Section 4

Acceleration Measurement Systems Deployed by SAMS

William M. Foster II

Agenda

- Purpose, Organization, & Requirements
- Acceleration Measurement Systems
  - History
  - Present Systems
    - Performance
    - Packaging
  - Future Systems
- Examples of Deployment
- Customers - How to request SAMS
- Conclusion

SAMS Project Purpose

Develop, deploy, and operate acceleration measurement systems to measure, collect, process, record, and deliver selected acceleration data to researchers (through Principal Investigator Microgravity Services) & other customers that require control, monitoring, and characterization of the microgravity environment on platforms/facilities such as drop towers, aircraft, sounding rockets, Shuttle, and International Space Station.

Organization

Microgravity Science Division
Chief - Jack Salzman
Deputy - Steve Simons

Microgravity Environment Branch
Chief - David Francisco
Program Manager - David Francisco
Discipline Scientist - Richard DeLombard

Office of Safety and Assurance
Lead - Vincent Lally
Safety - William Schoren
Quality Assurance - Henry Yee
Software - Hong Fu
Materials - Brian Jackson

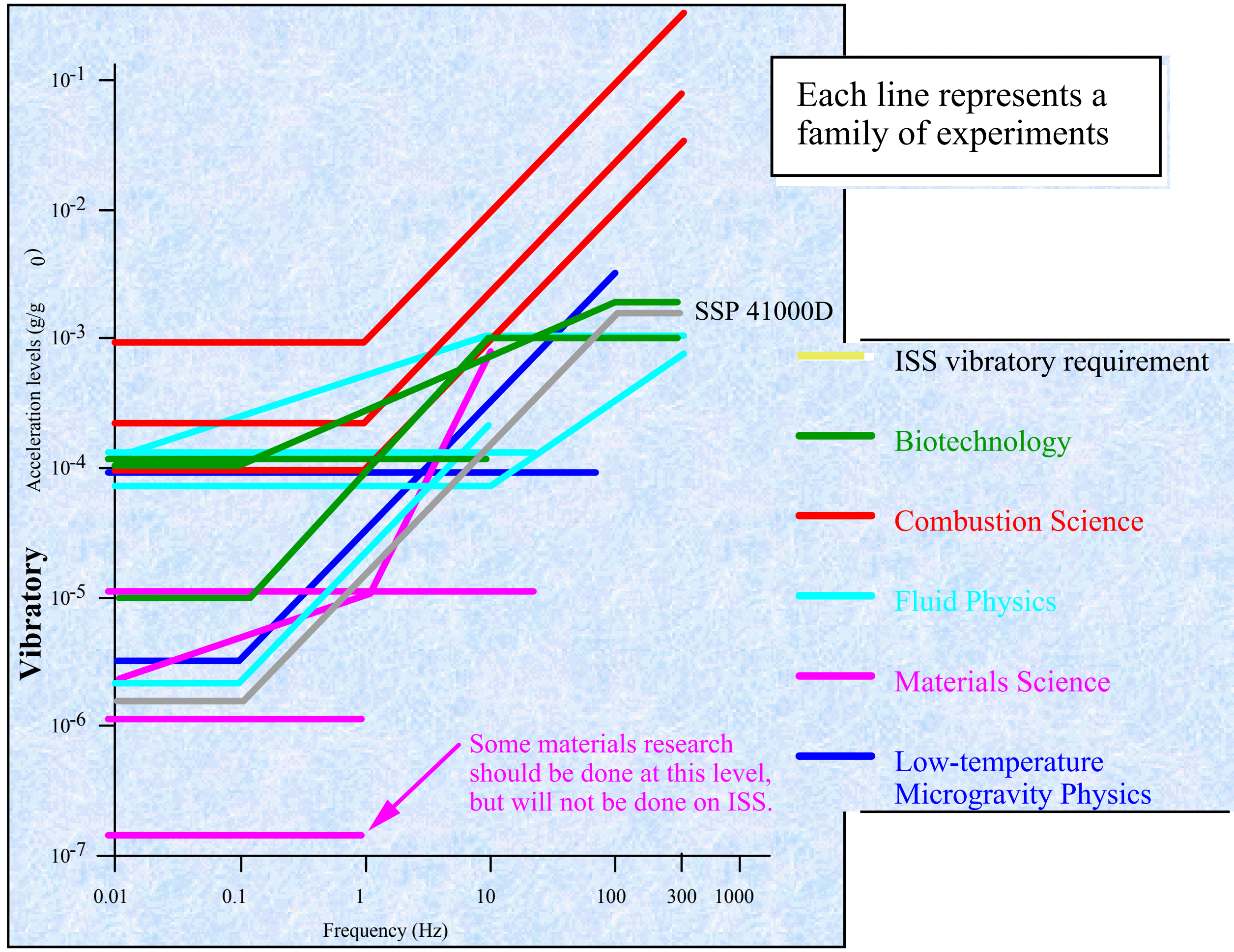
Space Acceleration Measurement Systems Project (SAMS)
Project Manager - William Foster
Lead STS/SR/Grd - Ron Sicker

Principal Investigator Microgravity Services (PIMS) Project
Project Manager - Kevin McPherson
Project Scientist - Kenol Jules

ZIN Technologies
Acceleration Manager- Carlos Grodsinsky
SAMS Lead - Raymond Pavlik
STS/SR/Adv. Tech Lead - Tom Kacpura
PIMS Lead - Nissim Lugasy

Microgravity Environment Measurement Requirements

- Vibratory:
  - Ranges from milli-g to sub-μg
- Quasi-Steady:
  - Below 1 μg
- Multiple payloads
- Minimize use of Resources
- Distribute data

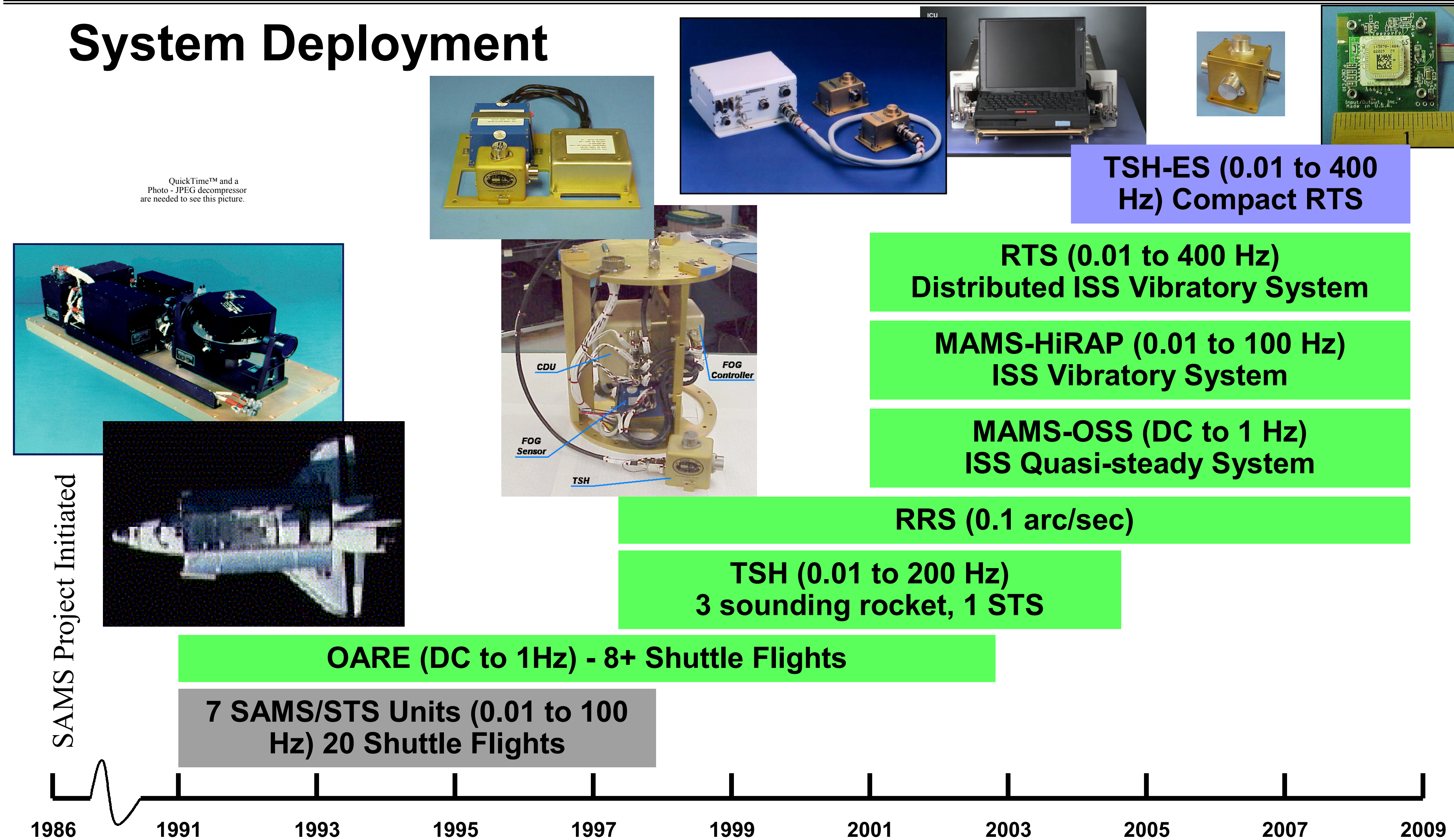


Acceleration Measurement Systems

History:

