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

Closeout Technical Interchange Meeting

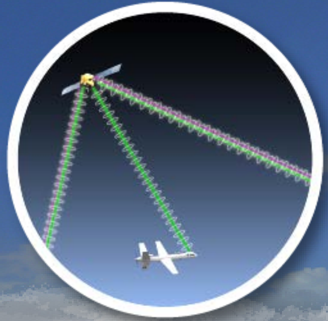
September 30, 2020 – October 1, 2020

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

Technical Interchange Meeting

Day 1

September 30, 2020



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

Welcome

Clint St. John

Chief Engineer, UAS Integration in the NAS Project

Platforms and Discussion

- **MS Teams Participants** ***(includes speakers, presenters, and invited guests)***
  - Platform: MS Teams
  - Discussion: MS Teams microphone and chat functions
    - Unless speaking, please leave your cameras/webcams off to preserve WiFi bandwidth
    - Use your mute/unmute button (e.g. remain on mute unless you are speaking)
    - Enter comments/questions in the MS Teams chat
    - Raise your hand if you wish to speak
    - Say your name and affiliation before you begin speaking

- **YouTube Participants** ***(includes the remainder of the participants / UAS-NAS Project stakeholders)***
  - Platform: YouTube Live Stream *(go to* https://nari.arc.nasa.gov/uas-nastim *for the link!)*
  - Discussion: Conferences.io
    - Enter https://arc.cnf.io/ into your browser
    - Select the UAS Integration in the NAS Virtual Technical Interchange Meetings

Need Help?

If you need logistical or technological assistance throughout the meetings, you can reach out to the NARI hosts through the following platforms:

- Email us directly at arc-cal-nari@mail.nasa.gov
- Enter your comment or question in the **conferences.io** platform
- Enter your comment or question in the **MS Teams** chat

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Wednesday, September 30, 2020

9:00 – 9:10	Welcome & Logistics, Clint St. John, Chief Engineer, UAS Integration in the NAS Project
9:10 – 9:20	Mission Director's Introduction, Bob Pearce, Associate Administrator, ARMD
9:20 – 9:50	Program Director's Introduction & NASA's Cohesive UAS Strategy, Lee Noble, Program Director, IASP
9:50 – 10:10	NASA's UAS Integration in the NAS Project Overview, Mauricio Rivas, Project Manager, UAS Integration in the NAS Project
10:10 – 10:40	UAS-NAS Command & Control Subproject Overview, Kurt Shalkhauser, C2 Technical Lead, C2 Subproject
10:40 – 11:10	Terrestrial Based UAS Command and Control, Kurt Shalkhauser, C2 Technical Lead, C2 Subproject
11:10 – 11:40	Satellite Based UAS Command and Control, Dennis Iannicca, Satcom Lead, C2 Subproject
11:40 – 12:20	UAM Command Control and Communications Study, Israel Greenfeld, UAM C3 Study Lead, C2 Subproject

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Wednesday, September 30, 2020

12:20 – 1:05	Lunch
1:05 – 1:35	UAS-NAS Detect and Avoid Subproject Overview, Jay Shively, Subproject Manager, DAA Subproject
1:35 – 2:05	Modeling and Simulation, Gilbert Wu, Modeling & Simulation Technical Lead, DAA Subproject
2:05 – 2:55	Guidance and Control, Tod Lewis, Guidance & Control Technical Lead, DAA Subproject
2:55 – 3:45	Human Systems Integration, Conrad Rorie, Human Systems Integration Technical Lead, DAA Subproject
3:45 – 4:00	Break
4:00 – 4:30	UAS-NAS Integrated Test & Evaluation Subproject - Overview & Live Virtual Constructive (LVC), Ty Hoang, Live Virtual Constructive Technical Lead, IT&E Subproject
4:30 – 5:00	UAS-NAS Integrated Test & Evaluation Subproject Flight Test, Sam Kim, IT&E Technical Lead, IT&E Subproject

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Wednesday, September 30, 2020

5:00 – 5:15	Day 1 Wrap Up, Mauricio Rivas, Manager, UAS Integration in the NAS Project
5:15	End of Day 1

Thursday, October 1, 2020

9:00 – 9:10	Welcome & Logistics, Clint St. John, Chief Engineer, UAS Integration in the NAS Project
9:10 – 9:40	FAA Research Transition Team Overview, Laurie Grindle, Director for Programs and Projects, NASA Armstrong Flight Research Center, and Nick Lento, Division Manager, ANG-C2 New Entrants Division, Portfolio Management and Technology Development Office, FAA
9:40 – 10:10	No Chase COA Demonstration, Sam Kim, IT&E Technical Lead, IT&E Subproject
10:10 – 10:40	Systems Integration and Operationalization (SIO) Overview, Kurt Swieringa, SIO Technical Manager, UAS Integration in the NAS Project
10:40 – 11:00	Systems Integration & Operationalization - Partner Briefing: Bell, Jennifer Andrews, Bell APT70 SIO Project Lead

UAS-NAS Technical Interchange Meeting Agenda—Day 1

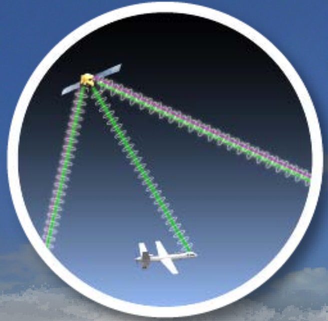
Thursday, October 1, 2020

11:00 – 11:20	Systems Integration & Operationalization - Partner Briefing: General Atomics Aeronautical Systems Inc, John Choi, Director, Special Purpose UAS
11:20 – 11:40	Systems Integration & Operationalization - Partner Briefing: American Aerospace ISR, David Yoel, CEO, American Aerospace Technologies Inc., & Ali Etebari, Vice President of Engineering, American Aerospace Technologies Inc.
11:40 – 11:55	Systems Integration & Operationalization – Questions & Answers
11:55 – 12:45	Lunch
12:45 – 1:15	Systems Integration & Operationalization FAA Perspective, Sabrina Saunders-Hodge, Director, Research, Engineering & Analysis Division (AUS-300) & Bill Stanton, Manager, UAS and Commercial Space Operational Integration, (AJT-3)
1:15 – 2:45	Stakeholder Panel Discussion: Technology and Community Benefits of the UAS-NAS Project, Moderated by Ed Waggoner, Deputy Associate Administrator for Programs, NASA ARMD (UAS Integration RTT Executive Co-Lead)
2:45 – 3:00	Break

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Thursday, October 1, 2020

3:00 – 3:30	RTCA SC-228 Status and Next Steps, John Moore, SC-228 Co-Chair, Associate Director of Systems Engineering, Collins Aerospace, Brandon Suarez, SC-228 Co-Chair, Technical Director for UAS Integration at General Atomics Aeronautical, & Steve Van Trees, (Former SC-228 DFO), Aircraft Certification Service, FAA
3:30 – 4:15	Panel Session: Remaining Gaps, Kurt Shalkhauser, C2 Technical Lead, C2 Subproject, Jay Shively, Subproject Manager, DAA Subproject, & Kurt Swieringa, SIO Technical Manager, UAS Integration in the NAS Project
4:15 – 4:45	Transition of Efforts Within NASA: Advanced Air Mobility (AAM) Mission, Davis Hackenberg, Advanced Air Mobility Mission Integration Manager, NASA ARMD
4:45 – 5:15	Transition of Efforts Within NASA: ATM-X Increasingly Automated Air Cargo Operations Subproject, Kurt Swieringa, Technical Lead, ATM-X Increasingly Automated Air Cargo Operations Subproject, Robert Fong, Subproject Manager, ATM-X Increasingly Automated Air Cargo Operations Subproject
5:15 – 5:30	Day 2 Wrap Up, Mauricio Rivas, Project Manager, UAS Integration in the NAS Project
5:30	End of Day 2



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

Mission Director’s Introduction

Bob Pearce

Associate Administrator, ARMD

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

Introduction & NASA's Cohesive UAS Strategy

Lee Noble

Director, Integrated Aviation Systems Program

History Toward Developing NASA's Cohesive UAS Strategy (1/3)

Realities in 2010...

