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

Korea Visit

May 22-23, 2017

Davis Hackenberg
Deputy Project Manager
**UAS-NAS Project Lifecycle**

**Timeframe for impact: 2025**

<table>
<thead>
<tr>
<th>Prior</th>
<th>Phase 1 [FY11 - FY13]</th>
<th>Phase 2 [FY17 - FY20]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Project Start</strong> May 2011</td>
<td><strong>KDP</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Early investment Activities</strong></td>
<td><strong>KDP-A</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Formulation</strong></td>
<td><strong>KDP-C</strong></td>
</tr>
<tr>
<td></td>
<td><strong>System Analysis:</strong> Concept of Operations (ConOps), Community Progress, etc.</td>
<td><strong>Flight Validated Research Findings to Inform Federal Aviation Administration (FAA) Decision Making</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Initial Modeling, Simulation, &amp; Flight Testing</strong></td>
<td><strong>Integrated Modeling, Simulation, &amp; Flight Testing</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Technology Development to Address Technical Challenges</strong></td>
<td><strong>Close-out</strong></td>
</tr>
</tbody>
</table>

**Key Decision Points**

- **SC-228 Deliverables**, i.e. Minimum Operational Performance Standards (MOPS) Complete
- **Initial Modeling, Simulation, & Flight Testing**
- **Integrated Modeling, Simulation, & Flight Testing**
- **Close-out**

**External Input**

- Technical input from Project technical elements, NASA Research Announcements, Industry, Academia, Other Government Agencies, Project Annual Reviews, ARMD UAS Cohesive Strategy

**Formulation**

- **Formulation Review**
- **Project Start May 2011**

**Phase 1**

- **KDP**

**Phase 2**

- **KDP-A**
- **KDP-C**
- **P1 MOPS**
- **P2 MOPS**
Project Goal

Provide research findings, utilizing simulation and flight tests, to support the development and validation of DAA and C2 technologies necessary for integrating Unmanned Aircraft Systems into the National Airspace System.
The FAA is using several domestic forums, in conjunction with several international forums to lay out the pathway for their priorities and investments.

**FAA Organizational Relationships**

- FAA UAS Center of Excellence performs strategic research to guide the FAA, while the test sites contribute essential inputs through UAS testing.

- World Radio Conference (WRC) and International Civil Aviation Organization (ICAO) UAS Study Groups are addressing UAS access from an international perspective.

- Industry developed technologies and vehicles brought directly to the FAA for risk based certification processes, inclusion special projects such as Pathfinders.

- Standards Organizations chartered to develop Technology Standards, such as RTCA SC-228 Detect and Avoid (DAA) and Command and Control (C2) MOPS.

- Inter-government groups such as the UAS Executive Committee (ExCom), Senior Steering groups, OSD Sense and Avoid (SAA) Science and Research Panel (SARP), and Research Transition Teams (RTTs).

- UAS Aviation Rulemaking Committee (ARC) groups implemented to solve specific problems as directed by the FAA.

**NASA has a leadership role within many domestic forums and participates in the international forums**
RTCA SC-228 Phase 1 MOPS Terms of Reference

• RTCA SC-228 Terms of Reference (ToR) defined a path forward to develop Minimum Operational Performance Standards (MOPS)

• Phase 1 MOPS are addressed by UAS-NAS Current (FY14 – FY16) Portfolio
  – Command and Control (C2) Data Link MOPS – Performance Standards for the C2 Data Link using L-Band Terrestrial and C-Band Terrestrial data links
  – Detect and Avoid (DAA) MOPS – Performance standards for transitioning of a UAS to and from Class A or special use airspace, traversing Class D and E, and perhaps Class G airspace

