412th Test Wing

War-Winning Capabilities … On Time, On Cost

DAWN

Distributed Acquisition Wireless Network

Community Update

U.S. AIR FORCE

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812th Advanced Instrumentation Test Squadron
JT4

Agenda

- DAWN Overview
- Progress Over the Past Year
- Flight Testing
- Lab Testing
- Lessons Learned
- Future of Wireless in Instrumentation Systems

DAWN Goals

- Edict from General Schaefer – Innovation Initiative
  - *Eliminate Orange Wire in Test Aircraft*

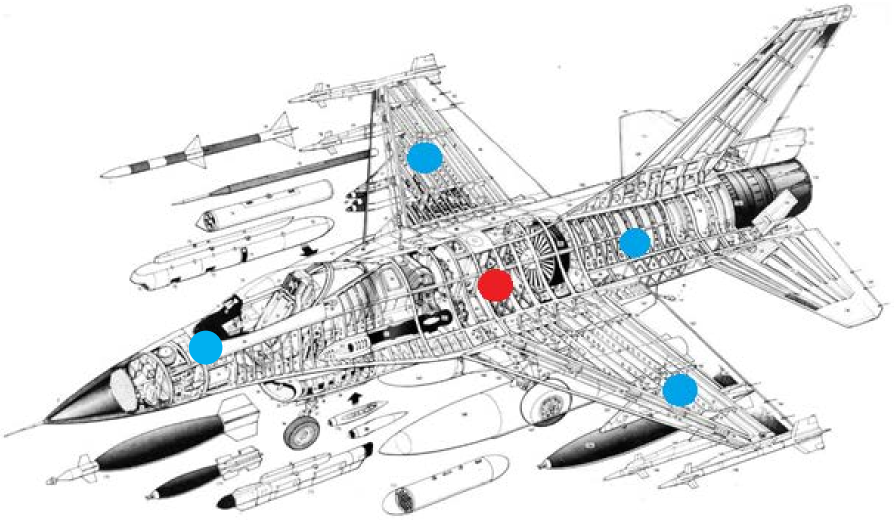
~~WIRELESS~~ → LESS WIRE

- Reduce aircraft modification and down time by reducing the quantity of orange wire needed to instrument an aircraft
- Eliminate routing/cabling workflow:
  - 30 terminations/day
  - 4 feet of cable/day

DAWN Conceptual Overview

- Distributed Acquisition Wireless Network
  - Intended for the wireless bulk transport of instrumentation data from aircraft extremities back to central instrumentation hub.

- **Nodal/Modular Approach**
  - Central & Satellite Nodes
  - Central node near main instrumentation hub
  - Satellite nodes near sensors
  - Field as many satellite nodes as needed



Central Node - Recorder & Network Data Selector

Satellite Nodes - Data Aquisition

DAWN Core Design Principles

- Low Power Consumption
  - Goal for battery operated, modular systems
- Bulk data transfer utilizing wireless Ethernet
  - Greatly reduce long runs of instrumentation wiring in aircraft
- Wireless Mesh Network
  - Multiple node network, non-LOS relay
- 900MHz ISM Band
  - Public band, no need for frequency clearance, non interference of other A/C systems
- Transmission across *Exterior* of Aircraft
  - Takes advantage of A/C skin shielding properties
- Maximize Bandwidth & Network Capacity

