Techniques for Improving Reliability of Wireless Sensor Networks in Flight Applications

Caneus / NASA Fly-by-Wireless Conference

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Invocon, Inc.
Innovative Concepts in System Engineering

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Agenda

- Company Background
- Introduction
- Methods for Improving Reliability
  - Hardware Methods
  - System Design Methods
  - Communication / Networking Methods
- Conclusion

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Invocon, Inc. Background

- Founded in 1986
- Located in Conroe, Texas
- Veteran-owned Small Business
- Applications:
  - Aircraft / Spacecraft Test and Evaluation
  - Missile-Defense
  - Civil Structural Monitoring
  - Industrial Monitoring
  - Automotive Testing
- Flight Opportunities:
  - 22 Shuttle flights, including 14 unique systems
  - 4 systems aboard the International Space Station
  - 3 Flights - Navy Target Missiles

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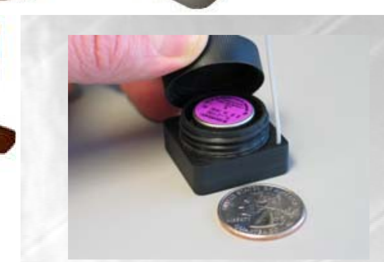
Flight Systems

- Self Contained
- Reduced Weight
- Low Integration Costs
- Short Turnaround Time
- Potential Uses:
  - Development Flight Instrumentation
  - Retrofit Flight Instrumentation
  - Integrated Vehicle Health Monitoring
  - Payload/Cargo Instrumentation & Control
  - Backup Control Systems
  - Vehicle Ground Inspections



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A Goal for Wireless Sensors and Controls

- To maximize the probability that the overall system will meet the given requirements within cost and size/mass constraints – ***System Dependability***
  - Reliability
    - Probability that a component will not fail during some period
  - Availability
    - Probability of failure plus recovery time
  - Redundancy

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Understanding System Requirements

- Understanding of system requirements is the most important factor in improving system dependability
  - Optimum methods for meeting requirements often radically different for distributed wireless system versus a centralized wired system
  - Considerations:
    - What data is needed?
    - Who needs the data?
    - When do they need it?
    - What relationship does this data have with other parameters?
    - What are the acceptable performance degradation scenarios?

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Methods for Improved System Dependability

- Hardware Methods
  - Watchdogs and Monitors / System Health Monitoring
  - Redundant Hardware within Node
  - Reducing Power
  - Easing the Environmental Extremes
- System Design Methods
  - Redundant Components / Cross Strapping
  - Reducing Communication Requirements
  - Reducing Real-time Requirements
- Networking / Communication Methods
  - Monitoring of Communication Link Parameters
  - Autonomously Configurable Communication Settings
  - Routing and Autonomous Network Configuration

