Design Considerations of Avionic Sensors and Systems for Wireless Avionics Intra-Communications (WAIC)

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HarcoSemco, Research and Development

WiSEE 2016

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Overview

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HarcoSemco Overview

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- A division of the TransDigm Group.
- Supplier of commercial, business, military jet, rotor and spacecraft markets for over 60 years.
- **Locations:**
  - *Branford, CT USA*
  - *Valencia, CA USA*
  - *Nogales, Mexico*
- **Example Product Offerings:**
  - RTD temperature sensors, thermocouple probes and harnesses, speed and pressure sensors, mass flow sensors, interconnect cable-harness assemblies and aerospace heaters.

Major Customers

AIRBUS HELICOPTERS · AgustaWestland · BOEING · GE · Hamilton Sundstrand · Pratt & Whitney · Rolls-Royce · SAFRAN · SIKORSKY · UTC Aerospace Systems · Honeywell · EMBRAER

DNV-GL ISO 9001 + AS9100 · Nadcap Accredited · EASA · FAA FEDERAL AVIATION ADMINISTRATION · IPC · DQS · CE · c RU us · Ex · UL

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Avionic Sensor Applications: Thermocouple Sensors

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Probes

- Single or multiple points of temperature measurement in the stream.
- Hermetically sealed, high-temp., flex cable with terminal lugs or connectors.

Rigid Integral Assemblies

- Completely rigid and hermetically sealed.
- Perfect where space is tight and standard cable designs would not hold up due to high heat or other harsh environments.

Flexible Assemblies

- Combination of rigid probes with high temp. cabling.
- Molded transitions and connector/backshell configurations.

Avionic Sensor Applications: RTD & Speed Sensors

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RTD Temperature Sensors

- Temperature Range: +40ºC to 200ºC.
- SIMx Temperature Range to 3000º F.
- Self-Heating Error: < 1ºC @ 15 mA Excitation Current.
- Stability: < 1ºC per year.

Speed Sensors

- Single-Coil, Multi-Coil, Variable Reluctance, Hall Effect.
- Lightweight stainless steel assembly.
- High accuracy.
- No moving parts.
- Harsh environment operation and extended temperature Range.

OAT

- Qualified to: RTCA/DO -160D & Mil-STD-F
- Designed to resist icing buildup
- Operating range: Sea Level to 60,000 ft; Mach: 0 to 0.6
- Temperature Range: -65°C to +85°C

Total Air Temperature (TAT) Sensor

- Computation of static air temperature and true air speed
- Used on US military aircraft
- Customizable mounting flange
- Customizable connector

Flow Sensors

- Thermal dispersion technology
- Customized flow rate and output
- Customized mounting ports
- Used in avionics ECS

Pressure Sensors

Engine Sensor Applications (Potential for wireless)

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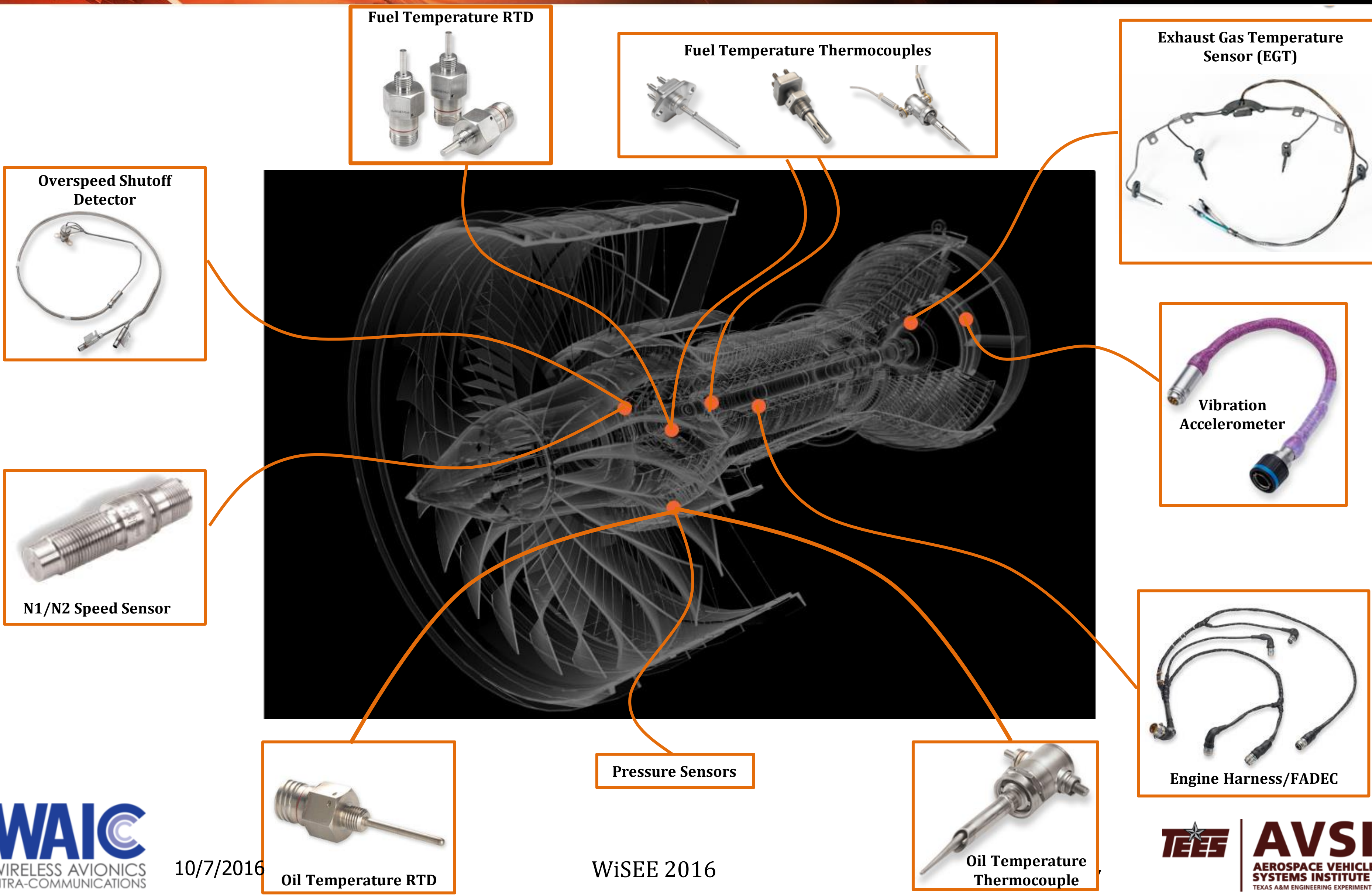
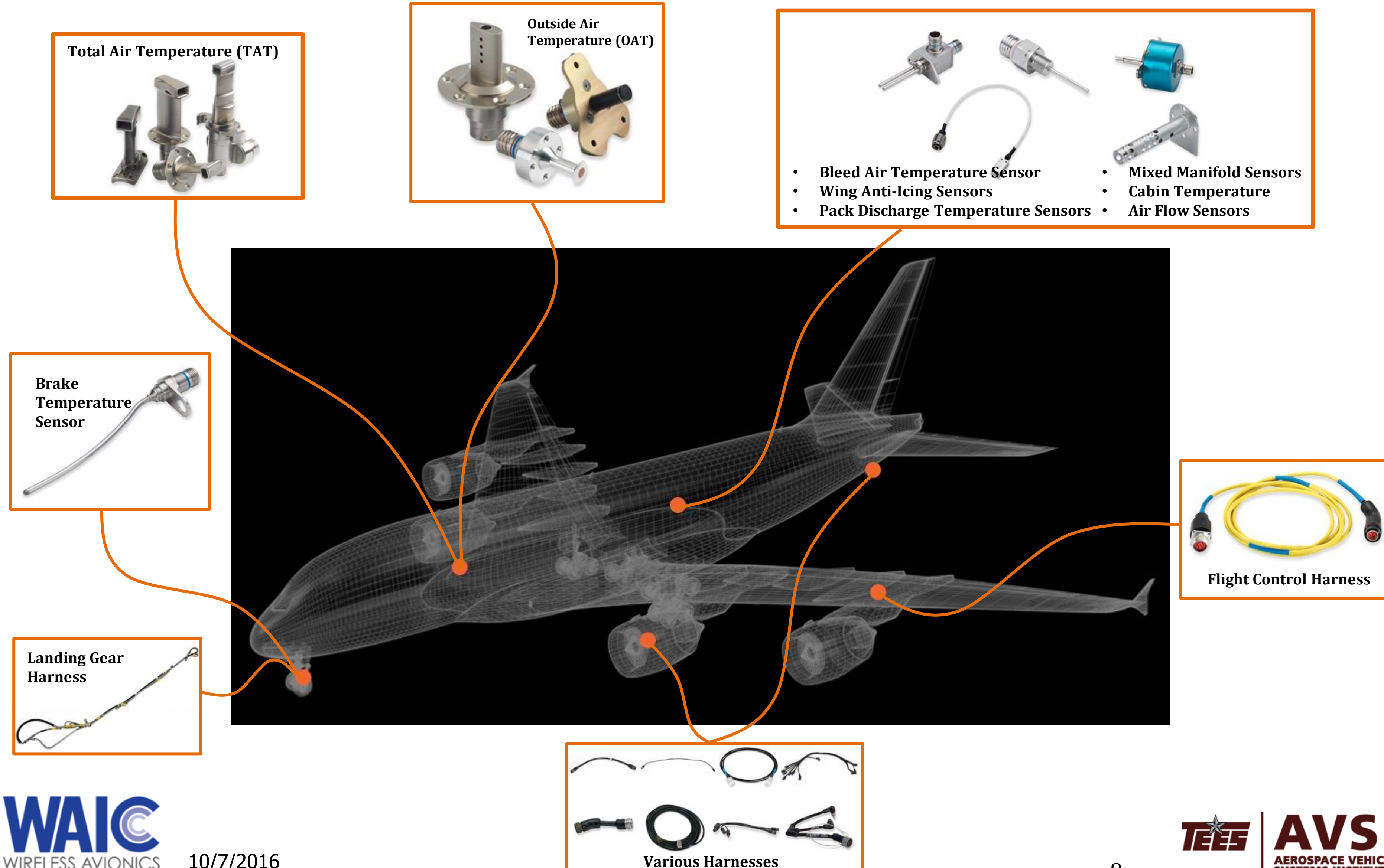


Fixed Wing Applications (Potential for wireless)



Conventional vs. Wireless Engine Sensor Technology-Advantages and Challenges

Pros and Cons of Wired Sensor Technology	
Pros	***Cons***
• Simple → Mechanical components only (wires, lugs, clamps and braid). • Repair harness is relatively simple. • Multiple wired links provides redundancy.	• Heavy (wiring). • Harness requires special nickel alloy conductors. • Installation of the harness is labor intensive, hence expensive to install/maintain.

