National Aeronautics and Space Administration

Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

UAS Control and Non-Payload Communication (CNPC) System Prototype Status

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I-CNS
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NASA – Rockwell Collins Cooperative Agreement

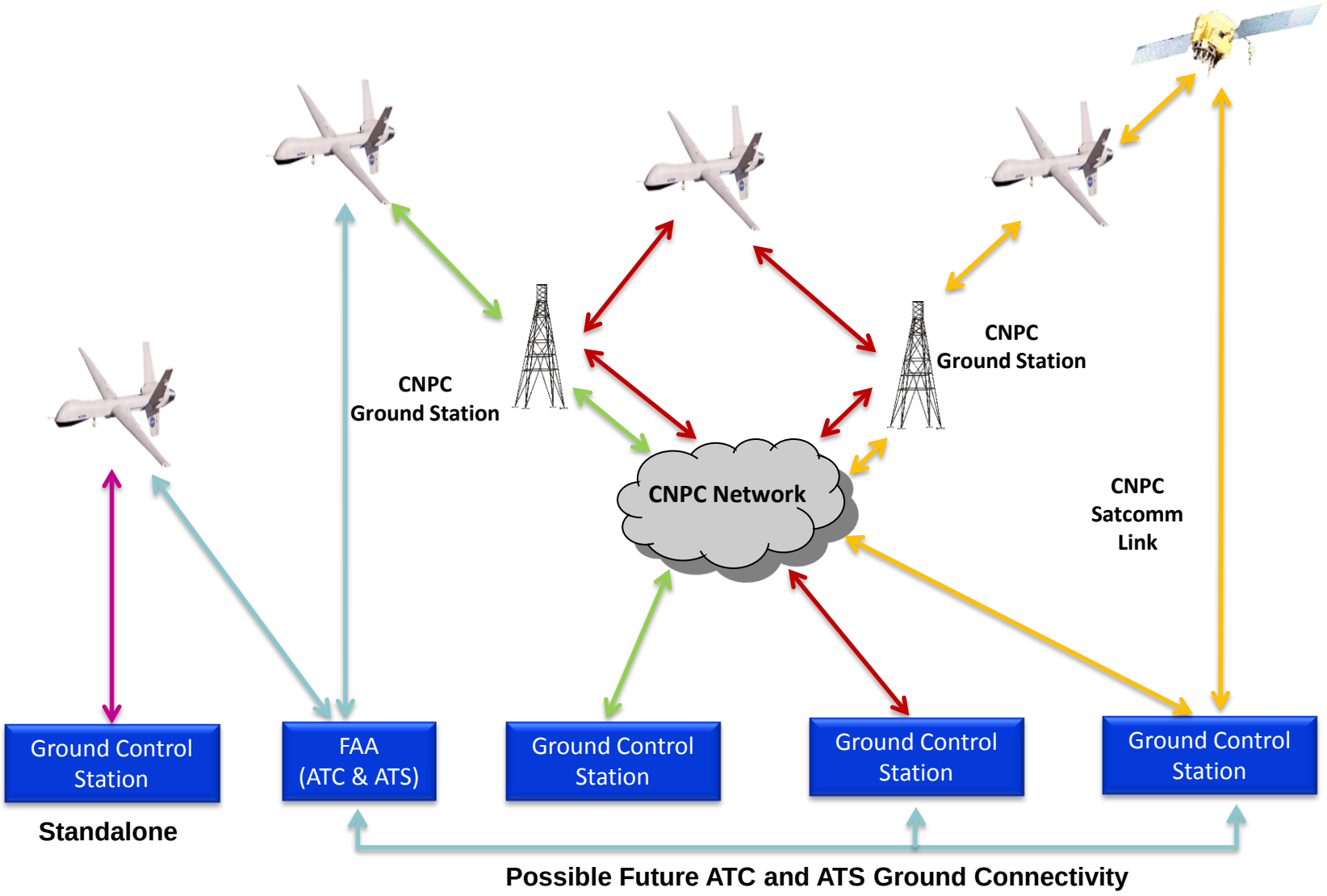
On Nov 1, 2011, NASA initiated a three-year shared resource cooperative agreement with Rockwell Collins to demonstrate and support the further development of a Unmanned Aircraft CNPC System.

- Develop both ground and airborne prototype CNPC radios to provide a basis for validating and verifying proposed RTCA SC-203 CNPC system performance requirements.
- Demonstrate a complete CNPC system, including interfacing to a ground based pilot station, transmission of CNPC data to/from more than one ground station, and onboard reception and transmission of CNPC data on more than one UA.

