Wireless Rotating Instrumentation Package (WRIP) Test Technology

Prepared for ITEA Test Technology Review - 2015

Tiffany Yates
Shane Klase

05 November 2015

U.S. Army Test and Evaluation Command

Redstone Test Center

Wireless vs. Mechanical Integration

Advantages of a Wireless Rotating Instrumentation Package (WRIP)

- No mechanical slipring
- No transmission modifications
- No standpipe required
- An inherently safer design
- Improved Reliability and Mean Time Between Failures (MTBF)
- Simpler to install and remove
- Physical wiring typically reduced by half
- Configurable for multiple aircraft

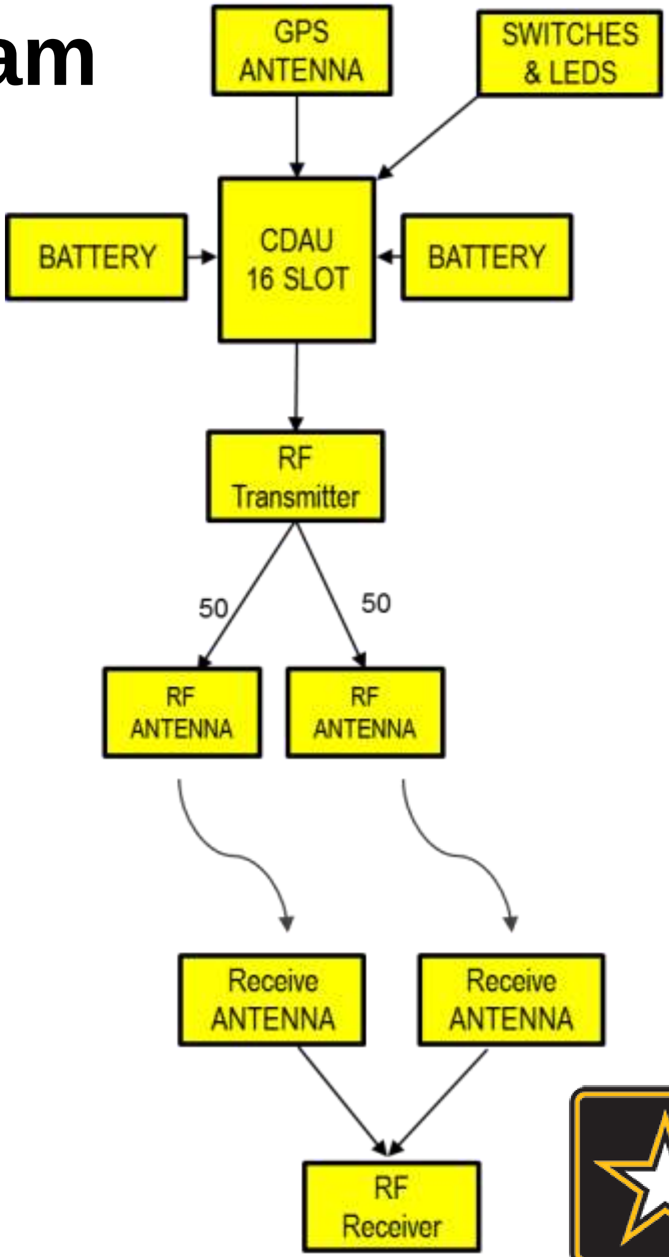
WRIP Design Requirements

- Use of existing mounting structure to minimize additional airworthiness requirements.
- 80 channels of strain gage, accelerometer, and/or voltage measurements
- 2 Mbits aggregate data rate per head
- WRIP design needed to support up to 5 hrs of continuous flight at maximum parameter capacity
- Ability to replace batteries in 30 minutes to support a second flight each test day
- RF short link needed to utilize a low power Lower L-Band Telemetry frequency range (1435-1535 MHz) or S-band (2200-2300 MHz)
- Data recording capability aboard the WRIP in addition to RF link, so data loss is not an issue
- GPS time tagging

