Wireless for Aerospace Applications

"Fly-by-Wireless" Vehicles
and
Evaluations of ISA100 Applications to Space-Flight

October 8, 2009

Presenter: NASA/JSC George Studor

- 2008 + : NASA Johnson Space Center Avionic Systems Division
- 1996 – 2008: NASA JSC/ Structural Engineering Division
  - Standalone wireless sensor operational applications to Space Shuttle and ISS
  - "Fly-by-Wireless" approach grew out of lessons learned
  - Post Columbia – Wireless Impact Detection System for Orbiter Wing Leading Edge
- 1994 – 1995: Montana State University
- 1990 – 1993: Space Station Freedom Program
  - SSF Verification Program Plan
- 1987 – 1990: Space Shuttle Program Integration and Operations
  - Past Challenger Accident Space Shuttle Program Plan for Return to Flight
- 1983 – 1987: Space Shuttle Program Engineering Integration
  - Orbiter periodic inspection and maintenance requirements and turnaround enhancements
- 1981 – 1982: Air Force Institute of Technology – MS, Astronautical Eng.
- 1977 – 1982: Air Force C-130 Pilot
- 1972 – 1976: USAF Academy – BS Astronautical Engineering

“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 to wired data connectivity to benefit the entire vehicle/program life-cycle.**

Focus Areas:

1. **System Engineering and Integration to reduce cables and connectors.**
2. **Provisions for modularity and accessibility in the vehicle architecture.**
3. **Develop Alternatives to wired connectivity (the “tool box”).**

“Fly-by-Wireless” Update

NASA/JSC “Fly-by-Wireless” Workshop	10/13/1999
USAF Reserve Report to AFRL	11/15/1999
DFRC Wireless F-18 flight control demo - Report	12/11/1999
ATWG “Wireless Aerospace Vehicle Roadmap”	2/12/2000
Office of Naval Research	2/16/2000
NASA Space Launch Initiative Briefing	8/7/2001
World Space Congress, Houston	3/8/2002
International Telemetry Conference	4/6/2004
VHMS TIM at LaRC	5/11/2004
CANEUS 2004 “Wireless Structural Monitoring Sensor Systems for Reduced Vehicle Weight and Life Cycle Cost”	10/28/2004
Inflatable Habitat Wireless Hybrid Architecture & Technologies Project:	9/2006
CANEUS 2006 “Lessons Learned Micro-Wireless Instrumentation Systems on Space Shuttle and International Space Station”	9/2006
CANEUS “Fly-by-Wireless” Workshop to investigate the common interests (applications/end-users and technologies) and discuss future plans.	3/27/2007
NASA/AIAA Wireless and RFID Symposium for Spacecraft, Houston	May, 2007
AVSI/other intl. companies organize/address the spectrum issue at WRC07	Nov 2007
Antarctic Wireless Inflatable Habitat, AFRL-Garvey Space Launch Wireless	July 2008
RFIs in NASA Tech Briefs	May 2008
RFI Constellation Program Low Mass Modular Instrumentation	Nov 2008
Gulfstream demonstrates “Fly-by-Wireless” Flight Control	Sep 2008
AFRL announces “Wireless Spacecraft” with Northrup-Grumman	Mar 2009
CCSDS Wireless Working Group	Apr 2009
1st JANNAF Wireless Sensor Workshop (launch vehicles DOD-NASA)	Apr 2009
1st Propulsion Wireless Group(aircraft jet engine industry)	Jul 2009
NASA Constellation Program Wireless DFI Options	Sep 2009

Space Shuttle and International Space Station Wireless Applications

Motivation

- Safety
- Capability
- Reliability
- Cost of Wired Infrastructure
- Cost of Change

Motivation: Safety

- Reduced time/impact to implement monitoring systems for unsafe conditions.
- Increased options for Sensing, Inspection, Display and Control.
- Fewer penetrations, wiring, total parts and operations support hazards.
- Fewer wiring/connector failure opportunities.
- More options to monitor, communicate or provide back-up control.
- Better upgrade opportunities to correct for safety deficiencies.

