The Internet of Things (IoT) for Aerospace

Discovery and System Health Technical Area
Technology Integration Projects Group

Rick Alena, Computer Engineer

Code TI - Intelligent Systems Division

NASA Ames Research Center

Ames Research Center

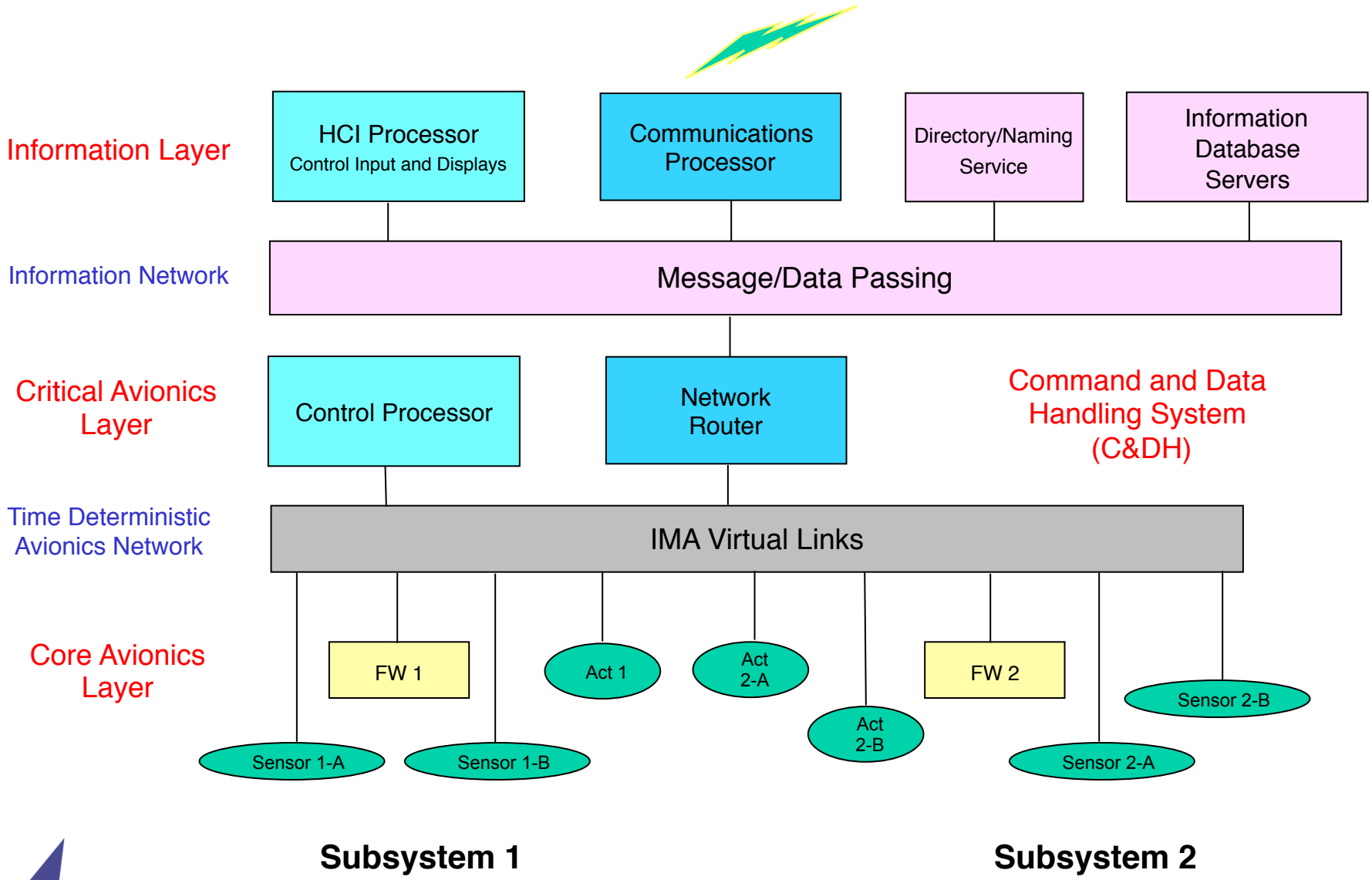
Internet of Things (IoT) Definition

- The **Internet of Things** (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. (Google)
- The **IoT for Aerospace** is a system of sensors and actuators interacting with data processing, communications systems, ground-based processing and humans (Author)
- For this presentation, we will focus on just the IoT components and architecture on-board a spacecraft or aircraft

Aerospace IoT Requirements

- Support deterministic real-time control – critical control loops
- Support required level of redundancy
  - Single fault tolerant for robotic missions
  - Double fault tolerant for human missions
- Support sensors for vehicle subsystem status monitoring
- Support interaction with crew and mission-control
- Support mission data acquisition, storage and communication
- Support advanced and evolving functions
  - Autonomy
  - Perception
  - Self-repair

Three-Tier Vehicle Information System Architecture



Ames Research Center

Aerospace IoT Components

- Human-Computer Interfaces
- Information Processors/Storage
- C&DH Processors
- Wired networks
- Wireless networks
- Network Routers
- Sensors
- Wireless Sensors
- Firmware controllers (FW)
- Actuators
- Communication links