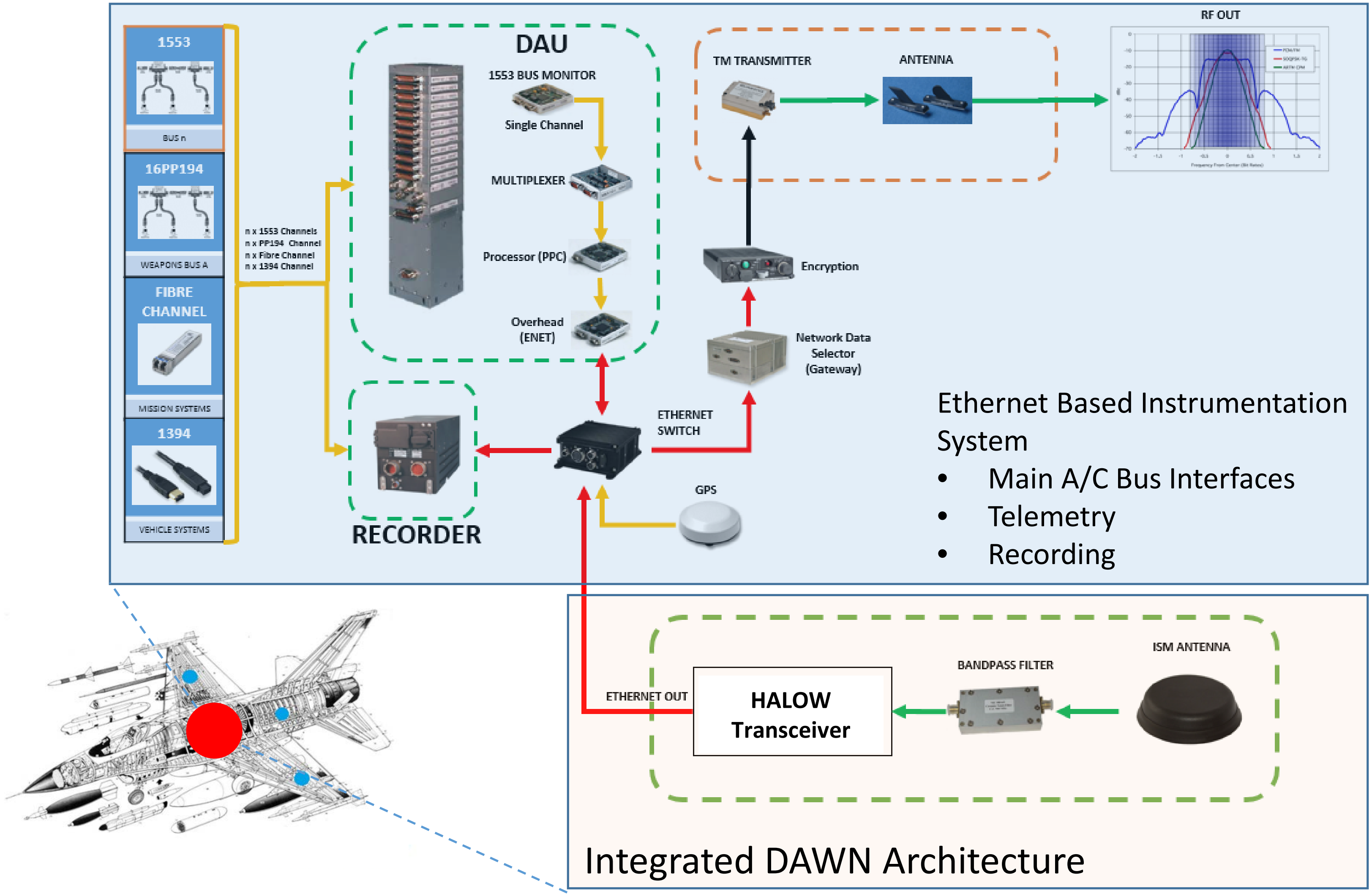
Data Acquisition Goals

- Diversified Technical Systems SLICE6
  - Originally developed for automotive crash testing
  - Modular
  - Physically small in size
  - Low power consumption
  - Streaming Ethernet output
  - Supports 1588 V1/V2 PTP
    - Measurements time tagged at acquisition
  - IRIG 106 CH 11 IP packet format

Wireless Transport & Timing Goals

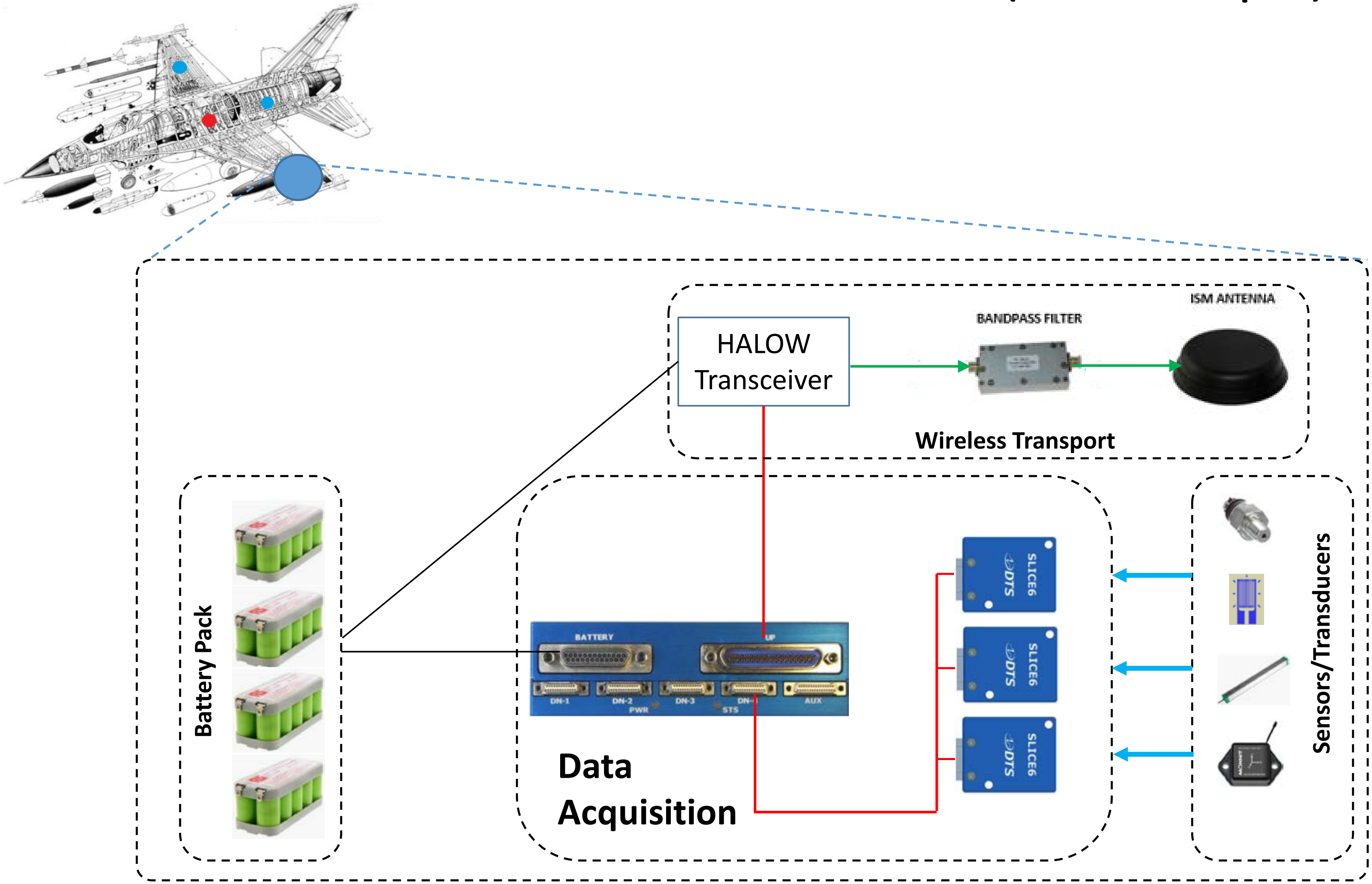
- 802.11ah Standard – HALOW (Std minted 2017)
  - Low power Wifi
  - Carrier frequency – 900MHz
  - Power Consumption: 7mW @ 0dBm output (spec)
  - Range: 150-200ft
  - Theoretical Max Bitrate of 347 Mbps (16 MHz channel)
  - Power saving features as part of the standard
- Feasibility of 1588 PTP synchronization across wireless links

