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Wireless Instrumentation System Opportunities and Challenges for Large Solid Rocket Motor Flight Applications

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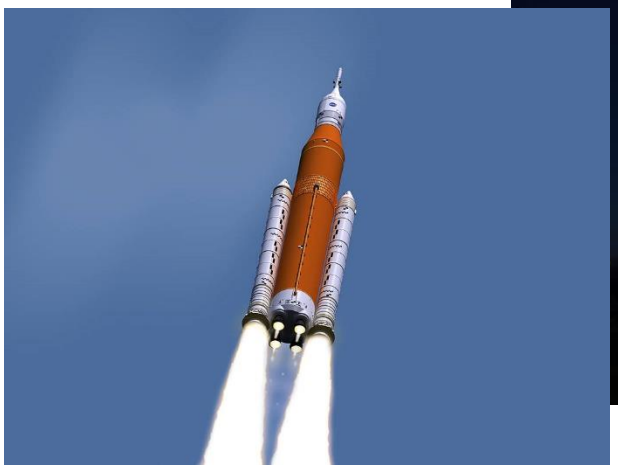
Overview

- Ideal flight measurement system for large Solid Rocket Motors (SRMs)
- Current typical SRM flight measurement system
- Potential wireless flight SRM measurement system
  - Target capabilities
  - Challenges
  - Potential path forward
- Summary



Flight Measurement System – ideal state

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Characteristics of an ideal flight measurement system for SRMs

- Minimal additional mass (compared to payload)
- Low installation/integration effort
- Minimal system setup/configuration effort
- Highly reliable (measurement system MTBF (mean time between failures) should be an order of magnitude greater than the asset being monitored)
- Readily scalable
- Minimal baseline cost - cost is a simple linear function of sensor count
- Flexible sample rates – from 1 to 100,000 sps (samples per second)
- Synchronized sample across the system (to 10% of sample rate)
- Immune to EMI
- Calibrated output in engineering units

Flight Measurement System – Typical Architecture

Sensor Outputs

- Radiometers
- Strain gages
- Thermocouples
- Pressure sensors
- Accelerometers
- Shock sensors
- Calorimeters
- Microphones

Data Acquisition Units (DAUs)

Power Distribution Unit (PDU)