System Example –
Wing Leading Edge Impact Detection System

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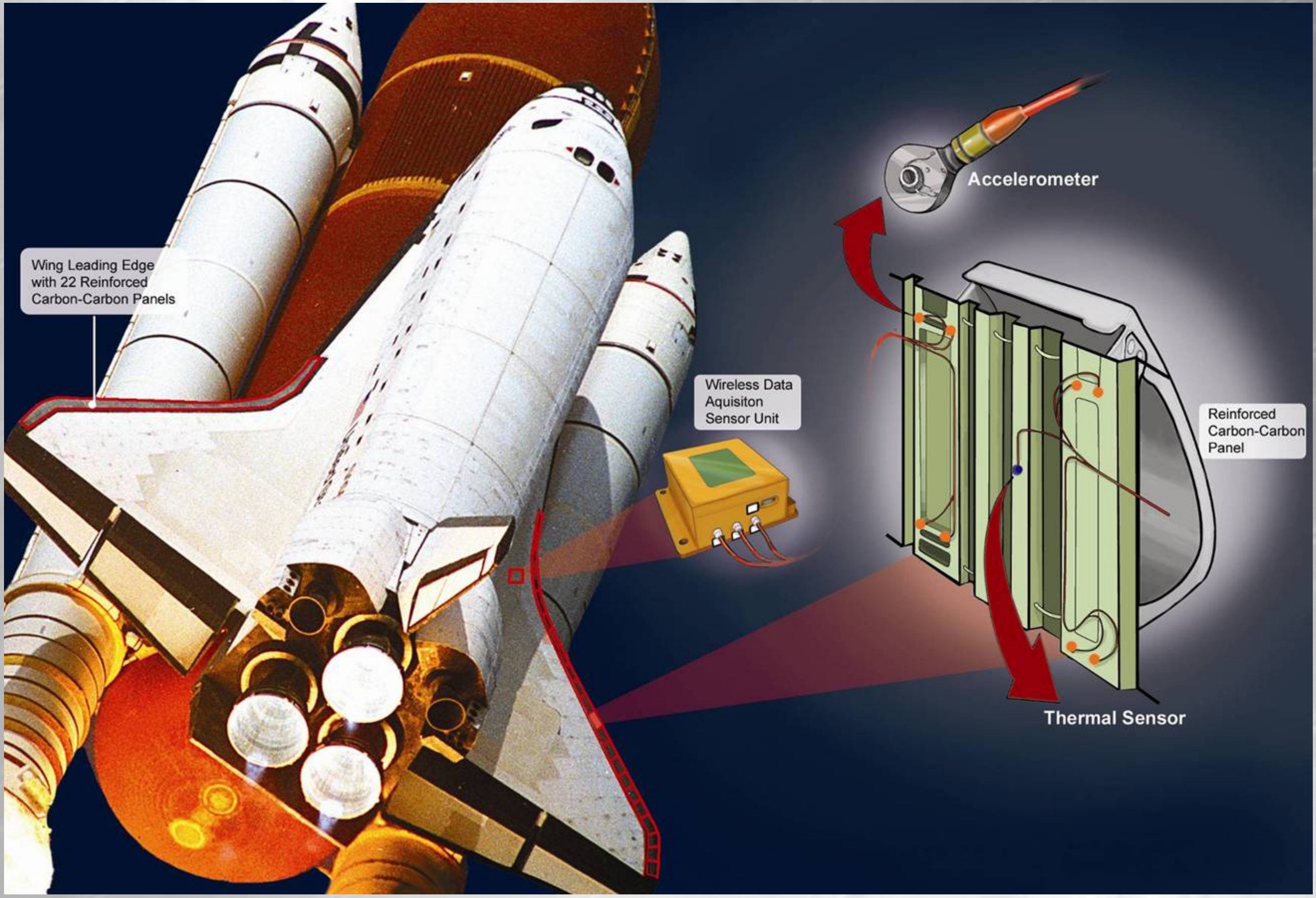

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Watchdogs and Monitors / System Health Monitoring

- Secondary microcontroller used for variety of watchdog functions
  - Current monitoring for radiation-induced latchup
    - Automatically cycles system power
  - "Jabber Control"
    - Resets system if unit transmits via RF or RS-485 inappropriately
    - *Unique to Wireless: A stuck-on transmitter can potentially bring down an entire system*
- System health monitoring information gathered and returned
  - Unit temperature
  - Battery voltage
  - Remaining battery life
- Analysis of acquired data can help to determine node health
  - Off scale
  - Noise level (either too high or too low)
  - Many others
- *Unique to Wireless : Once a remote node fails to communicate, it is impossible to determine the cause without accessing the unit*
  - *Health information needs to be gathered continuously and tracked*

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Redundant Hardware within Node

- Including redundant circuit elements within a particular node can be done
  - For example, multiple signal conditioning channels or radio transceivers that can be switched in upon failure of a particular string
- Relatively large additive cost in terms of complexity, size, and per unit cost
  - Options at the die level are often efficient
- Can make system multi-fault tolerant
- Thus far, we have found it more efficient to employ redundancy at the node level

