"Fly-by-Wireless" Update
Aug 24, 2010

Wing Leading Edge with 22 Reinforced Carbon-Carbon Panels

Accelerometer

Wireless Data Aquisiton Sensor Unit

Reinforced Carbon-Carbon Panel

**Example Shown:
Orbiter Wing Leading Edge
Impact Detection System**

Thermal Sensor

**Univ of Maine/IEEE/CANEUS Workshop
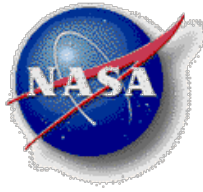NASA/JSC/EV/George Studor
(763) 208-9283**

- **What do we mean by "Fly-by-Wireless"?**
- **Common Problem and Motivation**
- **Recent Examples**
- **NASA's Future and Basis for Collaboration**

Vision:

> To <u>Minimize Cables and Connectors</u> and <u>Increase Functionality</u> 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 & integration methods to reduce cables & connectors.

2. Vehicle provisions for modularity and accessibility.

3. A "tool box" of alternatives to wired connectivity.

What it is NOT:

- A vehicle with no wires.
- Wireless-only for all control systems.

"Fly-by-Wireless" Focus Areas

(1) <u>System engineering and integration to reduce cables and connectors</u>,
- <u>**Capture the true program effects**</u> for cabling from launch & manned vehicles.
- <u>**Requirements**</u> that enable and integrate alternatives to wires.
- <u>**Metrics**</u> that best monitor progress or lack of progress toward goals.(# cables, length, # of connectors/pins, # of penetrations, overall weight/connectivity, total data moved/lb).
- <u>**Design Approach**</u> that doesn't assume a wires-only approach, but optimizes all practical options, providing for the inevitable growth in alternatives to wired connectivity.

(2) <u>Provisions for modularity and accessibility in the vehicle architecture</u>.
- <u>**Vehicle Zone Accessibility**</u> **–** Considers standalone sensors along with system assembly, inspections, failure modes/trouble-shooting, system/environment monitoring, remove & repair.
- <u>**Vehicle Zone Modularity**</u> **–** Vehicle wired buses provide power, two-way data/commanding, grounding and time in a plug-and-play fashion. Wireless networks are standardized by function and are also plug-and-play.
- <u>**Centralized & De-centralized approaches**</u> are available for measurement & control.
- <u>**Entire life-cycle**</u> considered in addition to schedule, performance, weight & volume.

(3) <u>Develop Alternatives to wired connectivity</u> for the system designers and operators.
- Plug-n-Play wireless devises
- Wireless no-power sensors/sensor-tags
- Standalone wireless smart data acquisition
- Standardized I/Fs, networks & operability
- Wireless controls – back-up or low criticality
- Robust high speed wireless avionics comm.
- Data on power lines, light, structure, liquids
- No connectors for bulkheads, avionics power
- Robust software programmable radios
- Light wt coatings, shielding, connectors
- RFID for ID, position, data, & sensing.
- Inductive coupling for rechargeable batteries

"Fly-by-Wireless" Activities

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"	10/28/2004
Inflatable Habitat Wireless Hybrid Architecture & Technologies Project:	9/2006
CANEUS 2006 "Lessons Learned Micro-Wireless Instrumentation	9/2006
CANEUS "Fly-by-Wireless" Workshop to investigate the common interests	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, Constellation Program Low Mass Modular Instr	May/Nov 2008
Gulfstream demonstrates "Fly-by-Wireless" Flight Control	Sept 2008
CANEUS 2009 "Fly-by-Wireless" Workshop	Mar 2009
AFRL announces "Wireless Spacecraft" with Northrup-Grumman	Mar 2009
CCSDS Wireless Working Group	Apr 2009
JANNAF Wireless Sensor Workshop	Apr 2009
ISA 100.11a finishes new standard for security for Industrial use	Sep 2009
NASA begins Wireless Avionics Community of Practice	May 2010
AVSI releases request for Agenda item at New World Radio Conference	Jun 2010
CANEUS/IEEE/Univ of Maine "Fly-by-Wireless" Workshop	Aug 2010

What Do the Two Industries Have in Common?

Wires!!

Aviation ⟷ **Space**

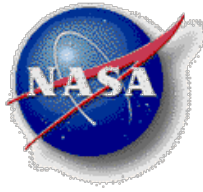|	wires	
Aircraft	⟷	Manned Spacecraft
Helicopters	⟷	Launch/Landing Systems
Unmanned Aerial Vehicles	⟷	Unmanned Spacecraft
Internal/External Robots	⟷	Internal/External Robots
Balloons	⟷	Inflatable Habitats
Crew/Passenger/Logistics	⟷	Crew/Scientists/Logistics
Jet Engines	⟷	Rocket Engines
Airports/Heliports	⟷	Launch Sites
Engineering Validation	⟷	Engineering Validation
Ground Support	⟷	Ground Support

Petro-Chemical Plants, Transportation Vehicles & Infrastructure, Biomedical, Buildings, Item ID and Location tracking

What do these have in common?