Present Systems
Future Systems

System Deployment



Acceleration Measurement History

- NASA Glenn Activity
  - Space Acceleration Measurement System (SAMS)
    - 20 Shuttle Flights, 7 Units (1991 to 1998)
    - MIR Space Station (1994 to 1997)
    - Measured Acceleration Range: 0.01 to 100 Hz
  - Orbital Acceleration Research Experiment (OARE)
    - 8+ Shuttle Flights, 1 Unit (1991 to Present)
    - Measures Acceleration Range: DC to 1 Hz
  - Acceleration Data Stored/Archived by Principal Investigator Microgravity Services
- Other Systems
  - High Resolution Accelerometer Package (HiRAP), JSC/LaRC
  - 3-Dimensional Microgravity Accelerometer (3DMA), UAH
  - Microgravity Measurement Device (MMD), JSC
  - Quasi-Steady Acceleration Measurement (QSAM), DLR
  - Microgravity Measurement Assembly (MMA), ESTEC/ESA

SAMS Present Sensors

- Vibratory Sensors (Q-Flex Accelerometers)
  - Remote Triaxial Sensor (RTS)
    - Modular expandable system to support ISS
  - Triaxial Sensor Head (TSH)
    - Primary system for ground operations (drop towers, KC-135)
  - Microgravity Acceleration Measurement System (MAMS) - HiRAP
    - Single system mounted in MAMS
- Quasi-Steady Sensors (Miniature Electro-Static Accelerometer)
  - Microgravity Acceleration Measurement System (MAMS) -OSS
    - OARE Sensor Subsystem (OSS)
  - Orbital Acceleration Research Experiment (OARE)
    - Shuttle support
- Roll Rate Sensor (RRS)
  - Measure rotational acceleration on sounding rockets

General Description: Remote Triaxial Sensor (RTS)

- Measures, digitizes, & compensates acceleration data (0.01 to 400 Hz)
- Components
  - **Electronics Enclosure (EE)**
    - Size: 9.1 in x 9.3 in. x 4.7 in. & 11 lb
    - PC/104 card stack (CPU, Ethernet, A/D, Control, Interface(2))
    - Mil-grade DC/DC converters & EMI Filter
  - **Sensor Enclosure (SE)**
    - Size: 5.6 in X 4.0 in. X 3.5 in. & 2.5 lb
    - Pendulous mass force balance accelerometers (3 QA-3000/3100 units)
    - Temp. compensation (in QA-3000/3100)
    - Alignment- orthogonality 0.1°; to base 0.5°
    - Delta Sigma 24 bit A/D Converter per axis
  - Custom Interface Cable (EE to SE’s)
- Power: 28 VDC, EE 8 W, SE 2.25 W
- Dynamic Range: 130 dB (0.1 µg to 1g)
- Selectable Frequency Ranges: 400, 200, 100, 50, 25 Hz
- Configured by & sends data to Interim Control Unit (ICU) across ethernet
- EE mounts in ISS racks, SE on payloads

EE Missions
- 122-F05 in EXPRESS Rack (ER) #2 (4/2001)
- 122-F04, F01, F07 in ER #3, 7, 8
- 122-F06 in Microgravity Science Glovebox

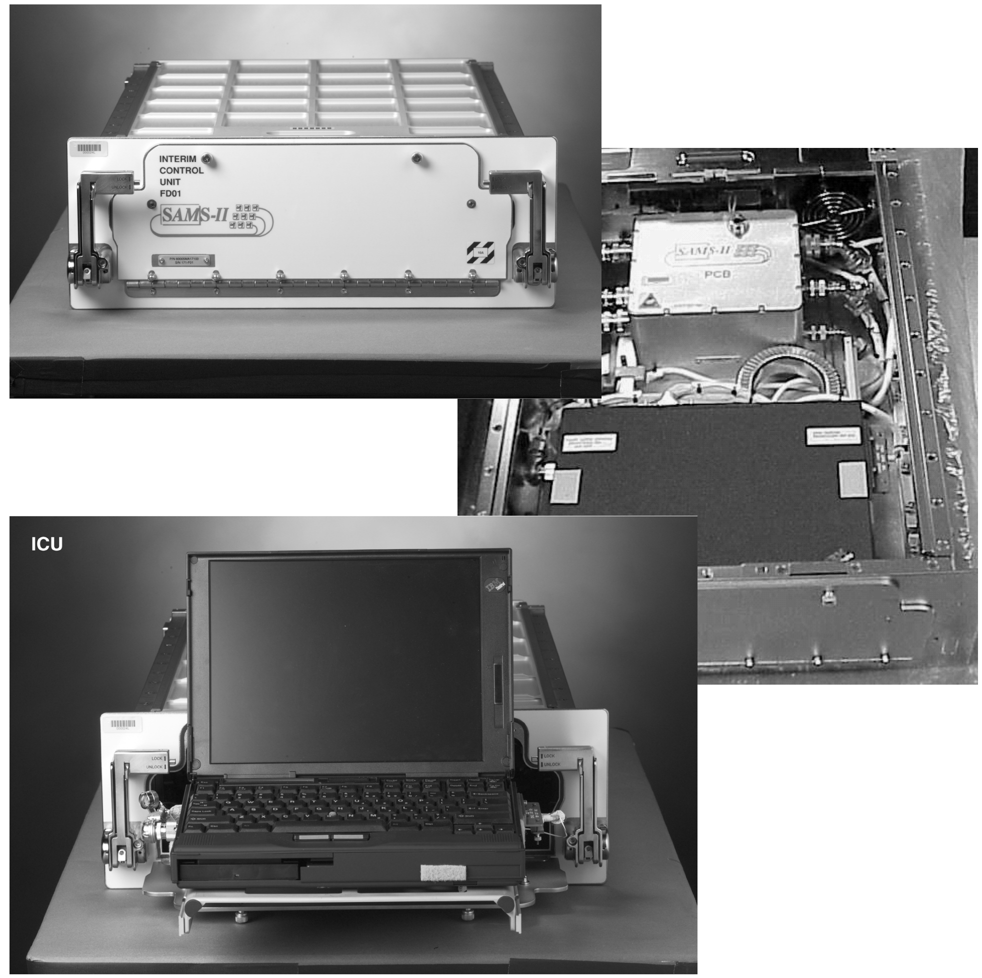
SE Missions
- 121-F06 Physics of Colloids in Space (PCS)
- 121-F02 PIMS
- 121-F03, F04, F05 ARIS-ICE
- 121-F08 Microgravity Science Glovebox

RTS Performance

REQUIREMENT	PERFORMANCE
System Noise **0.569 ug_{rms} 0.01-0.1 Hz** **5.69 ug_{rms} 0.1-100 Hz** **569 ug_{rms} 100-300 Hz**	**0.121 ug_{rms} 0.01-0.1 Hz** **2.0 ug_{rms} 0.1- 30 Hz** **4.0 ug_{rms} 30 – 300 Hz**
Accuracy **10% from 0.01 to 300 Hz**	• **Analysis 4.62% (1% initial calibration, 2.6% thermal, 1.1% two year cal)** • **Calibration data indicates 0.1% repeatable over 1 year.** • **Raw data is DC-coupled, PIMS demeans data**

RTS Control and Data Handling

- Interim Control Unit (ICU)
- IBM 760XD laptop, two 3GB hard drive. Modified for flight by ISS PCS
- Loads program and software coefficients to RTS-EE
- Used to buffer and transmit data for telemetry
- Provides a crew interface for control and data display



General Description: Triaxial Sensor Head (TSH)

- Measures, digitizes, & compensates acceleration data (0.01 to 200 Hz)
- Pendulous mass force balance accelerometers (3 QA-3000/3100 units)
- Selectable bandwidth
- Size: 2.9”x2.9”x2.8”
- Weight: ~1.1 lb
- Power: +/- 15VDC, 1.65W
- Digital data output & control through RS-422 serial interface
- Use with payload computer
  - Connect TSH, add power, and install software
  - Easy to synchronize data with other payload sensors
- Standalone applications (non-ISS)

TSH Missions
    ugSEG (KC-135 flight)
    SAL-6
    DARTFire

TSH/RRS Control and Data Handling

- Control & Data Acquisition Unit (CDU)
- Conditions & distributes power to attached sensors
- PC/104 industrial grade embedded system with real-time control software for data and command
  - CPU board i486 processor
  - 6 GB rotational hard drive for data storage
  - Serial I/O board
  - Analog/Digital I/O board
  - Ethernet board interface to SH EDSMU
  - LCD display for status and checkout
- Size: 5.3”x5.3”x5.0”

General Description: Microgravity Acceleration Measurement System (MAMS)

