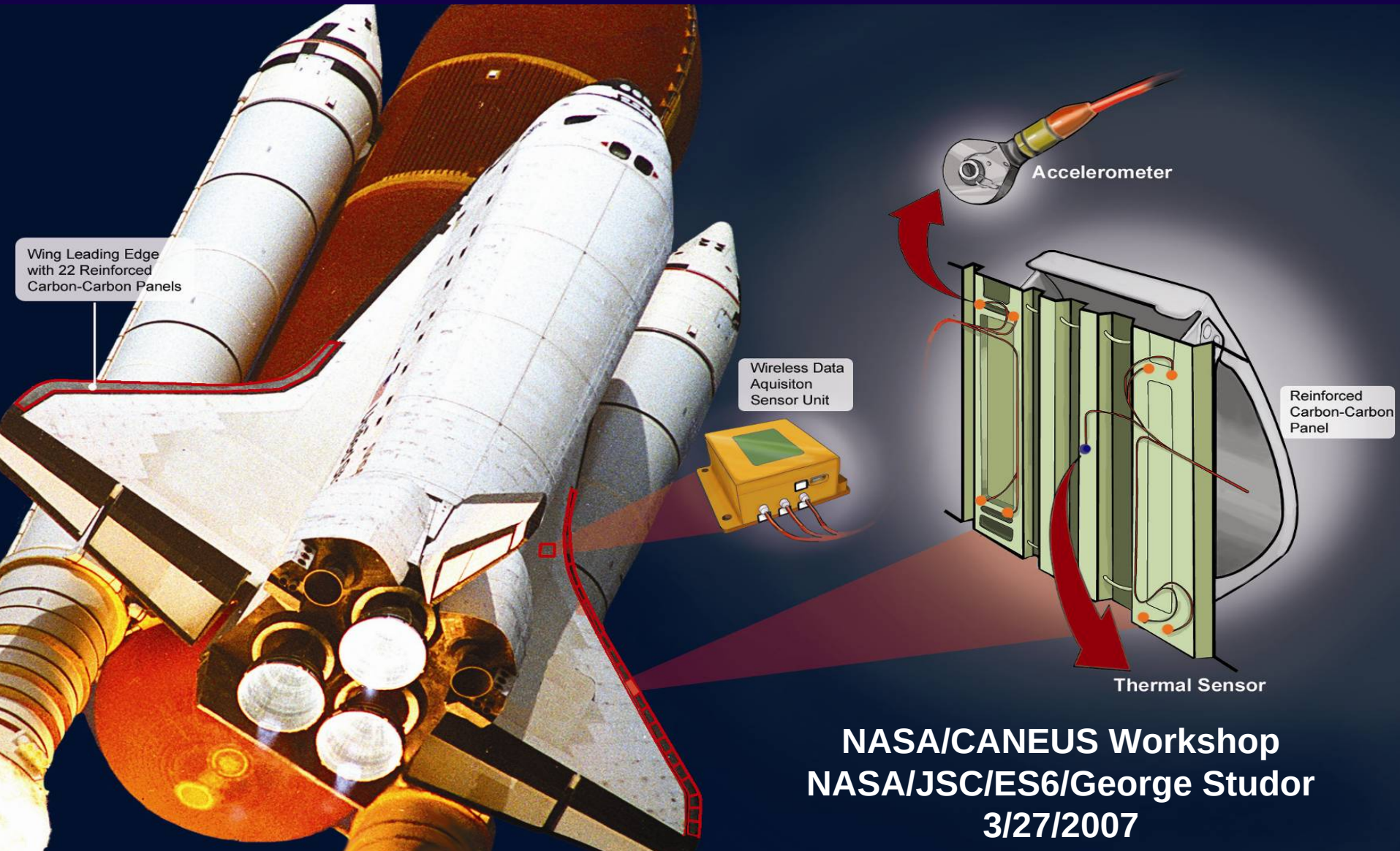
“Fly-by-Wireless” : A Revolution in Aerospace Architectures for Instrumentation and Control



NASA/CANEUS Workshop
NASA/JSC/ES6/George Studor
3/27/2007

“Fly-by-Wireless”

(What is it?)

Vision:

To minimize cables and connectors and increase functionality across the aerospace industry by providing reliable, lower cost, modular, and higher performance alternatives for a vehicle/program's life-cycle.

Why are we holding this workshop?

1. Increasing the maturity of the wireless state-of-the-art can help NASA’s Exploration Programs and other flight and ground test programs.

2. NASA research and flight experience can help accelerate the aerospace industry state-of-the art.

3. Partnerships developed in this common objective can lead to new innovations and applications we haven’t thought of yet.

4. A longer term international effort to reduce wires and connectors across the industry and around the world has shown to be of considerable interest.

CANEUS "Fly-by-Wireless" Workshop

(We've actually been talking about this for a number of years)

NASA/JSC 10/13/1999 "Fly-by-Wireless" Workshop

ATWG 2/12/200 "Wireless Aerospace Vehicle Roadmap"
USAF Reserve Report 11/15/1999;
DFRC Report 12/11/1999;
ONR 2/16/2000;
NASA Space Launch Initiative Briefing 8/7/2001;
World Space Congress 3/8/2002;
International Telemetry Conference 4/6/2004;
VHMS TIM at LaRC 5/11/2004;

CANEUS 10/28/2004 "Wireless Structural Monitoring Sensor Systems for Reduced Vehicle Weight and Life Cycle Cost"

CANEUS 9/2006 "Lessons Learned Micro-Wireless Instrumentation Systems on Space Shuttle and International Space Station"
- participants came ready to investigate a cooperative project on Aerospace Structural Health Monitoring.

CANEUS 3/27-28/2007 "Fly-by-Wireless" Workshop to investigate the common interests and discuss future plans.

CANEUS "Fly-by-Wireless" Project Goals

- **Establish an international forum through the CANEUS Organization to exchange public and published information on wireless alternatives and new innovations which precipitate cooperation and partnerships between industry/government customers, system innovators and technology developers.**

- **Promote understanding of the maturity and capability of alternatives to wired infrastructure, such as no-power instrumentation, standalone wireless data acquisition and processing systems, and wireless control redundancy improvements, in order to facilitate timely vehicle architecture accommodations and prioritize technology development.**

- **Identify solution paths for key challenges, such as FAA regulations, certification requirements, RF/EMI/EMC, structural design/access & spectrum management.**

- **Quantify the life cycle return on investment or mission need for various applications and opportunities to establish which investments and partnerships have promise.**

- **Identify and enable key partnerships to make progress in implementing "Fly-by-Wireless" in aerospace vehicles. Future workshop and project plans will address technology maturation, vehicle/program accommodations and incremental implementation.**

CANEUS “Fly-by-Wireless” Workshop Objectives

- **Communicate the CANEUS “Fly-by-Wireless” Vision and concept for Project Partnering.**
- **Understand the potential Aerospace Applications/End-User Needs and the state-of-the-art in applicable Technology Development.**
- **Develop cooperating Application/End User and Technology Provider associations that intend to further the "Fly-by-Wireless" vision.**
- **Provide communication of results and additional opportunities for further development of cooperative work and partnerships.**

CANEUS "Fly-by-Wireless" Workshop Objectives

Mar 27:

Session 1: Vision and Reality

1. Clarify and provide rationale for the "Fly-by-Wireless" Vision.

2. Address unknowns of using wireless with insight from FAA/NASA wireless certification expert authorities.

3. Provide motivation through examples from NASA's flight experience and recent breakthrough from Sandia National Labs.

Break: Visit RFID World Exhibit Hall and hear Keynote Speakers.

Session 2: Application/End User Needs

1. Provide insightful presentations on potential Applications and End User needs in the aerospace industry.

2. Begin scheduling process for Session 4: Technology developers can schedule themselves to meet with Application/End Users about mutual interests.
See CANEUS Information Table for Sign-up Sheets(15 minute blocks).

Dinner Speaker: Doug Comstock, NASA Director, Innovative Partnership Programs.

Session 1 Speakers

George Studor Structural Engineering Division, NASA/Johnson Space Center

"'Fly-by-Wireless': a Revolution in Aerospace Vehicles for Instrumentation and Control"

Karl Kiefer Invocon, Inc, President

"Real-World Experience in Wireless Instrumentation and Control Systems"

Robert Scully NASA/Johnson Space Center/EMI and

"Certification Process for Wireless and RFID Systems on space Shuttle and Space Station with implications for the Constellation Program."

Dave Walen FAA, Aviation Safety Chief Scientific and Technical Officer, EMI

"Perspectives on Aircraft Wireless System Certification"

Robert Brocato Sandia National Labs, RF and Optics Microsystems Applications Department Principle Member of Technical Staff

"Multiple Passive Sensors Interrogated with 1 mW of RF over 10 Meters: a Promising Foundation"

Stay for the Demonstration! **Sign up for "One-on-Ones"!!**

CANEUS "Fly-by-Wireless" Workshop Objectives (Continued)

Mar 28:

Session 3: Technology Developments:

1. Provide presentations on Technologies that can facilitate the "Fly-by-Wireless" vision in the aerospace industry.

2. Continue and finalize the scheduling process for Session 4.
   See CANEUS Information Table for Sign-up Sheets.

IEEE RFID 2007 "Fly-by-Wireless" Panel 12:00 – 1:30pm; Grapevine rooms 1,2,3

Session 4: Exploring Mutual Areas of Interest

1. Introduce the participants to the CANEUS Project to facilitate Aerospace Structural Health Monitoring over the coming years.

