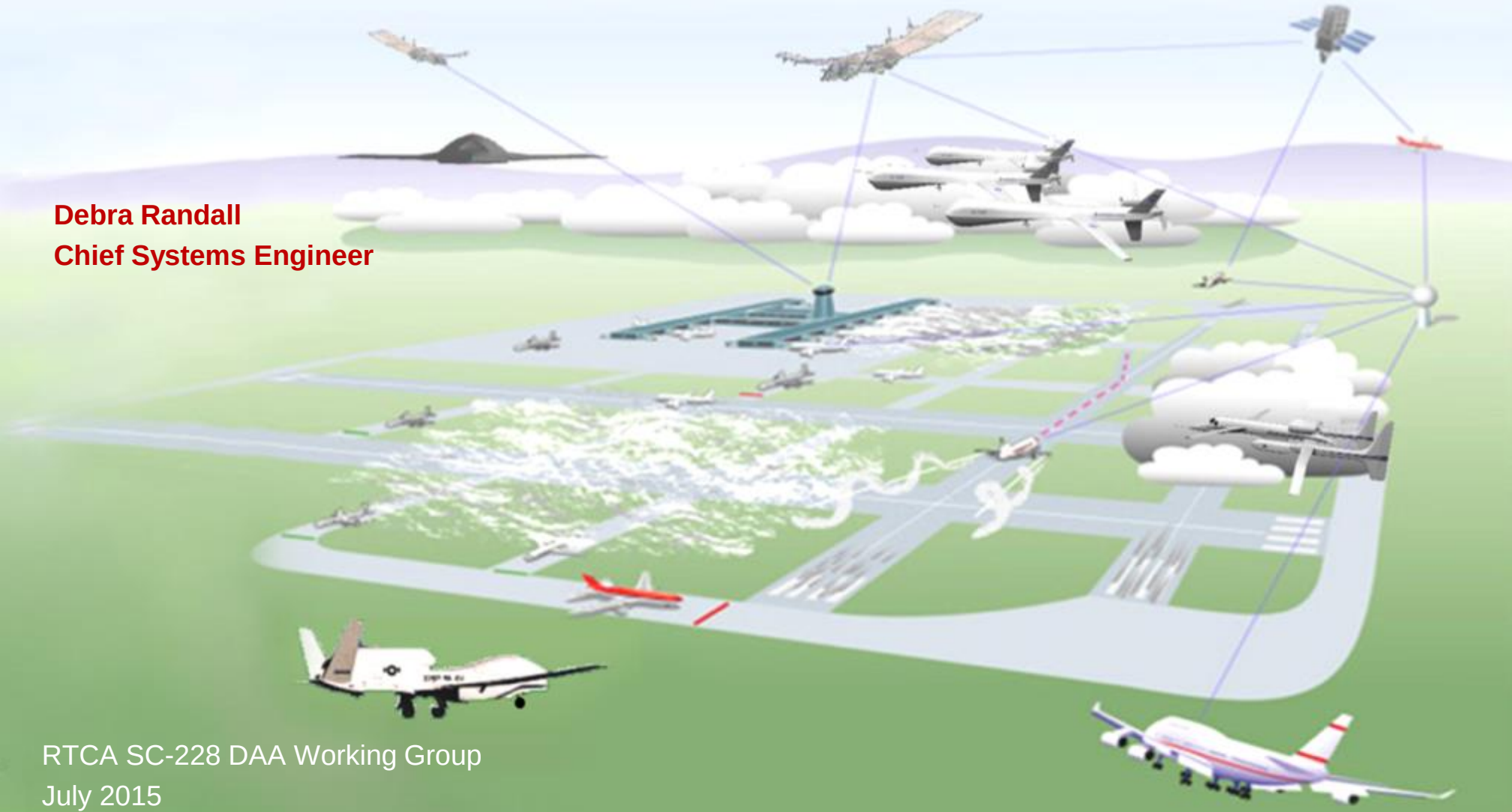
National Aeronautics and Space Administration

UAS in the NAS Flight Test Series 3



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Chief Systems Engineer

RTCA SC-228 DAA Working Group
July 2015

General Research Test Objectives

IHITL (Completed 7/25/14)

- Integrate and evaluate the state of UAS concepts and supporting technologies defined within the scope of the UAS in the NAS Project.
  - Evaluate and measure the effectiveness and acceptability of the SAA systems (algorithms and displays) to inform and advise UAS pilots
  - Evaluate and measure the interoperability and operational acceptability of UAS integration concepts in the NAS
- Characterize the test environment and identify areas of future research and development emphasis and reduce risk for the flight tests and capstone event

ACAS-Xu / SS (Completed 12/19/14)

- Conduct flight test risk reduction activities for FT3 and FT4
- Demonstrate Live, Virtual, Constructive (LVC) distributed test environment
- Demonstrate self-separation Concept of Operations (CONOPS) through real world scenarios
- Evaluate sense and avoid (SAA) algorithm performance with actual sensor data

FT3 (In Progress)

- Validate results previously collected during simulation testing (UAS CAS 2, IHITL, ACAS-Xu / SS, PT5) with live data.
  - Sensor performance, uncertainty
  - State data uncertainty
  - Wind compensation
- Evaluate TCAS II/SS interoperability
- Test fully integrated system in a relevant live test environment.
  - HSI Proof of Concept GCS and pilot guidance displays
  - CNPC performance
- Inform final DAA and C2 MOPS
- Reduce Risk for Flight Test Series 4.
  - More complex multi-intruder scenarios

FT4 (FY16)