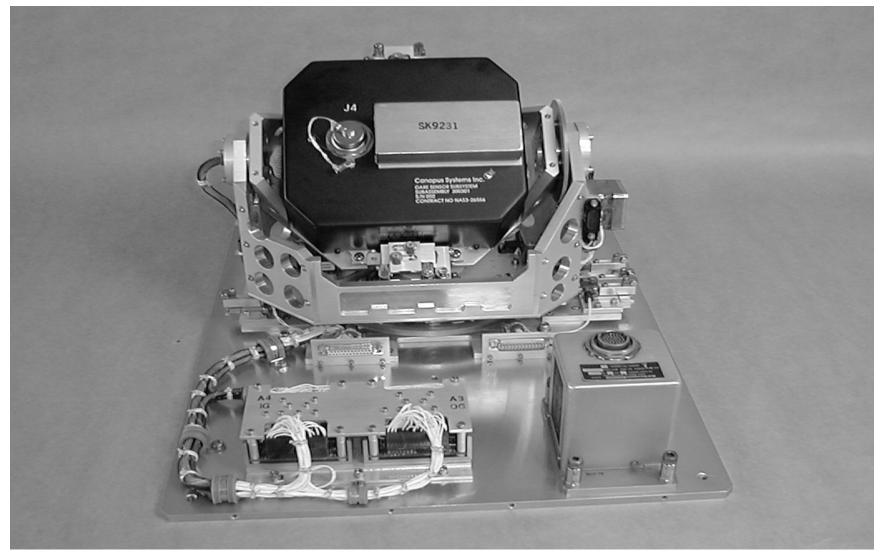
- Size: 21.86”H x 18.37”W x 23.55”D
- Weight :117 lb
- Location: EXPRESS Rack #1 ISS Flight 6A
- Power Interface: 28 VDC, 79 watts
- Data Interface: Ethernet EXPRESS Rack Interface Controller (RIC)
- Powered by RIC Software Controller after crew sets panel power switch to “ON”
- Thermal Control: Avionics Air Assembly cooling with internal circulating fan

General Description: MAMS - High Resolution Accelerometer Package (HiRAP)

- Vibratory accelerations in three orthogonal HiRAP sensing input axes, with an accuracy and resolution of 1/10th of the magnitude or one microgravity, whichever is greater, of the Space Station system acceleration limits from 0.01 to 100 Hz
- Data is sent to RIC for downlinking

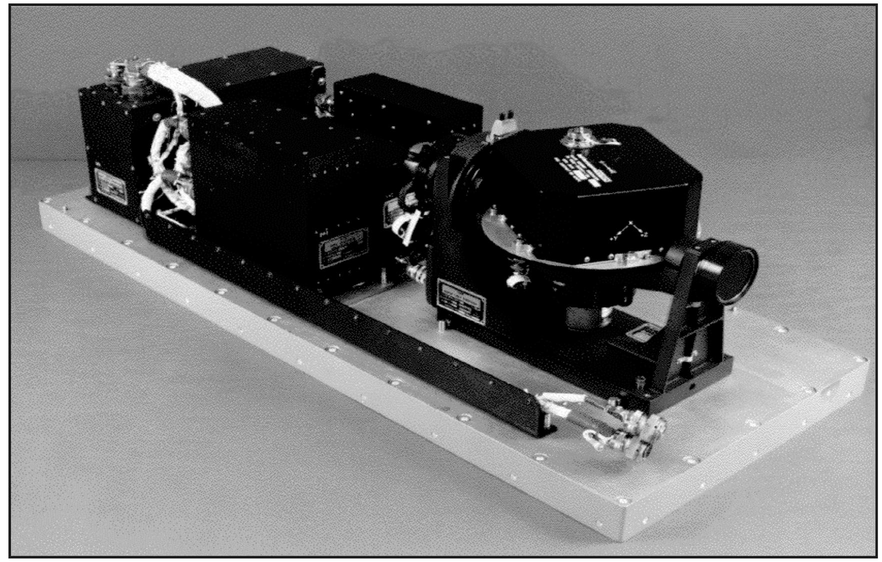
General Description: MAMS - OARE Sensor Subsystem (OSS)

- MAMS-OSS measures:
  - Vibratory accelerations (0.01 to 100 Hz) and quasi-steady accelerations (DC to 1 Hz) at its installed EXPRESS Rack (non-ARIS) in US Laboratory module
  - Quasi-steady accelerations in three orthogonal MESA sensor input axes, with an accuracy and resolution of 100 nano-g or better from the orbital rate to 1.0 Hz



General Description: Orbital Acceleration Research Experiment (OARE)

- Dynamic Range:
  - X axis: 3.1 nano-g to 10,000 micro-g
  - Y & Z axes: 4.6 nano-g to 25,000 micro-g
- Bandwidth: DC to 1 Hz where "DC" is at least as low as 10^{-5} Hz
- Accuracy: 20 nano-g on C range
- Linearity: 0.1%
- On-Orbit calibration for temperature/drift compensation
- High disturbance rejection, primarily just above the bandpass
- Data sampling at 10 sps
- Data storage: 4 Mbyte on instrument; unlimited at 32Kbps on external tape recorder



OARE Missions
8 STS

General Description: Roll Rate Sensor (RRS)

- Fiber Optics Gyroscope (FOG) - No moving parts
- Measures vehicle roll rate by light wave phase shift in opposing fiber coils
- Resolution = 0.1 arc-secs
- Size: 3.8”x4.4”x3.0” (sensors), 4.8”x5.0”x2.2” (controller)
- Weight: < 4 lbs
- Power: ~10 W