1. **Data, Power, Grounding Wires and Connectors for: Avionics, Flight Control, Data Distribution, IVHM and Instrumentation.**
2. **Mobility & accessibility needs that restrict use of wires.**
3. **Performance issues that depend on weight.**
4. **Harsh environments.**
5. **Limited flexibility in the central avionics and data systems.**
6. **Limited accessibility.**
7. **Need to finalize the avionics architecture early in the lifecycle.**
8. **Manufacturing, pre and post delivery testing.**
9. **Schedule pressure, resource issues, security and reliability.**
10. **Operations and aging problems.**
11. **Civilian, military, academic & international institutions.**
12. **Life-cycle costs due to wired infrastructure.**
13. **Need for Wireless Alternatives!!**

Common Motivations

- **Reduce Cost/Schedule of Wired Connectivity**

- **Increase Reliability/Maintainability**

- **Increase Safety**

- **Increase Security (some more than others)**

- **Increase System Functionality**

- **Changes in System Engineering & Integration, Vehicle Architecture and Technology Development/Awareness**

- **Decrease Size, Weight and Power**

Motivation: The Cost of Wired Infrastructure

- **Expenses for Cabled Connectivity** begin in the 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 - backup flight control is easier.
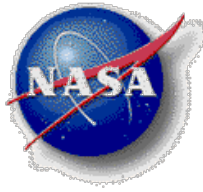
Motivation: The Cost of Wired Infrastructure

6. **Physical Restrictions:** Cabled connectivity doesn't always work well 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. Adding sensors adds observability to the system controls such as an autopilot.

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 to make changes 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 can be prohibitive.

Cost of Change for Wired Instrumentation

The earlier that conventional instrumentation requirements and design needs to be frozen, the greater the cost of change.

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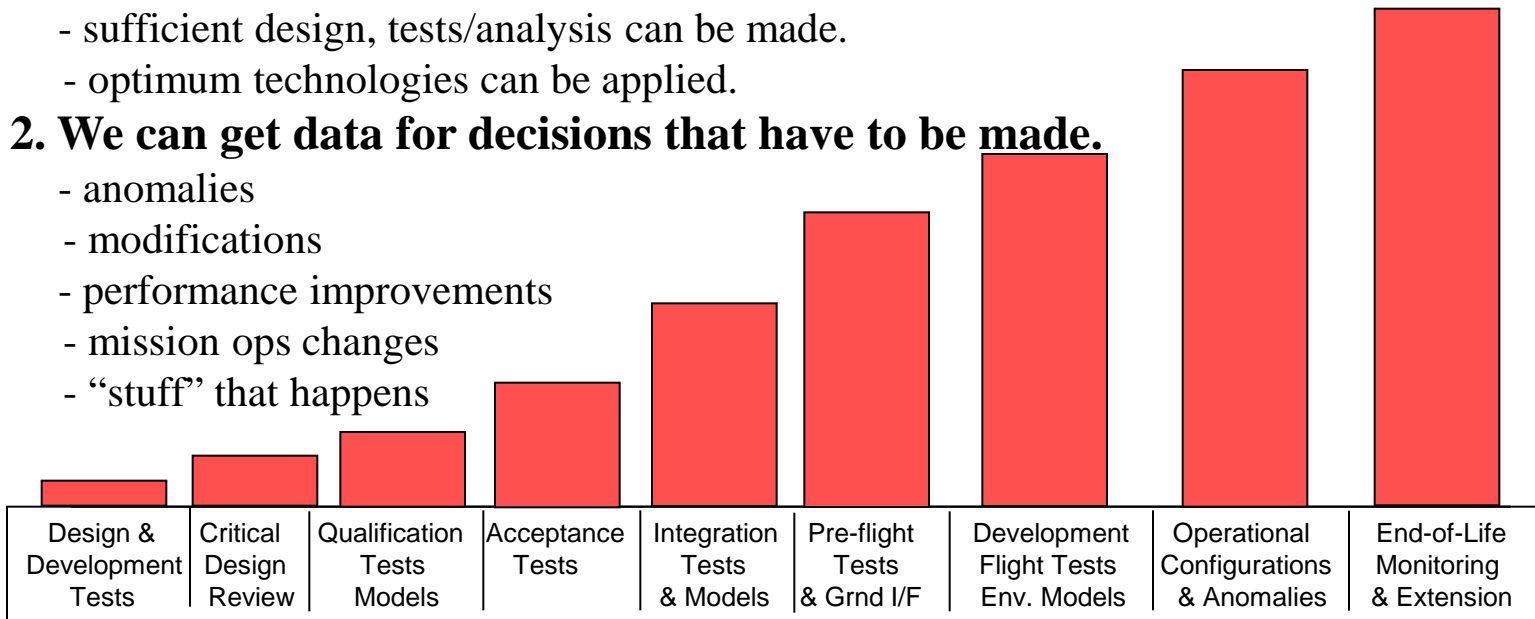- <u>Without mature/test systems and environments</u>, many costly decisions result.