Motivation: Capability

1. **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.

2. **Performance**: Weight penalties are reduced, not just due to the weight of the cables, but also insulation, bundles, brackets, connectors, bulkheads, cable trays, structural attachment and reinforcement. The weight reduction improves payload capability and mission operations. Upgrading various systems is more difficult with cabled systems. Adding sensors adds observability to the system controls such as an autopilot.

3. **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.

4. **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 - backup flight control is easier.

Motivation: 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 can be Increased:

Through Redundancy: All controllers, sensors, actuators, data storage and processing devices can be linked with greater redundancy. A completely separate failure path provides greater safety and reliability against common mode failures.

Through Structural and System Simplicity: Greatly reduced cables/connectors that get broken in maintenance and must be trouble-shot, electronics problems, sources of noisy data and required 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. Smart wireless DAQs reduce total data needed to be transferred.

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.

Motivation: Cost of Wired Infrastructure

- **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. **Cost of 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 wired connectivity or lack of measurements that come in the form of weight, volume, power, etc.
  5. **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.

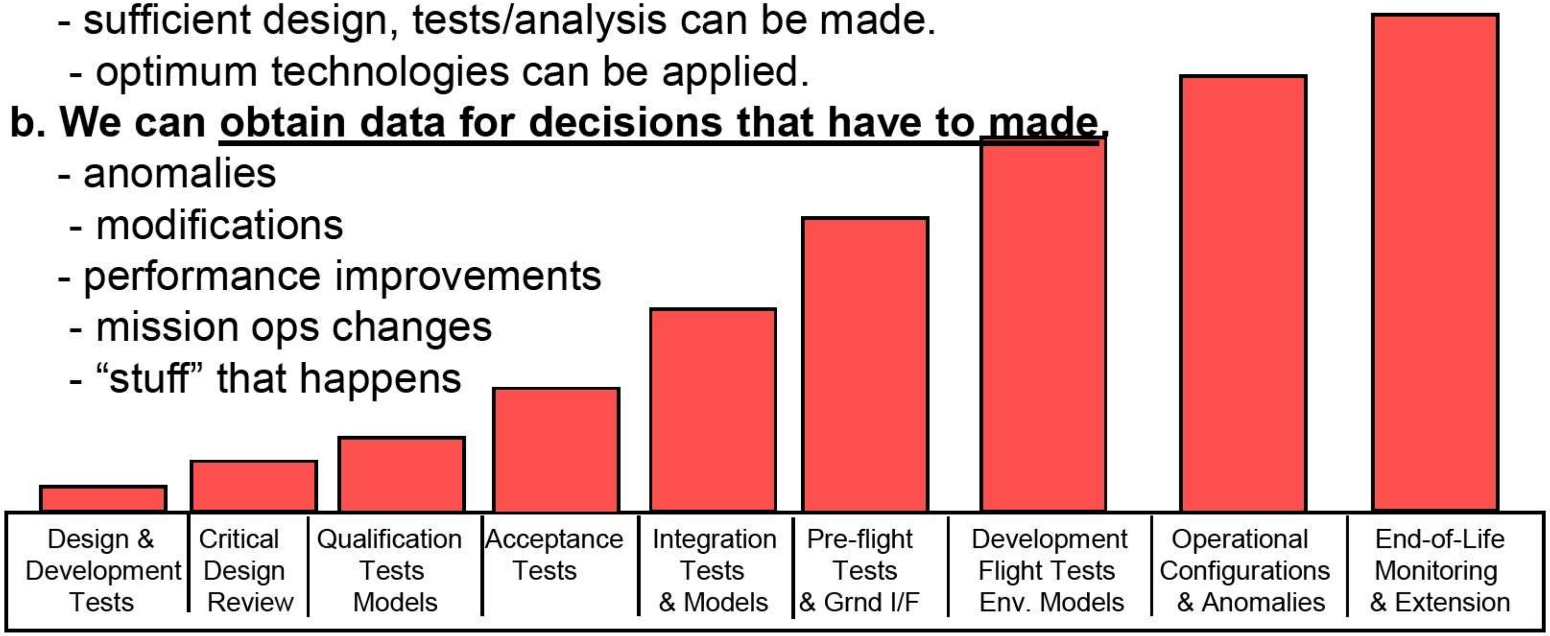
Motivation: Cost of Change:

