The Role of Wireless Instrumentation in the Vision for Space Exploration

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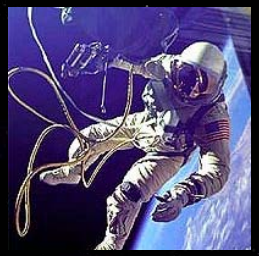
The Vision for Space Exploration

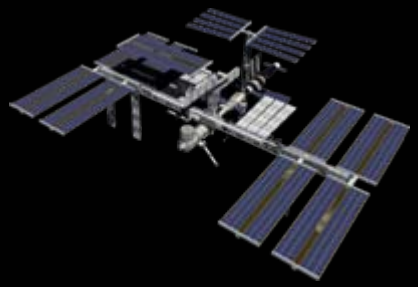
- 1958 – Project Mercury
  - To orbit a manned spacecraft around Earth;
  - To investigate man's ability to function in space;
  - To recover both man and spacecraft safely.



- 1961 – Apollo Program
  - To land humans on the Moon and bring them safely back to Earth

- 1972 – Space Shuttle Program
  - Lift heavy payloads into orbit.
  - Provide labs for carrying out scientific research.
  - Provide a platform for satellite retrieval and repair.
  - Return people and payloads to Earth.

- 1984 – Space Station Program
  - Develop a permanently manned space station



The Vision for Space Exploration

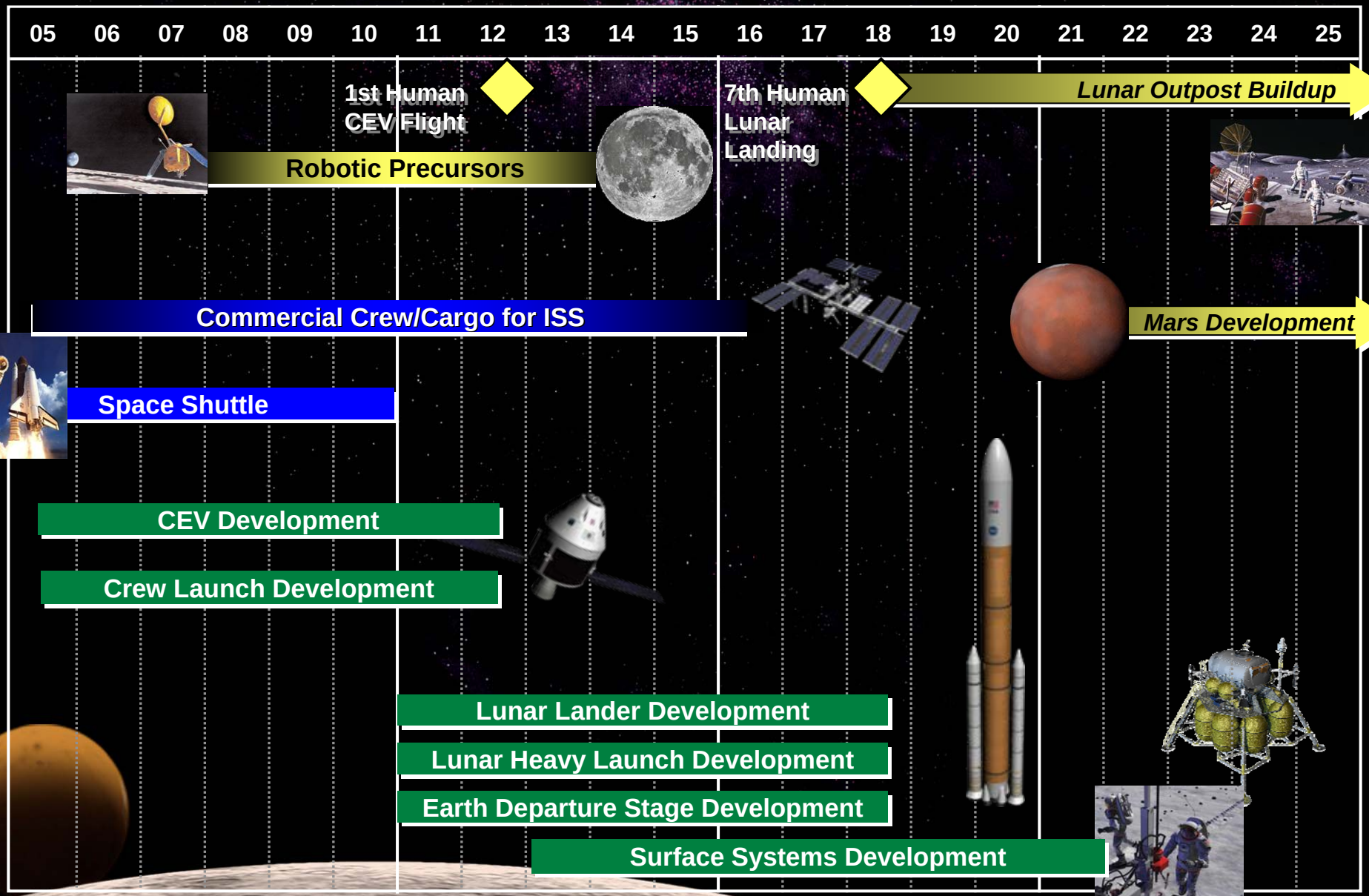
- 2004 – Vision for Space Exploration

  –Extend human presence across the Solar System, starting with a human return to the Moon by the year 2020, in preparation for the human exploration of Mars and other destinations;

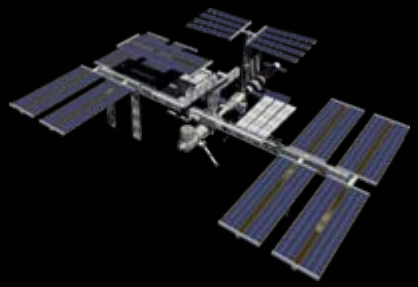
  –Develop the innovative technologies, knowledge and infrastructures both to explore and to support decisions about destinations for future human exploration;

"the vision is a journey, not a race"

NASA's Exploration Roadmap

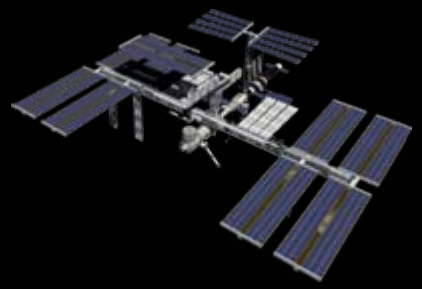


- To determine the best exploration architecture and strategy to implement the Exploration Vision, the Exploration Systems Architecture Study (ESAS) team was established at NASA Headquarters for a study to perform, among other things:
  - Development of a reference exploration architecture concept to support sustained human and robotic lunar exploration operations;
  - Identification of key technologies required to enable and significantly enhance these reference exploration systems and a reprioritization of near-term and far-term technology investments



Technology assessment determined that technology development projects are needed in 12 major areas:

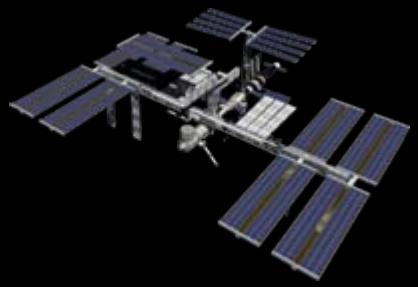
- Structures and Materials
- Protection
- Propulsion
- Power
- Thermal Control
- Avionics and Software
- Environmental Control and Life Support
- Crew Support and Accommodations
- Mechanisms
- In-Situ Resource Utilization
- Analysis and Integration
- Operations



- 52 technology development projects (supporting the 12 technology areas) were recommended in July, 2005. This list has since been reduced to 22 projects. The following slide is the current list of 22 Exploration Technology Development (ETD) projects under investigation

- A notional assessment of those ETD projects that may include wireless technologies has been performed.

