DS2 Follow-on Experiment

Ground Validation of Design Principles for High-G Environments

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Agenda

Saverio D'Agostino
- Background
- Objectives
- Experimental Design
- Preliminary Results

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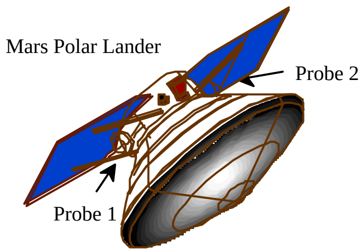
- Technical Approach
- Scope/Schedule
- System Architecture
- Software Design
- Test

New Millennium Program

- NMP Charter
- DS2 project: tasked to demonstrate technologies for network science studies
- 2 probes carried on Mars Polar Lander in 1999
- Inexpensive vehicle for network science
- Designs and materials developed for high G impact landing, in addition to other technologies not addressed here

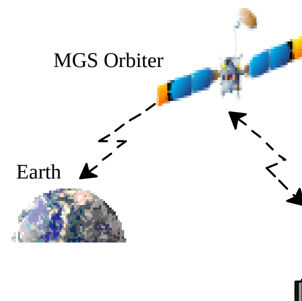
DS2 MISSION PROFILE

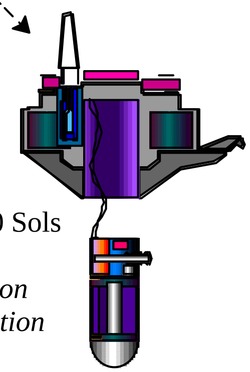


Cruise
11 months
Arrive December 3, 1999
No Microprobe Operations

Entry, Descent & Impact
Separation to Impact - 10 minute
Entry System Validation

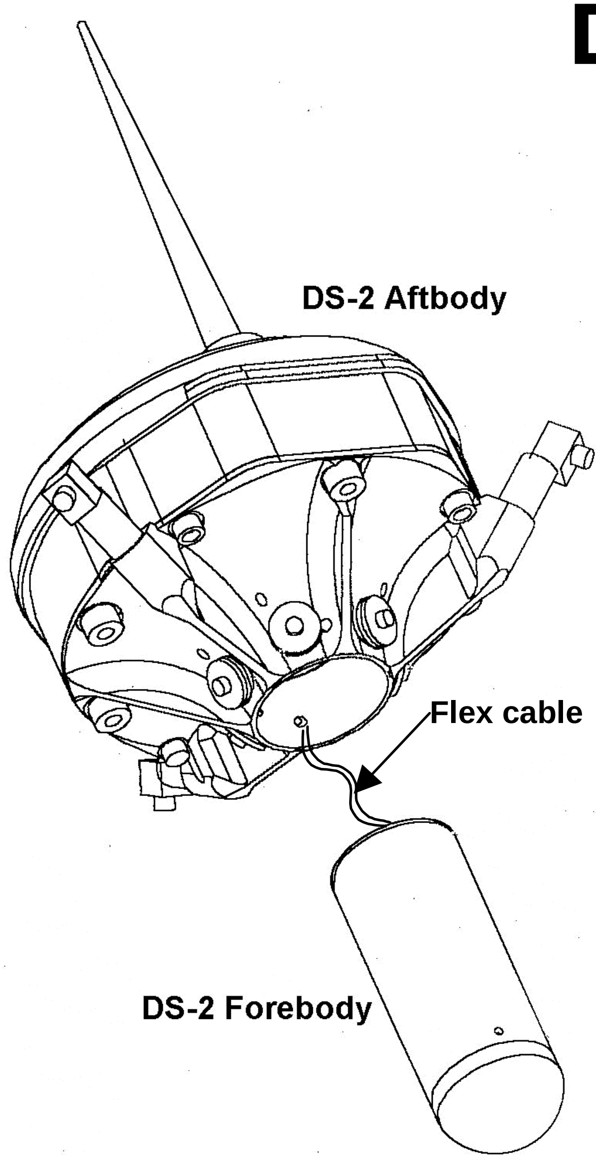
Launch
January 3, 1999
Delta 7425 II Launch Vehicle

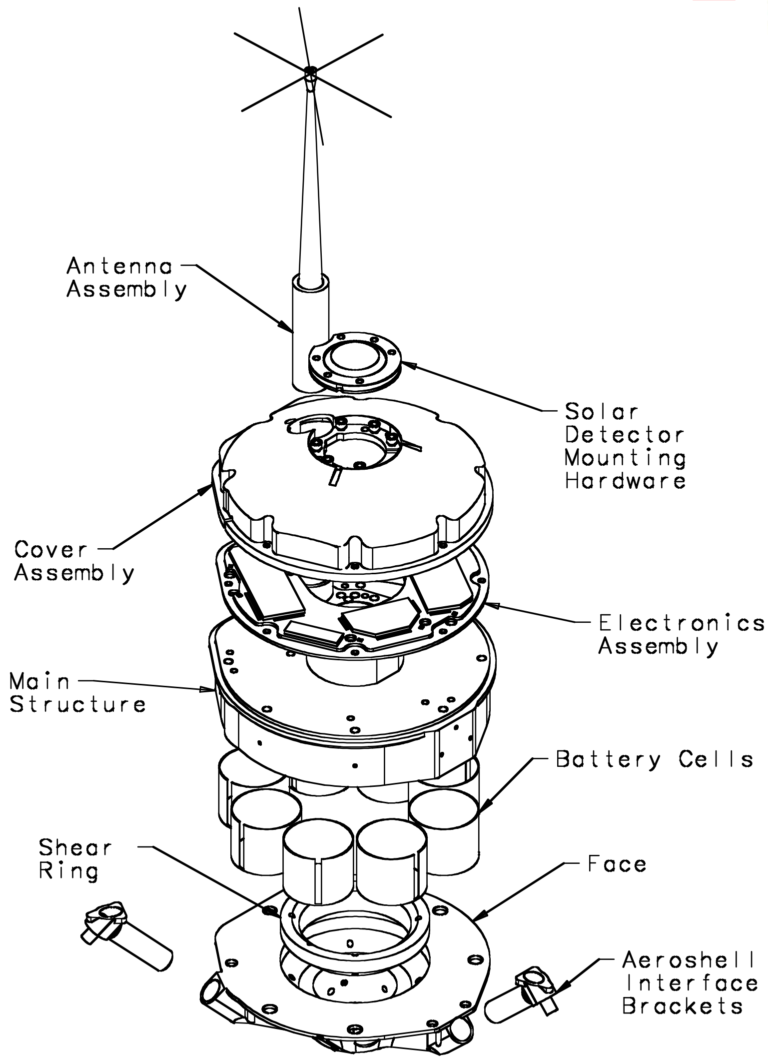




Landed Operations
Primary Mission: 1-10 Sols
Objectives:
Technology Validation
Science Data Collection

