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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Project Engineer, Communications Subproject

I-CNS
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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.
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

Possible Future ATC and ATS Ground Connectivity
### Cooperative Agreement Milestone Status

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Baseline Milestone Date</th>
<th>Current Milestone Date</th>
<th>Milestone Complete</th>
<th>Milestone Complete, Date Missed</th>
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<tbody>
<tr>
<td>Program Kickoff Meeting</td>
<td>11/1</td>
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<tr>
<td>Generate Program Plan</td>
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<td>11/28</td>
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<tr>
<td>Complete System Trade Studies</td>
<td></td>
<td>3/31</td>
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<tr>
<td>Generate System Specification</td>
<td></td>
<td>5/31</td>
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<tr>
<td>Preliminary Design Review</td>
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<td>8/9</td>
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<tr>
<td>Critical Design Review</td>
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<td>10/24</td>
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<tr>
<td>Fabricate First Prototype</td>
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<td>2/28</td>
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<tr>
<td>First Prototype Test</td>
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<td>5/31</td>
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<tr>
<td>Revision Design Review #1</td>
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<td>7/31</td>
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<tr>
<td>Fabricate Second Prototype</td>
<td></td>
<td>9/30</td>
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<td>Second Prototype Test</td>
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<td>1/31</td>
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<td>Revision Design Review #2</td>
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<td>Fabricate Final Configuration</td>
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<td>Program Close-Out Meeting</td>
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<td>10/31</td>
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</table>
Waveform Trade Study

**Seed Requirements (SC-203)**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Radios must operate in frequency bands 560 – 577 MHz (L band) and 5830 – 5931 (C band)</td>
<td>NASA Contract SIDW</td>
</tr>
<tr>
<td>L band and C band operations must be independent</td>
<td>NASA Contract SIDW</td>
</tr>
<tr>
<td>RF link availability for any single link &gt;= 99.8%</td>
<td>RTCA SC-203 CC016</td>
</tr>
<tr>
<td>Availability for simultaneous operation of L band and C band &gt;= 99.999%</td>
<td>NASA Contract SIDW</td>
</tr>
<tr>
<td>Must operate both air-to-ground and ground-to-air modes</td>
<td>NASA Contract SIDW</td>
</tr>
<tr>
<td>Aircraft density assumptions</td>
<td>ITU-R M.2171 P.54</td>
</tr>
<tr>
<td>Small UAs = 0.000002212 UA/km²</td>
<td></td>
</tr>
<tr>
<td>Medium UAs = 0.000194327 UA/km²</td>
<td></td>
</tr>
<tr>
<td>Large UAs = 0.00004375 UA/km²</td>
<td></td>
</tr>
<tr>
<td>Cell Service Volume Radius = 75 miles (L-Band)</td>
<td>RTCA SC-203 CC016</td>
</tr>
<tr>
<td>Maximum number of UAs supported per cell = 20 (basic services)</td>
<td>RTCA SC-203 CC016</td>
</tr>
<tr>
<td>Maximum number of UAs supported per cell = 4 (weather radar)</td>
<td></td>
</tr>
<tr>
<td>Maximum number of UAs supported per cell = 4 (video)</td>
<td></td>
</tr>
<tr>
<td>Tower height = 100 feet</td>
<td>PIC Assumption</td>
</tr>
<tr>
<td>Uplink Information Rates (Ground-to-Air)</td>
<td>ITU-R M.2171 Table 13</td>
</tr>
<tr>
<td>Small UAs = 2424 bps</td>
<td></td>
</tr>
<tr>
<td>Medium and Large UAs = 6,925 bps</td>
<td></td>
</tr>
<tr>
<td>Downlink Information Rates (Air-to-Ground)</td>
<td>ITU-R M.2171 Table 13</td>
</tr>
<tr>
<td>Small UAs (basic services only) = 4,008 bps</td>
<td></td>
</tr>
<tr>
<td>Medium and Large UAs (basic services only) = 13,573 bps</td>
<td></td>
</tr>
<tr>
<td>Small and Large UAs (basic, weather radar and video) = 64,333 bps</td>
<td></td>
</tr>
<tr>
<td>Frame rate must support 20 Hz to enable real time control</td>
<td>ITU-R M.2171 Table 23/24</td>
</tr>
<tr>
<td>Airborne Safety Link Margin = 5 dB</td>
<td>RTCA SC-203 CC016</td>
</tr>
<tr>
<td>Airborne radio transmit power = 10 W</td>
<td>RTCA SC-203 CC016</td>
</tr>
</tbody>
</table>

**Technology Candidates, Criteria, & Scoring**

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>System Level Factors Addressed</th>
<th>Downlink Multiple Access Candidates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link Margin at Full Capacity</td>
<td>Availability</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Airborne Transmitter Power</td>
<td>SWAP, Cost, Complexity</td>
<td>10 Watts peak</td>
</tr>
<tr>
<td>Multipath Mitigation</td>
<td>Availability, Cost, Complexity</td>
<td>Link margin, spreading, RAKE processing</td>
</tr>
<tr>
<td>Synchronization Required</td>
<td>Cost, Complexity</td>
<td>None beyond that required for TDD</td>
</tr>
<tr>
<td>Power Control Required</td>
<td>Cost, Complexity</td>
<td>Tight control mitigates near-far problem, 10-20% added complexity</td>
</tr>
<tr>
<td>Ground Signal Processing Complexity</td>
<td>SWAP, Cost, Complexity</td>
<td>10-20% added complexity</td>
</tr>
</tbody>
</table>

**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**
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

ATN Standards and Recommended Practices (Intl. Civil Aviation Org.)
- Application
- Presentation
- Session
- Transport
- Internetwork

OSI Network Layers
- Layer 7
- Layer 6
- Layer 5
- Layer 4
- Layer 3
- Layer 2
- Layer 1

NASA
- Joint / Distributed

NASA UA CNPC System

Rockwell Collins
NASA UA CNPC
High Level System Block Diagram

NASA UA CNPC SYSTEM

NASA COMM MANAGEMENT SUBSYSTEM

MESSAGE INTERFACE

ROCKWELL COLLINS RADIO SUBSYSTEM

HOST PLATFORM INTERFACES

ANTENNA INTERFACES

L-BAND C-BAND GPS
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 – Van Setup
Rockwell Collins
Hardware Test Bed Setup – Van Testing
Rockwell Collins
Hardware Test Bed Setup
NASA Glenn Research Center
Aircraft & Ground Station

L-Band

C-Band
• 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
• 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