Advantages to Wireless Sensors

- Lower purchase price
  - ✓ No harness, junction box required
- Lower cost of ownership
  - ✓ Reduction in weight due to absence of cable harness
  - ✓ Reduction in labor for installation/maintenance

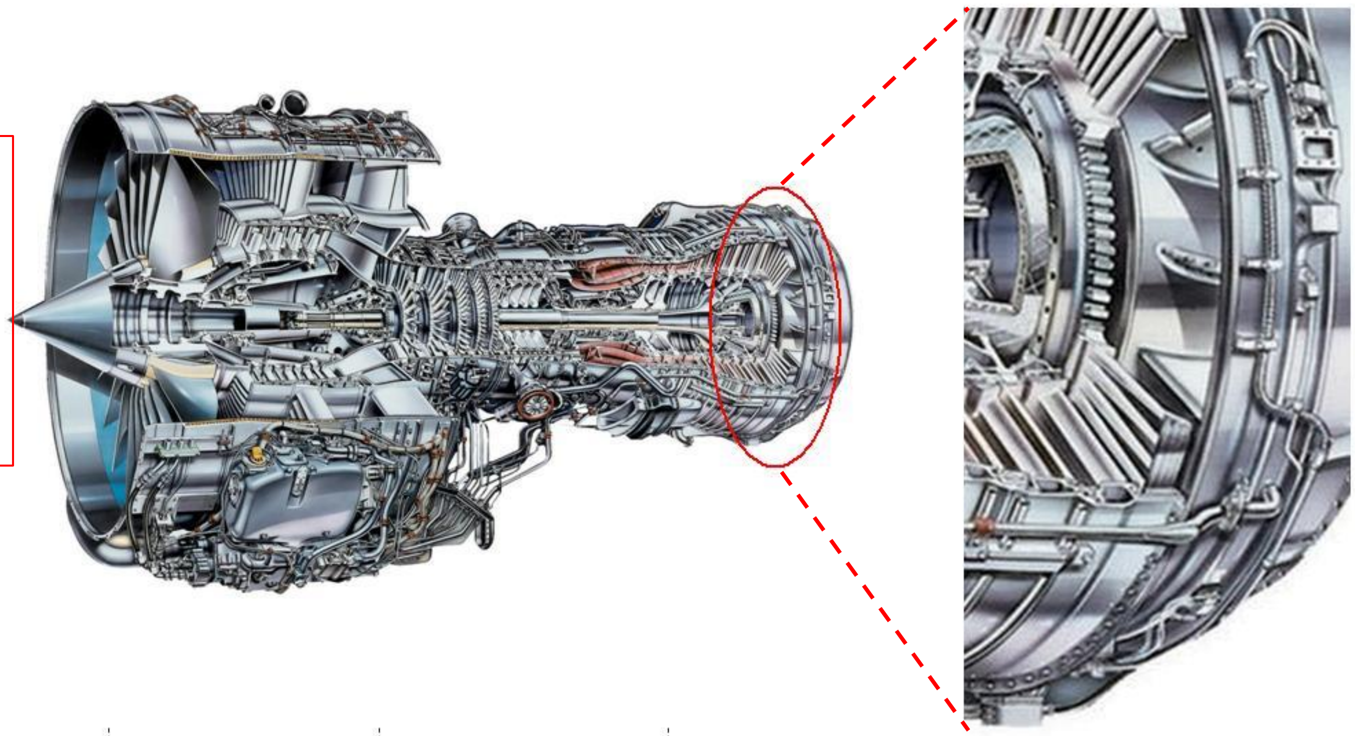
Challenges

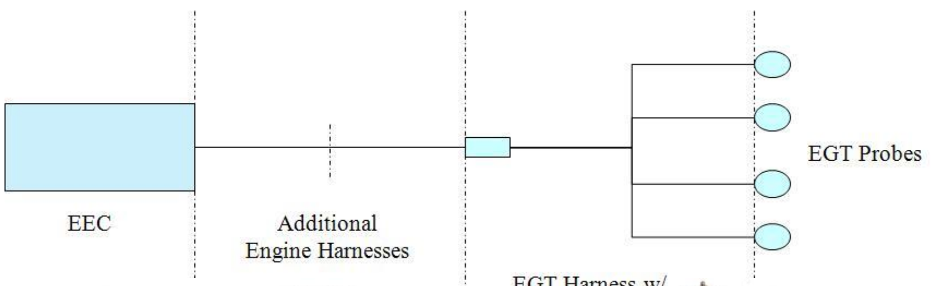
- High temperature environment (200-500°C) not suitable for conventional Si electronics
- Alternate electronics and power scheme required
- Make cost effective
- Reliability and MTBF

Example Wireless Engine Sensor Application - EGT

Challenges

- Harsh Environment
- How to Power?
- MTBF/Reliability?
- FADEC data rate requirement





Methods of Implementation?
Active vs. Passive Wireless Sensors

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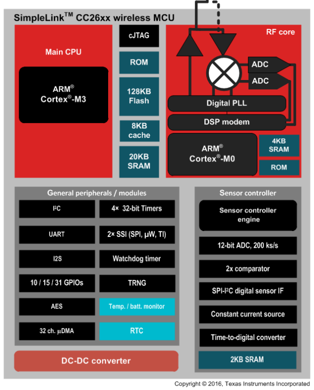
- Sensor technology dictated by application and location, *i.e.* engine, cabin, landing gear.

Active Wireless Sensor Technology	
Pros	***Cons***
• Capable of high-density integrated electronics. • Strong transmit signal, further communication range → less noise susceptibility. • Configurable RF modulation scheme and protocol.	• Processing power. • Supply power. • Limited operating temperature range and environment (RF design at extreme operating temperatures).

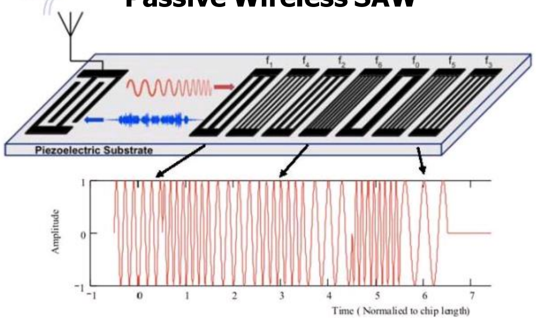
Passive Wireless Sensor Technology	
Pros	***Cons***
• Miniature size. • No need for external power source. • Potential for extreme environment operation employing high-temperature SAW substrates.	• Design could be more challenging, i.e. how to implement WAIC requirements of protocols, channelization, security, etc. • Limited communication range. • Must be paired with RF interrogator. • RF interrogator interference. • Will still electronics to survive DO-160 EMI, lighting, etc.

CC26xx Wireless MCU-Zigbee®



www.ti.com

Passive Wireless SAW



Malocha *et al.,* Sensors, 13, pp. 5897-5922, 2013

Wireless Avionics Intra-Communication (WAIC)

- ***WAIC*** – A cooperative of various aerospace industries and government agencies focused on developing wireless avionic systems.

<u>**The WAIC Team**</u>

- ❖ Airbus
- ❖ HarcoSemco
- ❖ Boeing
- ❖ Embraer
- ❖ GE Aviation
- ❖ Honeywell
- ❖ Rockwell Collins
- ❖ United Technologies
- ❖ NASA
- ❖ Thales

- Current Project focused on developing a set of system level requirements, protocol requirements, and recommendations aimed at accelerating the availability of WAIC-enabled applications.

WAIC Overview and Motivation

- **WAIC is:**
  - Radio-communication between two or more points on a single aircraft based on short range radio technology (< 100 m).
  - Part of a closed, exclusive network.
  - Only for safety-related applications.
  - Low maximum transmit power levels of 10 mW for low rate and 50 mW for high rate applications.

- **WAIC does not:**
  - Provide off-board air-to-ground, air-to-satellite, or air-to-air service.
  - Provide communications for passengers or in-flight entertainment.

- **Motivation:**
  - Goal is to add operational efficiencies and reduce the overall weight of systems; and include the ability to obtain more data from the aircraft systems and surfaces during all phases of flight.
  - The objective is to enhance efficiency and reliability while maintaining or improving current required levels of safety.
  - The intent is to NOT mandate equipage changes or to require additional costs to airlines.

ITU-R Report M.2283 contains technical characteristics and operational objectives for WAIC systems (update to M.2197)