• SC-228 Deliverables to RTCA PMC
  – C2 and DAA White Papers (Dec 2013) - Assumptions, approach, and core requirements for UAS DAA and C2 Equipment
  – C2, DAA, and Radar MOPS for Verification and Validation (Jul 2015) – Preliminary MOPS Including recommendations for a Verification and Validation test program
  – C2 Final MOPS (Jul 2016)
  – DAA and Radar Final MOPS (Nov 2016)
**RTCA SC-228 P2 MOPS Terms of Reference**

- RTCA SC-228 Terms of Reference (ToR) defined a path forward to develop Minimum Operational Performance Standards (MOPS)
  - Phase 1 MOPS were addressed by UAS-NAS (FY14 – FY16) Portfolio
  - Phase 2 MOPS included in the original ToR, but had several TBDs
    - ToR development team established to ensure DAA & C2 scope broad enough to fully enable the operating environments relevant UAS were expected to leverage (e.g. Manned Like IFR and Tweeners)

- Phase 2 MOPS ToR Scope
  - C2: Use of SATCOM in multiple bands and terrestrial extensions as a C2 Data Link to support UAS and address networking interoperability standards for both terrestrial and satellite systems
  - DAA: Extended UAS operations in Class D, E, and G, airspace, and applicability to a broad range of civil UAS capable of operations Beyond Visual Line of Sight (BVLOS)

- SC-228 Final Documents

<table>
<thead>
<tr>
<th>Phase 1 (To Be Published 2016)</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• C2 Terrestrial Datalink MOPS</td>
<td>• C2 SATCOM &amp; Network MASPS (Oct 2017 &amp; Jan 2019)</td>
</tr>
<tr>
<td></td>
<td>• Ground Based Primary Radar MOPS &amp; DAA MOPS Rev A (Sep 2019)</td>
</tr>
<tr>
<td>• DAA MOPS</td>
<td>• C2 SATCOM Data Link MOPS (Jul 2019*)</td>
</tr>
<tr>
<td></td>
<td>• Non-Cooperative Sensor MOPS &amp; DAA MOPS Rev B (Sep 2020)</td>
</tr>
<tr>
<td>• DAA Air to Air Radar MOPS</td>
<td>• C2 Terrestrial Data Link MOPS Rev A (Jul 2020)</td>
</tr>
</tbody>
</table>

* Date under discussion within RTCA SC-228
UAS-NAS Project Value Proposition

**NASA UAS-NAS Project Activities**

**C2 Performance Standards**
- Develop C2 Prototype SATCOM Systems
- Develop C2 Prototype Terrestrial System
  - Conduct C2 Flight Test and MS&A
    - Data Link
    - CNPC Spectrum
    - CNPC Security
    - BVLOS/BRLOS
    - ATC Interoperability
  - Develop C2 Requirements

**DAA Performance Standards**
- Develop DAA Test beds
- Conduct DAA Flight Test and MS&A
  - Human Factors
  - Performance Trade-offs
  - CONOPS
  - Well Clear
  - Interoperability
  - Collision Avoidance
  - Self Separation
- Conduct and MS&A
- Develop DAA Performance & Interoperability Requirements

**Integrated Test & Evaluation**
- Develop DAA Prototype System
- Develop Live Virtual Constructive (LVC) Test Infrastructure
- Conduct Technology and CONOPS testing
  - Conduct FT5 Test Scenarios
  - Conduct FT6 Test Scenarios
  - ACAS Xu FT2
  - No Chase COA

**Key Products**
- SATCOM MOPS
- Terrestrial MOPS

**Resultant Outcomes**
- C2 Performance Requirements to inform C2 MOPS
- DAA Performance Requirements to inform DAA MOPS
- Re-usable Test Infrastructure
- Non-Coop Sensor MOPS
- GBDAA MOPS
- DAA MOPS Rev A/B

**TC C2**
- RTCA Technical Standard Order (TSO)

**TC DAA**
- RTCA Technical Standard Order (TSO)
Project Goal

Provide research findings, utilizing simulation and flight tests, to support the development and validation of DAA and C2 technologies necessary for integrating Unmanned Aircraft Systems into the National Airspace System.