We <u>need to design in modularity and accessibility</u> 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 be <u>made.</u>
- anomalies
- modifications
- performance improvements
- mission ops changes
- "stuff" that happens

Design & Development Tests	Critical Design Review	Qualification Tests Models	Acceptance Tests	Integration Tests & Models	Pre-flight Tests & Grnd I/F	Development Flight Tests Env. Models	Operational Configurations & Anomalies	End-of-Life Monitoring & Extension

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Motivation: Increase Vehicle 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. <u>A completely separate access path provides greater safety and reliability against common mode failures</u>.

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 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.
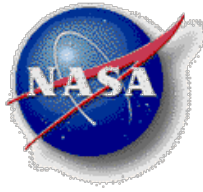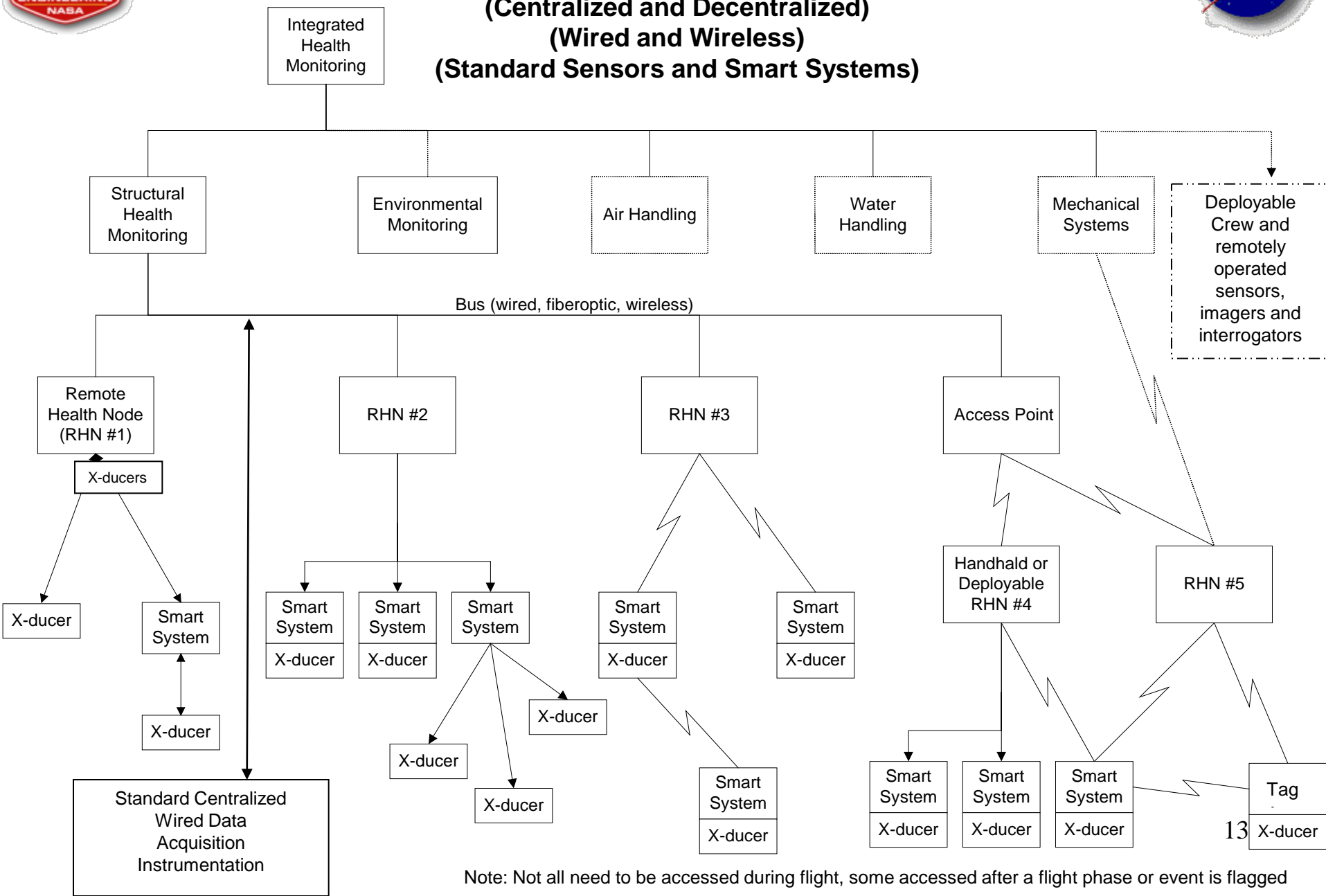
- **Reduced Response Time** to respond with changes in monitoring.