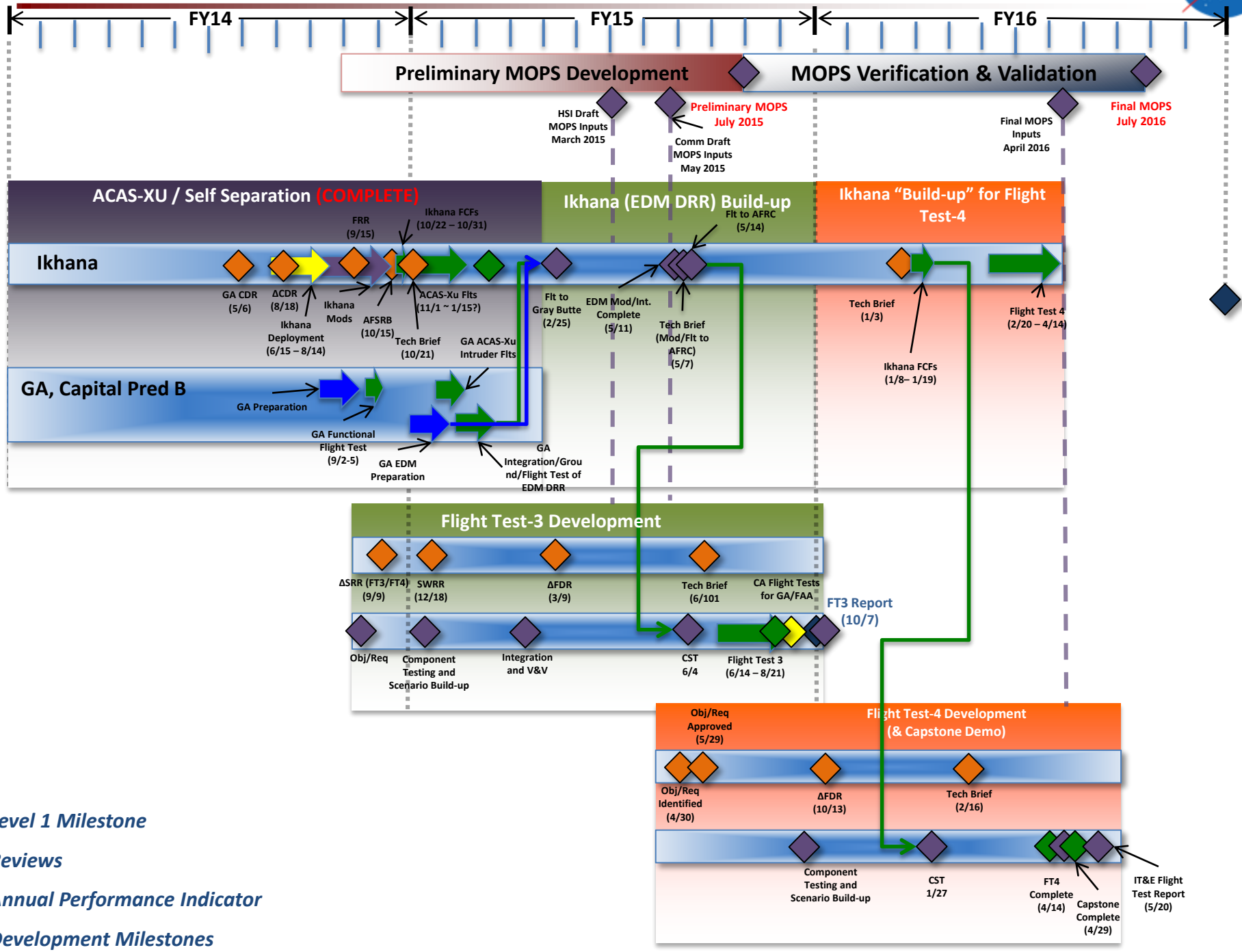
- Validate C2 and DAA MOPS
  - Challenging encounter geometries with 2 or more live aircraft
  - Negotiation between UAS pilot and ATC in complex/busy airspace
  - UAS capable of autonomous SA during lost link contingency

Capstone (FY16)

- Assess operational utility of UAS separation assurance and sense and avoid algorithms, ground control and air traffic display concepts
  - UAS line pilot flying surrogate or partner UAS
  - Mission-oriented, not test oriented

Timeline Not To Scale

IT&E Phase 2 Flight Tests



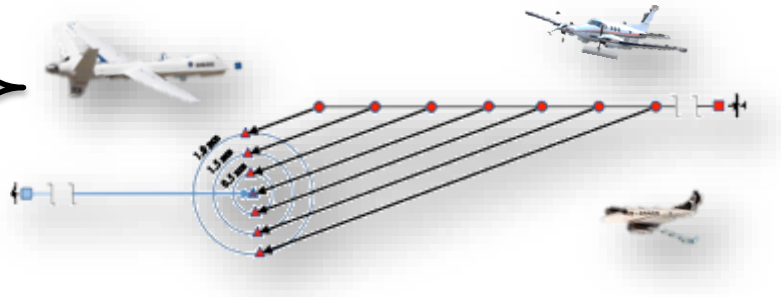
- *Level 1 Milestone*
- *Reviews*
- *Annual Performance Indicator*
- *Development Milestones*

Flight Test 3 Overview

Top Level Research Goals

Top Level Research Goals:

- **Validate results previously collected during project simulations with live data**
  - **Sensor performance, uncertainty**
  - **State data uncertainty**
  - **Wind compensation**
- **Evaluate TCAS II/SS interoperability**



- **Test fully integrated system in a relevant live test environment**
  - **HSI Proof of Concept GCS and pilot guidance displays**
  - **CNPC performance**
- **Inform final DAA and C2 MOPS**
- **Reduce risk for Flight Test Series 4**
  - **More complex multi-intruder scenarios**

Full Mission Scenario Evaluations

- **Live Ownship (Surrogate UA)**
- **Live and Virtual Intruders**
- **Representative Operational Mission**
- **UAS Pilot Participants using RGCS**

