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”
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

<table>
<thead>
<tr>
<th>Proj #</th>
<th>Title of Combined Project</th>
<th>ESAS Ctrl #</th>
<th>Project Title</th>
<th>New Projects Description</th>
<th>Potential for Wireless?</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structures, Materials, &amp; Mechanisms</td>
<td>1A</td>
<td>Lightweight Materials and Structures Technologies</td>
<td>Lightweight structures -- pressure vessel, insulation (vehicle)</td>
<td>Yes</td>
<td>Impact detection and evaluation, structural integrity of inflatables, thermal performance</td>
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<tr>
<td>1</td>
<td>Structures, Materials, &amp; Mechanisms</td>
<td>9D</td>
<td>Ultra-Low Temperature Mechanisms</td>
<td>Low temperature mechanisms (lunar permanent shadow region ops)</td>
<td>Yes</td>
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<tr>
<td>2</td>
<td>Ablative Thermal Protection System for CEV</td>
<td>2A</td>
<td>Ablative TPS and Structures for a Detachable, Human-Rated, Heatshield for ISS and Lunar Sortie Missions</td>
<td>Detachable, human-rated, ablative environmentally compliant TPS (ISS Mission TPS) - This new technology development for the TPS for both ISS and lunar sortie. Funding in the next years to maintain TPS stability.</td>
<td>Yes</td>
<td></td>
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<tr>
<td>3</td>
<td>LOX/Methane Propulsion System for CEV</td>
<td>3A</td>
<td>Integrated, Human Rated, Pressure Fed, LOX/CH4 Propulsion System (Tanks, Main, and RCS) for CEV Service Module</td>
<td>Human-rated, 5-20 K lbf class in space engine and propulsion system (CM for ISS orbital ops, lunar ascent and TEL pressure fed, LOX/CH4, with LADS tanks baseline, LOX/CH4, and hypergol off ramp). Work also covers 50-100 lbf non-toxic (LOX/CH4) RCS thrusters.</td>
<td>Yes</td>
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<td>3</td>
<td>LSAM Ascent Engine</td>
<td>3B</td>
<td>Deep Throttle, Human Rated, Pump Fed, LOX/LH2 Propulsion System for LSAM Descent Stage</td>
<td>Human-rated deep throttleable engine 5-20 K lbf engine (lunar descent, pumped LOX/LH2 baseline)</td>
<td>Yes</td>
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<td>3</td>
<td>LSAM Ascent Engine</td>
<td>3C</td>
<td>Human Rated, pump fed LOX/CH4 5-20 K lbf thrust class engines for upgraded lunar LOX/CH4 ascent engine</td>
<td>Human rated, pump fed LOX/CH4 5-20 K lbf thrust class engines for upgraded lunar LOX/CH4 ascent engine.</td>
<td>Yes</td>
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<td>3</td>
<td>LOX/Methane Propulsion System for CEV</td>
<td>3G</td>
<td>Long-Term Cryogenic Propellant Storage and Management for the Crew Exploration Vehicle</td>
<td>Long-Term Cryogenic Propellant Storage and Management for the Crew Exploration Vehicle.</td>
<td>Yes</td>
<td>Wireless mass, duration.</td>
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<td>4</td>
<td>Affordable SSME</td>
<td>3F</td>
<td>SSME Affordable High-Rate Production</td>
<td>Manufacturing and production to facilitate expandable, reduced cost, high production rate, SSMEs.</td>
<td>Yes</td>
<td>Micro PEM fuel cells with RFID</td>
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<td>5</td>
<td>Energy Storage</td>
<td>4B</td>
<td>Fuel Cells for Surface</td>
<td>Fuel Cells for Surface</td>
<td>Yes</td>
<td>Micro PEM fuel cells with RFID</td>
</tr>
<tr>
<td>5</td>
<td>Energy Storage</td>
<td>4E</td>
<td>Space rated Li-ion batteries</td>
<td>Space rated Li-ion batteries</td>
<td>Yes</td>
<td>w/microelectronics including RFID</td>
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<tr>
<td>6</td>
<td>Launch Vehicle Power</td>
<td>3K</td>
<td>Human Rated Non-Toxic 300 lbf Thruster for Crew &amp; Heavy Lift Launch Vehicles</td>
<td>Human-rated non-toxic 300 lbf thrust class thrust class RCS thrusters (for CLV and heavy lift upper stage) - This should be a larger thruster development attached to the above 100 lbf RCS and the LOX/CH4.</td>
<td>Yes</td>
<td>Temperature and heat rate sensors for mobile and realtime data</td>
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<tr>
<td>6</td>
<td>Launch Vehicle Power</td>
<td>4J</td>
<td>Non-Toxic Launch Vehicle Power for Thrust Vector and Engine Actuation</td>
<td>Launch Vehicle Power for Thrust Vector and Engine Actuation (non-toxic APUs) Covers both the power for the SSME and the SREIs and their systems.</td>
<td>Yes</td>
<td>Temperature and heat rate sensors for mobile and realtime data</td>
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<td>7</td>
<td>Thermal Control for Surface Systems</td>
<td>5A</td>
<td>Non-Toxic Active Thermal Control System Fluid</td>
<td>Human rated non-toxic active thermal control system fluid</td>
<td>Yes</td>
<td>Temperature and heat rate sensors for models and realtime data</td>
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<td>7</td>
<td>Thermal Control for Surface Systems</td>
<td>5B</td>
<td>Surface heat rejection</td>
<td>Surface heat rejection</td>
<td>Yes</td>
<td>Robust wireless communication systems</td>
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<td>8</td>