- **Increased Options** for sensing, inspection, display and control.

    - e.g. rotating equipment, human interfaces, unpowered areas.

- **Fewer Structural/Material Failure Points** - Penetrations, connectors, wiring, and sensor connection complexity.

- **Better Opportunities Correct/Upgrade** for safety deficiencies.

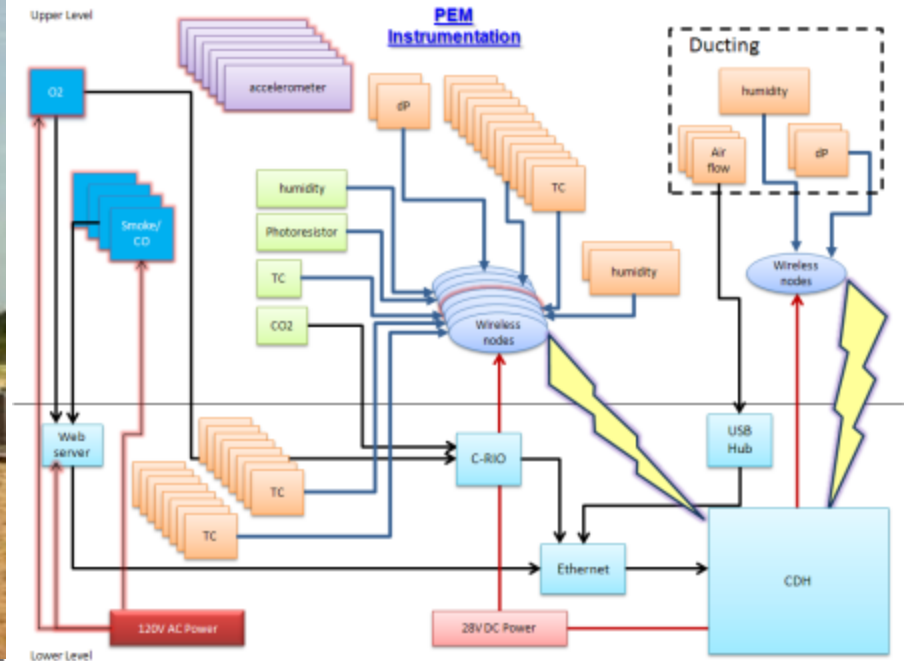- **Increase redundancy** with backup and add-on systems.

Conceptual Hybrid SMS Architecture

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

Integrated Health Monitoring

Structural Health Monitoring

Environmental Monitoring

Air Handling

Water Handling

Mechanical Systems

Deployable Crew and remotely operated sensors, imagers and interrogators

Bus (wired, fiberoptic, wireless)

Remote Health Node (RHN #1)

X-ducers

RHN #2

RHN #3

Access Point

X-ducer

Smart System

X-ducer

Smart System
X-ducer

Smart System
X-ducer

Smart System
X-ducer

Smart System
X-ducer

Smart System
X-ducer

Handhald or Deployable RHN #4

RHN #5

X-ducer

X-ducer

X-ducer

Smart System
X-ducer

Standard Centralized Wired Data Acquisition Instrumentation

Smart System
X-ducer

Smart System
X-ducer

Smart System
X-ducer

Tag
X-ducer

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

Airlock

Habitat

Location: JSC "Rockyard"
August 2010

Habitat Sensing:
CO_2, Smoke, Humidity
Air Flow, Air Pressure
Accelerometers, Temperatures
Also Wireless to Temperature in Airlock
Hybrid Instrumentation includes
JSC WSN Network of Dust-based sensor-nodes
Note: HDU is on its way to participate in the NASA "Desert RATS" testing in August.
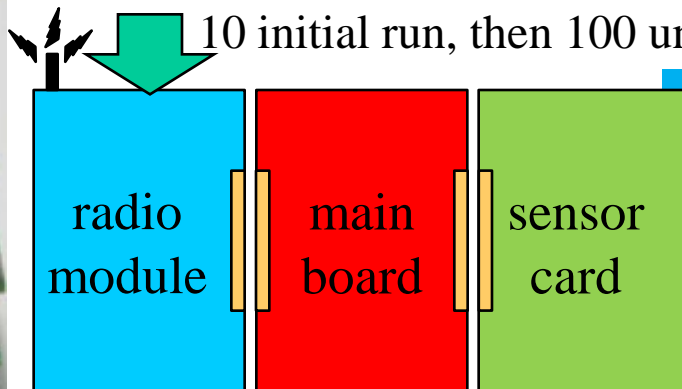
JSC Wireless Sensor Node Upgrades