- Awareness of the **increasing need to fly Unmanned Aircraft Systems (UAS)** in the National Airspace System (NAS)
- **UAS unable to routinely access the NAS** due to lack of:
  - Automated separation assurance integrated with collision avoidance systems
  - Robust communication technologies
  - Robust human systems integration
  - Standardized safety and certification
- **Aviation regulations were built assuming that a pilot is in the aircraft**... few regulations specifically addressed UAS
- **Technologies and procedures to enable seamless operation and integration of UAS in the NAS needed** to be developed, validated, and employed by the FAA through rule making and policy development

History Toward Developing NASA's Cohesive UAS Strategy (2/3)

UAS in the NAS Focus Areas...

- Developed Sense and Avoid (SAA) / Detect and Avoid (DAA) technologies and alerting algorithms
- Developed Command and Control (C2) Communications technologies
- Conducted Integrated Test and Evaluation (IT&E) through a series of simulations and flight tests including Human Systems Integration (HSI)
- Developed Live Virtual Constructive – Distributed Environment (LVC-DE) to enable live and virtual scripted encounters with subject pilots and FAA controllers

UAS Traffic Management (UTM) Focus Areas...

- Access to low-altitude airspace for large-scale unmanned aerial systems operations
- Engagement with industry to provide air traffic management services
- Collaborate with FAA on operations concept and allocation of responsibilities
- UTM research platform for cooperative airspace management that is cloud based and secure
- Nominal airspace operations and contingency management
- Vehicle technologies associated with conflict avoidance, geo-fencing conformance, vehicle-to-vehicle communications, safe landing, trajectory management under constraints, and last/first 50 feet

History Toward Developing NASA's Cohesive UAS Strategy (3/3)

- In 2015, NASA embarked on a UAS Airspace Access Community Needs Assessment
  - Internal assessment of research and gap analysis
- In 2016, NASA commissioned an Independent Team to evaluate NASA's internal assessment and to conduct an independent needs/gaps assessment by engaging multiple stakeholders across the UAS community
  - Independent team consisted of UAS community experts outside of NASA
  - Assessed ongoing research, future UAS community needs, and other investments and research opportunities consistent with Full UAS Integration
  - Culmination of this work was a detailed report to NASA with recommendations for a NASA cohesive "Full UAS Integration" strategy
  - NASA assessed the recommendations and finalized the Cohesive ARMD Full UAS Integration strategy

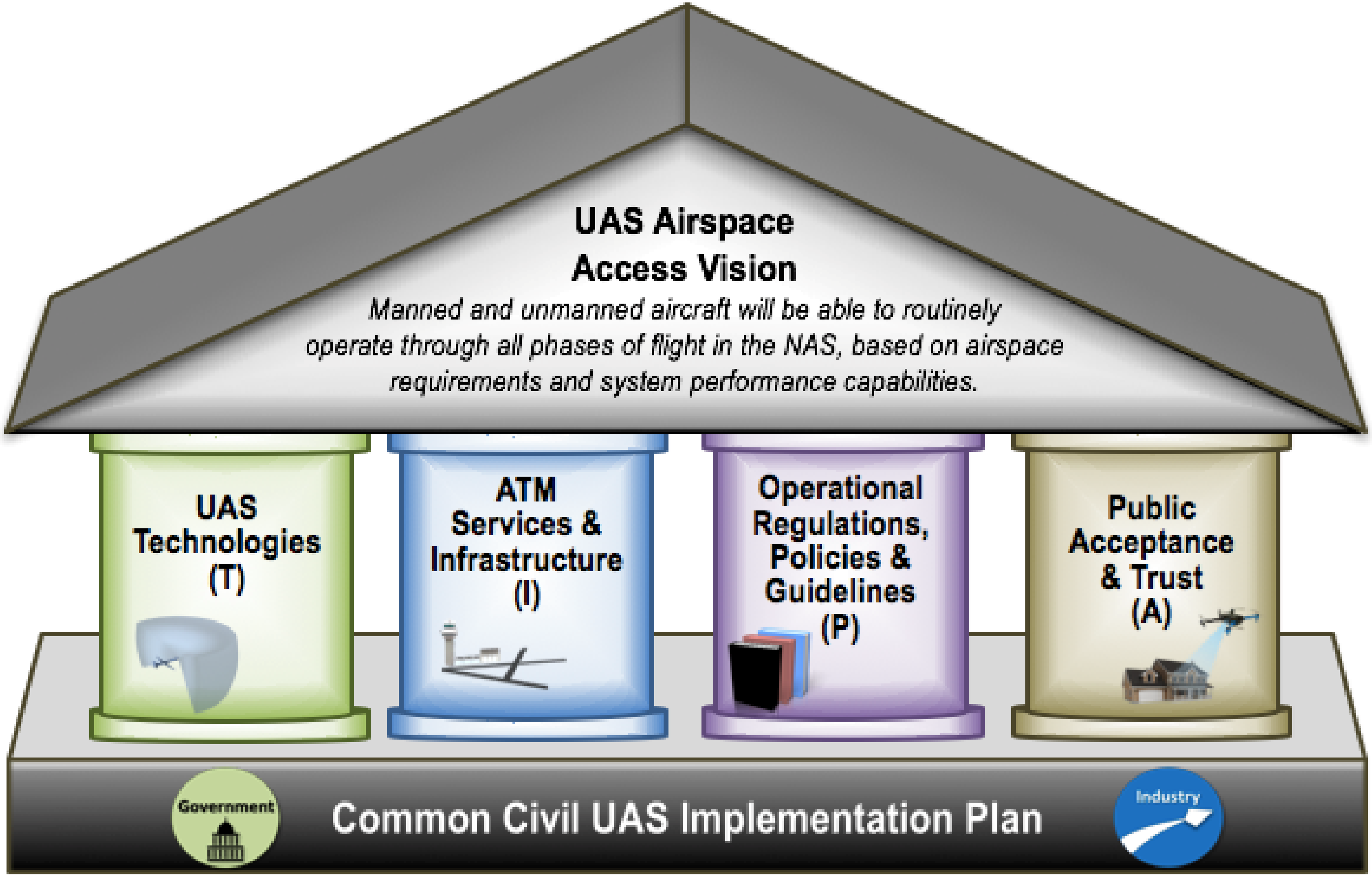
Then in February 2017...

- NASA rolled out the **Cohesive ARMD Full UAS Integration Strategy**
- A Vision, Strategic Plan, and Communication Strategy for...
  - Routine UAS access within the NAS
  - Concept for transitioning UAS access advancements toward integrating highly autonomous systems and on-demand mobility