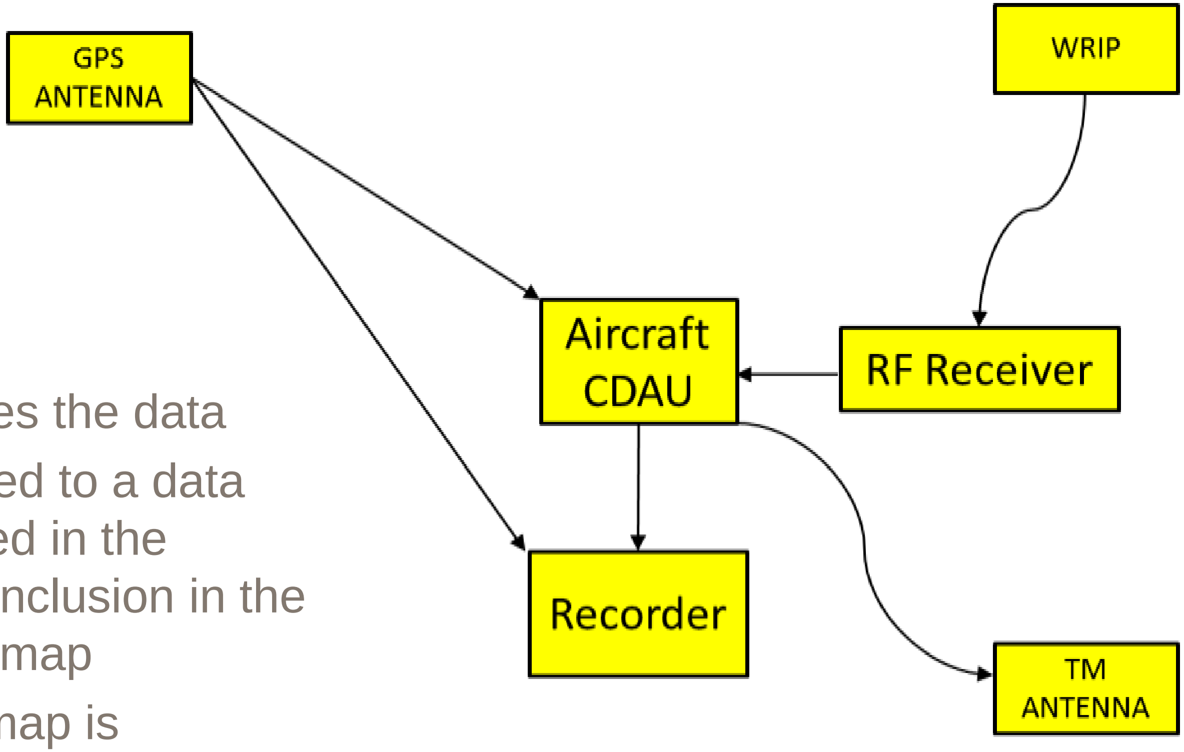
System Diagram

WRIP :

- Receives signals from sensors on rotating components
- Signals are collected and processed by the Common Airborne Instrumentation System (CAIS) Data Acquisition Unit (CDAU)
- Time is provided by a global positioning system (GPS)
- Two 24VDC batteries provide power to the CDAU and the radio frequency (RF) transmitter
- The RF transmitter receives data from the CDAU and transmits the data to the aircraft's RF receiver