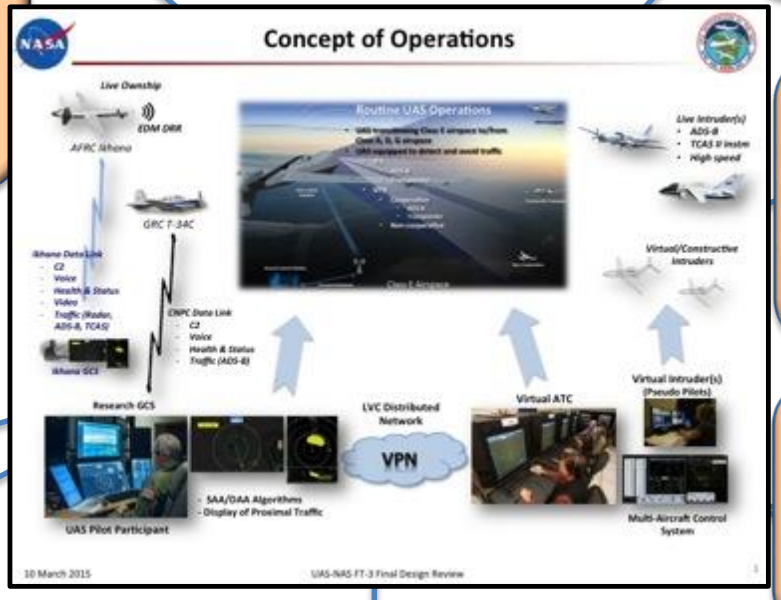
Integration Roles & Responsibilities Summary

NASA

Non-NASA

NASA – AFRC
(UAS-NAS / IT&E)
- Provide RGCS Infrastructure
- Provide LVC-DE Infrastructure
- Provide Intruder Aircraft (T-34 &/or King Air)
- Provide ownship aircraft (Ikhana)
- Test Conductor Station (SAF)

NASA - ARC
(UAS-NAS / HSI)
- Provide VSCS (from AFRL) and display definition



NASA - ARC
(UAS-NAS / SSI)
- Provide JADEM (Autoresolver) SAA
- Provide Uncertainty model
- Devise Encounter matrix

NASA - ARC
(UAS-NAS / IT&E)
- Provide HLA infrastructure
- Provide Pseudo pilot & Controller workstations (MACS)
- Develop traffic scenarios

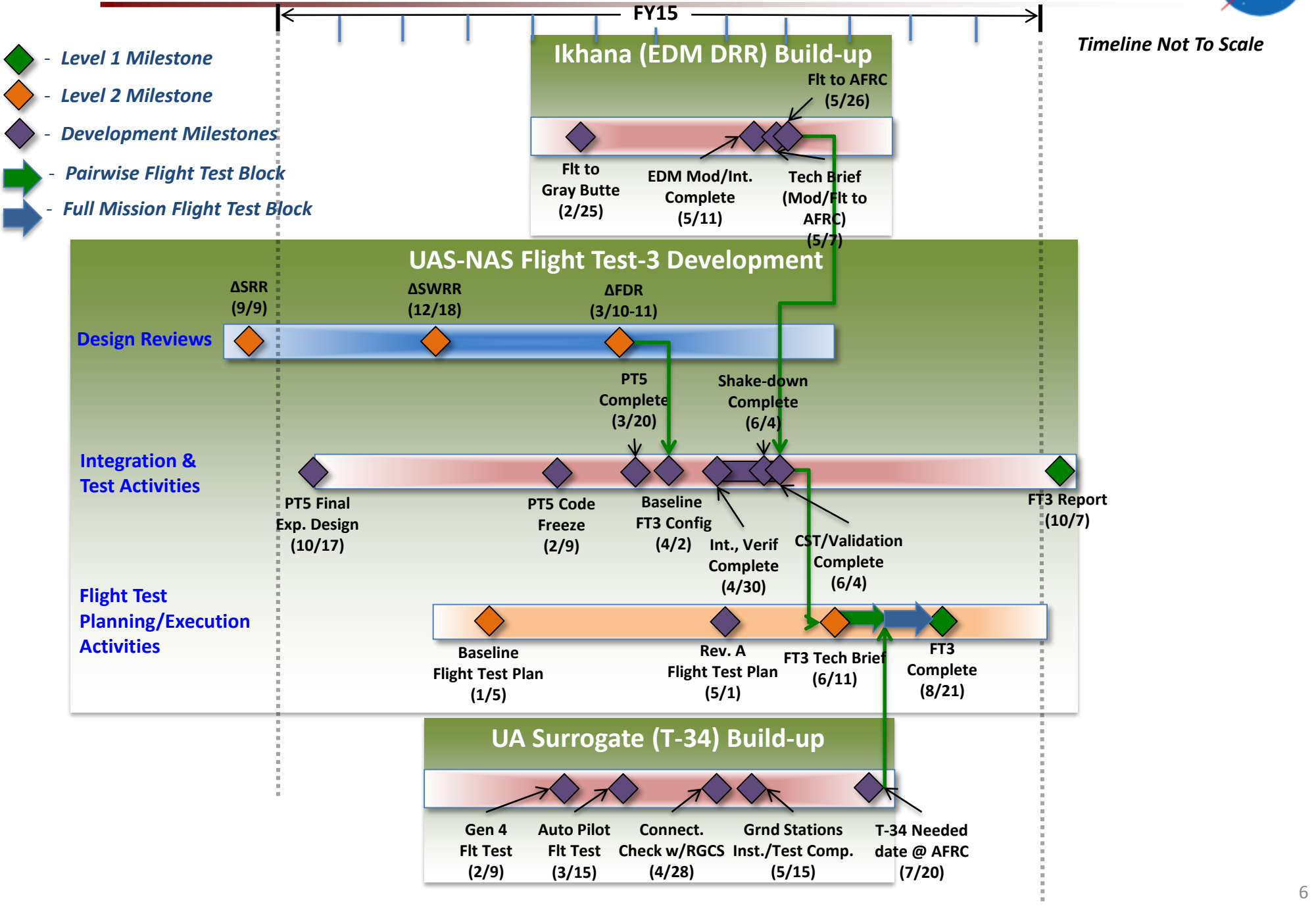
NASA - LaRC
(UAS-NAS / SSI)
- Provide DAIDALUS (Stratway+) SAA
- Devise Encounter matrix

NASA - GRC
(UAS-NAS / C2)
- Provide UA Surrogate Aircraft (T-34)
- Provide ownship and intruder (S-3)
- Provide CNPC infrastructure