Center Node Architecture (Concept)



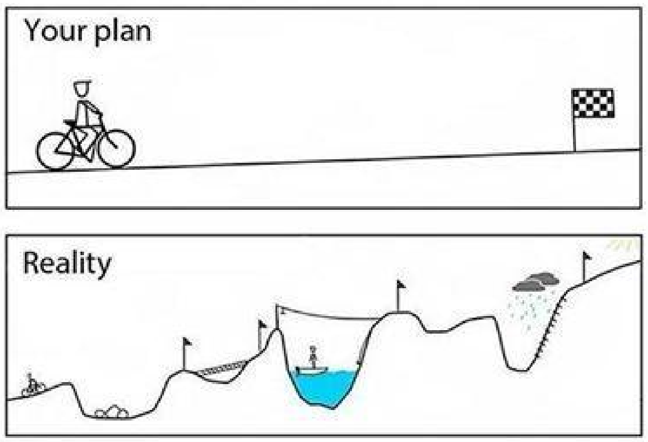
Integrity - Service - Excellence

Satellite Node Architecture (Concept)



Implementation Plan (May 2018)

- Execute contracts for DAS and HALOW
  - April - September 2018
- Identify test platform & create instrumentation design
  - September – November 2018
- Modify Aircraft
  - December 2018 – January 2019
- Flight Test
  - January 2019 – As Needed



Progress Since Last Year

- Slower than anticipated, but steady!
- System Haves
  - DTS Data Acquisition System
    - IRIG 106-17 CH 11 formatted data packets
    - Promiscuous streaming of data upon power-up
  - 900 MHz wireless transport solution
    - Silvus StreamCaster 4200 MIMO Radios
- System Have Nots
  - HALOW radios
  - 1588 PTP must be provided or additional hardware is required at satellite nodes to generate it
  - Battery power has not been developed or tested, still 28VDC A/C power required

Data Acquisition - Delivered!

- Diversified Technical Systems (DTS) Slice6
  - 6 Channel DAS
  - 9-15 VDC, < 2.5W per slice at max capacity
  - Daisy chainable, up to 10 slices per chain
  - Streaming Ethernet output
    - 2 port, 100 Mbps switch on-board
  - Small size – 30mm x 24mm x 10mm
  - Supports 1588 V1/V2 PTP
    - Measurements time tagged at acquisition
  - Available IRIG 106 CH 11 IP packet format
- Slice6 Distributor
  - Provides clean, filtered power for up to 4 Slice6 chains
  - Aggregates Ethernet traffic into a 1000 Mbps stream
  - Not required

Technological Setbacks

- HALOW hardware implementation
  - HALOW development did not progress enough to be a viable solution at this time
  - Standard itself is completely lacking in industry support
  - Still watching it closely; on paper it does provide many desirable features

HALOW Replacement
Silvus StreamCaster 4200

- 900 MHz wireless solution
- Multiple Input, Multiple Output (MIMO) based radio
- Size: 4.00”x2.63”x1.51”
  - OEM version available: 3.61”x2.15”x0.71”
- 100 Mbps total network capacity (50 Mbps w/single antenna)
- 4.8W – 16W @ 1W TX Power
- Fully featured radio/IP mesh network
- Web-based StreamScape Network Manager

Hurdles - Cybersecurity

- Extreme reluctance from test community for allowing 802.any to operate on an aircraft in conjunction with other aircraft systems that may be classified
  - *Caveat: Without ATO/IATT*
- Excerpt from F-16 Post Block Platform SSP:

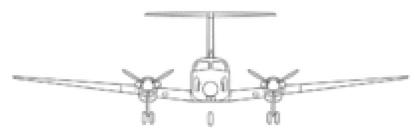
No Wireless Connectivity: No wireless devices are allowed to connect to the F-16 PIT system. Any connection through the 802.1X standard is strictly prohibited. Laptops and other devices have their wireless connectivity disabled. Maintenance laptops are specifically designed without any wireless capability.

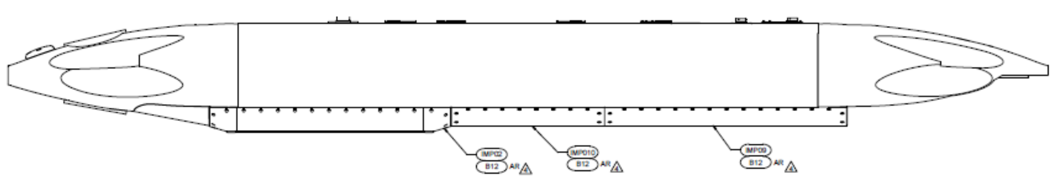
Hurdles -
Flight Test Priority

- Equipment & development delays
  - DAS delivered on time, but radios not received until late November (project requirement changed coupled with standard 90 day lead time)
- Edwards has an extremely busy flight test schedule
  - Design, mod management, fabrication, wiring, installation resources all very scarce
- Flight test platforms also very scarce
  - Difficult to get on flight schedule or have dedicated time on aircraft

