National Aeronautics and Space Administration

# UAS Integration in the NAS Project
# Flight Test Planning Status

**Laurie Grindle**

**Project Manager, UAS Integration in the NAS Project**

**NAC Aeronautics Committee**

**July 29, 2014**

# Outline

- **Phase 2 Project Overview**

- **Integrated Test Plans**
  - **Integrated Human in the Loop Simulation Status**
  - **Flight Campaign Planning**

- **Summary**

# Project Goal, Research Themes, & Technical Challenges

**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
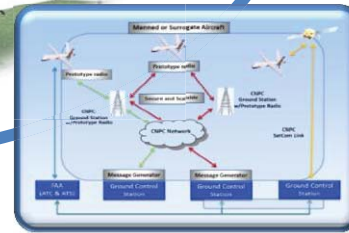
*TC-ITE: Integrated Test & Evaluation*
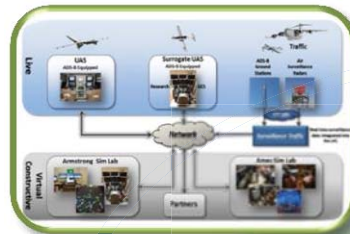
*TC-SAA: Sense and Avoid Performance Standards*
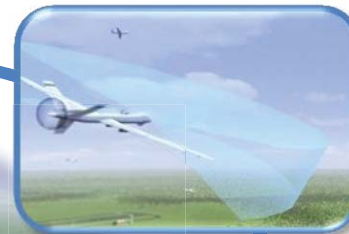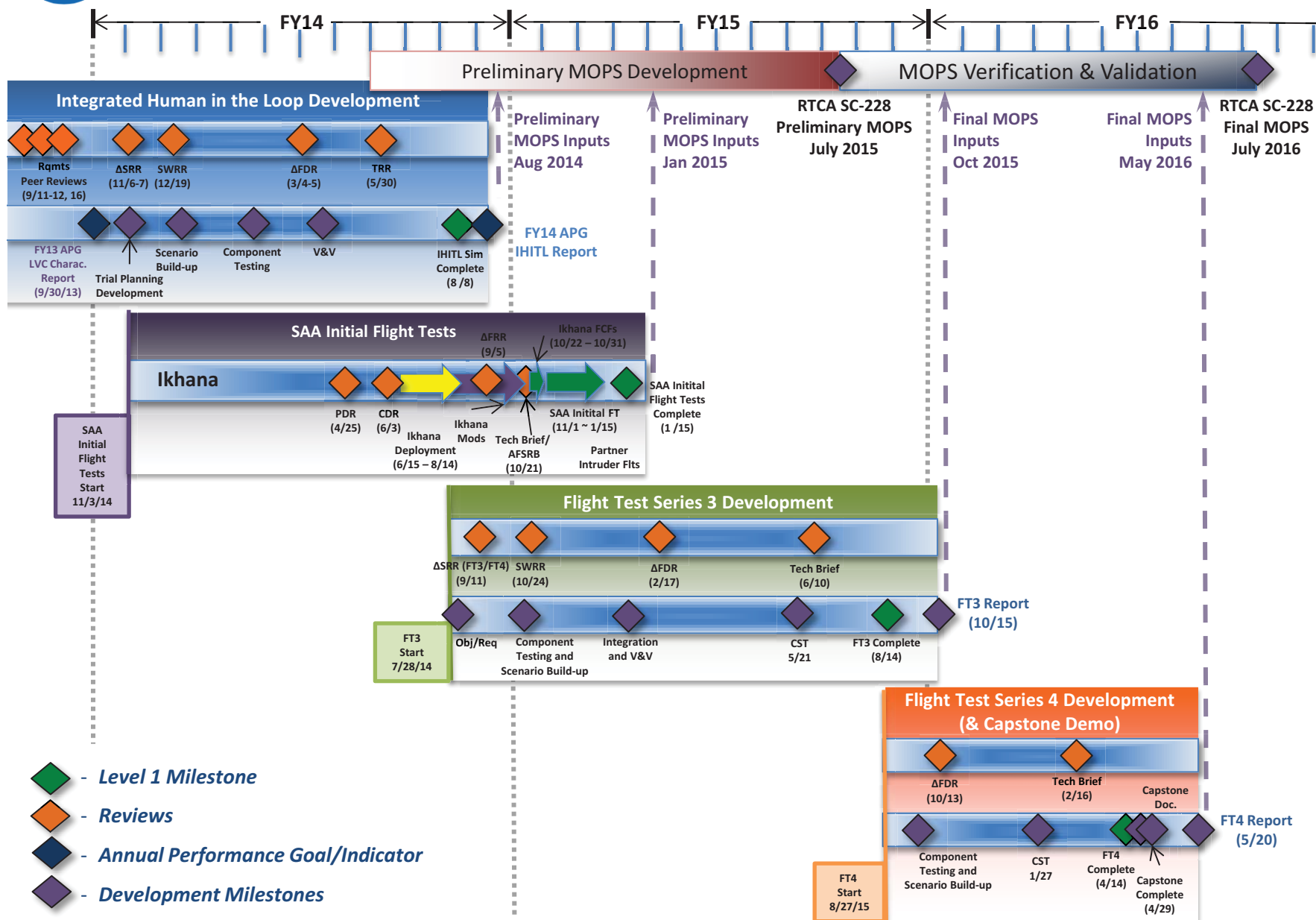
*TC-HSI: Human Systems Integration*
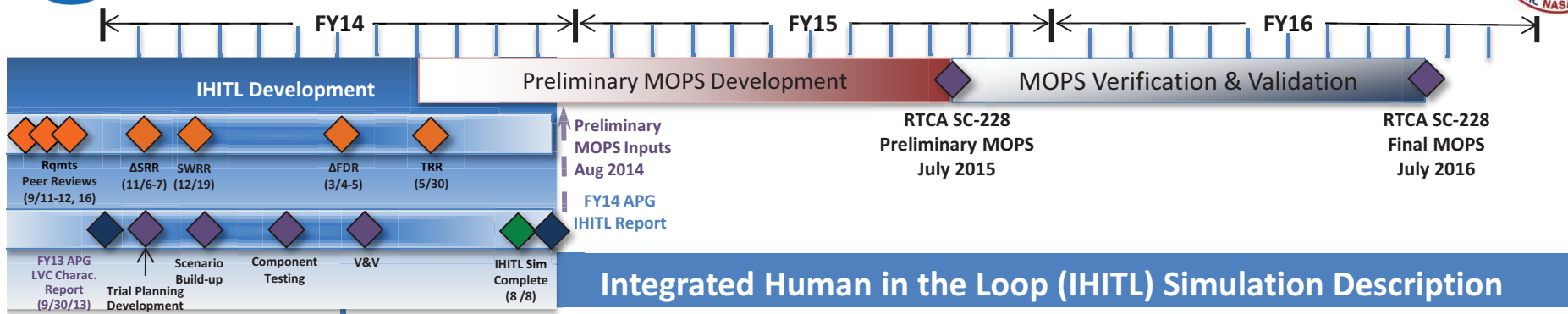
*TC-C2: Command & Control Performance Standards*