DS2 Probe

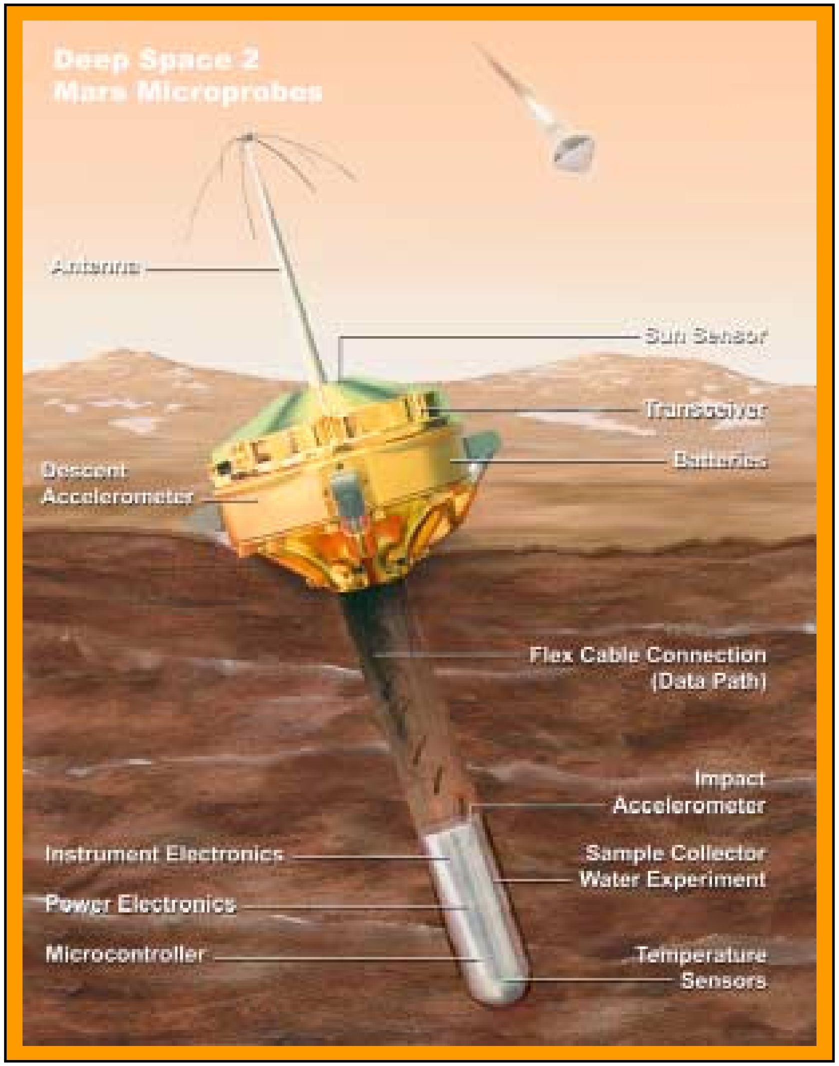




Forebody Separated From Aftbody

Aftbody Exploded View

DS2 Probe


Deep Space 2
Mars Microprobes
Antenna
Sun Sensor
Transceiver
Batteries
Descent
Accelerometer
Flex Cable Connection
(Data Path)
Impact
Accelerometer
Instrument Electronics
Sample Collector
Water Experiment
Power Electronics
Microcontroller
Temperature
Sensors

DS2 Limitations / Follow-On Rationale

- Testing program omitted powered impact tests due to time and budget constraints
- No data received from probes at Mars (1999)
- DS2 technologies not demonstrated in space
- Additional successful impact tests will further validate these technologies, and make them more viable for proposing on new missions

DS2 Follow-on Experiment

Purpose

- Validate the design principles and core technologies used in the DS2 project when subjected to an expected Mars mission impact environment.
- Provide an independent characterization of the impact environment.

Objectives

- Measure the performance of the selected technologies and validate design principles employed in the probe system after environmental tests that simulate the expected nominal impact and subsequent thermal conditions for the DS2 mission at Mars.
- Characterize the dynamic impact environment and test sensor technologies .
- Determine effects of impact on the parameters of the probe system, subsystems, and components.
- Provide a test vehicle for anticipated sensor systems for new proposals.

11 DS2 Design Principles Targeted for Testing

	DESIGN PRINCIPLE	COMPONENT OR UNIT	VALIDATION IMPACT TEST INSTRUMENTATION OR CONFIRMATION APPROACH
1	Materials selection and geometry base upon stiffness requirement to limit deflection	Integrated electronics/structure	Strain gauges on electronic substrates of both forebody and aftbody
2	Multiple transitions of compliance between components and supporting structure acts to reflect shock pulse and dampen high frequency components of pulse	Integrated electronics/structure, shock sensitive components	Pair of accelerometers with and without multiple interfaces, reference crystal survival and functionality post test
3	Compressive preloading utilized to prevent tensile loading and to minimize deflections	Integrated electronics & structures, forebody prism	Strain gauges on electronic substrates and structures

DS2 Design Principles, continued

	DESIGN PRINCIPLE	COMPONENT OR UNIT	VALIDATION IMPACT TEST INSTRUMENTATION OR CONFIRMATION APPROACH
4	Design loads based upon calculated average acceleration times 1.5 to 2.0	All structure and component mounting	Accelerometers and strain gauge suite being defined for forebody and aftbody
5	Uniformly support all components	Electronic components and interconnect	Functionality and post test observations and analysis
6	Clearances between moving part minimized; this is an extension of fully supporting all components	Mechanisms	Post test functionality and inspection
7	Electronic assemblies and fabrication baselined as “Direct Die Attach”	Electronics and sensors	Add strain guage die to confirm stresses experienced by active components; loads confirmed by accelerometers