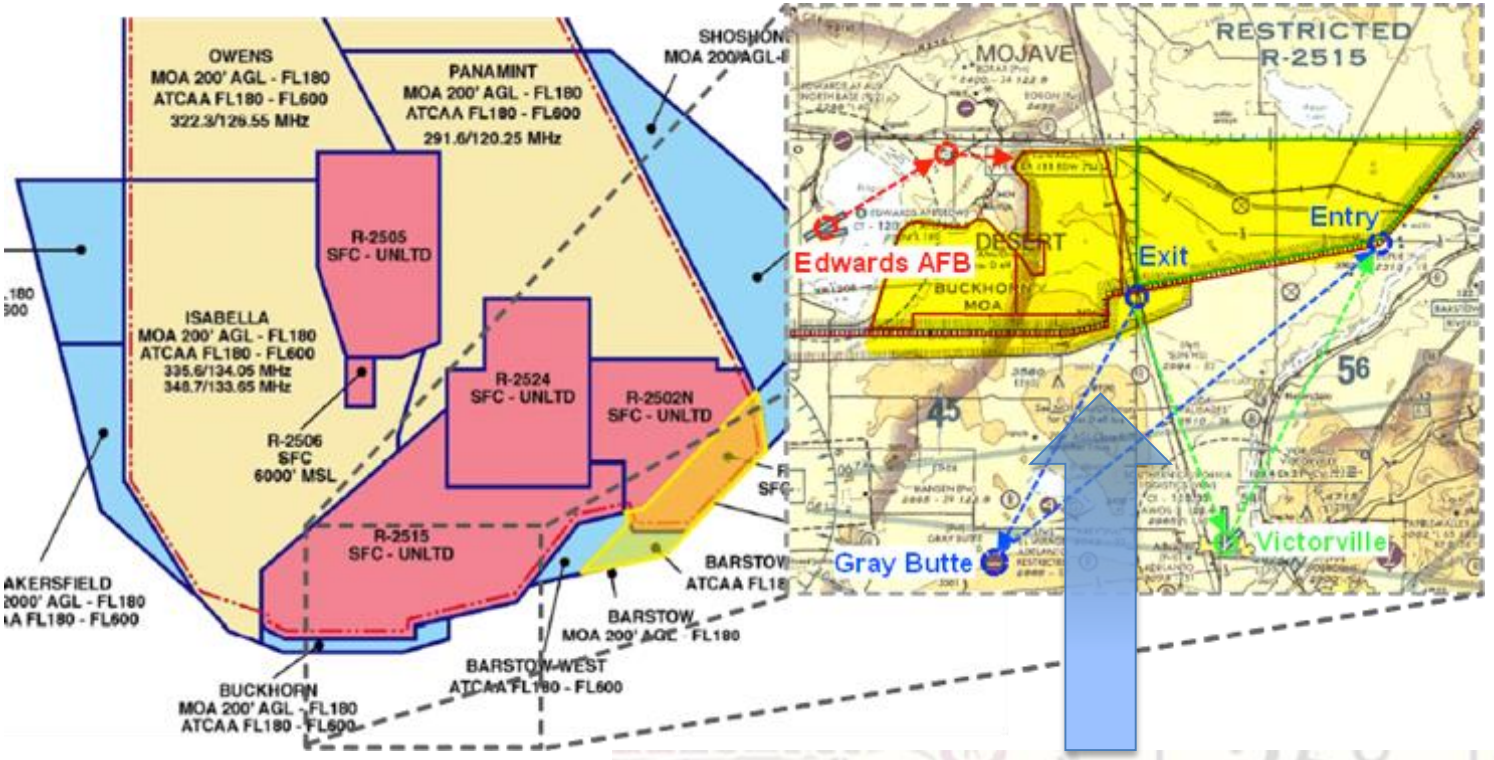
Honeywell
- Provide surveillance tracking software for SAA system
- Provide instrumented TCAS II equipped intruder aircraft

GA-ASI
- Provide proof of concept SAA system (EDM DRR, SAAP, etc.)
- CPDS Display and IO Server

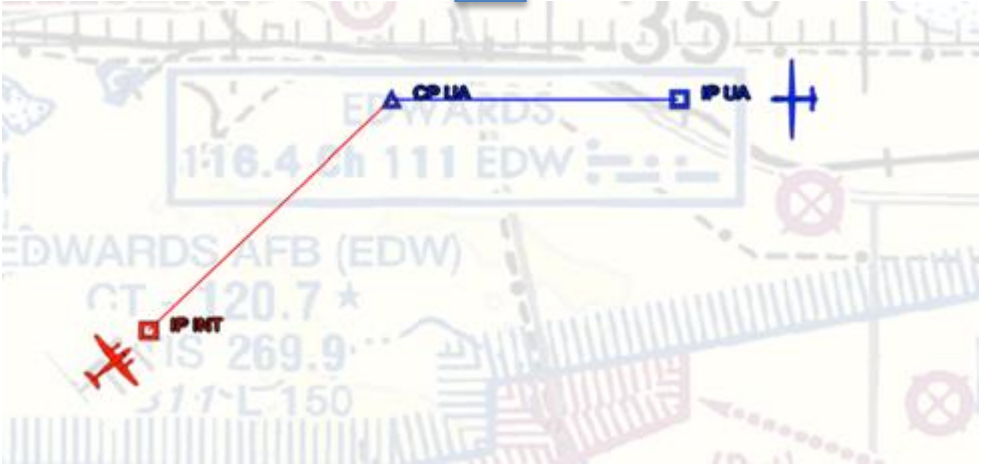
Flight Test Series 3 Milestones/Key Activities