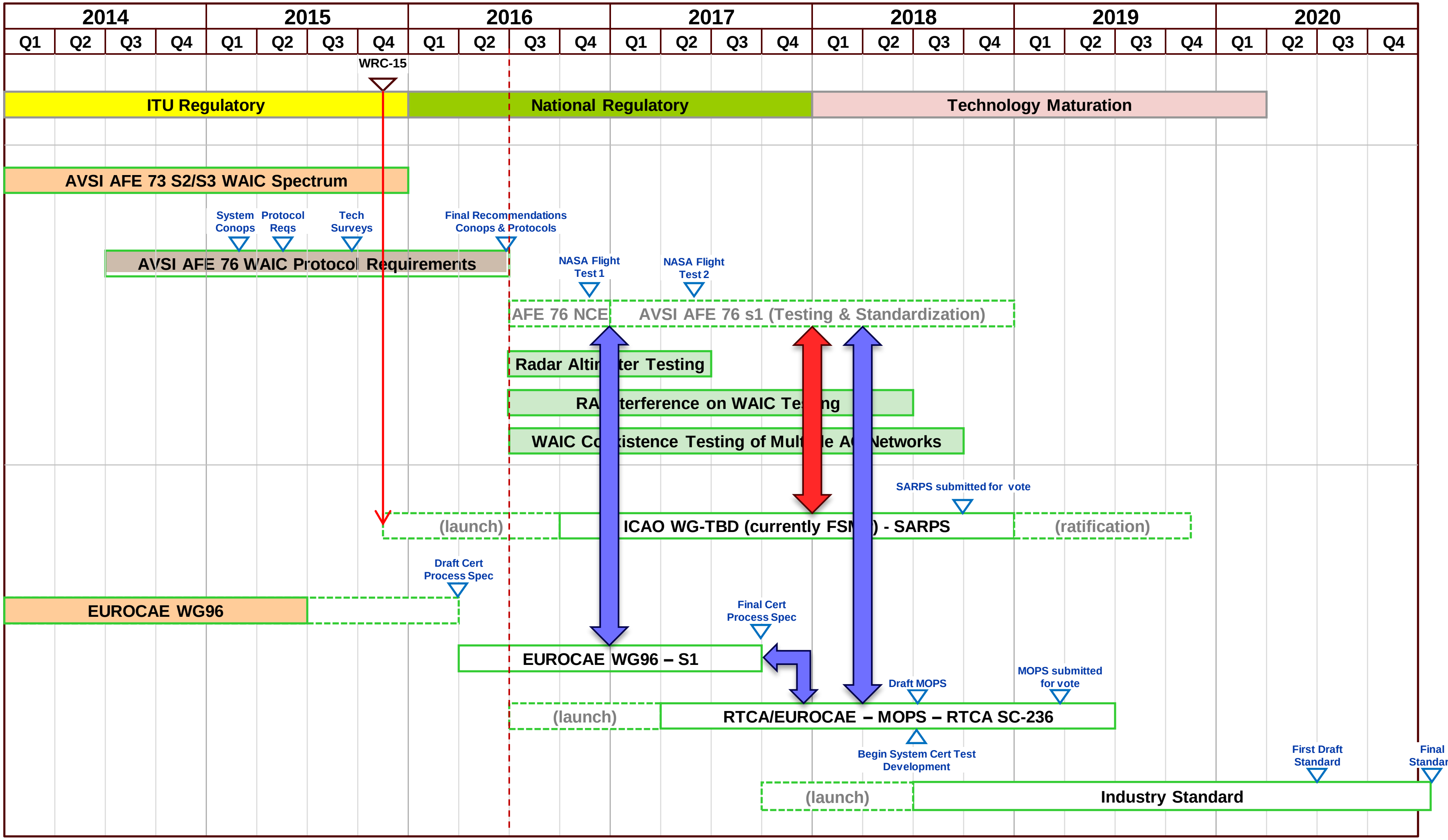
Importance of WAIC to Airlines

- **Safety Improvements:**
  - Provide dissimilar redundancy
  - Fewer wires means a reduction in connector pin failures, lower risk of cracked insulation & broken conductors.
  - Mesh networking could provide redundancy in emergencies.
- **Environmental Benefits:**
  - Reduced wiring and associated aircraft weight enables less fuel burn.
- **Increased Reliability**
  - Reduce amount of aging wiring
  - Simplify and reduce life-cycle cost of airplane wiring
  - Ability to obtain more data from aircraft systems and surfaces
  - Add new sensors and controls without additional wire routing
- **Provide operational efficiencies and associated cost savings.**
  - To monitor systems and surfaces that currently cannot be monitored without taking the aircraft out of service.
  - Enhance reconfigurability
- **~30% of wires are WAIC-substitution candidates**

AFE 76: Current Status

- Concept of Operations and Network Protocol documents completed.
- Revisions to begin January 2017.
- Radio altimeter testing planned at NASA to characterize interference to WAIC for purposes of protocol specification.
- RTCA Special Committee launched in June 2016 for MOPS development: SC-236 *“Standards for Wireless Avionics Intra-Communication System (WAIC) within 4200-4400 MHz”.*
- RTCA SC-236 working jointly with EUROCAE WG-96.
- SARPs are being developed through the ICAO process.

WAIC Roadmap

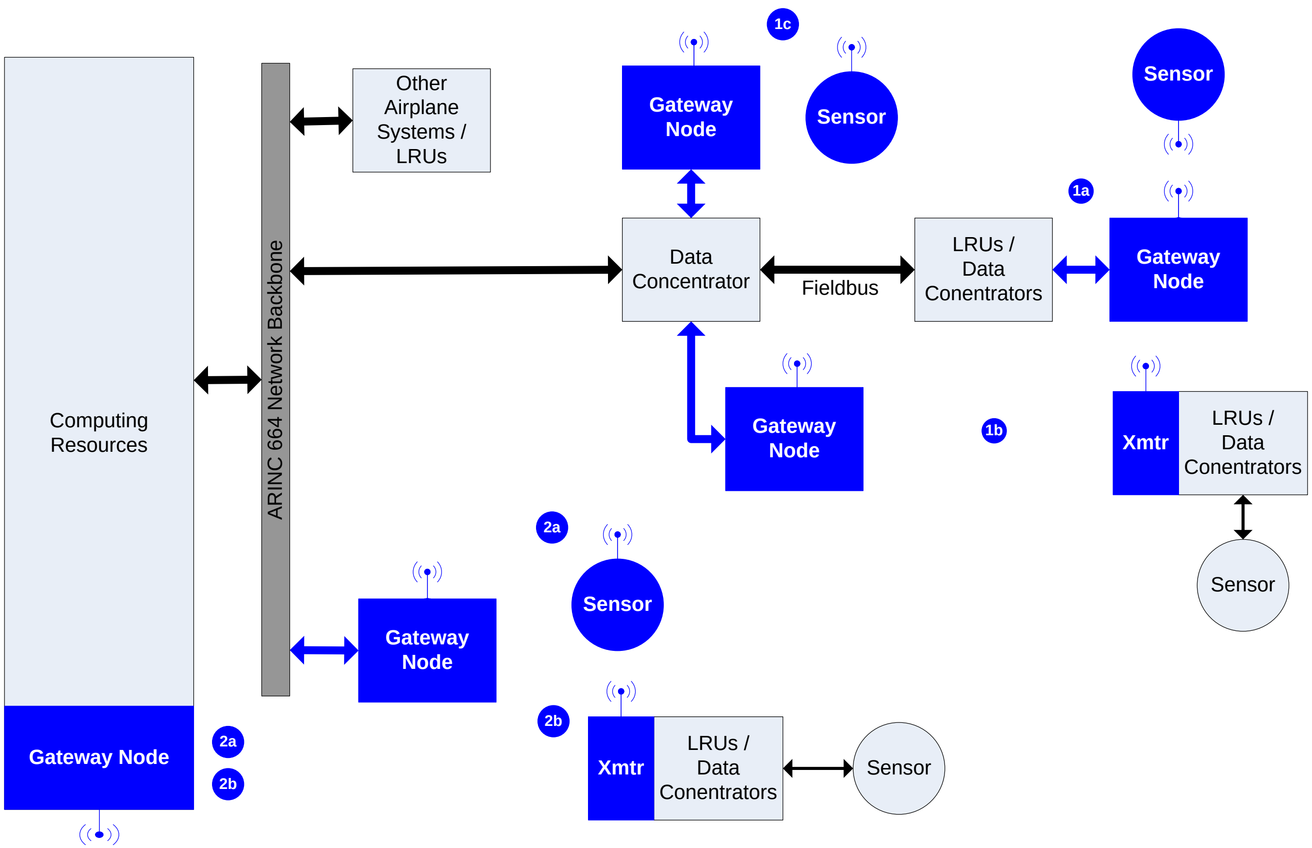


WAIC Classifications

- **Low Data Rate, Interior Applications (LI):**
  - Sensors: Cabin Pressure - Smoke Detection - Fuel Tank/Line – Proximity Temperature - EMI Incident Detection – Structural Health Monitoring - Humidity/Corrosion Detection
  - Controls: Emergency Lighting - Cabin Functions
- **Low Data Rate, Outside Applications (LO):**
  - Sensors: Ice Detection - Landing Gear Position Feedback - Brake Temperature - Tire Pressure - Wheel Speed - Steering Feedback - Flight Controls Position Feedback - Door Sensors Engine Sensors - Structural Sensors
- **High Data Rate, Interior Applications (HI):**
  - Sensors: Air Data - Engine Prognostic - Flight Deck/Cabin Crew Images/Video
  - Comm.: Avionics Communications Bus - FADEC Aircraft Interface - Flight Deck/Cabin Crew Audio / Video (safety-related)
- **High Data Rate, Outside Applications (HO):**
  - Sensors: Structural Health Monitoring
  - Controls: Active Vibration Control

WAIC Network Architecture

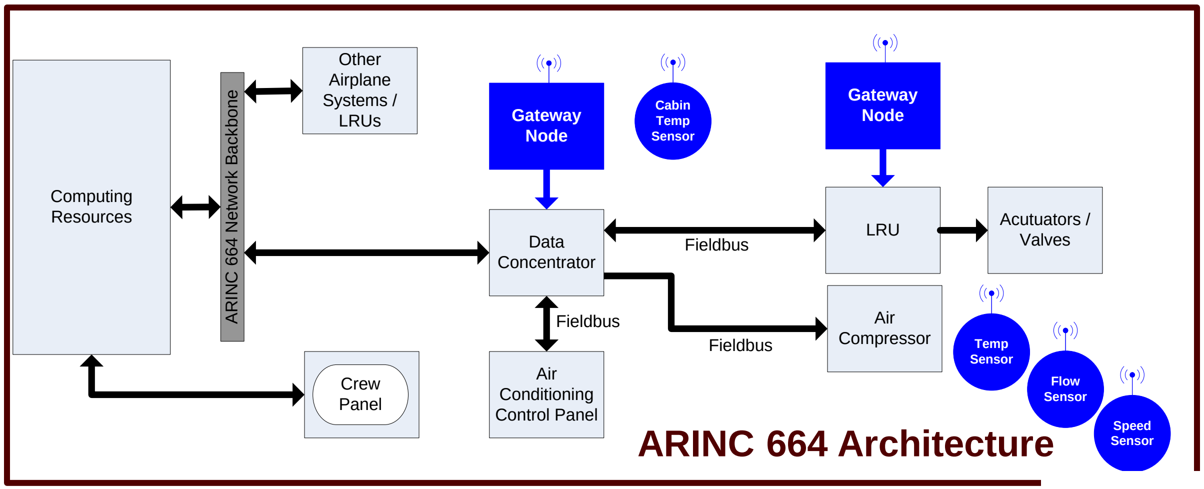
- WAIC Architecture on an ARINC 664 Network