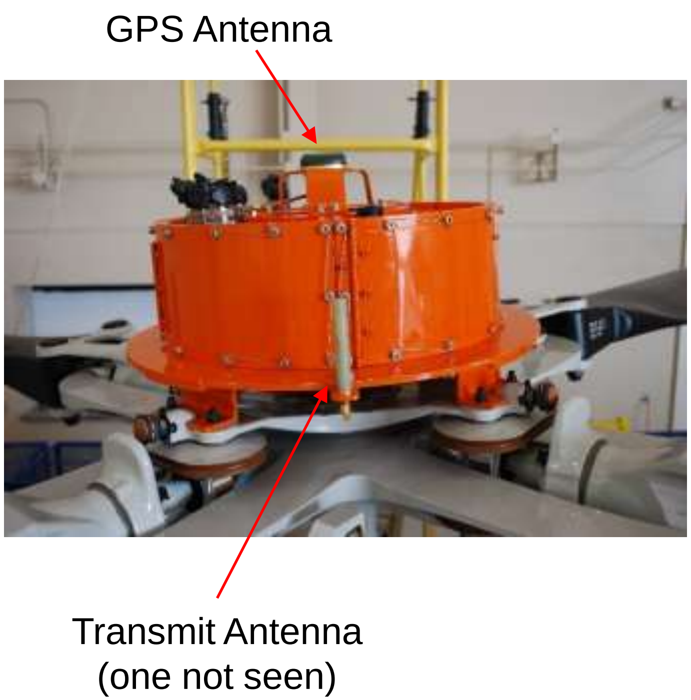


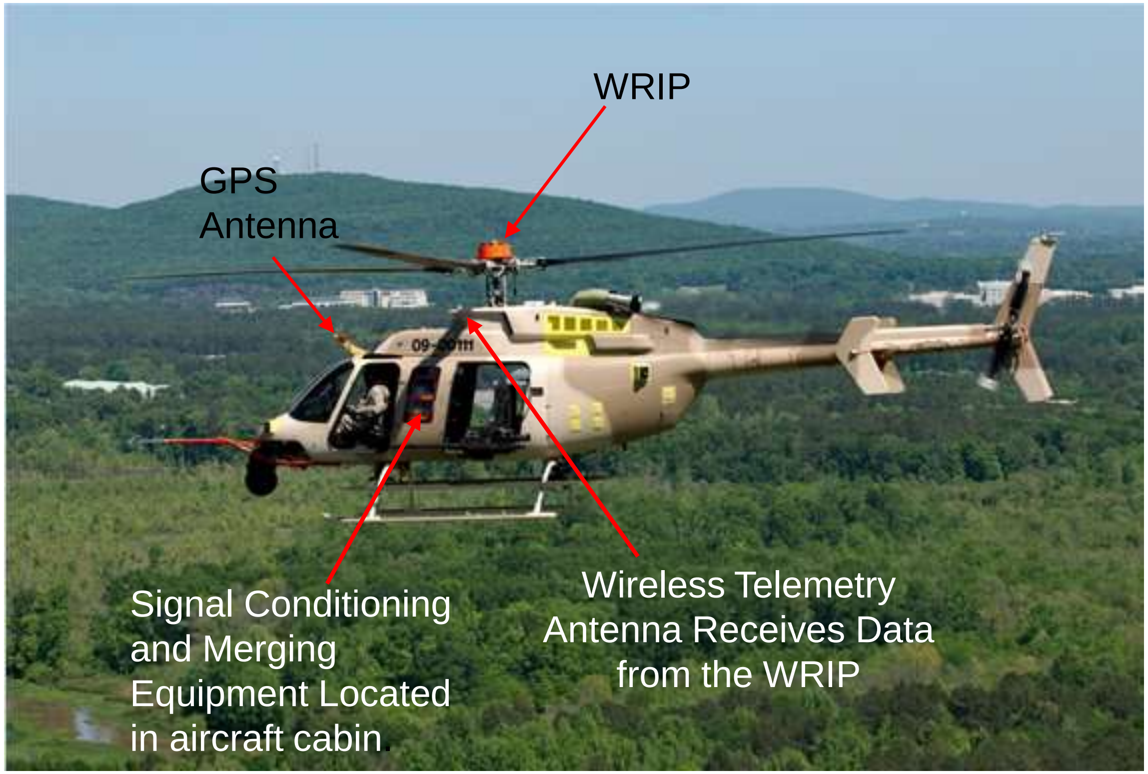
System Diagram



- RF receiver decodes the data
- Decoded data routed to a data merger card, located in the aircraft CDAU, for inclusion in the aircraft data frame map
- Data in the frame map is telemetered to the ground for real time observation.