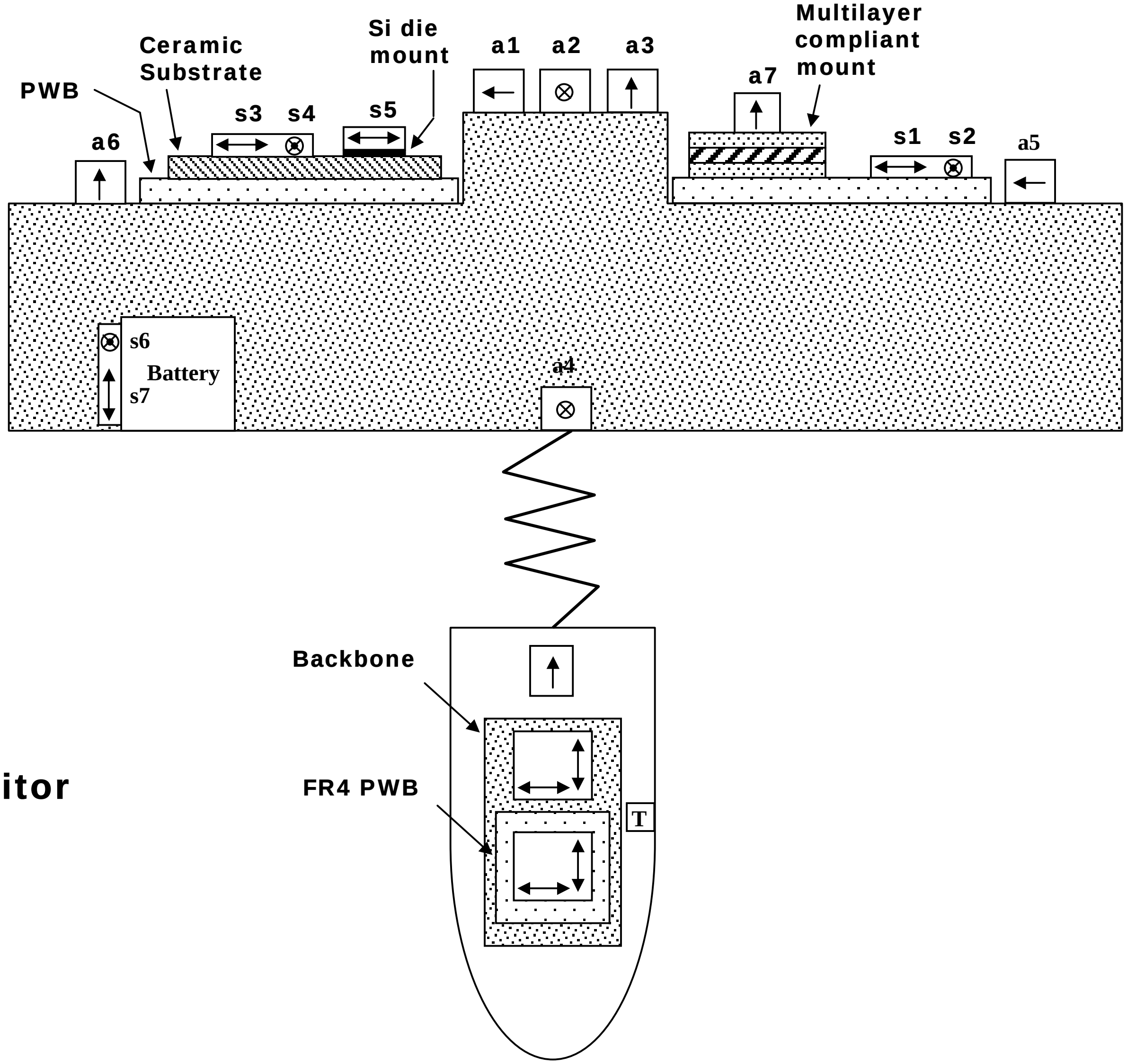
DS2 Design Principles, continued

	DESIGN PRINCIPLE	COMPONENT OR UNIT	VALIDATION IMPACT TEST INSTRUMENTATION OR CONFIRMATION APPROACH
8	Treat fluid filled batteries as pressure vessels and assemble to control deflection of case	Batteries	Strain gauges on battery case particularly in area of glass to metal feed-throughs in lid
9	Internal wiring of battery strain relieved and supported as fully as possible	Batteries	Pre and post test X-rays to observe motion of battery internal wiring
10	Stacked planar electrodes with extended insulating separators to minimize likelihood of shorting to case	Batteries	Pre and post test X-rays to observe motion of battery internal wiring
11	Fan fold deployment of umbilical from forebody to have no tension deployment	Forebody to aftbody flex circuit umbilical	Functionality after test, inspection

Probe Sensor Suite to Address Design Principles

- **Aftbody Sensors**
  - 6 accelerometers
  - 7 strain gauges

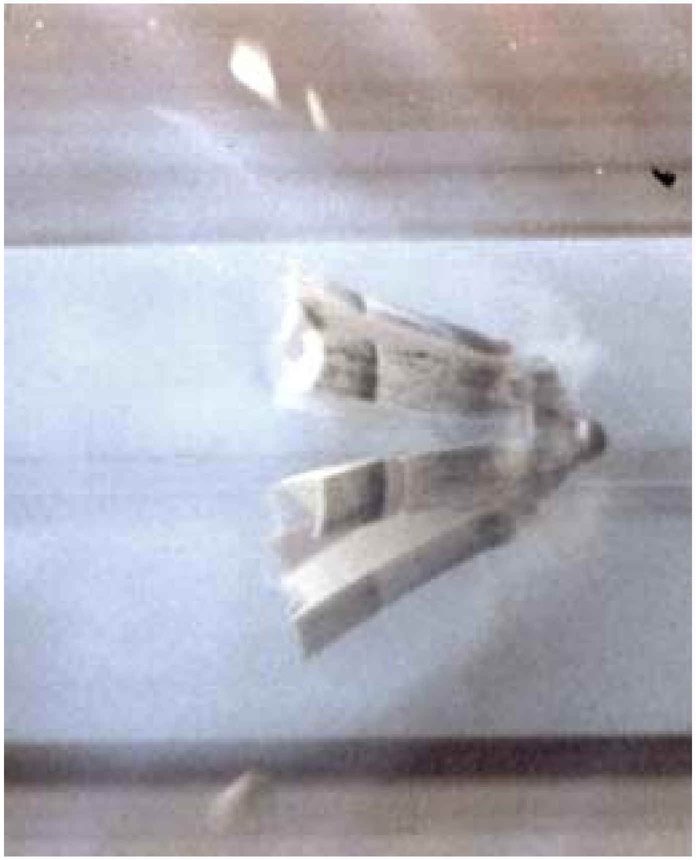
- **Forebody Sensors**
  - 1 accelerometer
  - 4 strain gauges
  - 1 temperature monitor



Impact Testing at EMRTC

Sandia Airgun and Probe in Sabot

Probe 2 Impact Test



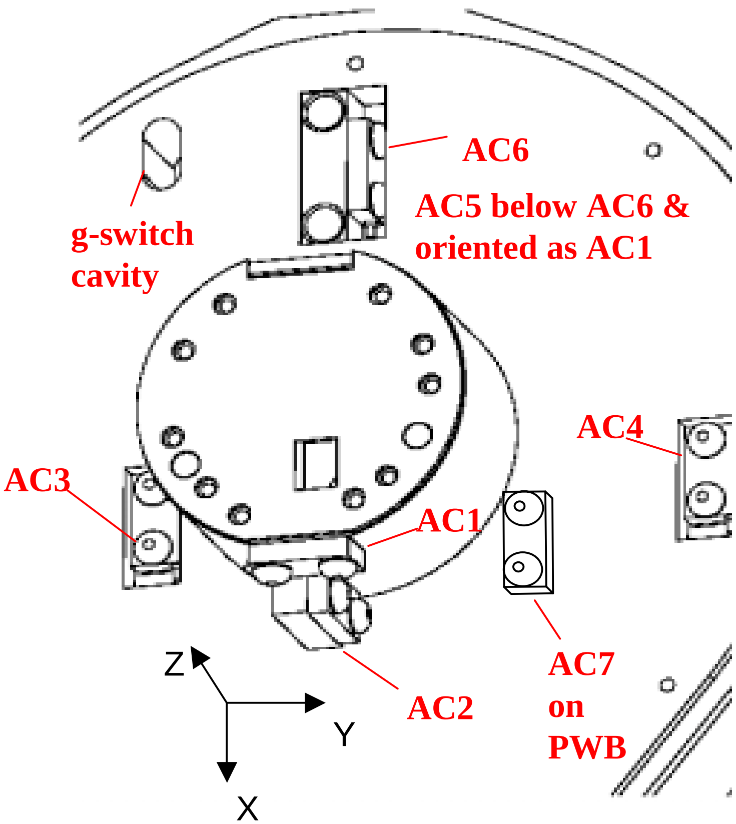
Streak image of probe in flight where sabot begins breaking up

Excavated side view of probe after impact

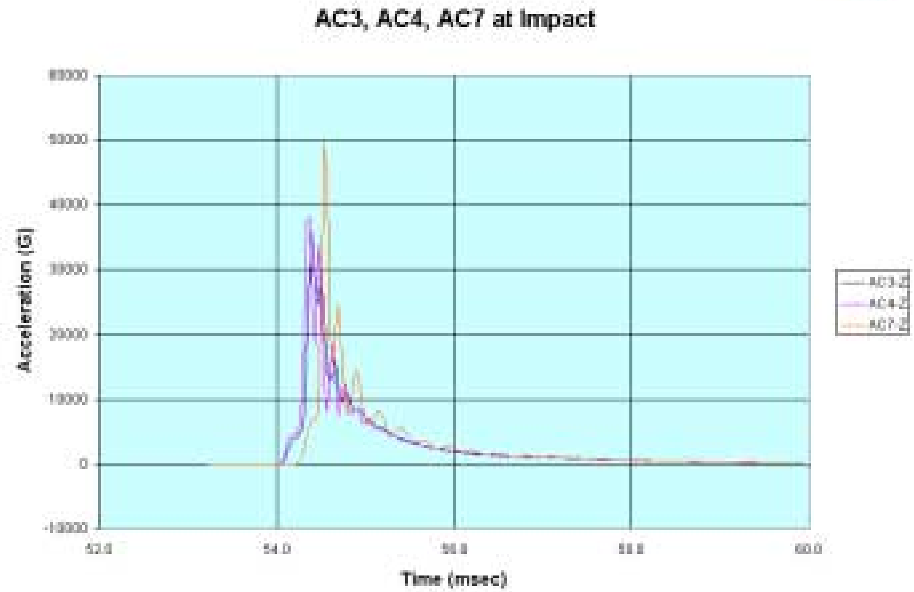
Z-axis Accelerometer Data and Double-integrated Results from Probe 2 Impact Test