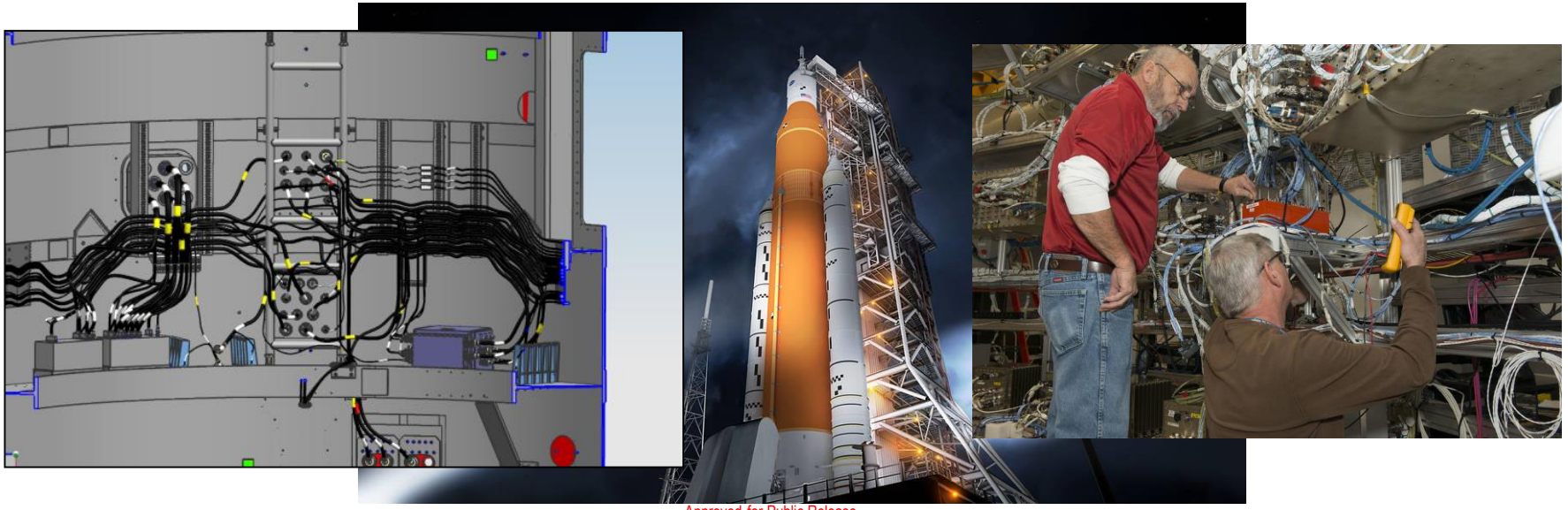
Battery

Data stream

Telemetry System and/or recoverable recorder

Flight Measurement System – current state

- Centralized measurement system architecture
  - Analog signals between sensors and DAUs
  - Significant weight in cable/harnesses and TPS (Thermal Protection System) – hundreds to thousands of pounds (typically 10's or 100's of sensors)
  - Not readily scalable
  - System cost is not linear with sensor count –
    - System backbone (DAUs, PDU, battery, main cables) can be half the cost or more of a small to medium sized system.
      - In other words, 1st measurement channel is very expensive, subsequent measurement channel cost is much less



Flight Measurement System – current state

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- Pros
  - Reliable
  - Proven (qualified)
  - Existing knowledge base
  - Established methods for calibration and signal integrity
  - Methods for synchronized sampling
  - Centralized power (single accessible power source facilitates checkout, maintenance and replacement as necessary)
- Cons
  - Instrumentation system often is part of the payload
  - Not readily scalable
  - Significant baseline cost
  - Analog signals susceptible to noise
  - Calibrated signal train methods often susceptible to human error
  - Cable/harness integration bulky and complicated

Flight Measurement System – Wireless

Sensor Outputs

- Radiometers
- Strain gages
- Thermocouples
- Pressure sensors
- Accelerometers Shock sensors
- Calorimeters
- Microphones

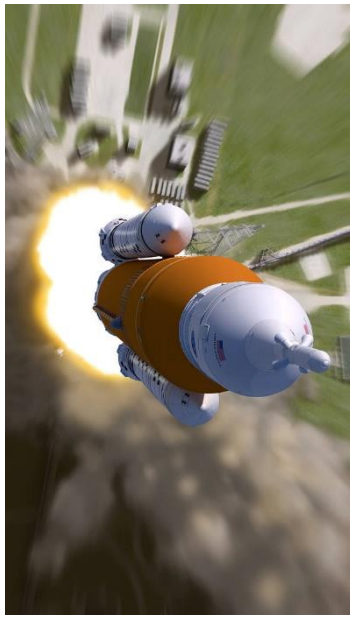
Data Acquisition Units (DAUs)

Power Distribution Unit (PDU)

Battery

Wireless Sensor System

Data stream



Telemetry System and/or recoverable recorder

Wireless Flight Measurement System – Objective

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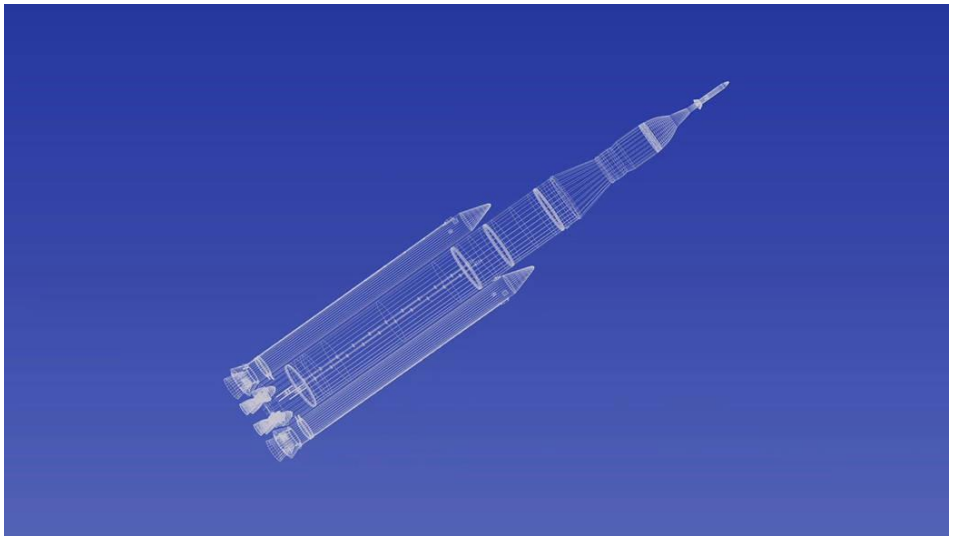
- Objective – Deliver a wireless, low cost, readily scalable Developmental Flight Instrumentation (DFI) system to support the collection of key sensor data during flight. As compared to the baseline DFI system it is to:
  - Reduce setup time by at least 25%
  - Reduce installation time and costs by at least 33%
  - Reduce weight (components and TPS) by at least 75% per channel