1. **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 mature/test systems and environments, many costly decisions result.

2. **We need to design in modularity and accessibility so that:**

   a. We can put off some decisions until:
   - sufficient design, tests/analysis can be made.
   - optimum technologies can be applied.

   b. We can obtain data for decisions that have to made.
   - anomalies
   - modifications
   - performance improvements
   - mission ops changes
   - “stuff” that happens



“Fly-by-Wireless” Focus Areas

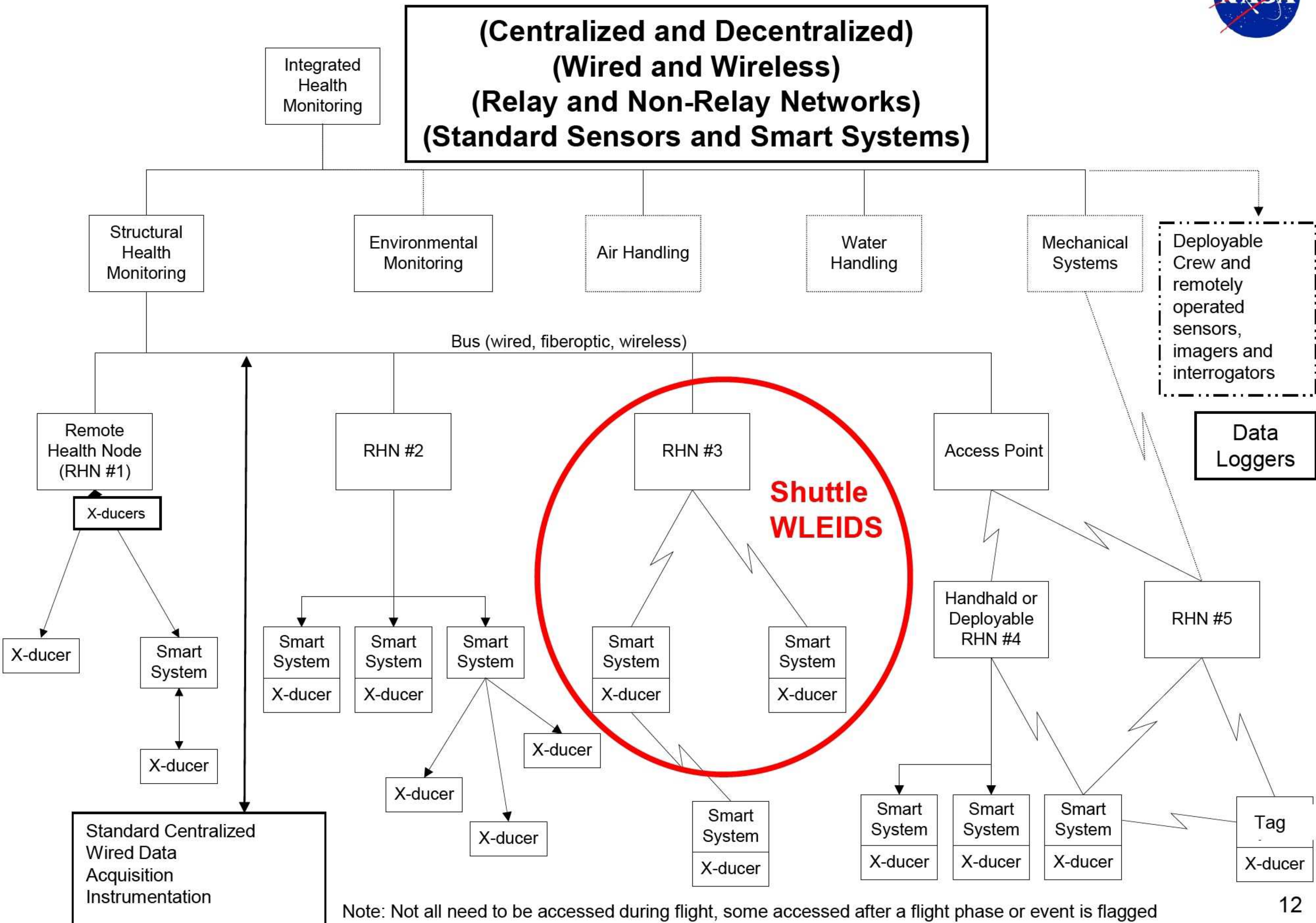
(1) **System Engineering and Integration to reduce cables and connectors**,
- Capture the true program effects for cabling from launch & manned vehicles
- Requirements that enable and integrate alternatives to wires
- Metrics that best monitor progress or lack of progress toward goals.
(# cables, Length, # 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 – back-up or low criticality
- Robust high speed wireless avionics comm.
- Data on power lines
- No connectors for avionics power
- Robust Programmable wireless radios
- Light wt coatings, shielding, connectors
- RFID for ID, position, data, & sensing.
- Inductive coupling for rechargeables