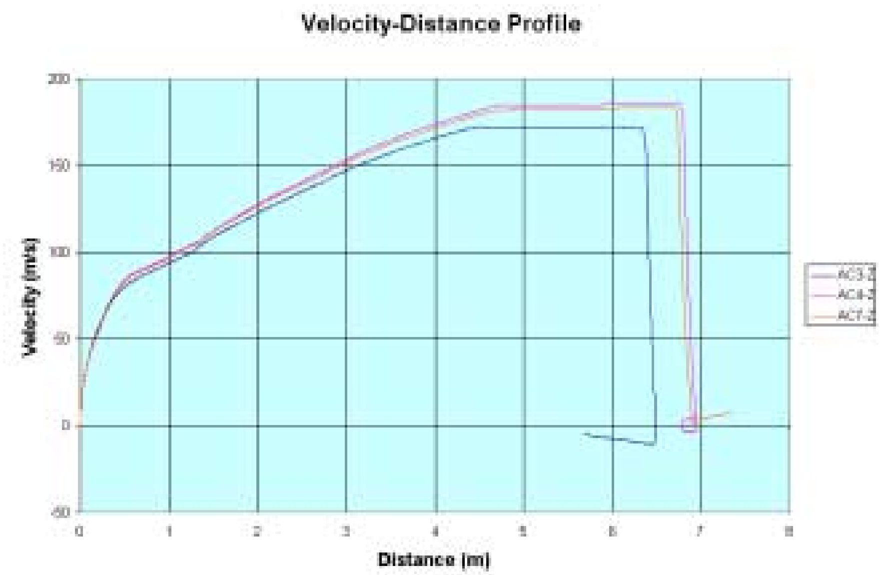
NEW MILLENNIUM PROGRAM

DS2 Follow-On Experiment

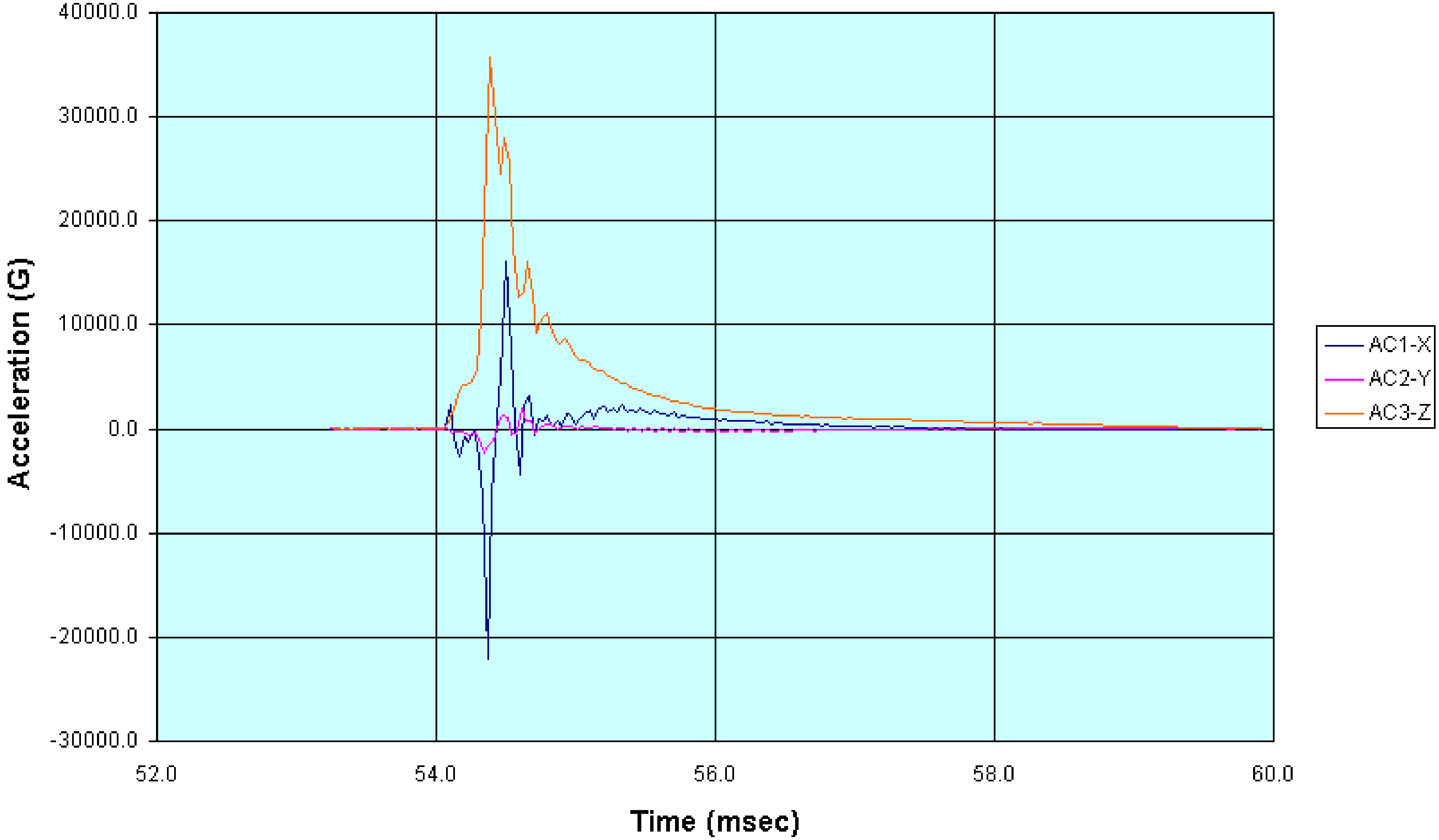


Aftbody Accelerometer locations and Orientations





Aftbody X-, Y- and Z-Accelerations at Impact



Impact Test Probe Development

Brent Blaes

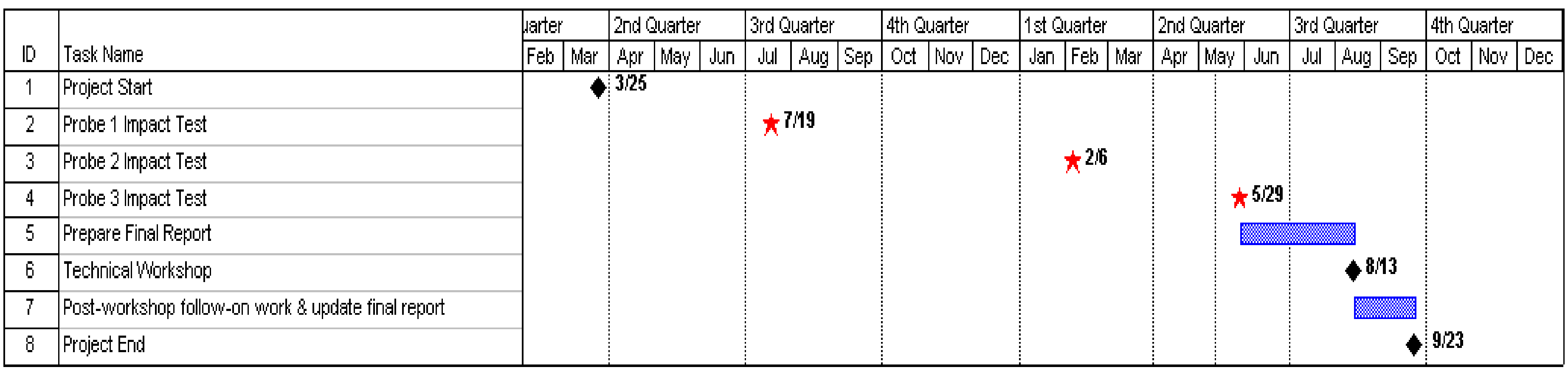
Technical Approach

- Use same basic mechanical design as DS2 probe
- Use DS2 spare parts (batteries, flex cable, face plate, forebody parts)
- Attempt to use commercial data logger
  - As backup, develop low-cost data logger using commercial off-the-shelf (COTS) parts
- Incorporate fault tolerance (use multiple independent data loggers)