# IT&E Integrated Test Flow



Preliminary MOPS Development

MOPS Verification & Validation

FY14 | FY15 | FY16

**Integrated Human in the Loop Development**

Rqmts Peer Reviews (9/11-12, 16)
ΔSRR (11/6-7)
SWRR (12/19)
ΔFDR (3/4-5)
TRR (5/30)

FY13 APG LVC Charac. Report (9/30/13)
Trial Planning Development
Scenario Build-up
Component Testing
V&V
IHITL Sim Complete (8 /8)

Preliminary MOPS Inputs Aug 2014
Preliminary MOPS Inputs Jan 2015
RTCA SC-228 Preliminary MOPS July 2015
Final MOPS Inputs Oct 2015
Final MOPS Inputs May 2016
RTCA SC-228 Final MOPS July 2016

FY14 APG IHITL Report

**SAA Initial Flight Tests**

ΔFRR (9/5)
Ikhana FCFs (10/22 – 10/31)

**Ikhana**

PDR (4/25)
CDR (6/3)
Ikhana Deployment (6/15 – 8/14)
Ikhana Mods
Tech Brief/ AFSRB (10/21)
SAA Initital FT (11/1 ~ 1/15)
Partner Intruder Flts
SAA Initital Flight Tests Complete (1 /15)

SAA Initial Flight Tests Start 11/3/14

**Flight Test Series 3 Development**

ΔSRR (FT3/FT4) (9/11)
SWRR (10/24)
ΔFDR (2/17)
Tech Brief (6/10)

Obj/Req
Component Testing and Scenario Build-up
Integration and V&V
CST 5/21
FT3 Complete (8/14)

FT3 Report (10/15)

FT3 Start 7/28/14

**Flight Test Series 4 Development (& Capstone Demo)**

ΔFDR (10/13)
Tech Brief (2/16)
Capstone Doc.

Component Testing and Scenario Build-up
CST 1/27
FT4 Complete (4/14)
Capstone Complete (4/29)

FT4 Report (5/20)

FT4 Start 8/27/15

- Level 1 Milestone
- Reviews
- Annual Performance Goal/Indicator
- Development Milestones

4

# IT&E Integrated Test Flow
# IHITL



Timeline: FY14 — FY15 — FY16

IHITL Development | Preliminary MOPS Development | MOPS Verification & Validation

Preliminary MOPS Inputs Aug 2014

FY14 APG IHITL Report

RTCA SC-228 Preliminary MOPS July 2015

RTCA SC-228 Final MOPS July 2016

Rqmts Peer Reviews (9/11-12, 16)
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TRR (5/30)

FY13 APG LVC Charac. Report (9/30/13)
Trial Planning Development
Scenario Build-up
Component Testing
V&V
IHITL Sim Complete (8 /8)

Legend:
- ◆ (green) - **Level 1 Milestone**
- ◆ (orange) - **Reviews**
- ◆ (dark blue) - **Annual Performance Goal**
- ◆ (purple) - **Development Milestones**