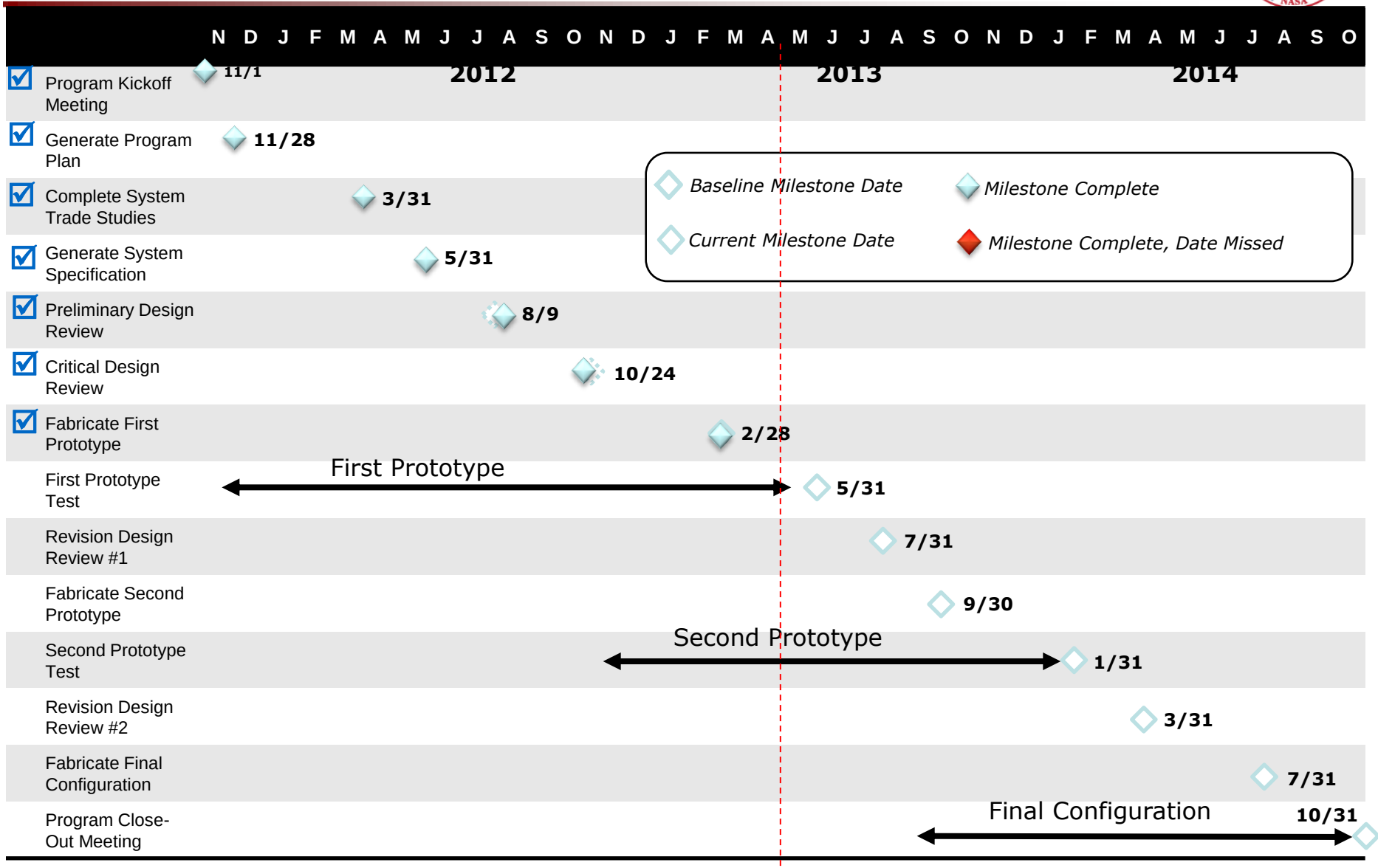
NASA – Rockwell Collins Cooperative Agreement

- Specific Rockwell Collins tasks include:
  - Identify signal waveforms and access techniques appropriate to meet CNPC requirements within the potential UAS CNPC frequency bands in a manner which efficiently utilizes the spectrum compatibly with other co- and adjacent channel bands services.
  - Develop radios capable of enabling CNPC system testing and validation.
  - Perform relevant testing and validation activities.
- The radios must operate in UAS radio frequency spectrum
  - 5030 MHz – 5091 MHz (C band)
  - 960 MHz – 977 MHz (L band)
- Multiple ground stations and multiple aircraft must be supported.