Ames Research Center

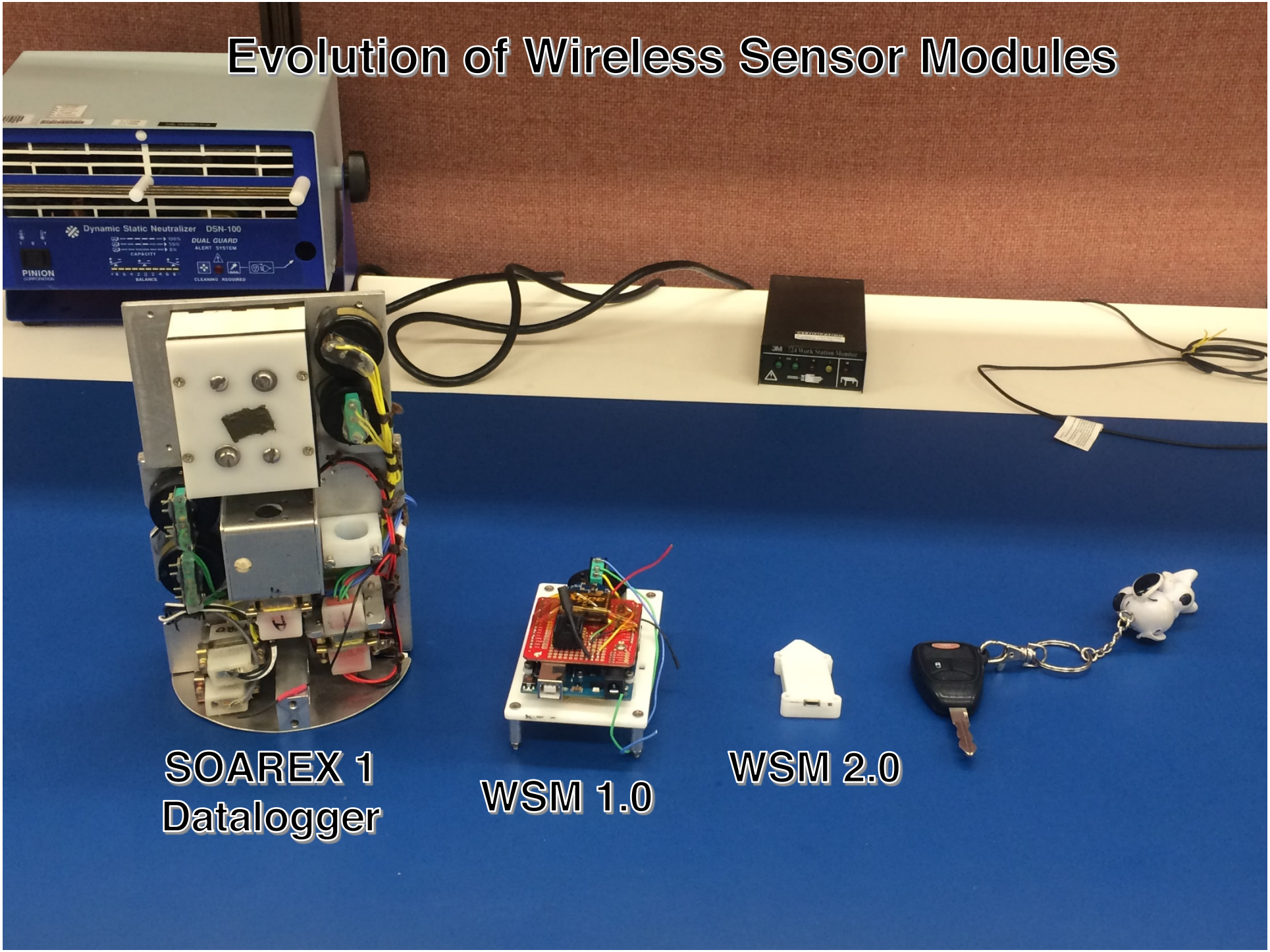
Wireless Technology Benefits for NASA

- WSN technology provides flexible aerodynamic and subsystem measurement capability
  - Flexibility in location, reduction in mass, volume and power
- Diverse and improved sensing, data acquisition and telemetry methods improves engineering insight into anomalies
  - Increases number of measurement points
  - Increases number of sensor and measurement types
  - Increases data rates per sensor
  - Decreases cost and schedule for Developmental Flight Instrumentation
- Add-on sensors can identify causes of safety issues or vehicle failures by instrumenting for specific hypothetical fault modes
- Sensor technology can be applied to NASA facilities
  - Wind tunnels
  - ARC jets
  - Propulsion test stands