Wireless Flight Measurement System – Target Capabilities

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- System capability targets
  - Up to 20 Mb/sec system bandwidth (40 Mb/sec preferred)
  - 12 bit A/D (16 bit preferred if bandwidth is not an issue).
  - Data packet loss less than 0.2 %
  - Data transfer must be secure
  - Data output stream format conforming to available standard with flight heritage would be preferred
  - Measurement Range > worst case full scale sensor range.
  - Transmission range > 120 ft (could use multiple nodes/mesh network to cover distance)
  - Broadcast signals within allowable Range Safety requirements
  - Total target error < 1.2 % of full scale reading
    - System error < 0.5 %
    - Maximum sensor error is gage dependent – target 0.2 to 1.0% of full scale range.

Wireless Flight Measurement System – Target capabilities

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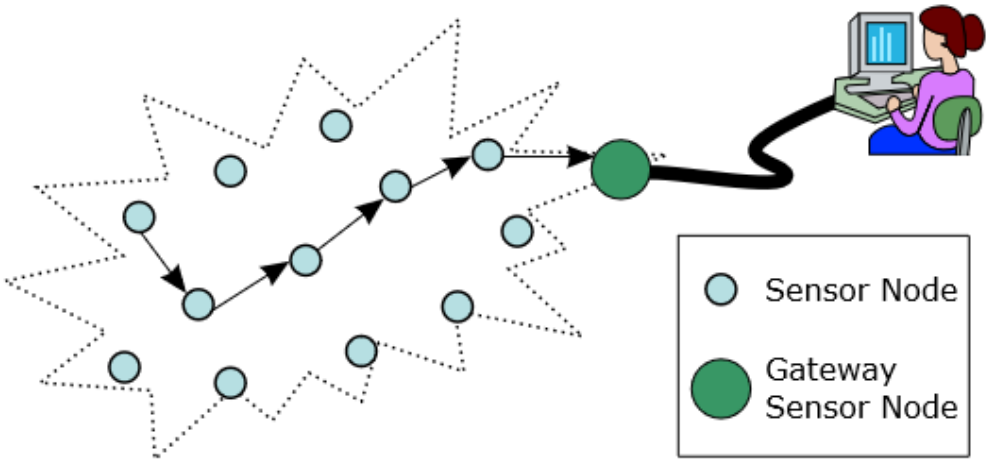
- Scalable and Flexible
  - 10 – 400 sensor channels of data
    - Up to 200 channels of low speed data (1-100 sps)
    - Up to 200 channels of mid speed data (250-10,000 sps)
    - Up to 20 channels of high speed data (25,000 – 100,000 sps)
  - Distributed DAQ capability
  - “Plug and Play” components
  - System which could support collection of data during ground transportation in addition to flight (at different sample rates from flight) would be preferred