Aircraft Platform Integrations
Bell 407

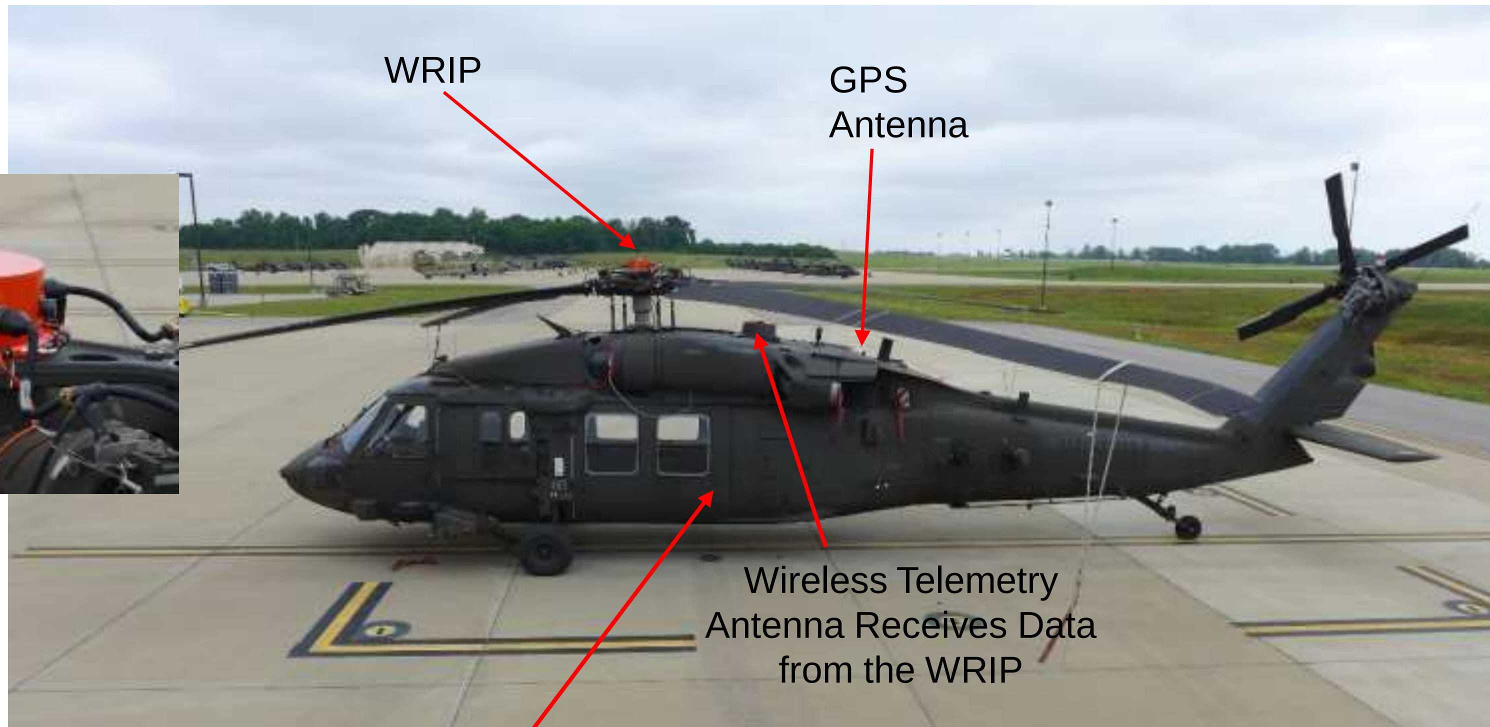




Aircraft Platform Integrations
H-60

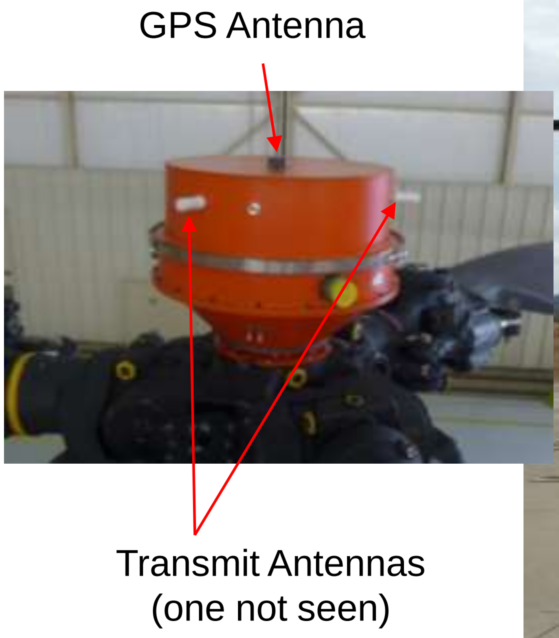
GPS Antenna

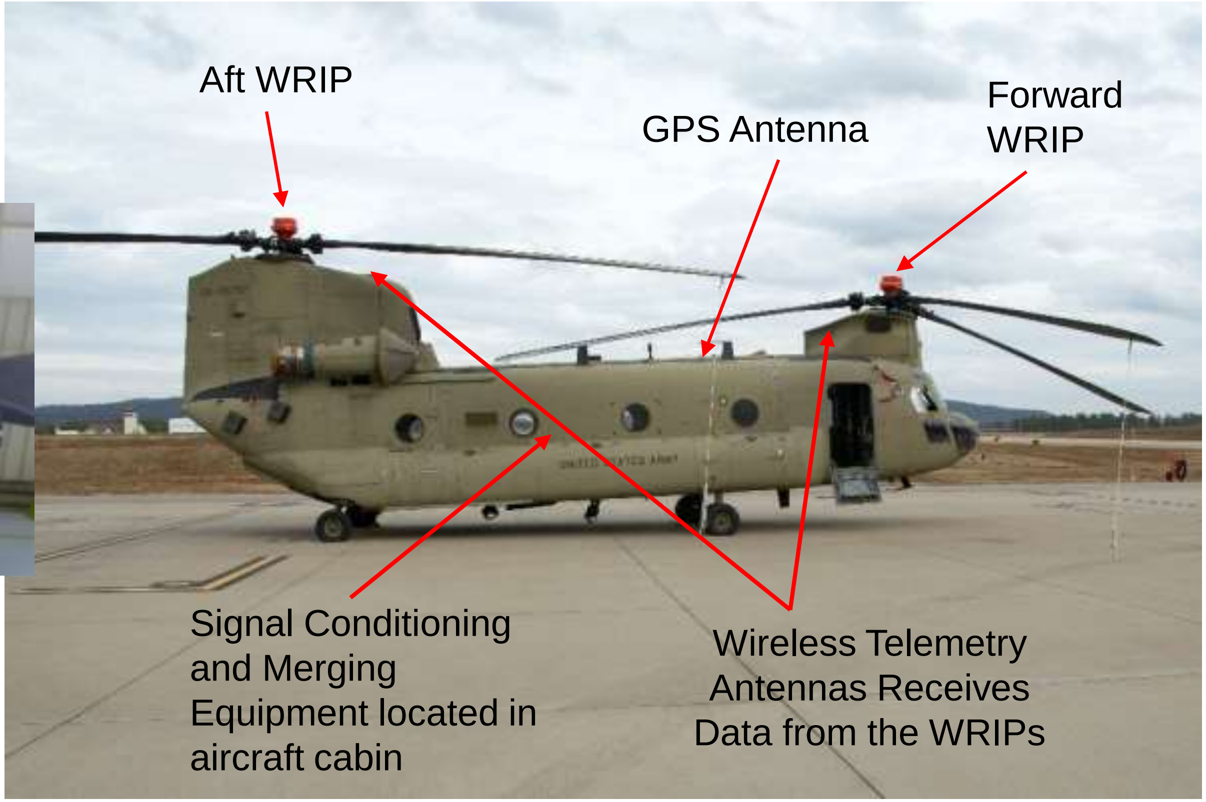
Transmit Antenna Configuration 1 (one not seen)