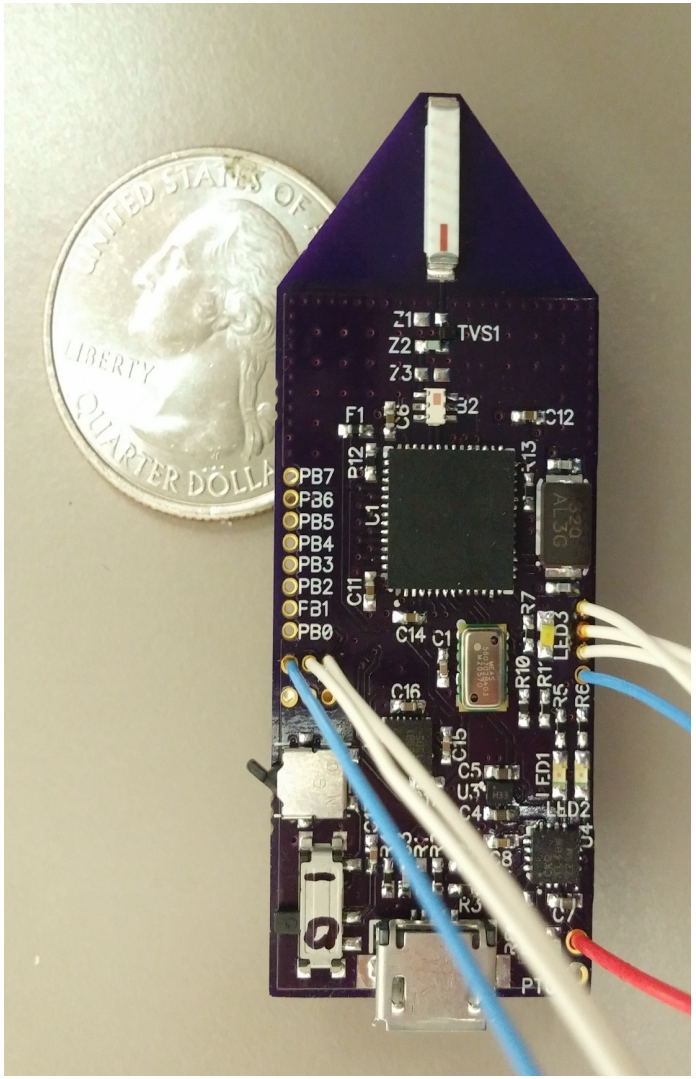
IoT Wireless Sensor Network Technology

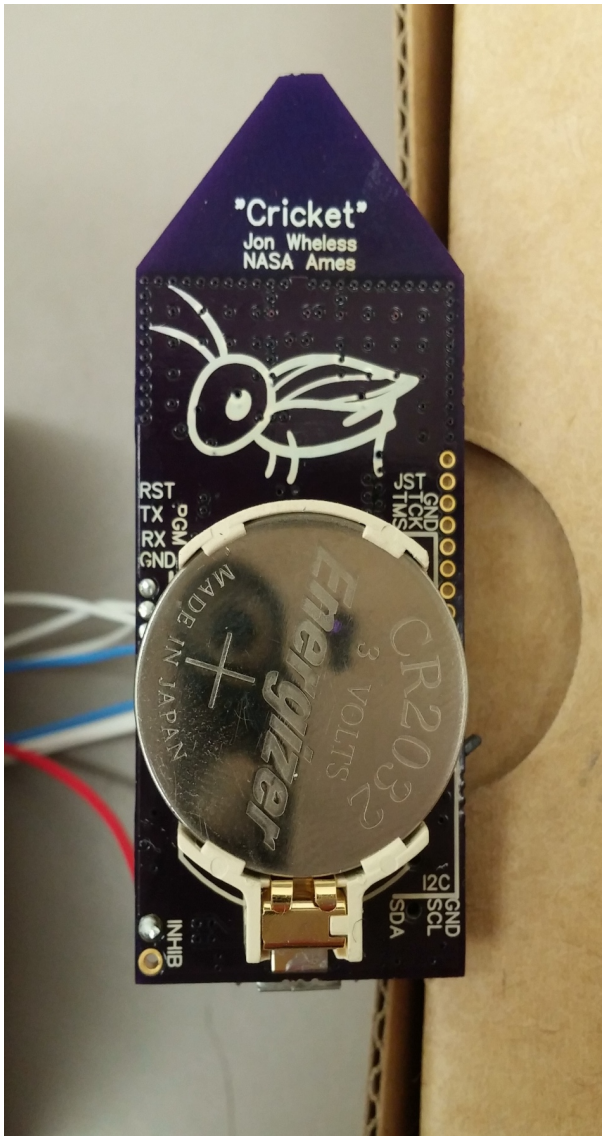
- Internet of Things (IoT) foundation
  - Custom gateways to Internet
  - Low-rate messaging
  - High-rate data streaming
- Wireless Network Standards
  - IEEE 802.14.5 Personal Area Network
  - ZigBee, ISA-100, LoPanIPV6 Protocols
  - Bluetooth LE
  - WiFi
  - Cellular – LTE, 4G, 3GPP
  - Passive - RFID
- Wireless Sensor Modules
  - System on a Chip (SoC)
  - Digital sensors
  - Analog sensors
  - 3-D printed housing

Evolution of Wireless Sensor Modules



Second-Generation Cricket WSM – Jon Wheless





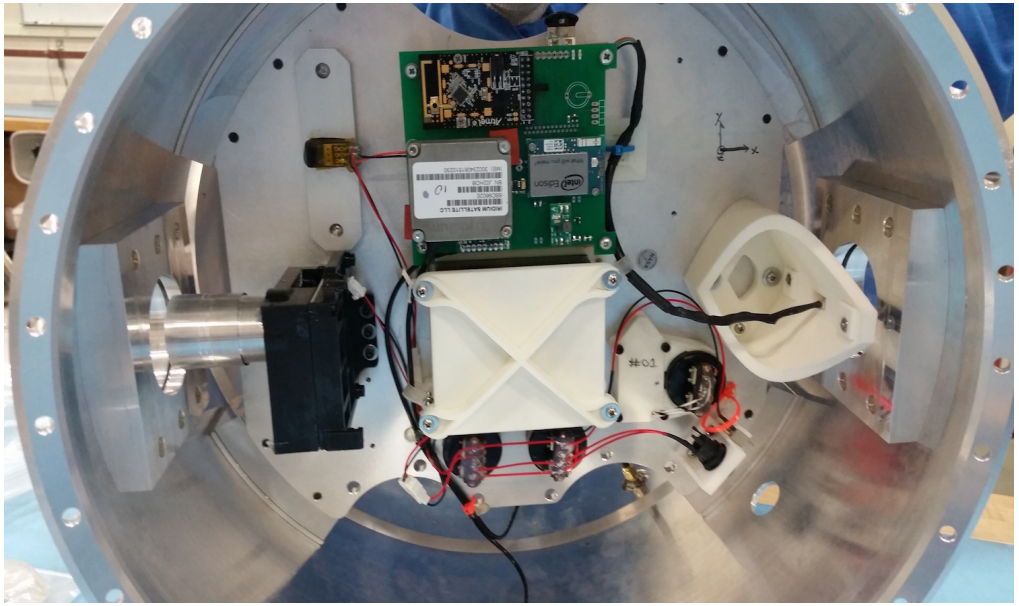
Ames Research Center

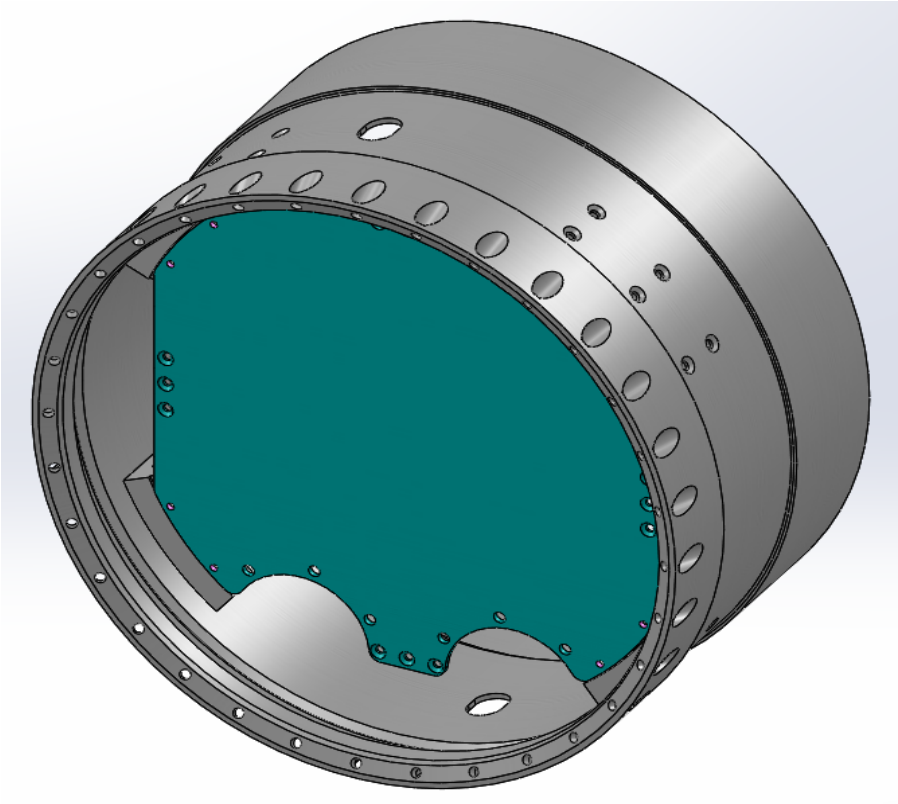
SOAREX-9 Sounding Rocket Flight Wireless Sensor Network (WSN) Objectives

