"Fly-by-Wireless" and Wireless Sensors Update
58th ISA International Instrumentation Symposium
June 5, 2012

Accelerometer

Wing Leading Edge
with 22 Reinforced
Carbon-Carbon Panels

Wireless Data
Aquisiton
Sensor Unit

Reinforced
Carbon-Carbon
Panel

Example Shown:
Orbiter Wing Leading Edge
Impact Detection System

Thermal Sensor

NASA/JSC/ES/George Studor
(763) 208-9283

- Vision/Problem
- Vehicle Architectures
- Add-on Instrumentation
- Special Topics

What Does the Aerospace Industry have in common?
Wires

Aviation	← →	Space

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

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

1. Data, Power, Grounding Wires and Connectors for: Avionics, Flt 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. Design issues to place wires early and design avionics.

8. Manufacturing, grnd/flight test

9. Operations & Aging Problems

10. Civilian, Military, Academic & International Institutions.

11. Life-cycle costs due to wired infrastructure.

12. **Need for Wireless Alternatives!!**

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"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	Oct 1999
USAF Reserve Report to AFRL	Nov 1999
DFRC Wireless F-18 flight control demo - Report	Dec 1999
ATWG "Wireless Aerospace Vehicle Roadmap" & ONR Wireless Mtg	Feb 2000
NASA Space Launch Initiative Meeting	Aug 2001
World Space Congress, Houston	Mar 2002
International Telemetry Conference	Apr 2004
VHMS TIM at NASA LaRC	May 2004
CANEUS 2004	Oct 2004
Inflatable Habitat Wireless Hybrid Architecture & Technologies Project:	Sep 2006
CANEUS 2006 "Lessons Learned Micro-Wireless Instrumentation"	Sep 2006
CANEUS/NASA "Fly-by-Wireless" Workshop- investigate common interests	Mar 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	Jul 2008
NASA RFIs for Low Mass Modular Instr	May/Nov 2008
Gulfstream demonstrates "Fly-by-Wireless" Flight Control	Sep 2008
AFRL announces "Wireless Spacecraft" with Northrup-Grumman	Mar 2009
CCSDS Wireless Working Group – NASA & International Space Partners	Apr 2009
JANNAF Wireless Sensor Workshop	Apr 2009
JANNAF Wireless Sensor Workshop	Dec 2010
ISA-NASA-BP Passive Wireless Sensor Technology Workshop	Jul 2011
International Workshop on Structural Health Monitoring - #8	Sep 2011
JANNAF Wireless Sensor Workshop	Apr 2012
ISA-NASA Passive Wireless Sensor Technology Workshop	Jun 2012
Wireless SAW Symposium – SAWHOT – Villach, Austria	Sep 2012
IEEE – Wireless for Space and Extreme Environments	Nov 2013

Working Together – We can't do it alone

Within Johnson Space Center:

- Center Chief Technologist, Engineering Directorate, Mission Ops, Facilities

Within NASA:

- Program Utilization - Space Shuttle, International Space Station, EVA,
- NASA Technology Roadmaps
- NASA HQ Office of Chief Technologist HQ
- NASA NESC - Technical Discipline Teams and Communities of Practice
  - Wireless Avionics, Robotic Spacecraft, NDE/Structural Health Monitoring

External to NASA:

- CCSDS Wireless Working Group (international standards)
- AVSI WAIC Project to obtain dedicated spectrum.
- ISA100 – Industrial low power wireless standards
- IEEE – Wireless for Space and Extreme Environments
- National Labs – Sandia, Oak Ridge, PNNL, etc.
- AF/DOD – Space Experiments – Plug-n-Play/Wireless Spacecraft
- University Programs and Space Grant Offices
- Working Groups, Workshops, Conferences, Individual Corporation Visits
- Partnership development.

- **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 -backup flight control is easier. 6

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. 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 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.

2.The earlier conventional instrumentation is fixed, 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 big 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 made.
- 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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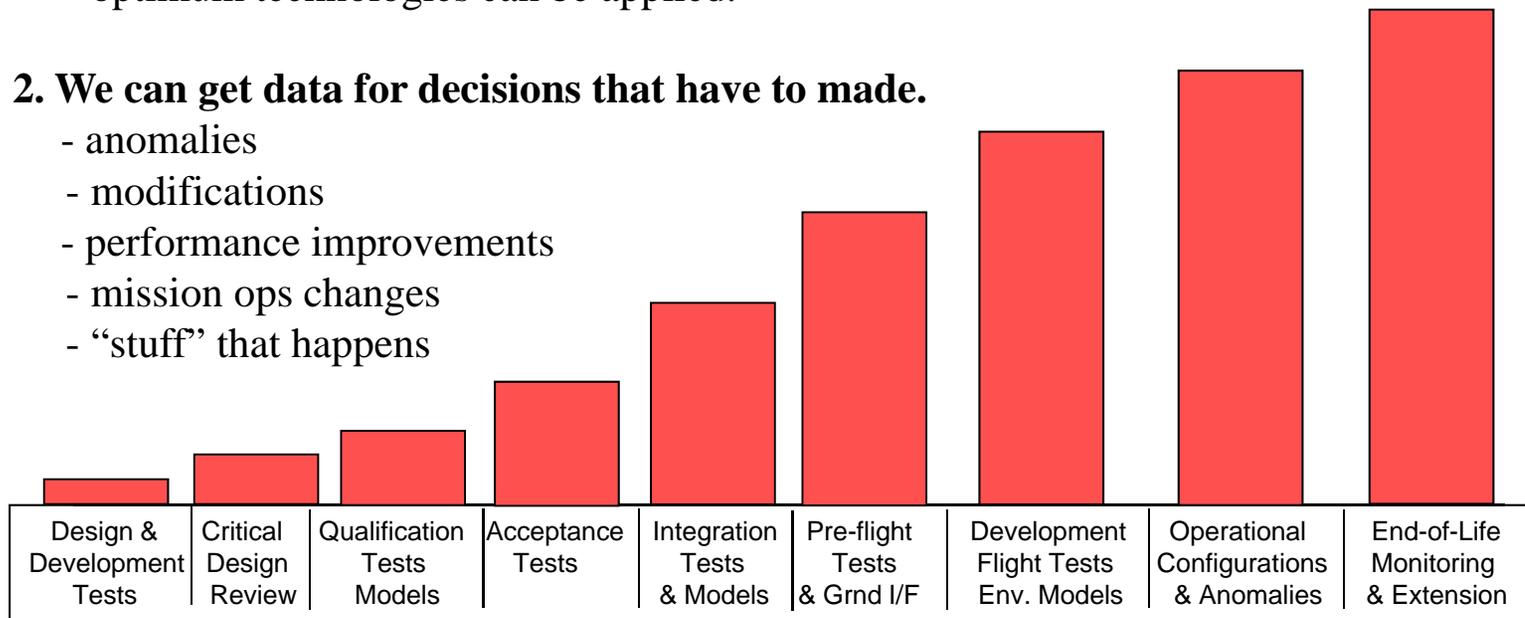
Vehicle Reliability Analyses must include: the End to End system, including man-in-the-loop operations, and the ability to do effective troubleshooting, corrective action and recurrence control.

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 failure 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 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.

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- Reduced time to respond to unsafe conditions where wiring is involved or where monitoring is needed.

