentation Reference Guide,” IEEE Aerospace Conference, March 2016, Big Sky, MT.

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Motivation

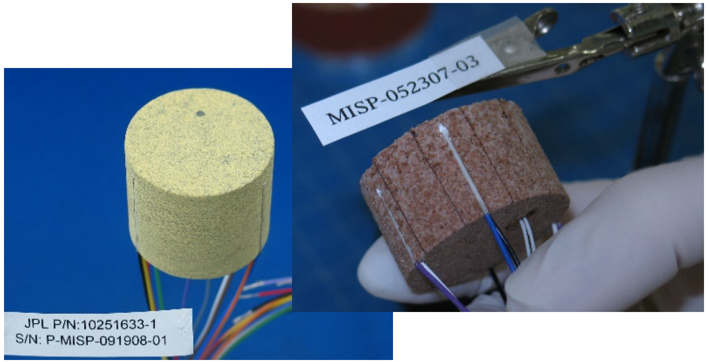
- To date, no Discovery or New Frontiers missions have EDL instrumentation
- In 2014, Agency leaders agreed to consider incorporating EDL instrumentation for every mission early in the planning phases
- Discovery-12 Announcement of Opportunity in 2014 had a requirement for an Engineering Science Investigation (ESI) for all mission concepts involving EDL
  - Goals and Objectives document prioritized possible measurements
  - 2 High and 1 Medium priorities had to be addressed, from 2 different categories
- New Frontiers-4 Community Announcement also indicated that ESI would be required for the mission concepts involving EDL
  - 5 out of the 6 mission concepts require EDL
  - Mission concepts: *Comet Surface Sample Return*, *Lunar South Pole Aitken Basin Sample Return*, *Venus In-Situ Explorer*, *Saturn Probe*, and *Ocean Worlds* (*Titan)*.

Need for a Standardized ESI Suite

- Principal Investigator-led missions are cost-capped, leading to concepts with high heritage and low risk tolerance
  - Typically entry systems have limited volume, mass, power, and data rate transfer
- A NASA-selected and endorsed ESI solution that is “off the shelf” would streamline design phase and provide mission proposers with a solution that satisfies the EDL community while remaining low risk
  - Advantage: lower cost and risk
  - Mission proposers would understand early in the mission definition stage what would need to be integrated in their concept (hardware, operations, etc)
  - But how to create a “one size fits most” sensor suite?

EDL Instrumentation Workshop

- Workshop held at Ames on August 19, 2015
  - Purpose was to formulate a Game-Changing Development (GCD) effort for FY17+, to produce a low-cost EDL instrumentation suite for Discovery and New Frontiers class missions
  - Attendees were NASA and DoD stakeholders and EDL instrumentation implementers
- Target was to create a ~$5M sensor package for competed missions (high TRL components)
  - A commercial, off-the-shelf (COTS) data acquisition system (DAS) best solution (not a custom-built electronics system)
  - Baseline sensor suite would be TPS thermal plugs only (forebody and/or aftbody)
- Identified the need for other optional sensors, depending on mission concept, planetary destination, vehicle configuration
- Sensors requiring development identified and deemed a high priority
  - In-depth thermal measurements in Heatshield for Extreme Entry Environment Technology (HEEET)
  - Recession sensor
  - Radiometer in an ablating material
  - Wireless sensors



Baseline: In-Depth TCs in TPS

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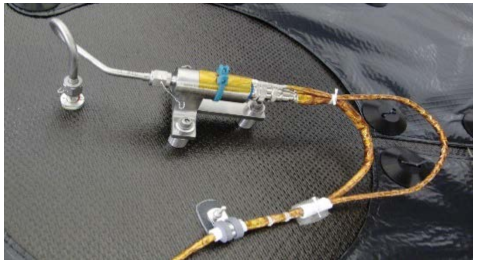

Option: Pressure Transducers

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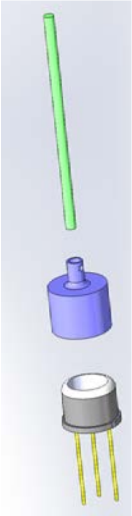


Option: Recession Sensors

etc

Commercial Data Acquisition Systems

- Following the workshop, a sub-group developed a set of requirements and desired known quantities for COTS-based DAS
- A Request For Information (RFI) was issued on November 16, 2015. Responses were received a month later, with 4 vendors responding. Two of the units described by the vendors met most of the requirements. Would need to test to confirm several aspects, such as:
  - Cold soak temperature survivability during interplanetary cruise
  - Dry Heat Microbial Reduction (DHMR) bake-out survivability
- Cost of the unit itself is inexpensive but for documentation and qualification by vendor, cost increases by about 3 times