- Collect data on ascent and re-entry temperature, air pressure, 3-axis acceleration, 3-axis rotation and 3-axis magnetic field using two second generation Wireless Sensor Modules (WSM)
  - One WSM on top side of payload tray, one WSM on bottom side of payload tray
  - Thermocouples monitoring outside and inside temperature of rocket skin
  - 3-D printed housing for flexible mounting and altitude switch inhibit
- Send WSN data to ground using ISM-band high-rate telemetry link
  - Collect real-time telemetry data from two WSMs at 1 full data set per second
  - Data link active during entire trajectory from 20K ft until LOS
- **All Objectives Met**
  - All hardware and software operated properly – 410 data sets downlinked
  - Thousands of data points show distinct phases of flight
    - First and Second stage ascent acceleration
    - Rocket de-spin operation
    - Microgravity free drift
    - Re-entry heating and deceleration

SOAREX-9 Flight Configuration

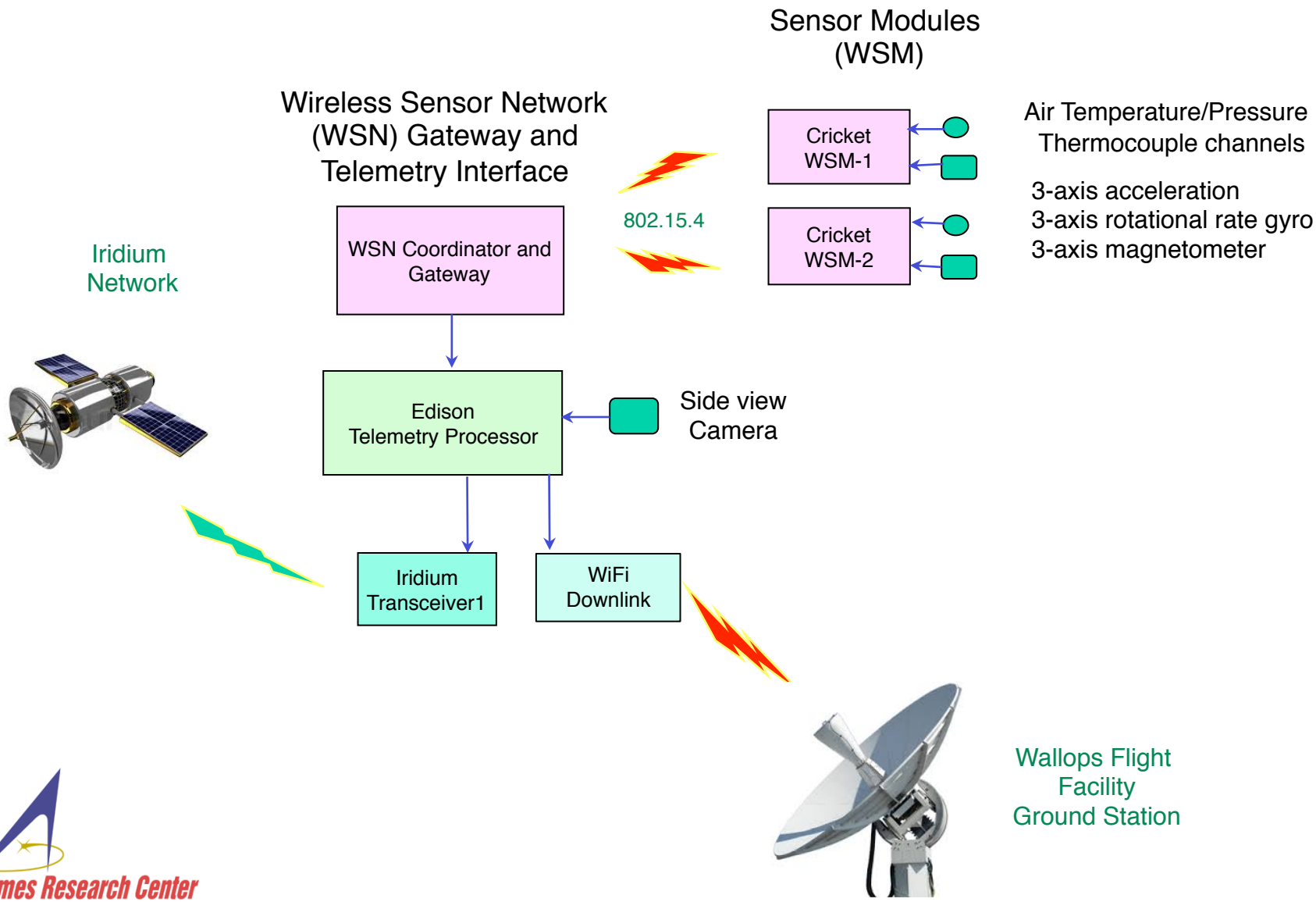
- SOAREX-9 was hosted aboard Wallops 41.114 sounding rocket
  - Design review held September 2015
  - Delivery and integration was January 2016
  - Flight was March 3, 2016
- SOAREX-9 was a 12” segment of a 14” diameter sounding rocket payload section aboard an improved Terrier-Orion booster