Current JSC WSN with
dust protocol (TSMP)
20 made so far

Initial Application:
8 nodes in HDU with up
to 10 channels each for
humidity, temperature
and differential pressure

Substitute New Radio Module
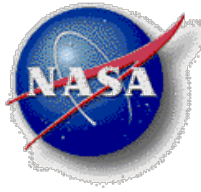**ISA100.11a** radio (Nivis, LLC)
10 initial run, then 100 units

Note: ISA100.11a is typically
for a low data rate system

Test WSN Nodes in Habitat Test Bed

WSN ISA 100.11a Testing at JSC:

RF issues:
- Data delivery reliability
  - multi-path, interference, noise
- Data throughput rate
- Interoperability-2.4 GHz 802.11

Power issues:
- Radio/networking component
- Low power, full mesh networking
- Sensing/processing component
- Scheduled & event-driven sensing

Application issues:
- Feasibility of sensing transients
- Usefulness of MAC-derived apps
- Time synchronization

Protocol issues:
- Which protocols best apply when?
- Modifying existing commercial protocols or using as-is
- Investigating future standards-based protocols

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Data Recorder Box

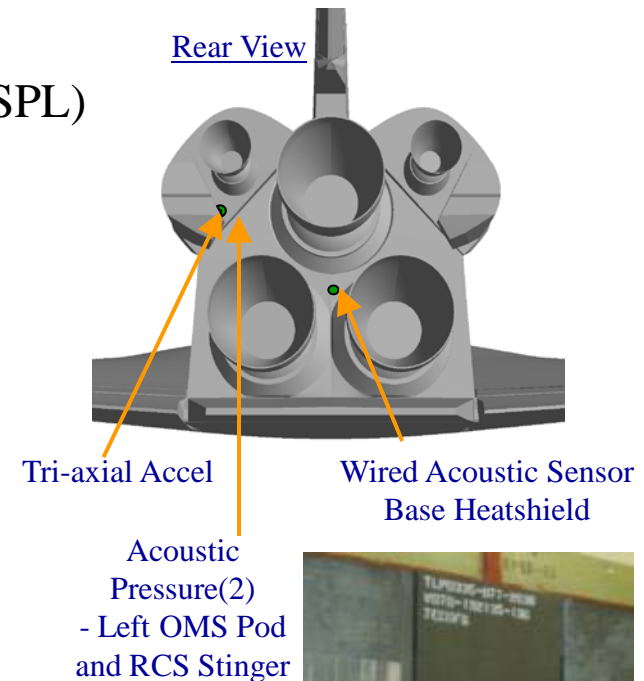Data Recorder Box

OMS Pod Loading due to Acoustic Pressure – potentially out of cert life

- Discovered at FRR, 2 weeks prior to STS-129 – Nov 2009
  - Add Triax inside OMS Pod – 20K/sec and high dynamic range

- Add Acoustic Monitoring – STS-130 and subs:
  - 20 -315Hz @ max 180 dB Sound Pressure Level (SPL)

Rear View

Tri-axial Accel

Wired Acoustic Sensor
Base Heatshield

Acoustic
Pressure(2)
- Left OMS Pod
and RCS Stinger

OV-104 WLEIDS
Recorder Location
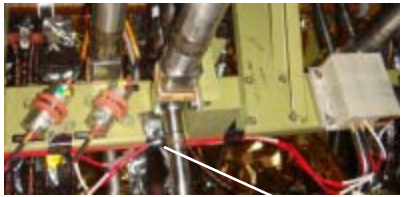
Accelerometer Location

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Wing Leading Edge Data Recorder
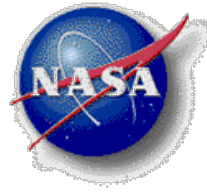High Data Rate
Low Data Rate

Micro Strain Gauge Unit (MSGU)

RR1 Tests at Caddo Mills, TX
Armadillo Aerospace
Tethered Lander flight test 05/22/10
Lander Free flight test 06/23/10