Reducing Power

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- Dead batteries are a major cause of node failure and take considerable time to replace

  "Astronauts have better things to do that replace 200 batteries a month"

- Even for powered systems, the complexity and cost of power electronics can be minimized through low-power design techniques

Easing the Environmental Extremes

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- Tradeoffs between mounting locations must be made
  - Environments for components
  - Installation costs
  - Impacts to vehicle
- Often short cables to sensor locations limit temperature and vibration
  - Also minimizes loading

Cryogenic Accelerometers

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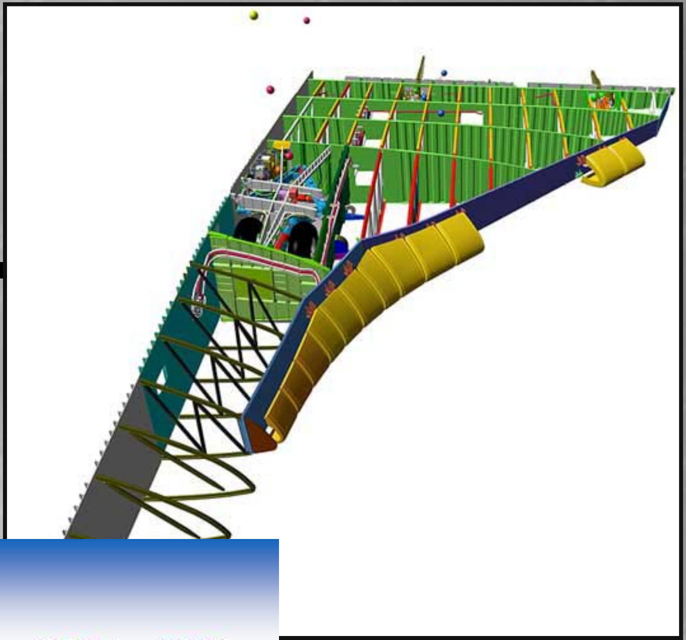
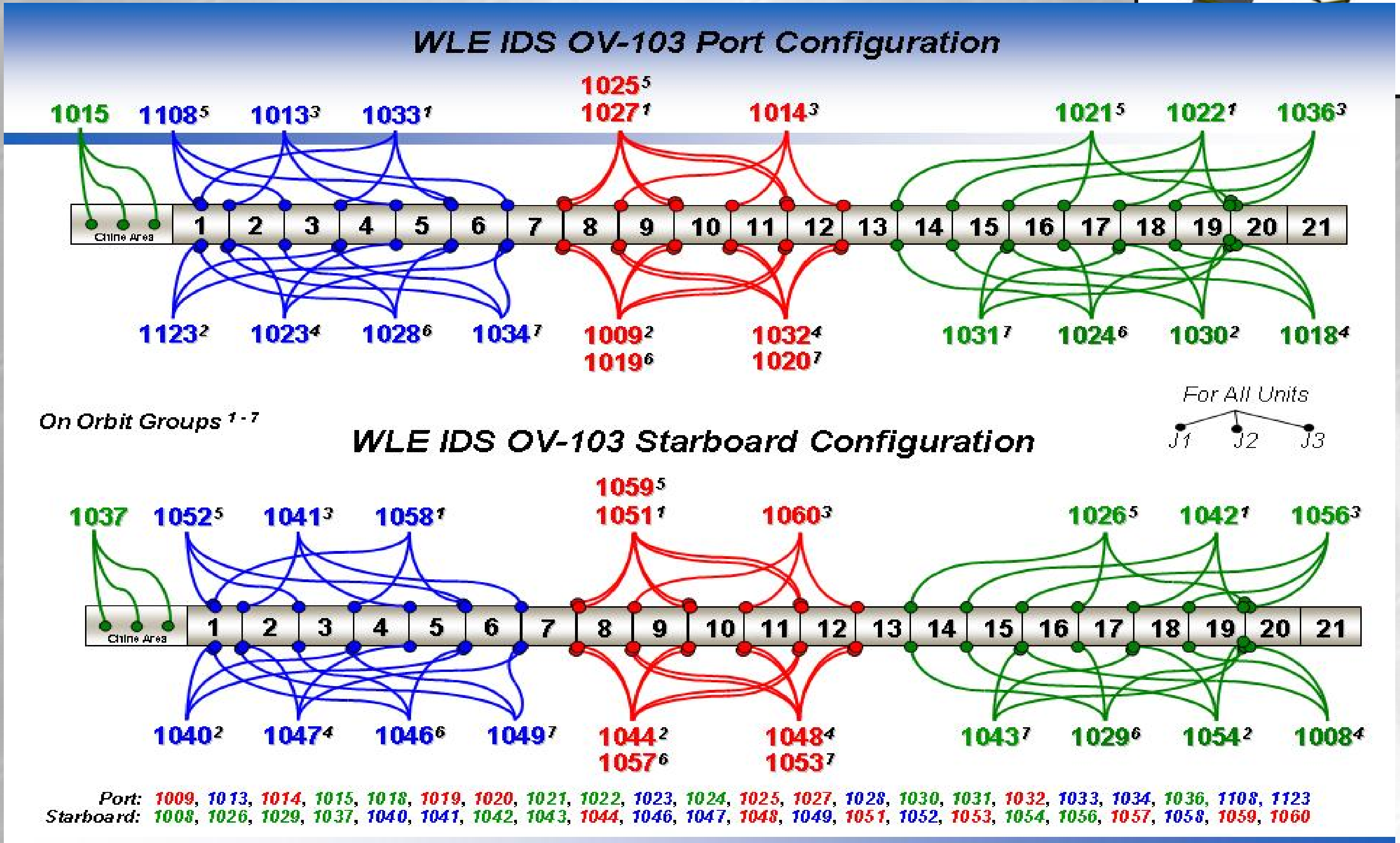
Redundant Components