Concept Civil UAS Communication Architecture



Cooperative Agreement Milestone Status



Waveform Trade Study

Seed Requirements (SC-203)

Requirement	Source
Radios must operate in frequency bands 960 – 977 MHz (L band) and 5030 – 5091 (C band)	NASA Contract SOW
L band and C band operations must be independent	NASA Contract SOW
RF link availability for any single link >= 99.8% Availability for simultaneous operation of L band and C band >= 99.999%	RTCA SC-203 CC016
Non-proprietary waveform	NASA Contract SOW
Must operate both air-to-ground and ground-to-air modes	NASA Contract SOW
Aircraft density assumptions Small UAs = 0.000802212 UA/ km^2 Medium UAs = 0.000194327 UA/ km^2 Large UAs = 0.00004375 UA/ km^2	ITU-R M.2171 P.54
Cell Service Volume Radius = 75 miles (L-Band)	RTCA SC-203 CC016
Maximum number of UAs supported per cell = 20 (basic services) Maximum number of UAs supported per cell = 4 (weather radar) Maximum number of UAs supported per cell = 4 (video)	RTCA SC-203 CC016
Tower height = 100 feet	RC Assumption
Uplink Information Rates (Ground-to-Air) Small UAs = 2424 bps Medium and Large UAs = 6,925 bps	ITU-R M.2171 Table 13
Downlink Information Rates (Air-to-Ground) Small UAs (basic services only) = 4,008 bps Medium and Large UAs (basic services only) = 13,573 bps Medium and Large UAs (basic and weather radar) = 34,133 bps Medium and Large UAs (basic, weather radar and video) = 234,134 bps	ITU-R M.2171 Table 13
Frame rate must support 20 Hz to enable real time control	ITU-R M.2171 Table 23/24
Aviation Safety Link Margin = 6 dB	RTCA SC-203 CC016
Airborne radio transmit power = 10 W	RTCA SC-203 CC016

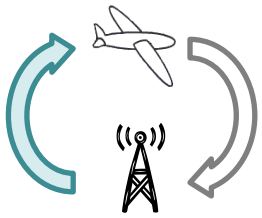
Technology Candidates, Criteria, & Scoring

Evaluation Criteria	System Level Factors Addressed	Downlink Multiple Access Candidates		
		CDMA	FDMA	TDMA
Link Margin at Full Capacity	Availability	Unacceptable	Reference	-13 dB for identical PA
Airborne Transmitter Power	SWAP, Cost, Complexity	10 Watts peak	10 Watts peak	200 Watts peak
Multipath Mitigation	Availability, Cost, Complexity	Link margin, spreading, RAKE processing	Link margin	Link margin, adaptive equalization
Synchronization Required	Cost, Complexity	None beyond that required for TDD	None beyond that required for TDD	Tight synchronization for low guard time overhead
Power Control Required	Cost, Complexity	Tight control mitigates near-far problem, 10-20% added complexity	Gross control mitigates near-far problem	Gross control beneficial but not required
Ground Signal Processing Complexity	SWAP, Cost, Complexity	10-20% added complexity	10-20% added complexity	Reference

Results

Ground-To-Air Link

Time Division Multiple Access
Constant Envelope
Binary Modulation Order



Air-To-Ground Link

Frequency Division Multiple Access
Constant Envelope
Binary Modulation Order

Time Division Duplexing

Datalink Technology Evaluation

Evaluation Criteria

Category	Criteria
Air/ground comm	Taxi / Surface / Preflight / Postflight Takeoff / Landing / Terminal En Route
Data Transmission	Addressed capability Repetition rate Command/Control Command/Control and ATC relay Command/Control, ATC relay, and surveillance
Mobility	Handoff Dynamic power control Adaptive modulation rates Active QoS returning
Security	Confidentiality Integrity Availability
Traffic QoS	Traffic cross-carrier distribution Traffic priority Traffic classes Traffic reliability/ARQ Dynamic bandwidth allocation RF statistics reporting
Certification / complexity	Technology Readiness Level Certification Risk Robustness Determinism Link Layer Compatibility
Waveform	Duplexing (TDD/FDD) Uplink multiplexing Downlink multiplexing Uplink modulation Downlink modulation