Flight Testing

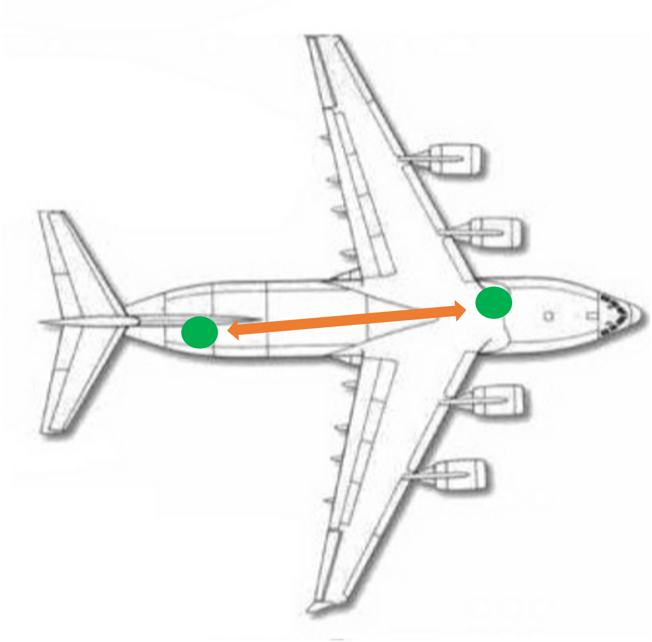
- Have yet to execute
- Plans and designs for 3 separate platforms
  - C-17
  - C-12
  - F-16
    - RASCAL Pod



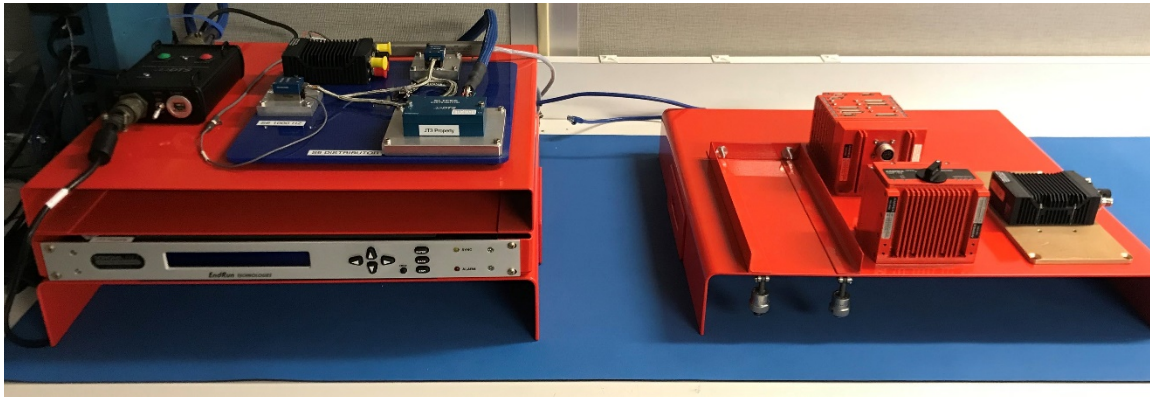


Flight Testing – C-17

- Utilize seat mounted instrumentation shelves in forward and aft sections of cargo cabin to demonstrate "in-flight" use of wireless instrumentation
- Flying lab setup



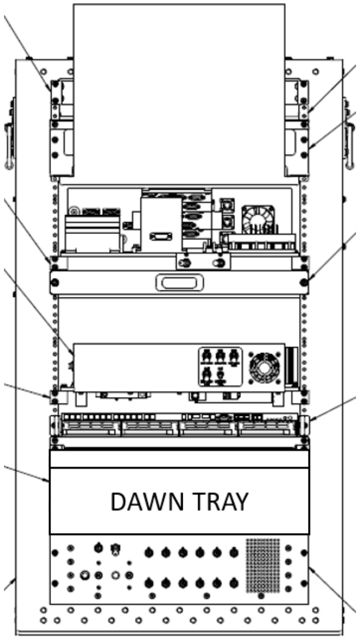
C-17

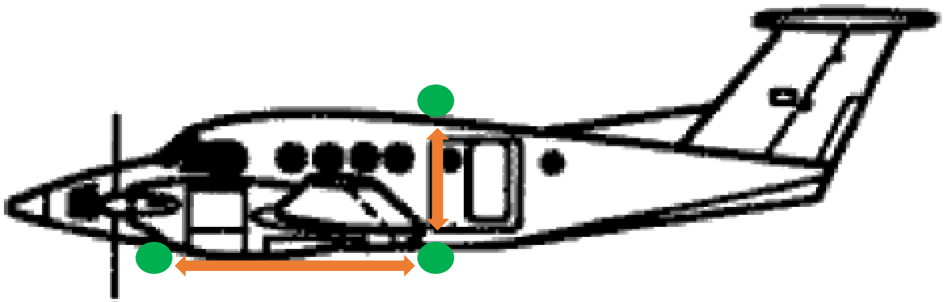


- Why do it?
  - Completely isolated instrumentation
  - Ease of installation
    - Trays tie down to seats
    - 1 wire bundle installed from forward to aft tray
  - Ease of design
  - Comparatively low execution cost
- Benefits
  - Proof of concept/Program of Record
  - Timing data
  - Community buy-in

Flight Testing – C-12

- Modify instrumentation rack already flown in C-12, closing link through external TM antennas