**ZFW (Dallas-Ft Worth)**

**ZOA (Oakland Center)**

## 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<br>  • Config1: Ames/Armstrong connectivity (ATC and Pilot test set-ups)<br>  • Config2: Langley/Ames connectivity (SAA-CA interoperability)<br>• Scenarios - Class E airspace operations near major TRACONs |
| Test Duration | June – July 2014<br>  • Config1 Test Set-up 1: ATC – 3 weeks (15 Controllers)<br>  • Config1 Test Set-up 2: UAS pilots – 2 weeks (10 pilots)<br>  • Config2 Test Set-up: ATC – 3 weeks (6 Controllers) |
| Tech Transfer | • Validated SAA, C2, HSI performance requirements and guidelines<br>• Community insight into LVC Infrastructure capabilities |
| Project Benefit | • Validates project models<br>• Risk reduction for SAA Initial Flight Test (FT) Series and Flight Test Series 3 (FT3)<br>• 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
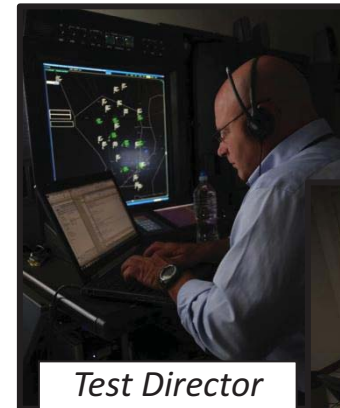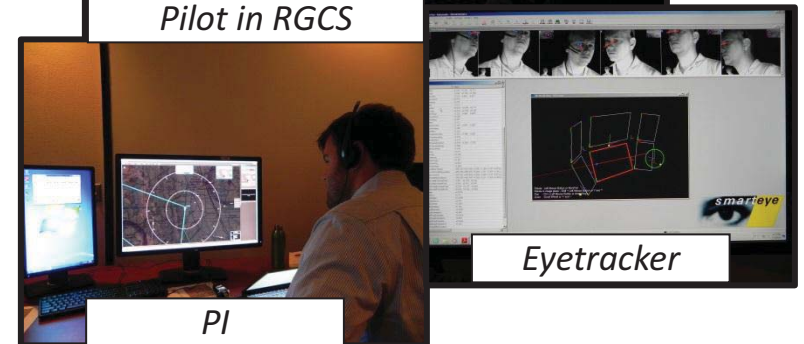


*Test Director*
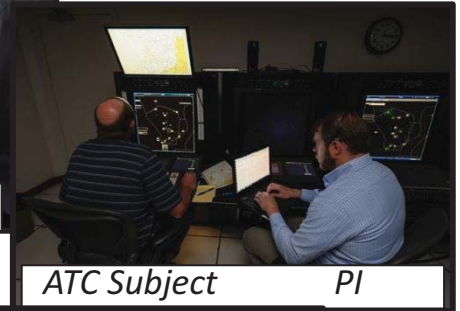
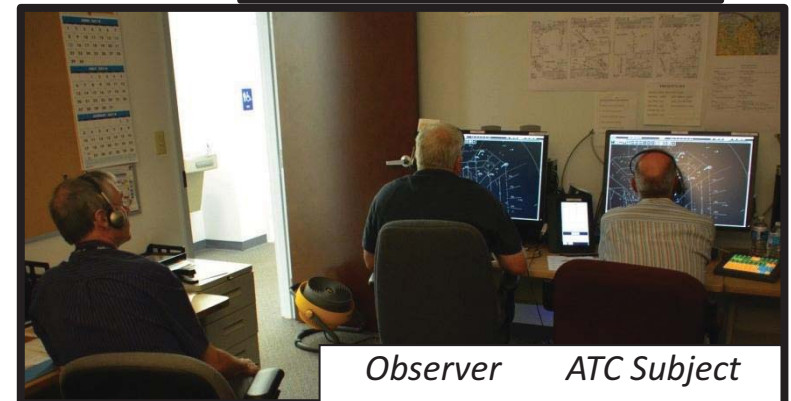*ATC Subject*     *PI*