- Increased options for Sensing, Inspection, Display and Control.

- Fewer penetrations, wiring and operations support hazards.

- Better upgrade opportunities correct for safety deficiencies.

"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??
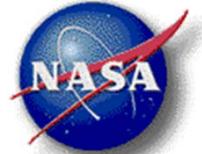
Conceptual Hybrid SMS Architecture for Future Space Habitats

(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)

RHN #2

RHN #3

Access Point

X-ducers

X-ducer

Smart System

X-ducer

Standard Centralized Wired Data Acquisition Instrumentation

Smart System
X-ducer

Smart System
X-ducer

Smart System
X-ducer

X-ducer

X-ducer

Smart System
X-ducer

Smart System
X-ducer

X-ducer

Smart System
X-ducer

Handhald or Deployable RHN #4

RHN #5

Smart System
X-ducer

Smart System
X-ducer

Smart System
X-ducer

Tag
12 X-ducer

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

NASA Fly-by-Wireless Technology Development
Must Leverage Work with Major Industry Sectors

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

Space Shuttle → **International Space Station(ISS)** →

Commercial Cargo and Crew to ISS →

Orion and Exo-LEO Manned Vehicles →

Next Gen Launch Vehicle for Human Mission →

Landers for Planets, Moons and Asteroids →

Remote (10-15% Manned) Habitat →

Robotic Spacecraft and Launch Vehicles →

Commercial Communications, Entertainment, Toys, Tools, Consumer Logistics

Petro-Chemical, Energy and Manufacturing Secure Wireless Sensing & Control

Medical and Biomedical Industry

Transportation Vehicles and Infrastructure

Building and Infrastructure Monitoring

Military Combat connections, Remote Sensing, Logistics, Onboard IVHM/SHM

Commercial Aircraft On-board Applications

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Our Space Vehicle Problem
One "Size" Does Not Fit all – we need choices

Interior
- Short Range
   (inches to several meters)
- Shirt-sleeve
- High multi-path compartments
- RF Isolation possible

Exterior
- Longer Range
   (inches up to many meters)
- Extreme temperatures/vacuum
- Multiple Configs
- RF Exposed to interference

Fixed
- Comm Nodes
- Monitors
- Location

Temporary
- Data Acquisition
- Location
- Standalone
- Integrated

Moving
- Human Sensors/Tools
- Robotic Sensors/Tools
- Mechanical

Variable Attributes:
DAQ Rates, Comm Rates, Robustness, Capacity(# sensors), etc. 14

- Participate in Requirements Development and Evaluation of:
  - Wireless HART/Zigbee systems
  - ISA-100-based 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
  - Wireless Sensor Data base – Work with multiple agencies

Some History at NASA

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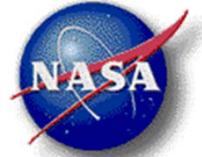
- **ISS Assembly** – Thermal limits too close for some avionics boxes during assembly and prior to hook-up… No power/data path available. External temperatures were needed for boxes in near real time.
Result: Wireless Data Acquisition System DTO leading to **Shuttle-based WIS(SWIS) for P6 & Z1.**

- **ISS Structural Loads/Dynamics i**s different at every assembly step, so <u>relocatable</u> 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 (WBMicro-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. **Ultrasonic WIS (UltraWIS), DIDS, & DLDS SBIRs**

Standalone Wireless Instrumentation for Shuttle/ISS

Evolution of Micro-WIS Systems (page 1)
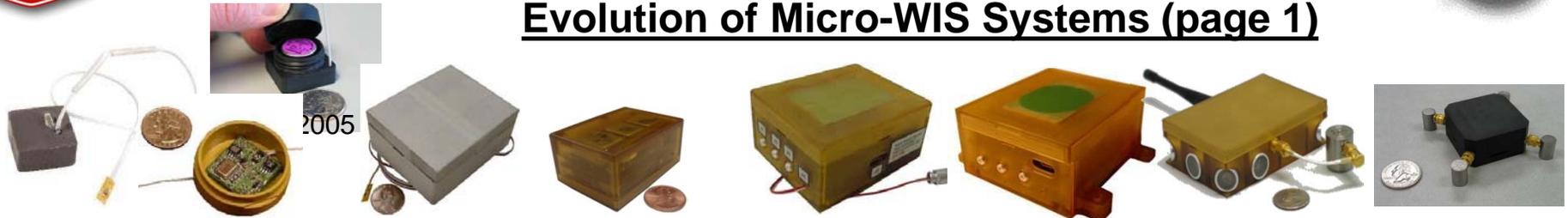
Micro-WIS XG

2005

System	MicroWIS (SBIR)	Extended Life MicroWIS	MicroSGU / MicroTAU	Wideband MicroTAU	Enhanced WB MicroTAU	Ultra-sonic WIS (SBIR)	DIDS (Phase 2 SBIR)
Date Certified	1997	2001	2000/2001	2002	2005	2007	2008
Purpose	IVHM	Thermal Models	Cargo Loads Cert Life Extension	MPS Feedline Dynamics	Wing Leading Edge Impacts	ISS Impact/Leak Monitoring	Structure Borne AE Leak Detection
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"x 1.5	3.4" x2.5"x 1.1"	1.7"x1.7"x.78"
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)	Up to 950KHz (on ea of 4 chnls)
Data Sync	No	No	Yes	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	On-demand, triggered or scheduled

915 MHz RFM chip-based: see MicroRF Network Protocol ICD: copies can be obtained through
Mr. Aaron Trott at Invocon, Inc – (281) 292-9903; atrott@invocon.com

Standalone Wireless Instrumentation for Shuttle/ISS

Evolution of Micro-WIS Systems (page 2)
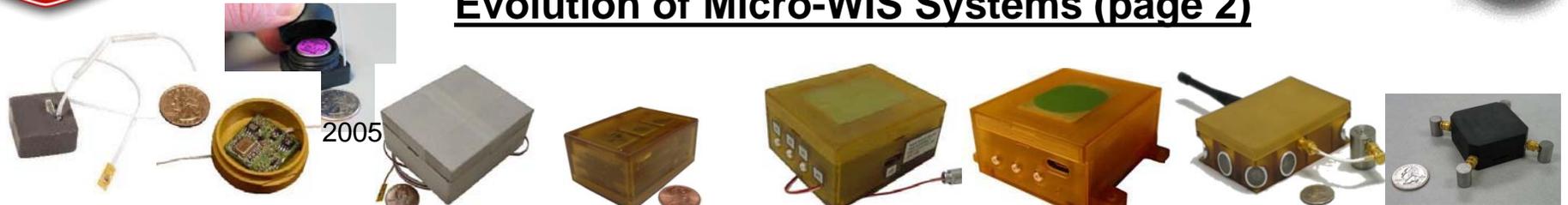
Micro-WIS XG

2005

| System	MicroWIS (SBIR)	Extended Life MicroWIS	MicroSGU / MicroTAU	Wideband MicroTAU	Enhanced WB MicroTAU	Ultra-sonic WIS (SBIR)	DIDS (Phs2 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	Very Low Power, fast Wakeup from any channel
Triggering	No	No	Data/Time Trigger	Data/Time Trigger	RF/Data/Time	Impact	AE any channel
Battery type	Tadiran 400mAhr	BCX Lithium C-cell	Tadiran 1000mAhr	BCX Lithium C-cell	Energizer L91 2-AA pack	BCX Lithium C-cell	L-91
Battery Life	9 months	10+ years	2-3 missions	1 mission	1 mission	3 years	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	Acoustic Emission Sensors Ultrasonic Microphones Accelerometers