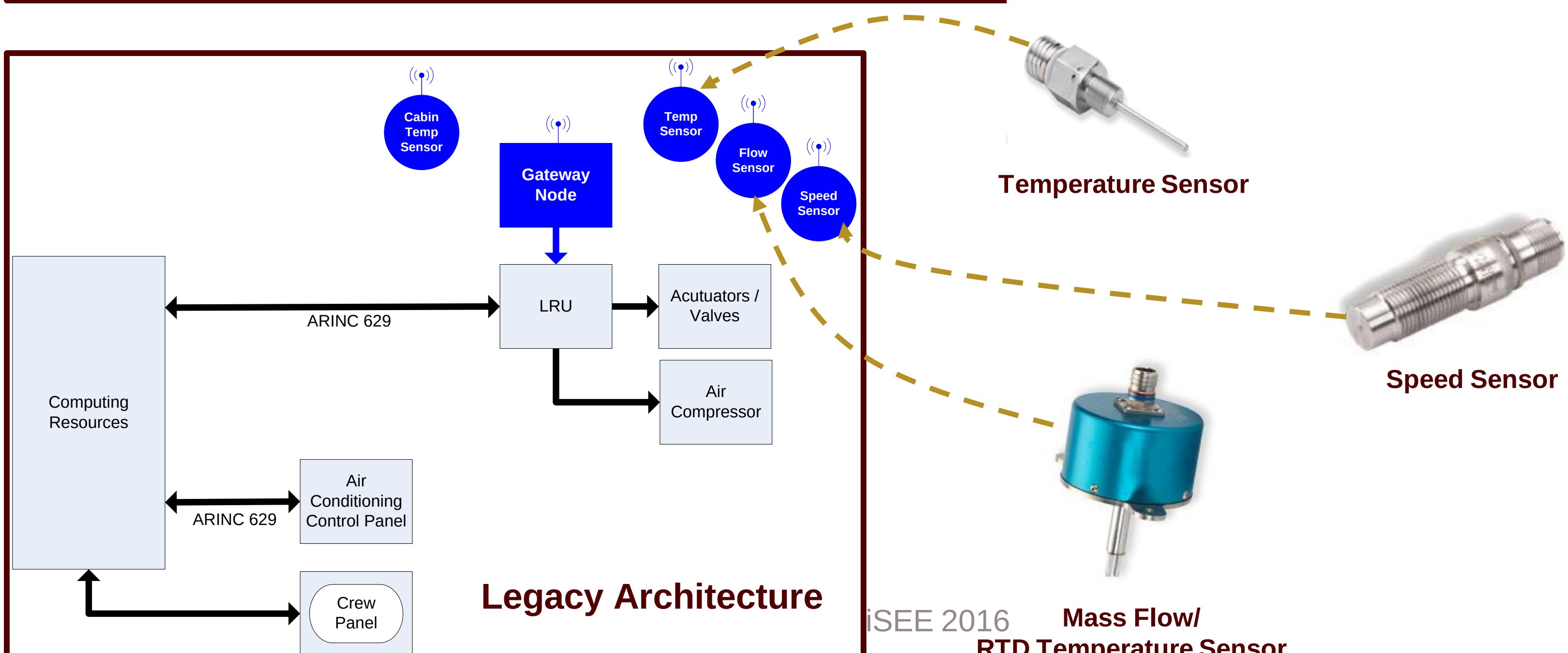
Scenarios

- (1a) would replace the wired sensor with a Gateway Node and wireless sensor combination.
- (1b) would keep the existing sensor and wired LRU interface intact. The LRU/Data Concentrator would be augmented to add WAIC capabilities.
- (1c) would replace the system LRU/Data Concentrator and wired sensor with a Gateway Node and wireless sensor combination.
- (2a) would replace the system LRU/Data Concentrator and wired sensor with a Gateway Node and wireless sensor combination.
- (2b) would keep the existing sensor and wired LRU interface intact. The system LRU/Data Concentrator would be augmented to add WAIC capabilities.

Example Cabin Interior WAIC System

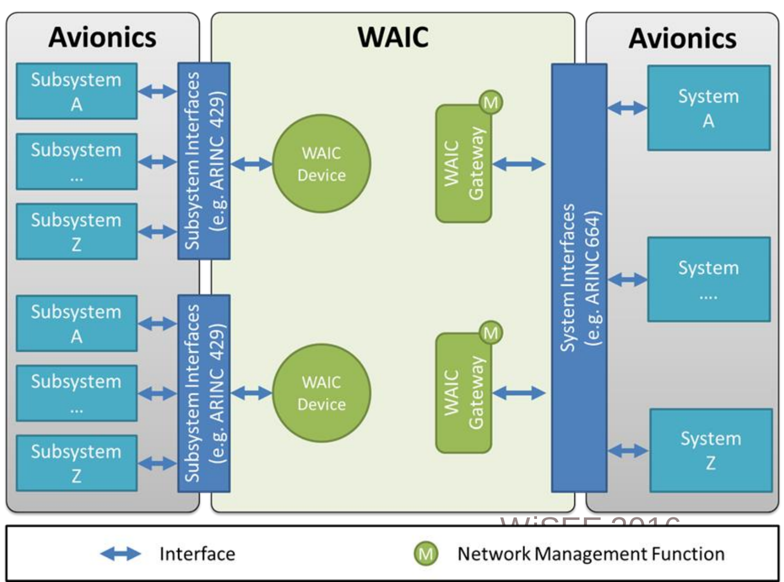


- WAIC on ARINC 664 Architecture, common field bus.
  - Wired sensors replaced with wireless sensors
- WAIC on Legacy Architecture
  - Wired sensors replaced with wireless sensors



WAIC Notional Architecture

- At least two WAIC Devices, one transmitting and one receiving.
- A WAIC device may serve as a wireless communication interface for multiple subsystems.
- *WAIC Gateway*:
  - Enables WAIC systems to communicate with other avionic systems connected to the wired aircraft network, but not part of the WAIC network.
  - Also used to route information between different WAIC devices.
- May serve as a wireless communication interface for multiple subsystems of different WEAS's.
- Controlled by a network manager→ Establishes control and data flow.



Nomenclature and Terminology
WEAS – WAIC-Enabled Avionics System
Shall – a mandatory action
Should – a strongly recommended action
May – an allowed action

WAIC Top-Level Requirements

- **Example Communication Requirements**
  - Must provide communication functionality for all WEAS’s
  - Each WAIC device or WEAS may have different data requirements.
  - Ability to meet delay boundaries required by WEAS.

- **Reliability and Determinism**
  - WEAS may require highly-reliable communication
  - Reliability requirements are WEAS dependent.
  - WAIC networks shall incorporate methods to guarantee communication reliability requirements for a particular WEAS.

- **Information Assurance**
  - In contrast to wired communications direct physical access is not required in order to manipulate wireless communications.
  - Thus, communication interfaces of WAIC networks are subject to potential information security threats. In this context, three general security threat conditions can be identified.
  - Threat Conditions → Confidentiality, Integrity, Availability

Radio Regulatory Requirements

- ***Spectral Efficiency***
  - MAC and PHY techniques, spectrally efficient transmission hardware and communication protocols.

- ***WAIC Radio Regulatory Provisions***

Req.	Description
R-1	WAIC network shall comply with the emission power level limits specified in the Radio Regulations.
R-2	WAIC networks shall only involve communication between WAIC devices located onboard the same aircraft; This shall not prohibit a WAIC network from detecting RF-energy emitted by WAIC networks onboard aircraft in proximity for the purpose of adapting its own transmission/reception characteristics.
R-3	WAIC devices should employ spectrally efficient network protocols, MAC and PHY techniques

Radio Regulatory Requirements

- ***RA Coexistence Requirements***
  - *Will be discussed next…*

Coexistence Requirements

- WAIC networks utilize a non-exclusive medium for communication.
- The radar altimeter (RA) band 4.2 – 4.4 GHz was promising since there was only one incumbent service.
- In consequence, WAIC network protocols have to ensure that WAIC networks and RA commonly using this frequency band can co-exist without causing mutual harmful interference.
- RA Interference causes deleterious effects such as:
  - Receiver Desensitization
  - Front End Overload
  - False altitude reports
  - Out of Band Interference
  - RA must meet ARINC-707 accuracy requirement of 1.5ft (2%) from -6.1 to 762 meters (-20 to 2,500 ft).

Resolution COM4/1 (WRC-15) - Protection/Precedence to RadAlts

RESOLUTION COM4/1 (WRC-15)

Use of Wireless Avionics Intra-Communications in the frequency band 4 200-4 400 MHz

The World Radiocommunication Conference (Geneva, 2015),

considering

a) that aircraft are designed to enhance their efficiency, reliability and safety, as well as to be more environmentally friendly;

b) that Wireless Avionics Intra-Communications (WAIC) systems provide radiocommunications between two or more aircraft stations integrated into or installed on a single aircraft, supporting the safe operation of the aircraft;

c) that WAIC systems do not provide radiocommunications between an aircraft and the ground, another aircraft or a satellite;

d) that WAIC systems operate in a manner that ensures the safe operation of an aircraft;

e) that WAIC systems operate during all phases of flight, including on the ground;

f) that aircraft equipped with WAIC systems operate globally;

g) that WAIC systems operating inside an aircraft receive the benefits of fuselage attenuation to facilitate sharing with other services;

h) that Recommendation ITU-R M.2067 provides technical characteristics and operational objectives for WAIC systems,

recognizing

that Annex 10 to the International Civil Aviation Organization (ICAO) Convention on International Civil Aviation contains Standards and Recommended Practices (SARPs) for safety aeronautical radionavigation and radiocommunication systems used by international civil aviation,

resolves

1 that WAIC is defined as radiocommunication between two or more aircraft stations located on board a single aircraft, supporting the safe operation of the aircraft;

2 that WAIC systems operating in the frequency band 4 200-4 400 MHz shall not cause harmful interference to, nor claim protection from, systems of the aeronautical radionavigation service operating in this frequency band;

3 that WAIC systems operating in the frequency band 4 200-4 400 MHz shall comply with the Standards and Recommended Practices published in Annex 10 to the Convention on International Civil Aviation;