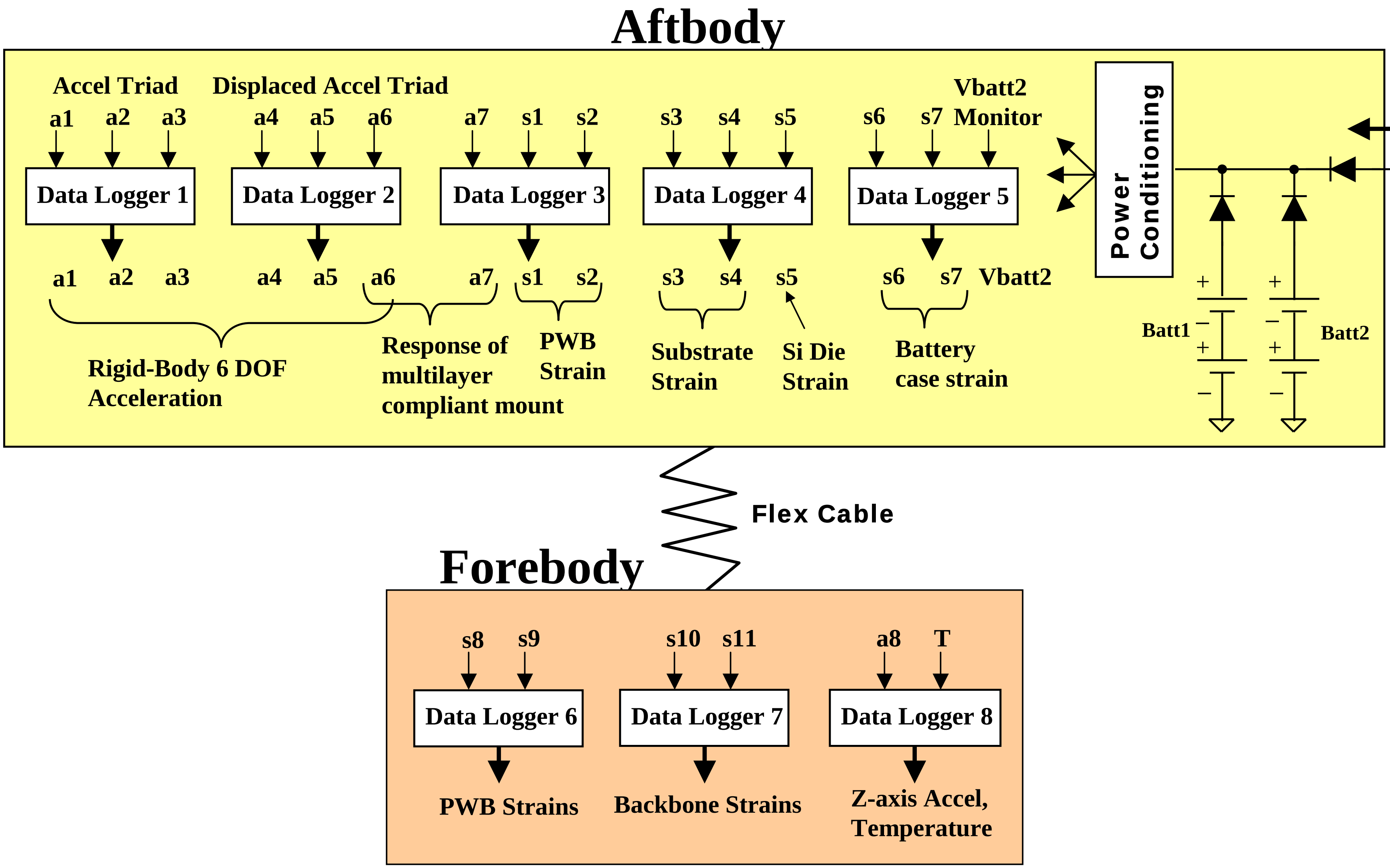
NEW MILLENNIUM PROGRAM
DS2 Follow-On Experiment

Scope and Schedule of Task

- Low cost, short duration effort
  - Three impact tests
    - Probe 1: Aftbody only – Survival test for custom data logger with one accelerometer channel
    - Probe 2: Full-up Aftbody (7 accelerometers + 7 strain gage channels)
    - Probe 3: Full-up probe - aftbody (7 accelerometers + 7 strain gages) and forebody (1 acceleromerer, 4 strain gages, 1 thermometer)



Probe Sensor Suite Handled by Eight Independent Data Loggers



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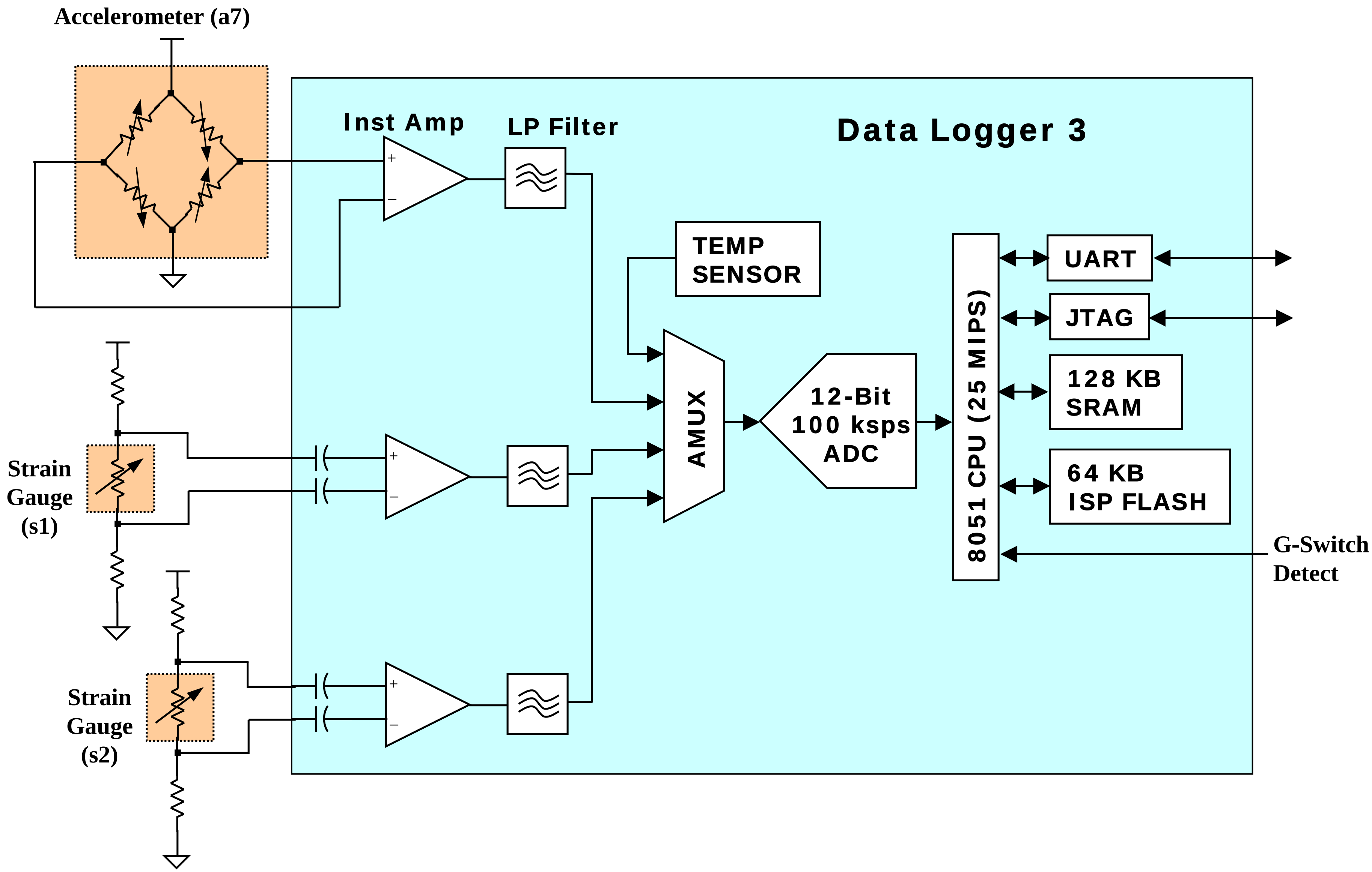
Data Logger Architecture