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

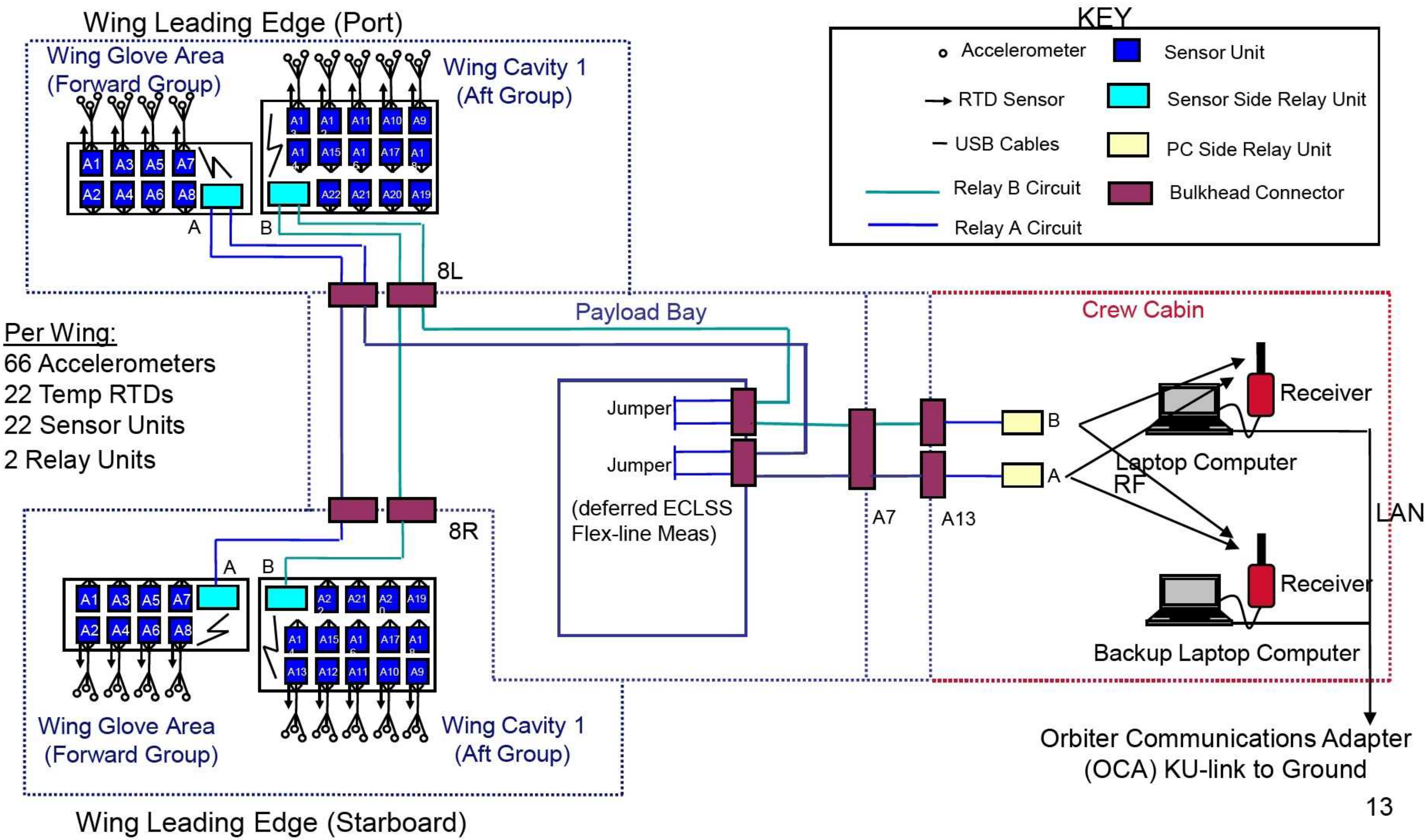
Conceptual Hybrid Architecture for Future Space Habitats