Ames Research Center

SOAREX-9 Flight Configuration

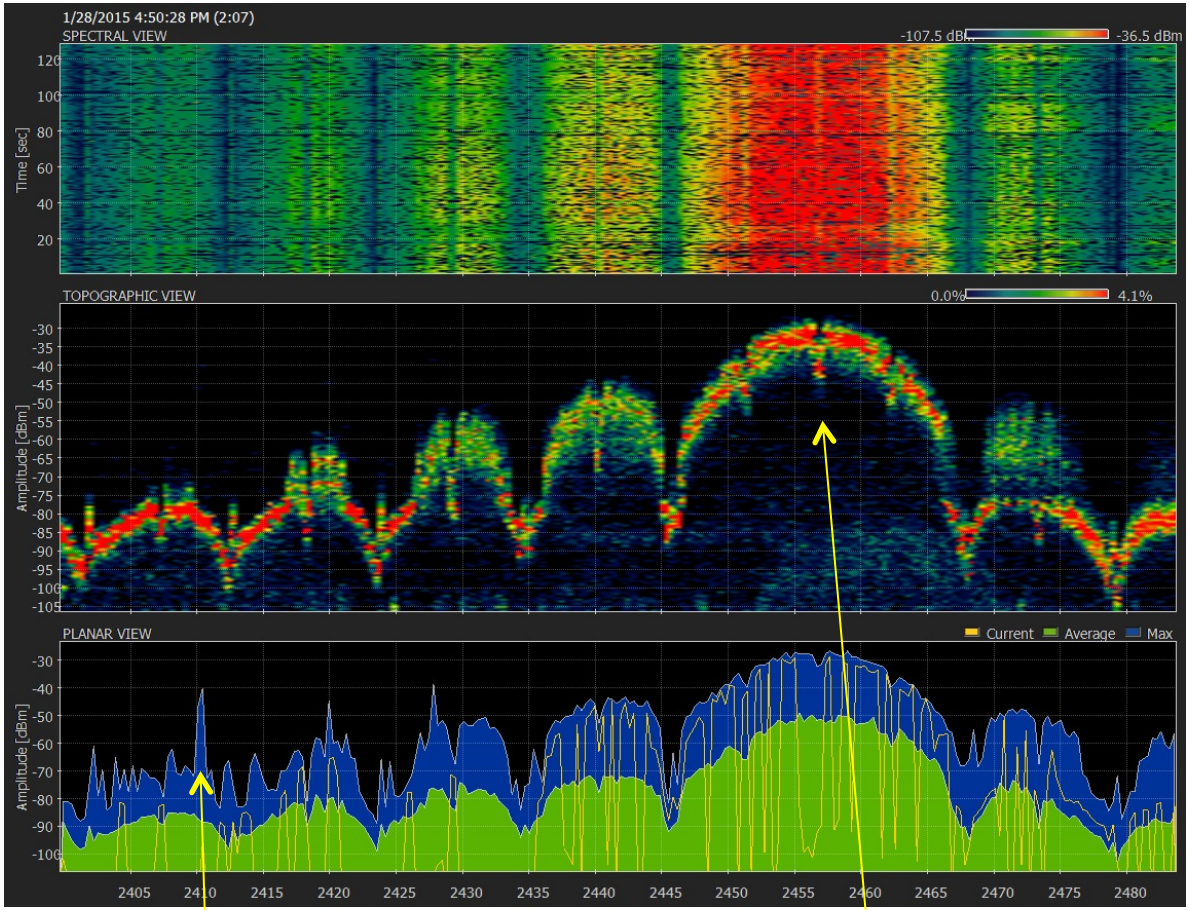


Ames Research Center

WSM Flight Qualification/Certification Results

- Basic flight qualification
  - RF testing showed FCC Part 15 compliance
  - TVAC testing showed no vulnerabilities
  - Shock and vibration test to ascent vehicle specifications
- Battery safety
  - Very small coin cell on WSM (ISS approved)
  - Flight proven batteries for S9 payload
- Range/Ascent vehicle Safety
  - Payload and WSM are launched powered down
  - Altitude switches ensure power-up above 20,000 feet
- RF safety
  - During “RF Avoidance” all transmitters are powered off

ISM-band Electromagnetic Compatibility Test



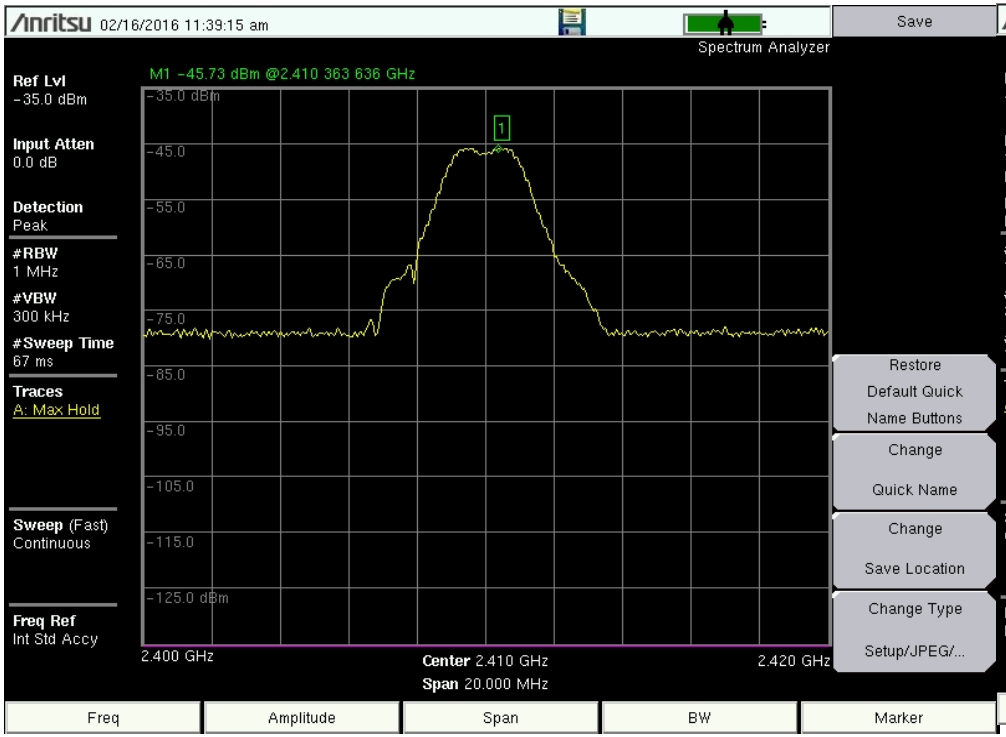
WSN – 30 dBm
2410 MHz

WiFi – 30 dBm
2450 MHz

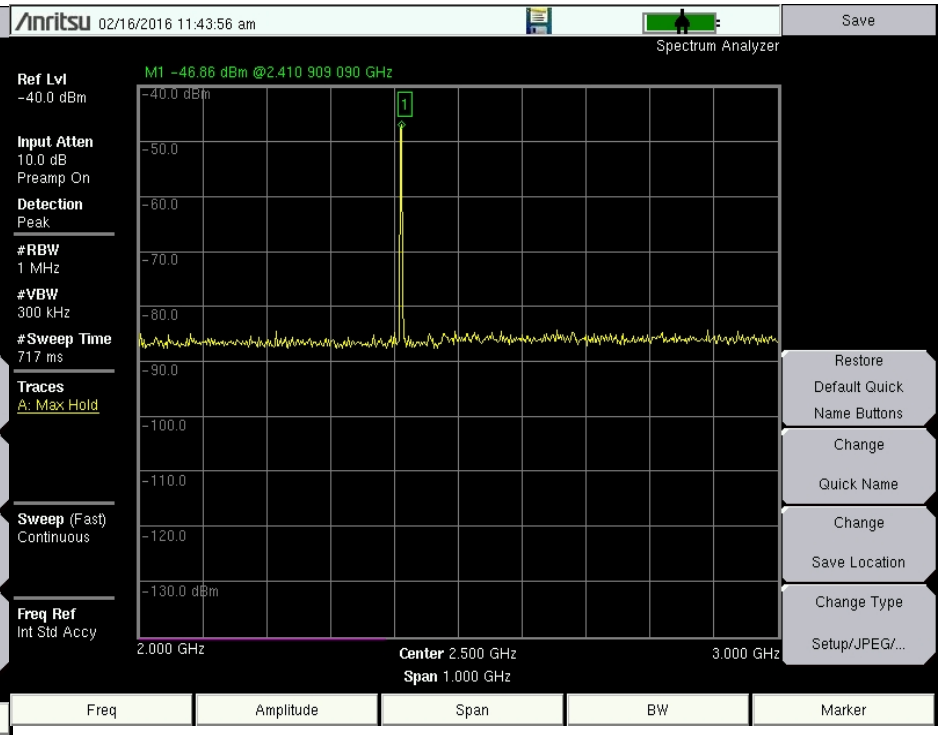
Spread Spectrum Modulation allows Co-existence