Pairwise Encounter Airspace

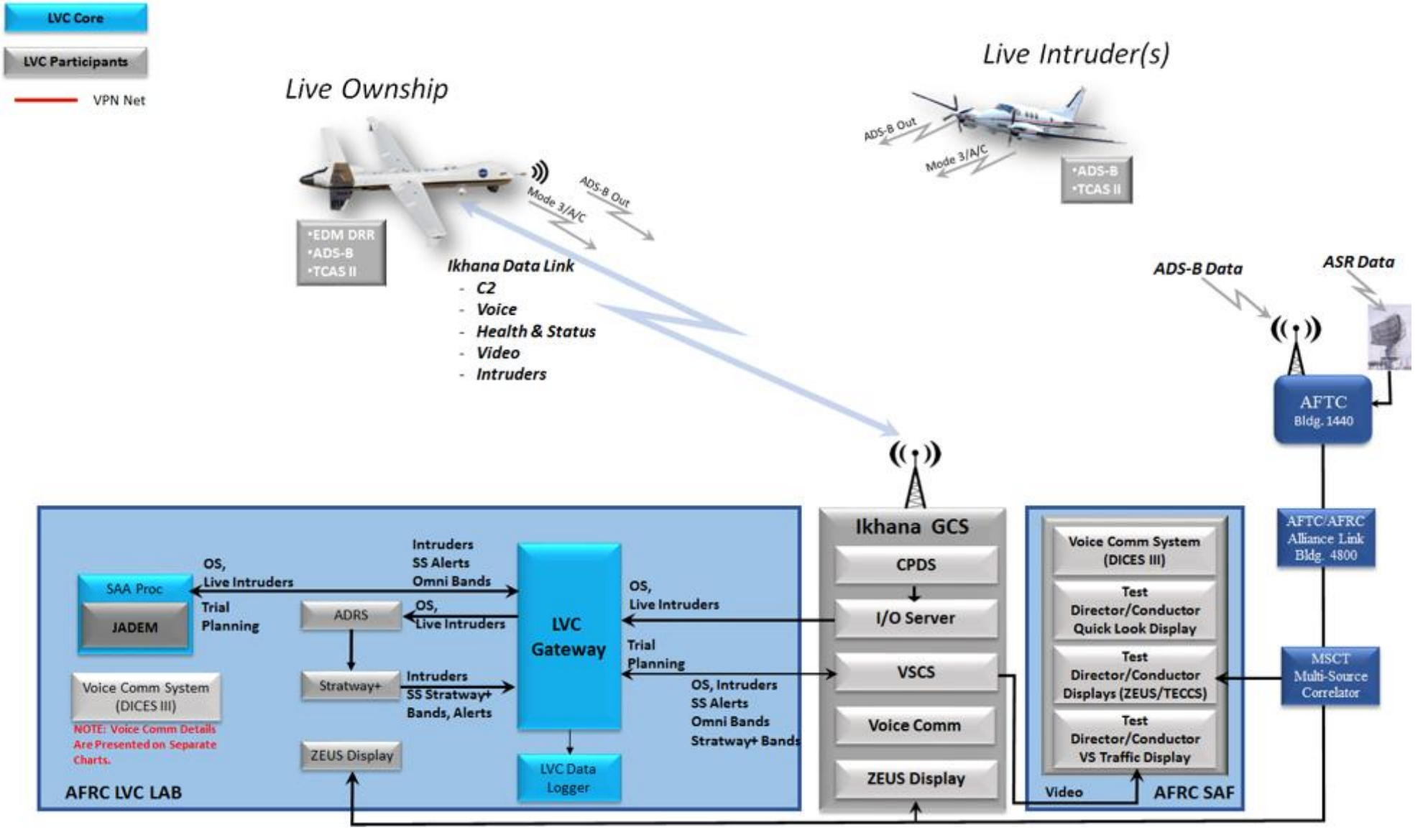


- Pairwise, low speed−low speed encounters that requires Ikhana ownship versus a low speed intruder aircraft (C90 or T-34C) [Configuration 1A];
- Pairwise, low speed−high speed encounters that requires Ikhana ownship versus S-3B [Configuration 1A];
- Pairwise, low speed−low/high speed encounters that requires Ikhana ownship versus multi-intruder aircraft (one low speed intruder (T-34C or C90) and one high speed intruder (S-3B) [Configuration 1A];
- Pairwise, high speed−low speed encounters that requires S-3B ownship versus a low speed intruder (T-34C or C90) [Configuration 1B].