*Pilot in RGCS*

*Eyetracker*

*PI*

# 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
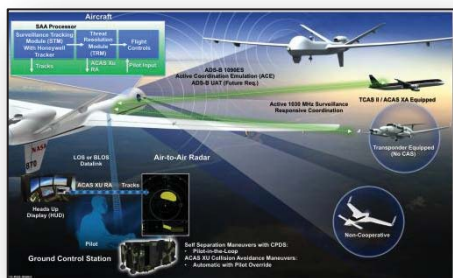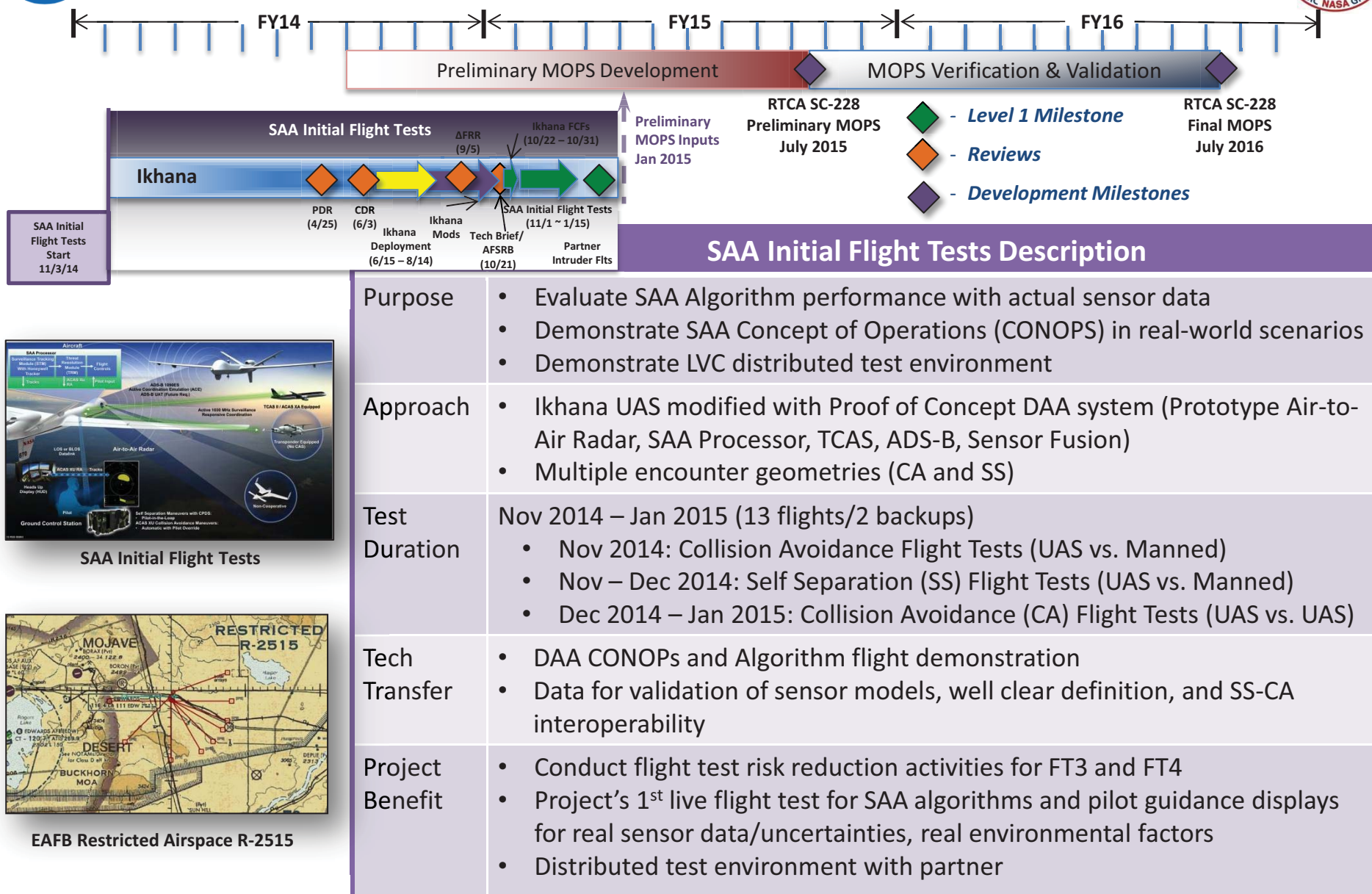

*Pilot Displays*


*Observer*      *ATC Subject*


*NASA Ames 747 Cab*

FY14 — FY15 — FY16

Preliminary MOPS Development | MOPS Verification & Validation

SAA Initial Flight Tests

Ikhana

ΔFRR (9/5)

Ikhana FCFs (10/22 – 10/31)

Preliminary MOPS Inputs Jan 2015

RTCA SC-228 Preliminary MOPS July 2015

RTCA SC-228 Final MOPS July 2016

- Level 1 Milestone
- Reviews
- Development Milestones

PDR (4/25)
CDR (6/3)
Ikhana Deployment (6/15 – 8/14)
Ikhana Mods
Tech Brief/ AFSRB (10/21)
SAA Initial Flight Tests (11/1 ~ 1/15)
Partner Intruder Flts

SAA Initial Flight Tests Start 11/3/14



SAA Initial Flight Tests



EAFB Restricted Airspace R-2515

## SAA Initial Flight Tests Description

| | |
|---|---|
| Purpose | • Evaluate SAA Algorithm performance with actual sensor data<br>• Demonstrate SAA Concept of Operations (CONOPS) in real-world scenarios<br>• 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)<br>• Multiple encounter geometries (CA and SS) |
| Test Duration | Nov 2014 – Jan 2015 (13 flights/2 backups)<br>• Nov 2014: Collision Avoidance Flight Tests (UAS vs. Manned)<br>• Nov – Dec 2014: Self Separation (SS) Flight Tests (UAS vs. Manned)<br>• Dec 2014 – Jan 2015: Collision Avoidance (CA) Flight Tests (UAS vs. UAS) |
| Tech Transfer | • DAA CONOPs and Algorithm flight demonstration<br>• 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<br>• Project's 1st live flight test for SAA algorithms and pilot guidance displays for real sensor data/uncertainties, real environmental factors<br>• Distributed test environment with partner |

# IT&E Integrated Test Flow
# Flight Test Series 3

FY14 | FY15 | FY16

Preliminary MOPS Development → MOPS Verification & Validation

RTCA SC-228
Final MOPS
July 2016

- ◆ - *Level 1 Milestone*
- ◆ - *Reviews*
- ◆ - *Development Milestones*

## Flight Test Series 3 Development

ΔSRR (FT3/FT4) (9/11) | SWRR (10/24) | ΔFDR (2/17) | Tech Brief (6/10)

Final MOPS Inputs Oct 2015

FT3 Report (10/15)

FT3 Start 7/28/14 | Obj/Req | Component Testing and Scenario Build-up | Integration and V&V | CST 5/21 | FT3 Complete (8/14)



**Flight Test Series 3 Infrastructure**

## Flight Test Series 3 Description

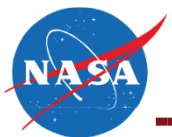| | |
|---|---|
| Purpose | • Flight test prototype SAA & C2 systems utilizing Research Ground Control Station (RGCS); conduct integrated flight test series to verify Preliminary DAA & C2 MOPS and validate sensor models<br>• Demonstrate system integration of surrogate UAS with CNPC, RGCS, and Self Separation (SS) Algorithms |
| Approach | • Increase complexity from IHITL through live aircraft incorporation and increased definition from MOPS<br>• 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<br>• 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<br>• Initiates verifications of the preliminary MOPS |
| Project Benefit | • Baseline FT4 System Architectures implemented<br>• Baseline flight test scenarios developed and validated |

# IT&E Integrated Test Flow
# Flight Test Series 4

**FY14** **FY15** **FY16**

- **Level 1 Milestone**
- **Reviews**
- **Development Milestones**

Preliminary MOPS Development | MOPS Verification & Validation

RTCA SC-228
Preliminary MOPS
July 2015

RTCA SC-228
Final MOPS
July 2016

**Flight Test Series 4 Development (& Capstone Demo)**

Final MOPS
Inputs
May 2016

FT4
Start
8/27/15

ΔFDR
(10/13)

Tech Brief
(2/16)

Capstone
Doc.