Signal Conditioning and Merging Equipment located in aircraft cabin

Aircraft Platform Integrations H-47

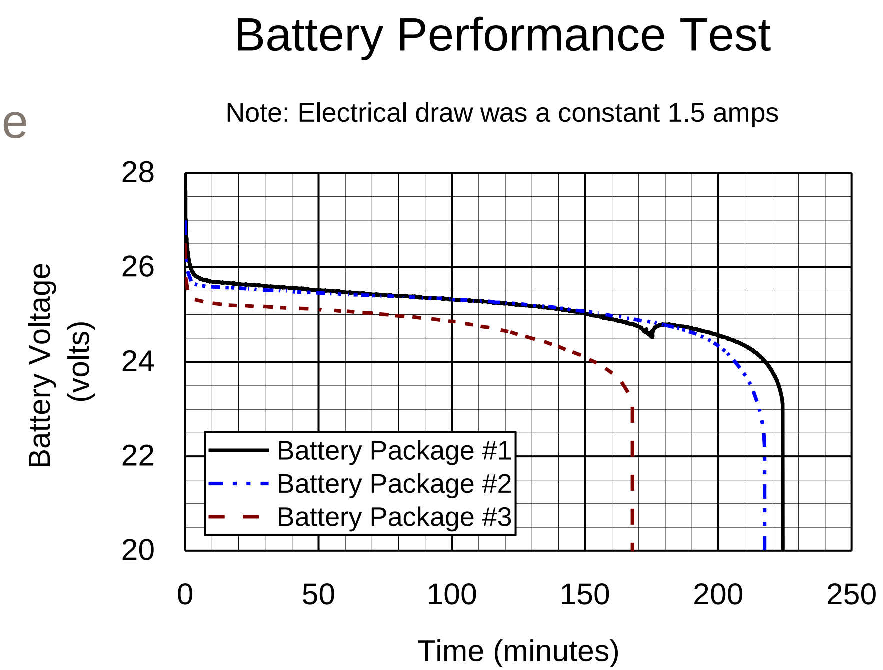




Battery

Factors for Battery Choice

- Require intrinsically safe charge and discharge characteristics, no thermal runaway, specific to on-board aircraft use
- Quickly Rechargeable
- High energy density, watt-hr vs. unit volume
- Ruggedized to withstand rotor head vibration
- Commercially available at the required voltage levels (24-28VDC)



Battery Tests

- Discharged new batteries and recorded performance
  - to identify lifetime of battery
  - provide battery discharge rate for real-time observation

Static & Dynamic Balance

Based on the location, mechanical balance is a critical design requirement for the WRIP

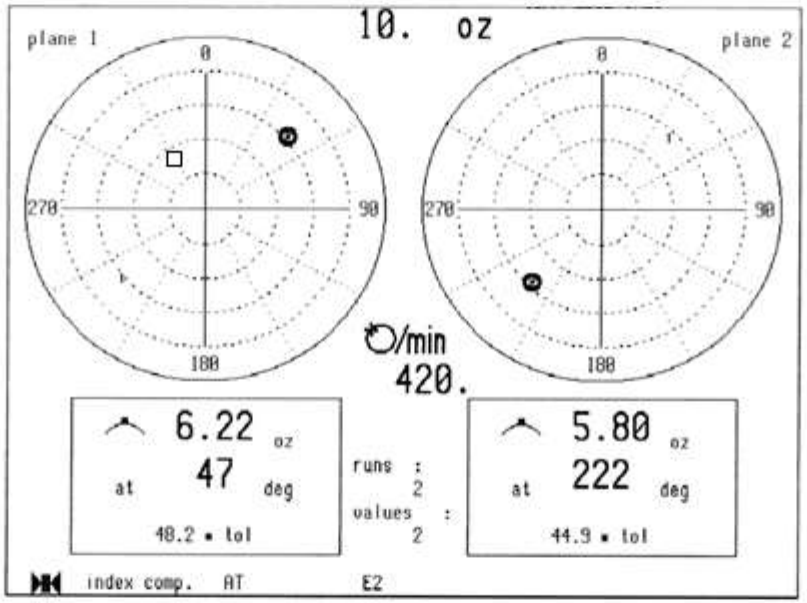
- The helicopter rotor system is sensitive to weight and vibration