Ames Research Center

Cricket WSM Electromagnetic Compliance Test



WSM 3 dB emissions spectrum at 2410 MHz



WSM emissions over 2 – 3 GHz

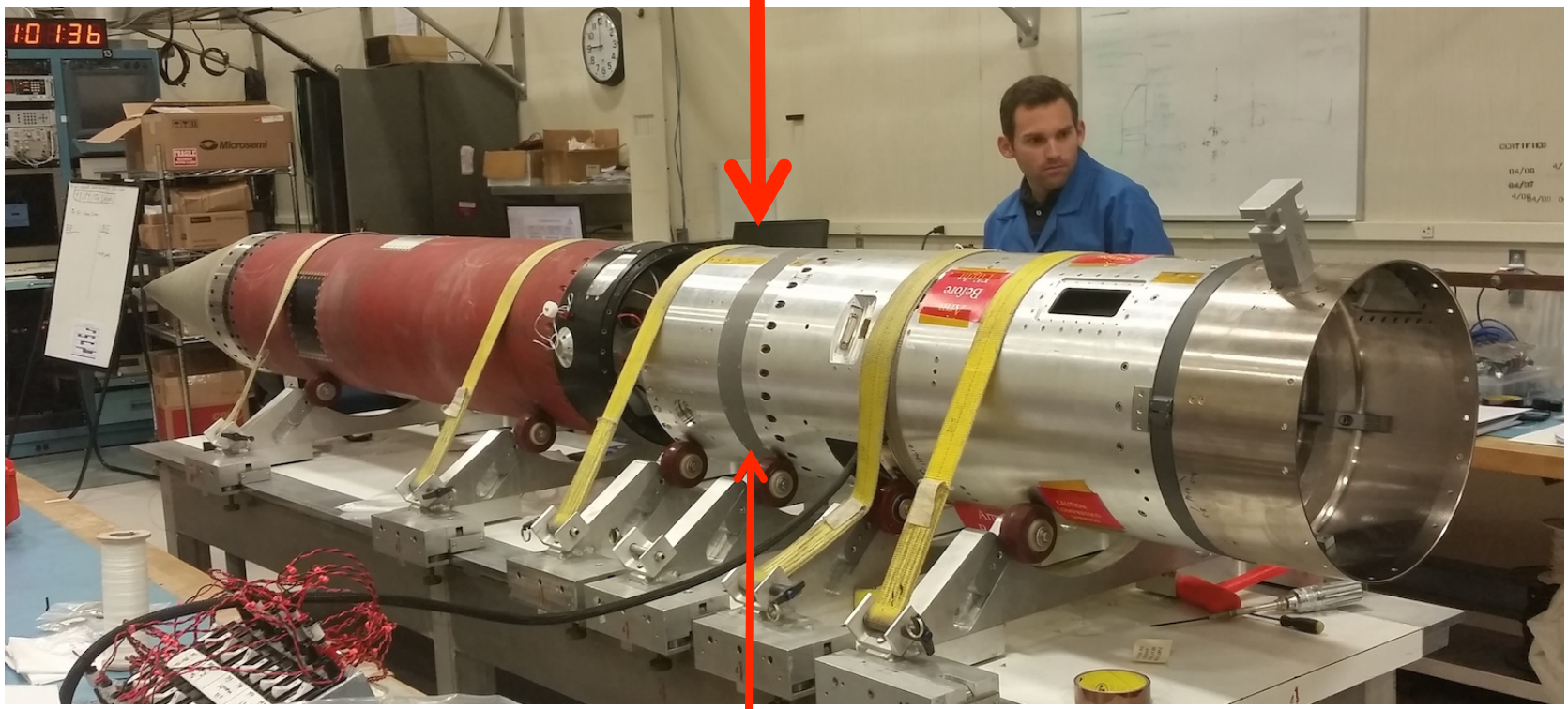
Cricket WSM complies with FCC Part 15 regulations

Ames Research Center

WSN Flight Integration and Test

- Deliver and integrate S9 flight unit in early January 2016
- Final payload integration and test at Wallops Flight Facility late January 2016

S9 flight unit in payload segment



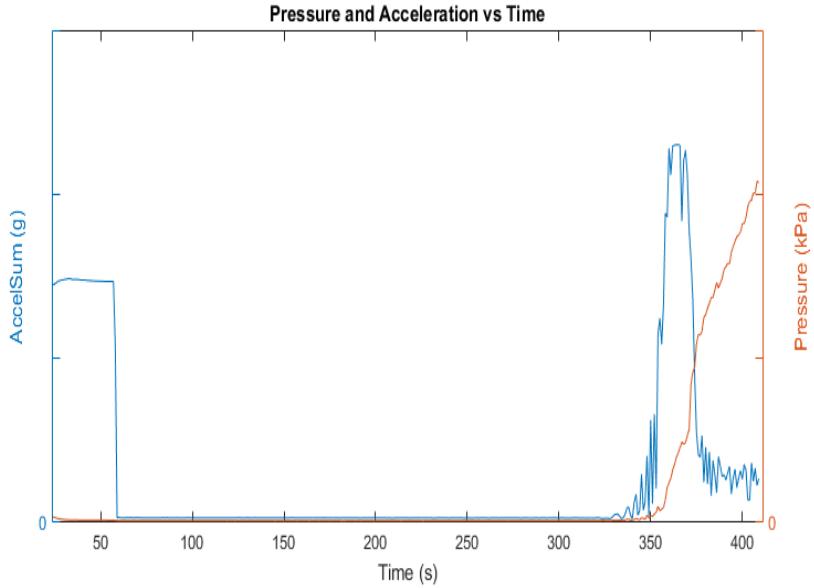
ISM-band wrap around antenna for downlink