2. Provide specific direction for Session 4 activities and expected results to identify mutual areas of interest and the level of interest.

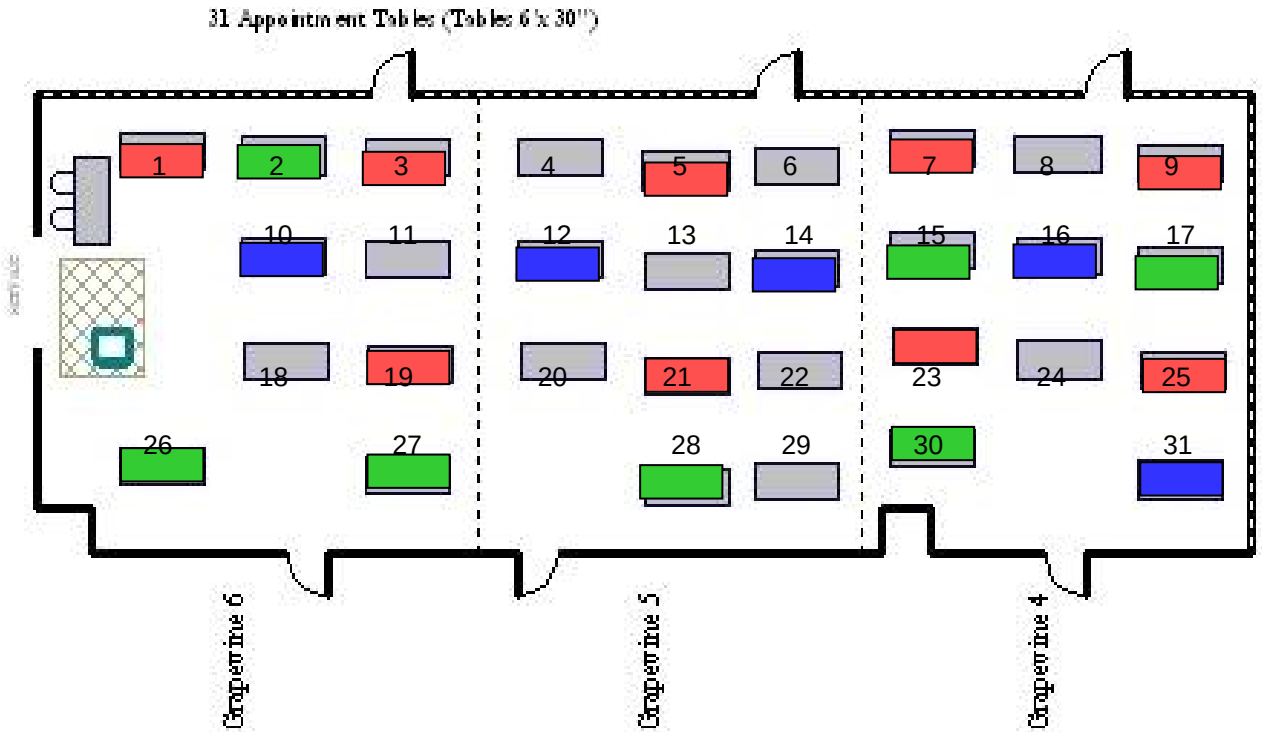
3. Conduct discussions between Application/End Users and Technology Providers – Technology developers come to each Application/End User Tables at their appointment time.
   See CANEUS Information Table for Sign-up Sheets.

4. Group Leads will collect and announce the general results up front by room.

5. Summarize the Workshop and Provide Future CANEUS Project Plans.

Session 4 Layout

“One-on-One” Appointment Tables



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Spacecraft Wireless
1-Villarreal
3-Barton
5-Dunaway
7-James
9-Coumar
19-Fink
21-Miller
23-Graves
25-Lyke

Wireless IVHM & Test
10-Freudinger
12-Szatskowski
14-Vestrum
16-Griner
31-Alena

Aircraft Wireless
2-Alves
15-Blair
17-Van Buiten
26-Smith
27-Pond
28-Mateus
30- Daniel

Others: Studor, Walen, TBD

Session 4: Application End User/Technology Provider Sign up Sheet (Example)

Application Presenter/End User: (Mr. So and So/ Organization XYZ)

Time	Technology Provider./Name/Org	Email/Contact Info	Potential Area of Mutual Interest	Level of Interest*
1:30	*Jon Brown/ATWG Corp.*	*J.brown@atwg.com*	*passive sensor-tag*	*A*
1:45				
2:00				
2:15				
2:30				
2:45				
3:00				
3:30				
3:45				
4:00				
4:15				

Comments:

Levels of Interest :

A. **Definitely** have a mutual interest that needs follow-up.
B. **Maybe**, more information will be exchanged to determine this.
C. **Maybe in the Future**, no interest currently, technology is potentially applicable, but not yet ready yet – talk again later.
D. **No Mutual Interest**, no future contact is necessary.
E. **Other** – Please describe in Comments section at the bottom.

"'Fly-by-Wireless'

a Revolution in Aerospace Vehicle Instrumentation and Control"

The Briefing

“Fly-by-Wireless” – It’s NOT just about Weight or Wireless Flight Control

- **Expenses for Cabled Connectivity** begin in Preliminary Design Phase and continue for the entire life cycle.
- **Reducing the quantity and complexity** of the physical interconnects has a payback in many areas.

1. **Failures of wires, connectors** and the safety and hazard provisions in avionics and vehicle design to control or mitigate the potential failures.
2. **Direct Costs**: Measurement justification, design and implementation, structural provisions, inspection, test, retest after avionics r&r, logistics, vendor availability, etc.
3. **Cost of Data not obtained:** Performance, analyses, safety, operations restrictions, environments and model validations, system modifications and upgrades, troubleshooting, end of life certification and extension.
4. **Cost of Vehicle Resources:** needed to accommodate the connectivity or lack of measurements that come in the form of weight, volume, power, etc.
5. **Reliability Design Limitations**: avionics boxes must build in high reliability to “make up for” low reliability cables, connectors, and sensors. Every sensor can talk to every data acquisition box, and every data acquisition box can talk to every relay box….

"Fly-by-Wireless" – It's NOT just about Weight or Wireless Flight Control

6. **Physical Restrictions:** Cabled connectivity doesn't work for monitoring: structural barriers limit physical access and vehicle resources, the assembly of un-powered vehicle pieces (like the ISS), during deployments (like a solar array, cargo/payloads, or inflatable habitat), crew members, robotic operations, proximity monitoring at launch, landing or mission operations.

7. **Performance**: Weight is not just the weight of the cables, it is insulation, bundles, brackets, connectors, bulkheads, cable trays, structural attachment and reinforcement, and of course the resulting impact on payloads/operations. Upgrading various systems is more difficult with cabled systems.

8. **Flexibility of Design:** Cabling connectivity has little design flexibility, you either run a cable or you don't get the connection. Robustness of wireless interconnects can match the need for functionality and level of criticality or hazard control appropriate for each application, including the provisions in structural design and use of materials.

9. **Cost of Change**: This cost grows enormously for as each flight grows closer, as the infrastructure grows more entrenched, as more flights are "lined-up" the cost of delays due to trouble-shooting and re-wiring cabling issues is huge.

Cost of Change for Instrumentation

The earlier conventional instrumentation is fixed, the greater the cost of change.

- Different phases uncover and/or need to uncover new data and needs for change.
- Avionics and parts today go obsolete quickly - limited supportability, means big sustaining costs.
- The greater number of integration and resources that are involved, the greater the cost of change.
- Without developed/test systems and environments, many costly decisions result.

