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

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

Presented by: Mr. Jim Griner
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>Event</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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</thead>
<tbody>
<tr>
<td>Program Kickoff Meeting</td>
<td>11/1</td>
<td>11/28</td>
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<tr>
<td>Generate Program Plan</td>
<td>3/31</td>
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<tr>
<td>Complete System Trade Studies</td>
<td>5/31</td>
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<tr>
<td>Generate System Specification</td>
<td>8/9</td>
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<tr>
<td>Preliminary Design Review</td>
<td>10/24</td>
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<tr>
<td>Critical Design Review</td>
<td>2/28</td>
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<tr>
<td>Fabricate First Prototype</td>
<td>7/31</td>
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<tr>
<td>First Prototype Test</td>
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<tr>
<td>Revision Design Review #1</td>
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<tr>
<td>Fabricate Second Prototype</td>
<td>9/30</td>
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<tr>
<td>Second Prototype Test</td>
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<tr>
<td>Revision Design Review #2</td>
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<tr>
<td>Fabricate Final Configuration</td>
<td>3/31</td>
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<tr>
<td>Program Close-Out Meeting</td>
<td>7/31</td>
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</table>

**Timeline:**

- **First Prototype:** 2/28 → 5/31
- **Second Prototype:** 9/30 → 1/31
- **Final Configuration:** 3/31 → 7/31
**Waveform Trade Study**

### Seed Requirements (SC-203)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radios must operate in frequency bands 560 – 977 MHz (L band) and 5030 – 5091 (C band)</td>
<td>NASA Contract SOW</td>
</tr>
<tr>
<td>L band and C band operations must be independent</td>
<td>NASA Contract SOW</td>
</tr>
<tr>
<td>RF link availability for any single link &gt;= 99.8%</td>
<td>RTCA SC-203 C0016</td>
</tr>
<tr>
<td>Availability for simultaneous operation of L band and C band &gt;= 99.999%</td>
<td>NASA Contract SOW</td>
</tr>
<tr>
<td>Must operate both air-to-ground and ground-to-air modes</td>
<td>NASA Contract SOW</td>
</tr>
<tr>
<td>Aircraft density assumptions</td>
<td>ITU-R M.2177: P.54</td>
</tr>
<tr>
<td>Small UAs = 0.0000000212 UA km^2</td>
<td></td>
</tr>
<tr>
<td>Medium UAs = 0.0000000000212 UA km^2</td>
<td></td>
</tr>
<tr>
<td>Large UAs = 0.000000000000212 UA km^2</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.2177: 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.2177: Table 13</td>
</tr>
<tr>
<td>Small UAs (basic services only) = 4,000 bps</td>
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</tr>
<tr>
<td>Medium and Large UAs (basic services only) = 13,573 bps</td>
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</tr>
<tr>
<td>Medium and Large UAs (basic, weather radar and video) = 34,133 bps</td>
<td></td>
</tr>
<tr>
<td>Frame rate must support 20 Hz to enable real time control</td>
<td>ITU-R M.2177: Table 25/24</td>
</tr>
<tr>
<td>Airborne safety link margin = 6 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>
<tr>
<td><strong>Evaluation Criteria</strong></td>
<td><strong>System Level Factors Addressed</strong></td>
</tr>
<tr>
<td>Link Margin at Full Capacity</td>
<td>Availability</td>
</tr>
<tr>
<td>Airborne Transmitter Power</td>
<td>SWAP, Cost, Complexity</td>
</tr>
<tr>
<td>Multipath Mitigation</td>
<td>Availability, Cost, Complexity</td>
</tr>
<tr>
<td>Synchronization Required</td>
<td>Cost, Complexity</td>
</tr>
<tr>
<td>Power Control Required</td>
<td>Cost, Complexity</td>
</tr>
<tr>
<td>Ground Signal Processing Complexity</td>
<td>SWAP, Cost, Complexity</td>
</tr>
</tbody>
</table>

### Technology Candidates, Criteria, & Scoring

**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

**Results**
- Time Division Duplexing
Datalink Technology Evaluation

Evaluation Criteria

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airframe communications</td>
<td>Very high</td>
</tr>
<tr>
<td>Data Transmission</td>
<td>Real-time</td>
</tr>
<tr>
<td>Security</td>
<td>High security</td>
</tr>
<tr>
<td>Traffic Clarity</td>
<td>High</td>
</tr>
<tr>
<td>Certification Complexity</td>
<td>High</td>
</tr>
<tr>
<td>Maneuver</td>
<td>Very high</td>
</tr>
</tbody>
</table>

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

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
- NASA

Joint / Distributed

Rockwell Collins

NASA UA CNPC System

Subnetwork Access Protocol
- Link Mgmt. Entity
- Data Link Services (Acknowledged Connectionless Data Link)
- Medium Access Control (MAC)
- NASA UAS CNPC Physical Layer
- Layer 2
- Layer 1
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 – 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
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 flight 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