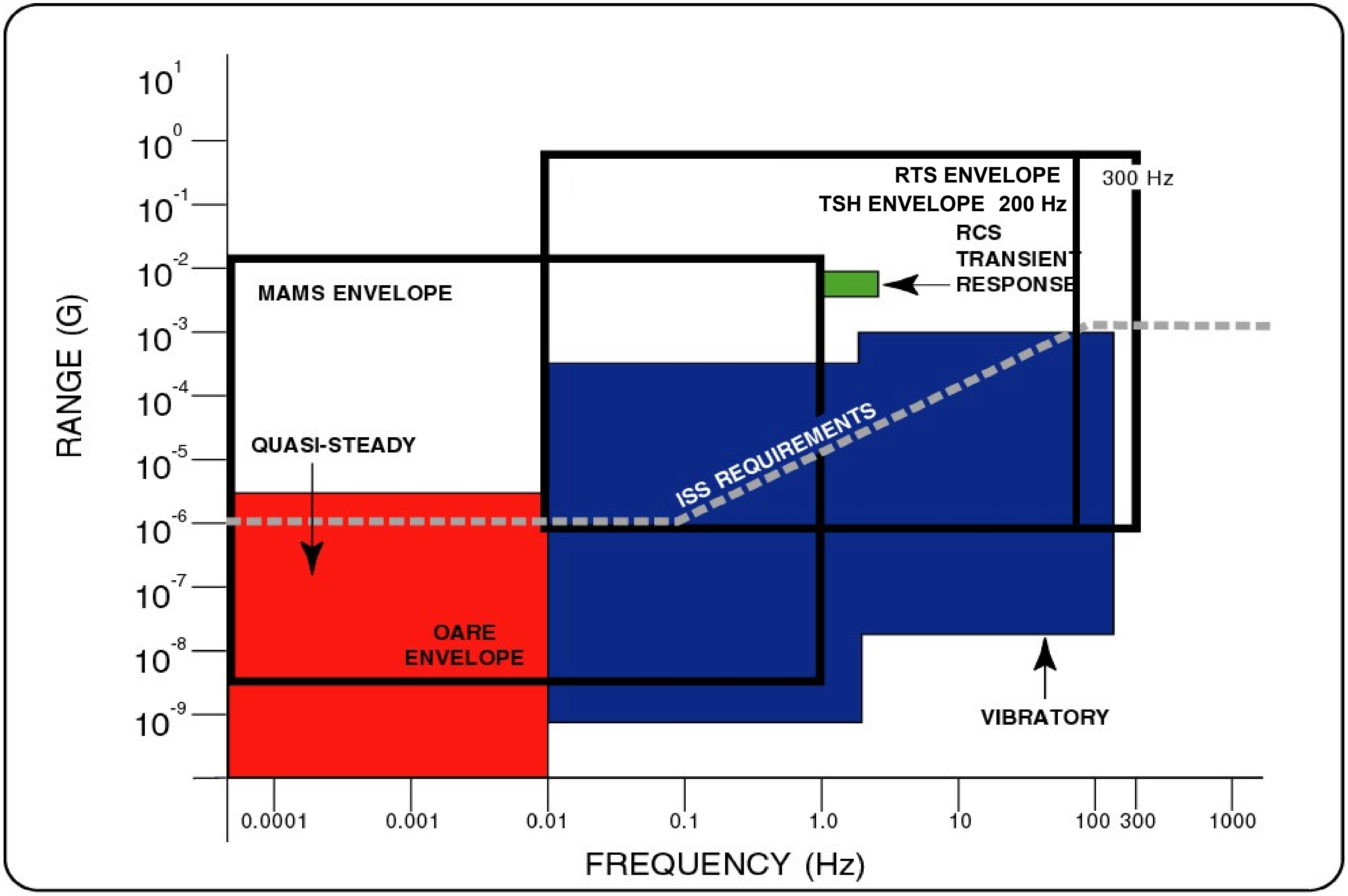
FOG Sensor

FOG Controller

Sensor Comparison Table

	RTS	TSH	RRS	OARE	MAMS
Description	3QA-3100 Allied Signal Accelerometers	3QA-3100 Allied Signal Accelerometers	Fiber Optic Gyroscope (Fibersense)	MESA Sensor, Calibration Table STS only	MESA and HiRAP Sensors, Calibration Table ISS only
Measured Quantity	Linear Acceleration	Linear Acceleration	Roll Rate	Linear Acceleration	Linear Acceleration
Dimensions (inches)	5.6x4.0x 3.5 (SE) 9.1x9.3x 4.7 (EE)	2.9x2.9x 2.8	3.8x4.4x 3.0 (Gyro) 4.8x5.0x 2.2 (Intf)	17x13x4 1	21.9x18 .4x23. 6
Weight (lbs)	2.5 (SE) 11 (EE)	1.1	3.75	117	117
Power (W)	2.25 (SE) 8 (EE)	1.6	~10	110	79
Data Interface	Ethernet	RS-422	RS-232	STS	Ethernet
Bandwidth	0.01-300 Hz	0.01-200 Hz	10 Hz Sampling	DC (10^{-5}) to 1 Hz	DC (10^{-5})-1 Hz (MESA) 10^{-4}-100 Hz (HiRAP)
Maximum Scale	1.1 g at G=1 0.11 g at G=10	1.25 g	190°/sec	10-25 mg	10-25 mg (MESA) 16 mg (HIRAP)
Resolution	0.1 µg 0.1/0.01 µg A/D	0.1 µg	0.1 arc-sec	3-4.6 ng	3-4.6 ng (MESA) 1 µg (HiRAP)
Current platforms/ facilities supported	ISS	STS, sounding rocket, KC-135	STS, sounding rocket	STS	ISS

SAMS Sensor Comparison

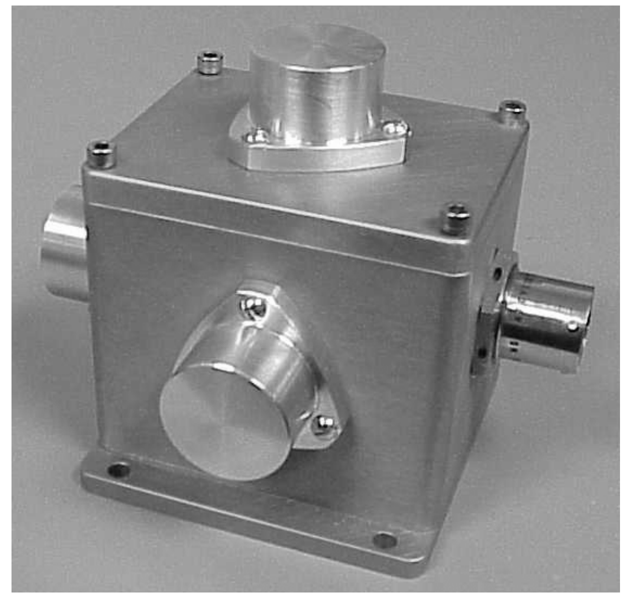


Future Development

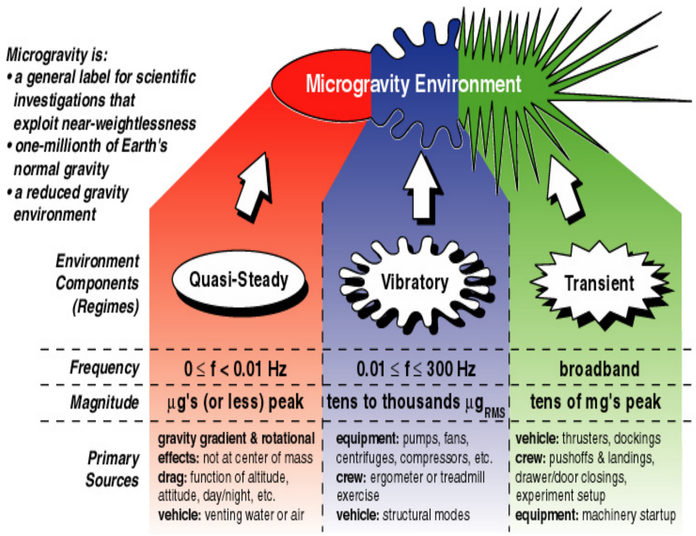
- Currently Funded
  - Sensor Size Reduction
    - Packaging Improvements Utilized
    - Sensor Miniaturization Technology Considered
    - Universal Serial Bus Port and Ethernet capabilities for TSH
    - Combination of existing systems and upgrades
    - MEMS Technology
  - Software Modifications to support communication of other Acceleration Systems with ISS Control Unit (ICU)
  - Identification of Disturbance Signatures on User Displays
- Possible Funded Work
  - Sensor mounting plates (enable sensors to be moved around in lab easily
  - Control Unit to replace ICU (ICU life is 3 years)
  - MAMS upgrade (5 year life)

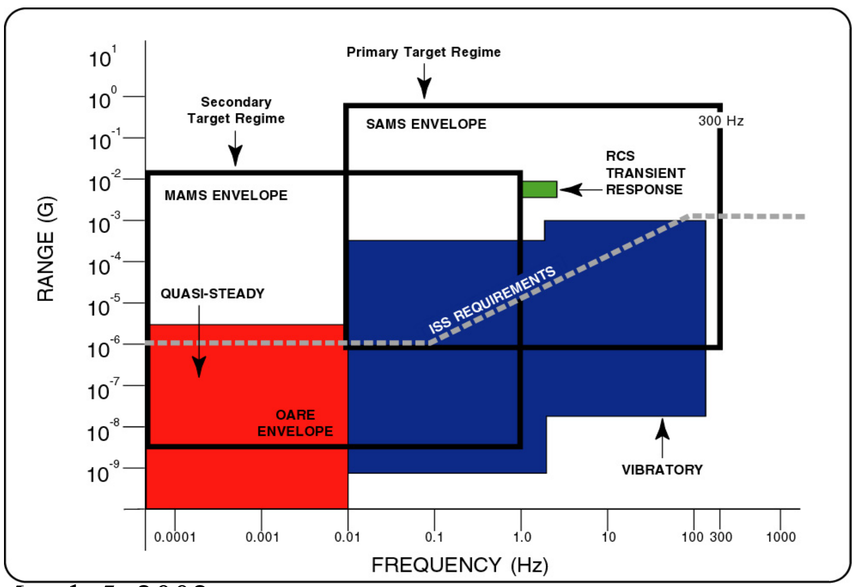
Triaxial Sensor Head – Ethernet/Standalone (TSH-ES)

- Ethernet interface
- Measures vibratory environment w/ selectable maximum sampling Rate from 7.8Hz to 1000Hz (Analog Bandwidth 0.01 to 375 Hz with 0.05 dB attenuation)
- 3 Orthogonal pendulous mass force-balance accelerometers
- Each axis is digitized using 24 bit Sigma-Delta Converter
- Each axis has a dedicated programmable gain amplifier
- Minimum of 135dB Stopband Attenuation
- Maximized oversampling rate, High order Modulator, and cascaded decimating digital filters allow for maximizing the signal to noise ratio

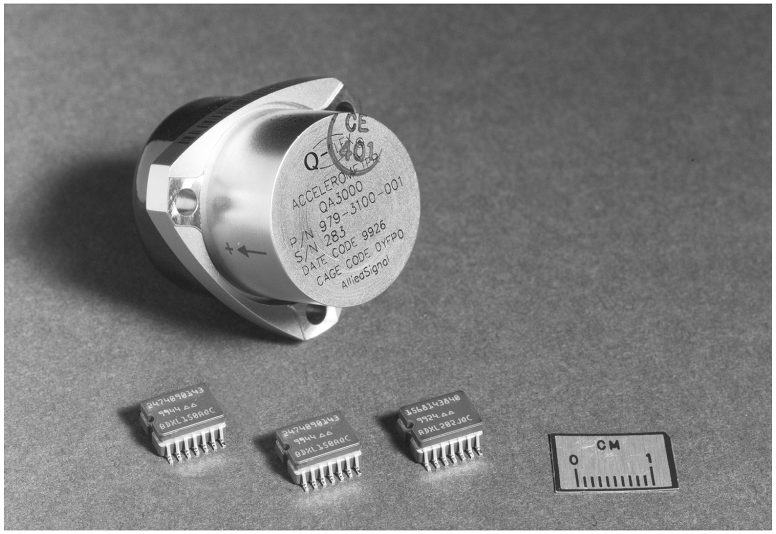


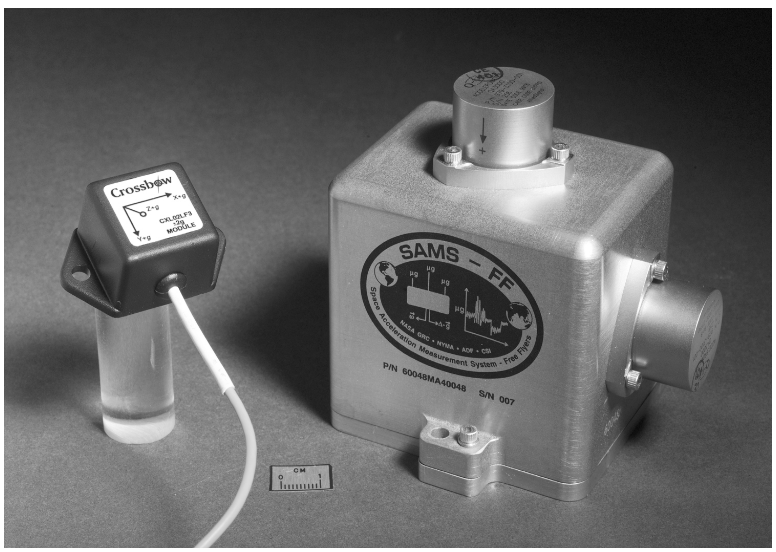
Space Acceleration Measurement Systems (SAMS)





