UAS Integration in the NAS Project
Flight Test Planning Status

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NAC Aeronautics Committee
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Outline

• Phase 2 Project Overview

• Integrated Test Plans
  – Integrated Human in the Loop Simulation Status
  – Flight Campaign Planning

• Summary
Goal: Provide research findings to reduce technical barriers associated with integrating Unmanned Aircraft Systems into the National Airspace System utilizing integrated system level tests in a relevant environment.

**Research Theme 1: UAS Integration** - Airspace integration procedures and performance standards to enable UAS integration in the air transportation system.

**Research Theme 2: Test Infrastructure** - Test infrastructure to enable development and validation of airspace integration procedures and performance standards.

**TC-ITE: Integrated Test & Evaluation**

**TC-HSI: Human Systems Integration**

**TC-SAA: Sense and Avoid Performance Standards**

**TC-C2: Command & Control Performance Standards**
**IT&E Integrated Test Flow**

**Integrated Human in the Loop Development**
- Preliminary MOPS Development
  - FY14 APG LVC Charac. Report (9/30/13)
  - FY14 APG IHITL Report
  - FY14 APG Peer Reviews (9/11-12, 16)
- Final MOPS Verification & Validation
  - RTCA SC-228 Final MOPS July 2016
  - Final MOPS Inputs May 2016
  - Final MOPS Inputs Oct 2015

**Ikhana**
- SAA Initial Flight Tests Start 11/3/14
- SAA Initial Flight Tests Complete 1/15
- SAA Initial Flight Tests Complete 7/28/14

**Flight Test Series 3 Development**
- FT3 Start 7/28/14
- FT3 Complete 8/14
- FT3 Report (10/15)

**Flight Test Series 4 Development**
- FT4 Start 8/27/15
- FT4 Complete 5/20

**Level 1 Milestone**
- Reviews
- Annual Performance Goal/Indicator
- Development Milestones
Integrated Human in the Loop (IHITL) Simulation Description

**Purpose**
- Evaluate and measure the acceptability with Air Traffic Controller (ATC) operations with increased simulation fidelity by adding Control and Non-Payload Communications (CNPC) time delay, a proof of concept Ground Control Station (GCS), and Visual Flight rules (VFR) cooperative and non-cooperative traffic

**Approach**
- 2 Live Virtual Constructive (LVC) configurations tested
  - Config1: Ames/Armstrong connectivity (ATC and Pilot test set-ups)
  - Config2: Langley/Ames connectivity (SAA-CA interoperability)
  - Scenarios - Class E airspace operations near major TRACONs

**Test Duration**
- June – July 2014
  - Config1 Test Set-up 1: ATC – 3 weeks (15 Controllers)
  - Config1 Test Set-up 2: UAS pilots – 2 weeks (10 pilots)
  - Config2 Test Set-up: ATC – 3 weeks (6 Controllers)

**Tech Transfer**
- Validated SAA, C2, HSI performance requirements and guidelines
- Community insight into LVC Infrastructure capabilities

**Project Benefit**
- Validates project models
- Risk reduction for SAA Initial Flight Test (FT) Series and Flight Test Series 3 (FT3)
- Foundational infrastructure integrated test supports SAA Initial FT, FT3, & FT4
IHITL Configuration 1 Status

• Test Setup 1 controller subjects data collection successfully completed
  – Experimental Design: Evaluate acceptability to the controller of maneuvers performed for self separation in order to remain well clear of other traffic
  – Four UAS mission scenarios with varying degrees of traffic density, self separation threshold values (time), and track deviations
  – Communication between ATC and pseudo-pilot

• Test Setup 2 pilot subjects data collection successfully completed
  – Experimental Design: Examine the effects of advanced traffic display elements and tools on pilots’ ability to remain well clear
  – Four levels of display information which included self separation advisories and resolutions
  – Pilot interaction with the UAS ground control station display to coordinate maneuvers with ATC and remain well clear