Technologies

Technology Family	Candidates
Cellular Telephony Derivatives	TDMA (IS-136), CDMA (IS-95A), CDMAone (IS-95B), GSM/GPRS/EDGE, CDMA2000, EV-DO, EV-DV, UMTS (W-CDMA, TD-CDMA, TD-SCDMA), LTE, DECT, Mobitex, Flash-OFDM
IEEE 802 Wireless Derivatives	IEEE 802.11, 802.15, 802.16, 802.20, ETSI HiperPAN, HiperLAN, HiperMAN
Public Safety and Specialized Mobile Radio	P-25, P-34, TETRA, TETRA Release 2 (TAPS, TEDS), TETRAPOL, EDACS, iDEN, IDRA, Project MESA
Custom Civil / Aeronautical Solutions	HF Data Link, ACARS, VDL Mode 2, VDL Mode 3, VDL Mode 4, VDL Mode 8, E-TDMA, ADL, B-VHF, UAT, Mode S, Gatelink, AMACS, LDL, L-DACS 1, L-DACS 2, STANAG 4660
Military	JTIDS/MIDS/JRE (Link 16), SINCGARS, EPLRS, HAVEQUICK, JTRS
APC Telephony	Airphone, AirCell, SkyWay

Scoring

No datalink technology is a perfect match for the CNPC system

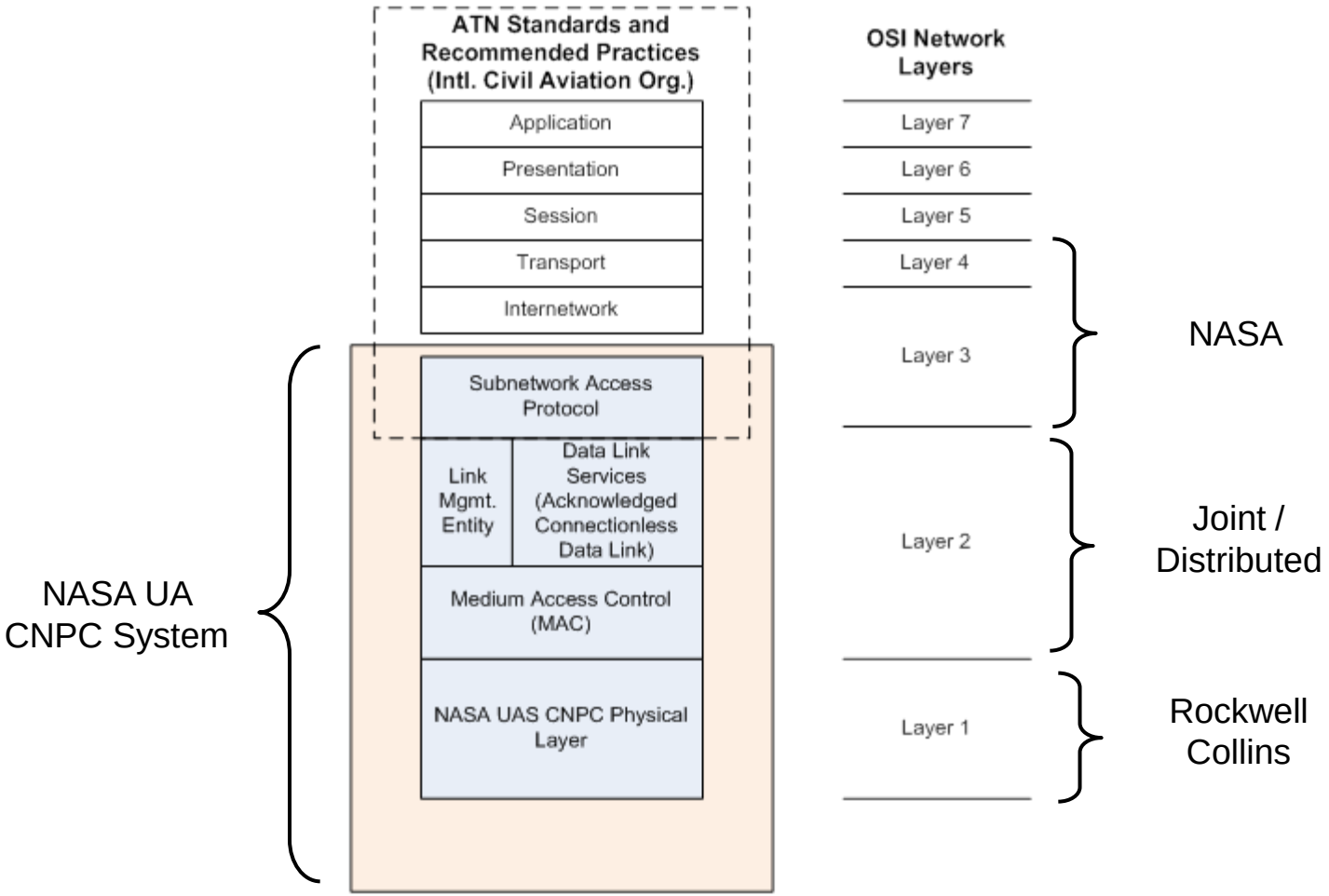
- All technologies must be modified to match the proposed waveform