Static Balance

- Weight & balance of each component is considered for WRIP system layout
- The static balance is assessed and corrected with the physical system once all components have been installed

Dynamic Balance

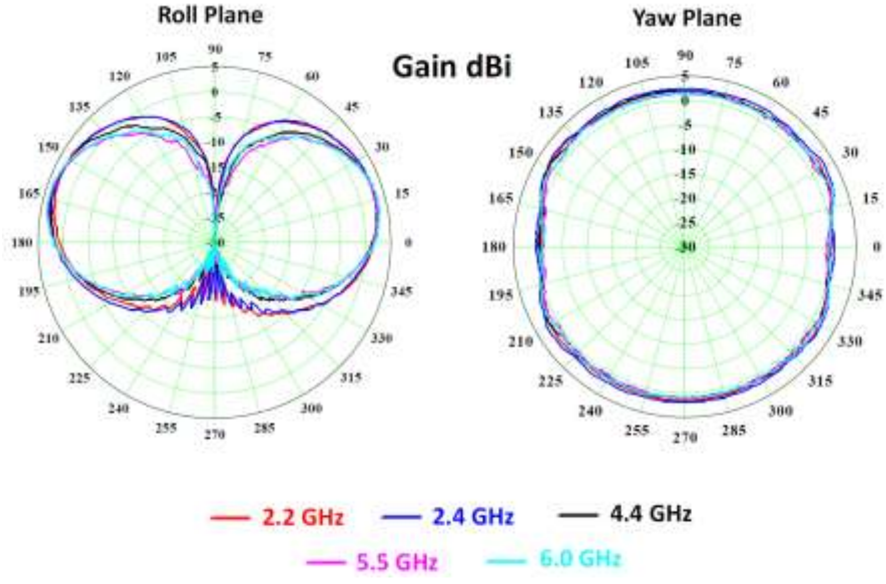
- The WRIP is dynamically tested in a lab at relevant operating rotational speeds including those for off-nominal conditions such as track-and-balance for maintenance and for autorotation



Antenna

Factors for Successful Links

- Antenna Geometry – Vary number/locations of transmit and receive antenna(s) to maintain line of sight (LOS)
- Signal Combination – Vary power divider/combiner ratios
- Antenna Polarization – Vary installation orientation of antennas to establish LOS through full rotor head rotation
- Antenna Types – Vary based on available space at favorable LOS locations and antenna orientations (button, flexslot, etc)
- Variable Power Levels – Vary RF transmission power to achieve adequate signal to noise ratio (SNR) and bit error rates (BERs)



Real-Time Monitoring Concerns

- **Data Delay**
  - The rotor data recorded by the cabin-mounted instrumentation were time aligned with the WRIP data
  - Measured transducer values and timing were compared
    - Measured values were equal
    - Timing discrepancy varied with the WRIP update rate
      - » The sample alignment between the WRIP and the aircraft packages is not constant
      - » The updated data of the WRIP will be processed and displayed based on the update rate of the aircraft system
      - » The time to transmit and receive the data is negligible, due to the short distance
      - » The latest value being held in the buffer will be utilized by the aircraft system
      - » The maximum delay seen was equal to the period 1 sample
  - The timing was satisfactory for real-time monitoring

Real-Time Monitoring Concerns

– **Data Dropout between the WRIP and the cabin-mounted instrumentation**
  - The dropout was sporadic (ranging between 0.5 sec and 120 sec between dropouts)
  - The dropout lasted for one sample (example Bell 407 sample rate is 1000 samples per second [sps])
  - The dropout was satisfactory for real-time monitoring

Aircraft/WRIP In-Flight Testing

Types of In-flight Testing for WRIP

- Envelope expansion to validate the performance of the WRIP
- Document any measurable changes in aircraft handling qualities

Flight Matrix

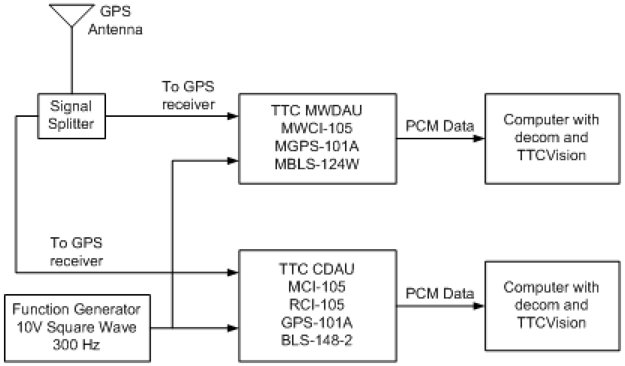
- Hover, ground and air taxi, traffic pattern tasks
- Low-airspeed flight (all cardinal directions) to the aircraft limits
- Forward flight speed sweep
- Maneuvers performed every 20 knots
  - Steady turns to high load factor / pushovers to low load factors
  - Steady heading sideslip
  - Short-term aircraft response (pulses and doublets)
  - Climbs and descents

Global Positioning System (GPS) Time Alignment

The data from the WRIP has to be aligned with data collected on the aircraft cabin-mounted instrumentation.