Wireless Flight Measurement System – Target capabilities

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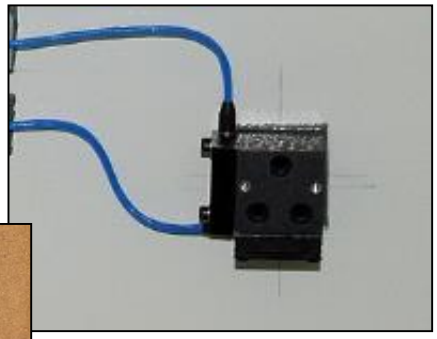
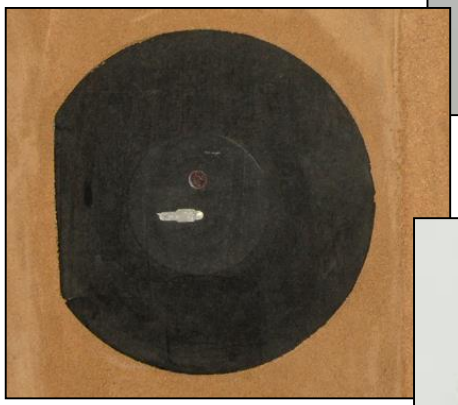
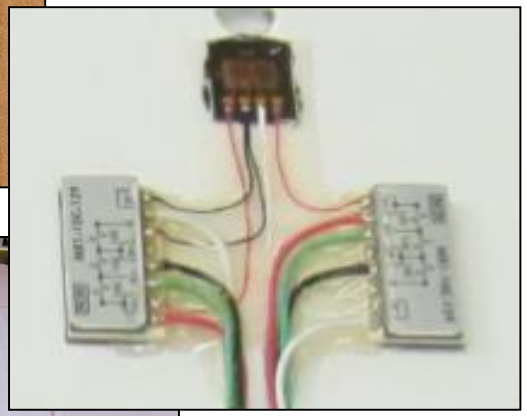
- Supported sensor types
  - Thermocouple (type K, S)
  - RTD
  - Accelerometer (ICP type)
  - DC accelerometer
  - Microphone
  - Bridge type
    - Strain
    - Pressure
  - Calorimeter/radiometer
  - Shock (likely the same as accelerometer)







Wireless Flight Measurement System – Target capabilities

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- Minimized system setup and integration costs
  - Appropriate metadata travels with sensor
    - Calibration information
    - Parameter number
    - Sensor specific info – type, model #, range (could be tied to parameter number and retrieved with post processing)
    - Gain settings
    - Filter settings (if digitized in sensor)
  - Cabling is minimized
    - Data digitized at the sensor or sensor node
    - Data transferred wirelessly
    - Power is provided locally
      - Local power scheme would need to support installation 2 years prior to flight
        - » “Sleep” mode up until flight then wake and support 0.5-2.5 minutes of flight data
        - » Scheme which would also support measurements during ground transportation would be preferred

Wireless Flight Measurement System – Target capabilities

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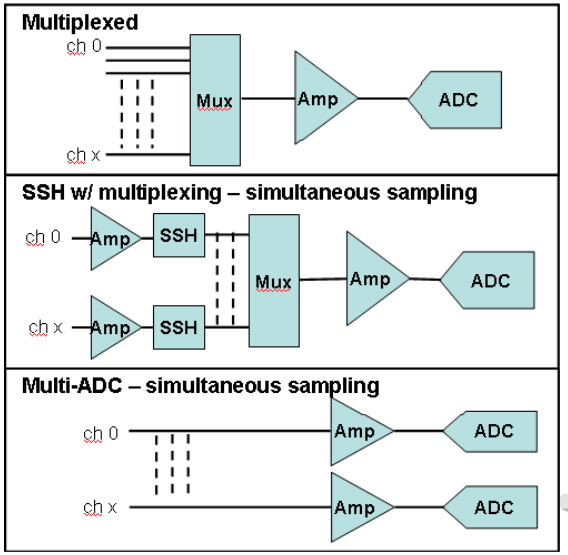
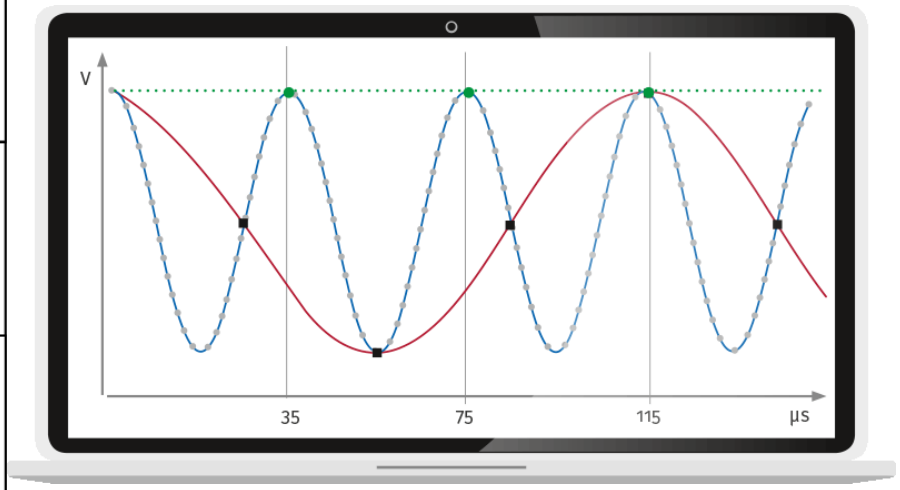
- Accurate sample acquisition timing/time stamp
  - Low-speed: sample timestamp accurate within 25% of sample period (10% preferred)
  - Mid-speed: timestamp accuracy within 25% of sample period. Relative channel to channel sample timestamp (synchronized sampling) accurate within 20% of sample period preferred (within 10% is ideal)
  - High-speed: timestamp accuracy within 25% of sample period. Relative channel to channel sample timestamp (synchronized sampling) accurate within 20% of sample period preferred (within 10% is ideal)