The study identified the 4 best datalink technologies

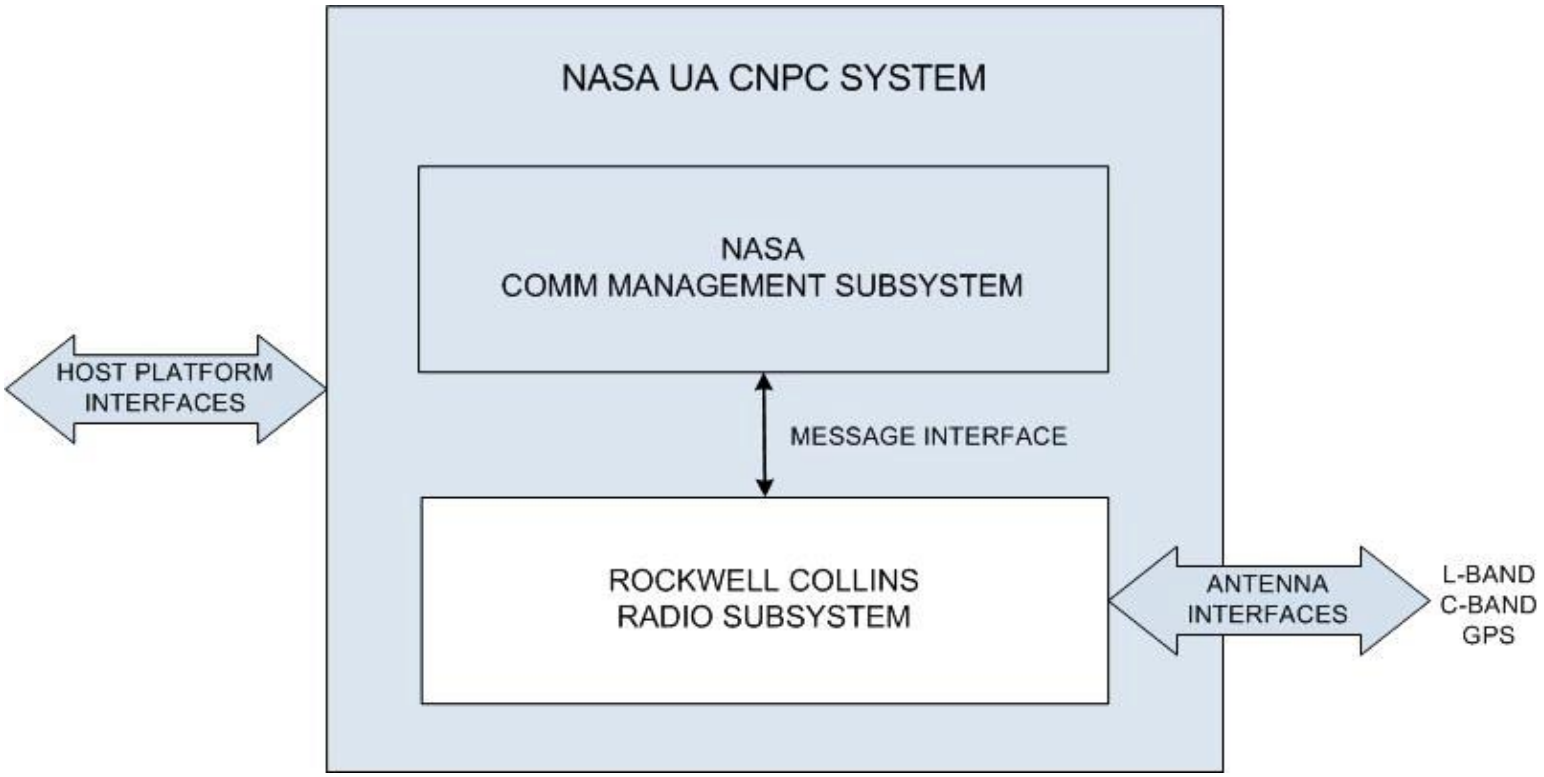
- LTE and IEEE 802.16 scored highest, P-34 and TEDS scored next best.

IEEE 802.16 was selected as the preferred datalink technology and will be used as the basis for development of the prototype CNPC system.