<td>Radiated Low Temperature Electronics</td>
<td>6A</td>
<td>Radiation Hardened/Tolerant Electronics and Processors</td>
<td>Radiation hardened/tolerant electronics and processors</td>
<td>Yes</td>
<td>Robust wireless communication systems</td>
</tr>
<tr>
<td>8</td>
<td>Radiated Low Temperature Electronics</td>
<td>6L</td>
<td>Low temperature electronics and systems (permanent shadow region ops)</td>
<td>Low temperature electronics and systems (permanent shadow region ops)</td>
<td>Yes</td>
<td>Robust wireless communication systems</td>
</tr>
<tr>
<td>Proj #</td>
<td>Title of Combined Project</td>
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<td>Comment</td>
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<tr>
<td>9</td>
<td>Integrated System Health Management</td>
<td>69</td>
<td>Integrated System Health Management (ISHM)</td>
<td>Integrated System Health Management - ISHM (CLV, LAS, EDS, CEV, Lunar ascent - descent, habitat - less new hydrogen sensor for on pad operation)</td>
<td>Yes</td>
<td>Local, distributed processing and storage, wireless data communication</td>
</tr>
<tr>
<td>10</td>
<td>Spacecraft Autonomy</td>
<td>6E</td>
<td>Spacecraft autonomy (vehicles &amp; habitat)</td>
<td>Spacecraft autonomy (vehicles &amp; habitat)</td>
<td>Yes</td>
<td>Local, distributed processing and storage, wireless data communication</td>
</tr>
<tr>
<td>11</td>
<td>Automated Rendezvous &amp; Docking Sensor</td>
<td>6F</td>
<td>Automated Rendezvous and Docking (AR&amp;D) Sensor</td>
<td>Automated Rendezvous and Docking (AR&amp;D) Sensor</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Reliable Software</td>
<td>6G</td>
<td>Reliable software</td>
<td>Reliable software / flight control algorithms</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Autonomous Precision Landing</td>
<td>6L</td>
<td>Autonomous Precision Landing and Guidance Navigation &amp; Control (GN&amp;C)</td>
<td>Autonomous precision landing and GN&amp;C (Lunar &amp; Mars) + possibly need same capability for Earth return as an alternative to storable fluids and RREP</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Exploration Life Support</td>
<td>7A</td>
<td>Atmospheric management</td>
<td>Atmospheric management - CMAS (CO₂, contaminants and moisture removal system)</td>
<td>Yes</td>
<td>Temperature, pressure, humidity, leak monitoring, etc</td>
</tr>
<tr>
<td>14</td>
<td>Exploration Life Support</td>
<td>7C</td>
<td>Air and Water Recovery Systems</td>
<td>Advanced air and water recovery systems</td>
<td>Yes</td>
<td>Temperature, pressure, humidity, leak monitoring, etc</td>
</tr>
<tr>
<td>15</td>
<td>Environmental Monitoring and Control</td>
<td>7B</td>
<td>Environmental Monitoring and Control</td>
<td>Advanced environmental monitoring and control</td>
<td>Yes</td>
<td>Portable radiation, air and water monitoring systems</td>
</tr>
<tr>
<td>16</td>
<td>Fire Detection &amp; Suppression</td>
<td>7D</td>
<td>Fire Protection</td>
<td>Fire Protection, Detection and Suppression</td>
<td>Yes</td>
<td>Portable combustion products monitoring</td>
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<tr>
<td>17</td>
<td>In-Situ Resource Utilization</td>
<td>10A</td>
<td>Demonstration of regolith excavation and material handling</td>
<td>Demonstration of regolith excavation and material handling for resource processing</td>
<td>Yes</td>
<td>Remote sensing</td>
</tr>
<tr>
<td>17</td>
<td>In-Situ Resource Utilization</td>
<td>10B</td>
<td>Demonstration of oxygen production from regolith</td>
<td>Demonstration of oxygen production from regolith</td>
<td>Yes</td>
<td>Remote sensing</td>
</tr>
<tr>
<td>17</td>
<td>In-Situ Resource Utilization</td>
<td>10C</td>
<td>Lunar Polar Resource Prospecting &amp; Collection</td>
<td>Demonstration of polar volatile collection and separation</td>
<td>Yes</td>
<td>Remote sensing</td>
</tr>
<tr>
<td>19</td>
<td>Systems Analysis &amp; Technology Assessment</td>
<td>11B</td>
<td>Systems Analysis and Technology Assessment</td>
<td>Technology Investment Portfolio Assessment &amp; Systems Engineering and Integration</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Supportability</td>
<td>12A</td>
<td>Supportability</td>
<td>Supportability (commonality, interoperability, maintainability, logistics, and in-situ fab)</td>
<td>Yes</td>
<td>Advanced, portable in-flight maintenance kit</td>
</tr>
<tr>
<td>21</td>
<td>Human-Robotic Systems for Surface Operations</td>
<td>12B</td>
<td>Human-system interaction</td>
<td>Human-system interaction (including robotics)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Human-Robotic Systems for Surface Operations</td>
<td>12C</td>
<td>Surface handling, transportation, and operations equipment (Lunar or Mars)</td>
<td>Surface handling, transportation, and operations equipment (Lunar or Mars)</td>
<td>Yes</td>
<td>Wearable computers for crew interaction</td>
</tr>
<tr>
<td>21</td>
<td>Human-Robotic Systems for Surface Operations</td>
<td>12D</td>
<td>Surface mobility</td>
<td>Surface mobility</td>
<td>Yes</td>
<td>Portable dust monitoring technologies</td>
</tr>
</tbody>
</table>
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