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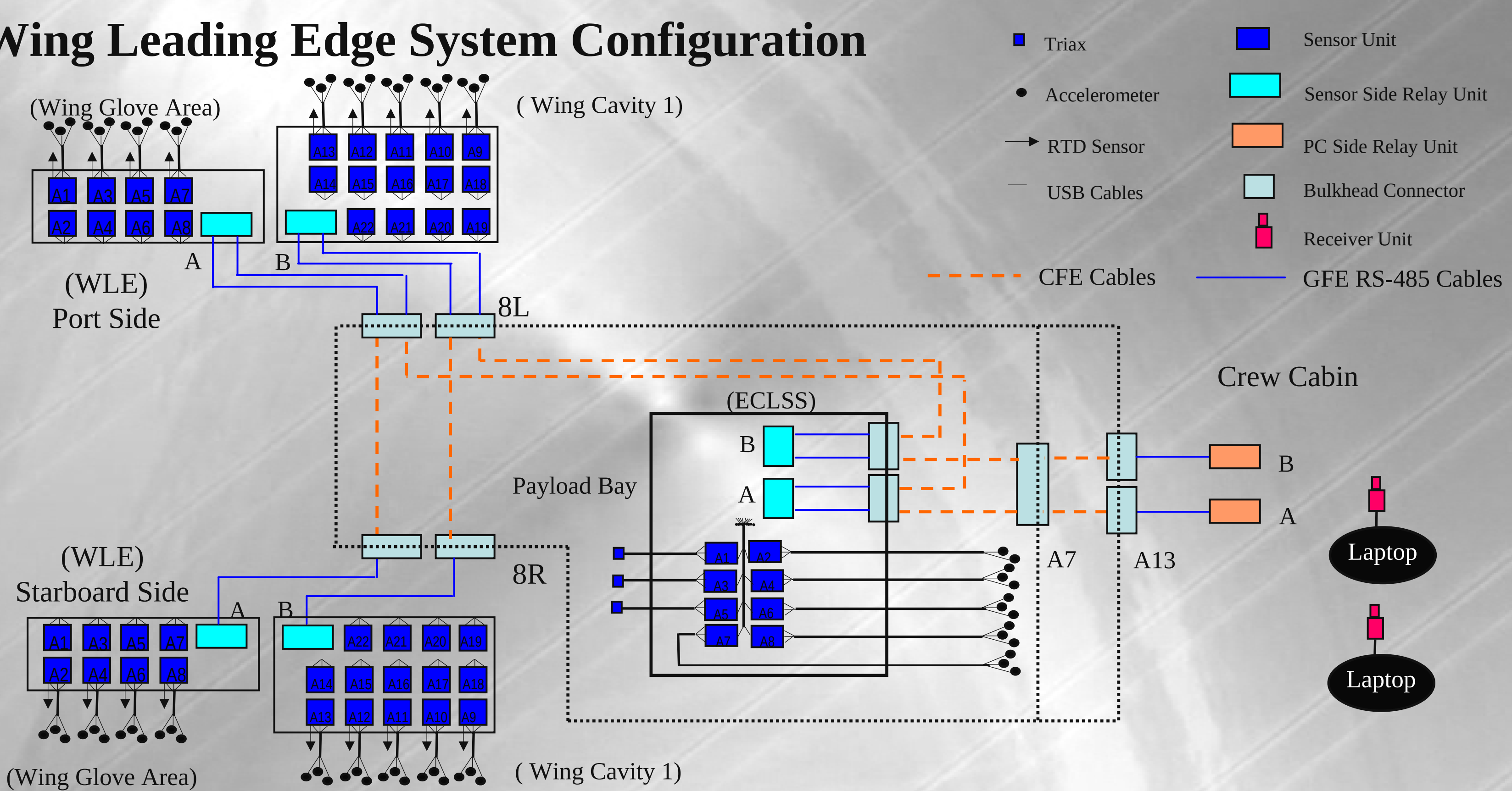
Redundant Components / Cross Strapping

