

“Fly-by-Wireless”:

A Revolution in Aerospace Vehicle Architecture for Instrumentation and Control

Abstract

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Aerospace vehicle programs have always counted 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/or repair a sensor. Wiring continues to be too expensive to remove once it is installed, even with the weight penalties. 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 alternatives to wired connectivity. This project motivates the aerospace industry and technology providers to establish:

- (1) A new emphasis for system engineering approaches to reduce cables and connectors.
- (2) Provisions for modularity and accessibility in the vehicle architecture.
- (3) A set of technologies that support alternatives to wired connectivity

What are the problems we are trying to address with this approach?

1. Failures of Wires and Connectors: A large percentage of trouble-shooting results from problems related to wires and connector failures. Provisions in avionics and vehicle design are essential to control and mitigate the hazards from these potential failures. Avionics systems must build in high reliability into electronics and conduct extensive analysis and test to increase the reliability cables, connectors, and sensors.
2. Direct Costs: 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 to the end of vehicle life.
3. The Price of Copper: Four times the price it was in 2002, the price of copper has to be a factor in economics of providing connectivity.
4. Cost of Change/Inflexibility: Changes are typically needed as the vehicle life-cycle progresses and missions are flown and experience is gained and problems are found. Instrumentation needs to be easily adaptable to these changing conditions.
5. Cost of late Changes: 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 no matter what the reason grows exponentially and trouble-shooting and re-wiring cabling issues can sometimes be the cause.
6. 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. The data acquisition systems have been typically centralized, limiting the number of channels and unique specifications available.
7. Cost of Vehicle Resources: Resources needed to accommodate the connectivity or lack of measurements 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 that involve new measurements or other changes. It is the job of the instrumentation team to minimize these, but haven’t had the luxury of alternatives to cables up till now.
8. Cost of Flexibility of Vehicle Design: 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 the lead time required for nominal or late requests.
9. 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. EMI/EMC and channel noise is always a consideration when running wires.
10. Physical Restrictions: Design and operations can make it impossible or impractical to use cabled connectivity for monitoring. Structural barriers can limit personnel access and connections to vehicle resources(like power and data). In-situ assembly and deployment of un-powered vehicle components can preclude wired connectivity. Other physical circumstances that drive the need for wireless communications for vehicles include operations performed by crew members, robots and robotic mechanisms, proximity monitoring at launch, landing or mission operations.
11. New Composite Structures: 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. The Negative Perception of Wireless Reliability and Safety: 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. Low power wireless operations near pyrotechnics and in explosive atmospheres has been certified on Shuttle.
13. Limited provisions for accommodating wireless connectivity: 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. Onboard wireless demands have been perceived to be too high for the frequency space available: Distributed processing options that are now available allow for distributed data acquisition systems to store raw data and produce answers to be transmitted, with raw data segments transmitted on request.
15. Wireless Instrumentation Systems have had to provide cables to the sensors: Where the sensor can be included with the small wireless package, gather and transmit data, this is not a problem, but many sensors must be mounted or suspended away from the data acquisition card. This wire from sensor to data acquisition box diminishes some of the advantages of using wireless systems.

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



What does a “Fly-by-Wireless” Program look like?

System Engineering and Integration Emphasis:

1. Develops measures of performance 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 establishes minimum requirements to maximize the FBW performance objectives, such as avionics bus and instrumentation modularity and vehicle zone architecture provisions for accessibility.
3. It “zero-baselines” cables and connectors, 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. Instrumentation Designers have many more options to consider when addressing measurement requests.
5. Connectivity needs beyond the justified wiring are managed by weight and CG by zone until such time that either a wired approach is approved or an alternative approach (e.g. data over power-lines) is selected.
6. Strategies for vehicle development and test 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. Vehicle avionics is modular and upgradeable 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. Vehicle design provides provisions for access, zone-by-zone, where instrumentation modularity requirements are combined with inspectability and maintainability requirements. Where appropriate, coatings, waveguides, and RF transparent structural ports facilitate RF communications and reduce intentional/unintentional interference.
3. Measurements can be easily added without significant cost and schedule impacts to enable engineers to troubleshoot systems, cargos and environments. Wireless devices and software are built to interoperability standards which enables a wide selection of options from various vendors. Commonality between wireless systems used in high reliability ground systems, air vehicles and space vehicles improves the selection for all.

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.

The “Fly-by-Wireless” approach helps flight programs inexpensively get data they need when they need it.