  (Note: The wireless technology assessment was not conducted as part of the overall ESAS activity and does not represent official NASA policy)



Exploration Technology Development Program -- Portfolio

Proj #	Title of Combined Project	ESAS Ctrl #	Project Title	New Projects Description	Potential for Wireless?	Comment
1	Structures, Materials, & Mechanisms	1A	Lightweight Materials and Structures Technologies	Lightweight structures -- pressure vessel, insulation (vehicle)	Yes	Impact detection and evaluation, structural integrity of inflatables, thermal performance
1	Structures, Materials, & Mechanisms	9D	Ultra-Low Temperature Mechanisms	Low temperature mechanisms (lunar permanent shadow region ops)		
2	Ablative Thermal Protection System for CEV	2A	Ablative TPS and Structures for a Detachable, Human-Rated, Heatshield for ISS and Lunar Sortie Missions	Detachable, human-rated, ablative environmentally compliant TPS (ISS Mission TPS) - This now technology development for the TPS for both ISS and lunar sortie. Funding in the out years to maintain TPS activities		
3	LOX-Methane Propulsion System for CEV	3A	Integrated, Human Rated, Pressure Fed, LOX/CH4 Propulsion System (Tanks, Main and RCS) for CEV Service Module	Human-rated, 5-20 K lbf class in space engine and propulsion system (CM for ISS orbital ops, lunar ascent and TEI, pressure fed, LOX/CH4, with LADS tanks baseline, LOX/ethonal, and hypergol off ramps) Work Also covers 50-100 lbs non-toxic (LOX/CH4) RCS th		
3	LSAM Ascent Engine	3B	Deep Throttle, Human Rated, Pump Fed, LOX/LH2 Propulsion System for LSAM Descent Stage	Human rated deep throttle-able engine 5-20 K lbf engine (lunar descent, pump-fed LOX/LH2 baseline)		
3	LSAM Ascent Engine	3C	Human rated, pump fed LOX/CH4 5 -20 K lbf thrust class engines for upgraded lunar LSAM ascent engine).	Human rated, pump fed LOX/CH4 5 -20 K lbf thrust class engines for upgraded lunar LSAM ascent engine).		
3	LOX-Methane Propulsion System for CEV	3G	Long-Term Cryogenic Propellant Storage and Management for the Crew Exploration Vehicle	Long-Term Cryogenic Propellant Storage and Management for the Crew Exploration Vehicle	Yes	wireless mass guage
4	Affordable SSME	3F	SSME Affordable High-Rate Production	Manfucturing and production to facilitate: expendable, reduced cost, high production rate, SSMEs		
5	Energy Storage	4B	Fuel Cells for Surface	Fuel Cells for Surface	Yes	Micro PEM fuel cells with RFID
5	Energy Storage	4E	Space rated Li-ion batteries	Space rated Li-ion batteries	Yes	w/microelectronics including RFID
6	Launch Vehicle Power	3K	Human Rated Non-Toxic 900 lbf Thruster for Crew & Heavy Lift Launch Vehicles	Human rated non-toxic 900 lbf thrust class thrust class RCS thrusters (for CLV and heavy lift upper stage) - This should be a bi-pro thruster development attached to the above 100 lbs RCS and the LOX-CH4		
6	Launch Vehicle Power	4J	Non-Toxic Launch Vehicle Power for Thrust Vector and Engine Actuation	Launch Vehicle Power for Thurst Vector and Engine Actuation (non-toxic APU) Covers both the power for the SSME and the SRBs two systems		
7	Thermal Control for Surface Systems	5A	Non-Toxic Active Thermal Control System Fluid	Human rated non-toxic active thermal control system fluid	Yes	Temperature and heat rate sensors for models and realtime data
7	Thermal Control for Surface Systems	5B	Surface heat rejection	Surface heat rejection	Yes	Temperature and heat rate sensors for models and realtime data
8	Rad Hard and Low Temperature Electronics	6A	Radiation Hardened/Tolerant Electronics and Processors	Radiation hardened/tolerant electronics and processors	Yes	Robust wireless communication systems
8	Rad Hard and Low Temperature Electronics	6L	Low temperature electronics and systems	Low temperature electronics and systems (permanent shadow region ops)	Yes	Robust wireless communication systems

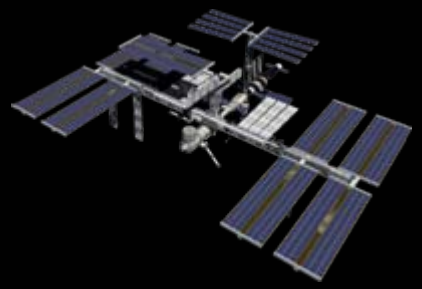
Exploration Technology Development Program -- Portfolio