A white paper was prepared based on lab testing performed by RTC

- Absolute Time: In all cases when both GPS receivers were locked the IRIG-B DC was within +/- ½ microsecond
- Experiments verified that card output timing differences could be viewed in the lab by comparing the IRIG B DC outputs from two cards on an oscilloscope
- Lab experiments verified that the GPS Delta-time registers correlate with the IRIG B DC differences providing confidence in the results
- When loss of GPS lock occurs the drift rate is between +/-10 microseconds per minute. However, upon re-acquiring lock(s) the drift rate returns to <1 microsecond as quickly as 60 microseconds/min



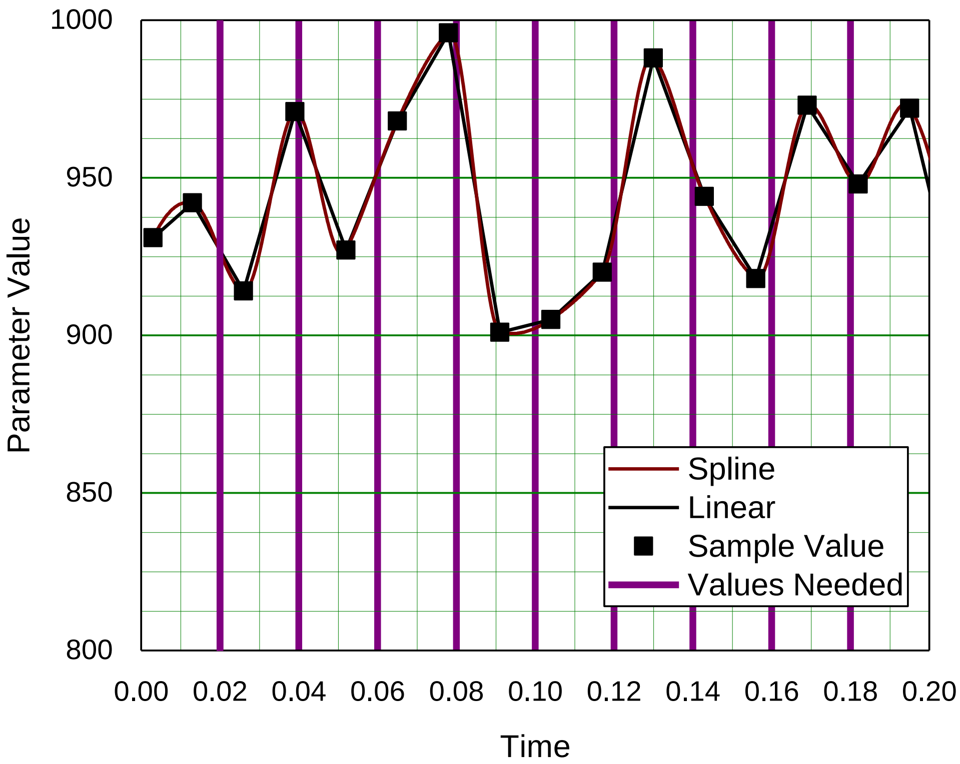
Data Replacement

Merging the recorded WRIP data with the recorded aircraft data streamlines the analysis process by reducing complexity. Many data analysis tools rely on data from a single data stream. Data merging was performed using raw IRIG-106 Chapter 10 formatted files.

- The WRIP system was recorded at a higher rate than required for analysis and filtered per original equipment manufacture requirements.
- All parameters recorded in the WRIP were transmitted and recorded on the aircraft cabin-mounted instrumentation
- Post flight - each rotating parameter value in the aircraft chapter 10 file was replaced with the data recorded in the WRIP chapter 10 file at that time.
- Multiple merge techniques were evaluated (See next slide)
  - Closest time
  - Linear interpolation
  - Cubic spline interpolation

Data Replacement

- **Closest time** – The WRIP data value closest to the timing on the aircraft data stream replaced the aircraft data.
  - The value could be off by as much as the highest sampling rate. Effects could be found during FFT analysis
- **Linear Interpolation** – The values recorded from the WRIP were linearly interpolated to find the parameter value at the time of the aircraft data stream
- **Cubic Spline Interpolation** – The values recorded from the WRIP interpolated using a cubic spline to find the parameter value at the time of the aircraft data stream
  - Little to no noticeable effect as compared to linear interpolation for the high sample rates collected