Technical Challenge-DAA: Detect and Avoid (DAA)

Technical Challenge-C2: Command and Control (C2)

Technical Challenge-SIO: System Integration and Operationalization (SIO)
C2 Subproject Structure for Project Phase 2

Command and Control

<TC-C2>

Subproject Manager (SPM)
Mike Jarrell, GRC

Subproject Technical Leads
Jim Griner, GRC

Ku/Ka-Band SATCOM
Terrestrial Extension
C-Band SATCOM
Integrated Flight Test Support (IT&E TWP)

C2 Performance Standards

Develop C2 Prototype System

Conduct C2 Flight Test and MS&A
- Data Link
- CNPC Spectrum
- CNPC Security
- BVLOS/BRLOS
- ATC Interoperability

Develop C2 Requirements

C2 Performance Requirements to inform C2 MOPS

RTCA
C2 MOPS
C2 Technical Standard Order (TSO)
**Recent Accomplishments: C2 Phase 1 MOPS**

### Spectrum Compatibility Analysis
**Objective:** Develop data and rationale to obtain appropriate frequency spectrum allocations to enable the safe and efficient operation of UAS in the NAS

**Accomplishment:** NASA conducted sharing study results delivered at the 2015 World Radiocommunication Conference (WRC-15) to support Ku & Ka Band frequency Allocations

### Verify and Validate C2 MOPS Requirements
**Objective:** Analyze the performance of fifth generation Control and Non-Payload Communication System (CNPC) prototypes

**Accomplishment:** Utilized Gen-5 radios at three CNPC ground stations and onboard GRC S-3B aircraft in order to collect data for performance in two relevant environments

---

Final C2 MOPS released through RTCA in July 2016
UAS Detect and Avoid Operational Concepts and Technologies

Project Goal

Provide research findings, utilizing simulation and flight tests, to support the development and validation of DAA and C2 technologies necessary for integrating Unmanned Aircraft Systems into the National Airspace System.

Technical Challenge-DAA: Detect and Avoid (DAA)

Technical Challenge-C2: Command and Control (C2)

Technical Challenge-SIO: System Integration and Operationalization (SIO)
Detect and Avoid (DAA) Performance Standard Operating Environments (OE)

Legend
Phase 1 Research Areas (FY14 – FY16)
Phase 2 Research Areas (FY17 – FY20)

DAA System for Operational Altitudes (> 500ft AGL)

HALE aircraft
FL-600

18K’ MSL

10K’ MSL

Top of Class G

DAA System for Transition to Operational Altitude

“VFR-like” UAS

“VFR-like” UAS

“VFR-like” UAS

Alternate DAA Sensors

ACAS Xu

ACAS Xu

ADS-B & ACAS Xu

ADS-B & ACAS Xu

ADS-B & ACAS Xu

ADS–B & TCAS–II

Non-cooperative Aircraft

Airborne Radar

Ground Based Radar

C2 Datalink

Ground Based DAA Data

UAS Ground Control Station

Cooperative Traffic

C2 Datalink

Terminal Area Ops

Cooperative Traffic
Detect and Avoid
<TC-DAA>
Subproject Manager (SPM)

Jay Shively, ARC
Subproject Technical Leads
Confesor Santiago, ARC, Tod Lewis, LaRC, TBD, ARC

Alternate Surveillance Requirements
Well Clear Alerting Requirements
ACAS Xu
External Collaborations
Integrated Events

SAA Performance Standards
Develop DAA Test beds
Conduct SAA Flight Test and MS&A
- Human Factors
- Performance Trade-offs
- Interoperability
- Self Separation
- CONOPS
- Well Clear
- Collision Avoidance
Develop SAA Performance & Interoperability Requirements
SAA Performance Requirements to inform DAA MOPS

RTCA
DAA MOPS
SAA Technical Standard Order (TSO)
Separation from other Aircraft

Detect-and-Avoid

CFR 91.113: “...each person operating an aircraft [shall] see and avoid other aircraft ... the pilot shall give way to that aircraft and may not pass over, under or ahead of it unless well clear.”