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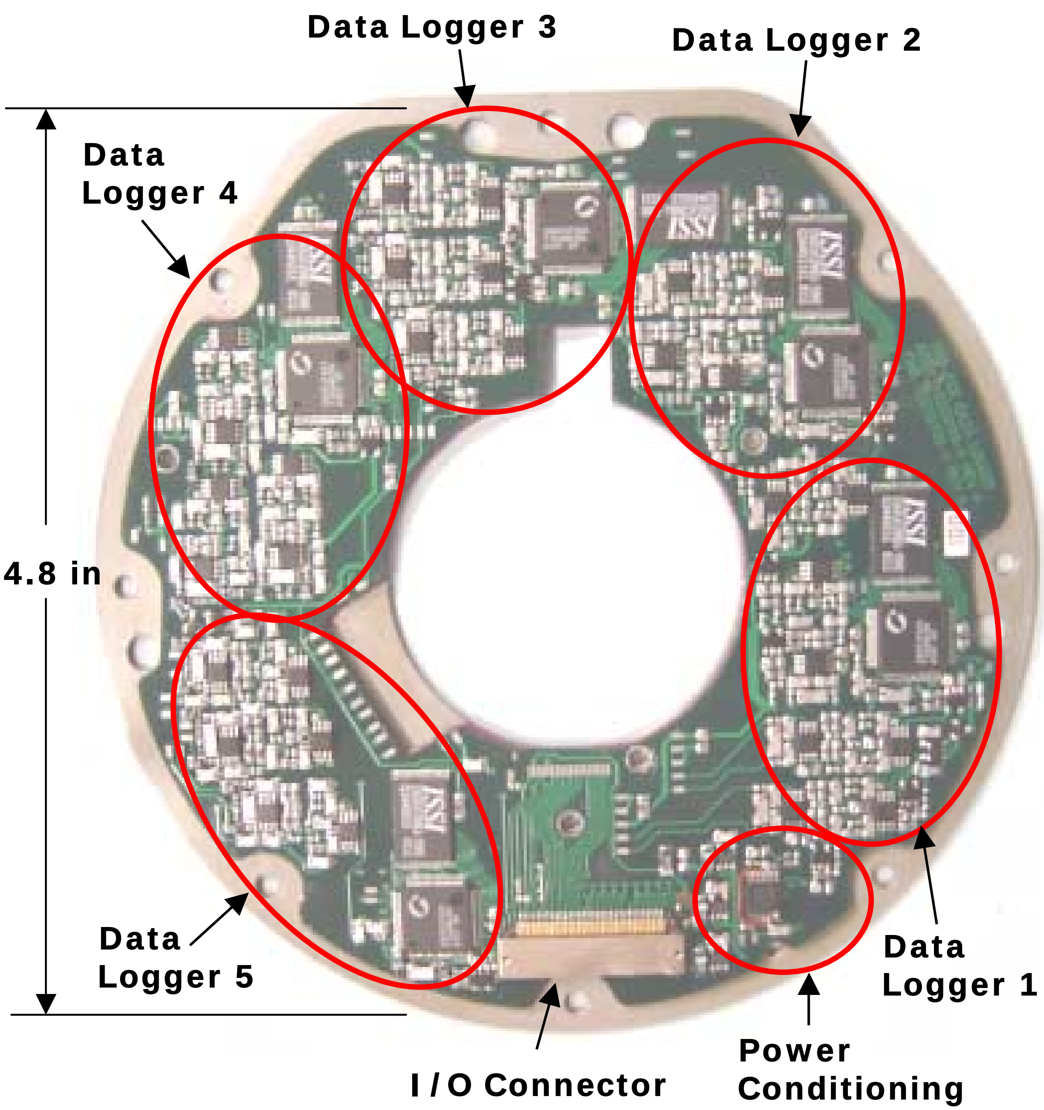
Aftbody PWB:
Five Custom Data Loggers



Commercial Data Logger

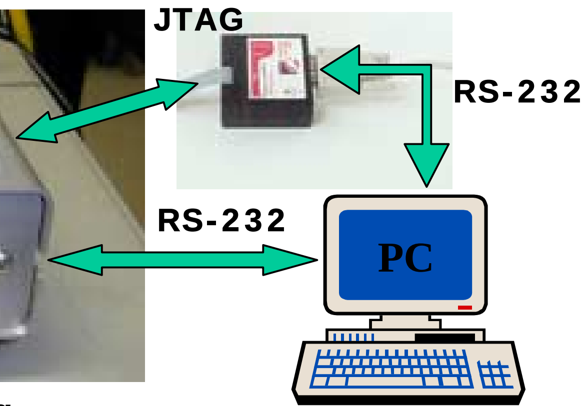
1.25 in Dia X 2.35 in Length

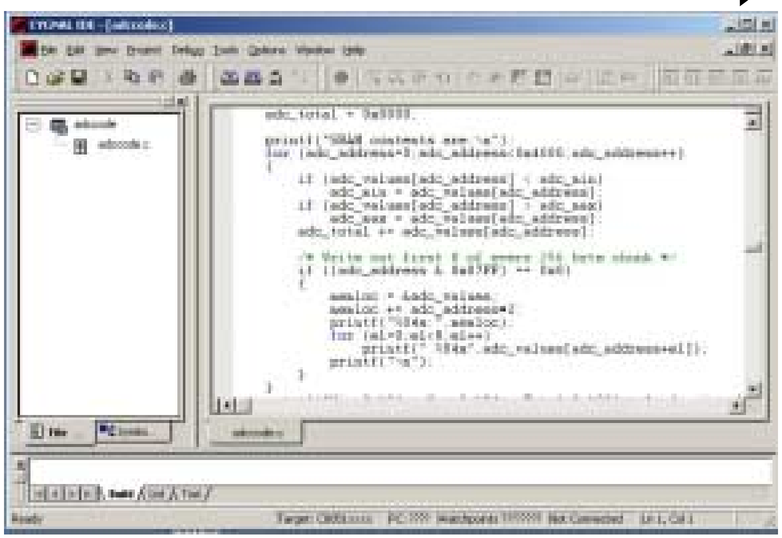
Advantages of Custom data Logger
- Less mass and volume
- Lower power
- In-circuit programmable via JTAG
- Sensor signal chain validation and calibration via RS232