• Contribution to Flight Test Series 3 Development: LVC flight test infrastructure development and system V&V
IHITL Configuration 2 Status

• Test Setup 3 controller subjects data collection and Traffic Alert and Collision Avoidance System (TCAS) encounter validation simulation successfully completed
  – Experiment Design: Evaluate acceptability to the controller of maneuvers performed for self separation in order to remain well clear of other traffic
  – Six UAS mission scenarios with varying voice communication delay, wind conditions, and self separation threshold values (Horizontal Miss Distance)
  – Controller acceptability of self separation maneuvers based on the well clear volume
  – Collection of performance metrics to determine SAA-TCAS interoperability

• Contribution to Flight Test Series 3 Development: Flight test encounter development
SAA Initial Flight Tests Description

**Purpose**
- Evaluate SAA Algorithm performance with actual sensor data
- Demonstrate SAA Concept of Operations (CONOPS) in real-world scenarios
- Demonstrate LVC distributed test environment

**Approach**
- Ikhana UAS modified with Proof of Concept DAA system (Prototype Air-to-Air Radar, SAA Processor, TCAS, ADS-B, Sensor Fusion)
- Multiple encounter geometries (CA and SS)

**Test Duration**
- Nov 2014 – Jan 2015 (13 flights/2 backups)
  - Nov 2014: Collision Avoidance Flight Tests (UAS vs. Manned)
  - Dec 2014 – Jan 2015: Collision Avoidance (CA) Flight Tests (UAS vs. UAS)

**Tech Transfer**
- DAA CONOPs and Algorithm flight demonstration
- Data for validation of sensor models, well clear definition, and SS-CA interoperability

**Project Benefit**
- Conduct flight test risk reduction activities for FT3 and FT4
- Project’s 1st live flight test for SAA algorithms and pilot guidance displays for real sensor data/uncertainties, real environmental factors
- Distributed test environment with partner
Flight Test Series 3 Description

Purpose
- Flight test prototype SAA & C2 systems utilizing Research Ground Control Station (RGCS); conduct integrated flight test series to verify Preliminary DAA & C2 MOPS and validate sensor models
- Demonstrate system integration of surrogate UAS with CNPC, RGCS, and Self Separation (SS) Algorithms

Approach
- Increase complexity from IHITL through live aircraft incorporation and increased definition from MOPS
- Focus scenarios on testing of SAA (sensitivity, pilot workload, and maneuver negotiation), C2 (CNPC Mixed Traffic Flight Tests including Integrated SAA), and human factors (RGCS utilized to evaluate pilot information requirements)

Test Duration
June – August 2015
- 36 flights/2 backups (3.5 hour flights)

Tech Transfer
- First fully integrated flight test including both prototype systems for both DAA and C2 MOPS
- Initiates verifications of the preliminary MOPS

Project Benefit
- Baseline FT4 System Architectures implemented
- Baseline flight test scenarios developed and validated
Flight Test Series 4 Description

Purpose

- Contribute to validation of final MOPS; flight-test SAA, CNPC, and RGCS in more stressed environments
- Demonstrate systems integration and evaluation of the state of UAS concepts and supporting technologies
- Demonstrate final LVC-DE configuration

Approach

- Challenging encounter geometries
- UAS pilot and ATC negotiation in complex/busy airspace
- Two aircraft with CNPC to assess link performance within the same spectrum
- Demonstrate CA-SS Interoperability, well clear compliance

Test Duration

- February - April 2016
  - 34 flights/2 backups (3.5 hour flights)

Tech Transfer

- DAA and C2 system refinements flight-tested
- Contributing to validation of final MOPS

Project Benefit

- Baseline technologies for Capstone demonstration
Flight Test Series 4

Live Ownship
- AFRC Ikhana
- EDM DRR

Ikhana Data Link
- C2
- Voice
- Health & Status
- Video
- Traffic (ADS-B and Radar)