Instrumentation for Inflatable Habitat in Antarctic (NASA-NSF 2007-8)

Honeywell SAW Passive Temp/Pressure Tag

Visible Assets - Rubee Tag - Temperature

Camera System
- External Cam
- InternalCam
- Motion Sense Cam (2.4GHz)

RFID System
- SAW Temp (433MHz)
- SAW Pressure (433MHz)
- RuBee Temp (131KHz)

ELM-WIS
- Ext. Thermal (916.5MHz)
- Photo Cell (916.5MHz)

Power Monitor System
- Watt Meter (2.4GHz/USB)
- Amp Meter

Air Qual Monitor System
- CO2 (418MHz)
- Humidity (418MHz)
- Internal Air Flow

Computer / DAQ

USB
USB
USB
USB

PC104 / DAQ

RS232
RS232
RS232
RS232
USB

Weather Station

RS232
RS232

McMurdo Station

Network Switch

Ethernet
Ethernet
Ethernet
Ethernet
128 Kbps
3 Mbps

NASA JSC Control Station

- Monitor <u>temperature</u> of experimental LOX tank wirelessly
  - 5 tags placed on exterior of tank
  - Tags placed at same level as wired internal temperature sensors
- System configuration
  - 7-element Tx antenna
  - 64-element Rx antenna
  - ~19 ft. baseline range
  - ~25 ft. tag range
  - Azimuth: tag boresight
  - Elevation: ~40° off tag bore-sight
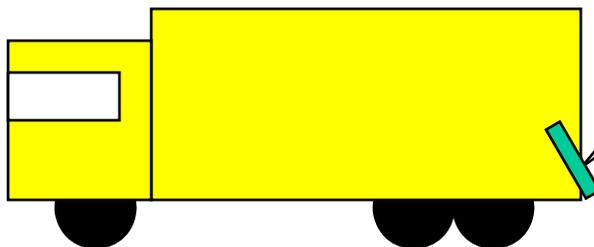
Garvey Spacecraft P-9 Rocket

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GarveySpace - Prospector 9
– Add-on Wireless Instrumentation Demo Aug 2008

Temperature Passive Sensor Tags (5 x 1 ch ea) – **SOMD/EC Project**
- Real-time data acq/display during tanking in Van
- Interrogator in back of van(2.4 Ghz) includes:
    - 2 electronics boxes 19" x 16" x 4"
    - 1 Antenna (3' x 2.5')

JSC/EV Passive Temperature -Tag
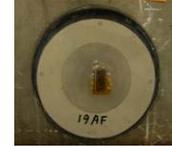
Temperature Sensor Data Loggers (6 x 1 ch ea) – **ELMWIS & Micro-recorder**
- Extended Life Micro-WIS   2.7" x 2.2" x 1.2"
    and Micro-WIS Recorders   1.75" dia x 1.0"
- 1 RTD each
- Wirelessly pre programmed before flight(916 MHz – 1 mw)
- Real-time data avail in van during tanking(1 sample/15 sec)
- Data downloaded post flight via RF or micro-connector

JSC/Invocon, Inc.

Triax Accelerometer Data Loggers (3 x 3 ch ea) – **WLEIDS**
- Wing Leading Edge Impact Detection System (Shuttle)
-1 Triax + 1 RTD each   3.25" x 2.75" x 1.5"
- Wirelessly pre programmed before flight(916 MHz-1mw)
- Status as req, Data downloaded after flight via USB port
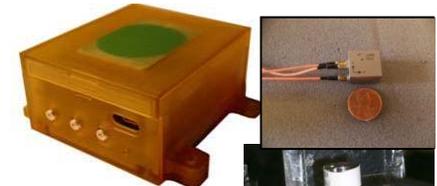
JSC/Invocon, Inc.

**Acoustic Emission Data Logger** (1 x 4 ch ea) - **DIDS**
- Distributed Impact Detection System   1.7" x 1.7" x .78"
- Wirelessly pre programmed before flight – 902-928 MHz
- Records "events" or periodically sampled as prescribed by user
- 1 mega-sample/sec, then data download after flight
- Characterize Tanking and other events

JSC/Invocon, Inc.
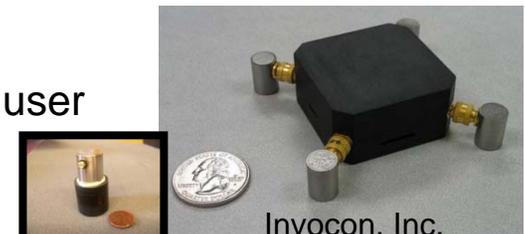
Invocon, Inc.

Crew Seat Detailed Test Objective (DTO) # 695

Lead: JSC/EV17/Nathan Wells

Effectivity: STS-119, 127, 128

Purpose: Obtain vibration specifications for unimpeded crew performance in conjunction with a Short Duration Bioastronautics Investigation (SDBI) to measure crew visual performance during launch.

A B C
D E F
G H I
J K L

Astronaut records visual function from middeck locker mounted card and other symptoms during launch profile (Middeck SDBI only)

Objectives:

• Data Collection during launch only

• Instrument 3 seats each flight

• Wireless Programming

Sensor Specifications:

• 3 VDC Battery powered

• Full Scale Range: +/- 14g

• Bandwidth: 1.5 Hz to 300Hz

• Data Sample Rate: 1000 samples/sec

• Resolution: 14mg

Accelerometers

Sensor Units (3) bonded to seat
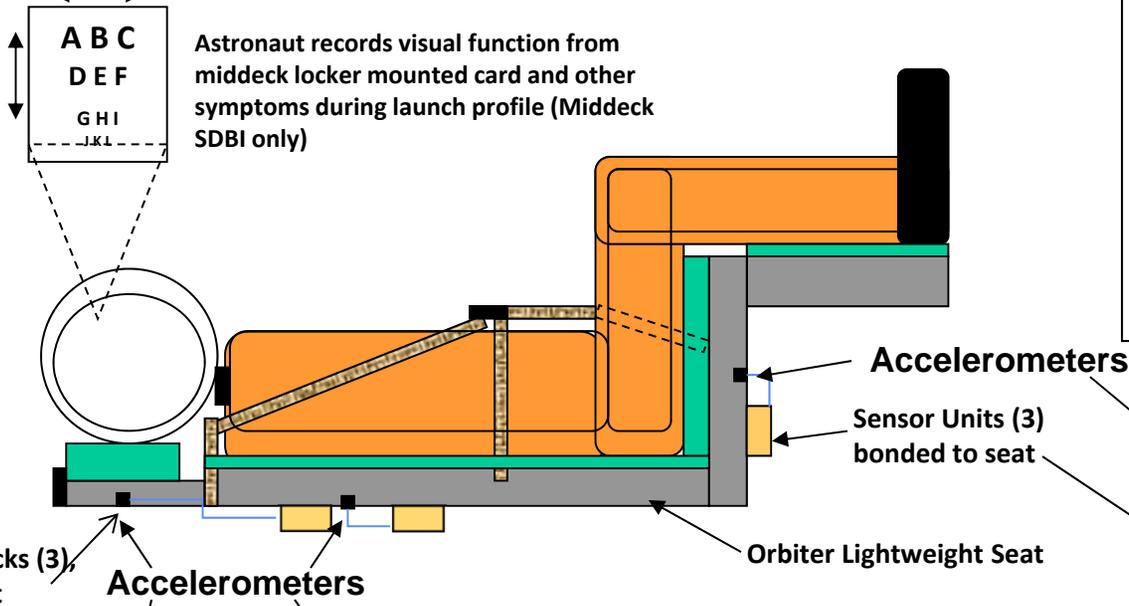
Triax accel blocks (3), Bonded to seat