4 that No. **43.1** shall not apply for WAIC systems,

instructs the Secretary-General

to bring this resolution to the attention of ICAO,

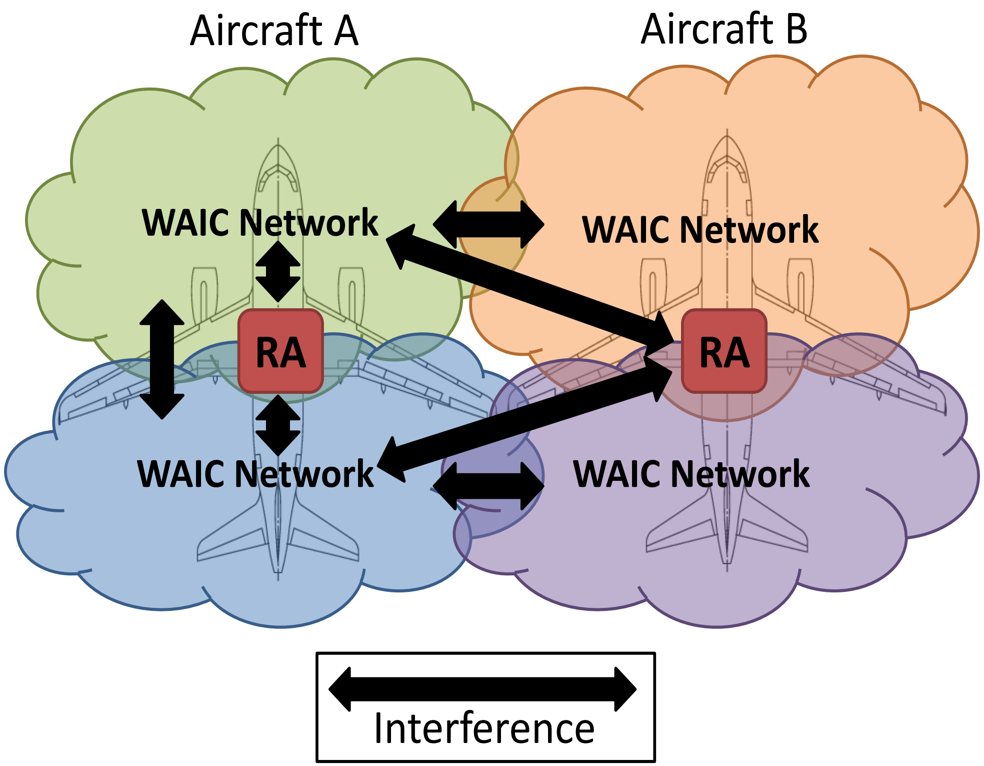
invites the International Civil Aviation Organization

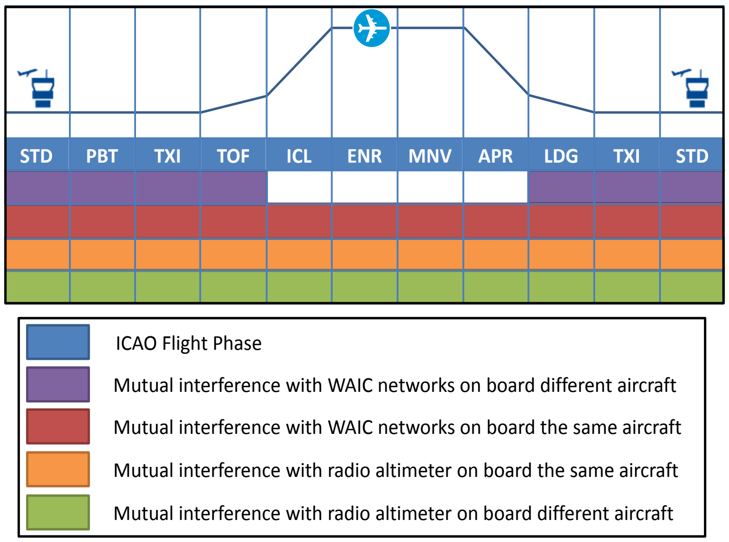
to take into account Recommendation ITU-R M.2085 in the course of development of SARPs for WAIC systems.

Key points of the Resolution

1. WAIC is defined as stations on-board a single aircraft and supporting safe operation of aircraft
2. WAIC must give protection and precedence to radio altimeters
3. WAIC must comply with ICAO SARPS – hence SARPS must be first developed

Coexistence Scenarios

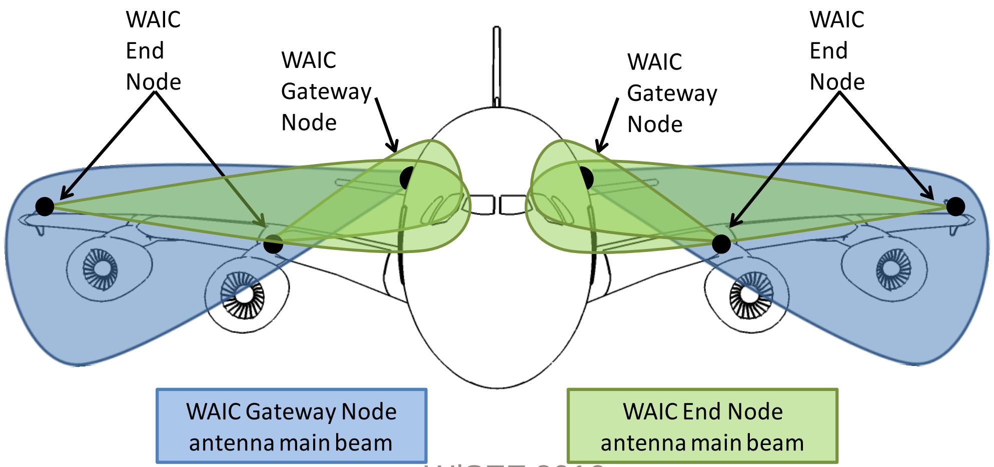




- Interference between RA's onboard aircraft equipped with WAIC.
- Interference between RA's onboard other aircraft within interference range.
- The latter is expected to arise during flight phases "Standing", "Pushback/Towing", "Taxi-Out", "Take Off", "Landing" and "Taxi-in".

Using Directional Antennas to Reduce Interference Effects

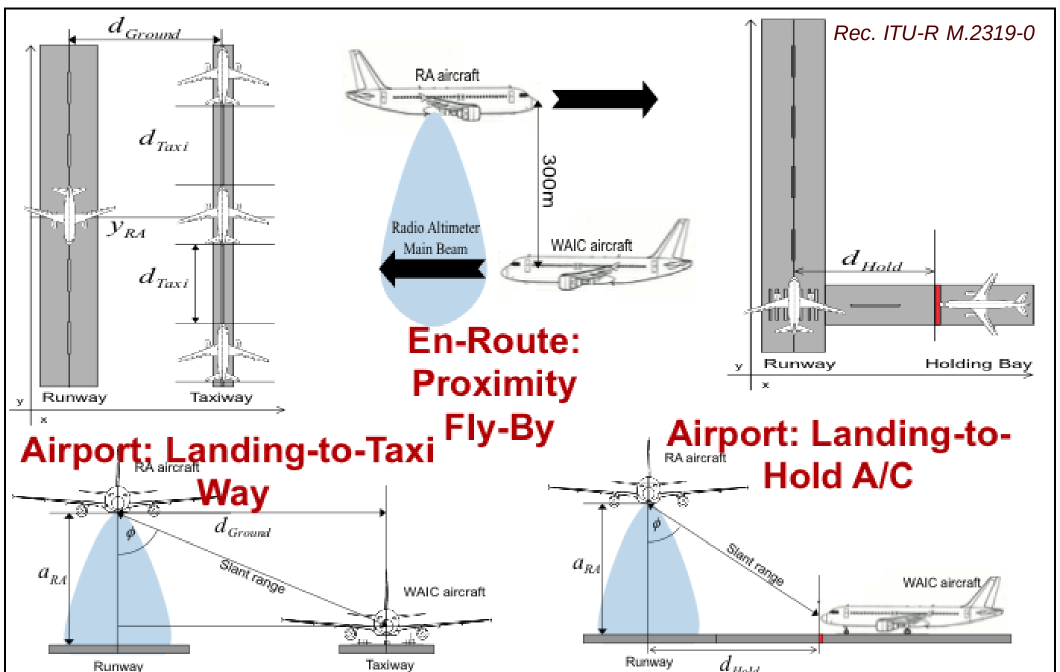
- **Compatibility Study:** Aircraft 1 outside WAIC system to Aircraft 2 RA.
  - Assumptions: Omni-directional antennas, single source interference.
  - **<u>Results:</u>** Additional measures (directional antennas) necessary.
- WAIC External Systems can shape the radiation pattern using directional antenna pattern controls as one potential mitigation technique for external WAIC systems.



Rec. ITU-R M.2319-0

Aircraft Shielding & Geometry Considerations

- **Case Study:** Assess in-flight and airport scenarios. Assume worst case (mainbeam-to-mainbeam)
  - *In-Flight Scenario* → WAIC aircraft in mainbeam of the other aircraft's RA.
  - Airport Scenario → Runway approach, WAIC AC taxiing.
    - Divided into taxiway and holding scenarios.
- Aircraft Shielding crucial to isolating WAIC Internal Systems from the Radio Altimeter without requiring additional mitigation techniques (35 dB).



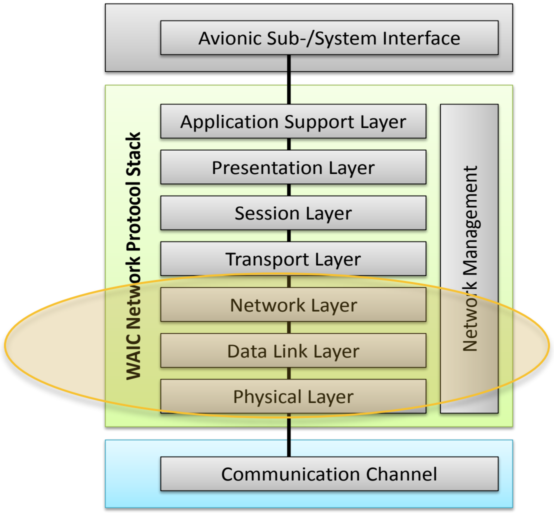
Studies were reported through ITU-R

- ITU-T Documents Finalized by Study Group 5
  - Generated for Agenda Item 1.17 in Working Party 5B
- Relevant ITU-R Recommendations and Reports:
  - Recommendation ITU-R M.2059
    - Radio Altimeter Protection Criteria, for non-interference analyses
  - Report ITU-R M.2283 – WAIC Technical Characteristics (replaces M.2197)
  - Recommendation ITU-R M.2067 – WAIC Characteristics Recommendation ITU-R M.[WAIC Conditions] –
    - recommends transmitter PSD limits – but not incorporated in Radio Regs
  - Report ITU-R M.2319 - WAIC_SHARING at 4 200-4 400 MHz
  - Report ITU-R M.2318 – WAIC Bands Studied below 15.7 GHz
  - Report ITU-R M.[WAIC_SHARING_22/23 GHz]
  - *Recommendation ITU-R P.525-2 – free space attenuation*

Standardization

Standardization is necessary for to ensure WAIC devices comply with radio regulations in the frequency band of 4.2 to 4.4 GHz.