Ikhana GCS
- Stratway+
- Autoresolver

CNPC Data Link
- C2
- Voice
- Health & Status
- Video
- Traffic (ADS-B)

34 flights/2 backups (3.5 hour flights)
Feb – Apr 2016

Remote CNPC GCS
- GRC S-3B
  - ADS-B
  - 2nd CNPC

AFRC Ikhana - Stratway+ - Autoresolver

UAS Pilot as Subject

Research GCS VSCS

Displays of Proximal Traffic SAA/DAA Algorithms Pilot Maneuver Guidance

ATC as Subject

ATC as Subject

Pseudo Pilots

Multi-Aircraft Control System

Virtual/Constructive Intruders

Live Intruder
- ADS-B
- Several options
  - NASA King Air
  - NASA T-34C

Live Ownship
- ADS-B Out
- GRC S-3B
- TCAS II Instm
- High speed

ADS-B Out
Capstone Description

Purpose
• Showcase the technologies developed on the Project, specifically: Sense and Avoid, Command and Control, and Human Systems Integration in a relevant test environment
• Increase public confidence in UAS

Approach
• Demonstrate the RTCA SC-228 Phase 1 MOPS (i.e. conduct UAS operations to/from Class A, through Class E, Class D, and possibly Class G)
  • Example: Flights conducted to and from dual use airports within Class D airspace and operated in the NAS in partnership with the FAA

Test Duration
April 2016
• 2 flights (3 hour flights)

Tech Transfer
• These are flight demonstrations and are not intended for data gathering

Project Benefit
• Provides opportunities for partnering with other NASA Mission Directorates (Science Mission Directorate), industry, and academia
Summary

• Project Phase 2 execution underway; Achieving excellent progress meeting the Project’s goals

• Integrated testing on track and progressing well

• Maintaining close contact with RTCA SC-228 to ensure Project work consistent with community needs
Backup Slides
FAA Designated Airspace Classes

CLASS E
- FL 600 MSL 18,000
  - Commercial Transport Aircraft
  - Transponder
  - Under ATC Control
  - IFR Required

CLASS A

CLASS E & G
- General Aviation Aircraft

Nontowered Airport

14,500 MSL

LAX Type Airport

CLASS B

ORF Type Airport

CLASS C

CLASS E
- IFR/ VFR Allowed
- VFR
  - ATC Control Not Required

Other Towed Airports

CLASS D

CLASS G

MSL - mean sea level
AGL - above ground level
FL - flight level
• UAS Subcommittee reported to NAC on July 30, 2013
## Integrated Test Progression