Full UAS Integration Vision of the Future

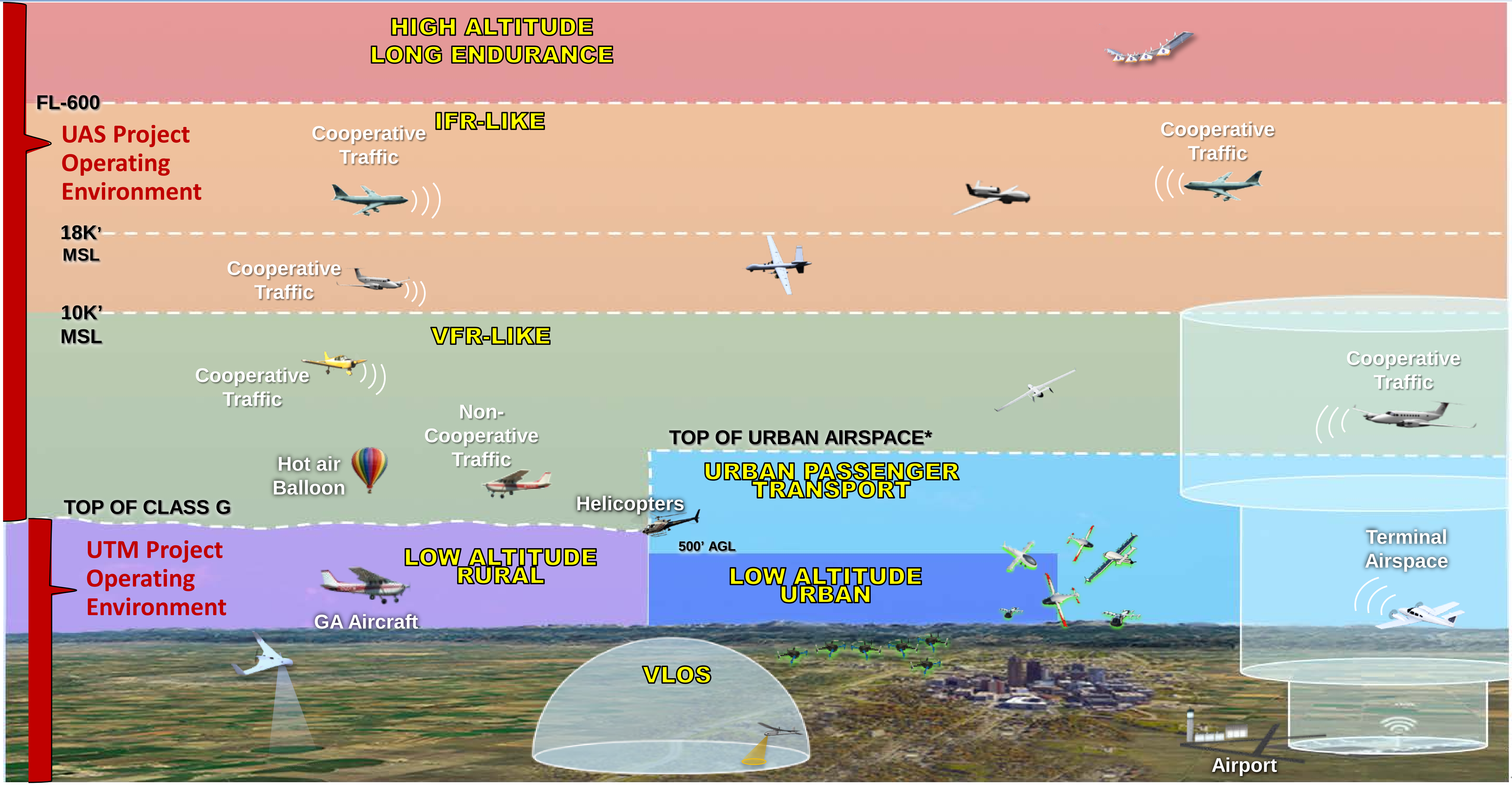
Manned and unmanned aircraft will be able to routinely operate through all phases of flight in the NAS, based on airspace requirements and system performance capabilities

UAS Airspace Integration Pillars and Enablers



The UAS Airspace Integration Pillars enable achievement of the Vision

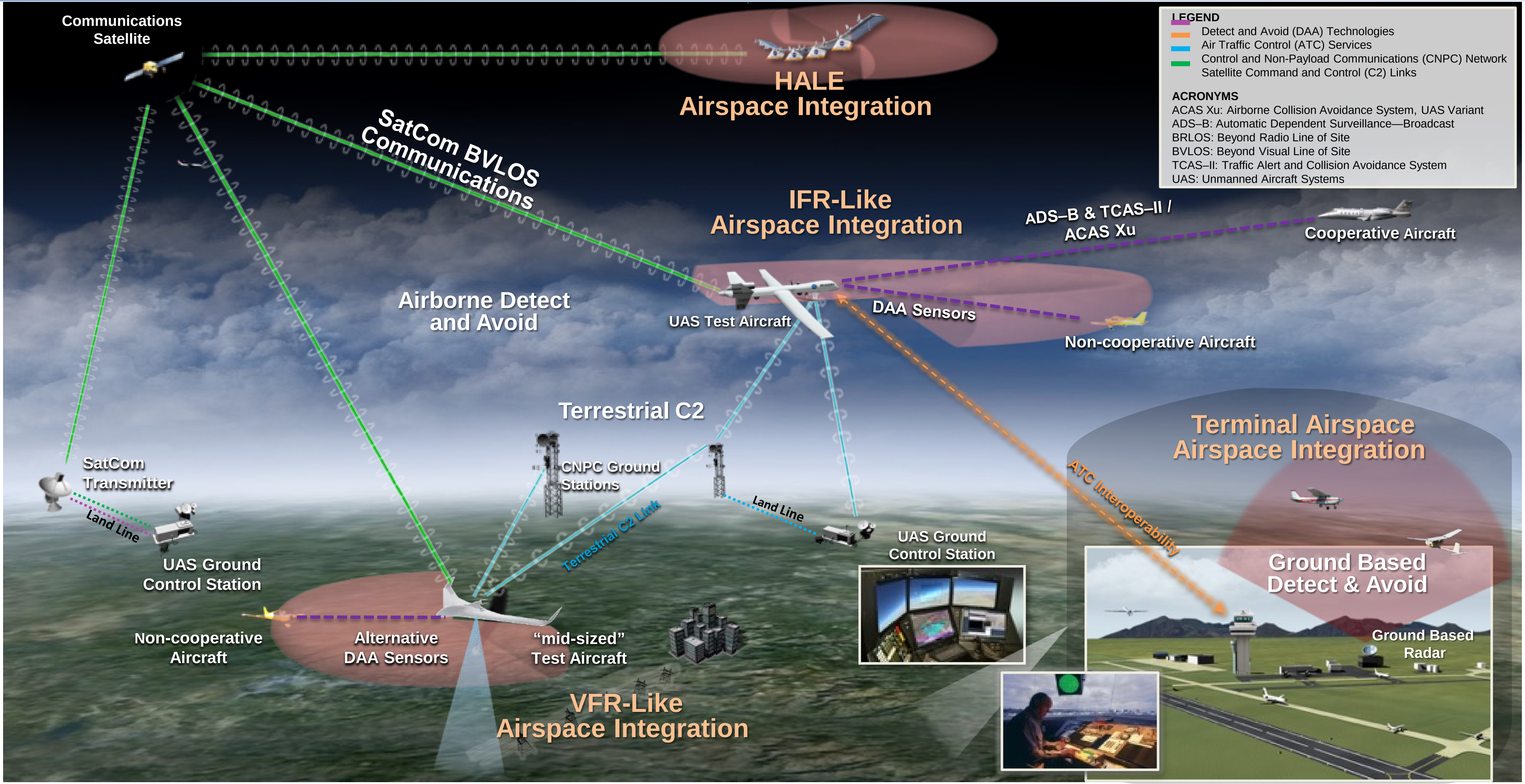
Commercial Operating Environments (OE)



Other Enabling Activities

- **Increased NASA/FAA collaboration** through joint involvement in Research Transition Teams (RTTs) enabled ongoing connectivity of research progress to inform rulemaking
  - RTTs recognized as a best practice
  - RTTs and WGs expanded as needed
- **NASA joined the UAS community to engage with RTCA WGs** to inform developing Minimal Operational Performance Standards for UAS
- **FAA has increased community engagement** and streamlined processes where possible
- **NASA has continued focus on leading research and technology development** to enable UAS operations in the NAS through the UAS-NAS and UTM Projects
- **Industry commercialization efforts have increased significantly**
  - Innovative business models and associated certification efforts for large aircraft are rapidly expanding
  - Innovations for package delivery, agriculture, and other uses for public good are emerging
- **NASA has increased engagement with the community** to demonstrate their use cases...