Ames Research Center

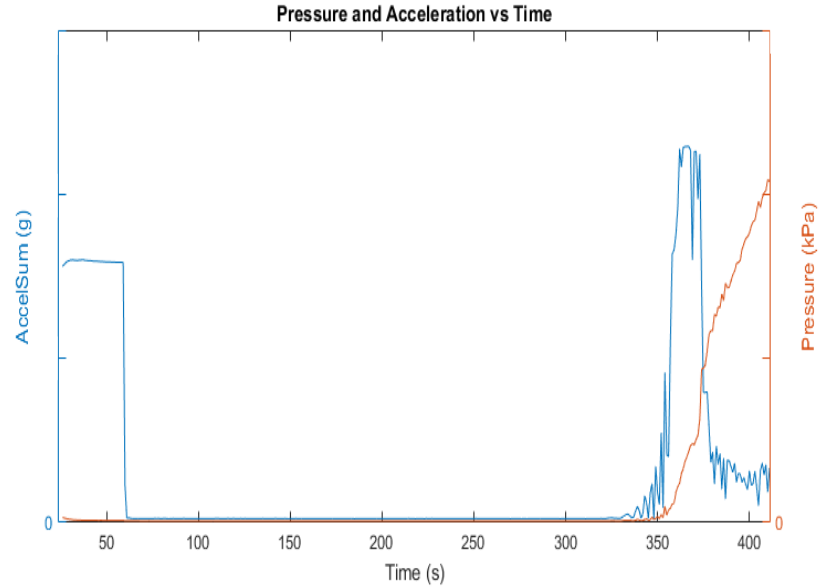
SOAREX-9 Flight Operations

- Payload Operations
  - Final Integration and Stack Vibration Test
- Mission Operations
  - PI, Deputy at Range Control Center
  - S9 Engineering and Antenna tracking team at Telemetry Control Center
- Telemetry analysis
  - WSM telemetry via Iridium SBD messages
  - WSM telemetry and camera images via ISM-band downlink