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NASAs Future: Current Manned Spaceflight Challenges

- **Space Shuttle:**

  - Monitoring for safety of flight thru end of program

  - Use of Shuttle assets after it is retired

- **ISS:**

  - Long term maintainability – all systems

  - Increased scope of on-orbit structural validation

  - Rapid module leak location system

  - ISS utilization increases – HD video, wireless audio, other WLAN needs

    - Drag-thru cables that impede rapid hatch closures

  - Need a new transportation method for getting to ISS post-Shuttle retirement

- **Future Programs:**

  - Ground test instrumentation, development flight test instrumentation

  - Operational flight instrumentation and deployments with EVA/robotic missions

  - Weight, power and volume reductions for vehicle and wireless systems

 - Standardization of wireless interfaces and systems

What's Needed?
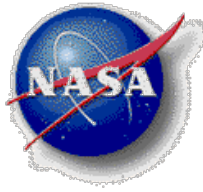
1. **Communication** of needs and capabilities –> Link the "Communities of Practice"
   - **Personal investment: News items/alerts, email and web-based networks**
   - **RFIs – Such as the flurry of them that happened this summer**
     http://nspires.nasaprs.com/external/solicitations/solicitations.do?method=init
   - **RFPs – SBIR/STTR Cycles, Challenges, Space Grant, etc.**
     http://sbir.gsfc.nasa.gov/SBIR/sbirsttr2010/solicitation/index.html
   - **IPP Seed fund: http://www.nasa.gov/offices/ipp/technology_infusion/seed_fund/index.html**
   - **NASA website(s) – Chief Engineer/Communities of Practice; Office of Chief Technologist**
   - **Other agencies – DOD, DOE, DOT, NIH, DHS**
   - **Industries: Oil and Gas; Aerospace; Medical; Transportation; Construction; Home**
2. **Business case studies: Cost – Benefit of Wires/Wireless; Metrics**
3. **Evaluate various "less-wire" technologies that are already being developed**
   - Cooperative exchange of testing, results and hardware/systems.
   - Use real world environments and test scenarios to solve a real problem.
4. **Architecture studies: Provisions for wireless, System Engineering Texts**
5. **Create the Wireless "Tool Box" - some priorities**

   - Smart Sensor-DAQ Micro-Miniaturization – Ex: WLEIDS -> System on a chip, Plug-n-play

   - Passive Wireless Sensor-Tag systems – increase channels, sensor types, miniaturize interrogator, work in typical avionics bays,

   - Extremely High Data Rate LANs for video and other sensors –VLAN is emerging

   - Standardized and Ruggedized Networks for reliability, modularity and competitive selection

NASA Wireless Avionics Community of Practice
(Internal leveraging)
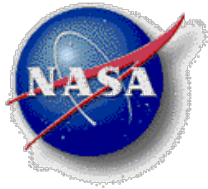
JSC/EV George Studor
Internal Website Live June 6th, 2010

Purpose: Mature NASA Wireless Avionics Connections technology and applications through an agency-wide forum to share information and capture knowledge, under the Avionics CoP.

Scope:
- Limited to on-vehicle and vehicle proximity RF wireless*
- Facilities used for vehicle test and check-out and wireless systems eval.
- Support Avionics CoP in reporting and issues identification/clarification.
- Wireless Avionics CoP is not a working group. Occasional issues may require CoP to help find experts to man teams external to it.
- Within a range that wires might otherwise have been run, but functionality or practicality may favor wireless.

**Members:** Lead: JSC/George Studor
Center POCs at each NASA center

SBIR/STTR Phase 2 Project Search (Cross-Agency Leveraging)