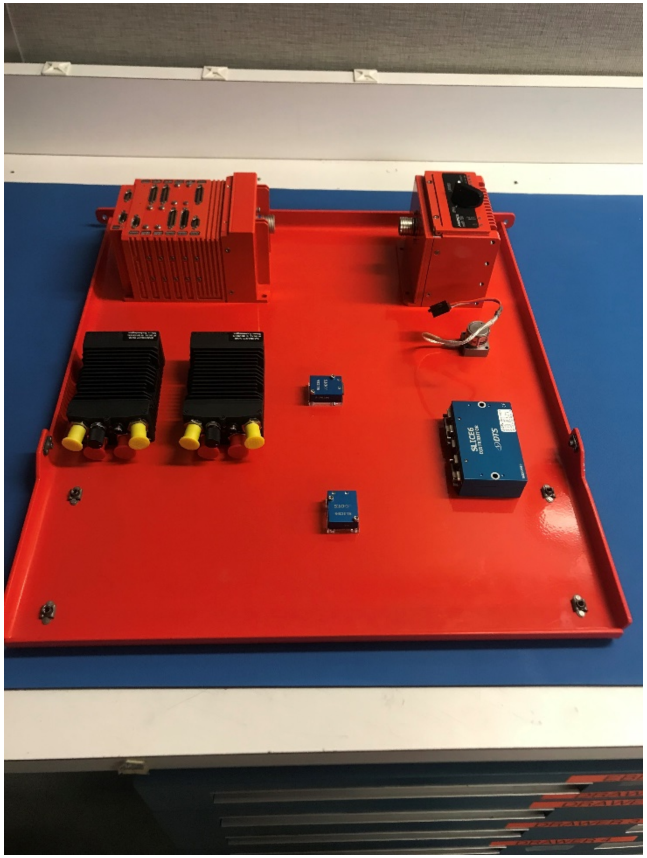




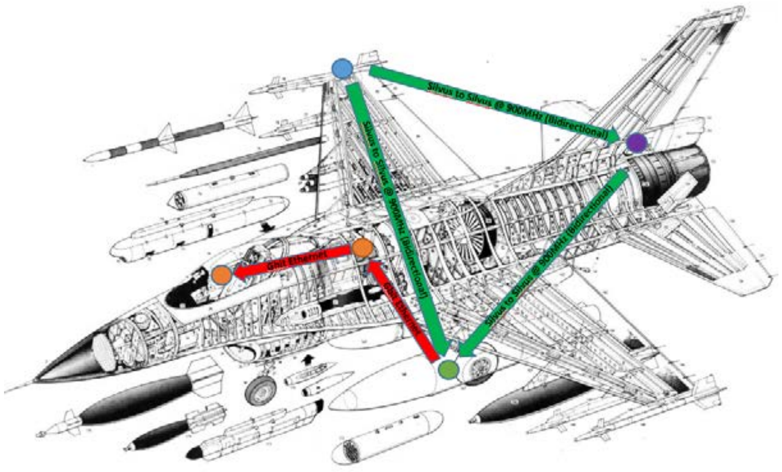
Transmit either between 2 lower antennas or between Upper and lower antennas

C-12

- Why do it?
  - Ease of installation
    - Stores mod, Interface Package
  - Ease of design
  - Low execution cost
- Benefits
  - Proof of concept
  - Community buy-in
  - Timing data
  - Transmission of signal on outside of aircraft



Flight Testing – F-16 Project



- Satellite Nodes - Sensors
  - LAU-129 stores on wingtips
  - Tail section
- Center Node – TM, Recording
  - RASCAL Pod
- Aircraft Instrumentation – A/C Busses, Video
  - Connectivity to aircraft instrumentation via RASCAL pod Gbit Ethernet

F-16 w/ RASCAL Pod

- Why do it?
  - Most representative DAWN system & solution
- Benefits
  - In-situ data
  - > 2 node mesh network
  - Network link performance testing
  - Network visibility testing via ground station fly-over

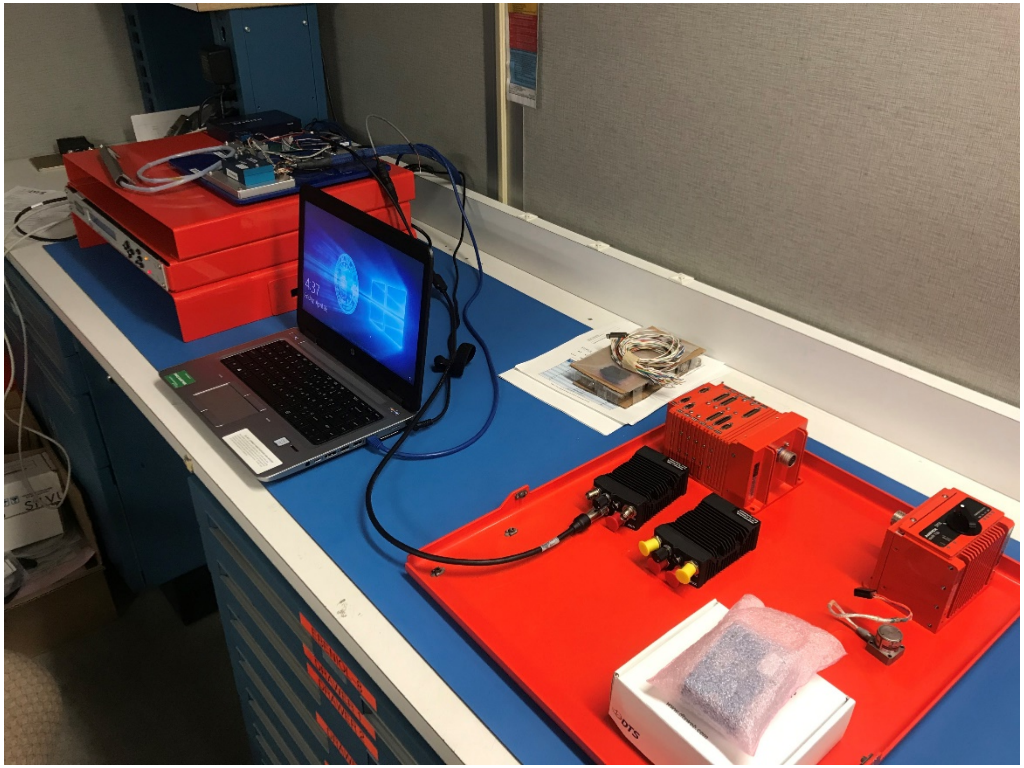
RASCAL POD

Development Technologies Flight Test Platform

- Reconfigurable Airborne Sensor, Communications & Laser
- Modified SUU-20 Rocket/Bomb Trainer
- Cleared to fly on most F-16s
- Streamlined modification process
  - Stores Mod = Quicker & easier design
- Filling out asset pool
  - 3 pods under TPS management
  - Additional 2 built for ENIE use
  - Many entities/customers are interested