Proj #	Title of Combined Project	ESAS Ctrl #	Project Title	New Projects Description	Potential for Wireless?	Comment
9	Integrated System Health Management	6D	Integrated System Health Management (ISHM)	Integrated System Health Management - ISHM (CLV, LAS, EDS, CEV, Lunar ascent - descent, habitat - Iso new hydrogen sensor for on pad operations)	Yes	Local, distributed processing and storage, wireless data communication
10	Spacecraft Autonomy	6E	Spacecraft autonomy (vehicles & habitat)	Spacecraft autonomy (vehicles & habitat)	Yes	Local, distributed processing and storage, wireless data communication
11	Automated Rendezvous & Docking Sensor	6F	Automated Rendezvous and Docking (AR&D) Sensor	Automated Rendezvous and Docking (AR&D) Sensor		
12	Reliable Software	6G	Reliable software	Reliable software / flight control algorithms		
13	Autonomous Precision Landing	6J	Autonomous Precision Landing and Guidance Navigation & Control (GN&C)	Autonomous precision landing and GN&C (Lunar & Mars) + possibly need same capability for Earth return as an alternative to stearable chutes and RLEP		
14	Exploration Life Support	7A	Atmospheric management	Atmospheric management - CMRS (CO_2, contaminants and moisture removal system)	Yes	Temperature, pressure, humidity, leak monitoring, etc.
14	Exploration Life Support	7C	Air and Water Recovery Systems	Advanced air and water recovery systems	Yes	Temperature, pressure, humidity, leak monitoring, etc.
15	Environmental Monitoring and Control	7B	Environmental Monitoring and Control	Advanced environmental monitoring and control	Yes	Portable radiation, air and water monitoring systems
16	Fire Detection & Supression	7D	Fire Protection	Fire Protection, Detection and Supression	Yes	Portable combustion products monitoring
17	In-Situ Resource Utilization	10A	Demostration of regolith excavation and material handling	Demostration of regolith excavation and material handling for resource processing	Yes	Remote sensing
17	In-Situ Resource Utilization	10B	Demonstration of oxygen production from regolith	Demonstration of oxygen production from regolith	Yes	Remote sensing
17	In-Situ Resource Utilization	10C	Lunar Polar Resource Prospecting & Collection	Demonstration of polar volatile collection and seperation	Yes	Remote sensing
18	System Design & Analysis Tools	11A	System Design and Analysis Tool Development	Tool Development for Architecture/Mission/Technology Analysis/Design, Modeling & Simulation		
19	Systems Analysis & Technology Assessment	11B	Systems Analysis and Technology Assessment	Technology Investment Portfolio Assessment & Systems Engineering and Integration		
20	Supportability	12A	Supportability	Supportability (commonality, interoperability, maintainability, logistics, and in-situ fab)	Yes	Advanced, portable in-flight maintenance kit
21	Human-Robotic Systems for Surface Operations	12B	Human-system interaction	Human-system interaction (including robotics)		
21	Human-Robotic Systems for Surface Operations	12C	Surface handling, transportation, and operations equipment (Lunar or Mars)	Surface handling, transportation, and operations equipment (Lunar or Mars)		
21	Human-Robotic Systems for Surface Operations	12E	Surface mobility	Surface mobility	Yes	Wearable computers for crew interaction
22			Dust		Yes	Portable dust monitoring technologies

Wireless Instrumentation Systems (WIS) Developments at JSC

- The assessment for the need for wireless for these new technology projects, was largely based upon past experience with the Space Shuttle and Space Station Programs

- NASA-JSC has developed a wireless instrumentation system capability that has been directed toward addressing the Space Shuttle and Space Station Programs for both vehicle and biomedical applications;



Wireless Instrumentation Systems (WIS) Developments at JSC

- The WIS development approach was an initiative to enable spaceflight programs to consider alternatives to traditional wired approaches.

- The wireless sensor systems enable substantial flexibility, addressing the following needs:

  - critical measurements identified/funded late in the life cycle of a project/program;

  - can evolve with the maturity and knowledge of the system, vehicle, environments, operations, age and problems needing investigation;

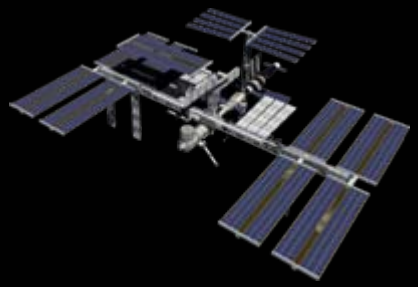
Wireless Instrumentation Systems (WIS) Developments at JSC

- easily relocated and/or reconfigured to support mobility and redundancy at various levels

- relay data across physical boundaries (deployable or dynamic structures, articulating joints, across hatches, etc.) where wires can't be integrated easily;

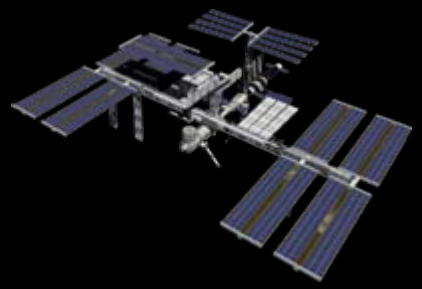
- adaptable to the design, operational phase or unique investigations required of the vehicle;

- evolve with technology improvements (due to ease of integration)

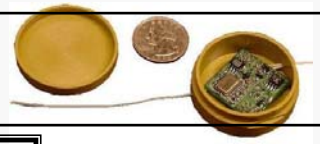


The Wireless Instrumentation System Vision

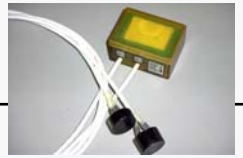
- To provide wireless instrumentation systems to monitor (and eventually control) entire vehicle systems and services to reduce overall weight, cost and risk and increase safety, operability and performance:
  - Upgraded Shuttle and Station capability;
  - Next-gen vehicle architectures that include (wired and wireless) instrumentation zones with distributed processing and local data storage, linked to vehicle avionics backbone and accessible to support upgrades and maintenance

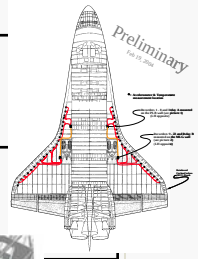


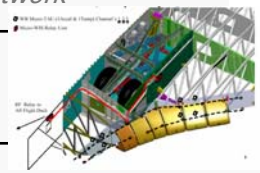
Wireless Instrumentation System Flight Projects



1997	WDAS	*On-orbit data recording, Relaying RF network*
1999	SWIS	*Modular Architecture*
	Micro-WIS	*Miniaturized ultra-low power, low rate RF sensors*
2000	IWIS	*High rate/high accuracy micro-gravity data acquisition, Synchronization*
2001	Micro-SGU	*Miniaturized, medium rate data recorder w/ RF interface*
	Micro-TAU	*Synchronization*
2002	Wideband Micro-TAU	*Very high rate data acquisition, Large Flash memory*
2003	ELMWIS	*10yr operational lifetime, Relaying network*
2005	EWBMTAU	*Local data processing*
Future	RF Health Node	*Real-time integration into vehicle data stream*
	Ultra-WIS	*Continuous vehicle health monitoring*
	SHMS	*Integrated crew (deployed and worn) health network*
	PSAW/Powerbox	*Robust transceivers for higher criticality applications, Power-scavenging technologies*