Note: Not all need to be accessed during flight, some accessed after a flight phase or event is flagged

WLEIDS System Overview

- Sensor Units can communicate with Cabin via Relay path A or B (we laid in a "C" relay line in case 2 was not enough)



"Wireless" Options for Onboard Spacecraft
It's a System Engineering Problem

- **Data Loggers: Not Real Time – no wireless time sync**
  - Wireless or wired download before/after use
  - Visual/Physical changes read with visual, RF or other interrogation
- **Non-Relay Networks: Real-Time, Fixed Range, Vehicle Configs, Environments, Msn**
  - One way RF: Sensor Broadcast to Receiver
    Transmitter Broadcast to actuator/controller
  - Two way RF: Wireless Sensor to/from Transceiver
    Wireless Actuator/controller to/from Transceiver
    Transceiver to/from RFID or Passive Sensor Tag
  - Optical Comm
  - Comm over DC Power Cables
  - Comm over Structure or Audio
  - Piggy back on other higher power RF Systems (airborne radar)
- **Relay Networks: Real-Time(throughput limited), Variable/Longer Range Sensor Configs, Environments**
  - **RF Sensor Networks**
  - Optical Communication Networks
  - Comm over DC Power Cable Network
- **Hybrid Networks:**
  - Non-Relay plus Relay Networks that augment wired, fiber-optic, direct-write, and other…

Add-on Measurement Systems: Shuttle & Space Station Applications

• **ISS Assembly** – Thermal limits too close for some avionics boxes during assembly and prior to hook-u
…. 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. Extended Life Micro-WIS (ELM-WIS)** developed for 10 year life at extreme temperatures.

• **Shuttle Structural Loads and Dynamics Concerns -** Strain data needed to extend cert life on SSME support strut. Accel data needed to validate Cargo-to-Orbiter Trunnion Dynamics and resulting loads to Cargo and internal equipment.
….**Result: Micro Strain Gauge Unit (Micro-SGU)and Micro-Tri Axial Accelerometer Units (Micro-TAU**).

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

• **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**).