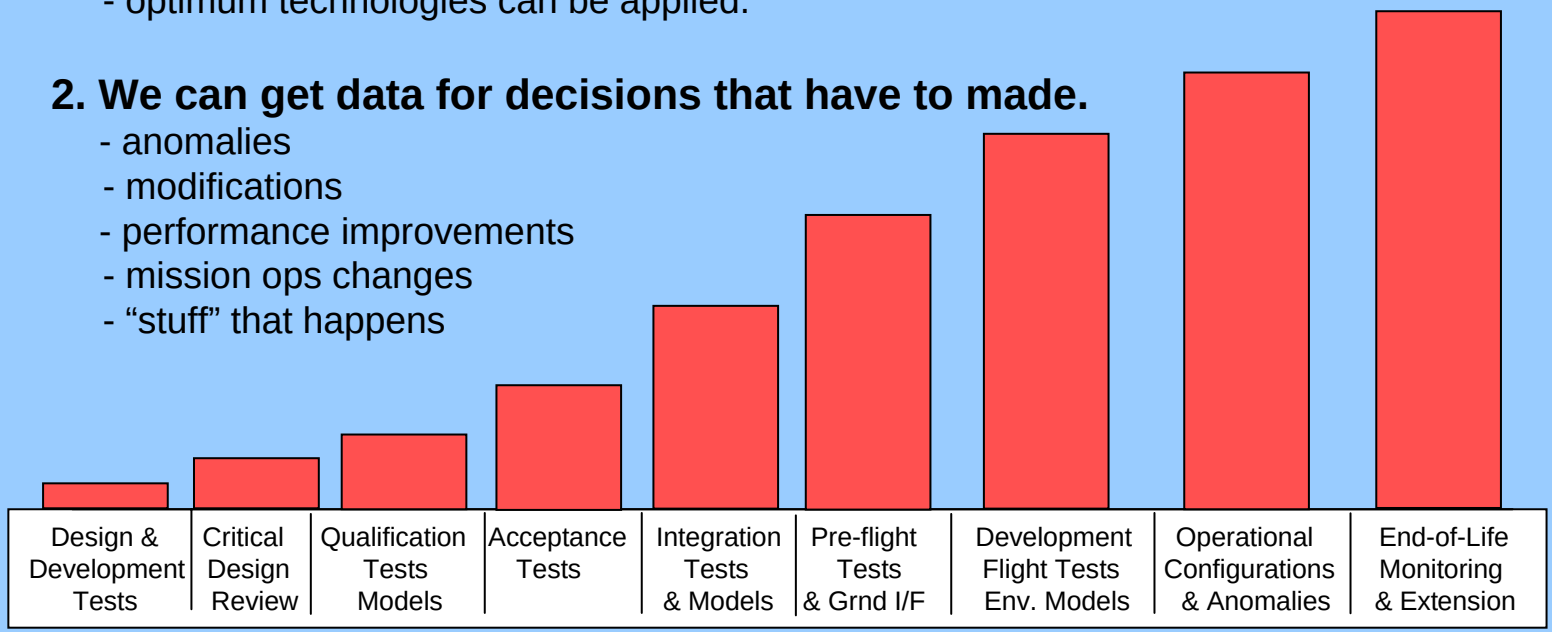
We need to design in modularity and accessibility so that:

1. We can put off some decisions until:

- sufficient design, tests/analysis can be made.
- optimum technologies can be applied.

2. We can get data for decisions that have to made.

- anomalies
- modifications
- performance improvements
- mission ops changes
- "stuff" that happens



Shuttle and Space Station Lessons Learned

Bo Bemunk's, Boeing (former head of System Int. Rockwell), gave a lessons learned presentation to NASA and contractors: He observed that data was lacking, and when it did become available, it was limited and the effect of late changes was significant, and under-estimated:

- Induced Environments Data Books
- Ascent Aerodynamics
- Structures
- Performance margin, modifications
- Aero-elasticity
- Lift-off loads
- Day of Launch I-Loads
- Design for Performance, not operations

George Studor's Lesson's Learned from Shuttle and Space Station:

- **Shuttle under estimated the impact of periodic inspection & maintenance** with poor accessibility in many areas: much lower flight rates and large down periods – cost model broke down. (I helped start the periodic inspections re-work with Pan Am/Rockwell in 1984)

- **Shuttle under-estimated the need to be able to trouble-shoot, inspect and modify**… when events happen, even much smaller than Challenger and Columbia losses, lack of accessibility and modularity hurts. (I lead the Program Plan for Challenger Return-to-Flight)

- **Shuttle needed a better way to get more data without running more wire**. The centralized data and power systems have been difficult to add to and change – driving conservative assumptions. (I flew WIS & Micro-Wireless as the only affordable solution)

“Fly-by-Wireless” Reliability

Vehicle Reliability Analyses must include: the End to End system, including man-in-the-loop operations, and the ability to do effective troubleshooting, corrective action and recurrence control.

With Wireless Interconnects, the overall Vehicle Reliability is Increased:

Through Redundancy: All controllers, sensors, actuators, data storage and processing devices can be linked with great redundancy.

Through Structural and System Simplicity: Greatly reduced cables/connectors that get broken in maintenance, must be trouble-shot electronics problems, sources of noisy data and require structural penetrations and supports.

Through Less Hardware: Fewer Cables/Connectors to keep up with

Through Modular Standalone Robust Wireless Measurement Systems: These can be better focused on the system needs and replaced/upgraded/reconfigured easily to newer and better technologies.

Through Vehicle Life-Cycle Efficiency: Critical and non-critical sensors can be temporarily installed for all kinds of reasons during the entire life cycle.

Through the Optimum Use of Vehicle and Human Resources: With the option of distributed instrumentation and control managed with much less integration needed with the vehicle central system, both system experts, hardware and software can concentrate on their system performance, instead of integration issues.

"Fly-by-Wireless" Focus Areas

(1) System Engineering and Integration to reduce cables and connectors,

- Capture the true program affects for cabling from launch & manned vehicles
- Requirements that enable and integrate alternatives to wires
- Metrics that best monitor progress or lack of progress toward goals.
  (# cables, Length, # of connectors, # penetrations, overall weight/connectivity)
- Design Approach that baselines cables only when proven alternatives are shown not practical - use weight and cg until cabling can be proven needed.

(2) Provisions for modularity and accessibility in the vehicle architecture.

- **Vehicle Zones** need to be assessed for accessibility – driven by structural inspections, system assembly, failure modes and inspections, and system and environment monitoring and potential component trouble-shooting, remove & repair.
- **Vehicle Zones** need to be assessed for resource plug in points to access basic vehicle power, two-way data/commands, grounding and time (not all zones get it).
- **Centralized & De-centralized approaches** are available for measurement & control.
- **Entire life-cycle** needs to be considered in addition to schedule, performance, weight.

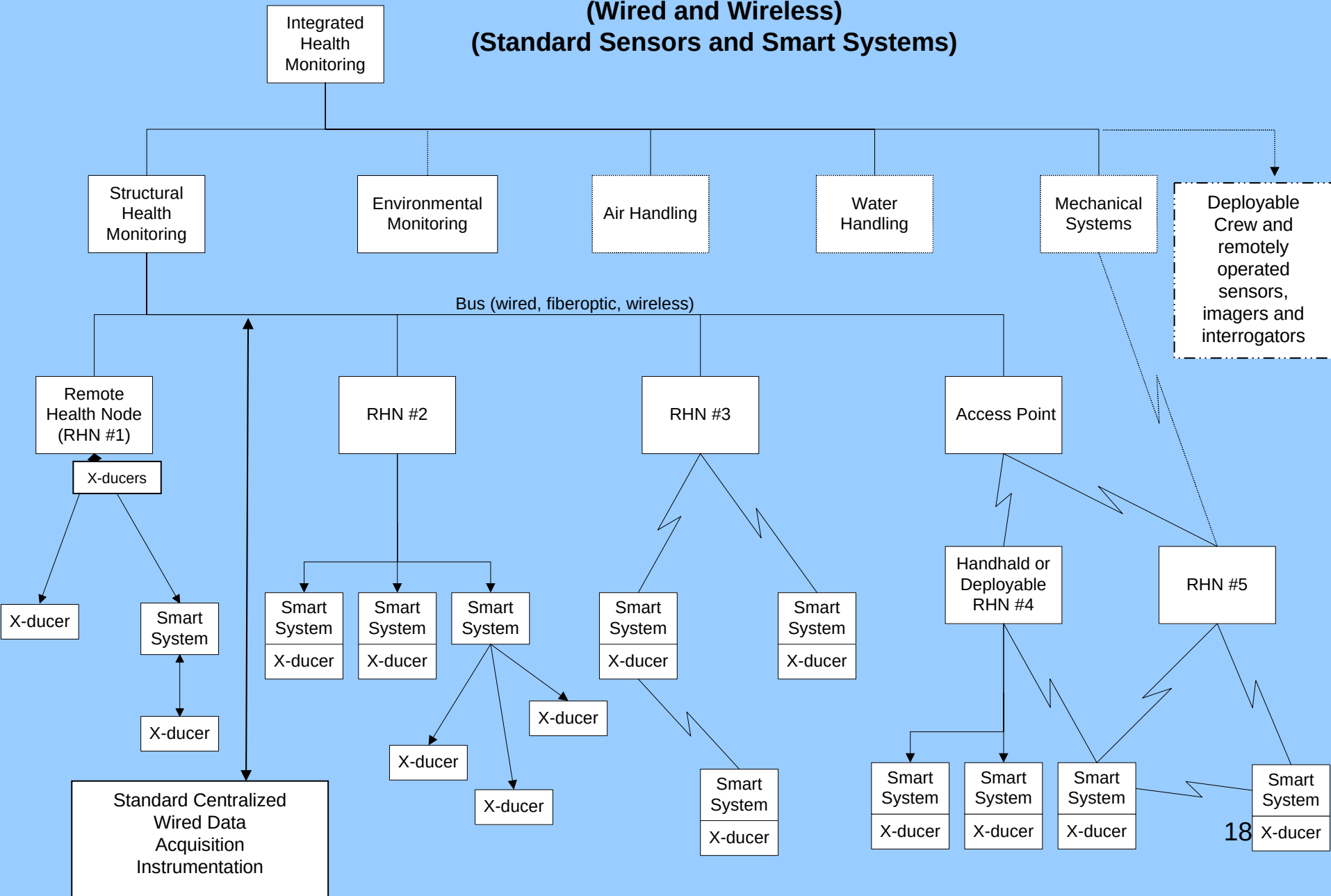
(3) Develop Alternatives to wired connectivity for the system designers and operators.

