"Fly-by-Wireless":
A Revolution in Aerospace Vehicle Architecture for Instrumentation and Control
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Principal Author: NASA/JSC/George Studor

Aerospace vehicle programs have always relied on the cables and connectors to provide power, grounding, data and time synchronization throughout a vehicle's life-cycle. Even with numerous improvements, wiring and connector problems and sensors continue to be key failure points, causing many hours of troubleshooting and replacement. Costly flight delays have been precipitated by the need to troubleshoot cables/connections and add or repair a sensor. Even with the weight penalties, wiring continues to be too expensive to remove once it is installed. Miles of test instrumentation and low flight sensor wires still plague the aerospace industry. New technology options for data connectivity, processing and micro/nano manufacturing are making it possible to retrofit existing vehicles like the Space Shuttle. New vehicles can now develop architectures that provide for and take advantage of alternate connectivity to wires. This project motivates the aerospace industry and technology providers to establish:

> (1) A new emphasis for <u>system engineering approaches to reduce cables and connectors</u>.
> (2) <u>Provisions for modularity and accessibility in the vehicle</u> architecture.
> (3) A set of <u>technologies that support alternatives to wired connectivity</u>
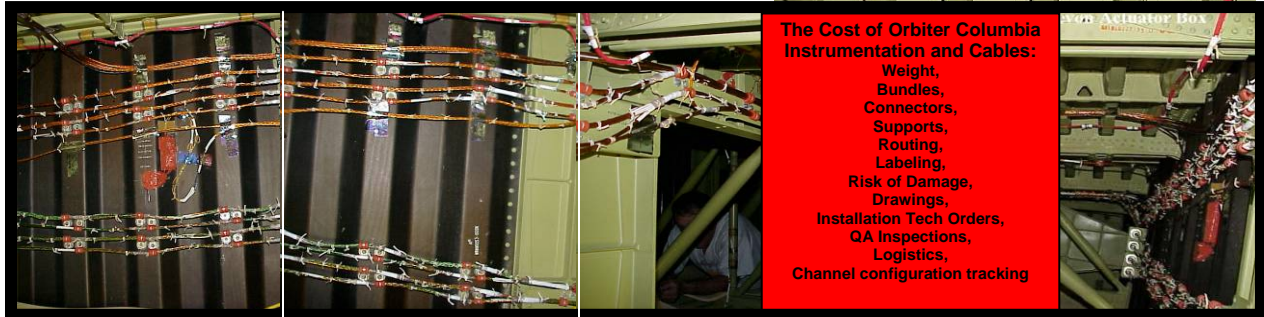
<u>What are the problems we are trying to address with this approach?</u>

1. <u>Failures of wires, connectors</u> and the safety and hazard provisions in avionics and vehicle design to control or mitigate potential failures. Avionics systems must build in high reliability into electronics and conduct extensive analysis and tests to "make up for" low reliability cables, connectors, and sensors.
2. <u>Direct Costs</u>: Measurement justification, design and implementation, structural provisions, inspection, test, retest after avionics r&r, logistics, vendor availability, etc. Every system team participates in the process of justifying sensors/data from the early design cycle through the end of vehicle life.
3. <u>The Price of Copper</u>: Four times the price it was in 2002, the price of copper has to be a factor in the economics of providing connectivity.
4. <u>Cost of Change/Inflexibility</u>: Changes are typically needed as the vehicle life-cycle progresses and missions are flown, experience is gained and problems are found. Instrumentation needs to be easily adaptable to these changing conditions.
5. <u>Cost of Late Changes</u>: Cost of change grows enormously as each flight grows closer, as the infrastructure grows more entrenched. As more flights are "lined-up", the cost of delays, regardless of the reason, increases exponentially and trouble-shooting and re-wiring cabling issues can sometimes be the cause.
6. <u>Cost of Data Not Obtained</u>: Performance, analyses, safety, operations restrictions, environments and model validations, system modifications and upgrades, troubleshooting, end-of-life certification and extension. The data acquisition systems have been typically centralized, limiting the number of channels and unique specifications available.
7. <u>Cost of Vehicle Resources:</u> Resources needed to accommodate the connectivity or lack of measurement come in the form of weight, volume, power, etc. Cable length and number of connectors are often not used as important metrics in assessing changes involving new measurements or other changes. It is the job of the instrumentation team to minimize these, but hasn't had the luxury of alternatives to cables until now.
8. <u>Cost of Flexibility of Vehicle Design</u>: Cabling connectivity has little design flexibility, and upgrades for avionics, sensors and cables are difficult. 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. The result is that the requested data is often not available when it is needed because of cost and lead time for nominal or late request.
9. <u>Performance</u>: Weight is more than 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. EMI/EMC and channel noise is always a consideration when running wires.
10. <u>Physical Restrictions</u>: Sometimes it is impossible or impractical to use cabled connectivity 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.
11. <u>New Composite Structures</u>: Fairly new to commercial aircraft and spacecraft, composite structures demand a degree of conservatism in their use, driving a desire for more test and health monitoring sensors.
12. <u>The Negative Perception of Wireless Reliability and Safety</u>: Wireless systems have been perceived to be unreliable for data acquisition and control. Yet for 10 years, NASA has been flying low power radio data

acquisition systems – useful for low criticality purposes with increasing functionality and dependence. Operations near pyrotechnics and in explosive atmospheres have been certified.