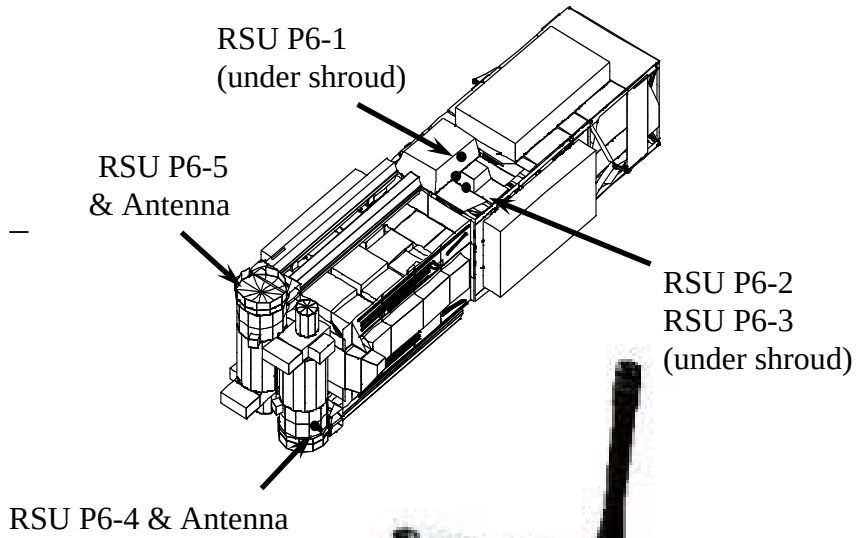
Wireless Instrumentation System Flight Measurements

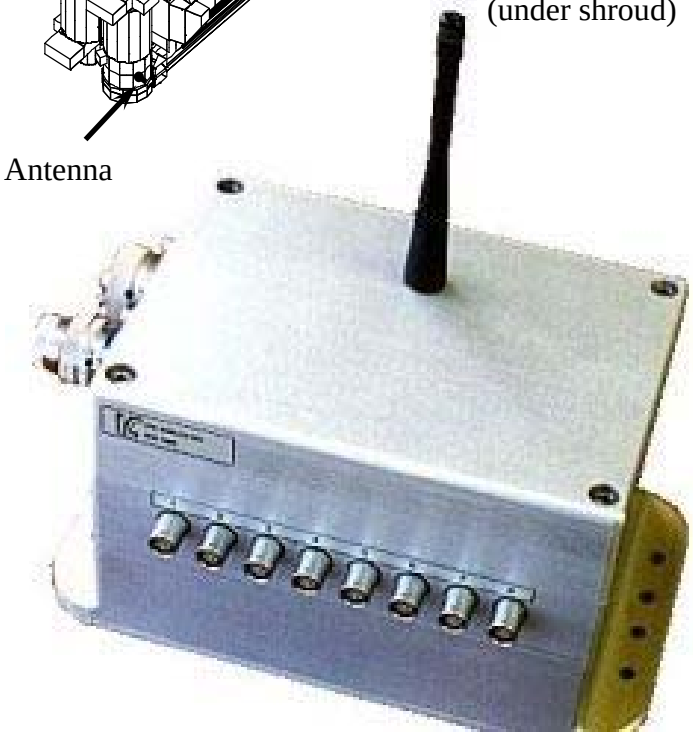
STS/Orb.	System	Temperature	Acceleration	Strain	Other	Total
83/	WDAS	27				27
94/	WDAS	27				27
96/	MWIS	6				6
101/	MWIS	6+2				8
106/	MWIS	6+2+12				20
92/	MWIS/ SWIS	6+12+40				58
97/	IWIS/WISFPP				1	1
98/	MWIS/ SWIS/ IWIS	40	12			52
100/	MWIS	14				14
104/	MWIS	14+9				23
108/	MWIS/ MTAU/ MSGU	14	8	22		44
109/	MSGU			24		24
110/	MSGU			24		24
111/	MSGU			24		24
112/	MTAU/MSGU		8	24		32
113/	MSGU			24		24
107/	MSGU			24		24
114/	EWBMTAU/ MWIS/MTAU/ MSGU	44+2	132+8	24		210

Wireless Instrumentation System Flight Measurements

Shuttle-Based Wireless Instrumentation System (SWIS)

- Launch to Activation thermal monitoring of ISS modules – ISS flights 3A (Z1) & 4A (P6)
- 200mW 2Mbit/sec 900MHz WLAN module
- Excellent coverage throughout module extraction and installation on ISS





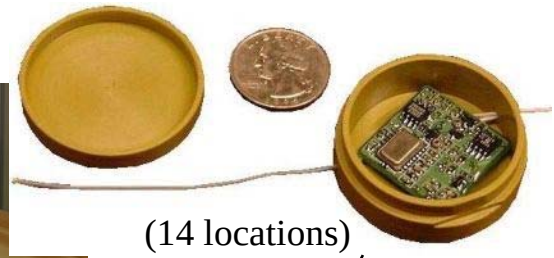
Wireless Instrumentation System Flight Measurements

Micro-Wireless Instrumentation System (Micro-WIS)

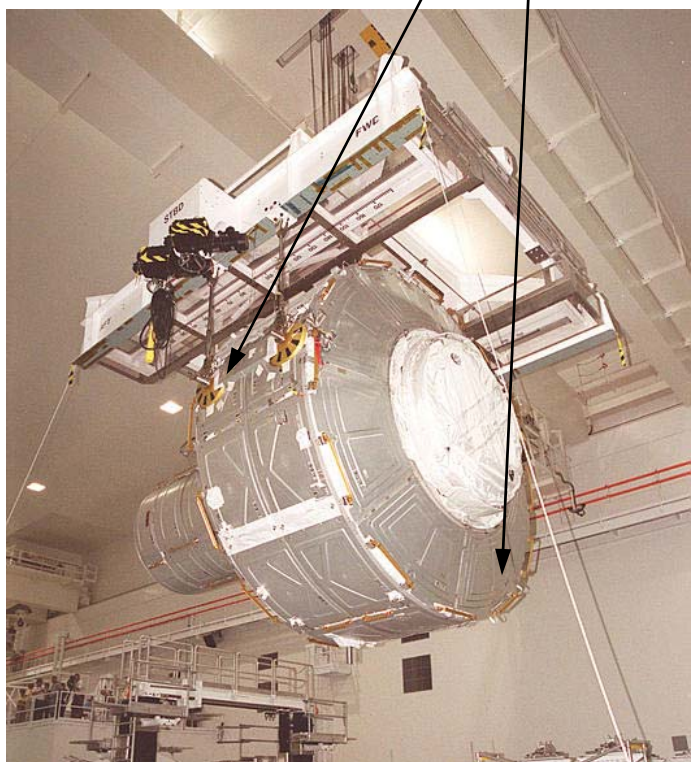
- The first Micro-WIS flight system
  - Low-power narrow-band radio module
  - External RTD and internal temp channels
  - 20 year life with C-cell battery
- Multiple flights, including Joint Airlock on ISS flight 7A
  - Decision to use came at L-2 months
  - Good RF coverage in Payload Bay, partial blockage due to Orbiter Docking System (ODS)