- **Radio Regulation Compliance**
  - ICAO: Standards and Recommendation Practices (SARPS)
  - RTCA: Minimal Operational Performance Standard (MOPS)
- **PHY Layer**
  - RTCA/EUROCAE (MOPS)
  - ARINC / SAE / IEEE / ETSI
- **Lower Network Protocol (PHY and MAC)**
  - ARINC / SAE / IEEE / ETSI
- **Lower and Upper Protocol**
  - ARINC / SAE / IEEE / ETSI



Experimental flight testing scheduled in 2016/2017 to address co-existence of WAIC systems with radio altimeters.

Flight Testing Overview

- **Flight Test Objectives**
  - Analyze the in-band interference susceptibility of 3 commonly used radio altimeter manufacturers (Honeywell, Rockwell-Collins and Thales).
  - Thresholds of radio altimeter tolerance to WAIC signals that will aid in designing optimal WAIC signal types for coexistence.
  - A flight test validation of WAIC systems and radio altimeter systems coexistence to support ICAO and RTCA.
  - Test data to support definition and validation of WAIC waveform modulations, protocols and con-ops in AVSI AFE 76.
- **2 Initial Flight Test Phases**
  - ***Phase 1:*** Direct injection of representative WAIC signals into RadAlt receive antenna.
  - ***Phase 2:*** Distributive representative WAIC transmitters about the aircraft.

Note: Additional RadAlt ground scattering tests are also in preparation

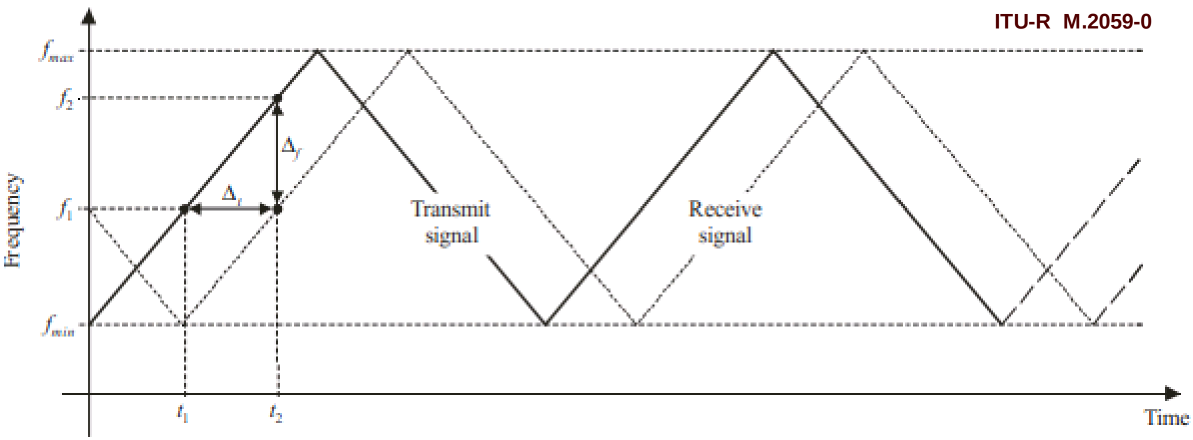
Flight Test Location

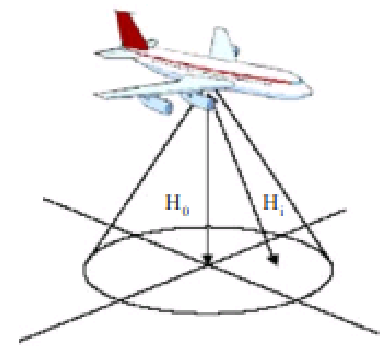
- **NASA Armstrong Flight Research Center**
  - *Edwards Air Force Base*, Palmdale CA

Radio Altimetry Background

- Operation can be frequency modulated continuous wave (FMCW) or pulsed.
- The difference between the transmit and receive frequencies (Δf) is proportional to the height of the aircraft.

Typical frequency modulated carrier wave radio altimeter transmitted and received signals





ITU-R M.2059-0

$$\Delta f = f2 - f1$$

Altitude Data Used For

- ✓ Automatic Flight Control
- ✓ Approach and Landing
- ✓ Ground Proximity Warning
- ✓ Terrain Awareness and Warning

- Knowing either Δ t or Δf , height can be calculated

$$H_0 = \frac{c\Delta t}{2} = \frac{c\Delta f}{2(\frac{df}{dt})}$$

where:

H_0 = height above the terrain (m)
c= speed of light (m/s)
Δt = measured time difference (s)
Δf = measured difference in frequency (Hz)
df/dt = transmitters frequency shift per unit time (Hz/s)

Protection Criteria

- ✓ Receiver overload
- ✓ Desensitization
- ✓ False altitude generation
- ✓ Out-of-band/in-band interference

Radio Altimeters Used for Testing

(1)

Rockwell Collins LRA-2100	
Dimensions	L = 15.6”, W = 3.64”, H = 7.7”
Weight	8.47 lb nominal (8.8 lb max.)
Input Power	115 V AC ±10%, 360 to 800 Hz
Mounting	ARINC 600
Software	DO-178A

(2)

Rockwell Collins LRA-900	
Dimensions	L = 15.6”, W = 3.64”, H = 7.7”
Weight	9.6 lbs
Input Power	115 V AC ±10%, 380 to 420 Hz
Mounting	ARINC 600
Software	DO-178A

(3)

Thales ERT-530	
Dimensions	L = 15.6”, W = 3.64”, H = 7.7”
Weight	< 9.93 lbs
Input Power	115 V AC 400 Hz
Mounting	ARINC 600
Certifications	DO-155/178A,/160B

(4)

Thales ERT-550	
Dimensions	L = 15.6”, W = 3.64”, H = 7.7”
Weight	< 9.93 lbs
Input Power	115 V AC 400 Hz
Mounting	ARINC 600
Certifications	DO-155/178A,/160B

(5)

Honeywell ALA-52B	
Dimensions	L = 15.6”, W = 3.64”, H = 7.7”
Weight	8.6 lb
Input Power	+28 VDC
Mounting	ARINC 600
Software	DO-178B, LA

Test Aircraft: Gulfstream G3


https://www.nasa.gov/centers/armstrong/multimedia/imagegallery/G-III_Aerodynamics/index.html

- Business jet developed by Gulfstream Aerospace.
- Equipped with 2 Radio Altimeters.
  - Primary → Thales ERT-530A
  - Secondary → Thales ERT-530A

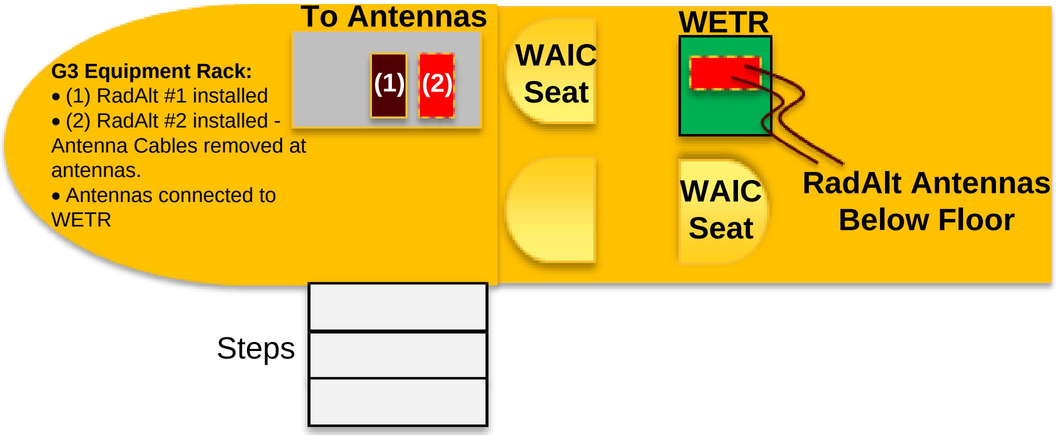
General characteristics

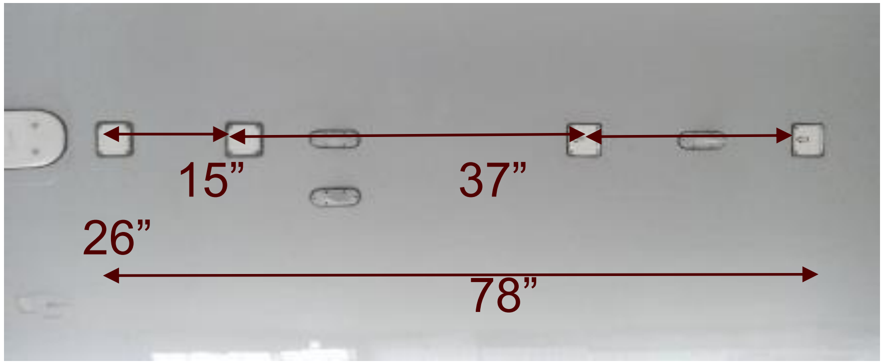
- ✓ **Crew:** Two or three
- ✓ **Capacity:** 19 passengers (standard seating)
- ✓ **Length:** 83 ft 1 in (25.32 m)
- ✓ **Wingspan:** 77 ft 10 in (23.72 m)
- ✓ **Height:** 24 ft 4½ in (7.43 m)
- ✓ **Wing area:** 934.6 sq ft (86.83 m²)
- ✓ **Aspect Ratio:** 6.0:1
- ✓ **Empty Weight:** 38,000 lb (17,236 kg)
- ✓ **Max. Takeoff Weight:** 69,700 lb (31,615 kg)
- ✓ **Engine:** 2 × Rolls-Royce Spey RB.163 Mk 511-8 Turbofan, 11,400 lbf (50.7 kN) each