• **Orbiter Flexline hoses** developing leaks(10 hours plus) – long duration monitoring during roll-out/launch.
Result: ECLSS Micro-WIS - used for measuring Shuttle Forward Nose area dynamics during Shuttle Roll-out, modified to support Shuttle Crew Seat Dynamics Measurements.

• **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)

• **ISS MMOD Impact/Leak Monitoring** is needed for high risk modules to reduce time necessary to locate a

Current Fly-by-Wireless Technology Development at NASA JSC

- Wing Leading Edge Impact Detection System
- Distributed Impact Detection System
- Distributed Leak Detection System
- Crew Seat Vibration Monitoring System
- External Wireless Backbone for ISS
- Short Range RFID Tags for ISS Inventory Systems
- Long Range Passive Sensor Tags: Temp, Pressure, Acceleration, Acoustic Emission, Position
- Plug-n-Play for Wireless systems (Standards based, Non-standards based)
- Scavenge Power, Rechargeable Systems and safe/high density Primary Batteries
- Test/Evaluation of various off-the-shelf standalone/networked wireless DAQs
- Wireless Position Determination
- Wireless Video and Evaluation of 60 GHz – HD Video
- MIMO systems
- Networks and sensors based on evolving industry standards(Zigbee, Wireless HART, ISA100).
- Networking/Building Teams in Industry/Other Government - Discussing Vision, Stimulating Partnering, Working on Standards and Developing and Evaluating Specific Technologies.

NASA Human Space-flight Programs

Fly-by-Wireless Technology Development/Application Thrusts

1/2009 **1/2012** **1/2015** **1/2018**

Space Shuttle

Wireless LAN, EVA,GPS etc, Add-on Instrumentation

ISS

Add-on Int/Ext Instrumentation, Wireless LAN/Services, Inventory, Flt Tests

Cxp Test

Add-on DFI, Wireless Standards & Interoperability, Passive Sensor-Tags, Facilities