- Multi-drop Bus-based systems
- Wireless No-power sensors/sensor-tags
- Standalone Robust wireless data acquisition
- Standard interfaces & operability
- Wireless controls
- Data on power lines
- Fiber-optic
- Robust wireless radios
- Light weight coatings and shielding
- RFID for Identification, position & data

Challenge: Why Can't Wireless connectivity be made to be as reliable as a wire??

Conceptual Hybrid SHMS Architecture for Future Space Habitats

(Centralized and Decentralized)
(Wired and Wireless)
(Standard Sensors and Smart Systems)



Wireless Instrumentation Systems Solving Unique Real-World Problems for Shuttle & Space Station

• **ISS Assembly** – Thermal limits too close for some avionics boxes during assembly and prior to hook-up... No power/data path available. External temperatures were needed for boxes in near real time. **Result: Wireless Data Acquisition System DTO** leading to **Shuttle-based WIS(SWIS) for P6 & Z1.**

• **ISS Structural Loads/Dynamics i**s different at every assembly step, so relocatable stand-alone accelerometer data acquisition units were needed to be RF time-synchronized, Micro-G sensitive. **Result: Internal WIS(IWIS) was first flown on STS-97 and is still in use today.**

• **Shuttle Temp Monitoring** – Validation of thermal models became important for design of modifications and operations, but the cost of conventional wire/data acquisition was prohibitive. **Result: Micro-WIS was developed by SBIR, first flown in a non-RF configuration.**

• **Shuttle Structural Loads and Dynamics Concerns** – SSME support strut strain data needed to refine certification life predictions for related parts. **Result: Micro Strain Gauge Unit (Micro-SGU**). **and Micro-Tri Axial Accelerometer Units (Micro-TAU**) for Cargo to Orbiter Trunion Dynamics/Loads.

• **Shuttle SSME Feed-line Crack Investigation:** High data rates, RF synchronization and more storage needed to see how Main Propulsion System flow-liner dynamics affect SSME Feed-line Cracks. **Result: Wide-band Micro-TAU.**

• **Shuttle Impact Sensors** were needed to determine if and where the Orbiter Wing Leading Edge has been impacted by debris. **Result: Enhanced Wideband Micro-TAU (EWB Micro-TAU**).

• **SRMS On-Orbit Loads were increased** because of contingency crew EVA repairs at the end of the boom - extension of the SRMS arm. **Result: Wireless Strain Gauge Instrumentation System (WSGIS) and Instrumented Worksite Interface Fixture (IWIF)** – EWBMTAU/Triax MEMS Accels (DC to 200hz)

• **Also used for measuring Shuttle Forward Nose area dynamics during roll-out (10 hours)**

• **ISS MMOD Impact/Leak Monitoring** is needed for high risk modules to reduce time necessary to locate a leak to vacuum so that it can be repaired. **Result: Ultrasonic WIS (UltraWIS) & DIDS SBIRs**

Evolution of Micro-WIS Systems (page 1)

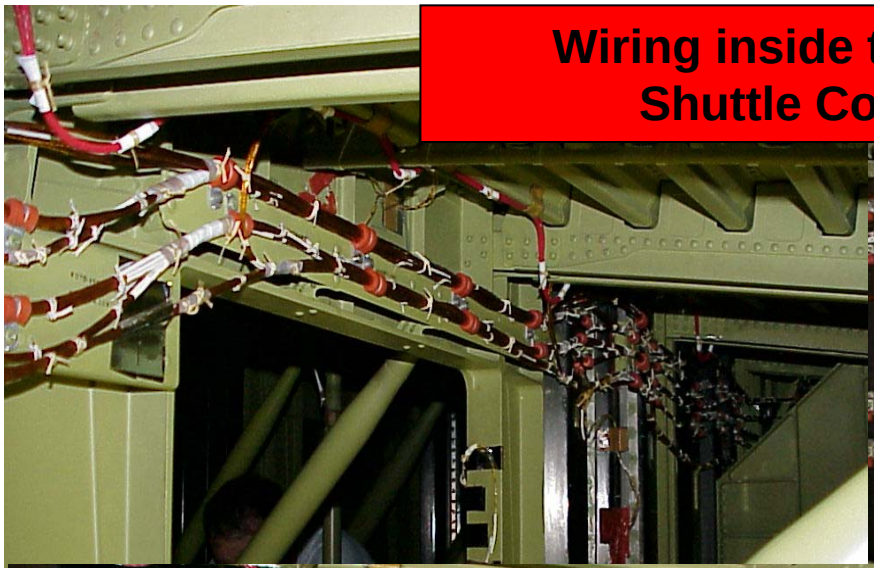
System	MicroWIS (SBIR)	Extended Life MicroWIS	MicroSGU / MicroTAU	Wideband MicroTAU	Enhanced WB MicroTAU	Ultra-sonic WIS (new Ph2 SBIR)
Date Certified	1997	2001	2000/2001	2002	2005	2007 (projected)
Purpose	IVHM	Thermal Models	Cargo Loads Cert Life Extension	MPS Feedline Dynamics	Wing Leading Edge Impacts	ISS Impact/Leak Monitoring
Dimensions	1.7” dia. x 0.5”	2.7”x2.2”x1.2”	2.7”x 2.2” x 1.2”	3.0”x 2.5” x 1.5”	3.25”x2.75”x1.5	3.4” x2.5”x 1.1”
Sample Rate	Up to 1Hz	Up to 1Hz	Up to 500Hz (3 channels)	Up to 20KHz (3 channels)	Up to 20KHz (3 channels)	Up to 100KHz (10 channels)
Data Sync	No	No	Yes	Yes	Yes	Yes
Data Storage	None	2Mbytes	1Mbyte	256Mbytes	256Mbytes	1Mbyte
Data Transmit / Relay	Real-time Transmit to PC	Real-time Transmit to PC / Relay	On-demand Transmit	On-demand Transmission	On-demand Transmission	On-demand Transmission

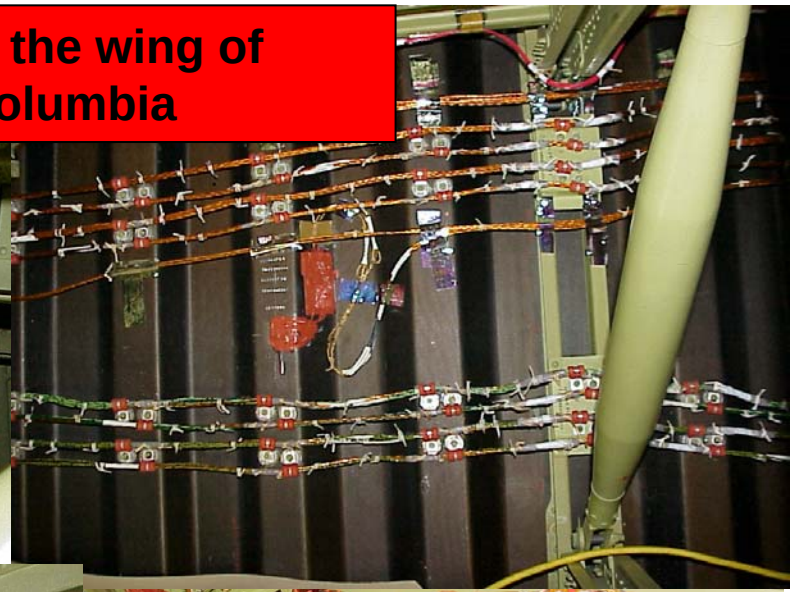
Micro-WIS XG

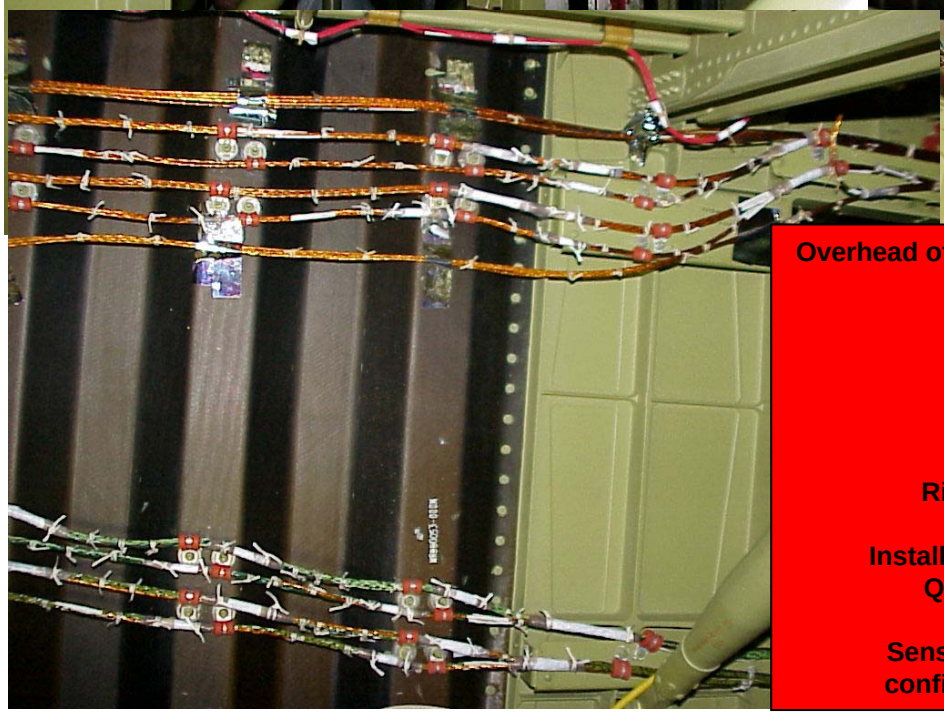
Evolution of Micro-WIS Systems (page 2)