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

<table>
<thead>
<tr>
<th>STS/Orb.</th>
<th>System</th>
<th>Temperature</th>
<th>Acceleration</th>
<th>Strain</th>
<th>Other</th>
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<td>44+2</td>
<td>132+8</td>
<td>24</td>
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<td>210</td>
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</tbody>
</table>
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)
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
Accelerometer (66 units) and temperature (22 units) sensors acquire data. 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. PC-side Relay Unit collects (via RS-485 serial bus) data from Sensor-side Relay Units. Sensor-side Relay Units collect (via RF) post-processed data from Sensor Units. Sensor Units record and post-process accelerometer and temperature readings during ascent and while on-orbit. Wing Glove Area (RH wing) is the location of the Wing Leading Edge Impact Detection System (WLE IDS).
Flight Hardware Certification Process

Typical Organizational Responsibilities for Certification

Program Office
(Shuttle/ Station / Constellation)

Principle Investigator

Operations
Requirements
- Mission Operations
- Flight Rules
- Manifest Requirements

Software / Hardware
Engineering
- Software / Hardware Design
- Vendor Interface
- Test / Certification
- System Verification

Vehicle Installation
& Check Out
- Installation
- Ground Processing
- Installation
- Checkout

Vehicle Integration
Engineering
- Vehicle Installation Design
- ICD Development

Safety & Mission
Assurance
- Hazard Analysis
- Verification & Validation
- Safety Verification
Typical Flight Hardware Test Program Flow

Qualification Test Program

Acceptance Functional Q1, Q2
Qualification / Acceptance Launch Vibration Q1
Qual / Acceptance IV H/W Thermal Q1
Qual / Acceptance Thermal / Vacuum Cycling Q1
Off-Gassing Q2
EMI Unit

HSI
System Level Functional

Acceptance Test Program

Acceptance Functional
Acceptance Random Vibration
Acceptance Thermal Cycle
Burn-In Test
Acceptance Functional

w/ Weight & Dimensions Check
w/ Weight & Dimensions
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

- Atmospheric Composition Monitoring
- Portable Toxic Gas Monitors
- Trace Gas Analysis
- Recycled Water Quality
- Dust and particulate monitoring
- Microbial Contamination
- Integration With Scientific Instruments

Lunar/Mars Base

Data Transfer and Interpretation or Corrective Action

Surface Operations

Transit
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