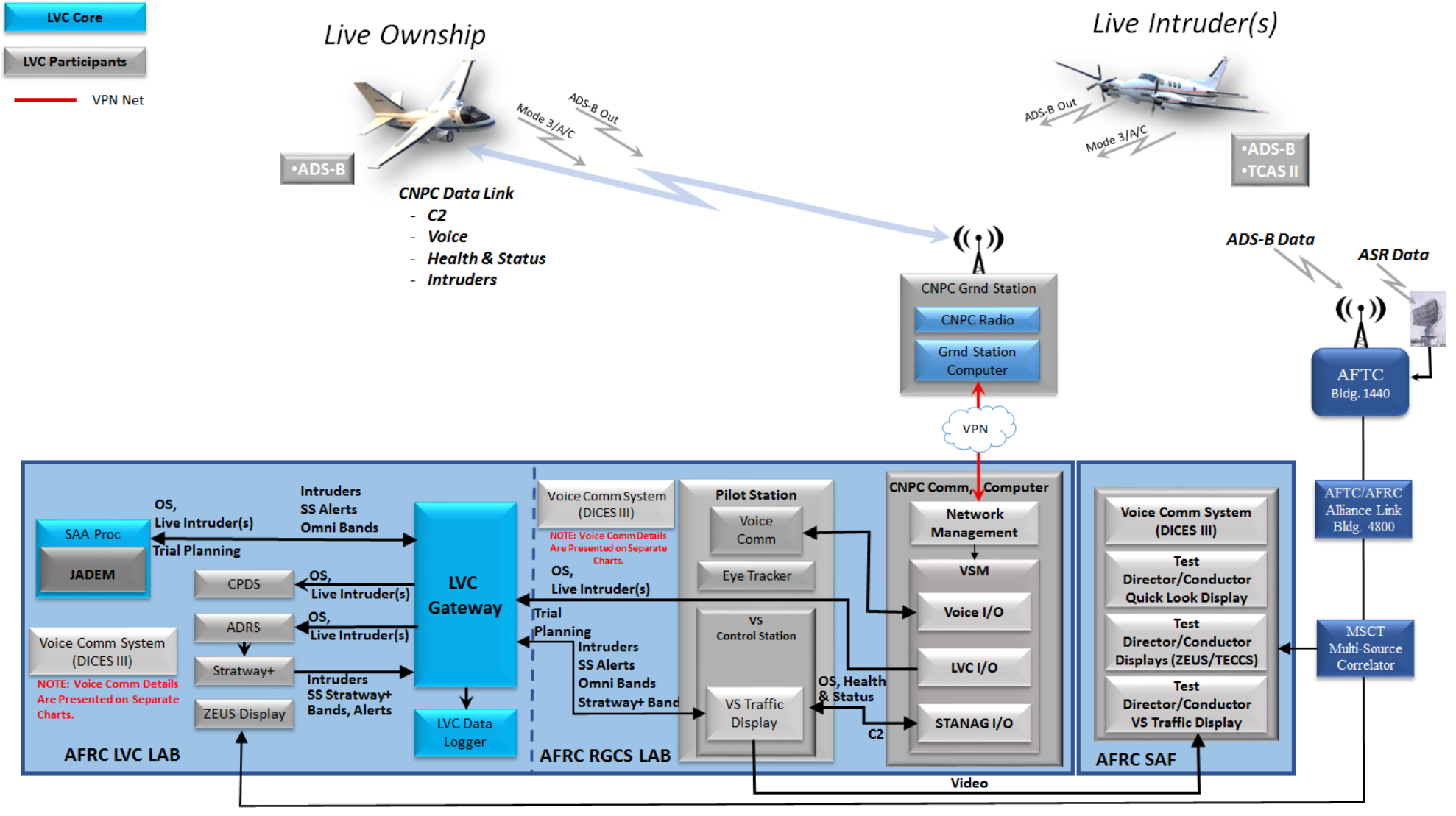


FT3: Configuration 1A (Pairwise-Low Speed Ownship) – Ikhana

Pairwise = 10 flights (~3.5 hr flights)



FT3: Configuration 1B (Pairwise-High Speed Ownship) – S-3B



Ikhana with EDM DRR

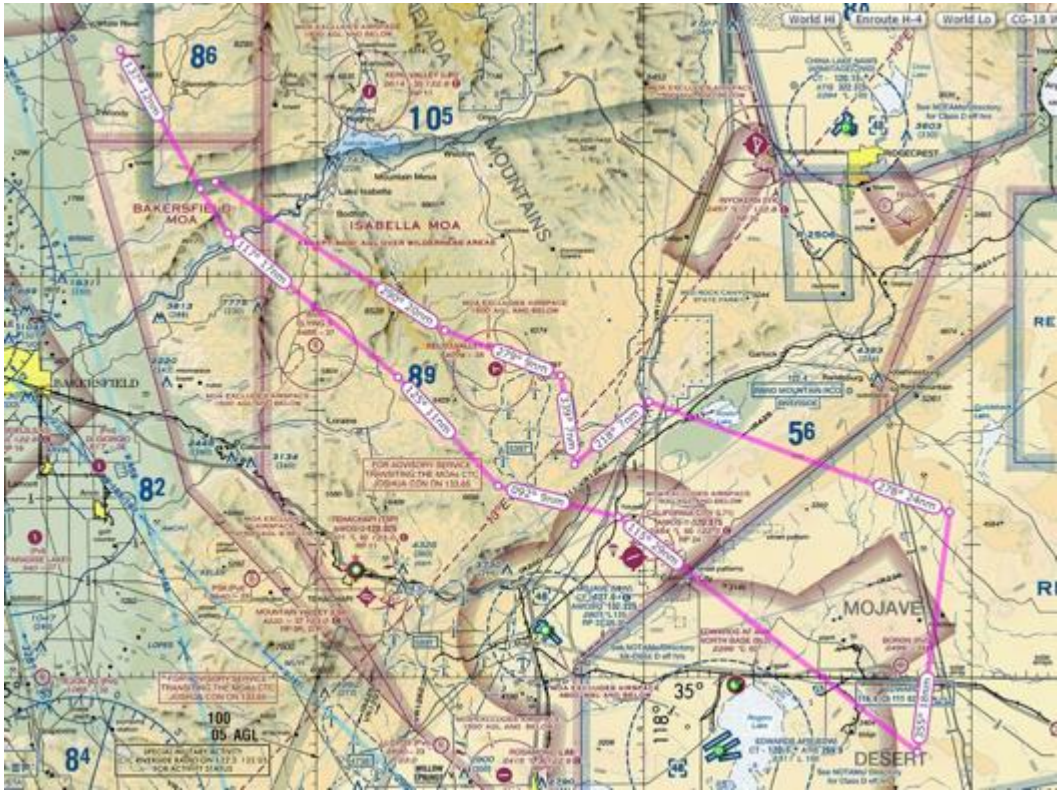
Configuration 1 Nomenclature

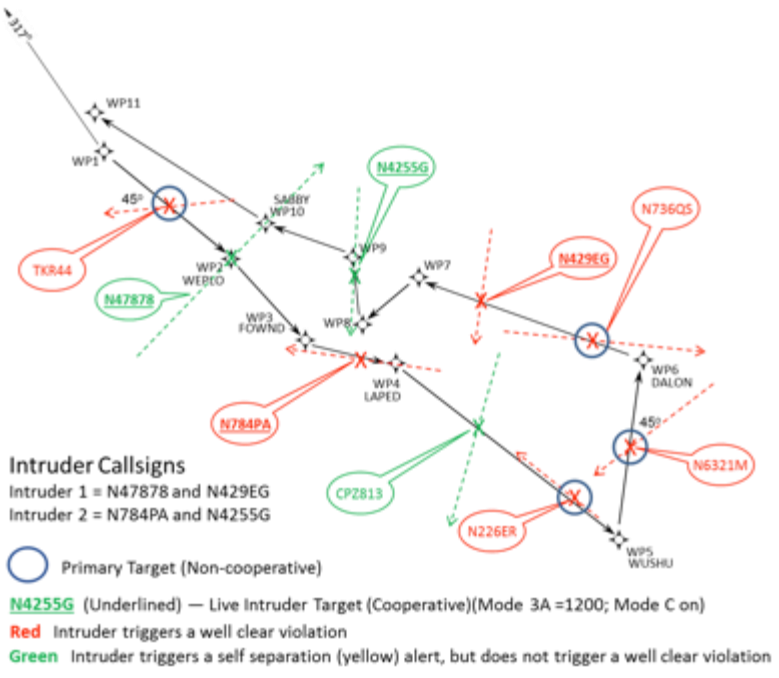
[Series] [Min Altitude Offset] [Vertical Profile] [Encounter Angle]