At approximately $1.3M for each 2 year project… there is a lot being invested.. Note: other agencies not listed: DOT, NIH, etc….
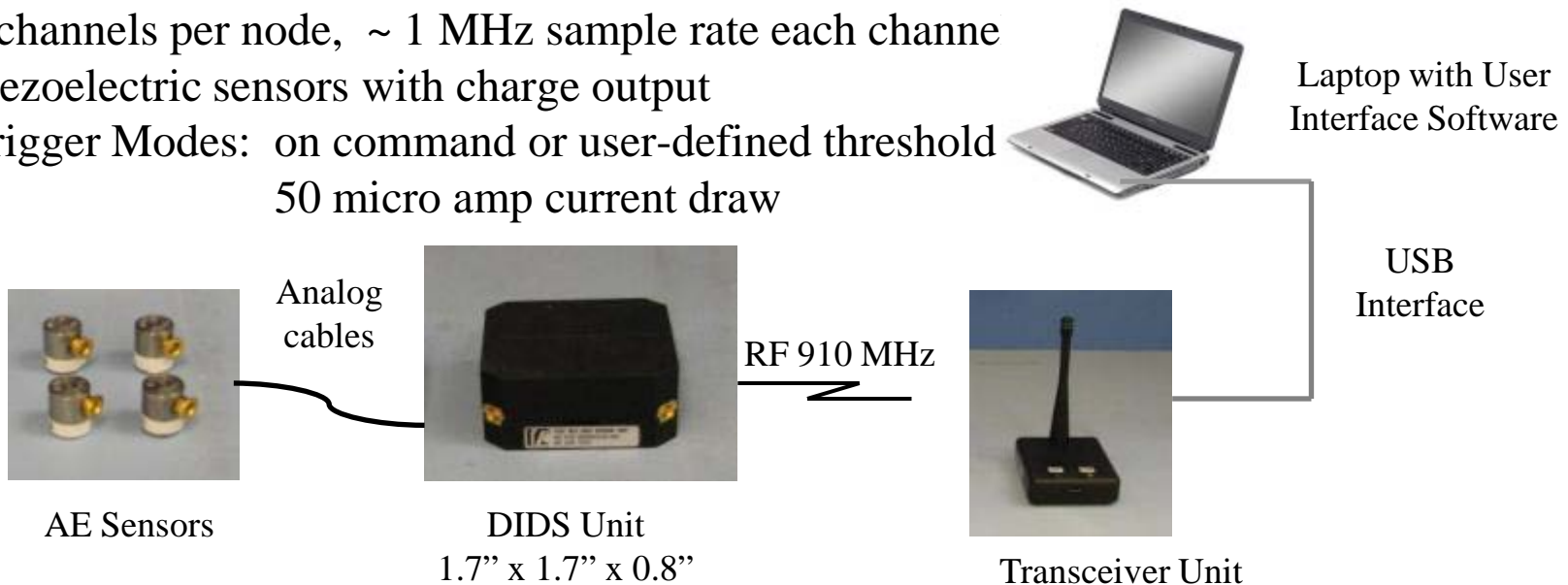And I haven't listed the many Phase 1 Projects…

Agency	Sensors	Networks	RFID	Avionics	Radio	Antennas	Total
Air Force	15	7	3	10	12	17	64
Army	12	11	9	0	8	17	57
CBD	1	1	1	0	0	0	3
DARPA	5	5	2	3	1	10	26
DHS	11	4	4	0	0	0	19
DOE	19	2	0	0	0	0	21
MDA	5	2	0	11	2	3	23
NASA	31	11	5	9	7	6	69
Navy	20	8	2	10	18	23	81
NIST	4	0	0	0	0	0	4
NSF	17	2	7	0	2	4	32
OSD	3	2	0	0	1	2	8
SOCOM	0	1	0	0	1	2	4
Total	143	56	33	43	52	84	
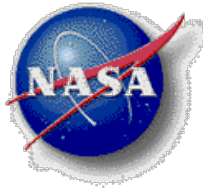
ISS Leak Location System
Let's make it smaller, faster cheaper

- **STEP 1: On-Orbit DTO to Characterize ISS AE Environment**

- **Use Distributed Impact Detection System (DIDS) – Phase 2 SBIR Project:**

    (works for leaks too)

- Record acoustic emission or acceleration "events" on structures or through air
    - Window of data is recorded upon detection of an event.
    - Event characterized by exceedance of programmed threshold value .
    - Software can perform a "forced trigger" to command a data take