Accelerometers

Orbiter Lightweight Seat
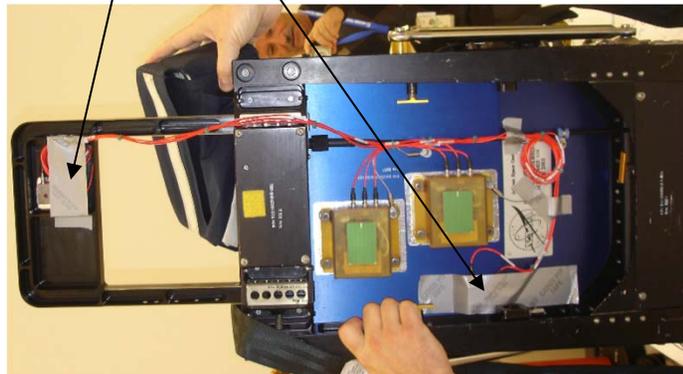
Seatback Configuration
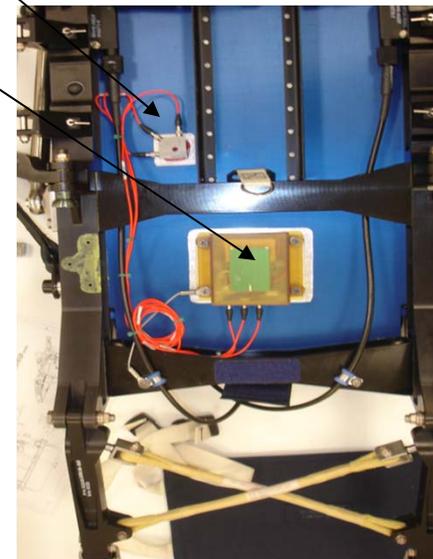
Seat Pan Configuration

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Mutual Interest Areas identified at
2007 "Fly-by-Wireless" Workshop
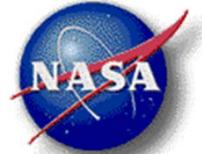
Aircraft:

 - Flight Test Support Kit: RFID tags, Active Tags/Loggers, Wireless Instrumentation
- Frequency Spectrum for International for On-board Wireless use: Critical Sensors, Wireless Controls
- Passive Tag System Improvements
- Weight Reduction in Helicopters
- Data Over Power lines
- Wireless Engine Monitoring
- Wireless Avionics Interconnects
- Aircraft Wireless Working Group
- Aircraft Wireless IVHM Working Group
- Aircraft Wireless Flight Control Working
          Group – Develop Super Autopilot
- Fly-by-Wireless Aircraft Test beds
- Life-cycle Cost/Benefit Analyses needed

Spacecraft:

- Weight Reductions
- Confidence in Wireless Connections
- Passive Tag System Improvements (2009)
- Wireless Instrumentation
- Add-on Standalone Instrumentation for Operations
- Wireless Avionics Connectivity, Standards, and "plug and play"
- Spacecraft Wireless/RFID Working Group
- Spacecraft Wireless IVHM Working Group
- Spacecraft Wireless for Habitats/Systems
- Onboard Wireless to external areas/systems
- Integrated Vehicle Architectures - Design
          for Fly-By-Wireless
- Life-cycle Cost/Benefit Analyses needed

VHM and Test:
- Standalone Wireless Instrumentation
- Secure Wireless Avionics
- Active and Passive RFID and Location Systems

- Passive RF Sensor-Tags
- Remote Operations – Internet Ops
- Scavenge/long-life battery Power

Potential Areas of Cooperation

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
Ground and Flight Testing	Cost/Responsive Changes
Wireless Bus/Avionics	Performance/Services
High Data Rates, Small Form Factor	Reliability/Security
Systems/Back-up Flight Control	Proof of Reliability/Safety
Passive Wireless Sensors	Perf/Cost Advantages
Wireless Sensor Data base	

Topics of Interest:

- Low Mass Modular Instrumentation RFI
- JSC Modular Instrumentation System
    - Availability to others as a set of modular stack node
    - RF Test Results – ISA100.11a vs Zigbee
    - Add Passive Wireless Sensor, NFC or RFID Interrogator
- NFC Sensors – how does this/will this fit in the trade-space?
- Navy Advanced Instrumentation Systems Technology(AIST) Program
- 60 GHz Wireless Communications /LAN - WiGig
- Wireless Sensor Data Base
- ISA - NASA Interactions

Low Mass Modular Instrumentation
– a 2008 NASA 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.
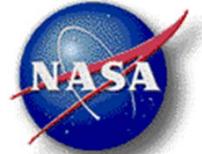
Modular Instrumentation System
NASA/JSC/EV/Paul Delaune & Patrick Fink

paul.b.delaune@nasa.gov

patrick.w.fink@nasa.gov

Rick Barton, Ray Wagner,

Scott Hafermalz, Hester Yim

A modular test platform <u>in use</u> and <u>available</u> from NASA/JSC for use as a versatile wireless networking and sensor acquisition and processing

Modular Instrumentation System (MIS)

The Modular Instrumentation System project is developed to support functions required for space environments, the MIS Project is focused on flexibility, reusability and economical ways to develop electronics and instrumentations for space applications. The project application is focused on the instrument and sensor technologies to support remote sensing, and for in-space and planetary surface activities, especially in life support and habitat systems and in-space vehicle systems supporting data acquisitions and sensor interfaces.

Communications

Sensor/Instrumentation Interfaces

Processors

Power Supplies

Available for Testing Now

Modular Instrumentation System Demo Unit

Power Supplies

28V Input Power Board

Battery or 5V Input Power

Current MIS Module Demo Unit

Processors

MSP430(A) Ultra Low Power uC Board

Concerto (F28M35x) uC Board (ARM & DSP)

Communications

ISA100 Wireless

ZigBee Wireless

Ethernet & Serial Interface Board

802.11b/g/n Wireless

802.15.4a UWB Wireless

Interface

4-20mA Sensor Interface

Multi-Sensor Board

Charge Amp board for a Tri-axis Accel & RTD

High Voltage Instrument

Sensor Instrument

Voltage Input Sensor

Solenoid Valve I/F

High Speed DAQ

= Modules in work

JSC MIS Components
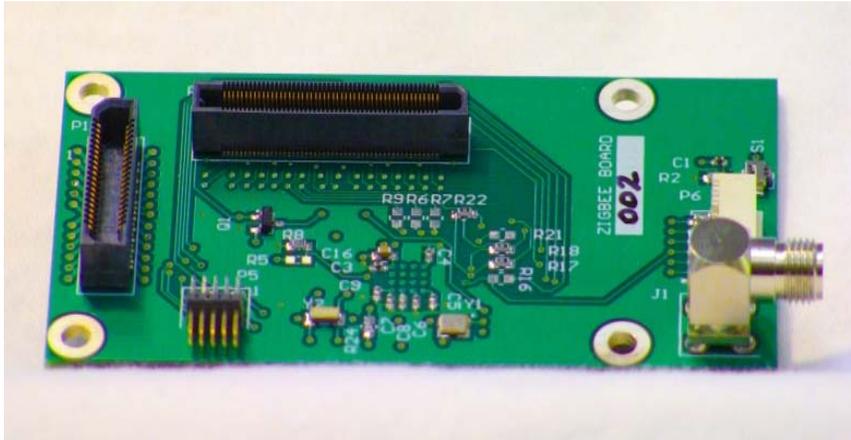
ZigBee Pro radio
(TI CC2530 ZNP)