Performance

- ✓ **Maximum speed:** 576 mph (501 knots, 928 km/h) (max cruise)
- ✓ **Cruise speed:** 508 mph (442 knots, 818 km/h) (long range cruise)
- ✓ **Service ceiling:** 45,000 ft (13,716 m)
- ✓ **Rate of climb:** 3,800 ft/min (19.3 m/s)

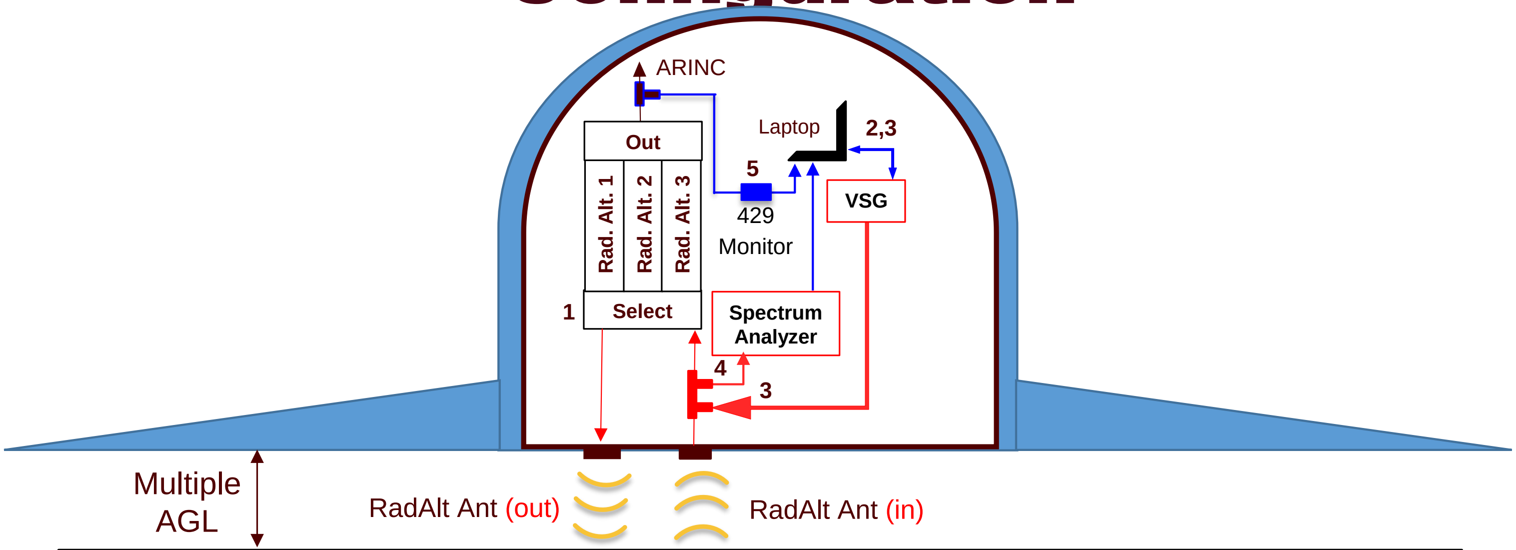
Gulfstream 3 – Tail #808 Floor Plan





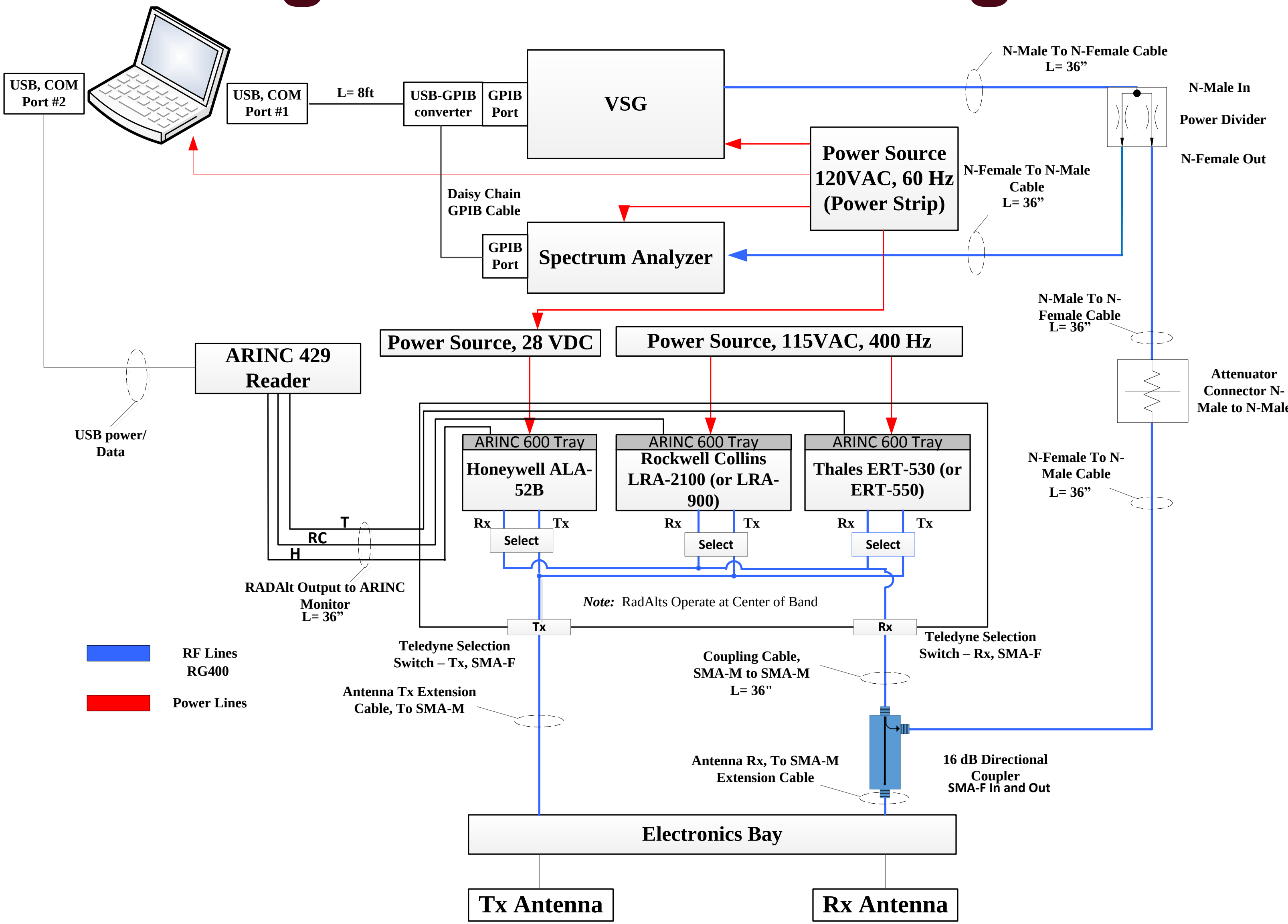
- Gulfstream 3 Floor Plan with WAIC Test Rack.
- WAIC Test Rack replaces aircraft seat on the starboard side.
- RadAlt #2 disconnected, antennas used with WAIC test rack.

Phase 1 Flight Test Aircraft Configuration



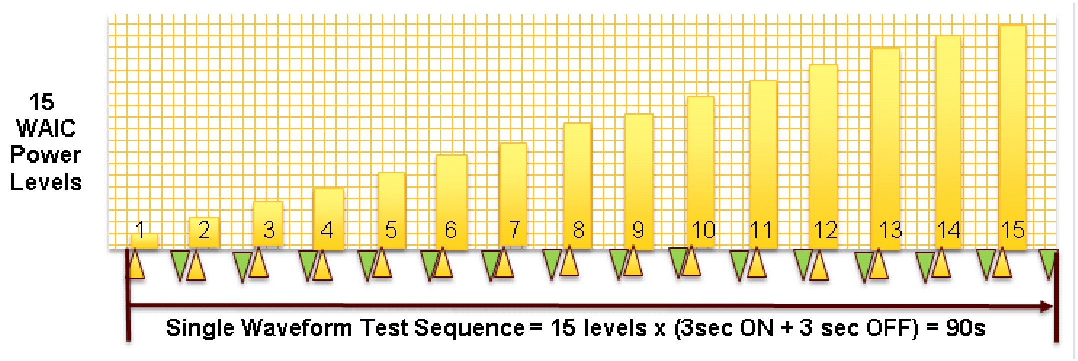
1. WETR with 3 Rad. Alts, TX/RX antenna wires connected to Teledyne RF switches.
2. Vector Signal Generator is loaded with WAIC files before flight from laptop.
3. Laptop script (parameter changes) drives the VSG to output WAIC files with frequency and magnitude changes, accounting for loss from Directional Couplers.
4. Laptop captures Spectrum Analyzer screen/data which monitors the combined RadAlt(In)+WAIC signal input to Radar Altimeter.
5. Laptop monitors 429 bus with an ARINC bus monitor.

Flight Test Block Diagram



Radio Altimeter Test Scenarios

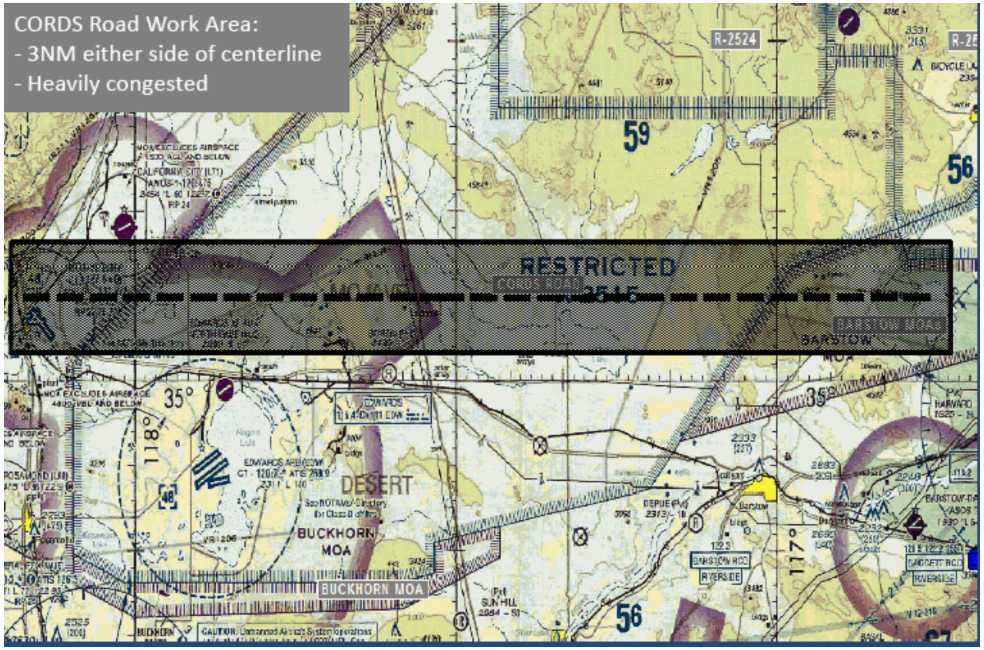
- **For constant AGL:** Record the effect of WAIC interference on each of 5 RadAlts at 5 altitudes.
  - 4 waveform types will be evaluated:
    - 2 Continuous Phase Signals (MSK)
    - 2 Orthogonal Frequency Division Multiplexing Signals (OFDM)
  - Waveforms will be increased in 15 (1dB) steps with signal power ON and OFF for each step.