Probe Interface Hardware

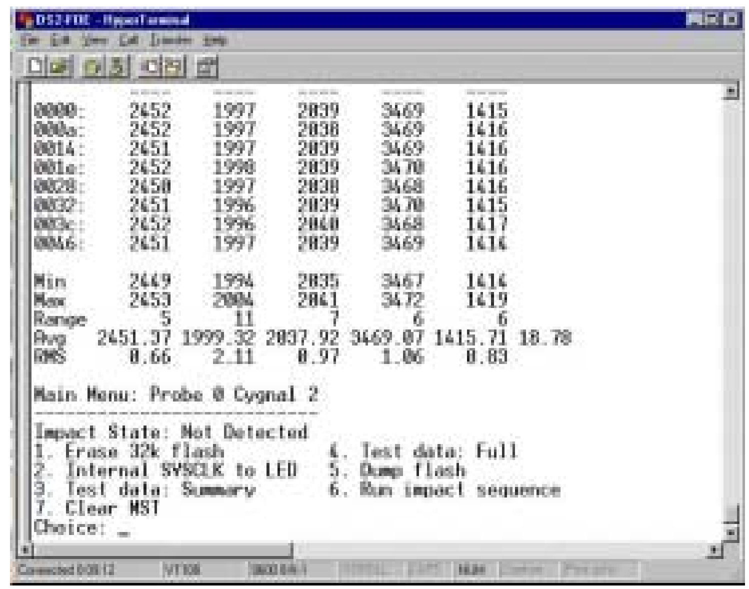
Probe

Control / Programming / Data Interface Box





Cygnal IDE: Programming / Debug



HyperTerminal: Control / Calibration / Data Dump

Data Logger Software: User Interface

```
Main Menu: Probe 2 Cygnal 0
---------------------------
Impact State: DETECTED
1. Erase 32k flash            4. Test data: Full
2. Internal SYSCLK to LED     5. Dump flash
3. Test data: Summary
7. Clear MST
Choice: 3

           AIN0     AIN1     AIN2     AIN3     TEMP
           ----     ----     ----     ----     ----
0000:      1993     1979     1973     3427     1431
000a:      1992     1979     1976     3428     1432
0014:      1992     1979     1975     3427     1432
001e:      1994     1979     1975     3428     1432
0028:      1992     1979     1976     3428     1432
0032:      1992     1979     1976     3428     1431
003c:      1992     1979     1975     3428     1432
0046:      1993     1979     1974     3428     1432

Min        1990     1977     1973     3425     1429
Max        1994     1981     1977     3429     1434
Range         5        5        5        5        6
Avg     1992.33  1979.04  1974.93  3427.30  1431.51  22.02
RMS        0.69     0.65     0.64     0.61     0.88
```

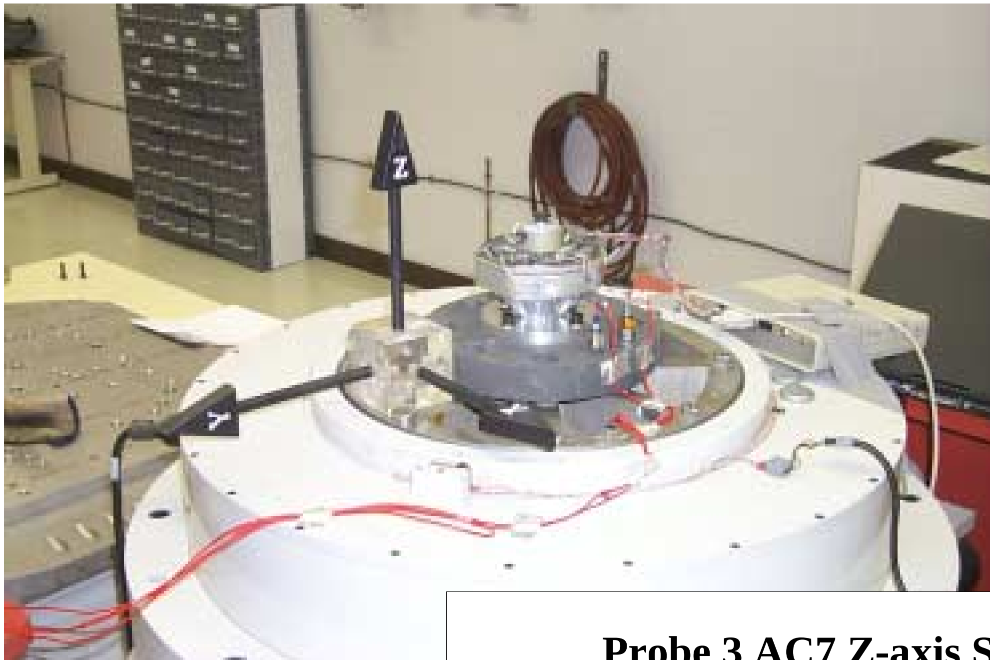
- **Software loaded into 8051 microcontroller-FLASH via JTAG**
- **User interface via standard serial RS-232**
- **Main menu identifies probe # and device #**
  - **Stored in separate nonvolitile FLASH EEPROM**
- **Option 2 allows output of internal clock**
  - **Each 8051 has unique clock speed**
  - **Measured speed hard coded into software**
  - **Used for precise sample rate generation**
- **Option 3 allows for user testing of sensors**
  - **5 sensors samples, including internal temp.**
  - **3,276 samples/sensor processed**
  - **Min/Max/Range/Avg/RMS provided to user**
    - **Allows for validating and calibrating analog circuitry**
- **Option 6 runs impact sequence software**
  - **Removed from menu when impact triggered**
- **Option 5 allows user to re-dump saved data**
  - **Dumps all data from impact capture**

Data Logger Software: Impact Sequence

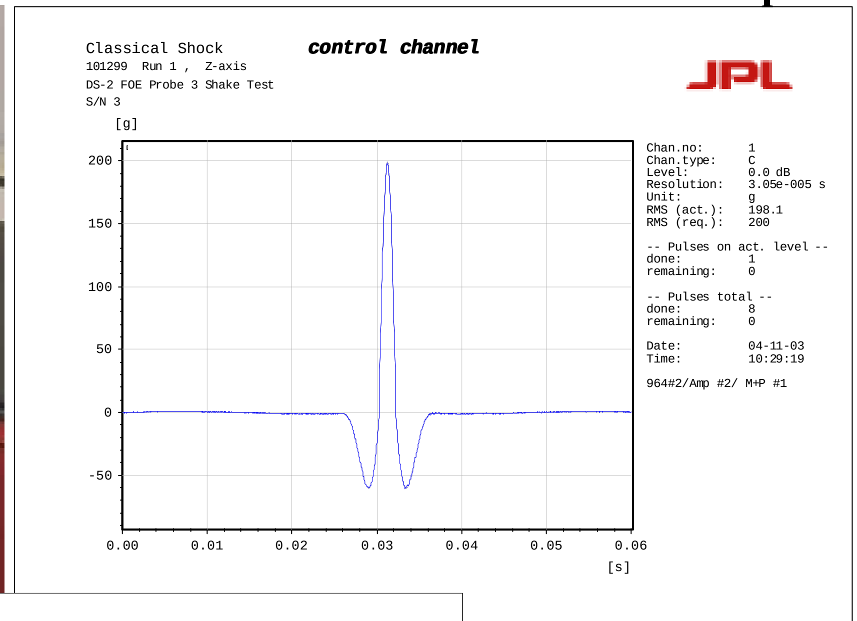
- Impact sequence started by user, verified by flashing LED on interface box
- 300 sample rolling buffer overwritten repeatedly until G-Switch detected
  - Initial acceleration down gun barrel triggers G-Switch (> 100 G)
  - Remaining 14,700 samples then captured
  - G-Switch transition noted within 300 sample buffer for post-impact data synchronization
- Different sampling frequencies between devices
  - 30ksps x 3 sensors, 45ksps x 2 sensors, 90ksps x 1 sensor
- Total data capture interval of 166 milliseconds based on 90ksps and 15,000 samples
- Impact data initially stored in on-board external 64k byte SRAM
- Impact data in SRAM burned into EEPROM immediately post impact
  - Approximately 2 seconds required to burn all data into EEPROM
  - User prevented from running another impact sequence once impact detected
  - Once data safely in EEPROM, even depleting battery does not erase data
- After impact data burned into EEPROM, 64 temperature samples taken
  - Allows for post-impact analysis of temperature induced clock speed variance
- Dump of impact data set consists of the following:
  - Sensor data during impact, 64 temperature samples, G-Switch location when triggered