ISA100.11a radio
(Nivis VN210)

Processor
(TI MSP430-F5438, MSP430F5438a)
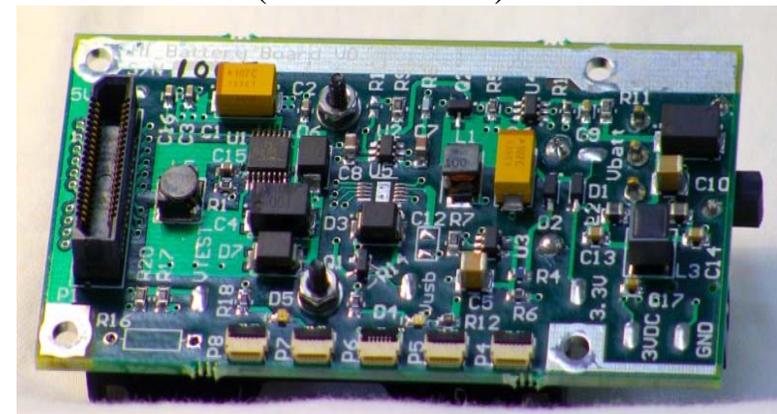
Power
(9V wall, AA battery x2)

photos by Mary Lynne Barends, NASA-JSC

Performance Comparison of Wireless Sensor Network Standard Protocols in an Aerospace Environment: ISA100.11a and ZigBee Pro

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*Abstract—Standards-based wireless sensor network (WSN) protocols are promising candidates for spacecraft avionic systems, offering unprecedented instrumentation flexibility and expandability. However, when migrating from wired to wireless data gathering systems, ensuring reliable data transport is a key consideration. In this paper, we conduct a rigorous laboratory analysis of the **relative performance of the ZigBee Pro and ISA100.11a protocols** in a representative crewed **aerospace environment**. Since both operate in the 2.4 GHz radio frequency (RF) band shared by systems such as Wi-Fi, they are subject at times to potentially debilitating RF interference. We compare message delivery rates achievable by both under varying levels of 802.11g Wi-Fi traffic. We conclude that while the simpler, more inexpensive **ZigBee Pro protocol performs well under moderate levels of interference,** the more complex and costly **ISA100.11a protocol is needed to ensure reliable data delivery under heavier interference.** This paper represents the first published, rigorous analysis of WSN protocols in an aerospace analog environment of which we are aware and **the first published head-to-head comparison of ZigBee Pro and ISA100.11a**.*

# JSC Modular Instrumentation System (MIS) Architecture – with PWST Augmentation

Passive SAW Sensors

Maybe PWST can reduce # of active nodes!

Passive Wireless Sensor Interrogator

RF-charged Passive RFID (Medium range)

Passive RFID & NFC Sensors (Close range)

RFID/NFC Interrogator

Power module

- battery
- energy harvesting (solar, vibration)
- mains (wired)

Comm. module

- handles data transport to External systems
- forms common network with other nodes
- can be wired or wireless

Controller module

- manages data acq.
- processes sensor data as needed
- formats data for transport to Ext. System

Sensor I/F module

Digital Sensors

Analog Sensors

- provides application-specific sensors, sensor conditioning
- only custom-designed component

Fixed vs Mobile Tags and Interrogator Configurations
Same basic system, different sensor – radio needs

<u>Fixed</u> Passive Sensors for Temp, HVAC, Lights, Leaks, Hazards and Earthquakes

Visitors Arriving for Secure Meeting with Smart, Long Range ID Cards recording check-points and location

People Walking

People Working

People on Break

Bldg WiFi Node

Equipment on the Move

Bldg WiFi Node

Mobile RFID Interrogation of Inventory

Bldg WiFi Node
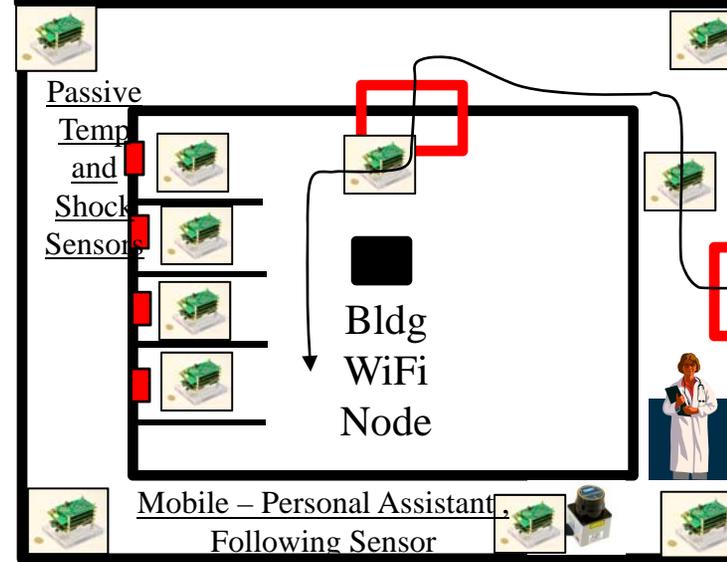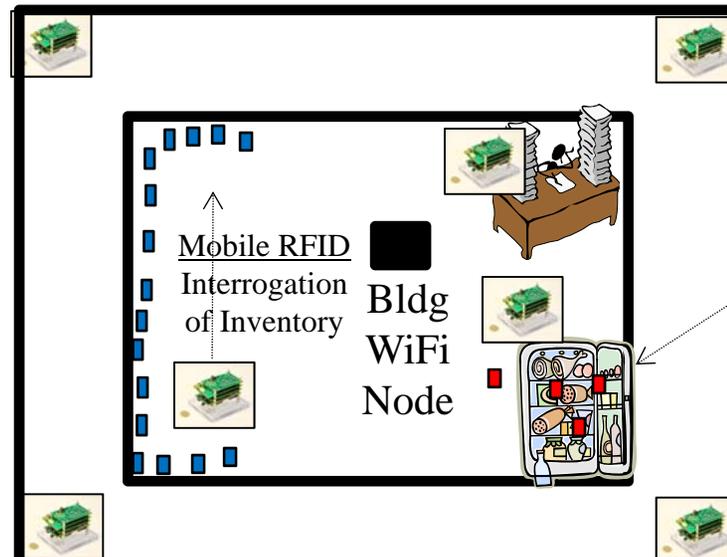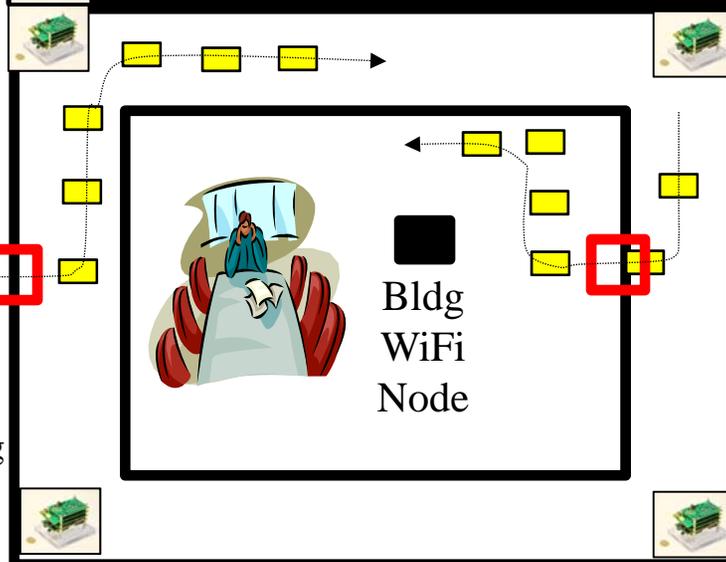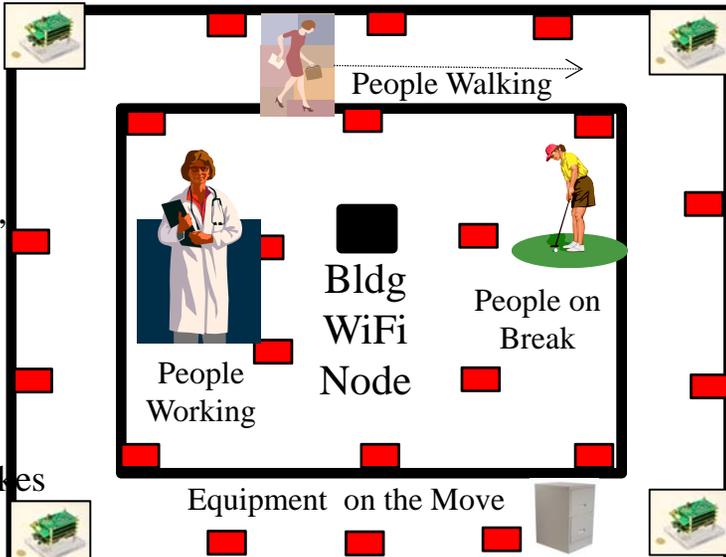
<u>Mobile or Fixed Reader</u> Food Spoilage Periodic Check and/or Monitoring