- Series
  - L = Low Speed Ownship
  - H = High Speed Ownship
  - M = Multiship
- Minimum Altitude Offset
  - 1 = 1000 ft
  - 2 = 2000 ft
  - 3 = 300 ft
  - 4 = 400 ft
  - 5 = 500 ft
  - 6 = 300 ft / 1000 ft
  - 7 = 1000 ft / 300 ft
  - 8 = 2500 ft
  - 9 = 4500 ft
- Vertical Profile (Ownship / Intruder)
  - 1 = H-Level / Level
  - 2 = Level / H-Level
  - 3 = Level / Climb
  - 4 = Level / Descent
  - 5 = Climb / Level
  - 6 = Descent / Level
  - 7 = Climb/Descent
  - 8 = Descent/Climb
  - 9 = Level / H-Level / L-Level
- Encounter Angle
  - A = 0 degrees
  - B = 20 degrees
  - C = 45 degrees
  - D = 90 degrees
  - E = 110 degrees
  - F = 135 degrees
  - G = 160 degrees
  - H = 180 degrees
  - J = -45 degrees
  - K = -90 degrees
  - L = -135 degrees
  - M = Turning 45 degrees
  - N = Turning 90 degrees
  - P = Zig-Zag
  - Q = 0 / 0
  - R = 0 / 45
  - S = 0 / 90
  - T = 0 / 135
  - U = 20 / -20
  - V = 45 / 90
  - W = 90 / 135
  - X = Turning 45 degrees / 180 degrees