Lab Build & Testing Results

- Silvus radios very intuitive and easy to use
- Transported digital video around lab
  - Packet loss when signal obstructions present



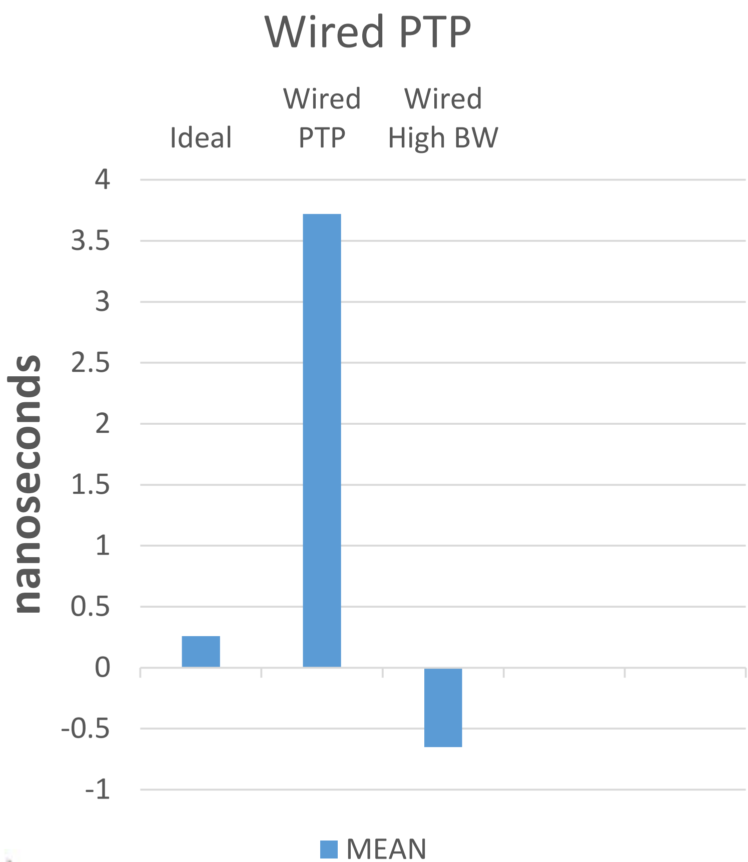
Timing Testing

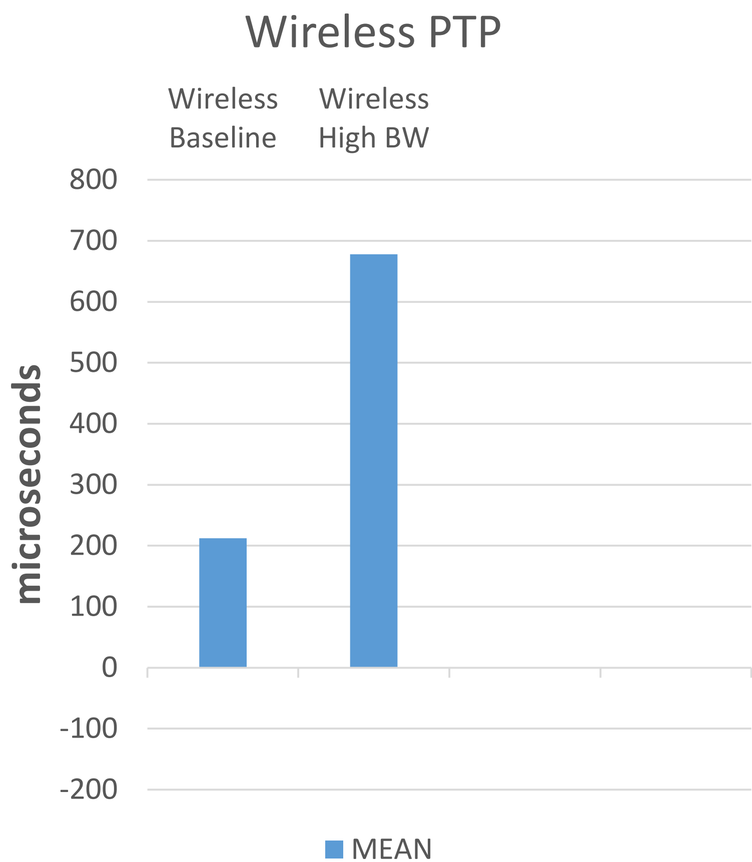
- Quantify synchronization of 1588 over wireless links
  - 802.11 by nature can be bursty and non-deterministic, this is borne out by lab testing
  - Silvus StreamCaster radios show similar limitations
  - 1588 not designed with wireless networks in mind