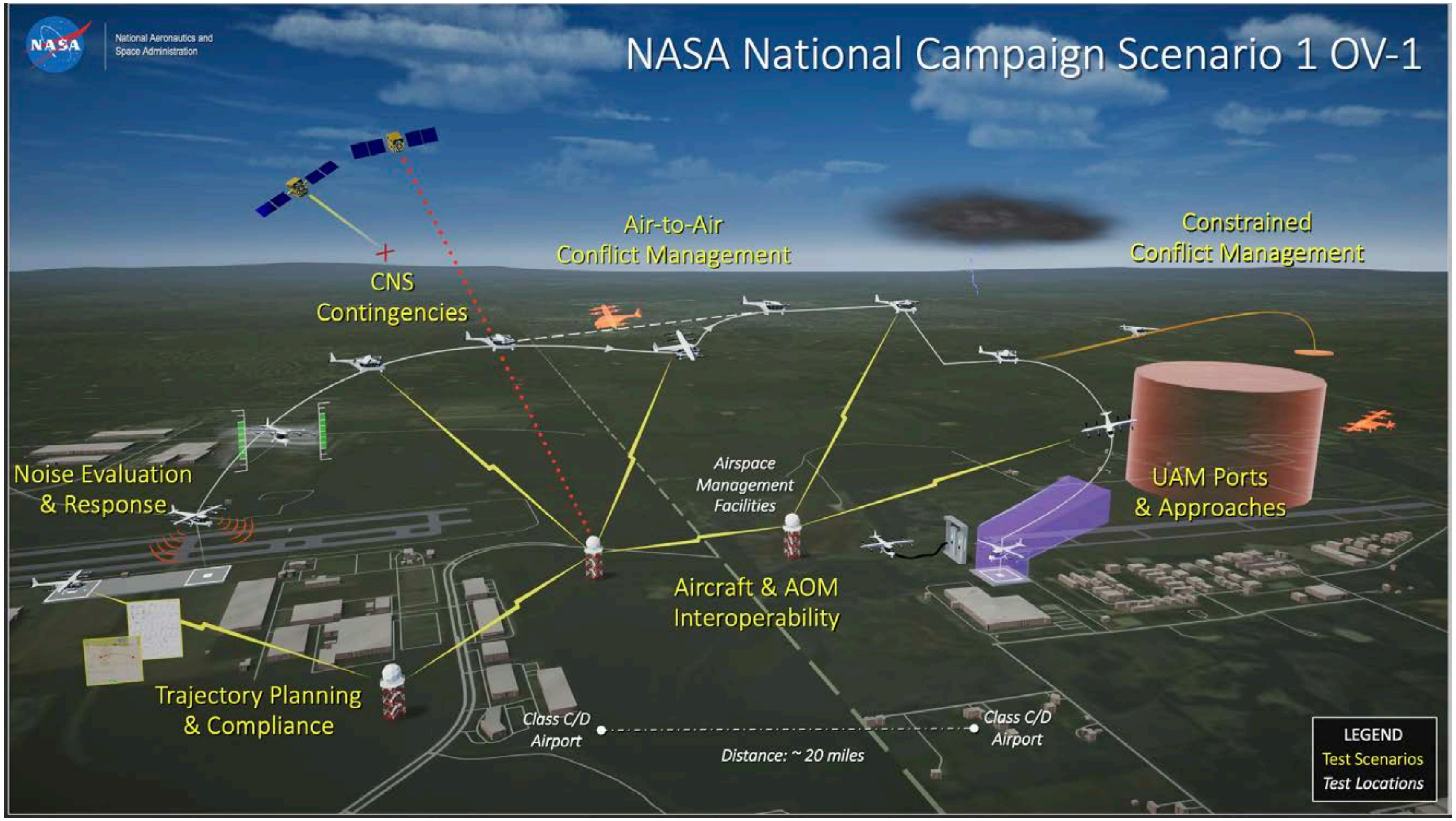
UAS-NAS Project – SIO Operational View Representation



Leveraging the UAS Strategy... Advanced Air Mobility (AAM) National Campaign Series

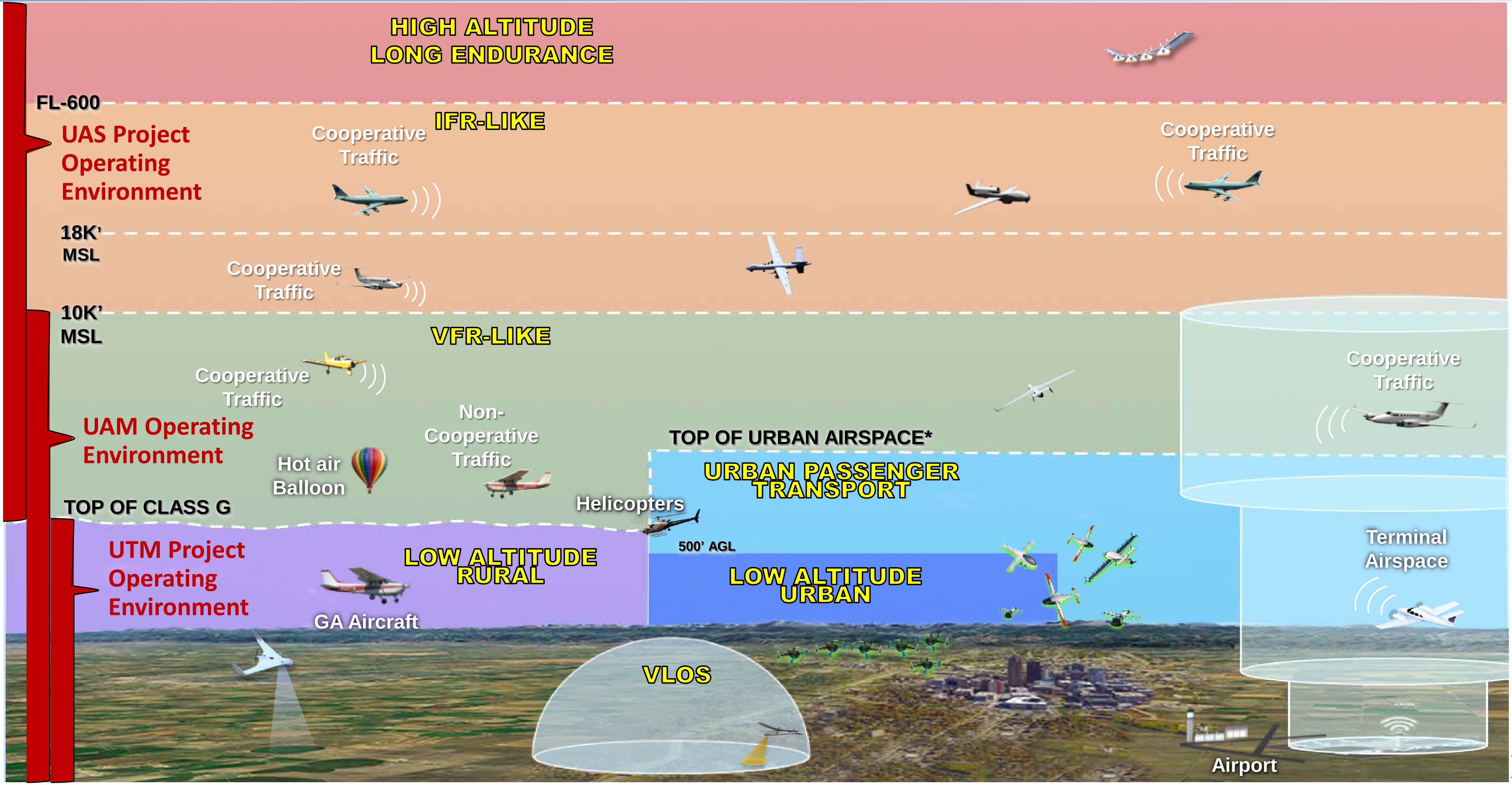
Leveraging the UAS Strategy... Advanced Air Mobility (AAM) National Campaign Series

Emphasis on Operational Scenarios and Remaining Flexible to Industry Needs



- NC-DT assesses the readiness of external ranges and partners to collect comprehensive data in support of NC-1
- NC-1 scenarios will move participants closer to operations by baselining operational expectations and identifying gaps in AAM
- NC-2-4, and associated developmental testing, will progressively mature advanced UAM vehicle configurations and automation research

Commercial Operating Environments (OE)

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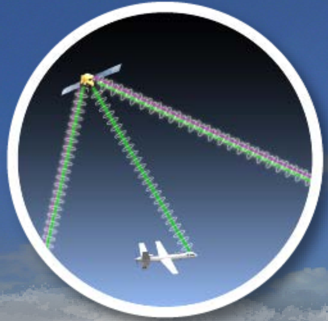


Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

NASA's UAS Integration in the NAS Project Overview

Mauricio Rivas

Project Manager, UAS Integration in the NAS Project

Section Outline

- Project Staff
- Development of UAS-NAS Goals & Objectives
- Phase 1
  - Plan, Purpose & Organization
  - Phase 1 Value Proposition
- Phase 2
  - Plan, Purpose & Organization
  - Phase 2 Value Proposition