*Time horizons of applicability are not to scale
Recent Accomplishments: DAA Phase 1 MOPS

Human Systems Integration “Part Task 6”
Objective: Conduct final V&V activity in support of the SC-228 DAA human machine interface requirements for displays, alerting, and guidance

Accomplishment: Verified pilot performance against minimum requirements, re-evaluated performance differences between a standalone and integrated DAA displays

DAA End to End V&V
Objective: Verify and Validate (V&V) a MOPS-representative Detect and Avoid (DAA) system in an End-to-End simulation environment representative of the MOPS

Accomplishment: Final closed-loop, pilot (model)-in-the-loop, end-to-end simulation evaluation of MOPS leveraging encounter sets from MOPS test cases & MIT/LL NAS encounter model

Final DAA MOPS scheduled to be released through RTCA in December 2016
Integrated Test & Evaluation

<TC-ITE>

Subproject Manager (SPM)
Heather Maliska, AFRC

Subproject Technical Leads
Sam Kim, AFRC, Jim Murphy, ARC

Integration of Technologies into LVC-DE
Simulation Planning & Integration
LVC-DE Infrastructure Sustainment
Integrated Flight Test

Integrated Test & Evaluation

Develop DAA Prototype System → Develop Live Virtual Constructive (LVC) Test Infrastructure → Conduct Technology and CONOPS testing → Re-usable Test Infrastructure

ACAS Xu FT2 Test Scenarios
Conduct FT5 Test Scenarios
Conduct FT6 Test Scenarios
Risk Reduction Approach To Integrated Test Flow
• Each test built upon the previous and reduced future risk.
• Lessons learned applied from one test to the next.

Integrated Human in the Loop Sim
- Preliminary MOPS Development
- MOPS Verification & Validation

ACAS-XU / Self Separation
- Preliminary MOPS Inputs Aug 2014
- Final MOPS Inputs Aug 2016

Flight Test-3
- Preliminary MOPS Inputs Jan 2015
- Final MOPS Inputs Oct 2015

Timeline Not To Scale
- Level 1 Milestone
- Reviews
- Development Milestones
Recent Accomplishments: DAA Phase 1 MOPS

Integrated Test and Evaluation FT4
Objective:
• Conduct Flight Test Series 4 integrating the latest SSI algorithms, HSI displays, and active test aircraft sensors using the Live, Virtual, Constructive test environment
• Document the performance of the test infrastructure in meeting the flight test requirements

Accomplishment: FT4 successfully completed on 6/30/2016
• 2 system checkout and 19 data collection flight tests
• 11 weeks (April 12 - June 30)
• 321 air-to-air encounters

Final DAA MOPS scheduled to be released through RTCA in December 2016
IT&E Capabilities: Providing the Infrastructure for Flight Testing

• Ownship – Ikhana
  – Build-up of DAA system (radar/ADS-B/TCAS) to meet researcher requirements
  – Logged over 190 hours of flight time with Ikhana for ACAS Xu, FT3 and FT4 data collection flights

• Intruder aircraft – 6 total aircraft
  – Met researcher objectives to represent many classes of aircraft
    • Slow-Speed, Mid-Speed, High-Speed
    • Cooperative vs. Non-Cooperative
    • Small, medium, large radar cross section
  – Equipped 4 aircraft with required sensors
  – Coordinated 25 crew members from 3 organizations
    • NASA, Air Force, Honeywell

• Flight Test Stats
  – ACAS Xu: 9 flights, 170 encounters flown (1 intruder)
  – FT3: 11 flights, 212 encounters flown (multiple intruders)
  – FT4: 19 flights, 321 encounters flown (up to 4 intruders/enc.)
IT&E Capabilities:
Encounter Design and Range Coordination