- **Advanced Microgravity Acceleration Measurement Systems (AMAMS)**
- The anticipated users are all disciplines in microgravity science research program, life science and vehicle communities that require local measurements of the on-orbit environment.
- The deliverable is an advanced acceleration measurement system developed to the level that it could be tested in ground facilities and adaptable for space flight.
- The impact would be a 25% to 75% reduction in required resources (volume,power & mass) to collect low gravity data on orbit.
- This development work is a new thrust for a very experienced team that has delivered multiple Space Acceleration Measurement Systems.



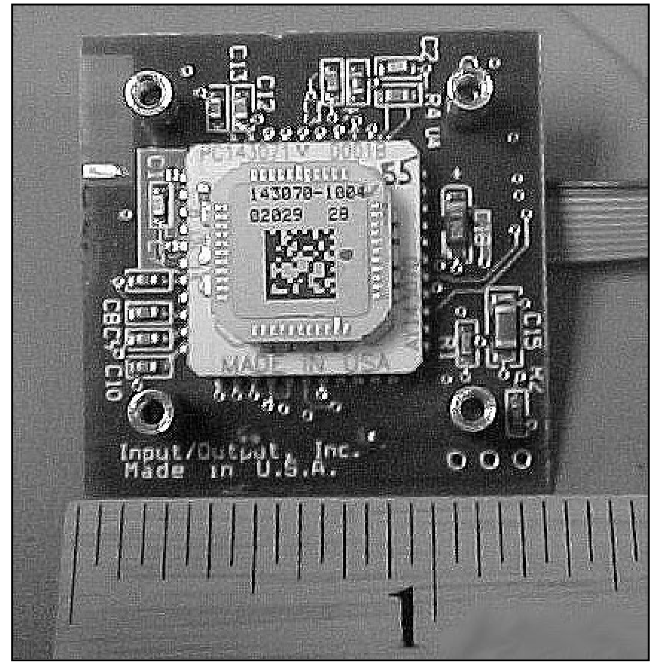


• AMAMS continued

- Significant cost and resource savings may be achieved by utilizing MEMS versus Q-Flex accelerometers.
- The Q-Flex accelerometers used on Shuttle missions to measure 10^{-6} g_{rms} cost \$4000 each. Commercial MEMS sensors cost \$25 and can resolve 10^{-3} g_{rms}. Prototypes with capabilities to 10^{-5} g_{rms} are becoming available.
- The primary objective is to develop, package and test a prototype acceleration measurement system capable of measuring the same sensitivity as SAMS and provide a standard interface to a payload's data system, in a significantly smaller package.

General Description: MEMS Based Triaxial Sensor Head with MEMS Accelerometer (TSH-MEMS)

- Currently under development
- Funded by Instrument Technology Development grant from NASA Headquarters
- Reduced size, weight and power compared to current TSH designs
- Goal is to approach performance achieved by current TSH design. Performance limited by:
  - Smaller size of MEMS sensor limits low frequency response
  - Silicon sensor is more sensitive to temperature changes than currently used quartz sensors
  - Component selection for size and power reduction
- Control through RS-422 interface (1st generation)

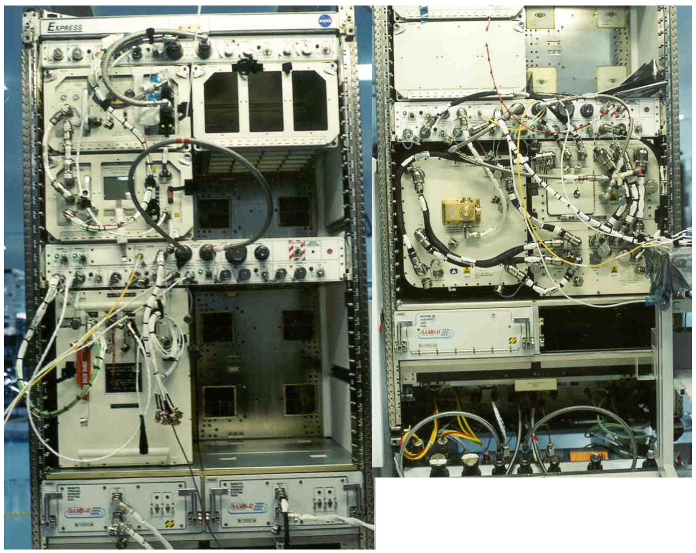


Applied MEMS (Input/Output Company)
SF1500A MEMS Accelerometer
is the selected sensor for the TSH-MEMS

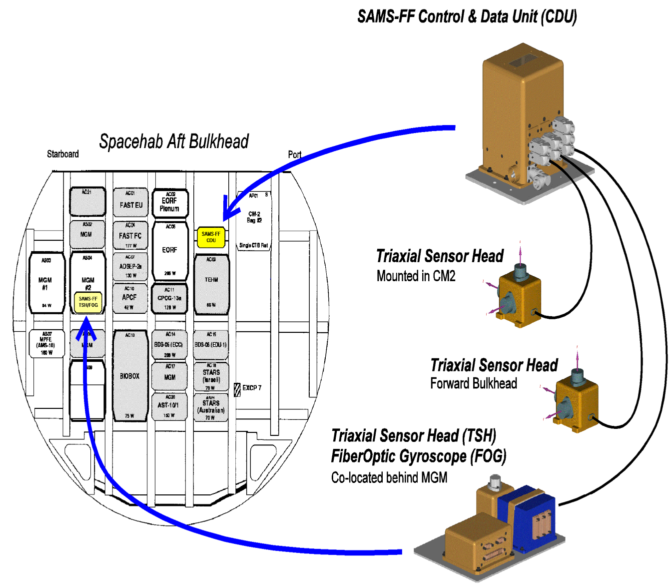
Examples of Deployment

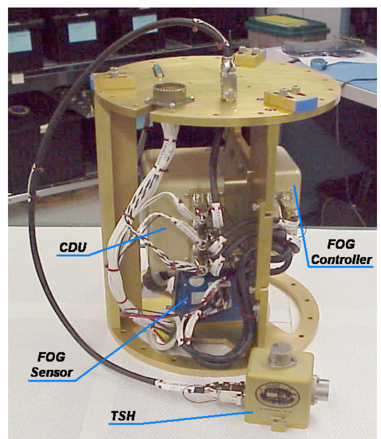
Space Flight Carriers

International Space Station
Sensors: RTS, TSH, MAMS
Control System: Interim Control Unit



Space Shuttle
Sensors: TSH, FOG, OARE
Control System: Control & Data Acquisition Unit

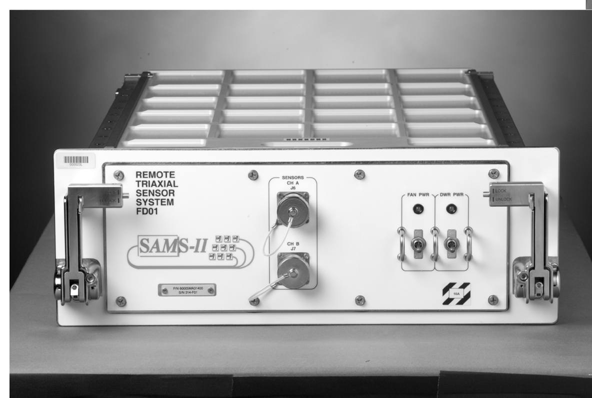


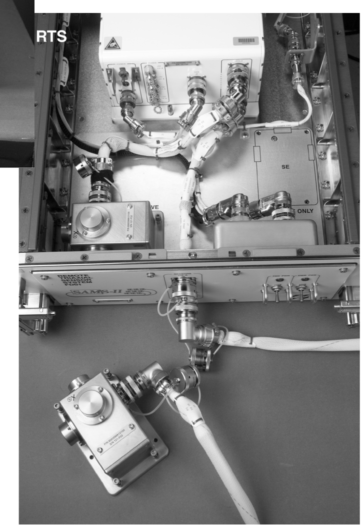


Sounding Rocket
Sensors: TSH, FOG
Control System: Control & Data Acquisition Unit