Wing Leading Edge System Configuration



- *Unique to Wireless – Wireless Systems provide unique opportunities for cross strapping systems with minimal effort*
  - *Every node can communicate with every other node*

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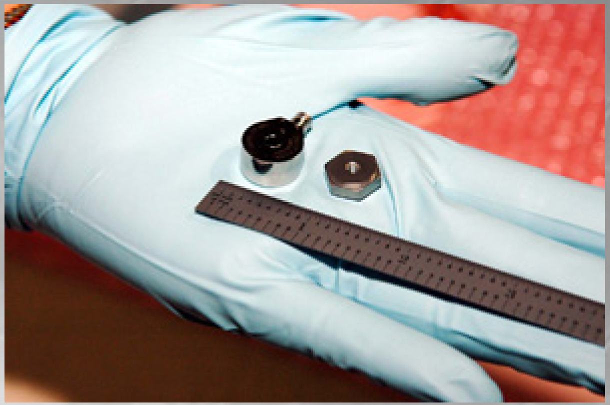
Costs of Redundancy



- Installation and integration time and cost
- System costs
- Mass and volume penalties

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Reducing Communication Requirements

- During ascent, the entire system acquires 3.2Gbytes of data
  - Unreasonable to transmit all data via RF
- Data reduction algorithms are often required to minimize the quantity of data that must be transmitted.
  - However, care must be taken to not diminish the amount or quality of *information* contained in the returned data.
    - **Peak G's**
      The system is able to generate a summary list of the highest raw acceleration values and the associated timestamps to be downlinked.
    - **Root Mean Square (RMS) Peaks**
      Sliding window RMS calculation on the raw data
    - **Relative RMS Peaks**
      Removes the background noise-floor level from the RMS calculation above.
      - SRB ignition, etc., can be removed
  - All data is maintained in memory at the node until post-flight
- *It can be very difficult to convince engineers that remote data reduction is acceptable*