Rockwell Collins / NASA Design Lead Allocations



NASA UA CNPC
High Level System Block Diagram



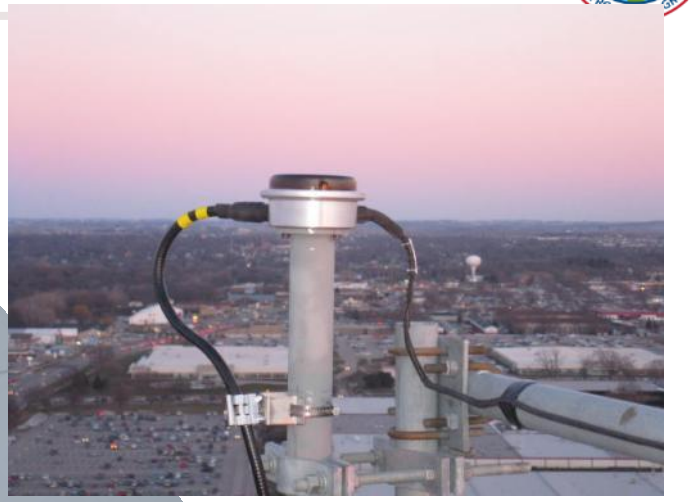
Summary of Spiral Definitions

- First Prototype
  - L Band only
  - All uplink and downlink modes mechanized
    - Uplink TDMA 1, 4, 8, 12, 16, 20 slots
    - Downlink FDMA, 3 service channels (C2, weather, video)
  - One ground station, one aircraft, point to point

- Second Prototype
  - C Band focus, with updates to L band
  - Tower-to-tower handoffs supported
  - Doppler updates for C band

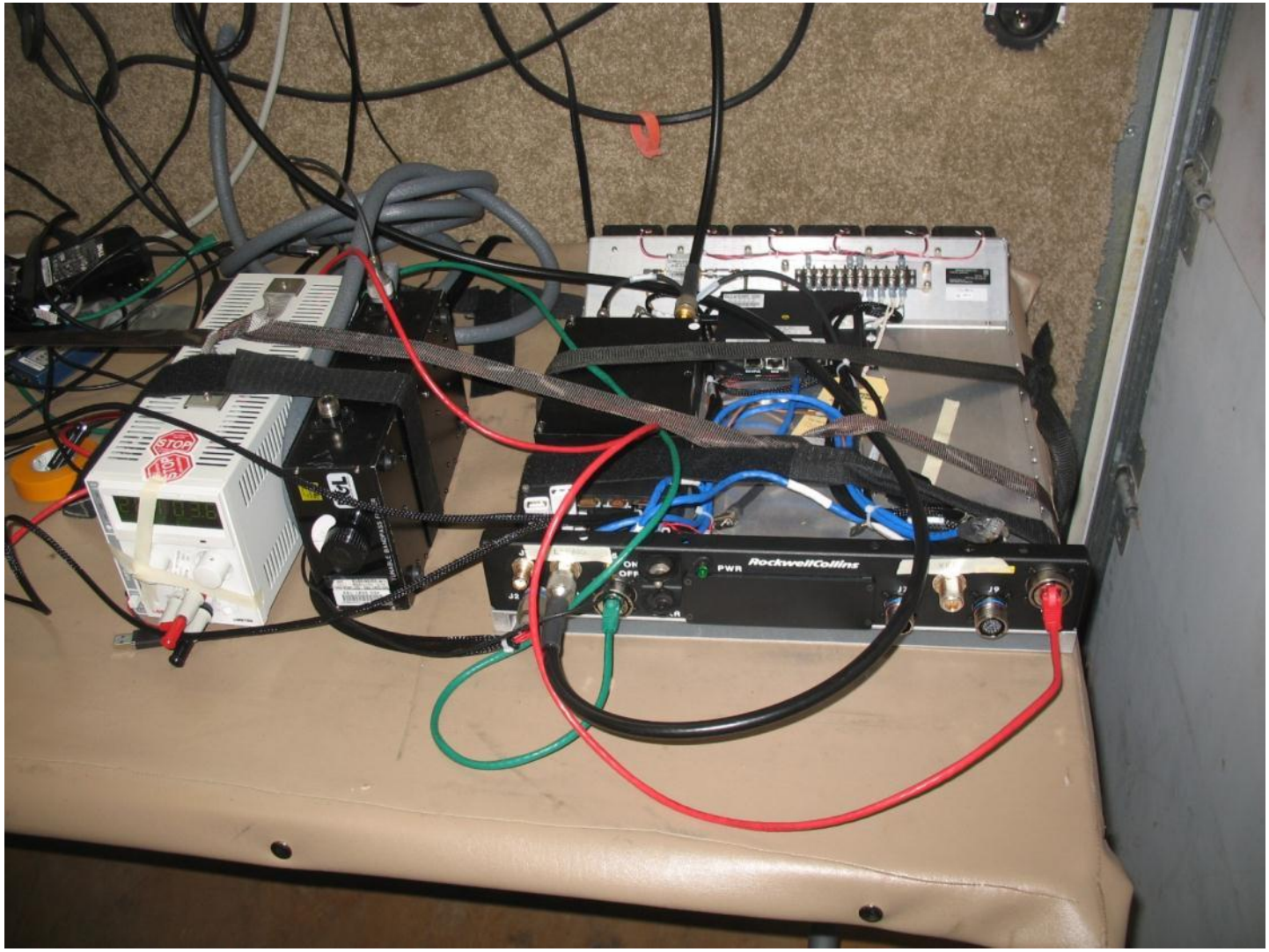
- Final Configuration
  - Multiple tuners in single receiver
  - Adaptive equalization, if required
  - Other new features as needed, until funding runs out