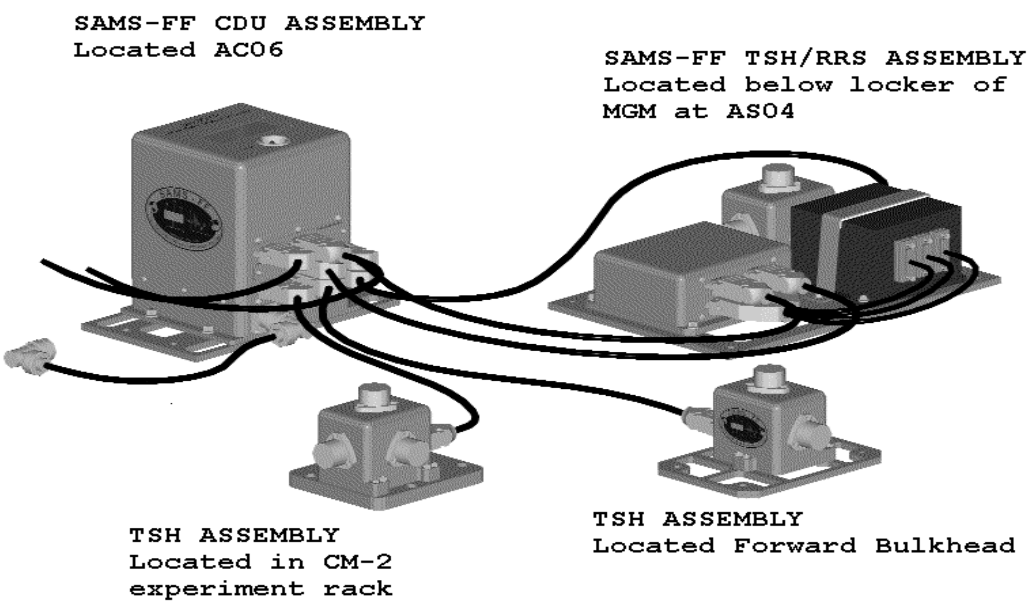
RTS Deployed in an ISIS Drawer

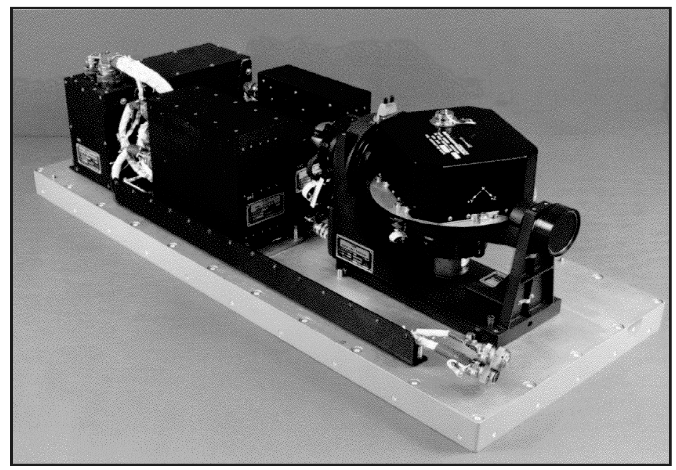
- Contains RTS-EE and two RTS-SE (active and spare)
- Ethernet and Power connections are performed in the rear
- Slides into standard ISIS drawer location.
- Modified Boeing ISIS Power/Stowage Drawer.





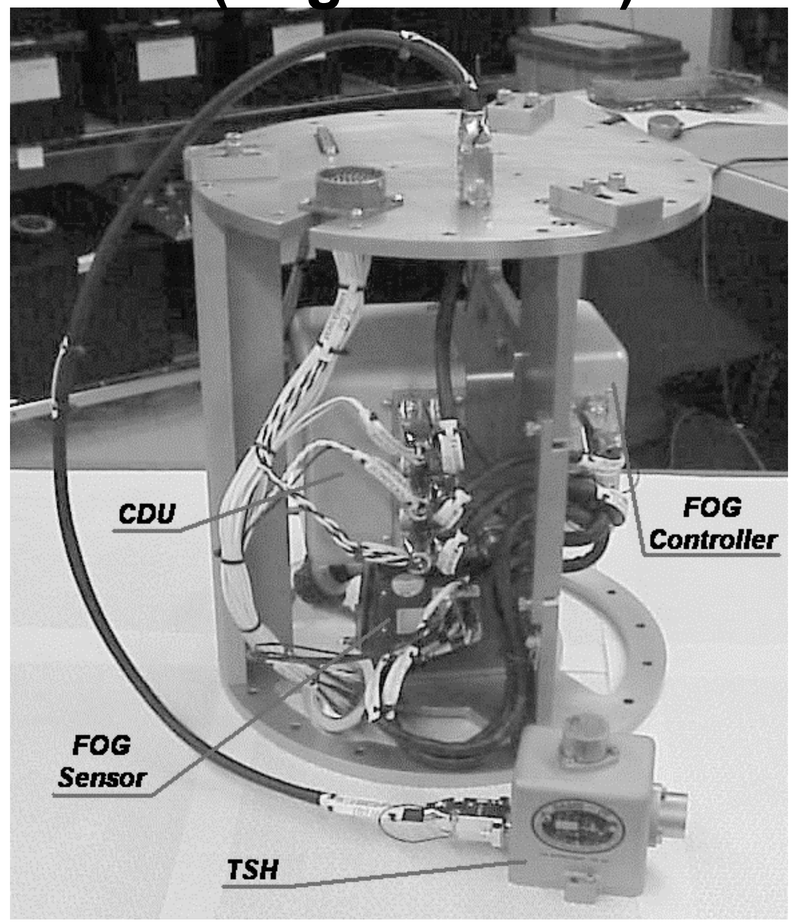
General Description: System Configuration for STS-107





Terrier-Orion Sounding Rocket (Flight 41.020)

- First flight of a new class of sounding rocket
  - 14” diameter
  - Payload weight including SAMS and Microscale heaters was approx 469 lbs
  - µg time (180-220 seconds)
  - Flown at WFF (water recovery)
  - SAMS mission goals
  - Characterize acceleration environment of vehicle during µg period
  - Support Microscale heaters experiment
  - Implement downlink for real-time data display
  - Payload available to support reflights with minor expense

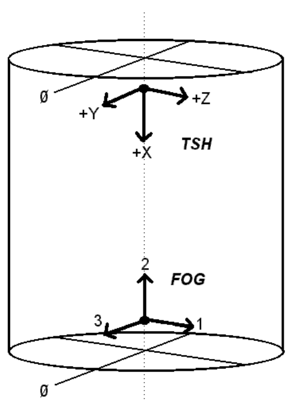


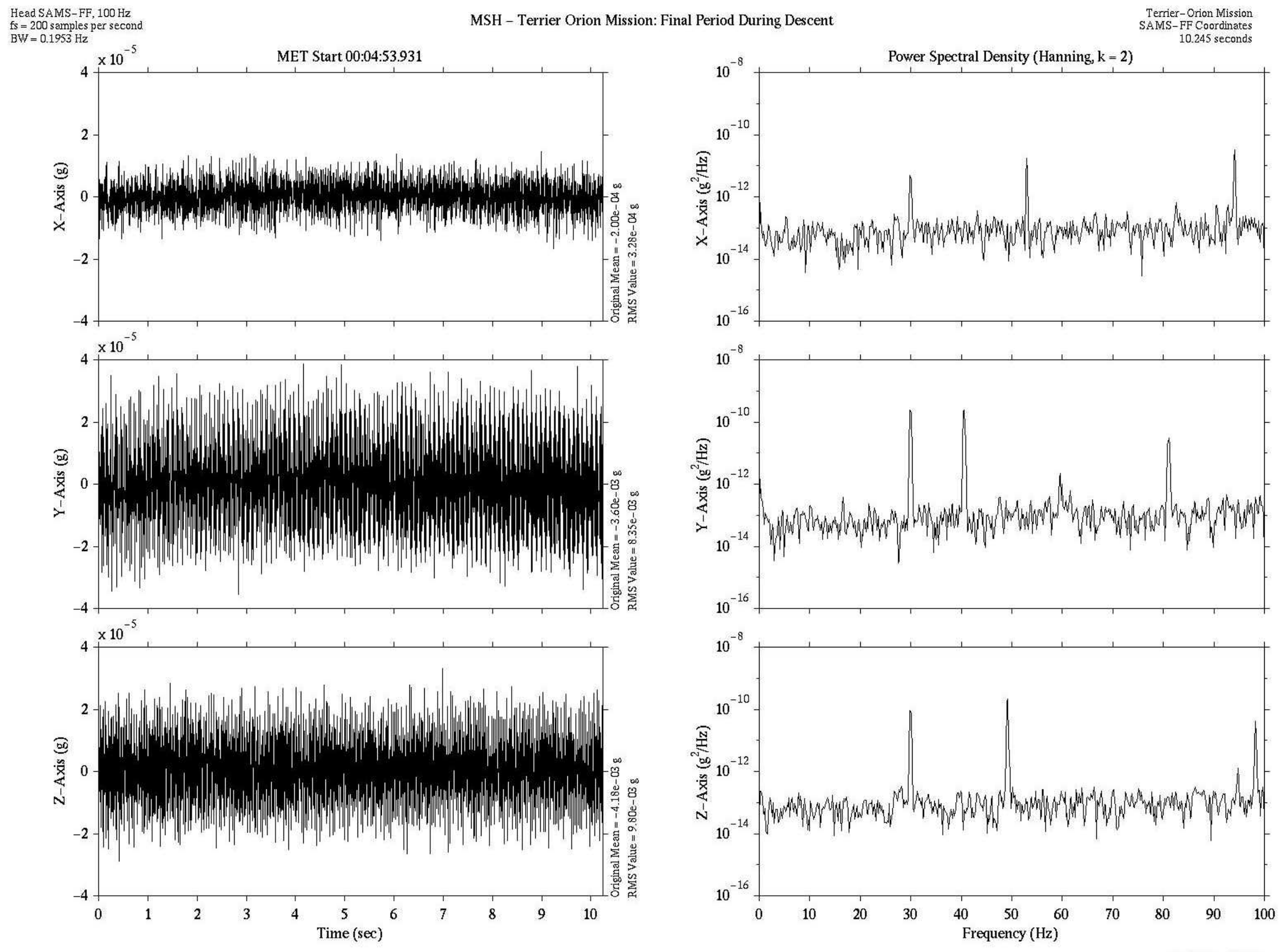
SAMS System Flown on Terrier-Orion Sounding Rocket Flight 41.020 on December 17, 1999.