PairwiseGeometries_20150427

Full Mission Flight Airspace

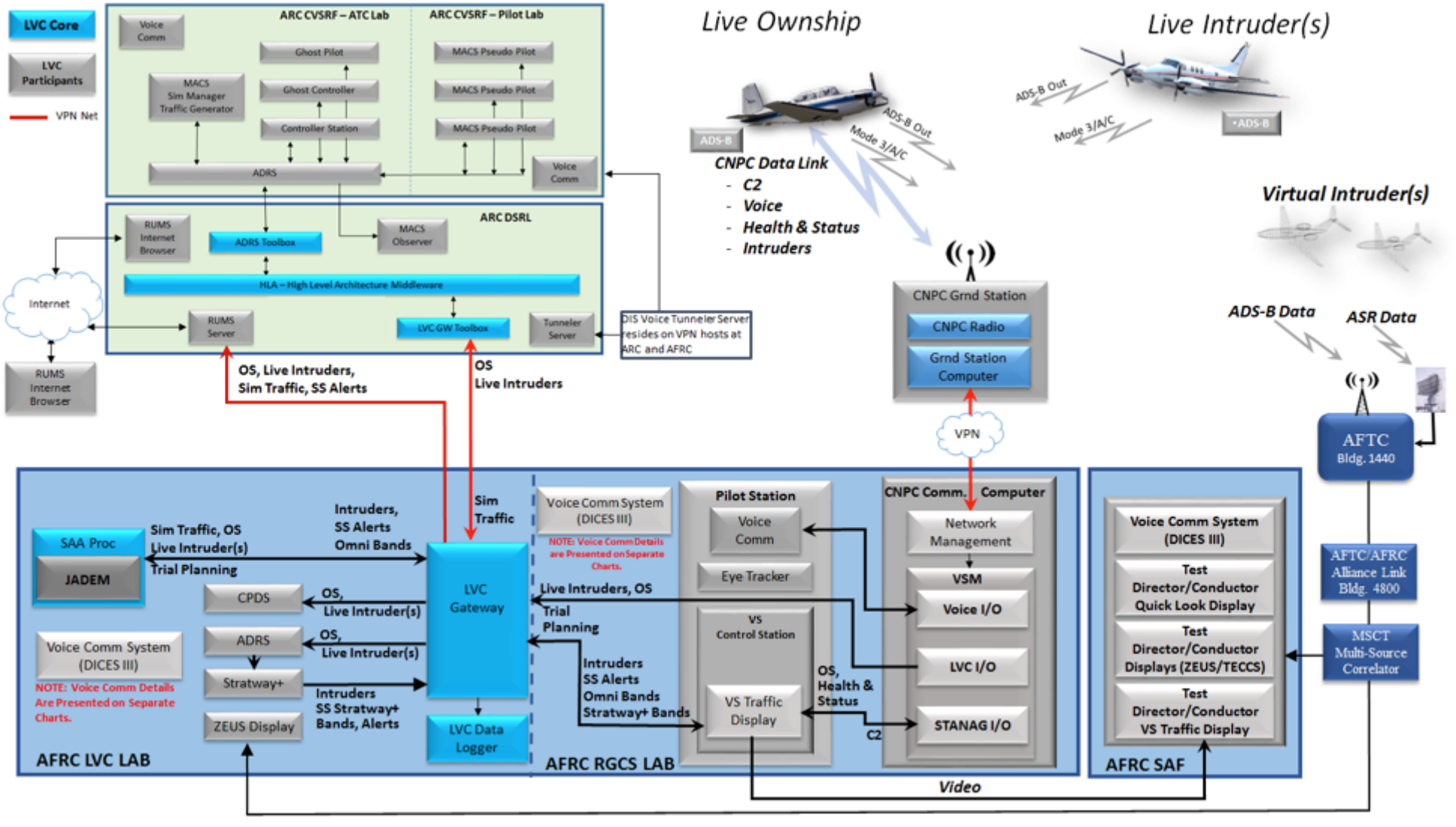




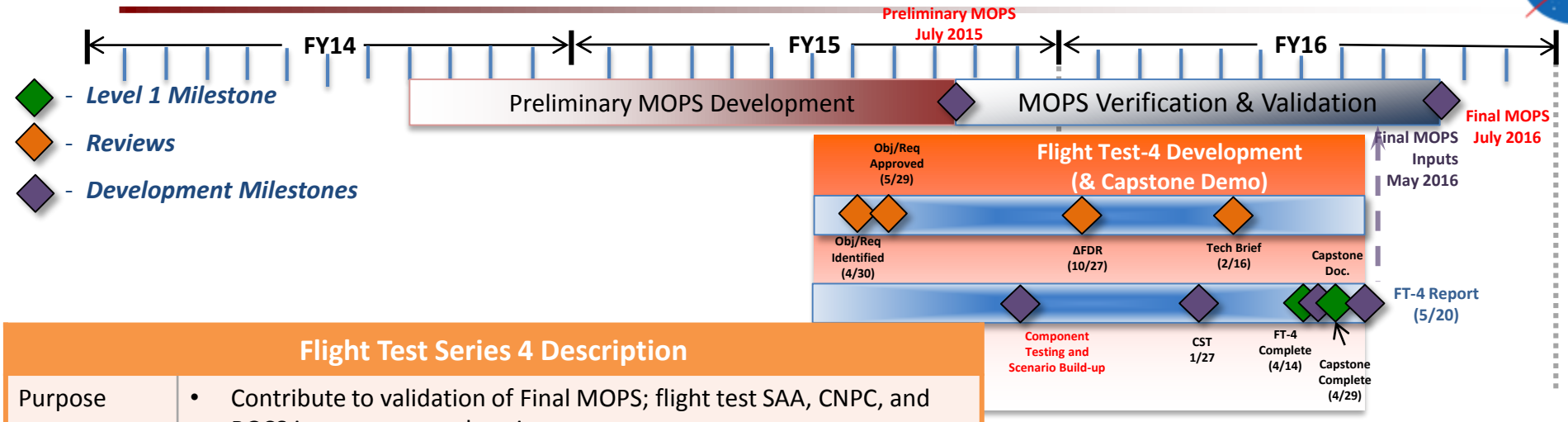
- Full Mission flown entirely within R-2508 Complex
- Airspace includes: R-2515 + Porterville, Bakersfield & Isabella MOAs
- Altitudes 12-15K ft MSL
- 40 min mission (T-34C ownship aircraft)
- 2-live intruders (King Air & T-34) performing 2 runs each
- 5-virtual intruders performing 1 run each

FT3: Configuration 2 (Full Mission Scenario) – Surrogate UA

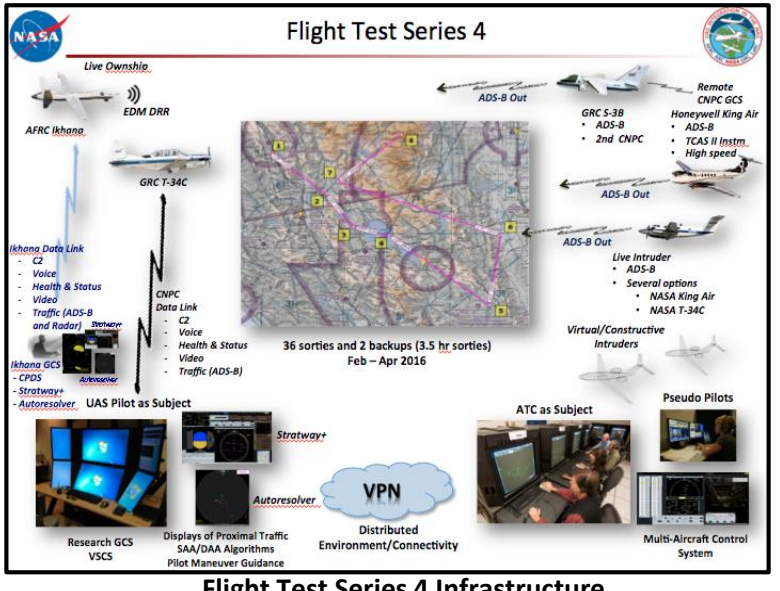
Full Mission = 12 flights (~2 hr flights)



IT&E Integrated Test Flow for Flight Test Series 4



Flight Test Series 4 Description	
Purpose	• Contribute to validation of Final MOPS; flight test SAA, CNPC, and RGCS in more stressed environments • Demonstrates systems integration and evaluation of the state of UAS concepts and supporting technologies • Demonstrate final LVC-DE configuration
Approach	Increased complexity from FT3 • 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	Feb - Apr 2016 • 34 flights/2 backups (3.5 hr 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 Infrastructure

FT4 Top Level Goals and Objectives

Top Level Research Goal:

- **Conduct flight tests in a relevant environment to contribute to the validation of the final Phase 1 DAA and C2 MOPS**

Top Level Research Objectives:

- **Evaluate the performance of the DAA system against cooperative and non-cooperative aircraft encounters**
- **Evaluate the integrated DAA performance of the and CNPC system**
- **Evaluate UAS pilot performance in response to DAA maneuver guidance and alerting with live intruder encounters**
- **Evaluate the effectiveness of the DAA system to enable timely coordination between UAS pilots and air traffic control**
- **Evaluate TCAS-SS Interoperability**
- **Validate final Phase 1 MOPS**
- **Characterize the performance of the flight test and simulation environment**

FT4 Planning

- NASA general assumption – no major infrastructure changes between FT3 and FT4
  - This assumption applies to SC-228 as well, any gaps found through the V&V process which could potentially be addressed during NASA flight test can't require major infrastructure changes

- Objectives and requirements are under development
  - The document is planned to be ready for review the end of June
  - SC-228 members are participating in the planning activities

- Key upcoming dates
  - This week – working group outcomes
  - July 24 - Draft DAA MOPS distribution for comment, leverage V&V spreadsheet to identify gaps
  - October 1 - FDR Preparation
    - FDR October 27
  - January 7 – Finalize Test Plan
    - The test plan gets written and distributed 3 months prior, which means the October – early December (due to holidays) time frame is when final inputs are required