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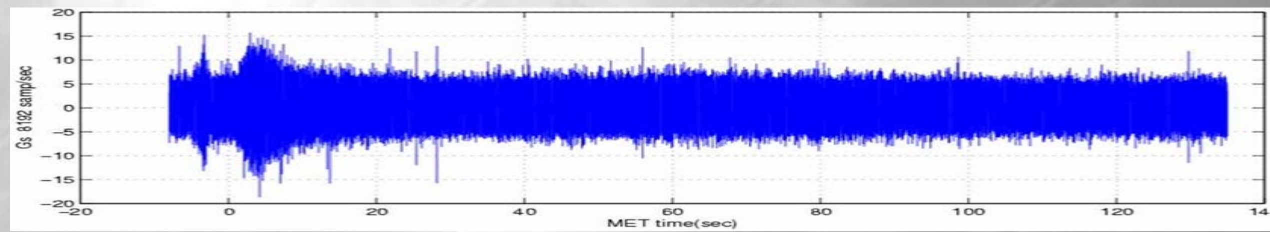
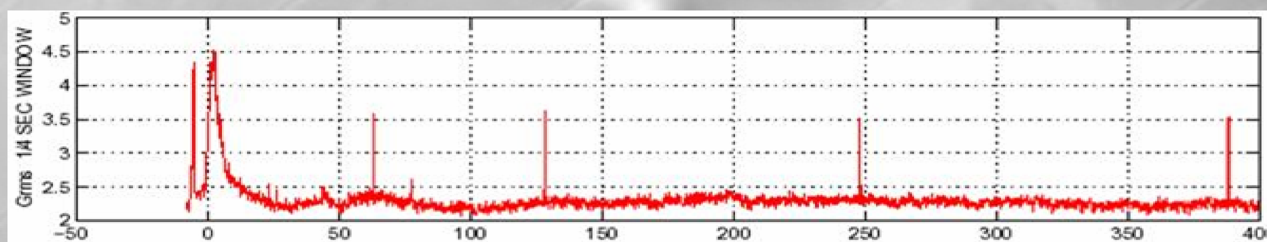
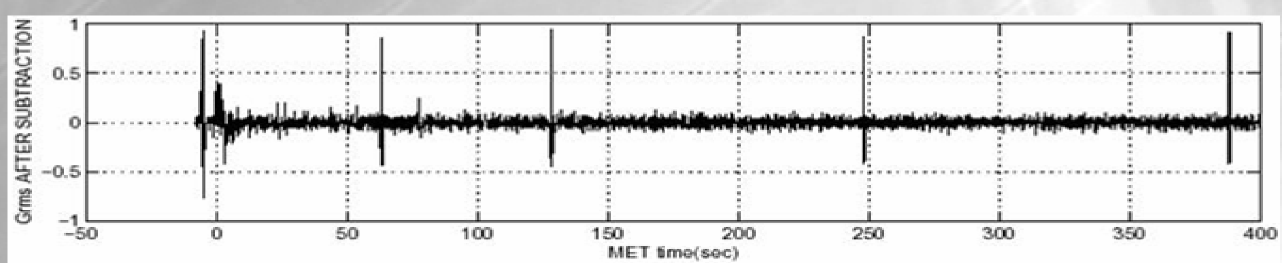
Reducing Communication Requirements



Raw Flight Data Set (Prior to Adding Impact Signals).



RMS Peaks Algorithm Results with Impact Signatures Added



Relative RMS Peaks Algorithm Results with Impact Signatures Added

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Reducing Real-time Requirements

- Maximum latency requirement for data reception is a critical specification
  - Particular monitoring and control applications require low and deterministic latencies
    - Stricter requirements for RF data link
  - Many applications can handle days or months
- Minimum level of synchronization between multiple nodes also critical
  - For distributed systems, often only the timing information needs to be transferred during acquisition
    - Data can be stored locally along with synchronization information