Terrier-Orion Sounding Rocket Mission Results-TSH

General: ***The SAMS sensors consisted of a TSH and a FOG. Total time for TSH acceleration measurements was 277seconds.***

TSH Data: ***Data has appearance of noise floor data, with maximum amplitude of 2.7 ug . PSD has no significant peaks, and noise floor is near 10^{-14} g2/Hz.***





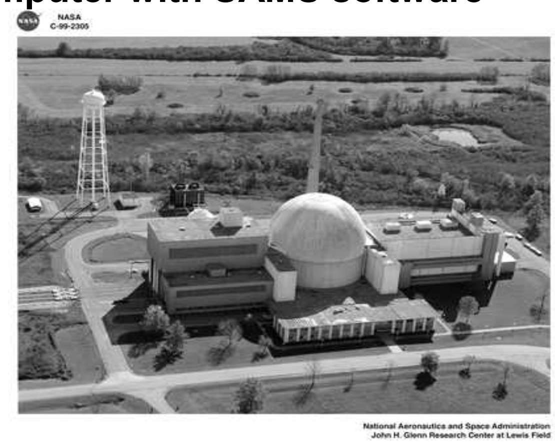
Aircraft and Ground Facilities

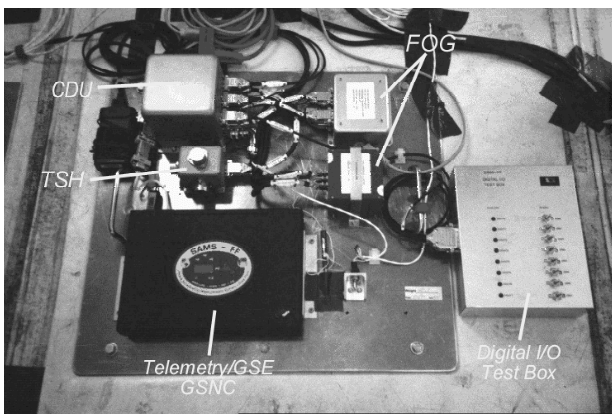
Drop Tower

Sensors: TSH
Control System: Control & Data Acquisition Unit

Plum Brook Station

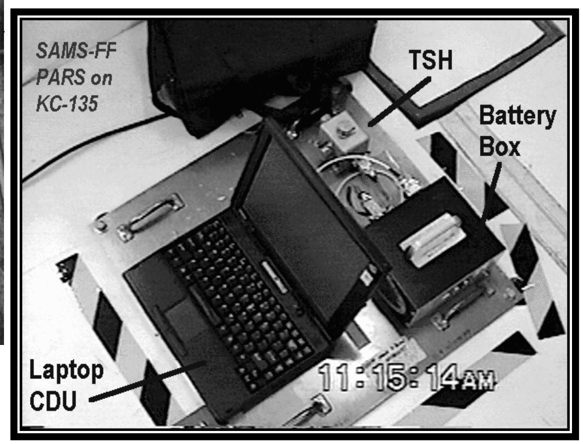
Sensors: TSH
Control System: Space Power Facility Computer with SAMS software





KC-135

Sensors: TSH, FOG
Control System: Control & Data Acquisition Unit

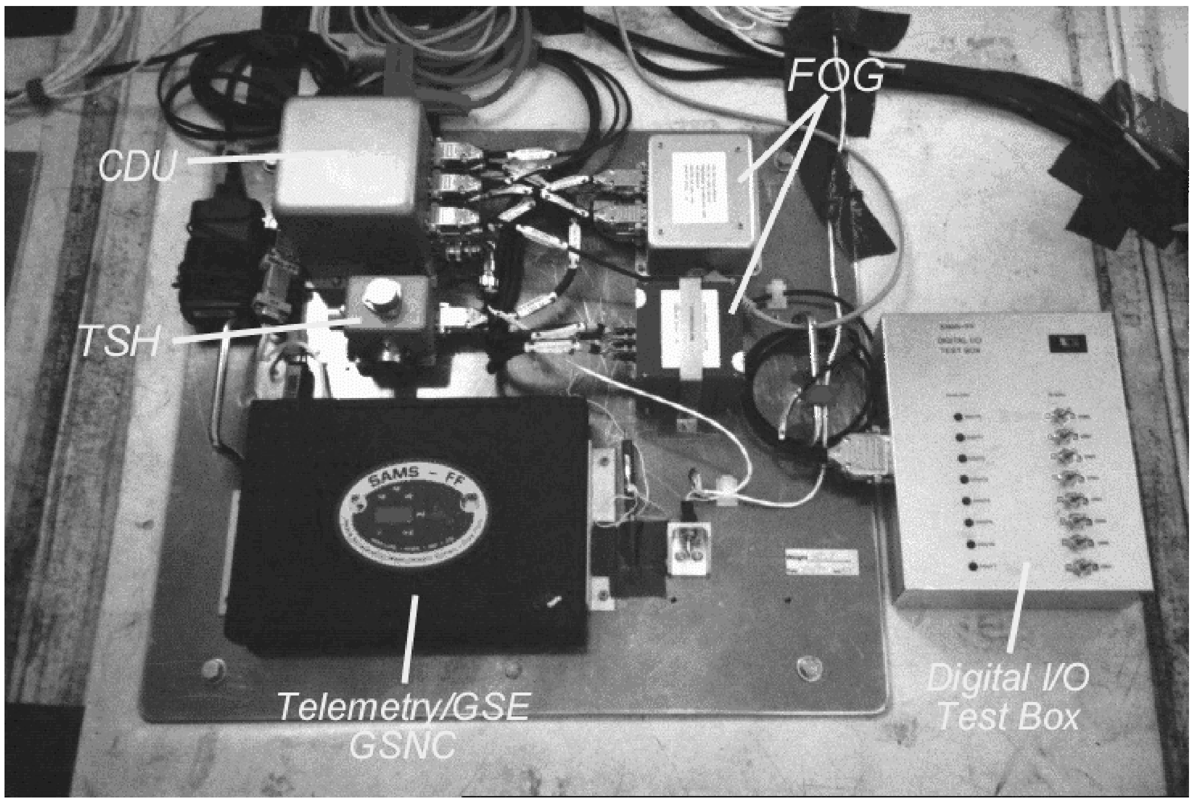


Parabolic Aircraft Rating System

Sensors: TSH
Control System: PC Laptop with SAMS Software

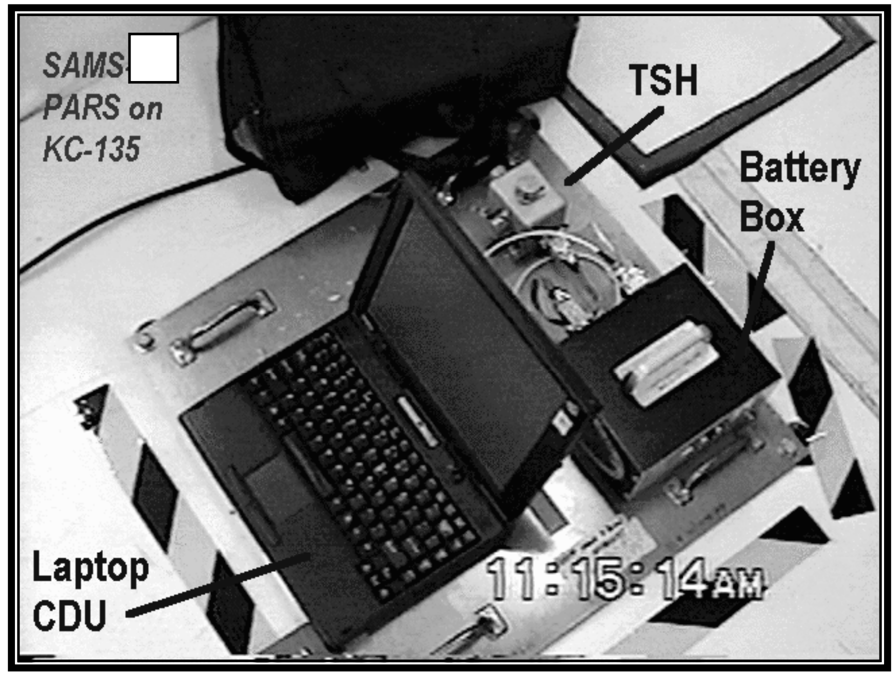
KC-135 Platforms in Support of Microscale Heaters