13. <u>Limited provisions for accommodating wireless connectivity:</u> In current vehicle designs, lack of access and utilities in many zones make the use of new wireless options less attractive, and sometimes impossible.

14. <u>Onboard wireless demands been perceived to be too high</u> for the frequency space available, but distributed processing options now available allow for distributed data acquisition systems to store raw data and produce answers to be transmitted, with raw data segments, on request.

15. <u>Wireless Instrumentation Systems have had to provide cables to the sensors:</u> This diminishes some of the advantages of using wireless systems. Now, with the advent of active and passive sensor-tags, that set of cables can be eliminated! In a wireless instrumentation architecture, every sensor can talk to every data acquisition box, and every data acquisition box can talk to every relay box. In wireless control, actuators and controllers are able to talk to all sensors and each other.

Figure 1:   Wiring Inside the Wing of the Orbiter Columbia costs more than length and weight.

The Cost of Orbiter Columbia Instrumentation and Cables: Weight, Bundles, Connectors, Supports, Routing, Labeling, Risk of Damage, Drawings, Installation Tech Orders, QA Inspections, Logistics, Channel configuration tracking

What does a "Fly-by-Wireless" Program look like?

System Engineering and Integration Emphasis:

1. Develops <u>measures of performance</u> to match the vision, such as number of cables and connectors, sensor system and cable weight, length and number of penetrations and connectors, etc.

2. It <u>establishes minimum requirements</u> to maximize the FBW performance objectives, such as <u>avionics bus and instrumentation modularity</u> and <u>vehicle zone architecture provisions for accessibility.</u>

3. It <u>"zero-baselines" cables and connectors,</u> so that each cable/cable length is fully justified as a requirement that is shown to be a fixed/long-term requirement, and performance measures actively pursued.

4. <u>Instrumentation Leads have many more options to consider</u> when addressing measurement requests.

5. <u>Connectivity needs</u> beyond the justified wiring are <u>managed by weight and CG by zone</u> until such time that either a wired approach is approved or an alternative approach (e.g. data over power-lines) is selected.

6. <u>Strategies for vehicle development and test</u> plan on the ability to change/upgrade sensing/instrumentation. Lower criticality measurements make their way in first, beginning with ground and flight test programs.

Vehicle Architecture Provisions for Modularity and Accessibility:

1. <u>Vehicle avionics is modular and upgradeable</u> to provide ports (similar to a USB in on personal computers) on the vehicle avionics bus, and MDMs that have wireless nodes. At each milestone of the vehicle program, data sensor and system changes are more practical because the cost of change is decreased, and benefits are more immediate.

2. <u>Vehicle design provides provisions for access,</u> zone-by-zone, where instrumentation modularity requirements are combined with inspectability and maintainability requirements. Where appropriate, coatings, waveguides, RF transparent structural ports facilitate RF communications and reduce intentional/unintentional interference.

3. <u>Measurements can be easily added</u> without significant cost and schedule impacts to enable engineers to troubleshoot systems, cargos and environments. Wireless devices and software are built to <u>interoperability standards</u> enable a wide selection of options from various vendors, aided by commonality <u>between air and space vehicles.</u>

Technology Alternatives to Cables and Connectors, Adaptive Modular Instrumentation:

1. Standalone Wireless data acquisition and active Sensor-tags provide strap-on instrumentation with remote access.

2. No-power RFID and Passive Sensor-Tags provide direct access to sensors with no battery or cables at a distance.

3. Robust and Adaptive radios adjust characteristics to optimize RF comm for interference/low signal-to-noise.

4. Onboard RF Interoperability and Frequency Authorizations are approved internationally across aerospace.

5. Adaptive instrumentation hubs are made to avionics "plug-and-play" standards for quick reconfiguration.

6. Data transmission on power lines is certified for certain applications.

7. Fiber-optic systems are also "plug and play" for high density measurements at high data rates.

8. Light weight coatings and shielding is developed for EMI/EMC and RF Interference.

9. Ground & Flight test instrumentation with wireless connectivity to standalone data acquisition or direct to sensors.

Summary: "Fly-by-Wireless" give programs the data they want, when they need it most, for the least impact.