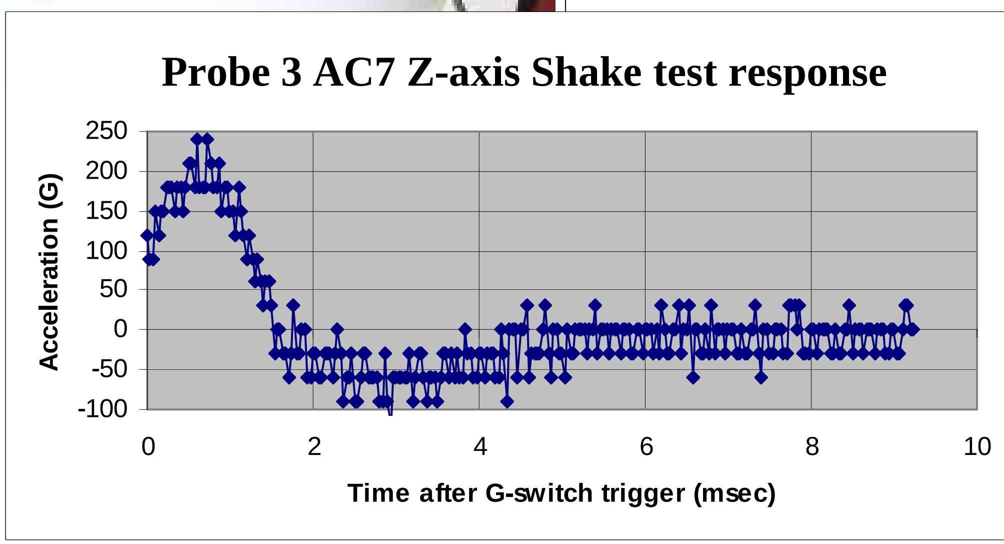
Probe 3 Aftbody Shake Test

Shake table setup

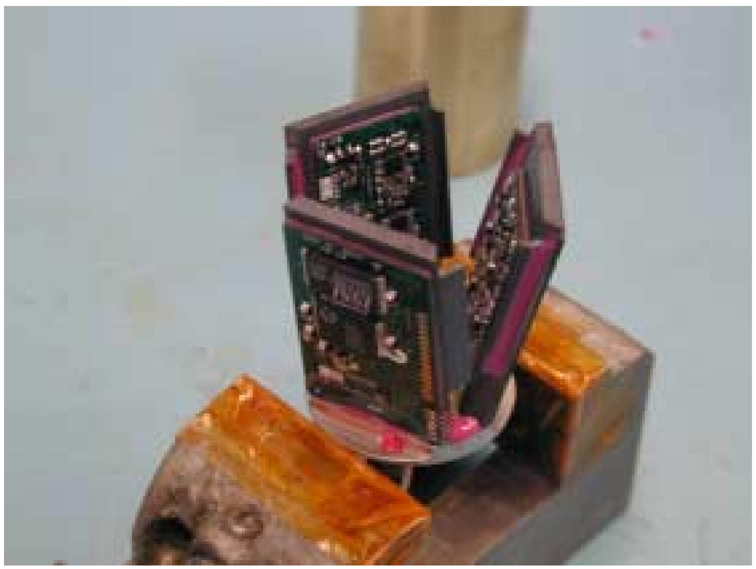


Shake table Z-axis accelerometer output

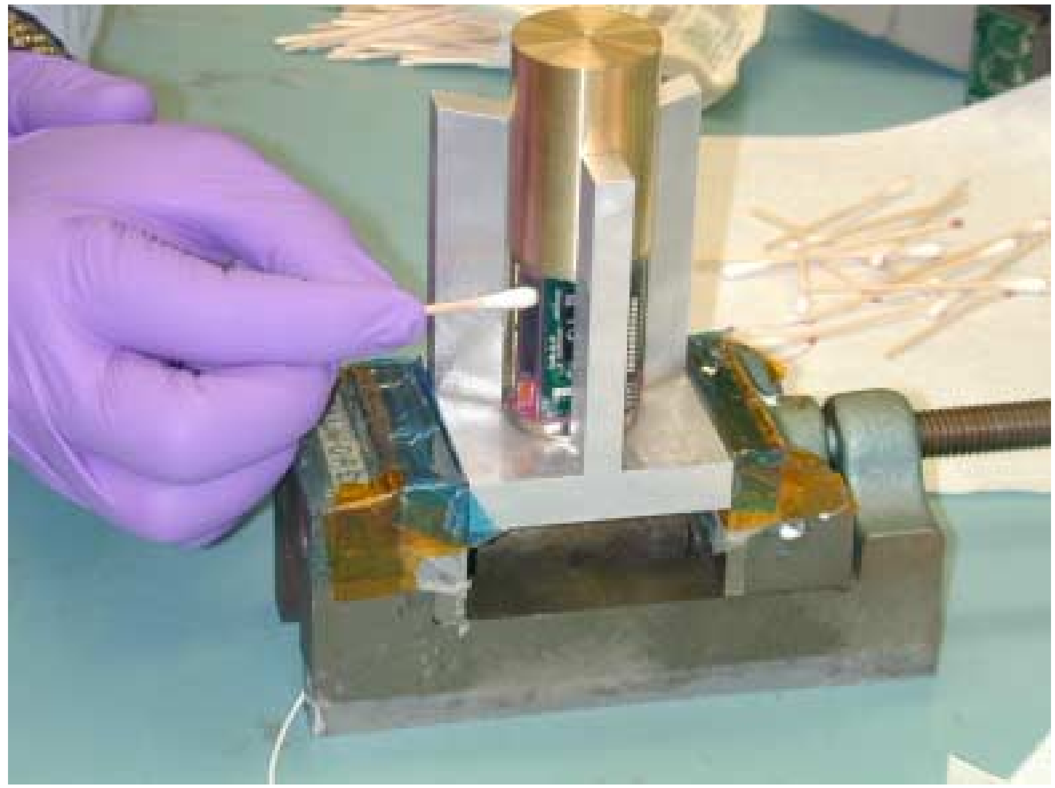




Assembly of Forebody Prism for Probe 3



Epoxy applied to backbone edges and bottom end plate



Completed prism held in alignment by assembly fixture while epoxy cures.