UAS Integration in the NAS Organizational Structure

As of 07/16/20

Host Center

AFRC Director of Programs
Laurie Grindle
Deputy Director
Brent Cobleigh

Program Office

IASP Program Director
Lee Noble (Acting)
Deputy Program Director
Nateri Madavan

Program External Interfaces

ExCom, Senior Steering Group, RTCA Steering Committee, UAS Aviation Rulemaking Committee

Project Support

- Lead Resource Analyst – Josh Martin, AFRC
- Lead Proc Officer – Rosalia Toberman, AFRC
- Scheduler – Lynda Clinton, AFRC
- Risk and Outreach Lead – Jamie Turner, AFRC
- Doc/Change Mgmt – Eleonor Barron, AFRC
- SIO Support – Arya Abrego, AFRC
- Admin Support – Sandra Rodriguez, AFRC
- Resource Analyst – Warcquel Frieson, ARC
- Resource Analyst – Julie Blackett, GRC
- Resource Analyst – Sarah Puckett, LaRC

Project Office

- Project Manager (PM) – Mauricio Rivas, AFRC
- Deputy PM – Peggy Cornell, GRC
- Chief Engineer – Clint St. John, AFRC
- Deputy Chief Engineer – Gaudy Bezos-O'Connor, LaRC
- Staff Engineer – Doug Wada, AFRC

- Senior Advisor for UAS Integration – Chuck Johnson
- SIO Technical Manager – Kurt Swieringa, LaRC

Project External Interfaces

FAA, DoD, SARP, RTCA SC-228, RTCA SC-147, Industry, etc.

Aero Centers

- Brad Flick – ARD, AFRC
- Huy Tran – ARD, ARC
- Tim McCartney – ARD, GRC
- Mary DiJoseph – ARD, LaRC

Subprojects

Command and Control (C2) SPM
Mike Jarrell, GRC

C2 Subproject Technical Lead
Kurt Shalkhauser, GRC

Detect and Avoid (DAA) SPM
Jay Shively, ARC

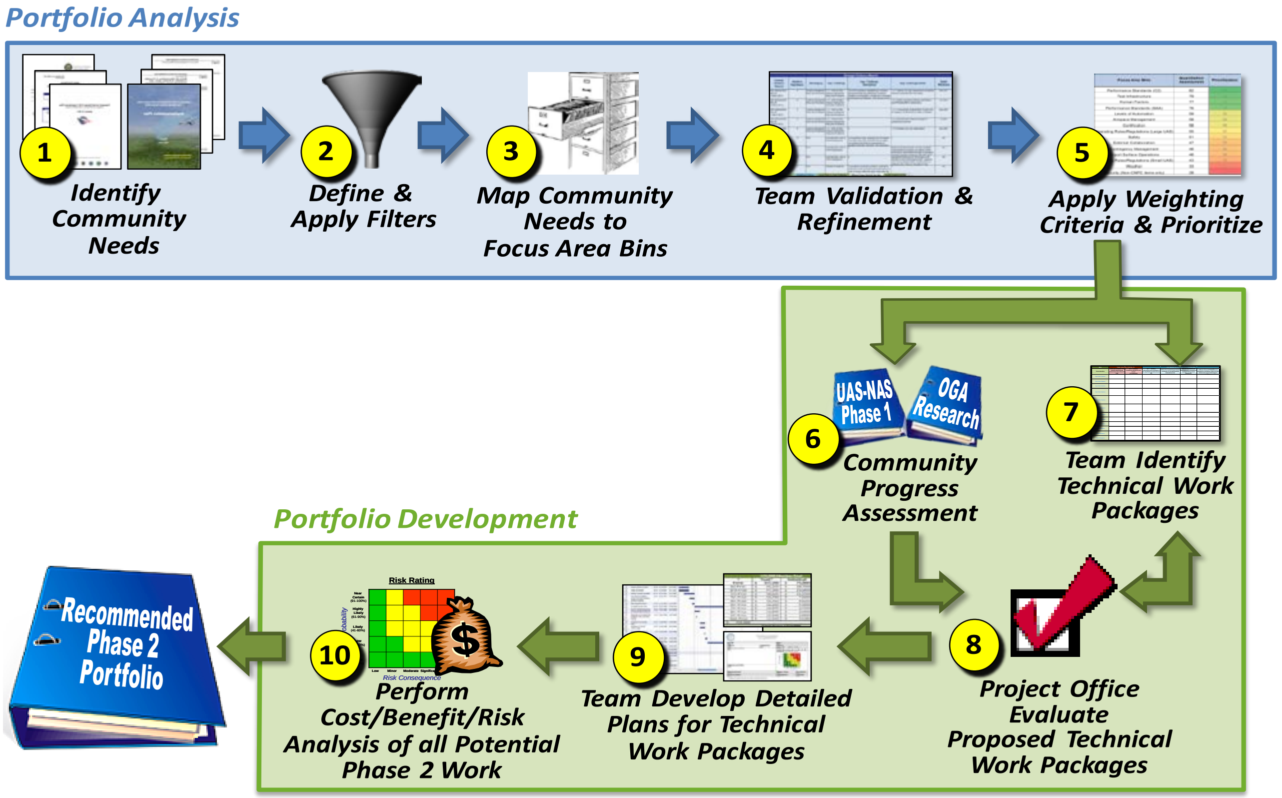
DAA Subproject Technical Leads
Gilbert Wu, ARC; Conrad Rorie, ARC; Tod Lewis, LaRC

Integrated Test and Evaluation (IT&E) SPM
Robert Navarro, AFRC

IT&E Subproject Technical Lead
Sam Kim, AFRC; Ty Hoang (Acting), ARC

ARD: Aeronautics Research Director, PM: Project Manager, SPM: Subproject Manager, SIO: Systems Integration and Operationalization

Community Needs Influence on Portfolio and Technical Challenges



- Content Decision Process included an evaluation of the technical needs of the UAS Community
- Resultant prioritized list, and Community Progress Assessment, of Focus Area Bins served as the foundation for Portfolio and Technical Challenges
- Technical Challenges, Technical Work Packages, and detailed executable Schedule Packages were evaluated using a cost/benefit/risk progress to determine the final portfolio