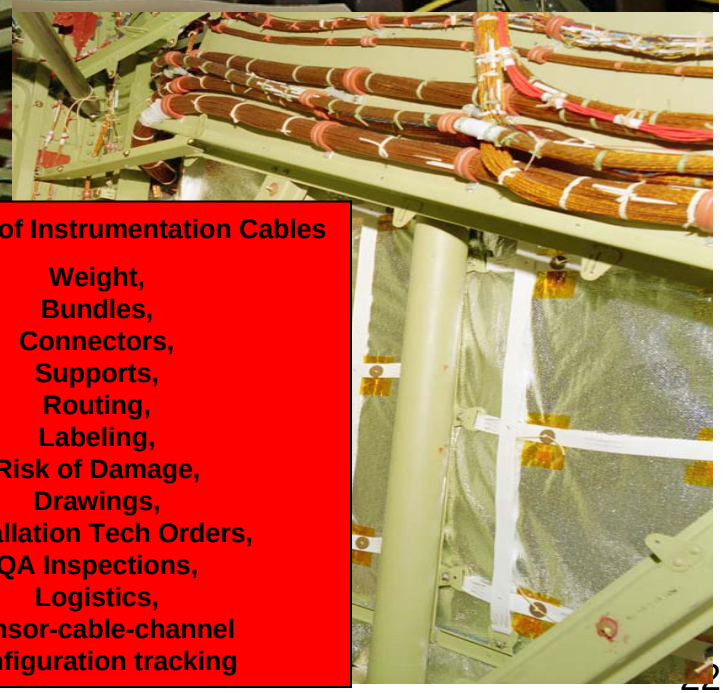
System	MicroWIS (SBIR)	Extended Life MicroWIS	MicroSGU / MicroTAU	Wideband MicroTAU	Enhanced WB MicroTAU	Ultra-sonic WIS (new Ph2 SBIR)
Local Data Processing	No	No	8bit micro-controller	High-speed DSP Not used on data	High speed DSP Numerous Routines	High speed DSP Numerous Routines
Triggering	No	No	Data/Time Trigger	Data/Time Trigger	RF/Data/Time	Impact
Battery type	Tadiran 400mAhr	BCX Lithium C-cell	Tadiran 1000mAhr	BCX Lithium C-cell	Energizer L91 2-AA pack	BCX Lithium C-cell
Battery Life	9 months	10+ years	2-3 missions	1 mission	1 mission	3 years
Sensor Types	Temperature (Flight Cert) and Resistive sensors: Strain, Accelerometer, Pressure	Temperature (Flight Cert) and Resistive sensors: Strain, Accelerometer, Pressure	Acceleration & Strain (Flight Cert) or Resistive sensors. Includes Pressure as Trigger Channel.	Accelerometer & Temperature (Flight Cert) or Piezoelectric and Resistive Sensors	Accelerometer & Temperature (Flight Cert) or Piezoelectric and Resistive Sensors	Ultrasonic Microphone and Acoustic Emission