Laptop-based Receiver

Temperature Sensor/Transmitter

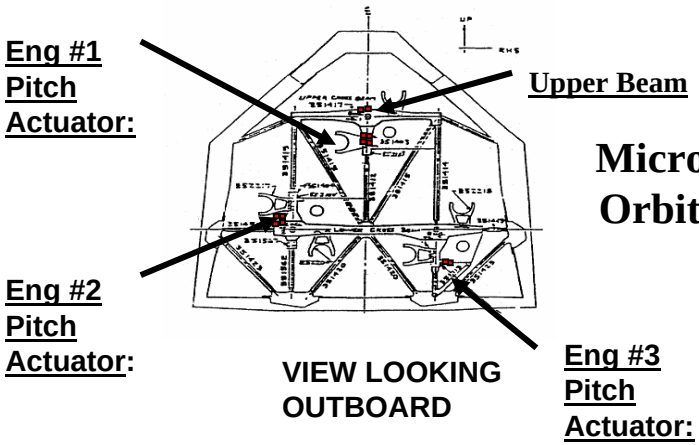


(14 locations)

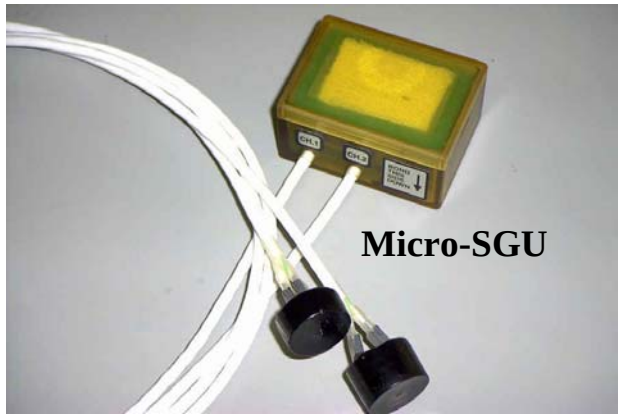


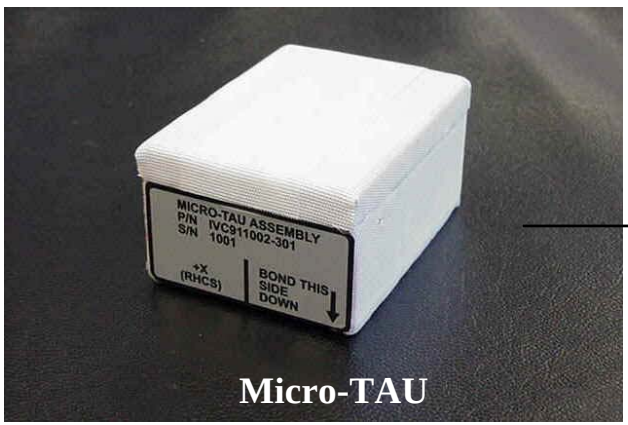
Wireless Instrumentation System Flight Measurements

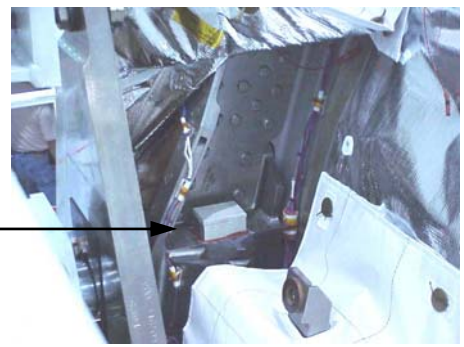
Micro-WIS Strain Gage Unit (Micro-SGU) and Micro-WIS Tria-axial Accelerometer Unit (Micro-TAU)



Micro-SGU Installations in Orbiter Aft Compartment



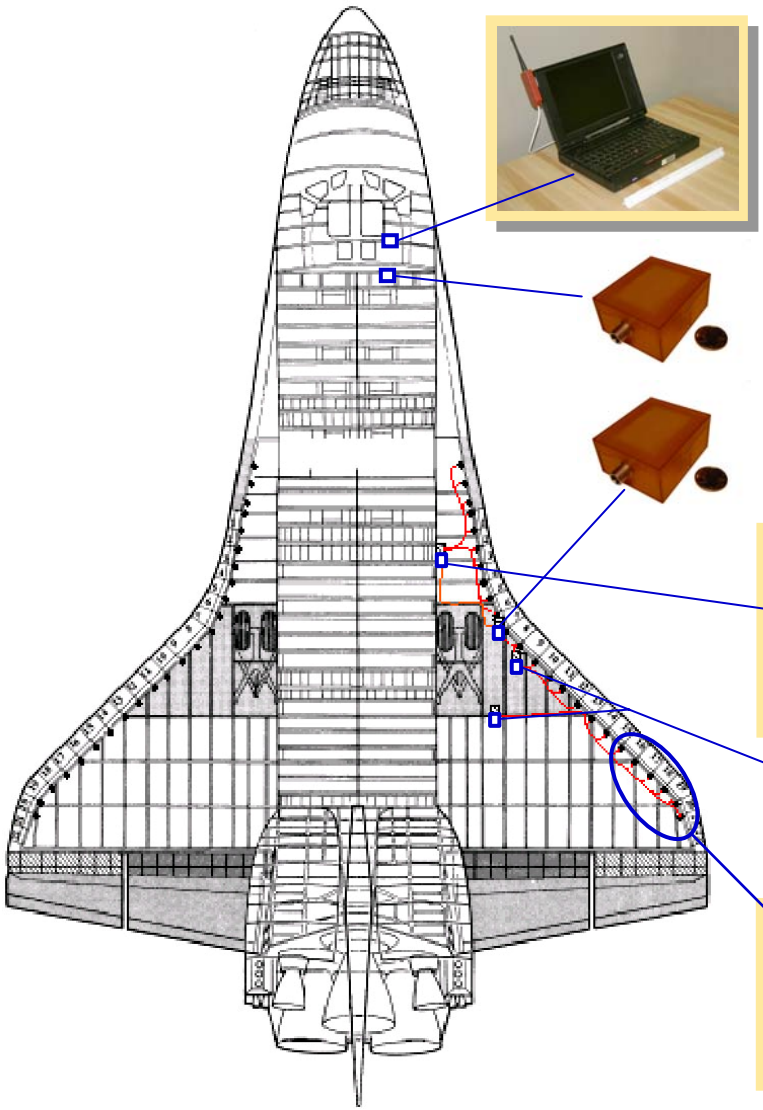




STS-108 Micro-TAUs in Shuttle Payload Bay

Wireless Instrumentation System Flight Measurements

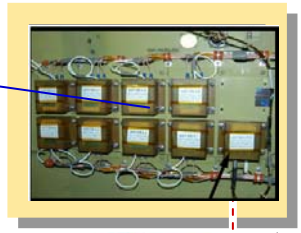
Wing Leading Edge Impact Detection System (WLE IDS)



5 Laptop-based Receiver Assembly collects (via radio frequency) data from Personal Computer-side Relay Unit and dumps data to PC for downlink to Mission Control