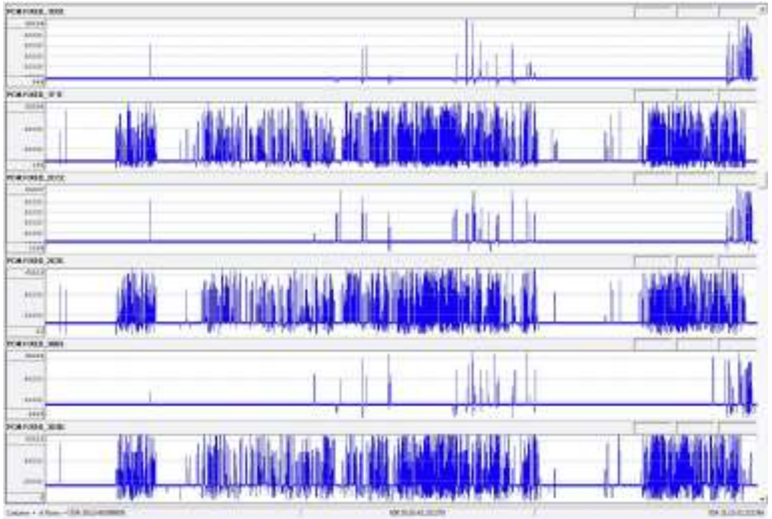
Summary of Utilization

WRIP Success Stories

Aircraft Type	Hours of Operation	Issues
Bell 407	204	1 recorder failure
OH-58F (Kiowa)	97	-
CH-47F (Chinook)	36	1 battery failure
UH-60M (Blackhawk)	21	-

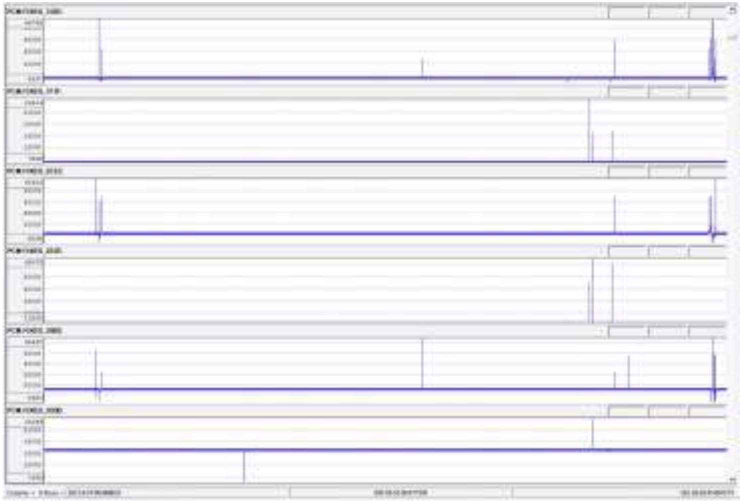
Future Upgrades In Progress

Transmitter data without –STC



Ideas for Improvement

- Transmitter Development – utilize space time coding (STC) capable hardware
  - Space-Time-Coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer.
- This is extremely beneficial when rotating about a main rotor mast, trying to maintain adequate link. Alleviates issues related to multi-pathing and wave cancellation.



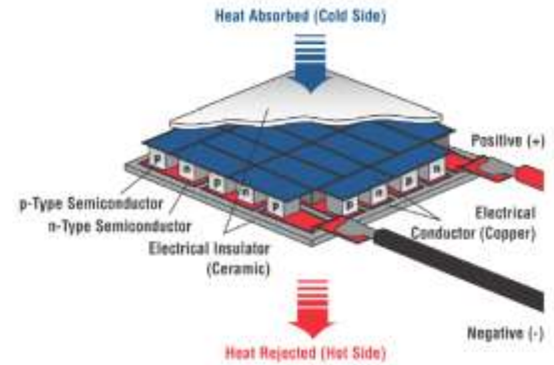
Transmitter data with –STC

U.S.ARMY

Future Upgrades

Ideas for Improvement

- Maintenance Link – Provides a ground to WRIP link to use for power on/off operation, calibration, and system setup
  - Currently this function is performed by technician who must climb to the WRIP on top of the aircraft.
- Alternate Power Sources
  - Air Powered DC
  - Thermoelectric Modules
  - Vibration energy harvesters



References

- White Paper, *TTC GPS-101 Timing*, Redstone Test Center, March 2013
- White Paper, *Aviation Flight Test Directorate Chapter 10 PCM Merger Utility Description,* Redstone Test Center, May 2013
- Test Results, *407 WRIP Dynamic Balance Results*, Schenck Trebel Balancing Service, June 2011