Wiring inside the wing of Shuttle Columbia





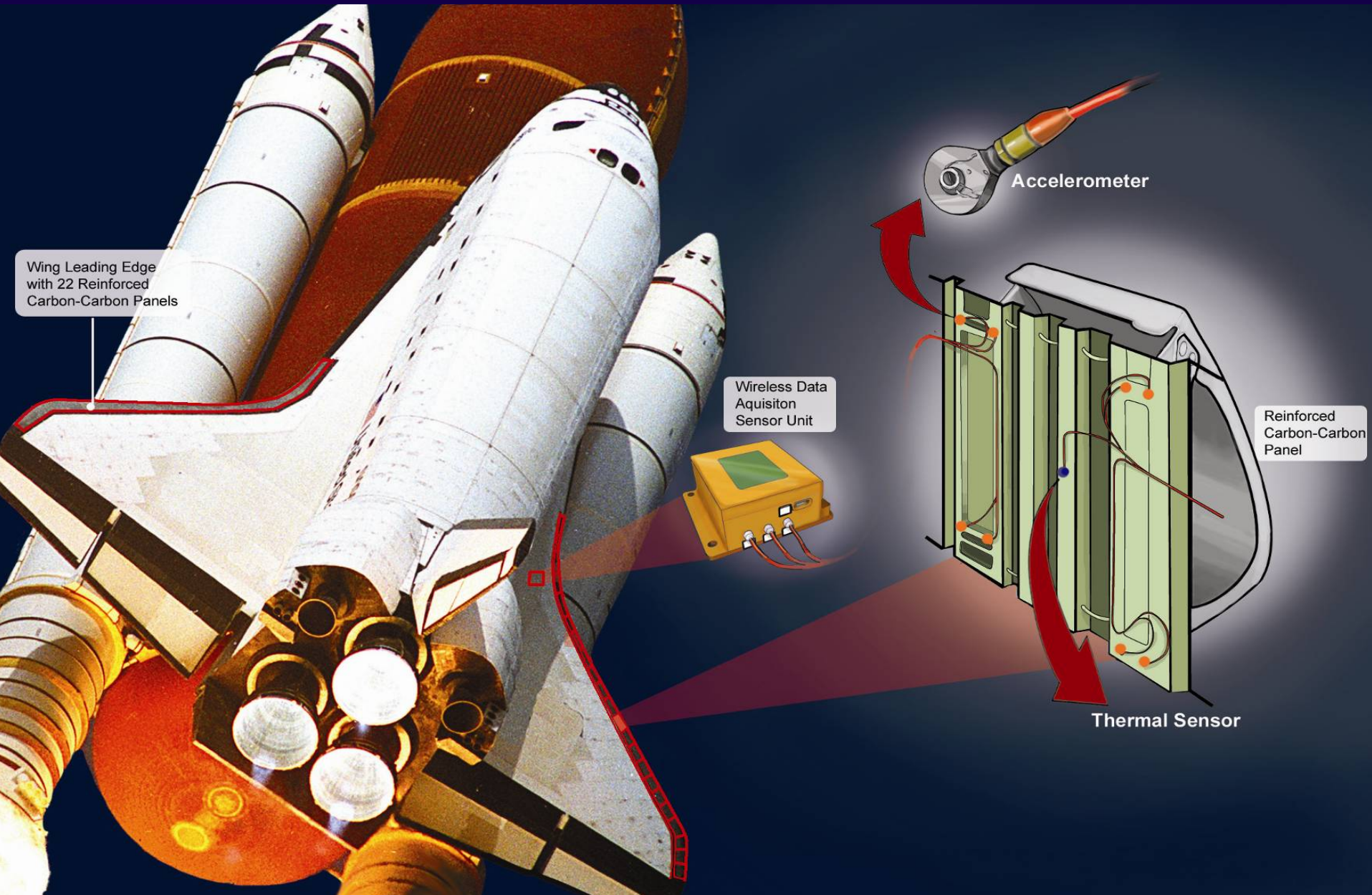




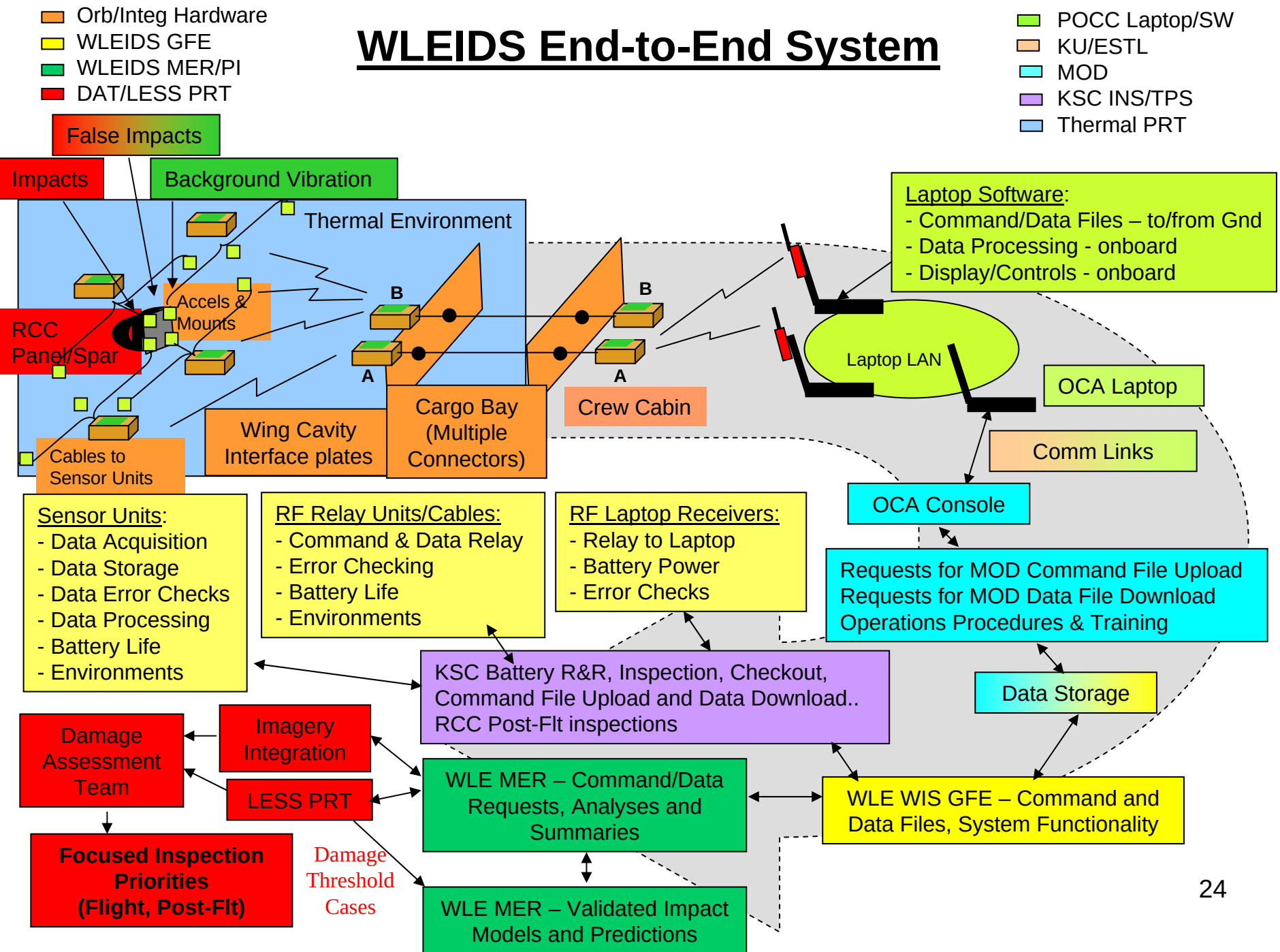
Overhead of Instrumentation Cables

Weight,
Bundles,
Connectors,
Supports,
Routing,
Labeling,
Risk of Damage,
Drawings,
Installation Tech Orders,
QA Inspections,
Logistics,
Sensor-cable-channel configuration tracking

Wing Leading Edge Impact Detection System
A JSC Government Furnished Equipment(GFE) Project

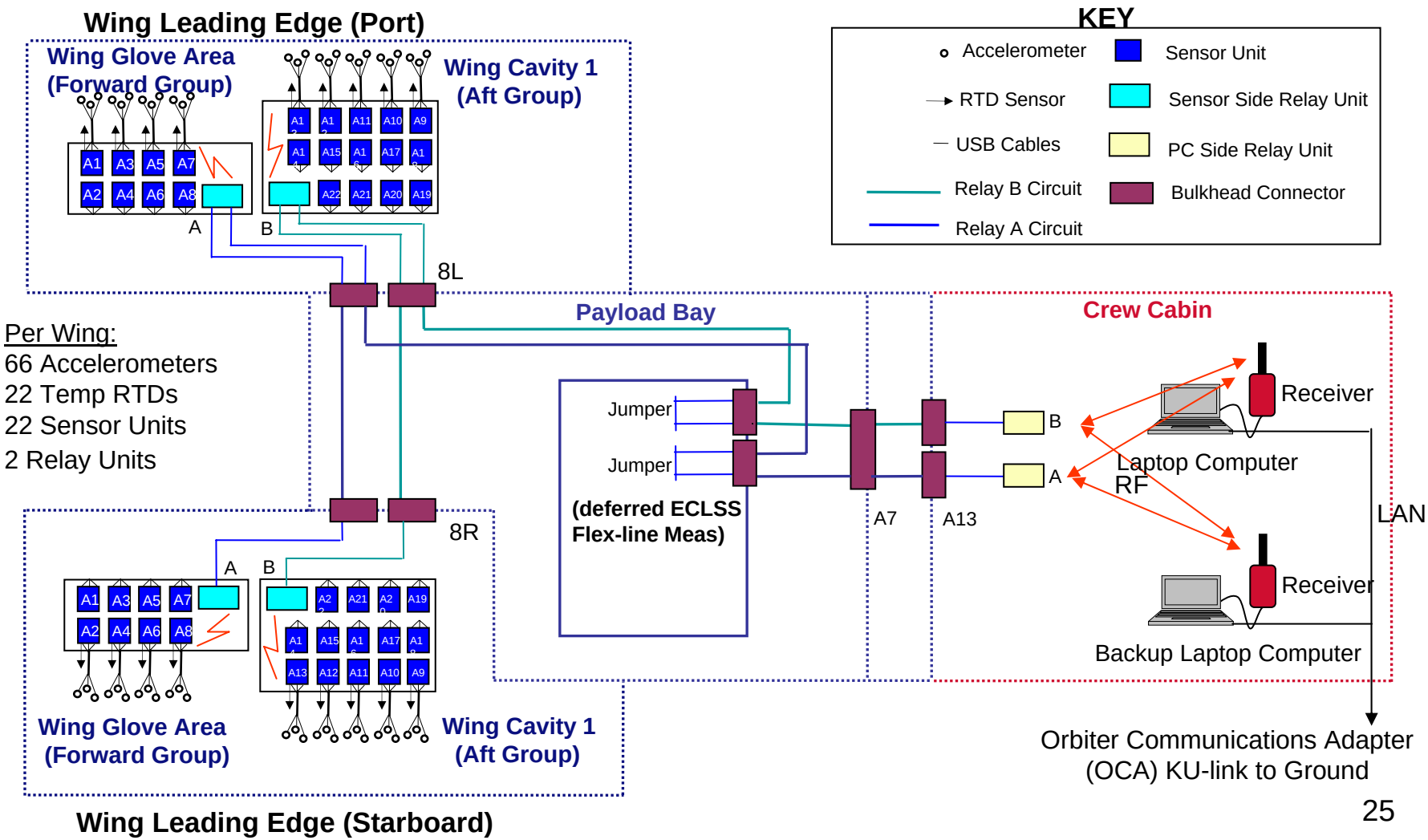


WLEIDS End-to-End System



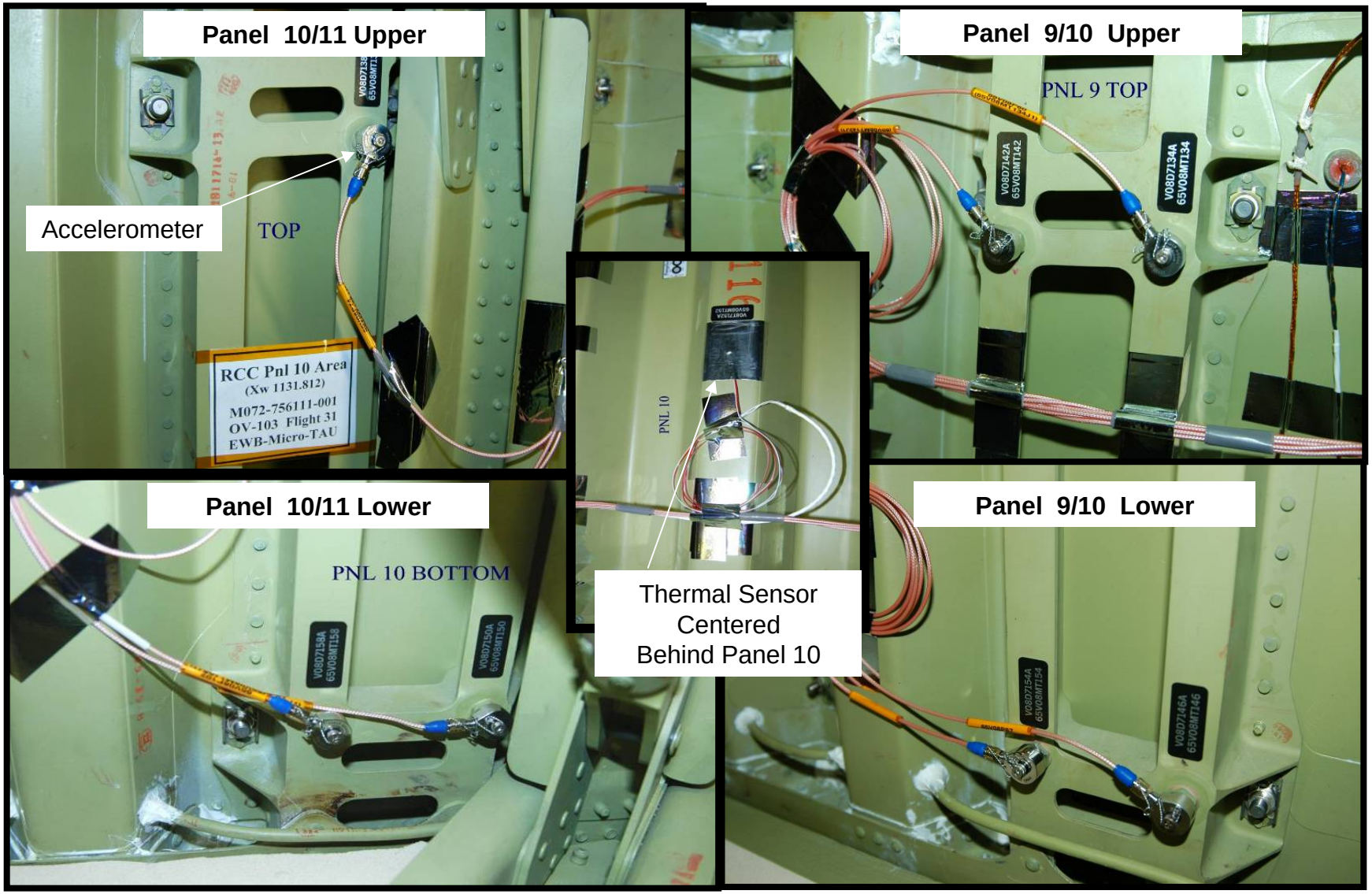
WLEIDS System Overview: Vehicle Wiring Diagram