Wireless Flight Measurement System – Target capabilities

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- Component ruggedization
  - Able to operate under SRM (Solid Rocket Motor) loads and environments (with appropriate mounting configurations and TPS)
- Minimal mass
  - Target 0.5 kg/measurement including sensor, DAQ (data acquisition), data transfer and TPS
- Ease of Installation/Integration
  - Physical installation time and processes should be equivalent to existing sensors
  - System setup
    - Self discovery
    - Built in channelization
- Cost
  - Baseline system cost should be no more than 10% of total; linear cost increase per channel beyond that

Wireless Flight Measurement System – challenges

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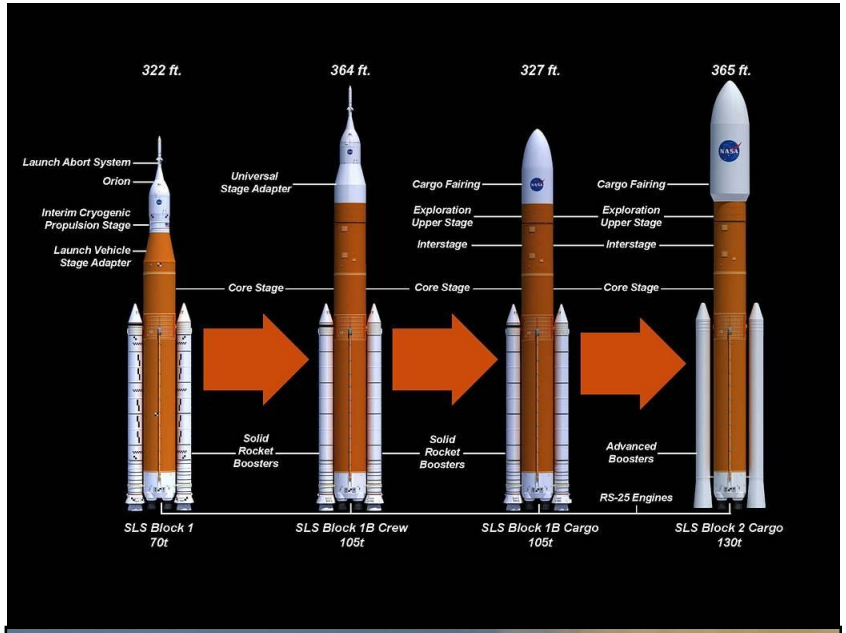
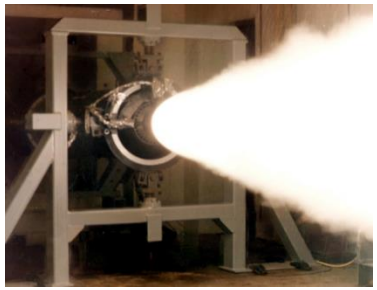
- Challenges
  - Cylindrical asset – transmission signal shadowing
  - Power
    - Sensors/system installed up to 2 years prior to launch
  - Synchronized sampling
    - Target is 10% of sample rate – especially for vibration/shock sensors
  - Data output stream
    - Data output formats compatible with existing telemetry systems
  - Common protocol/standards
    - Ability to mix and match components from multiple vendors
  - Multiple sample rate states desired
    - Low rate prior to launch, higher rate after
  - Address Range Safety concerns regarding wireless signals operating near Flight Safety System components

Wireless Flight Measurement System – potential path forward

- Insertion opportunities
  - SLS (Space Launch System) – block upgrades
  - GBSD (Ground Based Strategic Deterrent), will replace Minuteman
  - Hypersonics
  - other
- Technology maturation
  - Various subscale and static test platforms





Wireless Flight Measurement System – Summary

- A successful wireless flight instrumentation system that addressed challenges with power, data transfer and reliability would potentially offer distinct advantages over existing systems, particularly in regards to mass, integration time, flexibility and cost.