Project Purpose—Phase 1

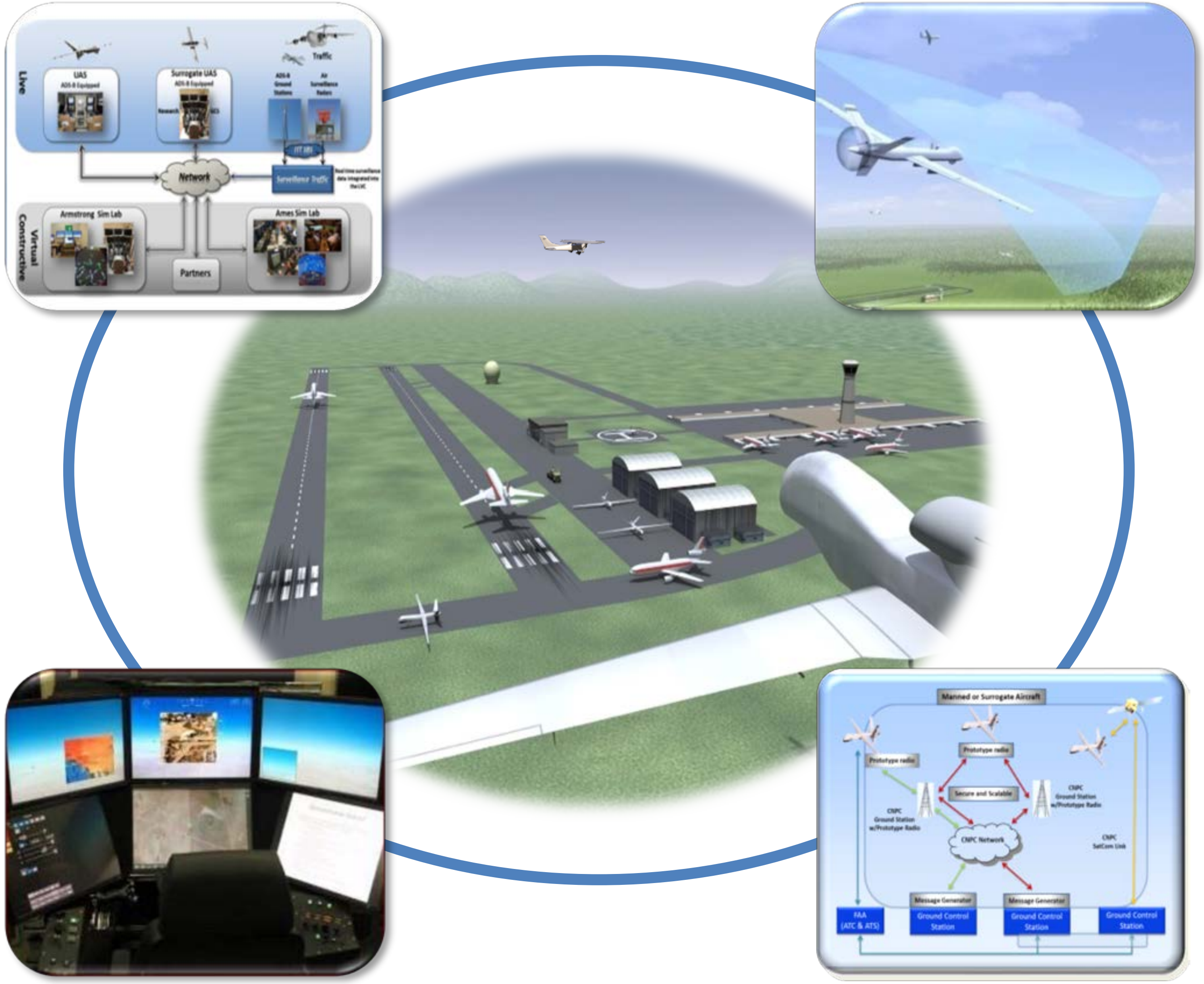
- **NASA recognized:**
  - The growing need for UAS access to the NAS
  - The potential economic growth in the US from an emerging UAS industry
  - The need for requirements and regulations addressing UAS access to the NAS
  - The unique capabilities at NASA to transition concepts, technologies, algorithms and knowledge to stakeholders

- **Objectives**
  - Develop a body of evidence to inform key decision makers in establishing policy, procedures, standards and regulations for enabling routine UAS access in the NAS
  - Provide methodologies for development of airworthiness requirements and data to support development of certification standards and regulatory guidance
  - Establish the infrastructure for the integrated test and evaluation (IT&E) environment for UAS Integration in the NAS simulations and flight demonstrations

Phase 1 Technical Work Organization

TC-ITE: Integrated Test & Evaluation

TC-SAA: Sense and Avoid Performance Standards



TC-HSI: Human Systems Integration

TC-C2: Command & Control Performance Standards

UAS Integration in the NAS Project

Phase 1 MOPS Value Proposition Flow Diagram

NASA UAS-NAS Project Activities | **Key Products** | **FAA Outcomes**

TC C2 — C2 Performance Standards

- Develop C2 Prototype System →
- Conduct C2 Flight Test and modeling, simulation and analysis (MS&A)
  - *Data Link*
  - *CNPC Spectrum*
  - *CNPC Security*
  - *LOS*
  - *BLOS*
  - *ATC Interoperability*
- → Develop C2 Requirements

C2 Performance Requirements to inform C2 MOPS → RTCA C2 MOPS → C2 Technical Standard Order (TSO)

TC SAA — SAA Performance Standards

- Develop SAA Performance Testbed →
- Develop SAA Interoperability Testbed →
- Conduct SAA Flight Test and MS&A
  - *Performance Trade-offs*
  - *Interoperability*
  - *Self Separation*
  - *CONOPs*
  - *Well Clear*
  - *Collision Avoidance*
- → Develop SAA Performance & Interoperability Requirements

SAA Performance Requirements to Inform MOPS → RTCA DAA MOPS, RTCA RADAR MOPS → DAA Technical Standard Order (TSO), RADAR Technical Standard Order (TSO)

TC HSI — Human Systems Integration

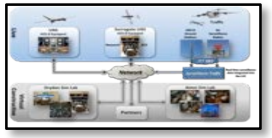
- Develop Prototype GCS →
- Conduct Human Factors (HF) Flight Test and MS&A
  - *Contingency Management*
  - *Pilot Response*
  - *Autonomy*
  - *SAA*
  - *C2*
  - *Displays*
- → Develop HF Guidelines for SAA, C2 & GCS

HF Performance Requirements to inform MOPS and HF Guidelines → RTCA DAA MOPS, RTCA C2 MOPS → DAA Technical Standard Order (TSO), C2 Technical Standard Order (TSO)

TC ITE — Integrated Test & Evaluation

- Develop LVC Test Infrastructure →
- Conduct TC Specific Testing
  - Conduct IHITL
  - Conduct SAA Initial Flight Test Scenarios
  - Conduct FT3 Test Scenarios
  - Conduct FT4 Test Scenarios

Re-usable Test Infrastructure

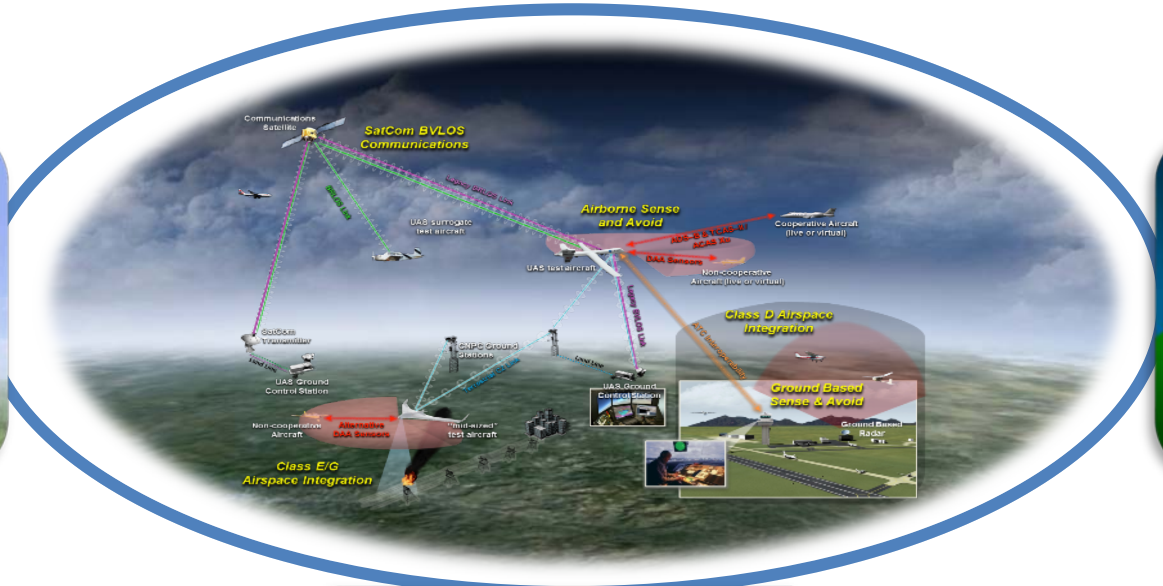


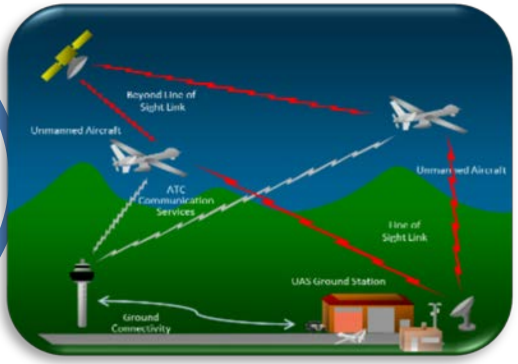
Test Data for MOPS Development → RTCA DAA MOPS, RTCA RADAR MOPS → DAA Technical Standard Order (TSO), RADAR Technical Standard Order (TSO)

Project Purpose—Phase 2

- **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**
  - Provided research findings to RTCA SC-228 to further develop and validate SC-228 Phase 2 MOPS for DAA performance and interoperability and for terrestrial C2
  - Conducted a series tests to evaluate the technologies in test environments representative of the NAS
  - Facilitated the transition of the research findings to the stakeholders by emphasizing partnerships and collaborations