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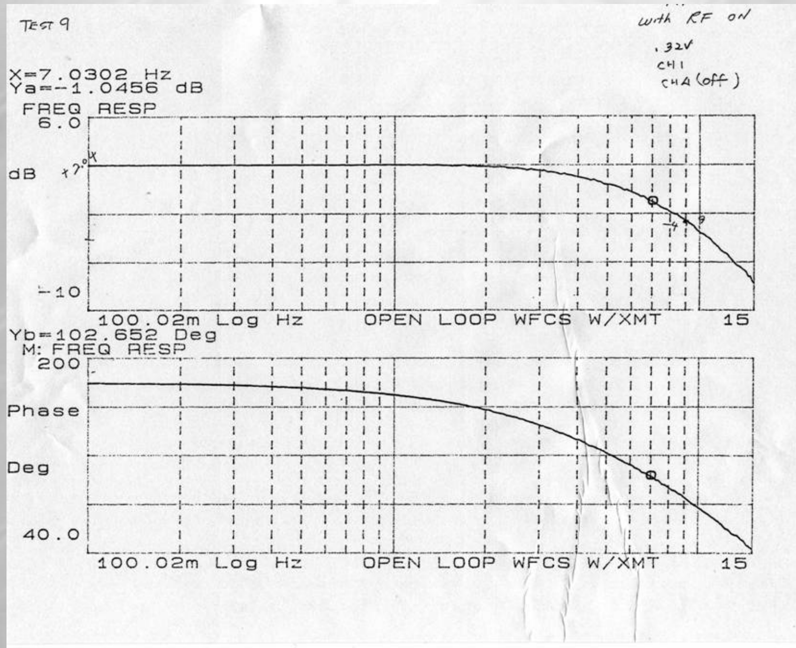
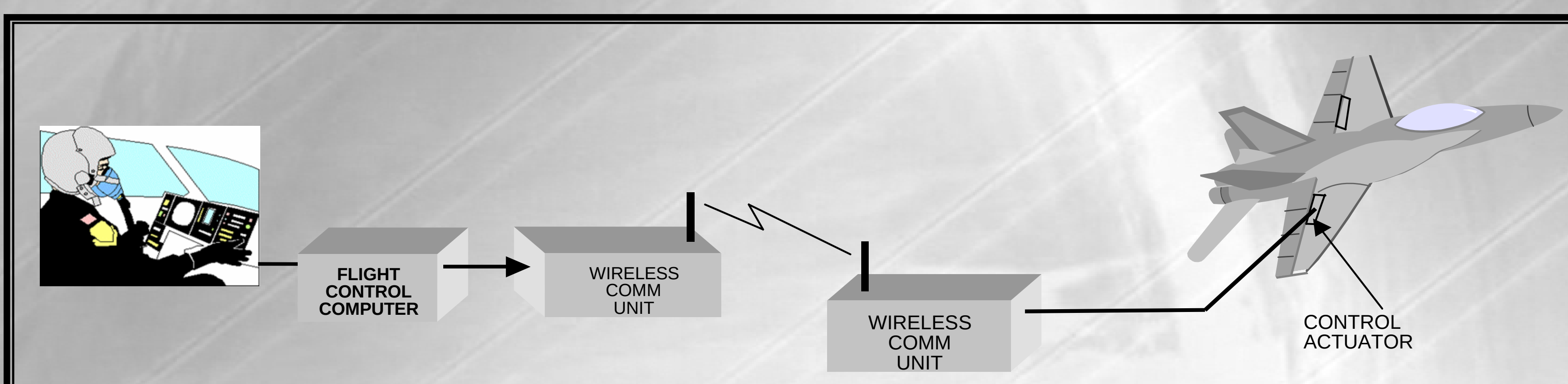
Reducing Real-time Requirements



- NASA Dryden
  Wireless Flight Control System
  - **<u>PURPOSE:</u>** Define and demonstrate a prototype wireless control system that can be tested and flown on the F-18 NASA test aircraft.