Orion **Orion Block 2?**

Add-on Instrumentation, Wireless LAN, Inspection, Modular Instr back-bone

Ares 1 **Ares V**

Add-on Instrumentation Modular Instrumentation

Altair Lander

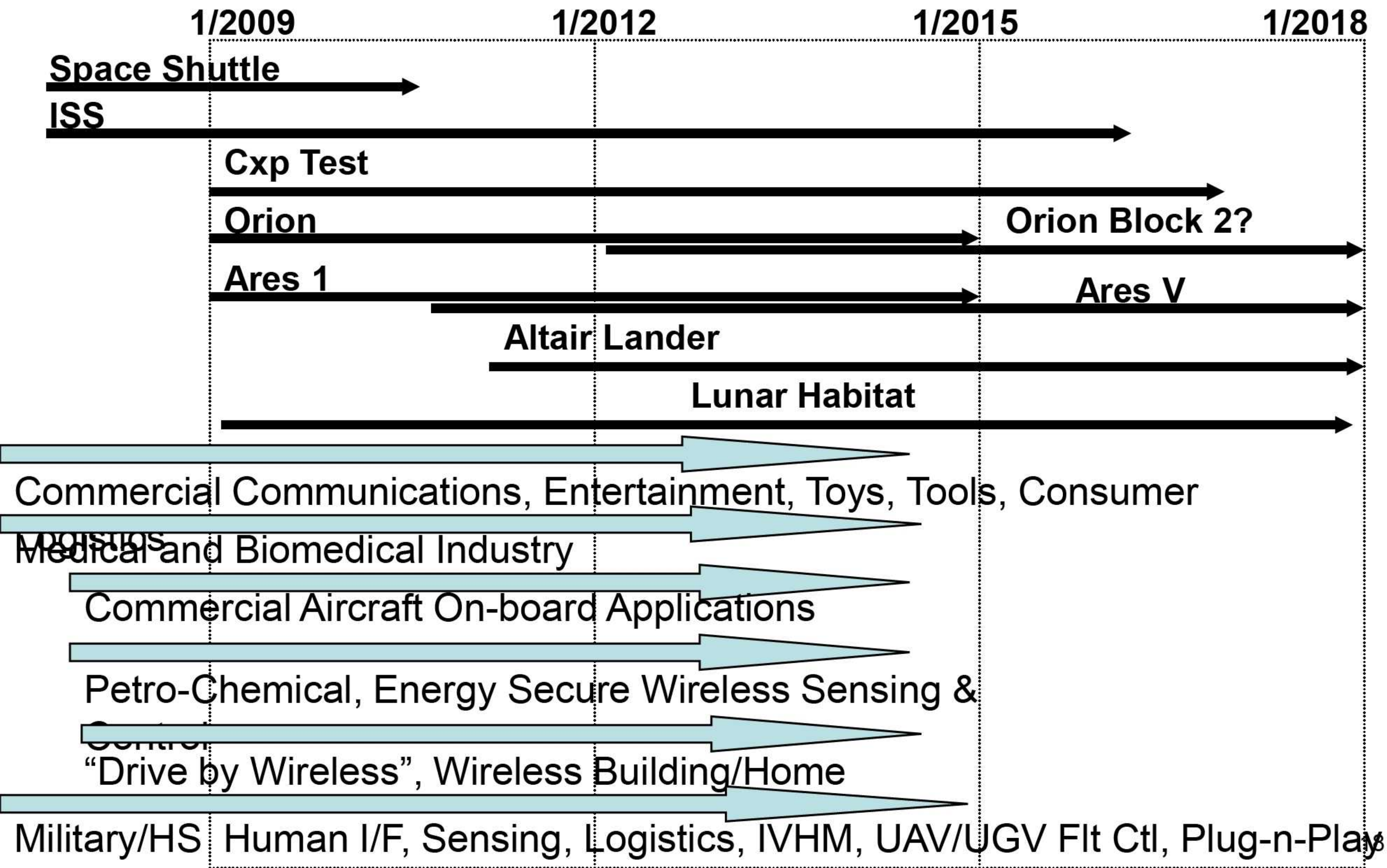
Add-on/Modular Instr, Wireless back-up controls for non-critical systems

Lunar Habitat

Modular Instrumentation and displays, sensor feeds to non-critical systems, back-up safety-related sensing, some primary controls for non-critical systems, robotic controls, Extensive Lunar Surface System EVA/Robotic/Sensor network

NASA Fly-by-Wireless Technology Development

Must Leverage Work with Major Industry Sectors



ISA – 100 Areas of Interest to NASA

- Participate in Requirements Development and Evaluation of:
  - Evaluation of Wireless HART/Zigbee systems
  - Evaluation of new ISA-100.11a systems
  - Trustworthiness
  - Advanced Power sources for Micro-electronics
  - Accommodations for non-standard systems
  - Impacts/compatibility with CCSDS standards
  - Accommodation of Plug-n-play architectures
  - New Working Groups(starting with Interest & Study groups):
    - Very Smart Wireless Sensor Nodes
    - Short and Long Range Passive Sensor-Tags
    - Integrated vehicle/facility architecture processes
    - Life-cycle cost of wired vs wireless infrastructure
    - “Communities of Practice” for wireless applications

Constellation Program Low Mass Modular Add-O Instrumentation

RFI

16--LOW MASS MODULAR DEVELOPMENT FLIGHT INSTRUMENTATION SYSTEMS

Solicitation Number: FL-1
Agency: National Aeronautics and Space Administration
Office: Dryden Flight Research Center
Location: Office of Procurement

POC: Mauricio Rivas, Ricardo Arteaga, George Studor

CxP Low Mass Modular Instrumentation

Problem: The measurements we want are hard to get when we need them. They aren't in the contracts, so they cost time & money to get, and impact performance, cost, maybe safety if we don't.

Why?