- Sensor Units can communicate with Cabin via Relay path A or B



WLEIDS System Overview:

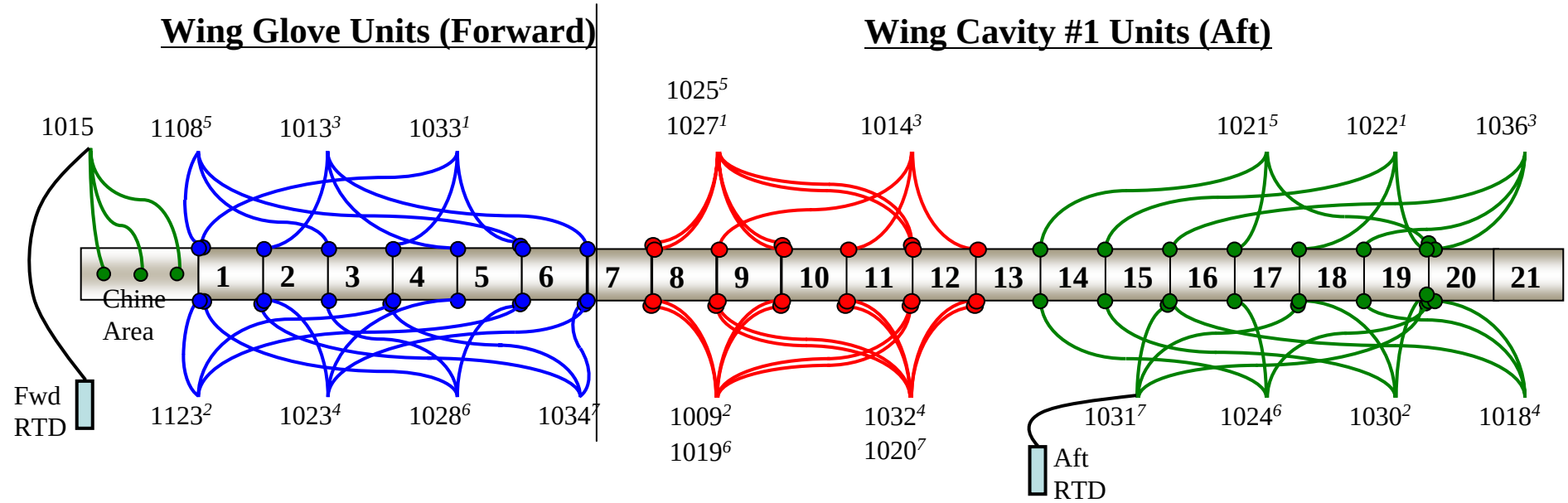
Accelerometer Installation on Shuttle Wing Spar Interior



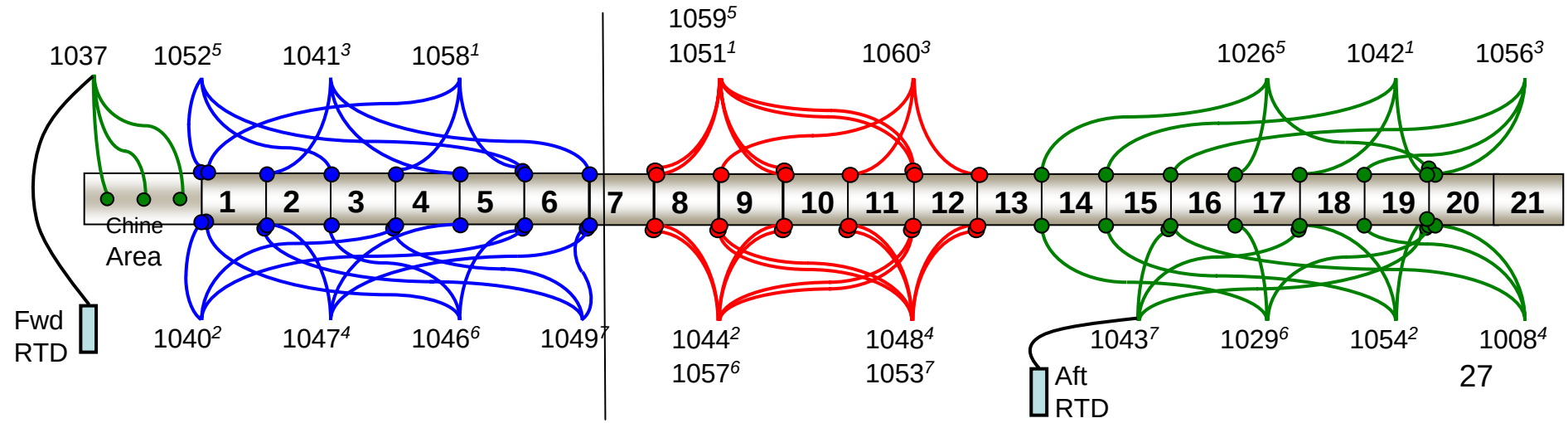
Photographs looking forward inside port wing

Accelerometer to Sensor Unit Cross-Strapping

STS-121 Port Wing Accelerometer – Sensor Unit Configuration



STS-121 Starboard Wing Accelerometer – Sensor Unit Configuration

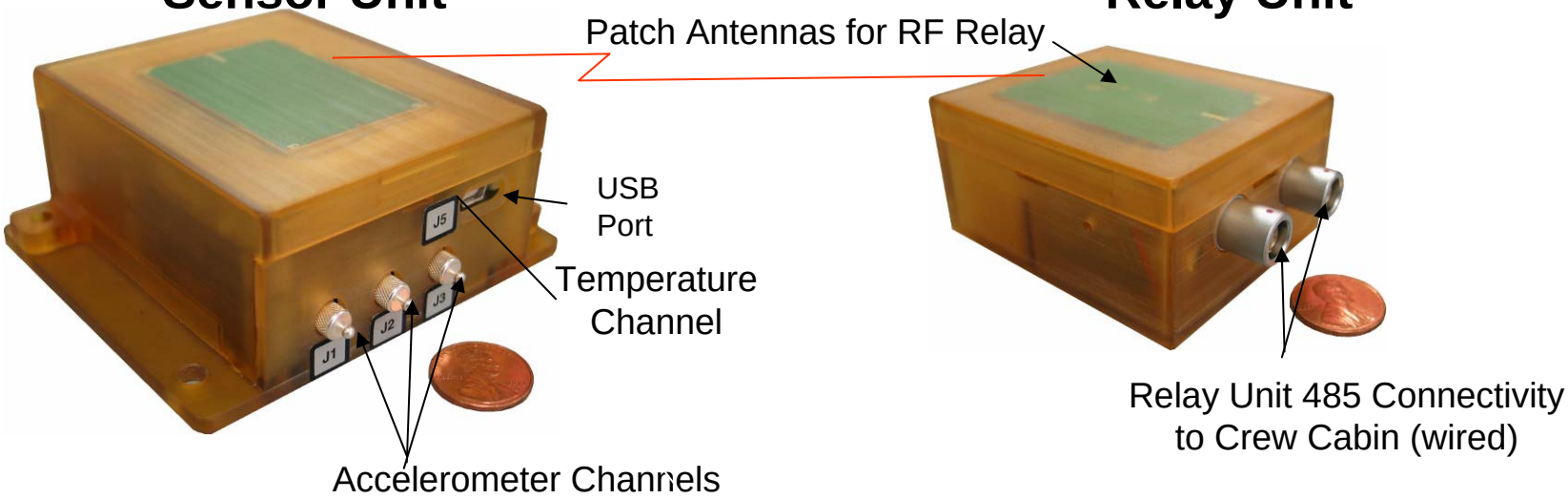


WLEIDS System Overview: GFE Hardware

Enhanced Wide-band Micro-Triaxial Accelerometer Unit (EWB Micro-TAU)

Sensor Unit

Relay Unit



Original Plan:
Lithium BCX C-cell Battery (low temps but too hazardous)

Current Configuration:
Two L91 AA LiFeS2 cells (dies at 0 deg F)

In Work:
Add Voltage Regulator

WLEIDS System Overview: Sensor Unit Installation

(Sometimes you need to Compromise the Vision for Safety & Operations)

Sensor Unit installation went from flexible (individually located & oriented near sensors) boxes attached with RTV, to two groups of sensor units bolted in rigid patterns on uniquely designed plates, creating high G-loads & reduced communication reliability.