FT4 Report
(5/20)

Component
Testing and
Scenario Build-up

CST
1/27

FT4
Complete
(4/14)

Capstone
Complete
(4/29)

## Flight Test Series 4 Description

| | |
|---|---|
| Purpose | • Contribute to validation of final MOPS; flight-test SAA, CNPC, and RGCS in more stressed environments<br>• Demonstrate systems integration and evaluation of the state of UAS concepts and supporting technologies<br>• Demonstrate final LVC-DE configuration |
| Approach | • Challenging encounter geometries<br>• UAS pilot and ATC negotiation in complex/busy airspace<br>• Two aircraft with CNPC to assess link performance within the same spectrum<br>• Demonstrate CA-SS Interoperability, well clear compliance |
| Test Duration | February - April 2016<br>• 34 flights/2 backups (3.5 hour flights) |
| Tech Transfer | • DAA and C2 system refinements flight-tested<br>• Contributing to validation of final MOPS |
| Project Benefit | • Baseline technologies for Capstone demonstration |
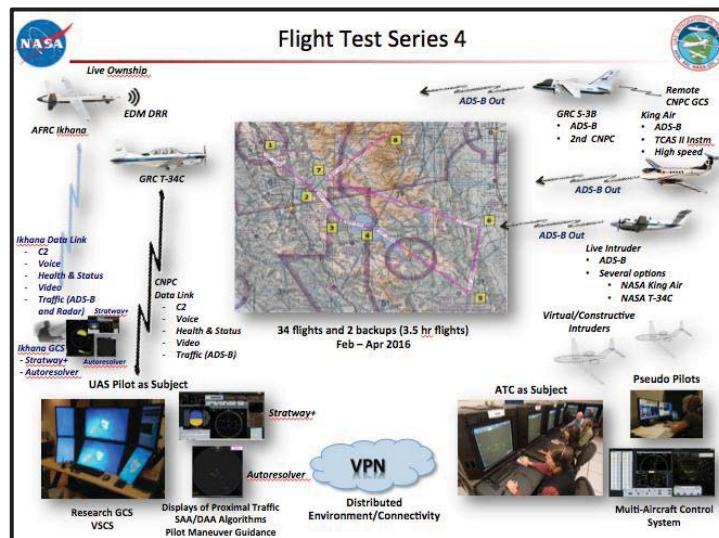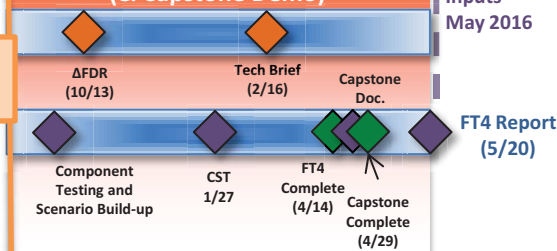


**Flight Test Series 4 Infrastructure**

**Live Ownship**



EDM DRR

**AFRC Ikhana**

**GRC T-34C**

ADS-B Out

**Remote CNPC GCS**

**GRC S-3B**
- ADS-B
- 2nd CNPC

**King Air**
- ADS-B
- TCAS II Instm
- High speed

ADS-B Out

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

Stratway+

**Ikhana GCS**
- Stratway+
- Autoresolver

Autoresolver

**UAS Pilot as Subject**

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

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

ADS-B Out

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

**Virtual/Constructive Intruders**

**Pseudo Pilots**

**ATC as Subject**

**Research GCS VSCS**

Stratway+

Autoresolver

**Displays of Proximal Traffic SAA/DAA Algorithms Pilot Maneuver Guidance**

**VPN**

**Distributed Environment/Connectivity**
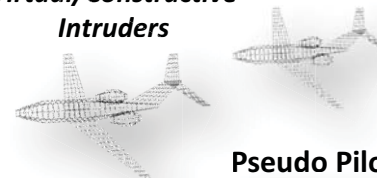
**Multi-Aircraft Control System**

# IT&E Integrated Test Flow
# Capstone



- ◆ (green) - *Level 1 Milestone*
- ◆ (orange) - *Reviews*
- ◆ (purple) - *Development Milestones*

Timeline: FY14 | FY15 | FY16

Preliminary MOPS Development | MOPS Verification & Validation

RTCA SC-228 Preliminary MOPS July 2015

RTCA SC-228 Final MOPS July 2016

Final MOPS Inputs May 2016

**Flight Test Series 4 Development (& Capstone Demo)**

ΔFDR | Tech Brief | Capstone Doc. | FT4 Report

Component Testing and Scenario Build-up | CST | FT4 Complete | Capstone Complete

## 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 <br> • 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) <br>   • 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 <br> • 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 |