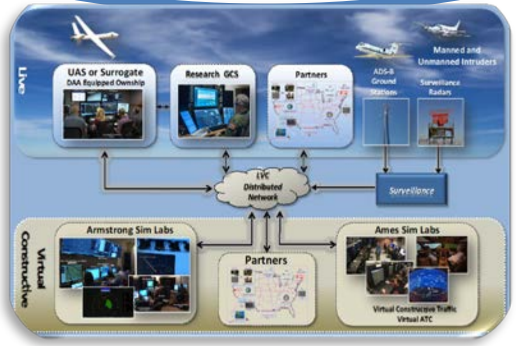
Phase 2 Technical Work Organization





Technical Challenge-DAA: Detect and Avoid (DAA)

Technical Challenge-C2: Command and Control (C2)



Systems Integration and Operationalization (SIO)

UAS Integration in the NAS Project
Phase 2 MOPS Value Proposition Flow Diagram

NASA UAS-NAS Project Activities

TC C2 — C2 Performance Standards

- Research C2 SatCom Systems
- Develop C2 Prototype Terrestrial System

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

→ Develop C2 Requirements

TC DAA — DAA Performance Standards

- Develop DAA Test beds

→ Conduct DAA MS&A and Flight Test
Human Factors Performance Trade-offs
Low Cost SWaP sensors
Well Clear
Collision Avoidance

→ Develop DAA Performance & Interoperability Requirements

Integrated Test & Evaluation

- Develop DAA Prototype System

→ Live Virtual Constructive (LVC) Test Infrastructure

→ Conduct Technology and ConOps testing

- ACAS Xu FT2
- No Chase COA
- Conduct FT5 Test Scenarios
- Conduct FT6 Test Scenarios

SIO — Systems Integration and Operationalization

- Develop Robust NASA/Industry Partnership

→ Document certification and airworthiness approaches
→ Integrate Essential Technologies

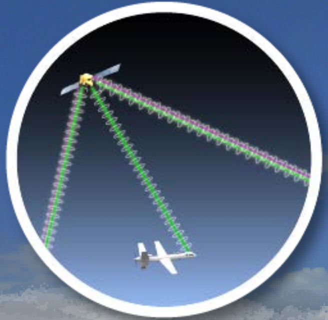
→ Conduct Demo

Key Products

- *C2 Performance Requirements to inform C2 MOPS*
- *DAA Performance Requirements to inform DAA MOPS*
- *Re-usable Test Infrastructure*
- *Progress Toward Certification*

Resultant Outcomes

- RTCA Terrestrial MOPS; RTCA SatCom MASPS → C2 Technical Standard Order (TSO)
- RTCA Non-Coop Sensor MOPS; GBDAA MOPS; RTCA DAA MOPS Rev A/B → DAA Technical Standard Order (TSO)
- Certification Insights



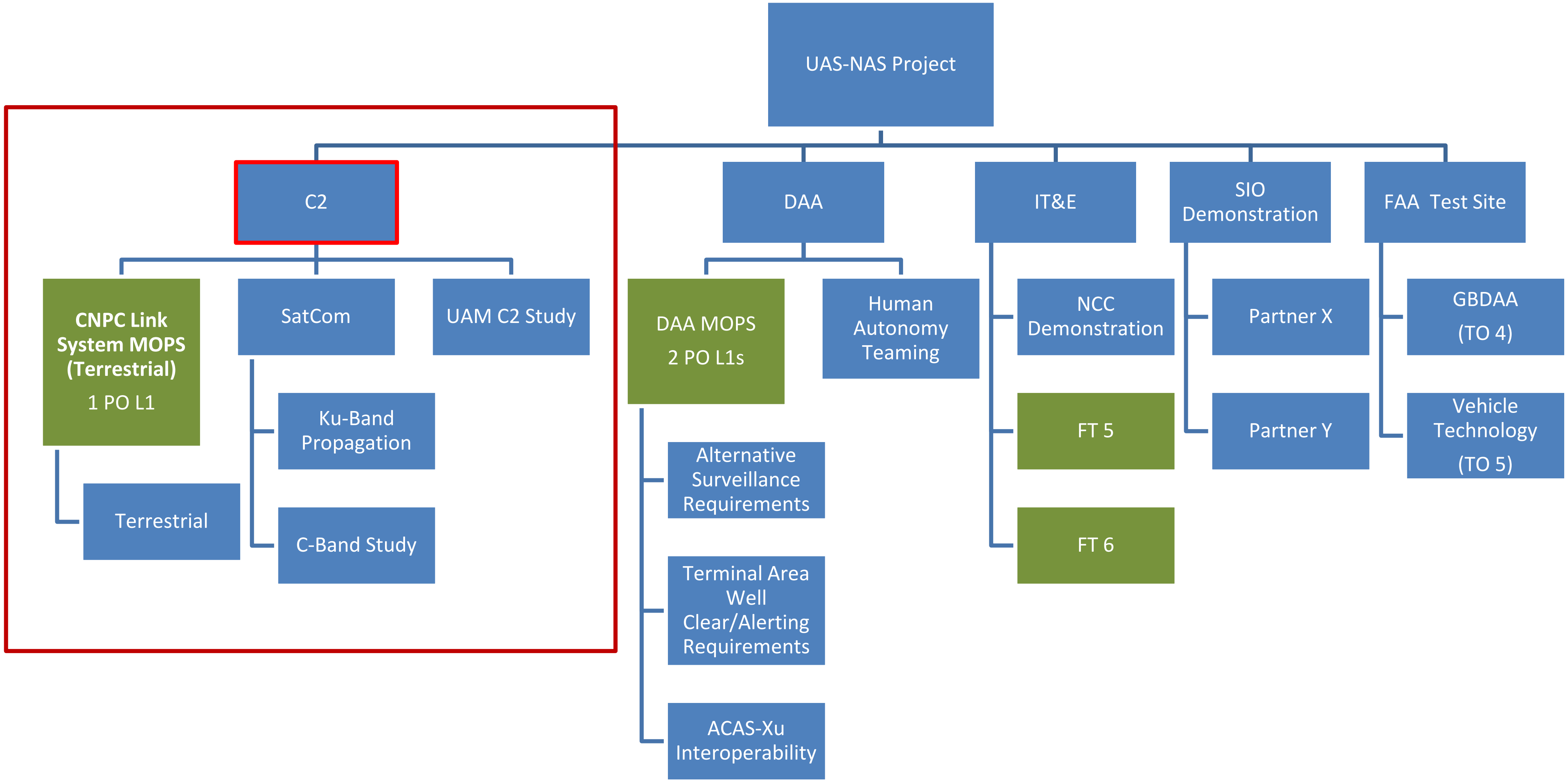
Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Command and Control Subproject Overview

Kurt Shalkhauser

C2 Technical Lead, C2 Subproject

UAS-NAS Structure



C2 Subproject Overview

What is Command and Control (C2)?

The 1988 NATO definition reads: Command and control is the exercise of authority and direction by a properly designated individual [Remote Pilot in Command] over assigned resources [Unmanned Aircraft] in the accomplishment of a common goal [Flight Mission].