<u>Passive Temp and Shock Sensors</u>

Bldg WiFi Node

Mobile – Personal Assistant, Following Sensor

<u>Mobile, High-Value, Sensitive, Or Hazardous Assets</u>

Next Steps

Current Status:

- MIS nodes tested and wireless performance published.
- Demonstrated that ISA 100.11a is more robust for
    fixed nodes at low data rates
- Working towards a flight application to be used on ISS
- Adding USB in addition to Ethernet Board output
- Adding 4 channel piezo sensor acquisition board

Future:

Need version for wireless nodes in motion with high sample rates

- Add 802.15.4a radio capability
- Add WiGiG 60GHz – 6 or 7 Gbps
- Demo Standard RFID Interrogator with MIS

(SHM:JSC/ES
George Studor)

- Find Passive Wireless Sensor developer/end user interested in demonstrating PWST interrogator utility/challenges with MIS to obtain lower cost per sensor location – fewer wireless nodes needed.
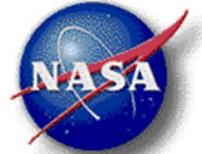
NFC Sensors – www.Gentag.com
NFC TEMPERATURE SENSOR TAGS
Passive Version and Battery-Assisted Logger Versions
GT-301

http://www.gentag.com/documents/File%204.pdf
http://www.gentag.com/documents/GT301.pdf

Overview:
- Available either as passive or battery-assisted logging sensors
- Wireless temperature sensing combined with unique ID
- Standard sensing range from –20 C up to +60 C
- Custom 0.1 C technology available for diagnostic applications
- Compatible with NFC cell phones
- Anti-collision supported (reads and writes multiple tags simultaneously)
- Use of NFC cell phones, PCs or Wi-Fi readers ensures worldwide usability and creation of mesh sensor networks

Passive – No Battery

The passive sensor reports the real time temperature, the unique ID number and sensor data each time it is interrogated either by a fixed or mobile reader such as an NFC cell phone. Passive temperature sensors typically are less accurate than battery-assisted sensors.

Battery Assisted

The battery-assisted sensor self-activates without the need of an external reader. The sensor can be programmed by the user with an NFC cell phone to activate temperature measurements every x seconds, minutes or hours, and pre-define temperature limits or thresholds can be set. Thus the sensor provides a historical report of temperature exposures and exposure times for any tagged product.

Custom Sensor

GENTAG can custom design and produce NFC sensors for a variety or special medical or industrial applications including implantable sensors or sensors for rugged environments.

NFC SENSORS – www.Gentag.com

Generic NFC Sensor Platform (Illustration Only)

External Digital Sensor Ports

External Analog Sensor Ports

Internal Temperature Sensor
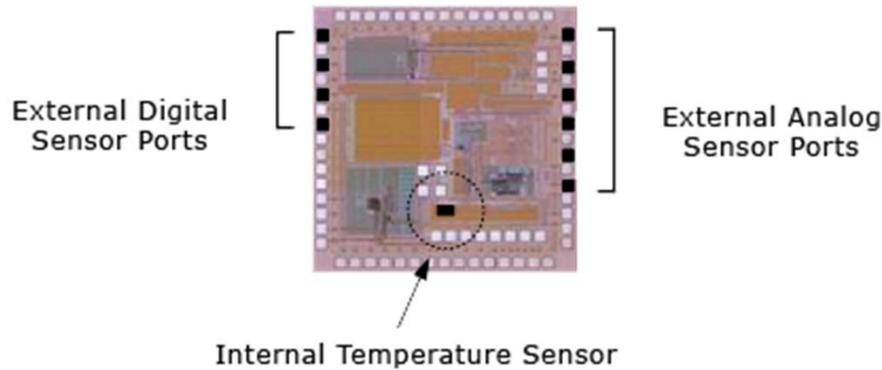
GENTAG NFC Bio-Marker - Urine-based Mobile health data acquisition/processing

Example: prostate cancer monitoring based on a newly discovered biomarker referred to as PCADM-1

TEST
POSITIVE
SEE YOUR
DOCTOR

GENTAG NFC smart skin-patch
 - Patient ID and Fever Onset(temperature)
Under Development:
- glucose-monitoring skin patch
- UV-monitoring skin patch
- pressure monitoring skin patch
- biomarker skin test patch

NFC RADIATION OR CHEMICAL SENSORS GT-320

- Single Use and Disposable
- Pre-Calibrated Sensor with Unique ID
- Maximum Measurable Dose: 10,000 rad
- Passive or Battery-Assisted Logger
- Standard or Radar-Responsive(15 miles)