4 PC-side Relay Unit collects (via RS-485 serial bus) data from Sensor-side Relay Units

3 Sensor-side Relay Units collect (via RF) post-processed data from Sensor Units

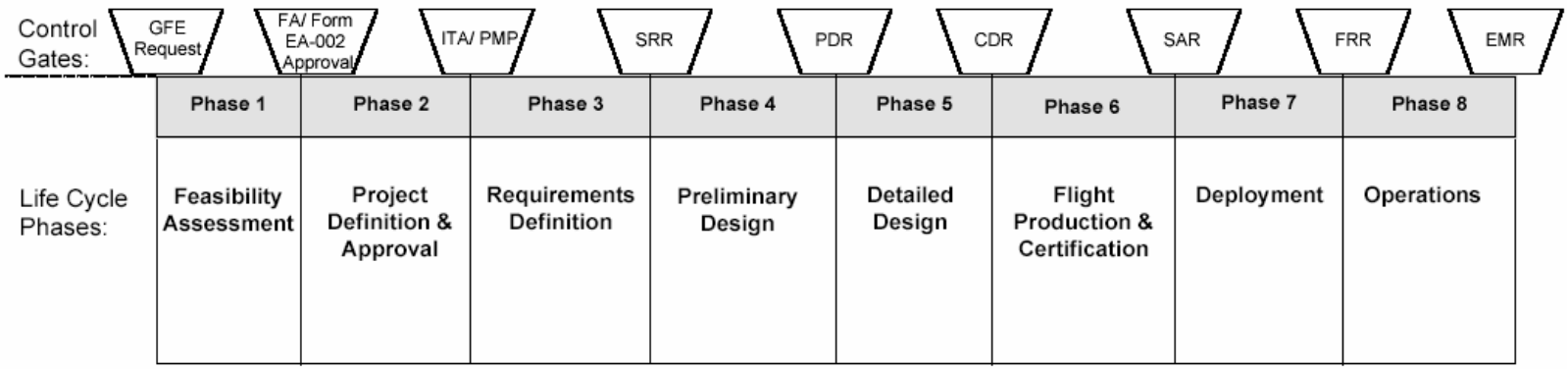


2 Sensor Units record and post-process accelerometer and temperature readings during ascent and while on-orbit

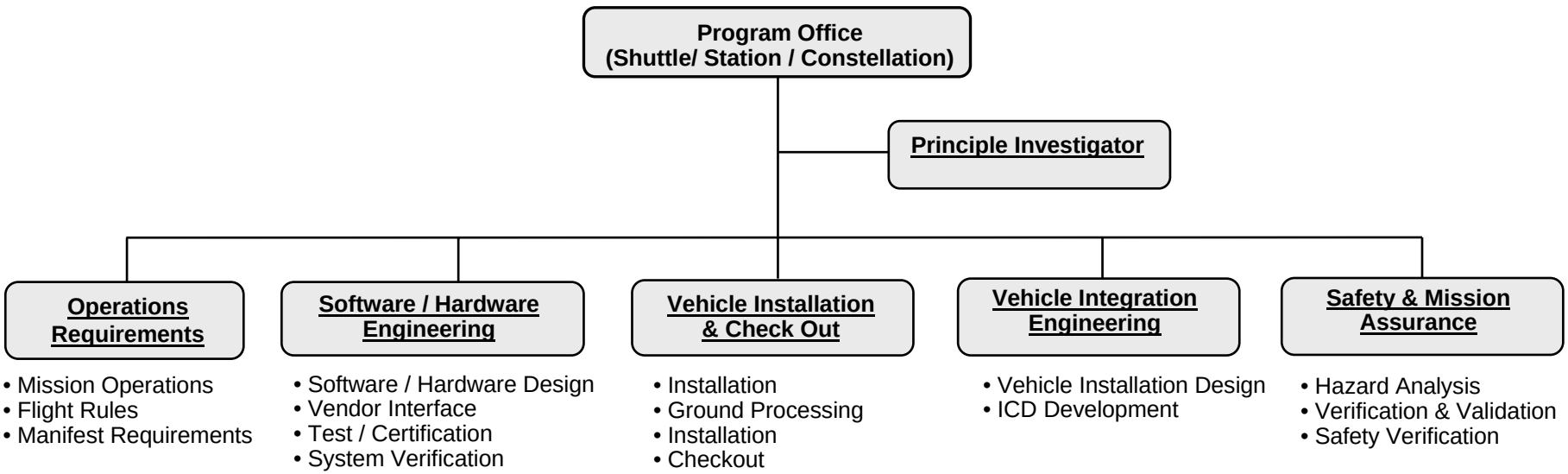
Wing Glove Area (RH wing)