Timing Testing Results

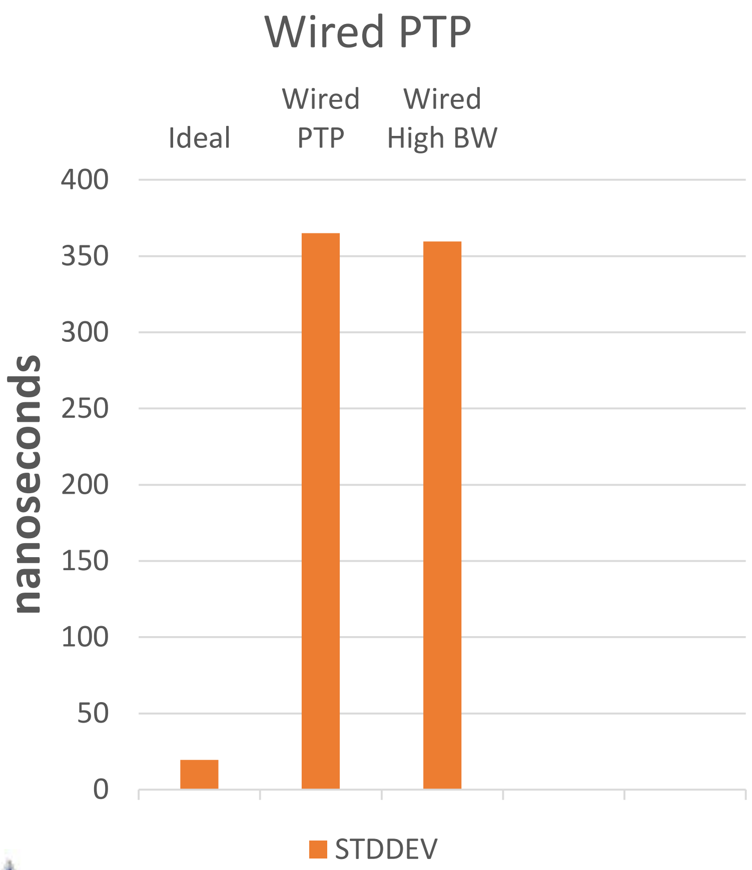
- Performed by DTS
- Test Setup – 5 Configurations
  - Ideal: Time server connected directly to S6, PTP traffic only
  - Wired Baseline: Introduces non-PTP Ethernet switch, PTP traffic only
  - Wired Streaming Data: Same as previous, with high BW data
  - Wireless Baseline: PTP traffic only
  - Wireless High BW streaming

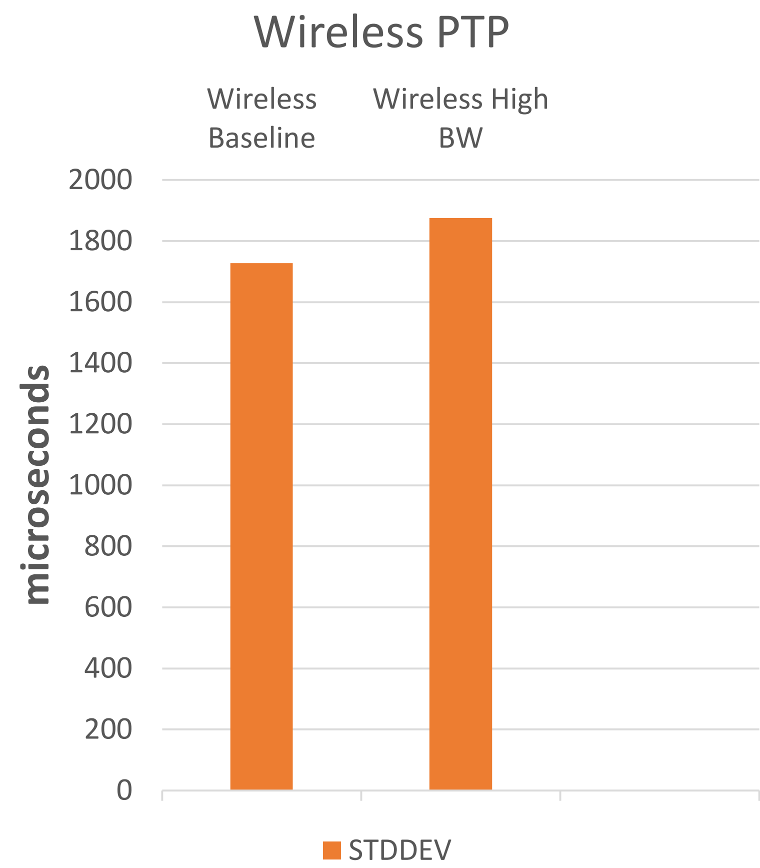
PTP Timing Results – Offset From Master Mean





PTP Timing Results – Offset From Master Standard Deviation

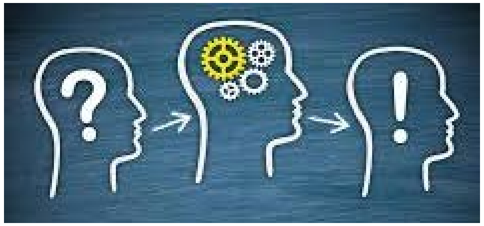




PTP Timing Results – Analysis

- "PTP relies on the assumption of symmetrical network latency between upstream and downstream network elements. This works well in a wired network as latency between elements is relatively stable, deterministic, and symmetrical. In a wireless network the latencies are asymmetric as the wireless network fabric negotiates packet transmission and manages link robustness across multiple network nodes. This unpredictable and asymmetric latency negatively impacts the latency calculation and increases timing uncertainty."
  - From *DTS SLICE6 Air Wireless IEEE-1588, Characterizing SLICE6 AIR Timing Accuracy over Wireless Networks*
- A number of parties have investigated mitigation techniques for wireless PTP, as yet nothing is standardized.

Lessons Learned



- Be very wary of new tech that lacks wider industry support – *802.11ah Standard*
- Nothing happens "fast" in aircraft flight test
- Need a platform for development – RASCAL POD!!
- Wireless not a new paradigm for instrumentation, but rather can be a very effective niche solution for specific applications
- Getting the right combination of capabilities is challenging

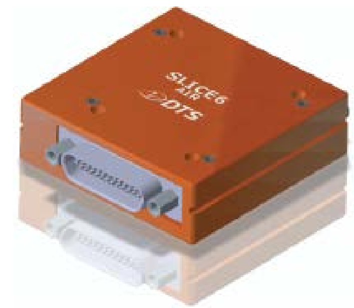
~~WIRELESS~~ → LESS WIRE

What's Next?