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Radar Responsive Tags: GT-1000

http://www.gentag.com/documents/GT1000.pdf

- Radar-Responsive Tags developed at Sandia National Labs for the US Military.
- RR-Tags lead to E911 system in the US (emergency geolocation of cell phones).
- GENTAG owns exclusively the civilian (non-military – lower power) sensor version of the technology
- Applications include:
  - geolocation
  - geofencing
  - use in cell phones
  - diagnostics
  - wide area in-building RTLS

> Gentag
> 3299 K Street, NW
> Suite 100
> Washington, DC 20007
> 240-994-2236

Technical Characteristics (Civilian Version)
- FCC approved frequency
- Range: Up to 15 miles (2 miles average at ground level)
- Geolocation accuracy: up to 3 feet
- Battery Assisted
- Battery life: >1 year
- Tags can be combined with any sensor
- Size: ~credit card (ASIC version with battery – to be developed)
- Mobile reader infrastructure can be set up anywhere (including aircraft) or can be fixed and overlaid with existing infrastructure (e.g. cell phone towers)

Advanced Instrumentation Systems Technology(AIST) Mission

George Shoemaker, Ph.D.
AIST Executing Agent
Phone: 401-832-5304
george.shoemaker@navy.mil

Developmental Tests

Operational Tests

Live Fire Tests

I.   Time, Space, Position Information (TSPI)
II.   Advanced Sensors
III. Advanced Energy & Power Systems
IV.   Non-Intrusive Instrumentation
V.   Range Environmental Encroachment
VI.   Human Systems

Decrease size, weight & power (SWaP)

AIST Non-Intrusive Instrumentation

- **Non-Intrusive Instrumentation Data Management Reduced Size, Weight & Power (SWaP)**

MEMS Shear Stress Fiber Optic Sensor

Microelectronics

Wideband

ZigBee™

"Orange Gear"
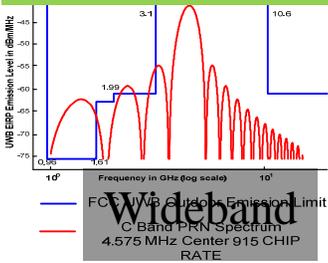
IEEE 1451

Wireless Comms

Massive Storage

Thin-Film Li Ion
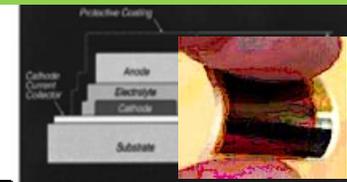
AIST
Non-Intrusive Instrumentation Topics

1. Non-Intrusive Instrumentation Data Management Techniques
2. Decreased Size, Weight and Power (SWaP) of Non-Intrusive Instrumentation
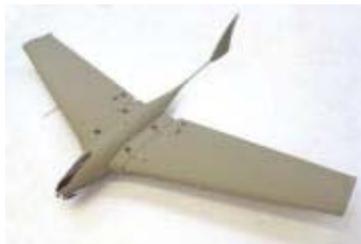
Micro UAV
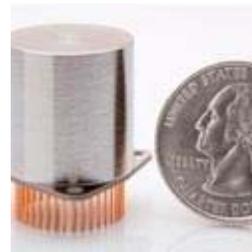
Magnetic Resonance Gyro
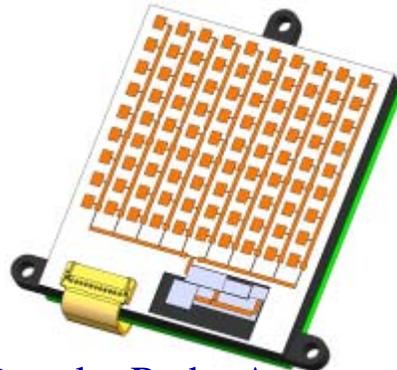
LiNbO3 Holocube

Doppler Radar Antenna
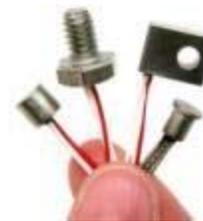
Micro Sensors

60 GHZ – Not allowed on Aircraft or Spacecraft in the U.S.

- **FCC restriction of 60 GHz in airplanes is Part 15, para 15.255(a)(1):**

  http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=8d73357270138a187ef105314bfa10b8&rgn=div5&view=text&node=47:1.0.1.1.16&idno=47

  "15.255 Operation within the band 57–64 GHz:

  a) Operation under the provisions of this section is not permitted for the following products:

  (1) Equipment used on aircraft or satellites."

- Rationale – uncertain
- Advantages to remove the restriction are Big
  - – small, high data rates, wide unlicensed band, and low power.
- WiGig is a strong, emerging Standard with many end users driving the price down.
- Could fly add-on 60GHz applications in aircraft operations overseas
- Could request use of an Aircraft-to-Ground System Application would be permitted
  - - such as data/video up and download at the gate or ends of runways.
- Propose Project to Remove Aircraft 60GHz – implications for Spacecraft?
  - - really need to understand more of the rationale before starting this.

60GHz Demo – Epsilon Lambda

- Epsilon Lambda V-band video link demonstration in the F-15
  - tested with all bays closed
  - transmitter in bay 6 to a receiver in bay 3
  - metal barrier - only one small opening
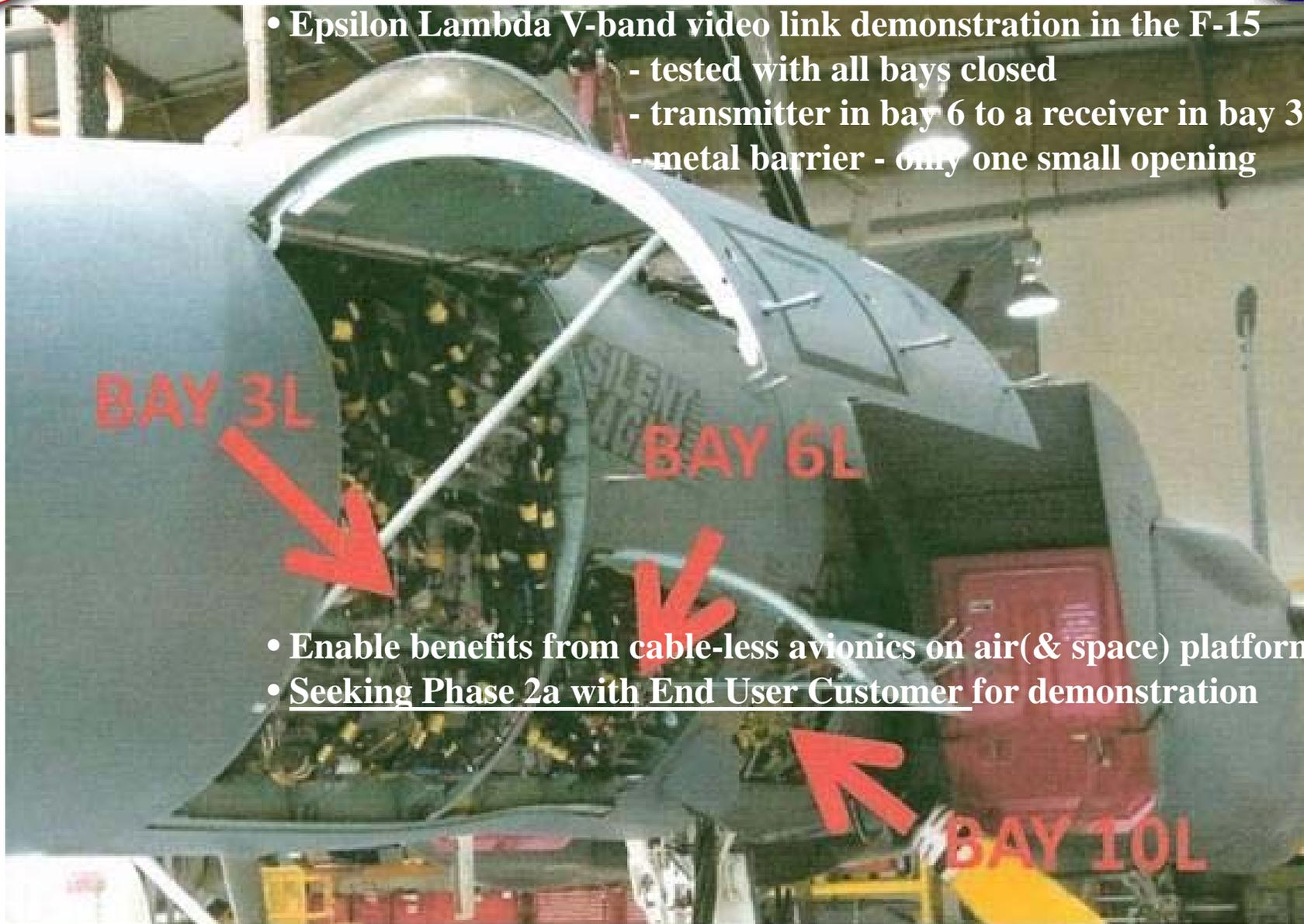
- Enable benefits from cable-less avionics on air(& space) platform
- Seeking Phase 2a with End User Customer for demonstration