- If it is off-vehicle, we usually have to use a lot of wires and there is a lot of overhead with wiring.
- If it is on-vehicle or interfaces with the vehicle on the ground, we have to integrate the system into the vehicle and operate it remotely.
- If it needs to be a part of the vehicle systems, we have to develop the measurement systems in parallel with the basic vehicle.
- That means we don't know all we will need to measure when we specify the measurement systems.

Solution: Standalone Add-on Measurement Systems/Team

Low Mass Modular Instrumentation Forward Plan

1. Capture what we have done, what we are doing, what we know.
2. Define what we think we are looking for.
3. Look for/at what is out there.
4. Build the database.
5. Build the in house inventory – or know where it is.
6. Test the systems or have them demonstrated to/for us on site.
7. "Kit-up" the system as is & define what it is ready to do/where.
8. Field test selected systems that hold more promise of near term applications in ground or flight vehicle tests.

Low Mass Modular Instrumentation – CxP RFI

What are some our Goals?

- Maximize
  - Total useable data return for validation of vehicle, environment & ops.
  - Reliability/probability of obtaining the desired data.
  - Measurement system responsiveness, modularity, interoperability.

- Minimize:
  - Total mass and size required to make non-critical measurements.
  - Need for power, active cooling, comm or other vehicle resources.
  - Integration and operations, unique mods. installation and checkout.
  - Ground installation/servicing and mission operations required.
  - Life-cycle costs compared to conventional measurement systems.
  - Effort to establish RF, EMI and EMC certification for flight.
  - Reliance on single vendors by the use of common standards.
  - Need for data transfer and vehicle data storage provisions.
  - Impact to vehicle/crew safety, reliability and mission success.

Low Mass Modular Instrumentation – CxP RFI

What are some Technology Objectives to help us reduce mass and life cycle costs?:

(1) Micro-size and minimum weight, including connectivity.
(2) Very low power, low maintenance, long-life between servicing.
(3) Least number of wires/connectors required, including wireless or no connectivity.
(4) Minimum integration and operations to achieve for modularity.
(5) Smart DAQs with User Specifiable calibration, scheduled and even-triggered modes.
(6) Smart DAQs with Processing/Storage allowing reduction of total data transfer.
(7) Robust/Secure Wireless networking and synchronization between DAQs and even between sensor and DAQ.
(8) Plug-and-play wireless interoperability.
(9) Plug-and-play DAQ to avionics integration.
(10) Open architecture standards to promote multiple vendors with competitive solutions.
(11) Wide variety of data acquisition rates – 1 sample per hour to 1 megasample/sec
(12) Robustness with respect to projected environments.
(13) Wide variety of sensor types such as: temperature, dynamic and quasi-static acceleration, dynamic and static strain, absolute and dynamic pressure, high rate acoustic pressure, calorimeters, dosimeters, radiometers, shock, air flow, various hand-held sensors etc.

Potential Areas of Cooperation in Outside Agencies/Industry

Common Technology Areas	Common Outcomes
Less Wire Hybrid Architectures	Performance/Life Cycle $
Wireless Sensors/Instrumentation	Flight Worthiness
- Exchange Existing	Installation Simplicity
- Evaluate New	Operations Maturity
- Identify Improvements	Application Acceptance
- Improve Standards	Cost/Performance
Ground and Flight Testing Changes	Cost/Responsive
Wireless Bus/Avionics	Performance/Services
	Reliability/Security
Systems/Back-up Flight Control	Proof of Reliability/Safety
	Perf/Cost Advantages

Conclusion

- NASA and Aerospace depend more and more on cost-effective solutions that can meet our requirements.
- ISA-100.11a is a promising new standard and NASA wants to evaluate it.
- NASA should be involved in understanding and contributing to other ISA-100 efforts that contribute to "Fly-by-Wireless" and it's objectives.
- ISA can engage other aerospace groups that are working on similar goals and obtain more aerospace industry perspective.

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