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<thead>
<tr>
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<tbody>
<tr>
<td>GCS</td>
<td>• Research Ground Control Station (RGCS) with traffic displays and alerting logic</td>
<td>• RGCS with UAS Surrogate (T-34C) Command and Control</td>
<td>• RGCS with UAS Surrogate (T-34C) C2 • Multiple GCSs</td>
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<tr>
<td>SAA Algorithms</td>
<td>• Self separation, idealized sensor data</td>
<td>• Integration of collision avoidance into surrogate or simulated</td>
<td>• CA algorithm integrated into UA partner or self separation only</td>
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<tr>
<td>UAS</td>
<td>• Simulated</td>
<td>• UAS Surrogate (T-34C)</td>
<td>• UAS Surrogate (T-34C) • SAA equipped UAS</td>
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<td>Sensor</td>
<td>• Simulated</td>
<td>• Simulated on board UAS Surrogate</td>
<td>• On board SAA, partner or simulated</td>
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<tr>
<td>Surveillance</td>
<td>• Modeled mixed ADS-B and radar</td>
<td>• ADS-B/TIS-B, modeled and real</td>
<td>• ADS-B/TIS-B, modeled and real</td>
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<tr>
<td>Traffic</td>
<td>• Simulated</td>
<td>• UAS/UAS Surrogate • Simulated Traffic</td>
<td>• UAS/UAS Surrogate • Live Traffic • Simulated Traffic</td>
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<tr>
<td>Command and Control Link</td>
<td>• Modeled</td>
<td>• Prototype Equipment – single aircraft</td>
<td>• Prototype Equipment – multiple aircraft</td>
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<tr>
<td>Acronyms</td>
<td>Description</td>
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<tr>
<td>ADS-B</td>
<td>Automatic Dependent Surveillance - Broadcast</td>
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<td>AFRC</td>
<td>Armstrong Flight Research Center</td>
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<td>ARC</td>
<td>Ames Research Center/Aviation Rule Making Committee</td>
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<td>ARMD</td>
<td>Aeronautics Research Mission Directorate</td>
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<td>BLOS</td>
<td>Beyond Line of Sight</td>
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<td>Command and Control Subproject</td>
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<td>CA</td>
<td>Collision Avoidance</td>
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<td>Controller Acceptability Study</td>
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<td>CNPC</td>
<td>Control and Non-Payload Communications</td>
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<td>CONOPS</td>
<td>Concept of Operations</td>
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<td>CST</td>
<td>Combined Systems Test</td>
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<td>DAA</td>
<td>Detect and Avoid</td>
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<td>DRR</td>
<td>Due Regard Radar</td>
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<td>Engineering Development Model</td>
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<td>FDR</td>
<td>Final Design Review</td>
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<td>GCS</td>
<td>Ground Control Station</td>
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<td>GRC</td>
<td>Glenn Research Center</td>
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<tr>
<td>HITL</td>
<td>Human-In-The-Loop</td>
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### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>HSI</td>
<td>Human Systems Integration Subproject</td>
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<td>IFR</td>
<td>Instrument Flight Rules</td>
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<tr>
<td>IHITL</td>
<td>Integrated Human-In-The-Loop</td>
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<tr>
<td>ITE or IT&amp;E</td>
<td>Integrated Test and Evaluation Subproject</td>
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<td>LaRC</td>
<td>Langley Research Center</td>
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<tr>
<td>LVC</td>
<td>Live Virtual Constructive</td>
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<td>LVC-DE</td>
<td>Live Virtual Constructive Distributed Environment</td>
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<td>MOPS</td>
<td>Minimum Operational Performance Standards</td>
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<td>NAS</td>
<td>National Airspace System</td>
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<tr>
<td>OSD</td>
<td>Office of the Secretary of Defense</td>
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<tr>
<td>PDR</td>
<td>Preliminary Design Review</td>
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<td>RGCS</td>
<td>Research GCS</td>
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<td>RT</td>
<td>Research Theme</td>
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<td>RTCA SC</td>
<td>RTCA Special Committee</td>
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<tr>
<td>SA</td>
<td>Situational Awareness/Separation Assurance</td>
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<tr>
<td>SAA</td>
<td>Sense and Avoid</td>
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<td>SARP</td>
<td>Science and Research Panel</td>
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<td>SRR</td>
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<td>SS</td>
<td>Self Separation</td>
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<td>sUAS</td>
<td>Small Unmanned Aircraft System</td>
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<td>TCAS</td>
<td>Traffic Alert and Collision Avoidance System</td>
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<td>Definition</td>
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<td>TIS-B</td>
<td>Traffic Information Services - Broadcast</td>
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<td>TRACON</td>
<td>Terminal Radar Approach Control</td>
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<td>Unmanned Aircraft Systems</td>
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<td>Unmanned Aircraft Vehicle</td>
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<td>V&amp;V</td>
<td>Verification &amp; Validation</td>
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<td>Visual Flight Rules</td>
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<td>Virtual Private Network</td>
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<td>VSCS</td>
<td>Vigilant Spirit Control Station</td>
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<tr>
<td>WG</td>
<td>Working Group</td>
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<tr>
<td>ZFW</td>
<td>Dallas Fort Worth FAA Air Route Traffic Control Center</td>
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<tr>
<td>ZOA</td>
<td>Oakland FAA Air Route Traffic Control Center</td>
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