**LEGEND:**
- DAA Technologies
- Air Traffic Services
- CNPC Network
- Legacy C2 Links
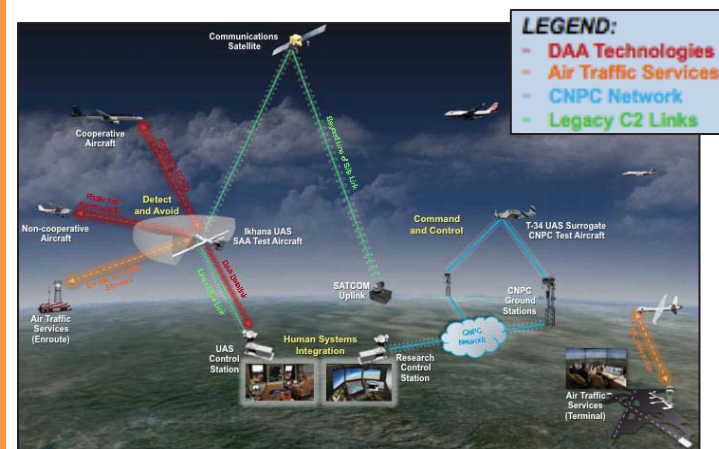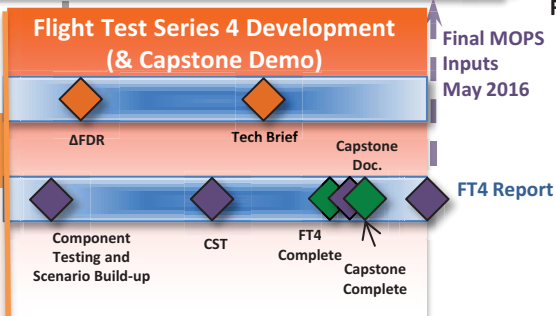
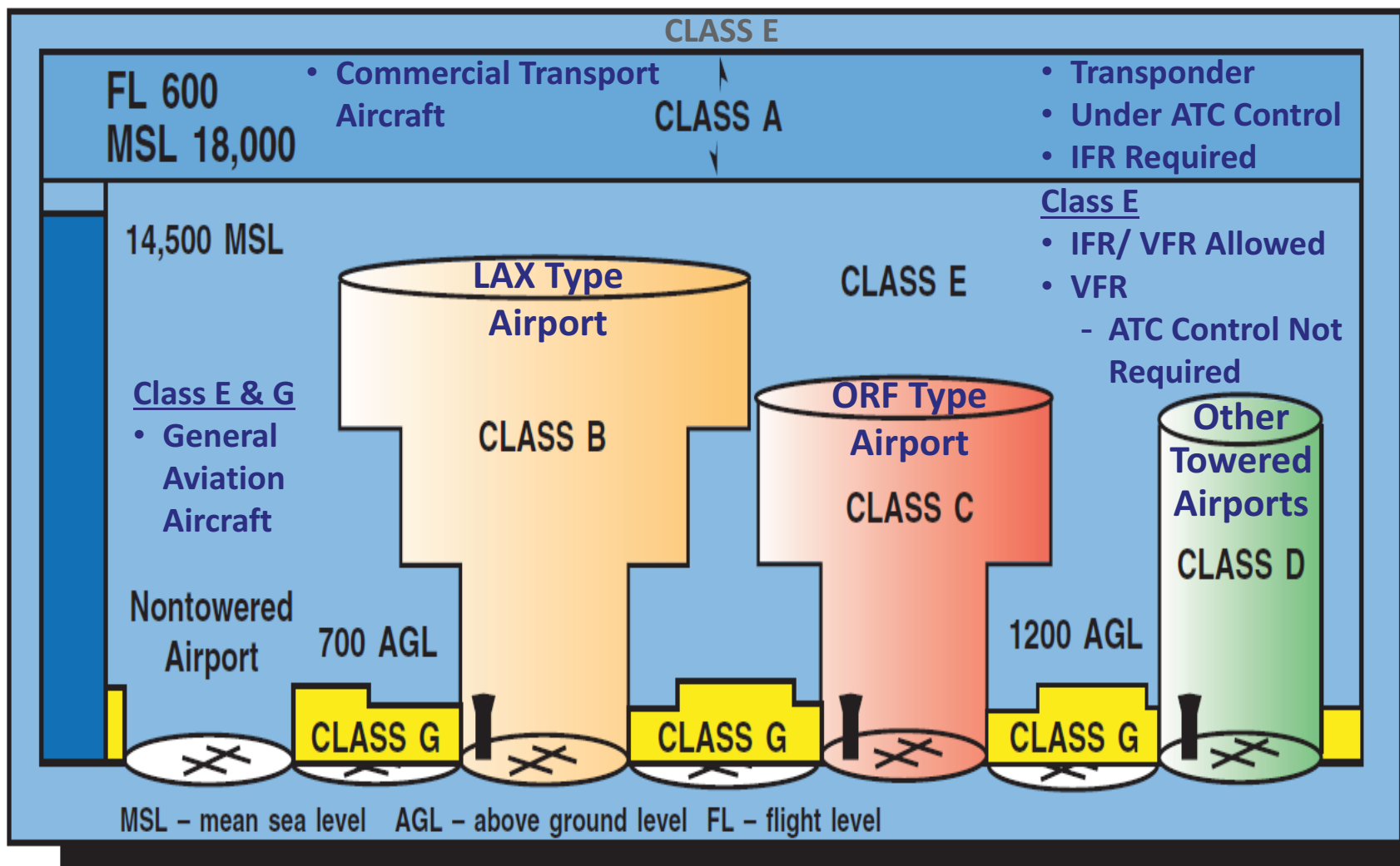**Project Operational View 1 (OV-1)**