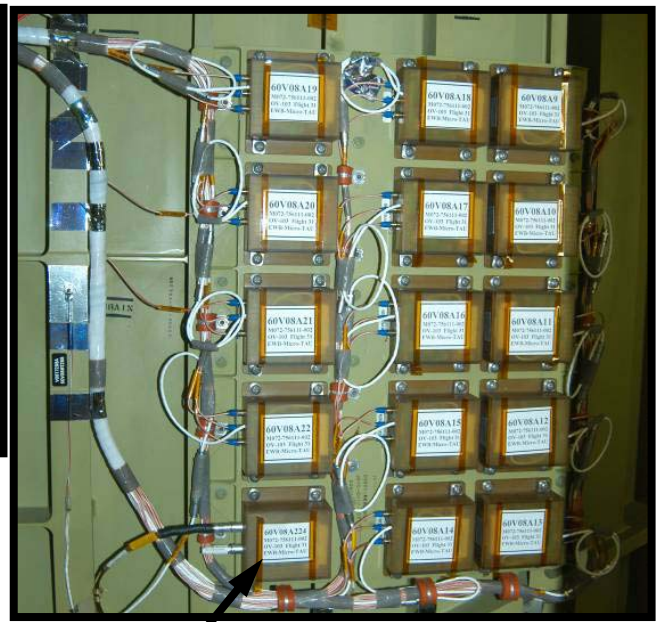
Rationale:

- Avoid Li-BCX Explosive Hazard at high temps if hole develops in wing RCC/Tile
- Ease of battery replacement – near wheel well access panel
- Avoid critical hazard if hardware comes loose in the wing
- Avoid risk of damaging sensitive struts in the wing

Forward Sensor Unit Group
8 sensor units

RF Relay Unit A

Aft Sensor Unit Group
14 sensor units



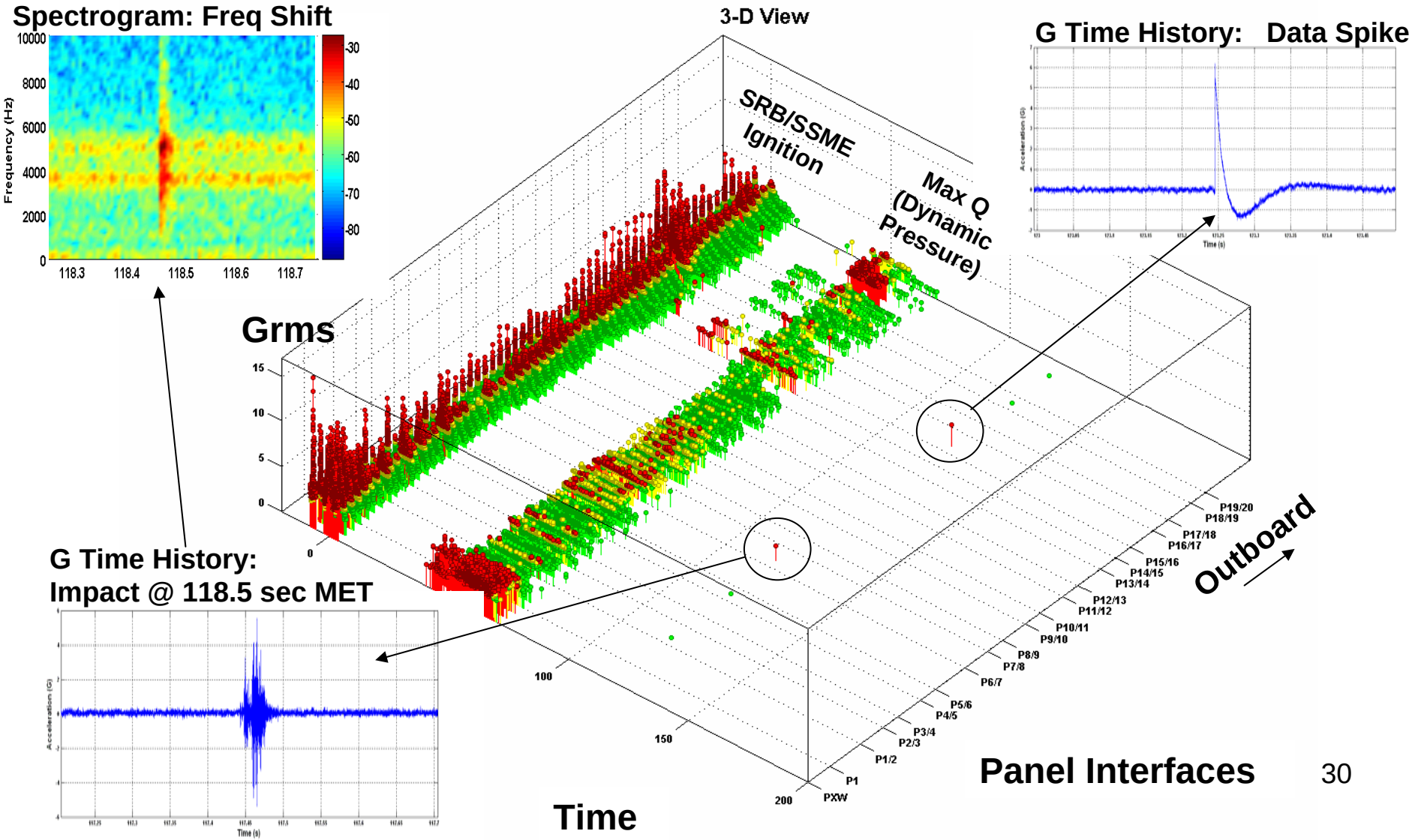
RF Relay Unit B

Inside the crew cabin
2 Cabin Relay Units

Cabin Relay Unit (A & B) communicates with wing Relay Unit A or B and sends data to laptop

STS-114 Ascent Data Analysis: Mission Tools

Half second time history downloads used to distinguish between real impact events and data anomalies



Passive (no Power) Micro-wave Sensor Tags
Current Sandia Prototype: Part of NASA Sponsored Technology Development

Interrogator/Receiver Prototype

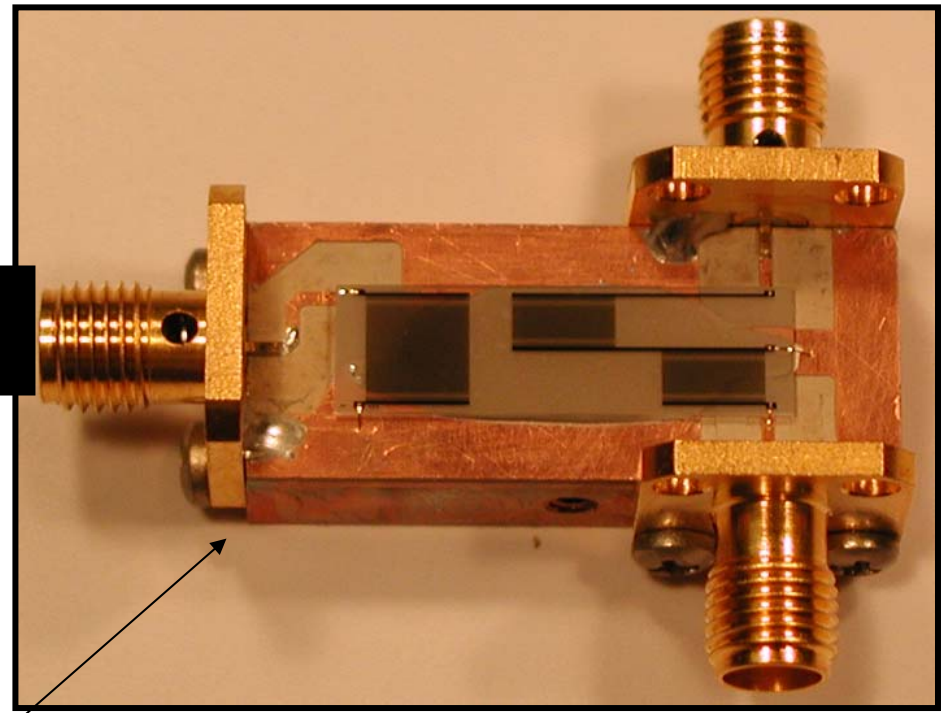
-69 MHz and 71 MHz Operating Freq

- up to 1 Megahertz sample rate

Sensor Port: - Variable Impedance Input

-Inductive pressure: 200 nanohenrys

- High impedance piezo sensor input



1 meter wire antenna

(Connector for Proto-type only)

Approximately 1” x ½” x ½”
SAW Correlators attached to Brass Base
Plastic cover (not shown)

Reference
(50 ohm)

Session 1 Speakers

George Studor Structural Engineering Division, NASA/Johnson Space Center

"'Fly-by-Wireless': a Revolution in Aerospace Vehicles for Instrumentation and Control"

Next up:

Karl Kiefer President, Invocon, Inc., Conroe Texas

"Real-World Experience in Wireless Instrumentation and Control Systems"

Robert Scully NASA/Johnson Space Center/EMI and

"Certification Process for Wireless and RFID Systems on space Shuttle and Space Station with implications for the Constellation Program."

Dave Walen FAA, Aviation Safety Chief Scientific and Technical Officer, EMI

"Perspectives on Aircraft Wireless System Certification"

Robert Brocato Sandia National Labs, RF and Optics Microsystems Applications Department Principle Member of Technical Staff

"Multiple Passive Sensors Interrogated with 1 mW of RF over 10 Meters: a Promising Foundation"

Stay for the Demonstration! **Sign up for "One-on-Ones"!**