BAY 3L

BAY 6L

BAY 10L

60GHz Demo – Epsilon Lambda
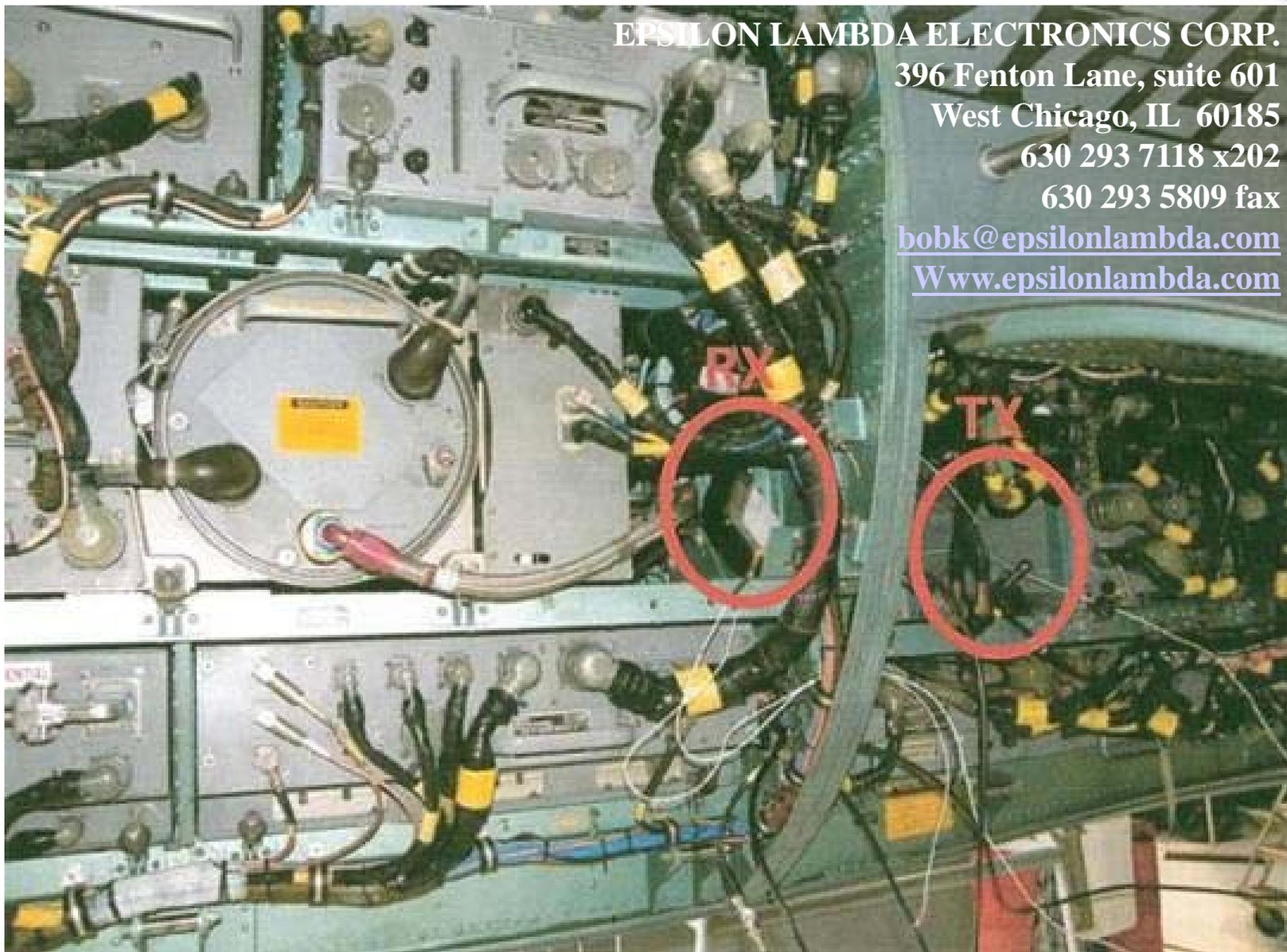
EPSILON LAMBDA ELECTRONICS CORP.
396 Fenton Lane, suite 601
West Chicago, IL 60185
630 293 7118 x202
630 293 5809 fax
bobk@epsilonlambda.com
Www.epsilonlambda.com

RX

TX

4

Wireless Sensor Database

- **What?**

  Team with other Gov Agencies, Industry and Academia to create a forum where new wireless sensor options can be cataloged. Advertised performance and maturity can be substantiated (or not) by folding in experience and testing in different applications and environments from all sources.

- **Why?** Increased knowledge of the State-of-the-Art will:
  - Less time/cost searching for solutions
  - Data base feeds operations and cost models/simulations
  - Avoid missing "the best" product for our needs
  - Create Better RFIs
  - Create more competition
  - Avoid duplication in R&D
  - Create Community among all sectors

- **When?** ASAP – the technology is already running way ahead of what we know individually.
- **How?** Needs a Champion, a Founding Team and an Agreement of Support
- **Who?**
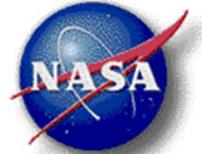
How might we NASA work with ISA-100 Organizations?

• Share emerging technology developments, test results, standards and end user needs…

• Look for common ground to potentially develop joint proposals that have payback for multiple end users.

• Look at vehicle system architectures that facilitate integrating new systems or upgrades.

• Look at SE&I level motivation/metrics that address advantages and concerns.

• Look at use of common test beds inside and outside of NASA and aerospace.

• Work with others to create a Wireless Sensors Database

• Lead/promote Wireless "Communities of Practice".

Comments/Questions?   George Studor (763) 208-9283
george.f.studor@nasa.gov