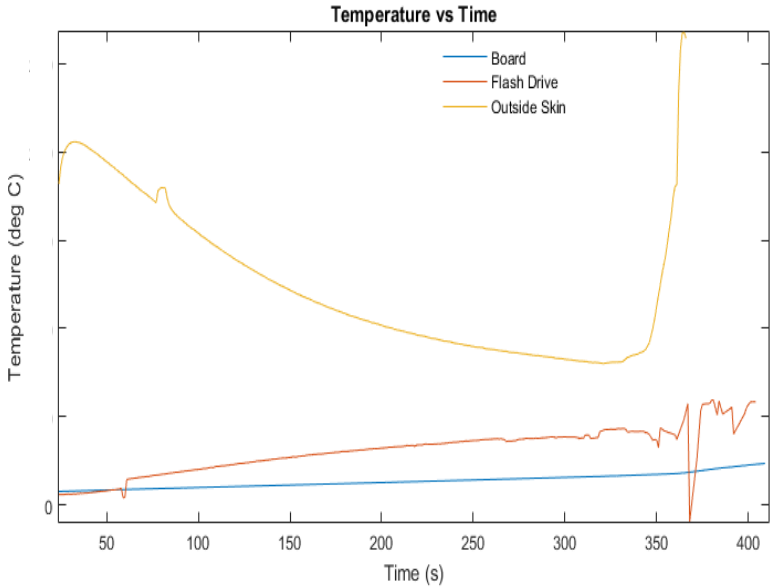
SOAREX-9 Wireless Sensor Flight Data

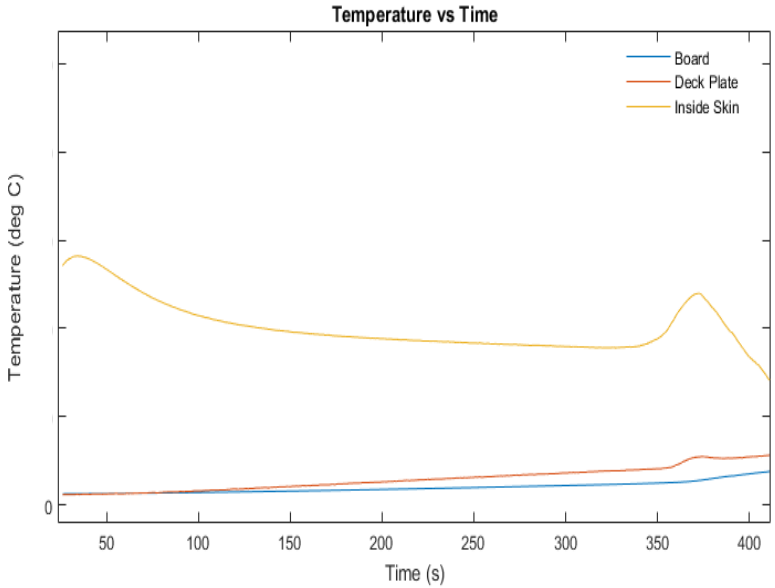


Cricket #01

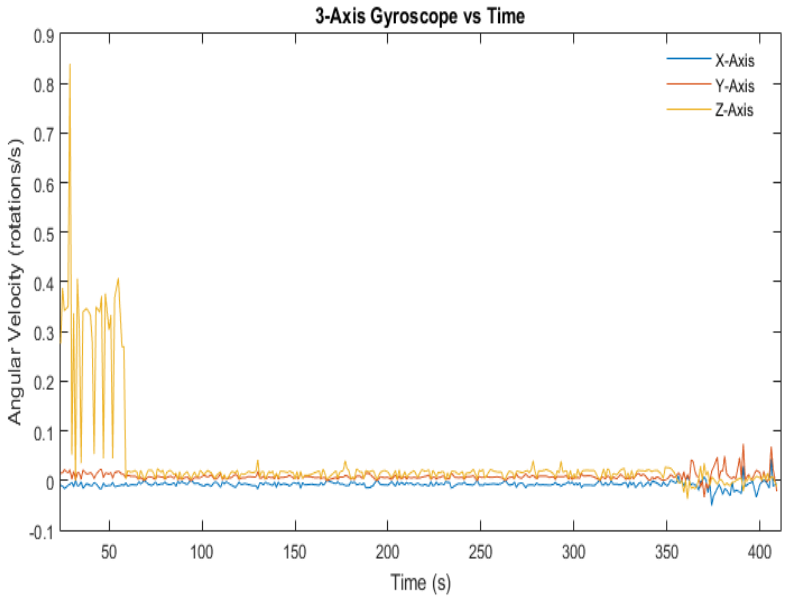


Cricket #02

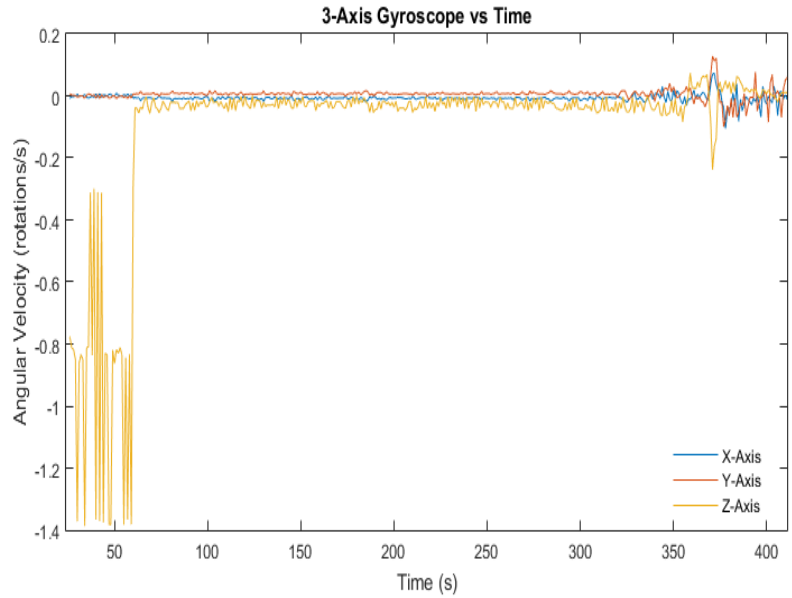




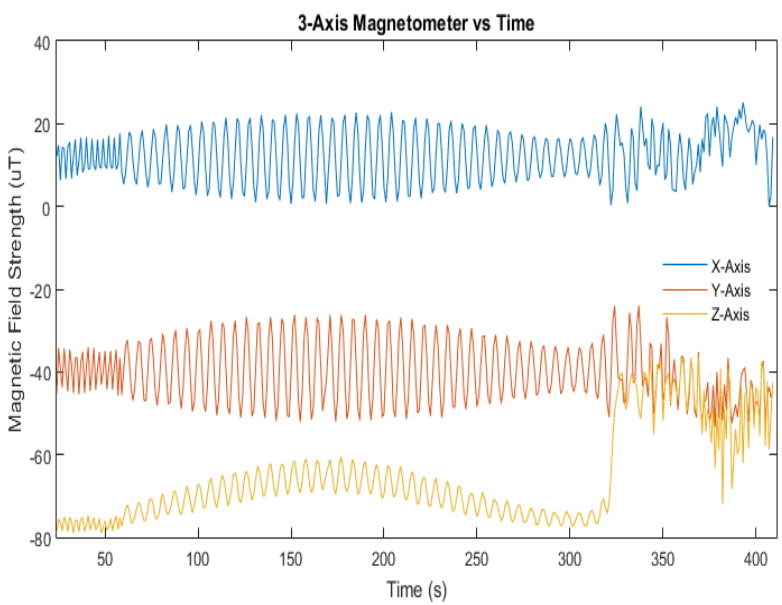
SOAREX-9 Dynamic Flight Data

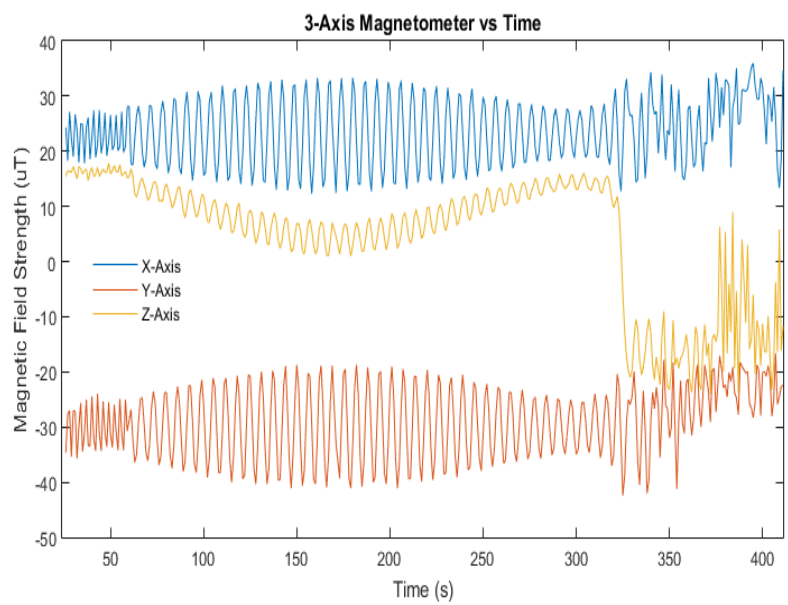


Cricket #01



Cricket #02





WSN Flight Test Data Analysis

- 410 data sets received on ISM-band downlink, one per second from 30 Kft altitude until Loss of Signal (LOS) covering 7 minutes of flight time
- Both WSM modules showed very similar data
- Ascent acceleration measured during second stage burn
- Reentry deceleration measured at top of atmosphere
- Outside skin temperature measured during ascent and reentry
- Inside temperature remained within reasonable range
- Gyros showed effect of spin motors, magnetometers showed spin rate
- Rotational gyro data and magnetic field data were faulty
  - Rotational rates should have been constant.
  - Magnetic field variations were significantly under-sampled during spin stabilization
  - After despin, gyro and magnetic field data looks accurate

WSN Flight Test Future Work

- Follow-up SOAREX-N planned for suborbital flight late FY17
  - Flight Test of multiple technology experiments including JSC developed Passive Wireless Sensor subsystem
- Development of WSM software continuing
  - Improved battery life
  - Improved sample rates
  - Incorporation of network layer protocols
- Team producing WSM development kit
  - Allows other sensors to be integrated on breadboard
  - Software modified to produce generic values
  - Multiple interfaces available for sensors
    - Analog
    - Digital

SOAREX Development and Operations Team

- Marcus Murbach (RD)
- Ali Guarneros-Luna (QS)
- Andy Gonzales (RD)
- Rick Alena (TI)
- Jon Wheless (UCSC)
- Cedric Priscal (SGT)
- Austin Tanner (MEI)
- Ray Gilstrap (IO)
- Thom Stone (CSC)
- Gabe Pearhill
- Ryan Rivas (UCB)
- Thomas Shu (SJSU)
- Rick Morrison (SJSU)