**Airspace Planning**
- Primarily Mercury Spin, 4 Corners & Buckhorn MOA (red outline)
- 1,000 ft AGL (4.2K ft) to 20K ft MSL
- Extensions (west / north) may be requested real time for encounters that need the additional airspace
- Ops outside of test area (blue shaded areas) are planned to be performed early (before 0800) when airspace is relatively empty
- Operations between 0600 and 0700 are under Joshua control and have less geographical constraints

**Airspace Extensions** (Blue Shaded Areas)
- Conducted early 0600-0800 preferably
- Pre-coordinated 24-48 hours in advance
- Requested real-time with SPORT (after 0700)

**Coordination with Edwards Range**
- Coordination of range/operating area borders and UAS keep out zones.
- Ikhana must remain within R-2515 at all times.
- Intruder aircraft can use Buckhorn MOA, plus areas shaded in blue

**Encounter design accomplished by operations working group with researchers and partners.**
- Encounter requirements coordinated with System Safety Working Group to ensure flight safety.
- Mitigations designed into flight test planning (safe separation, training, testing, offsets, procedures, etc..)
Flight Test Card #1

1. TC announces COMEX time.
2. Announce "<Callsign>, IP Inbound, altitude & special procedure review" crossing IP.
3. On condition at IP.
4. TC calls "terminate" when run complete.
5. TC announces next Card Number.

Losing link mission:
- Deconfliction Alt: 10000

Adios-B IN
- Display: JADEM, DAIAD, CPDQS
- Maneuver: Off, Advisor, AUTO
- Sensor Select: Tracker, Radar, ADS-B, TCAS

Abort procedure:
- Maintain heading
- 10000
- Right
- 123

Comex Time:

<table>
<thead>
<tr>
<th>WPT</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Alt</th>
<th>Dist</th>
<th>KGS</th>
<th>Leg Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP11</td>
<td>N34° 54.14'</td>
<td>W117° 24.19'</td>
<td>10000</td>
<td>5.0</td>
<td>150</td>
<td>3+00</td>
</tr>
<tr>
<td>CPA1</td>
<td>N34° 54.14'</td>
<td>W117° 30.29'</td>
<td>10000</td>
<td>2.5</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>CPAS2</td>
<td>N34° 54.08.2&quot;</td>
<td>W117° 31.20&quot;</td>
<td>10000</td>
<td>0.0</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

Comex Time:

<table>
<thead>
<tr>
<th>WPT</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Alt</th>
<th>Dist</th>
<th>KGS</th>
<th>Leg Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP115</td>
<td>N34° 51.67'</td>
<td>W117° 36.71'</td>
<td>10000</td>
<td>6.0</td>
<td>180</td>
<td>3+00</td>
</tr>
<tr>
<td>MP27</td>
<td>N34° 53.26'</td>
<td>W117° 34.78'</td>
<td>10000</td>
<td>0.7</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>CPA32</td>
<td>N34° 53.32.2&quot;</td>
<td>W117° 34.17&quot;</td>
<td>10000</td>
<td>0.7</td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>

Guidance:
- CPDQS Guidance
- Intruder 2 TCAS
- Do not overshoot planned route. Expect Ownership Maneuver.

NOTES:
- Ownership Maneuver, Intruder 1 - CPDQS Guidance, Intruder 2 TCAS
- Guidance can be to CLIMB or MAINTAIN ALTITUDE.
- Tolerance: ± 8 sec, ± 5 kts, Direction: Lateral, Vertical
Summary

• UAS-NAS Project has developed robust capabilities supporting initial developments of DAA and C2 Technologies

• Significant work is remaining to lead the community towards ensuring DAA and C2 technology are interoperable with the entire National Airspace System.

• The project is dedicated to driving the community towards robust and innovative solutions that apply to DAA, C2, and other necessary vehicle technologies