- Immediate Goals
  - C-12 flight testing
  - Further technology development
- Long Term Goals
  - Solve current major technical issues including Cybersecurity
  - Demonstrate on other platforms
  - Keep getting smaller
  - Find wireless instrumentation's place

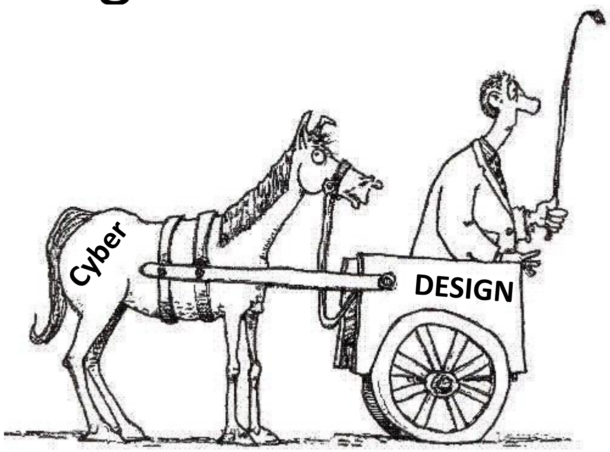
DAWN - What's Next? DTS Slice6 Air

- Fully air worthy packaging of Slice6
  - MIL-STD 810G & MIL-STD 461G
- Supports IRIG Ch10/11 Ethernet streaming & Record-in-Place
- TmNS (IRIG Ch 24) formatted packet streaming under development
- Integrated 1588 PTP Grandmaster Clock under development
- Available on-board recording
- Production ready later this year



DAWN – What's Next? Cybersecurity

- Overcoming Cybersecurity Reluctance through documentation, analysis, and testing
- Design security in from the beginning!
  - Follow RMF Process
  - StreamCaster radio network not a traditional Wifi network
  - AES 256, FIPS 140-2 compliant
  - Well defined & static network boundary
  - Reduce Tx power to cover only aircraft



DAWN – What's Next Cybersecurity

- Vulnerability
  - End-point spoofing (data exfiltration)
  - Denial of service (packet flooding)
  - Jamming (RF interference)
  - Wireless encryption technologies continue to be exploited (AES can be, WPA/WPA2 cracked, WPA3 fixes those issues but not widely available yet
- Risk mitigation techniques
  - Encryption
  - MAC filtering
  - Reduce power to limit network range
  - Administrative protections on hardware
  - NSA Type 1 encryption available to use but very costly in terms of equipment and management
- ***Continuous Monitoring!***

Wireless – What's Next? Synchronization

What good is wireless when wires are still required?

Single Grandmaster Clock

- Make the RF work with the protocol
- Make the protocol work with the RF
- Many studies have been done
- Either way, NRE will be required

Multiple Grandmaster Clocks

- Each independent module has its own GMC
- Requires GPS receivers and GMCs at each node
- Adds a lot of complexity and hardware to the synchronization system

Wireless – What's Next? Power

What good is wireless when wires are still required?

Battery Power

- Pros
  - Closest to operationally feasible
  - Recent and continuous technological improvements
- Cons
  - Size/Weight
  - Recharging
  - Energy density
  - Safety

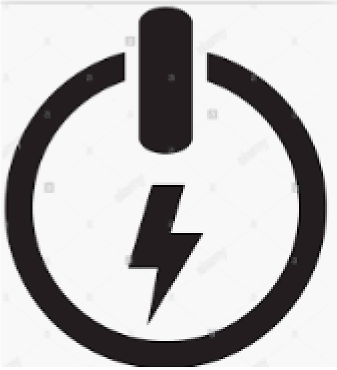
Energy Harvesting

- Pros
  - No batteries required
  - Small size
- Cons
  - Low power output
  - Technology is a ways off

Wireless – What's Next?
Mod Master Power Control

What good is wireless when wires are still required?

- Pilots/Operators have complete, single switch power control over instrumentation system
- With disconnected, modular systems, this becomes more complicated
- Possible solutions:
  - Shift in policy
  - Wireless power relays



The Place of Wireless in Flight Test Instrumentation

- Too early to tell what wireless *is* or *is not*
- **Wireless *may* not**:
  - Be a replacement for traditional systems
  - Be suited to completely eliminate orange wire
- **Wireless *may***:
  - Be A flexible, modular toolkit that fits specific requirements
    - Quick reaction mods – temporary add-ins to existing systems
    - Wearables
  - Open new ways to think about flight test & instrumentation
  - Combine multiple wireless technologies into single systems

Wireless *IS*

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14. ABSTRACT

Recent Air Force innovation initiatives have spurred the test and evaluation community to re-evaluate all aspects of the flight test paradigm. Within the realm of flight test instrumentation, aircraft modification time was identified as a significant sink for both time and cost. This is largely due to the lengthy process of installing and/or removing large amounts of instrumentation, aka "orange wire", throughout the aircraft. To combat this, several wireless instrumentation solutions are being developed. One such solution, dubbed the Distributed Acquisition Wireless Network (DAWN), was created with the aim of replacing large, long wire bundle runs from terminal aircraft locations, such as the wingtips and tail section, back to the centralized instrumentation hub near the center of the aircraft, with a wireless mesh network. This mesh network acts as a bulk wireless transport mechanism for instrumentation data collected in these remote aircraft locations. DAWN was previously briefed in 2018, and this presentation aims to update the T&E community on the progress, successes, failures, lessons learned, and our path forward with this type of instrumentation solution.

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