# 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**

CLASS A

- **Transponder**
- **Under ATC Control**
- **IFR Required**

14,500 MSL

LAX Type Airport

CLASS E

**Class E**
- **IFR/ VFR Allowed**
- **VFR**
  - **ATC Control Not Required**

CLASS B

**Class E & G**
- **General Aviation Aircraft**

ORF Type Airport

CLASS C

**Other Towered Airports**

CLASS D

Nontowered Airport

700 AGL

1200 AGL

CLASS G

CLASS G

CLASS G

MSL – mean sea level    AGL – above ground level    FL – flight level

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# UAS Subcommittee Report Findings and Observations

- UAS Subcommittee reported to NAC on July 30, 2013

Report on UAS Subcommittee

Presented by:
**Dr. David Vos**
Member, UAS Subcommittee

NAC Aeronautics Committee Meeting
NASA Headquarters
July 30, 2013

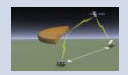## Subcommittee Findings and Observations
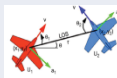
- The current UAS in the NAS program largely excludes "Small UAS". The Phase I econometric studies suggest that this segment may have the largest near-term economic impact. The Subcommittee recommends that future ARMD efforts include technology specifically applicable to Small UAS, for example, to enable BLOS and other non-VFR operations

- When developing MOPS and other outputs of the program, seeking the broadest applicability to all classes of UAS should be considered.

- The Subcommittee feels that broad community awareness is essential to the success of the UAS in the NAS mission, and recommends increased emphasis on public outreach and awareness related to the program. For example, the proposed Capstone demonstration can play an important role in showcasing the project's results.

- The Subcommittee strongly recommends that ARMD continue and expand its broad involvement in UAS technologies and programs, toward the goal of ARMD, NASA and the USA being the world leader in this field.
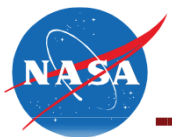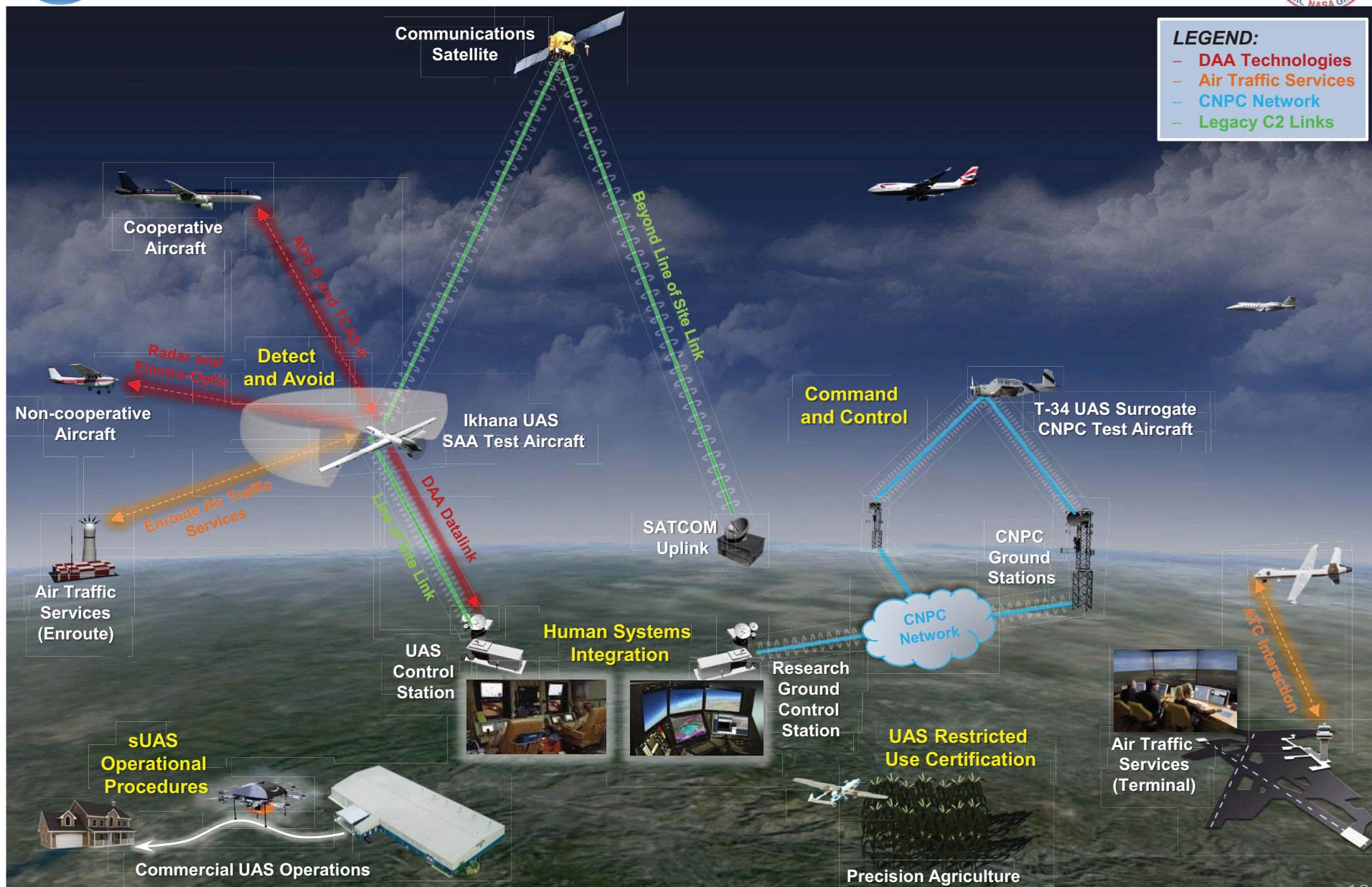
# Integrated Test Progression