  - Specific events to be noted:
    - First instance of radio altimeter output to differ between the ON and OFF state.
    - Altimeter accuracy just meets DO-155 specification for that altitude.
    - Altimeter loses lock (Null Acquisition Mode)

Flight Test Area

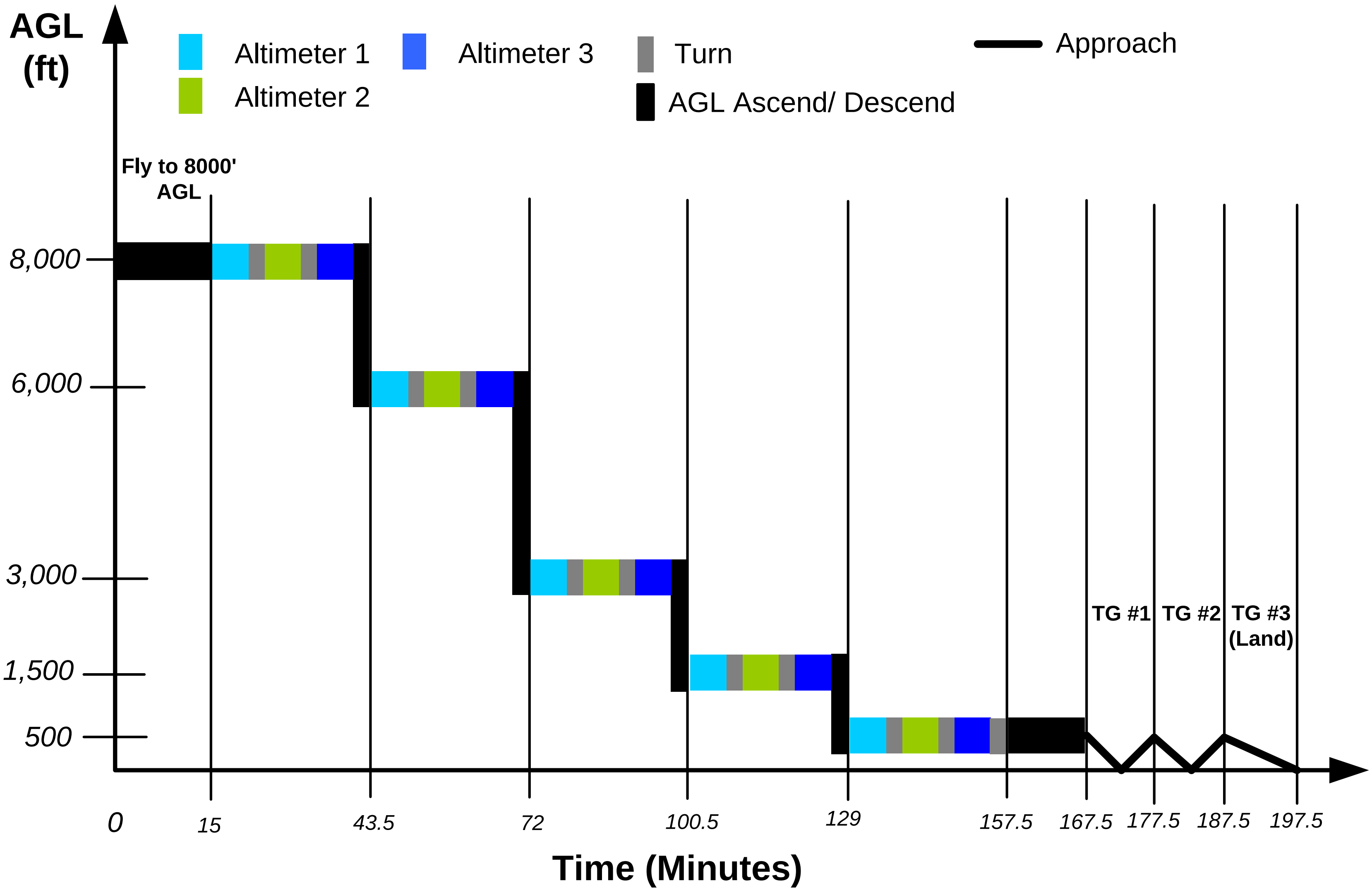
- R-2515, CORDS Road, north of Edwards Air Force Base.
- 40 NM legs, 3 NM either side of the center line.
  - 13.33 minute legs at 180 knots, 16.55 minute legs at 145 knots.
  - 3 minute turns for “dog-bone” flight path.
- 15 minutes flight to start point.



Flight Test Profile

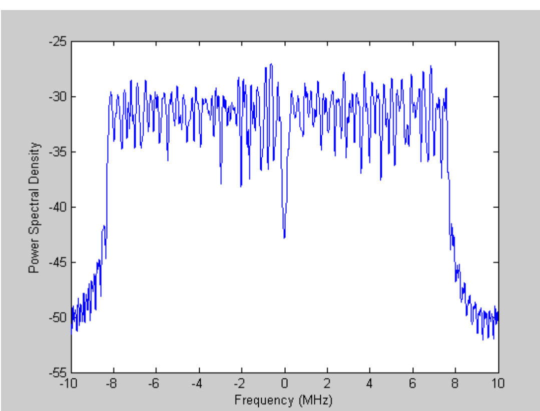
- **Start**
- **Fly to start point:** Set altimeter 1, waveform 1 ~**15 minutes**
- **Each Altitude:**
  - **Altimeter 1**
    - For 4 Waveforms: (1.5 minutes*4) + (10 sec. waveform switch*3) = **6.5 Min.**
    - Turn, switch to waveform 1, switch to altimeter 2 = **3 Min.**
  - **Altimeter 2**
    - For 4 Waveforms: (1.5 minutes*4) + (10 sec. waveform switch*3) = **6.5 Min.**
    - Turn, switch to waveform 1, switch to altimeter 2 = **3 Min.**
  - **Altimeter 3**
    - For 4 Waveforms: (1.5 minutes*4) + (10 sec. waveform switch*3) = **6.5 Min.**
    - Turn + Descend, switch to waveform 1, switch to altimeter 2 = **3 Min.**
  - **Total Time Per Altitude: <u>28.5 Min.</u>**
- **3 Altimeters over 5 Altitudes:** 28.5 Min. x 5 altitudes = **142.5 Min.**
- **Fly and settle to approach #1 position**: ~**10 Min.**
- **Touch and go's (500 ft AGL):** 10 minutes each x 3 = **30 Min.**
- **Total time, 3 altimeters:** 142.5 + 10 + 30 = **<u>182.5 Min.</u>**
- **End**

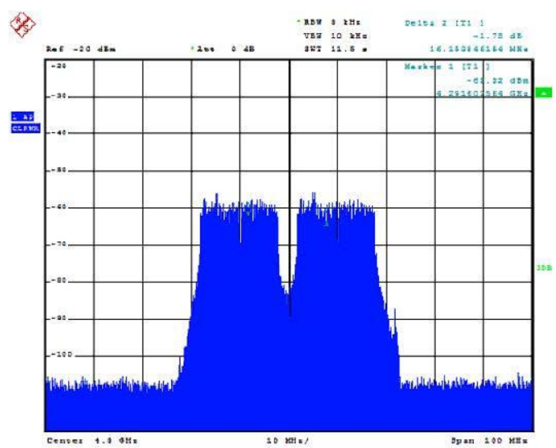
Flight Test Profile

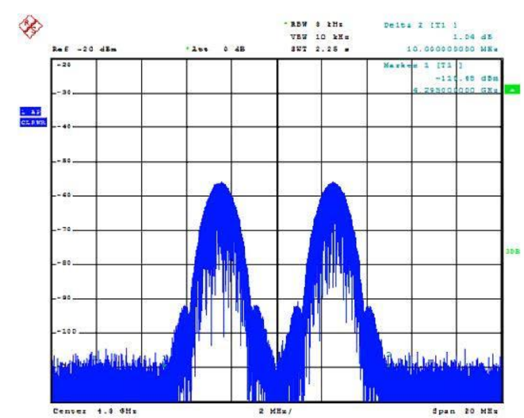


Signal Generation for Injection

- MATLAB OFDM simulated baseband signal loaded into vector signal generator.
- Based on the IEEE 802.11 parameters; 52 subcarriers, 312.5 kHz carrier separation, 20 MHz bandwidth and 16 MHz occupied bandwidth, 20 Msps (3.2 µs data symbol duration with a 0.4 µs guard length).
- OFDM (Left) and MSK (Right).
- Center frequency – Center of band, 4.3 GHz







Conclusions and Future Direction

- The WAIC team is actively engaged with the regulatory agencies (ICAO, RTCA, EUROCAE) to develop a standardized set of technical requirements which will allow WAIC to coexist with on-board radio altimeters and provide a cost-effective, reliable alternative to wired aircraft systems.
- AFE-76 is actively engaged in network protocol and MOPS/SARPS development.
- Location of WAIC sensors will dictate sensor technology (active/passive)
- Low power radios preferred where energy is scarce.
- Implementation of WAIC systems strive to reduce cost to the airlines, enhance aircraft safety and provide redundancy through wireless links.
- Complete “Phase 1” flight testing, continue with “Phase 2” testing and prototype development.

Thank You

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