First Prototype Testing – Tower Setup
Rockwell Collins

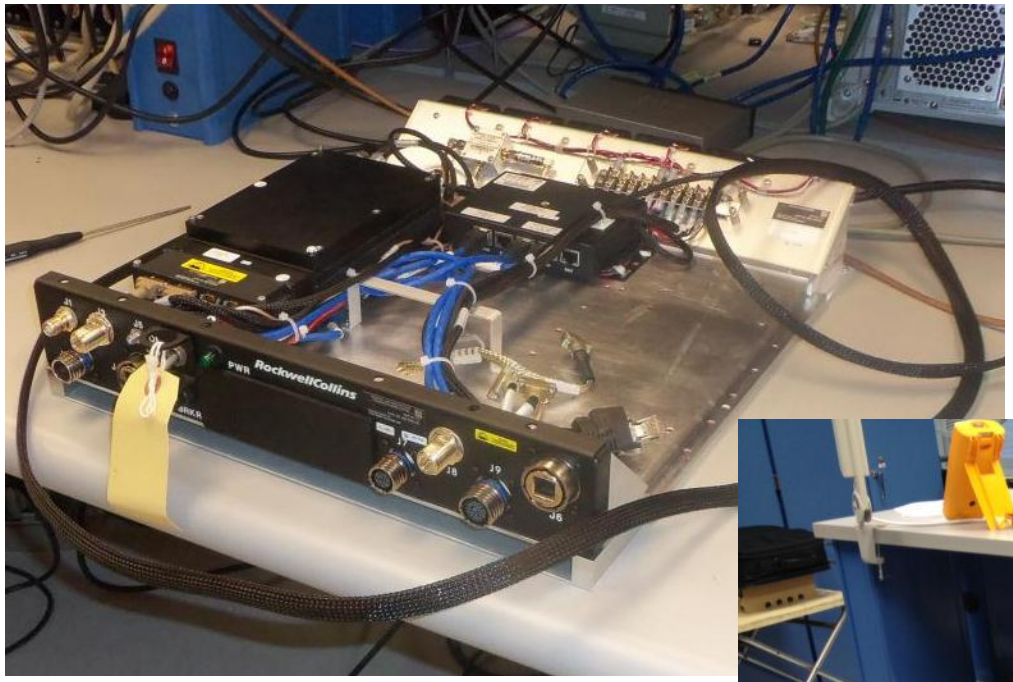


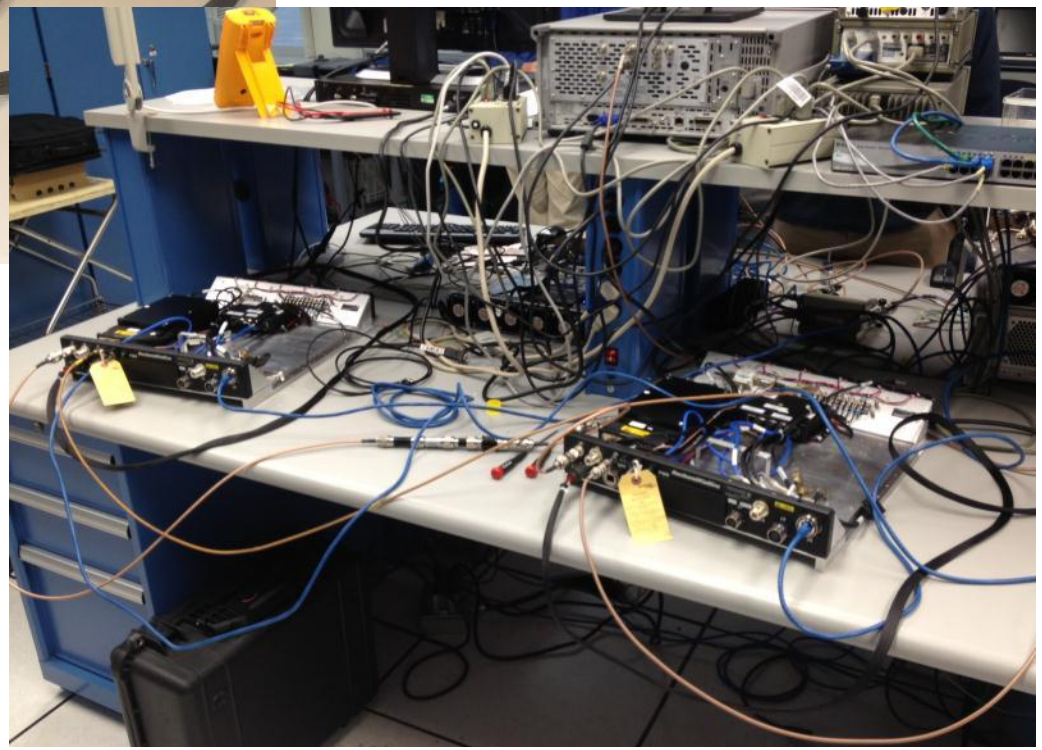
First Prototype Testing – Van Setup
Rockwell Collins

Hardware Test Bed Setup – Van Testing Rockwell Collins

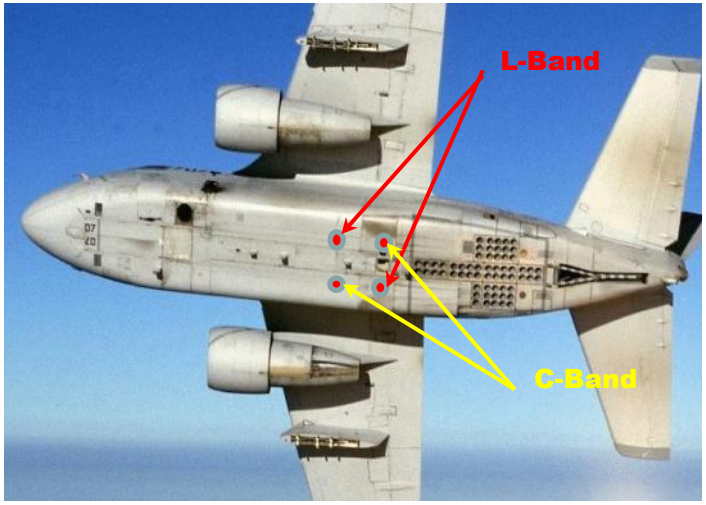


Hardware Test Bed Setup
NASA Glenn Research Center





Aircraft & Ground Station



Flight Test – Gen 1
May 2013

- L-Band Radio only
- One Aircraft – One Ground Station
- Omni on aircraft, sector on the ground station (Flight testing will take into account ground antenna pattern)
- Limited live flight data from aircraft
- All other data emulated from script (Basic data set only)
- Without incorporating layers 3 and above
- No Security
- Capture parameters: Telemetry, RF, and Raw Data

Flight Test – Gen 2
March 2014

- L-Band and C-Band Radios (simultaneous operation not required)
- One Aircraft – Two Ground Stations
- Omni on aircraft, sector on the ground stations (Flight testing will take into account ground antenna pattern)
- Expanded live data sent from aircraft
- All other data emulated from script (Basic + Weather)
- No Security
- Basic handoff capabilities exercised
- IPv6 implemented, which may exercise IPv6 mobility
- Capture parameters: Telemetry, RF, Data, and mobility/handoff

Flight Test – Gen 2 with Security September 2014

- Same setup as in the Gen 2 fight tests, adding security mitigations to the CNPC link

Final Config (Integrated FT#3) May 2015

- L-Band and C-Band Radios (simultaneous operation not required)
- One Surrogate Aircraft Three Ground Stations
- Omni on aircraft, sectored array at the ground stations
- Expanded live data set sent from aircraft and ground control station
- Remaining data parameters emulated from script (Basic + Weather + Video)
- Security enabled
- Handoffs exercised
- Mobile IPv6 across different networks
- Surrogate aircraft controlled from remote pilot station
- Capture parameters: Telemetry, RF, Data, mobility/handoff, security, and control messages

Final Config (Integrated FT#4) March 2016

- Same configuration as in Integrated Flight Test #3
- Addition of one manned aircraft flying CNPC radios.
- This additional manned aircraft will be utilizing an emulated ground control station