- System characteristics:
    - 4 channels per node, ~ 1 MHz sample rate each channe
    - Piezoelectric sensors with charge output
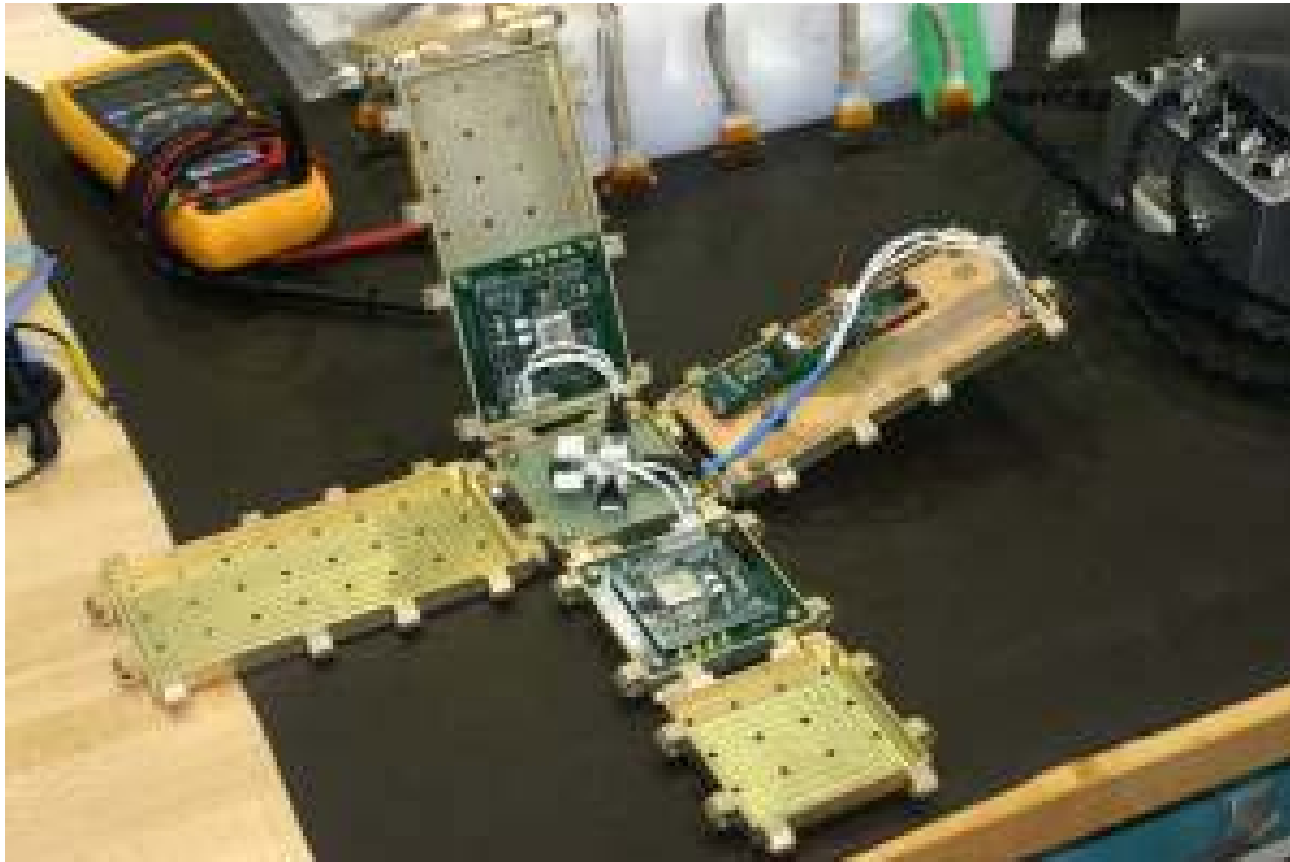   - Trigger Modes: on command or user-defined threshold
        50 micro amp current draw

Laptop with User Interface Software

USB Interface

Analog cables

RF 910 MHz

AE Sensors

DIDS Unit
1.7" x 1.7" x 0.8"

Transceiver Unit
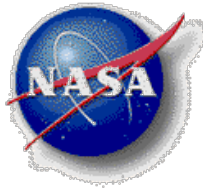
Several AFRL SBIR awards for CubeSats

Start with reducing the 15 pin connectors in a typical Cube-sat

SDM – Satellite Data Module
ASIM – Applique Sensor Interface Module
XTED – eXtended Transducer Electronic Datasheets

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New Tool Box for Maintenance Work

Data Loggers – wireless and non

Wireless Sensor Network
- Standalone deployable Central Node

Active & Passive Sensor Tags
- Interrogators for Both Tags

Smart Bar Code/RFID Inventory system
- Stored Information and Location

High Data Rate Node:
-Wireless Work Control IPad – Massive Storage
- High res photos/drawings
- Wireless Location (Internal & External)
- On-board link to Vehicle Systems

Rechargeable or Long-Life Batteries
Scavenge Power options for in-flight

Plug-and-Play Antennas
RF Troubleshooting Equipment

…..Plus Flashlight and Screwdriver

Avionics Bays are Typically Crowded

Aerospace Sensing is a common need…
Aerospace Sensors Working Group
(NASA-lead, Industry and other Agency attended)
- Practical Ways to get across bulkheads without connectors
- Communicate reliably in a harsh environment with extreme
multipath (but at least it is short range and not dynamically changing)
- Modular access points to change and upgrade configurations

Power Scavenging for Wireless Standalone Sensors

EADS Thermal Scavenging Sensor for VHM

Aug 12, 2010

Forwarded to me from Embraer rep on AVSI Team…
stay connected through Working Groups and informal contacts.

http://www.newelectronics.co.uk/article/26986/EADS-reveals-developments-in-aerospace-energy-harvesting-.aspx

Let's Make the Effort to Work Together!!