Reducing Real-time Requirements

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- Shuttle Rollout Accelerometer System
  - Synchronized between multiple wireless sensors to within ±4μs.
  - Flexible dual basestation design with relaying synchronization and IRIG timing

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Monitoring of Communication Link Parameters

- Returning, tracking, and storing RF link parameters is highly desirable
  - Error rates
  - Received Signal Strength
  - Link Quality
- Valuable for links in both directions

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Autonomously Configurable Communication Settings

- Configurable settings available in newest low-power RF transceivers
  - Output Power
  - Frequency
  - Modulation
  - Data Rates
- Optimization of performance in varying environments is possible
  - Multipath fading
  - Mobile nodes
  - Variable sources of interference
- Fall back to reduced performance levels during intermittent periods of interference, etc.
- *Considerable network coordination necessary for all settings changes (except maybe output power)*

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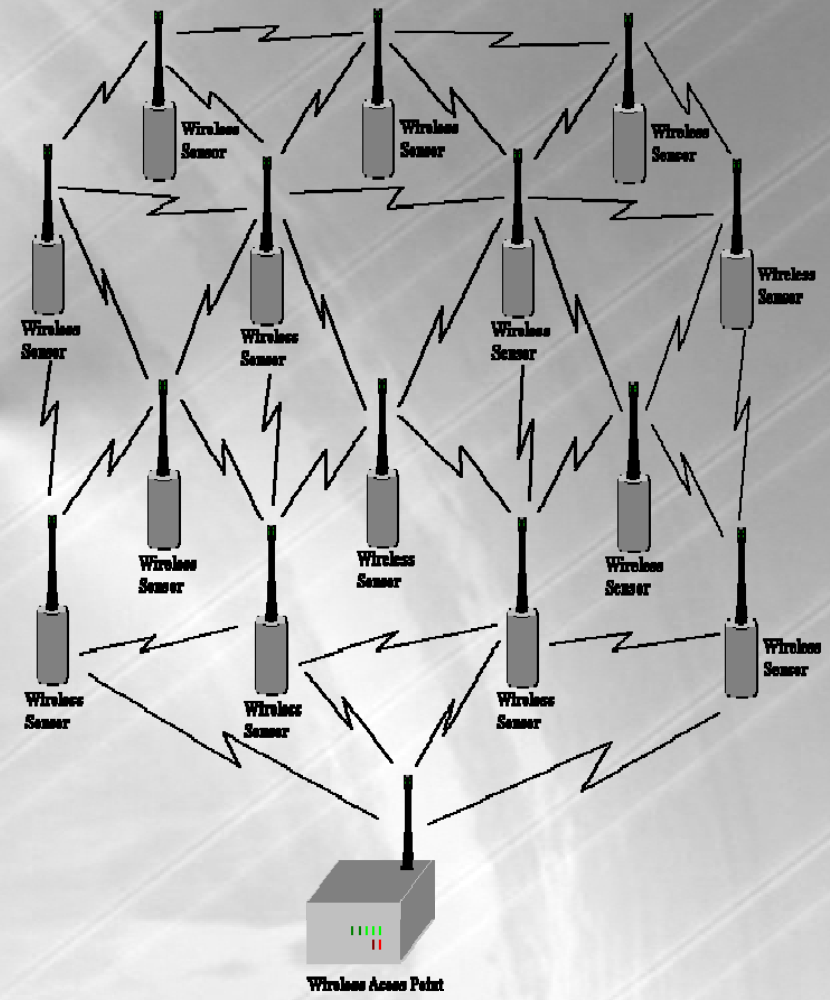
Routing and Autonomous Network Configuration

- Routing via multi-hop communication improves reliability
- However, compromises are made in:
  - Power consumption
  - System response time
  - Throughput
  - Software complexity
  - Non-deterministic behavior



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Conclusion

- Understanding overall system requirements in the various areas described is the key to optimizing System Dependability for Wireless Instrumentation Applications
- Based on the system requirements, many methods and techniques for system optimization are possible:
  - Hardware Methods
  - System Design Methods
  - Communication / Networking Methods

Questions?

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