1 Accelerometer (66 units) and temperature (22 units) sensors acquire data

Flight Hardware Certification Process

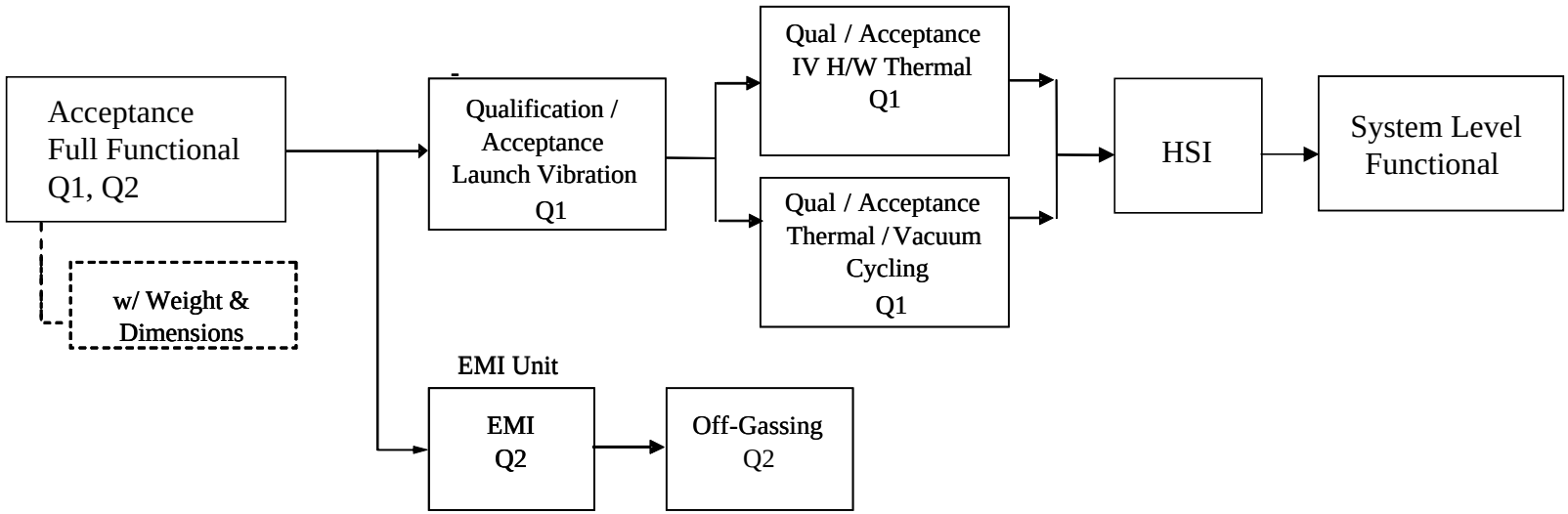


Typical Organizational Responsibilities for Certification

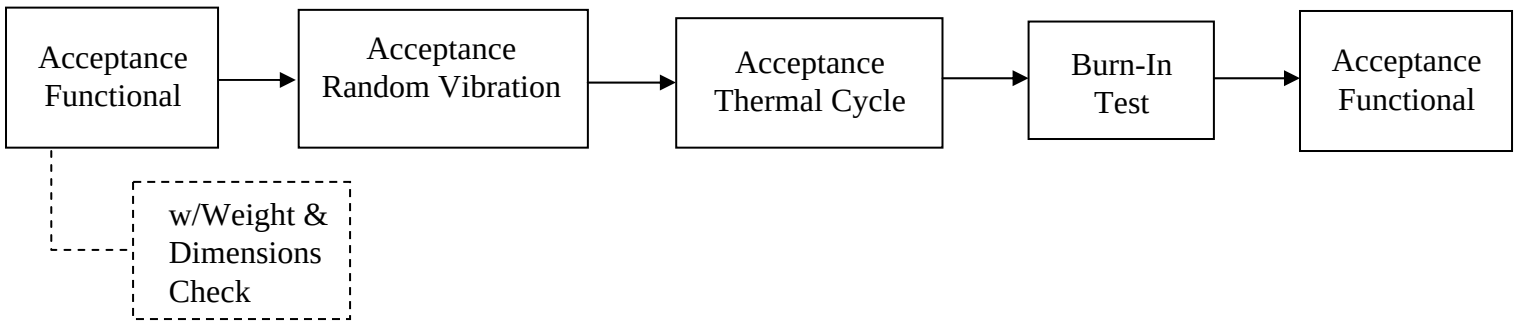


Typical Flight Hardware Test Program Flow

Qualification Test Program



Acceptance Test Program



Design Considerations For Simplifying the Certification/Implementation Process for COTS Wireless Systems

- Electrical Design
  - Electrical de-rating
  - Thermal management
  - Reliability screening of key components
  - Radiation tolerance
  - Parts traceability
  - Low power / Sleep Mode
  - Conformal coating of circuits
  - RF Assessments
    - Link margins
    - Receiver sensitivity
    - Interference effects
  - EMI compatibility

- Mechanical Design
  - Robust housing/mounting design
  - Locking connector interfaces
  - Fastener traceability
  - Materials selection
  - Critical Design Loads & Vibration Test Levels
  - Factors of Safety, Material Properties, Temperature
  - Margins of Safety
  - Fracture Control
  - Each fastener used in a safety critical application shall incorporate two separate verifiable locking features.
  - Depressurization/Repressurization Analysis

Design Considerations For Simplifying the Certification/Implementation Process for COTS Wireless Systems

- Software / Firmware Design
  - Field Upgradeable
  - Traceability
  - Self tests / diagnostics
  - Remote commanding capability
  - Watch-dog timer
  - Near real-time calibration
- System Design
  - Modular / Expandable
  - Standard physical interfaces
  - Standards-based
  - Redundant capability
  - Standard power interfaces
  - Data throughput
  - Data storage
  - Ease of maintenance
    - Battery change-out
    - Firmware upgrades
    - Installation

Verification/Validation Summary

- Functional Verification
- Strength and Fracture Control
- EEE / De-rating
- Power Consumption Analysis
- EMI
- Vibration Testing
- Thermal Testing /Analysis
- Mechanical Design Analysis (I/F tolerance, design features and Process callouts)
- Pressure and Pressure rate of change
- Materials Certification
- Humidity
- Hazard Analysis
- Safety Assessment

Other Wireless Activities

Orbiter Wing Leading Edge Impact Detection System Upgrade

- Firmware upgrades and battery voltage regulator;

External WIS

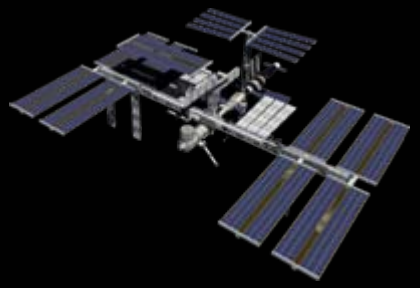
- Micro-gravity accelerometer system to assess ISS truss dynamics;
- First flight on STS-115

Ultrasonic WIS (JSC/LaRC) & Distributed Impact Detection System (LaRC)

- Airborne and structure-borne ultrasonic impact/leak detection/location systems;
- High potential for ISS

Power Scavenging Technologies (JSC In-house Development)

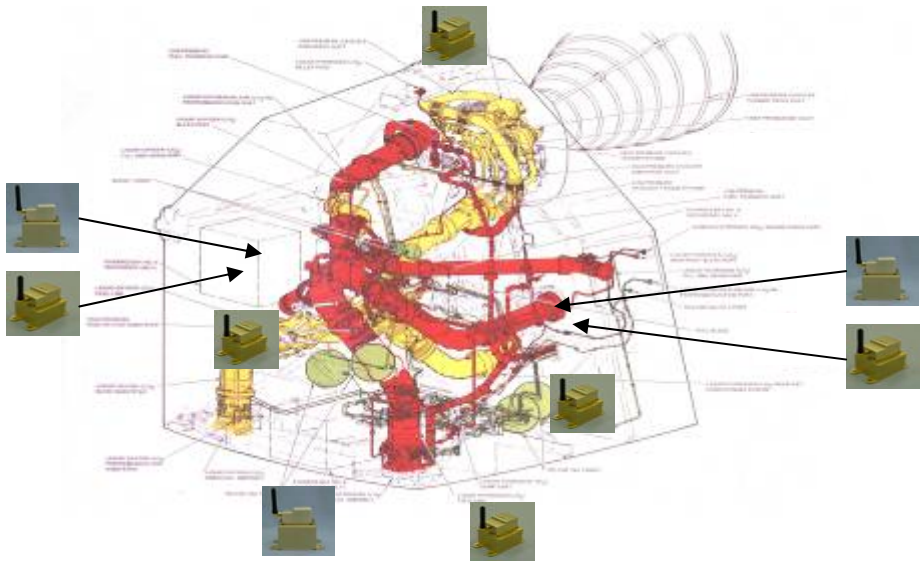
- Energy harvesting technologies utilizing available resources (light, motion, thermal differences, etc.);
- “Solar cooker” and “oven-box” prototypes in development

