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>
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<tr>
<th>Prior</th>
<th>Phase 1</th>
<th>Phase 2</th>
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<td>[FY11 - FY13]</td>
<td>[FY14 - FY16]</td>
<td>[FY17 - FY20]</td>
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<td>Formulation</td>
<td>KDP</td>
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<td>Review</td>
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<td>Project Start</td>
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#### Early investment Activities
- **Formulation**

#### External Input
- System Analysis: Concept of Operations (ConOps), Community Progress, etc.

#### Key Decision Points
- SC-228 Deliverables, i.e. Minimum Operational Performance Standards (MOPS) Complete

#### Technology Development to Address Technical Challenges
- Initial Modeling, Simulation, & Flight Testing
- Integrated Modeling, Simulation, & Flight Testing
- Integrated Modeling, Sim, & Flight Testing
- Close-out

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

**Technical Challenge-DAA:** Detect and Avoid (DAA)

**Technical Challenge-C2:** Command and Control (C2)

**Technical Challenge-SIO:** System Integration and Operationalization (SIO)

**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.
FAA Organizational Relationships

- The FAA is using several domestic forums, in conjunction with several international forums to lay out the pathway for their priorities and investments.

**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.**

**FAA 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.

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**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

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<th>Phase 1 (To Be Published 2016)</th>
<th>Phase 2</th>
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<td>DAA MOPS</td>
<td>C2 SATCOM Data Link MOPS (Jul 2019*)</td>
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<tr>
<td>DAA Air to Air Radar MOPS</td>
<td>C2 Terrestrial Data Link MOPS Rev A (Jul 2020)</td>
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* 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
  - Interoperability
  - CONOPS
  - Well Clear
  - Collision Avoidance
  - Self Separation
- 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 Technology and CONOPS testing
- ACAS Xu FT2
- No Chase COA
- Conduct FT5 Test Scenarios
- Conduct FT6 Test Scenarios

**Key Products**
- SATCOM MOPS
- Terrestrial MOPS
- Non-Coop Sensor MOPS
- GBDAA MOPS
- DAA MOPS Rev A/B

**Resultant Outcomes**
- C2 Performance Requirements to inform C2 MOPS
- DAA Performance Requirements to inform DAA MOPS
- Re-usable Test Infrastructure
- DAA Technical Standard Order (TSO)
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

**Project Goal**

**Technical Challenge-DAA:** Detect and Avoid (DAA)

**Technical Challenge-C2:** Command and Control (C2)

**Technical Challenge-SIO:** System Integration and Operationalization (SIO)
UAS Satcom and Terrestrial Command and Control Operating Environments (OE)

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

SATCOM C2 Data Link
Communications Satellite

Cooperative Traffic
Ku/Ka SATCOM Link

Terrestrial C2 Data Link

“VFR-like” UAS
Top of Class G

“IFR-like” UAS

Terrestrial C2 Data Link Network
CNPC Network

FL-600
18K’ MSL
10K’ MSL

SATCOM Transmitter
C-Band SATCOM Link

SATCOM/BLOS Link

Non-cooperative Traffic

UAS Ground Control Station
UAS Ground Control Station

CNPC Ground Stations

Legend

Phase 1 Research Areas (FY14 – FY16)
Phase 2 Research Areas (FY17 – FY20)
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
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 Transition to Operational Altitude

HALE aircraft

FL-600

18K' MSL

10K' MSL

Top of Class G

DAA System for Operational Altitudes (> 500ft AGL)

"VFR-like" UAS

Alternate DAA Sensors

ADS-B & ACAS Xu

ACAS Xu

Non-cooperative Aircraft

Airborne Radar

C2 DataLink

GBDAA Data

UAS Ground Control Station

Terminal Area Ops

Cooperative Traffic

Ground Based Radar

Cooperative Traffic

Phase 1 Research Areas (FY14 – FY16)

Phase 2 Research Areas (FY17 – FY20)
DAA Subproject Structure for Project Phase 2

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
IT&E Subproject Structure for Project Phase 2

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

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

ACAS Xu FT2 Conduct FT5 Test Scenarios Conduct FT6 Test Scenarios
UAS-NAS Project - DAA and C2 Operational View Representation

Legend:
- Detect and Avoid (DAA) Technologies
- Air Traffic Control (ATC) Services
- Control and Non-Payload Communications (CNPC) Network
- Command and Control (C2) Links

Acronyms:
- ACAS Xu: Airborne Collision Avoidance System, UAS Variant
- ADS–B: Automatic Dependent Surveillance—Broadcast
- BRLOS: Beyond Radio Line of Site
- BVLOS: Beyond Visual Line of Site
- TCAS–II: Traffic Alert and Collision Avoidance System
- UAS: Unmanned Aircraft Systems

Communications Satellite
SatCom BVLOS Communications

IFR-Like Airspace Integration
- Airborne Detect and Avoid
- UAS test aircraft
- DAA Sensors
- ADS–B & TCAS–II / ACAS Xu

Terrestrial C2
- CNPC Ground Stations
- Terrestrial C2 Link

VFR-Like Airspace Integration
- "mid-sized" test aircraft
- Alternative DAA Sensors

IFR-Like Airspace Integration
- Non-cooperative Aircraft
- Land Line

VFR-Like Airspace Integration
- UAS Ground Control Station
- Land Line

Terminal Airspace Airspace Integration
- ATC Interoperability

Ground Based Detect & Avoid
- Ground Based Radar
- "mid-sized" test aircraft

Non-cooperative Aircraft
UAS-NAS Build-up of IT&E Infrastructure for P1 Flight Test

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.

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

**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.

ADS-B IN:
DISPLAY:
MANEUVER:
SENSOR SELECT:

10000

DECONFLICITION ALT: 10
LOST LINK MISSION: 10

11000

DECONFLICITION ALT: 11000

ABORT PROCEDURE

RIGHT
123

COMEX TIME:

IP WIND:

WPT  LATITUDE  LONGITUDE  ALT  DIST  KGS  LEG TIME

IP11  N34° 54.14’  W117° 24.19’  10000  5.0  150  3+00
CPA1  N34° 54.14’  W117° 30.29’  10000  6.0  150  3+00
CPAS2  N34° 54.08’  W117° 30.23’  10000  6.0  150  3+00

NOTES:

1. OWNSHIP Maneuver. Intruder 1 – CPDLS Guidance. Intruder 2 TCAS
2. Guidelines can be to CLIMB or MAINTAIN ALTITUDE.
3. TOLERANCE: ±8 sec ±5 kts

MANEUVER: YF3
GUIDANCE: PROBE
TOLERANCE: ±8 sec ±5 kts
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