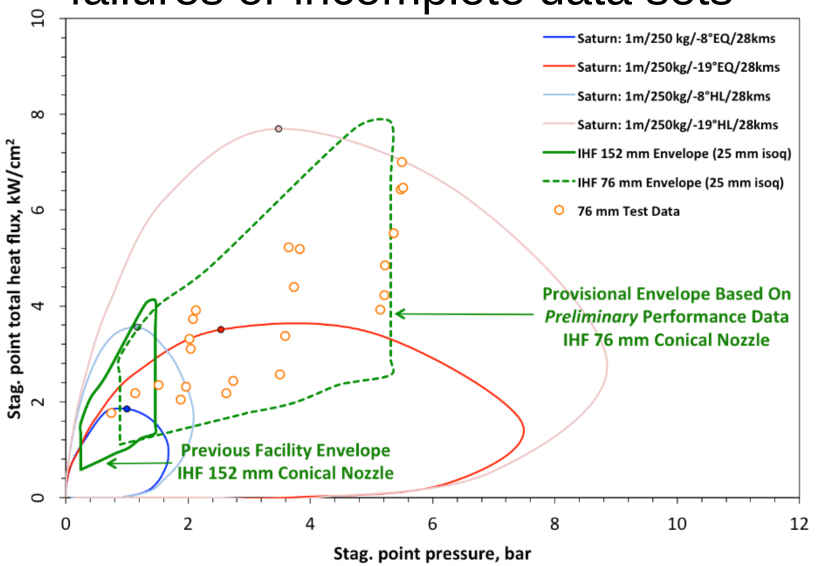
	Notes
Environments/survivability	
Operational temperature range	-40C to +80C
Non-operational temp range	
Cold soak exposure time (cruise)	hours to months/years
Launch/EDL exposure times	minutes to hours (thermal soak)
Ground testing thermal cycling	+/- 10C above/below max/min flight
DHMR/sterilization	
Acceleration loads	0 to 200 G
Shock loads (mechanical/pyro)	
Radiation	
SEU handling	
Mechanical interface	
Footprint	as small as possible desired
Total volume	as small as possible desired
Mass/mass properties	as small as possible desired
Mounting hardware/attachments	describe
Modularity (data storage, etc) and # of	describe
Orientation constraints	describe any constraints
Mating connector type	list recommended type, height may be an
Electrical interface	
Power Consumption: max, average	MEDLI was 30W, less for smaller missions?
Operating Voltage	Lower than 28V operating voltages needs a power regulator
Over Voltage Protection	Desired
Transient Voltage Protection	Desired
Data System Serial Interface (UART, RS4	RS422 is a fairly standard spacecraft serial interface
Programming Interface and Software	Info Requested (Not a Requirement)
*******Thermocouples***	
Thermocouple Type	Type R, K used

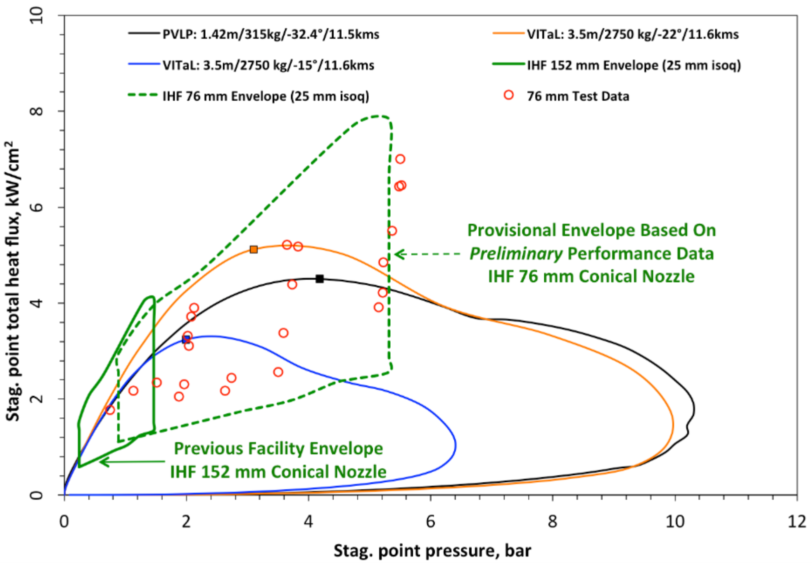
Cost Drivers

- Qualification (including environmental tests) and calibration testing are expensive
  - High heritage sensor hardware is relatively inexpensive
  - For TCs and pressure transducers, each sensor generally < $10k
  - However, many units need to be procured: flight units, flight spares, qualification units, development units, etc.
- Integrating the sensors onto the vehicle is not difficult, but standardized methods for installation would reduce cost
  - Limit developing new processes, procedures, tooling for every mission
  - New drawings may still need to be generated
- Off-the-shelf sensors may not meet mission specific requirements
  - Example: supersonic pressure transducers for MEDLI2 (heatshield cold temperatures during interplanetary cruise)

Methods to Minimize Cost

- Use TRL 6+ sensors only
- Qualify and calibrate sensors for bounding cases (such as Saturn/Venus entries)
  - TCs in different materials: SLA, PICA, HEEET: arcjet testing at high heat fluxes/loads/pressures/shear
  - Environmental testing
- Use heritage integration/installation procedures
- Accept higher data return risk (but at no harm to the mission)—there may be failures or incomplete data sets





From D. Prabhu, I. Terrazas-Salinas, E. Noyes, and J.Balboni, NASA TM-2015-218934, Nov 2015

Current Status and Forward Plans

- Strategic Capabilities Assets Program (SCAP) is in the process of purchasing 2 of the COTS DAS units identified in the RFI process
- GCD Program unlikely to fund project with a FY17 start, based on current budget projections
  - A NASA-developed ESI package will not be offered to proposers for NF-4
  - Proposing teams must develop custom solutions to meet ESI requirement for NF-4
- Science Mission Directorate has funded Ames to develop in-depth thermal instrumentation for HEEET, starting immediately
  - Leverage HEEET team's arcjet coupon model designs and processes
  - Develop plug installation and integration techniques
  - **Deliver designs and "best practices" to NF-4 teams that utilize HEEET**

Questions?