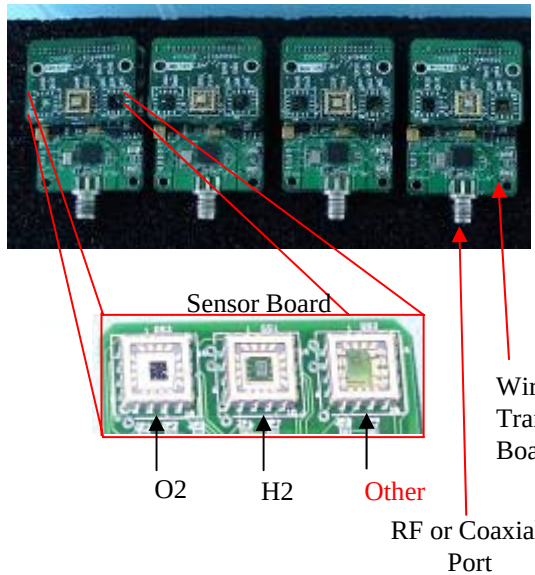


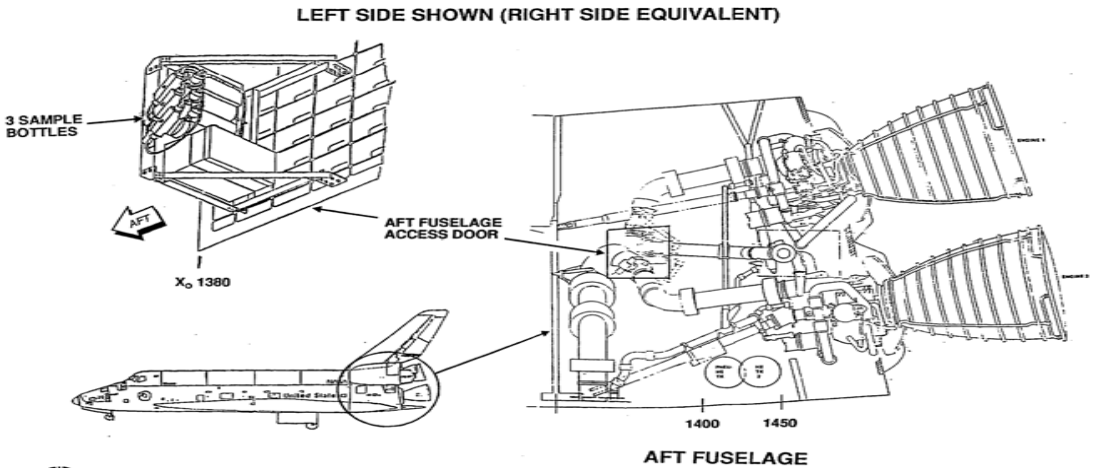
Other Wireless Activities

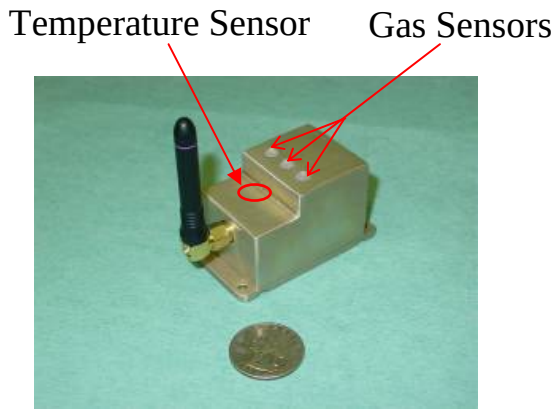
Aft Compartment Hazardous Gas Sensors

* Illustrated Sensor Locations are approximate







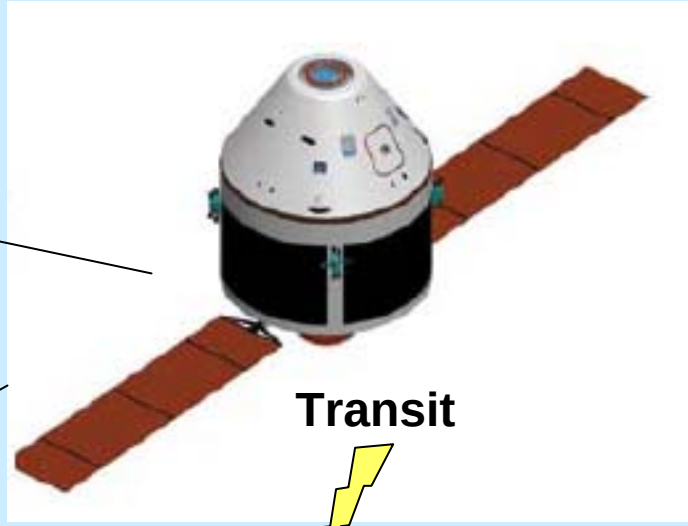


Future Environmental Monitoring Systems

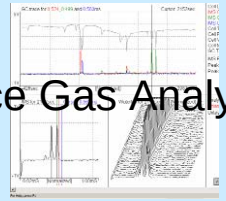
Integration With Scientific Instruments

Atmospheric Composition Monitoring

Portable Toxic Gas Monitors



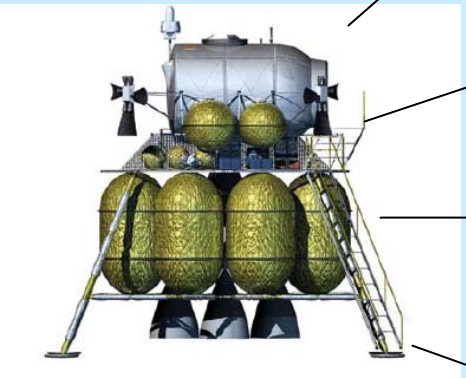
Transit



Trace Gas Analysis

Data Transfer and Interpretation or Corrective Action

Recycled Water Quality



Lunar/Mars Base

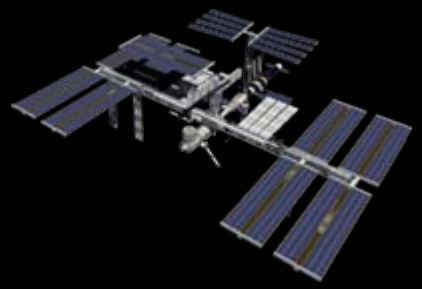
Dust and particulate monitoring

Microbial Contamination

Surface Operations

Space Exploration Wireless Future

- A number of Exploration System technology development activities anticipated to include standalone wireless instrumentation.
  - Environmental Monitoring and Control
    - Atmosphere, Temperature, Pressure, Humidity, Light, Acoustics, Toxicology, Radiation, etc.
  - Physiological Monitoring
    - Heart rate, ECG and EEG, etc.
  - Vehicle and Surface Systems
    - Temperature, Heat rate, Acceleration, Strain, Acoustic Emissions
  - Inventory Management
- By merging the lessons learned from past flight experience with the new wireless technologies of tomorrow, these challenges can be met.



“Crossing the Next Frontier,” Wernher von Braun, Collier’s (March 22, 1952)

Artwork by Chesley Bonestell