- Reflight of hardware used on 41.020

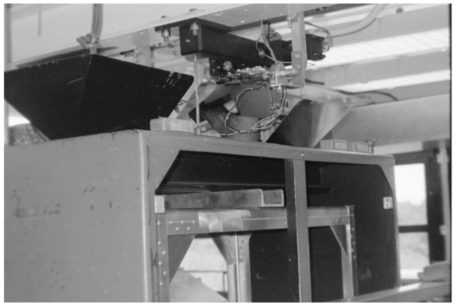


Permanent PARS: Parabolic Aircraft Rating System

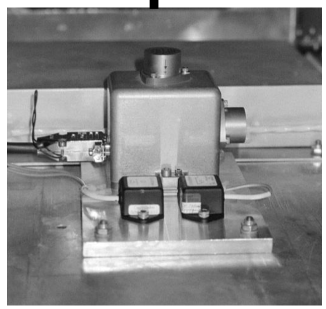
- The SAMS project is providing a permanent PARS system for the KC-135 to support experimenters
- This system will support all flight weeks, not just GRC campaign weeks
- Rating, as well as magnitude and duration immediately after the parabola is complete
- Archived data will be available after the flights
- Initial delivery will be a TSH, CDU and an LCD
- The system will be expanded to have multiple TSHs, user inputs (for timing), and maybe a roll rate sensor

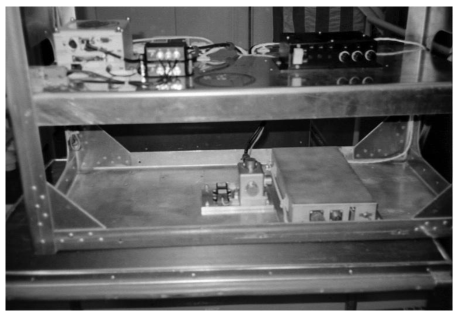


2.2 Second Drop Tower Characterization



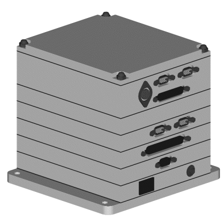
Drop Tower Release Mechanism





Closeup of Hardware

View Down the Drop Tower

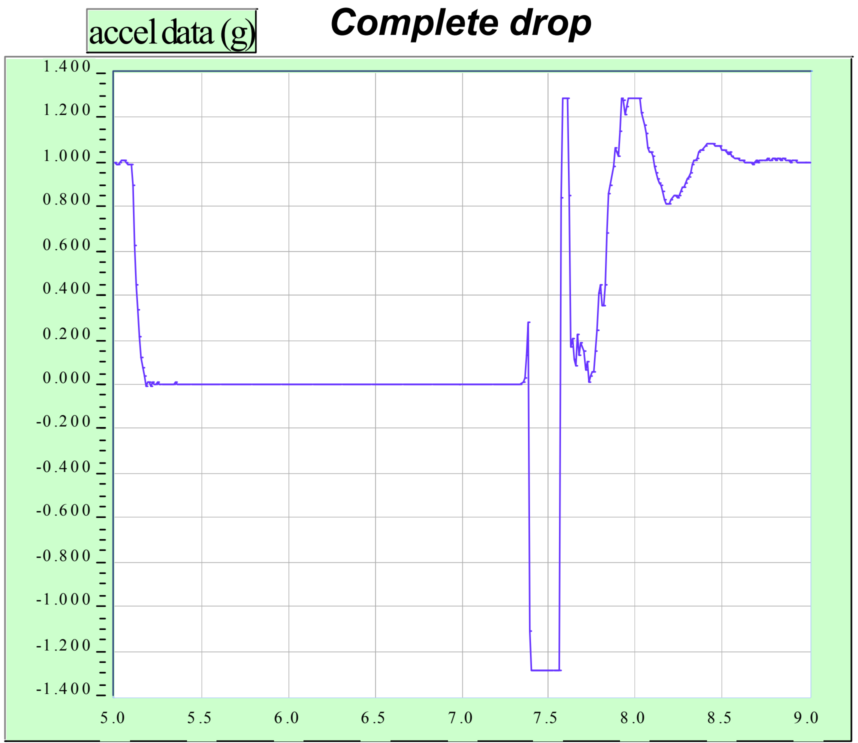


- Performed an initial characterization of the acceleration environment of the NASA GRC 2.2 Second Drop Tower
- System consisted of a CDU (RTD) and TSH
- Support week of drops
  - Check acceleration levels
  - Confirm system operation
  - See if any accel bias shift
- Permanent system will be configured based on the results of the testing

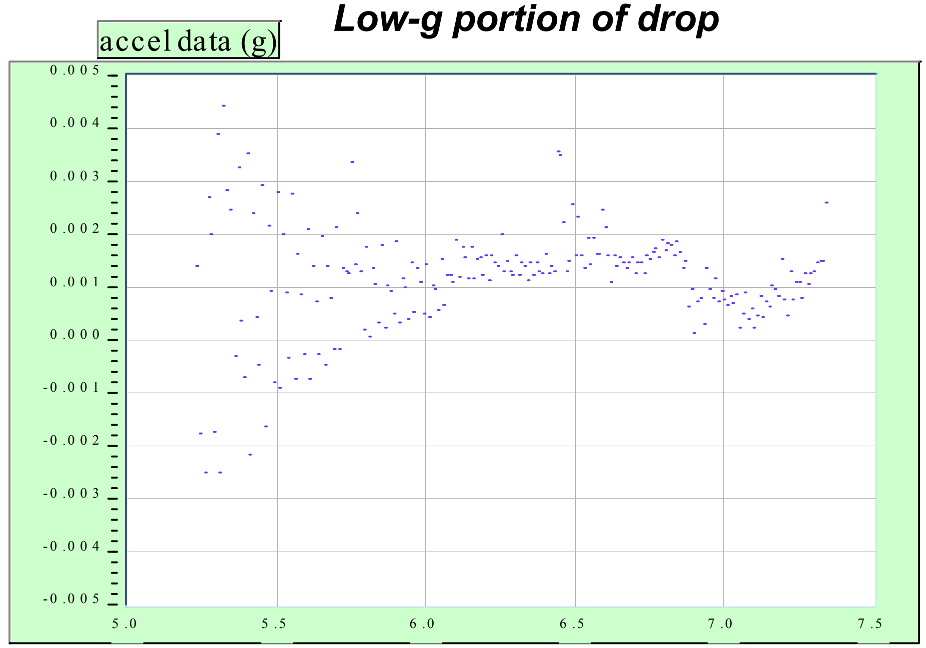
2.2 Second Drop Tower - June 21, 2000

Data from the vertical axis (X) in 2nd drop.

Complete drop



Low-g portion of drop



No appreciable bias or scale factor shift measured on the accelerometers due to the shock of the landing.

Customers - How to request SAMS.

Current Customers for SAMS

- PI Microgravity Services (PIMS)
- ISS Customers
  - ARIS EXPRESS Racks #2, 3, 7, 8
  - Physics of Colloidal Spheres (PCS) Experiment
  - ARIS ICE
  - Microgravity Science Glovebox
    - SUBSA
  - Fluids and Combustion Facility (FCF)
- Shuttle
  - STS-107 Payloads
- Ground/KC-135
  - PARS
  - SoRGE

How to get a sensor or system

- Contact SAMS (see next page) to identify need.
- SAMS may request a memo requesting support based on requirement for additional resources
- SAMS will include new work in project scope
- An Integration Control and Agreement Document (ICAD) or Memorandum of Understanding (MOU) will be created
- SAMS will provide a system based on the ICAD or MOU

Conclusion

- The SAMS Project has several systems that can be configured to support a variety of microgravity platforms
- SAMS and PIMS will work with you to find the best system for your purposes

For more information:
William M. Foster II
SAMS Project Manager and ISS Lead
w.m.foster@grc.nasa.gov
216-433-2368

Ron Sicker
STS/Ground Lead
ronald.sicker@grc.nasa.gov
216-433-6498