| Test Element | IHITL [FY14] | FT3 [FY15] | FT4 [FY16] |
|---|---|---|---|
| GCS | • Research Ground Control Station (RGCS) with traffic displays and alerting logic | • RGCS with UAS Surrogate (T-34C) Command and Control | • RGCS with UAS Surrogate (T-34C) C2<br>• Multiple GCSs |
| SAA Algorithms | • Self separation, idealized sensor data | • Integration of collision avoidance into surrogate or simulated | • CA algorithm integrated into UA partner or self separation only |
| UAS | • Simulated | • UAS Surrogate (T-34C) | • UAS Surrogate (T-34C)<br>• SAA equipped UAS |
| Sensor | • Simulated | • Simulated on board UAS Surrogate | • On board SAA, partner or simulated |
| Surveillance | • Modeled mixed ADS-B and radar | • ADS-B/TIS-B, modeled and real | • ADS-B/TIS-B, modeled and real |
| Traffic | • Simulated | • UAS/UAS Surrogate<br>• Simulated Traffic | • UAS/UAS Surrogate<br>• Live Traffic<br>• Simulated Traffic |
| Command and Control Link | • Modeled | • Prototype Equipment – single aircraft | • Prototype Equipment – multiple aircraft |

# UAS-NAS Project OV-1



LEGEND:
- DAA Technologies
- Air Traffic Services
- CNPC Network
- Legacy C2 Links

Communications Satellite

Cooperative Aircraft

ADS-B and TCAS-II

Radar and Electro-Optic

Detect and Avoid

Non-cooperative Aircraft

Enroute Air Traffic Services

Beyond Line of Site Link

Ikhana UAS SAA Test Aircraft

DAA Datalink

Line of Site Link

Command and Control

T-34 UAS Surrogate CNPC Test Aircraft

SATCOM Uplink

CNPC Ground Stations

Air Traffic Services (Enroute)

UAS Control Station

Human Systems Integration

Research Ground Control Station

CNPC Network

ATC Interaction

Air Traffic Services (Terminal)

sUAS Operational Procedures

UAS Restricted Use Certification

Commercial UAS Operations

Precision Agriculture

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# Acronyms

| | |
|---|---|
| ADS-B | Automatic Dependent Surveillance - Broadcast |
| AFRC | Armstrong Flight Research Center |
| ARC | Ames Research Center/Aviation Rule Making Committee |
| ARMD | Aeronautics Research Mission Directorate |
| ATC | Air Traffic Controller |
| BLOS | Beyond Line of Sight |
| C2 | Command and Control Subproject |
| CA | Collision Avoidance |
| CAS | Controller Acceptability Study |
| CDR | Critical Design Review |
| CNPC | Control and Non-Payload Communications |
| CONOPS | Concept of Operations |
| CST | Combined Systems Test |
| DAA | Detect and Avoid |
| DRR | Due Regard Radar |
| EDM | Engineering Development Model |
| FAA | Federal Aviation Administration |
| FDR | Final Design Review |
| FT | Flight Test |
| GCS | Ground Control Station |
| GRC | Glenn Research Center |
| HITL | Human-In-The-Loop |

# Acronyms

| | |
|---|---|
| HSI | Human Systems Integration Subproject |
| IFR | Instrument Flight Rules |
| IHITL | Integrated Human-In-The-Loop |
| ITE or IT&E | Integrated Test and Evaluation Subproject |
| LaRC | Langley Research Center |
| LVC | Live Virtual Constructive |
| LVC-DE | Live Virtual Constructive Distributed Environment |
| MOPS | Minimum Operational Performance Standards |
| NAS | National Airspace System |
| OSD | Office of the Secretary of Defense |
| PDR | Preliminary Design Review |
| RGCS | Research GCS |
| RT | Research Theme |
| RTCA SC | RTCA Special Committee |
| SA | Situational Awareness/Separation Assurance |
| SAA | Sense and Avoid |
| SARP | Science and Research Panel |
| SRR | System Requirements Review |
| SS | Self Separation |
| sUAS | Small Unmanned Aircraft System |
| SWRR | Software Requirements Review |
| TC | Technical Challenge |
| TCAS | Traffic Alert and Collision Avoidance System |

# Acronyms

| | |
|---|---|
| TIS-B | Traffic Information Services - Broadcast |
| TRACON | Terminal Radar Approach Control |
| TRR | Test Readiness Review |
| UAS | Unmanned Aircraft Systems |
| UAV | Unmanned Aircraft Vehicle |
| V&V | Verification & Validation |
| VFR | Visual Flight Rules |
| VPN | Virtual Private Network |
| VSCS | Vigilant Spirit Control Station |
| WG | Working Group |
| ZFW | Dallas Fort Worth FAA Air Route Traffic Control Center |
| ZOA | Oakland FAA Air Route Traffic Control Center |