C3

C2

Command → *Exercise of Authority*

- *Each UAS has only one secure, command authority called the Remote Pilot In Command (RPIC)*

Control → *Direction within Authority*

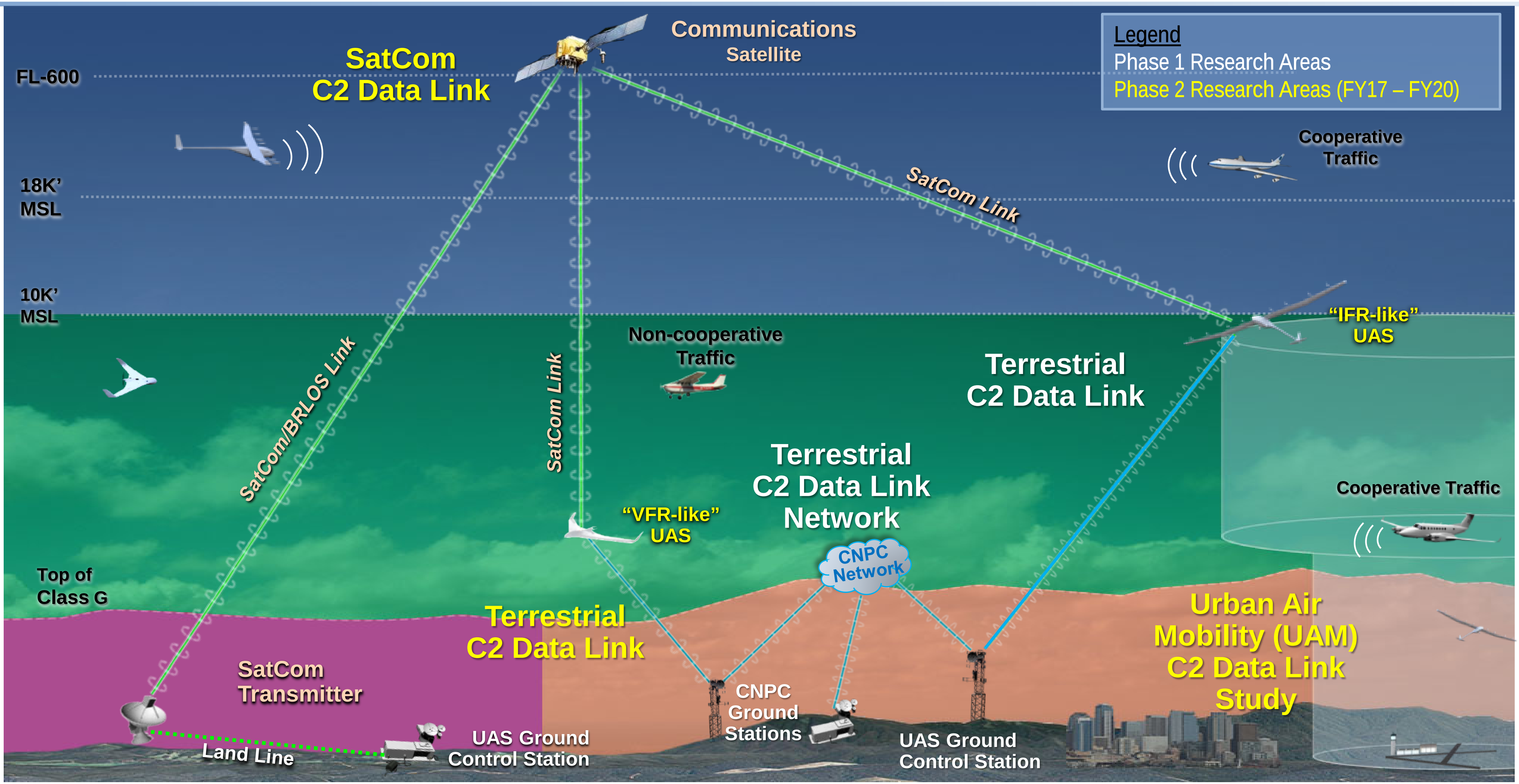
- *Reliable control of the Unmanned Aircraft flight systems*

Non-Payload Communications → *Information needed to efficiently and effectively accomplish a mission*

- *Surveillance data from/to the UAS to maintain well clear*
- *Avionics Telemetry from the UAS to monitor UAS Systems state & health*
- *Navigation Telemetry from the UAS to monitor & verify aircraft flight data*
- *Coordination with Air Traffic Control (via UAS C2 / AM Voice Radio)*

The scope of the UAS C2 Subproject is more accurately referred to as Command, Control & Non-Payload Communications (C3), aka "CNPC"

UAS Command and Control Operating Environments



Context of Effort

Beginning State

Civil UAS access to the NAS was hampered, in a communications perspective, by:

- Lack of allocated frequency spectrum for Civil UAS CNPC
- Lack of minimum system performance standards for civil UAS communication systems
- Both of above were needed before the FAA could develop UAS communication policies and guidance.

Desired End State

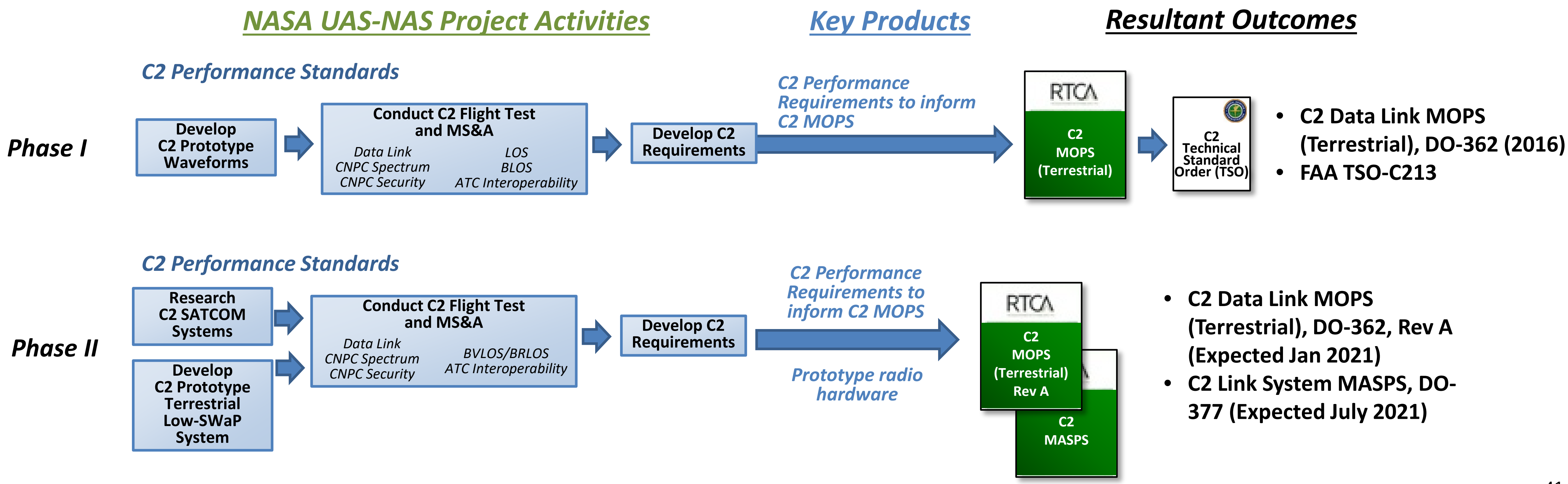
Sufficiently mature technology, standards, and regulatory guidance exist to enable Civil UAS to leverage allocated frequency spectrum for routine access to the NAS

Stakeholders

- FAA Spectrum Office
- RTCA SC-228 C2 Working Group
- UAS Community
- International Civil Aviation Organization (ICAO)
- International Telecommunications Union (ITU) World Radiocommunications Conference (WRC)

C2 Technical Challenge

Technical Challenge: Develop Satellite (SatCom) and Terrestrial-based Command and Control (C2) operational concepts and technologies in support of standards to enable the broad range of UAS that have Communication, Navigation, and Surveillance (CNS) capabilities consistent with IFR operations and are required to leverage allocated protected spectrum



Technical Challenge—Tasks

- **Provide the technical body of evidence (i.e. data and rationale) to obtain and support frequency spectrum allocations for the safe and efficient operation of UAS in the NAS**

- **Work with national and international organizations to develop Standards for the CNPC link**

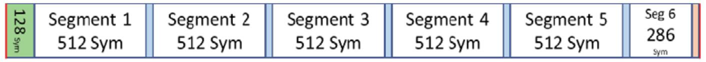
- **Develop and validate candidate UAS CNPC system/subsystem test equipment which complies with standards and frequency regulations for UAS;**
  - Conduct technology assessments, air-ground propagation characterization, supporting systems studies and analyses
  - Perform analyses and propose security recommendations for UAS operations
  - Perform analyses to support recommendations for integration of CNPC and ATC communications

- **Develop technical materials to support further satellite communications spectrum allocations for BLOS CNPC systems**

UAS-NAS Command & Control (C2) Subproject—Phase I FY12-FY16

Waveform Development

Five generations of prototype Control and Non-Payload Communications (CNPC) radio waveforms were used to validate Minimum Operational Performance Standards (MOPS)

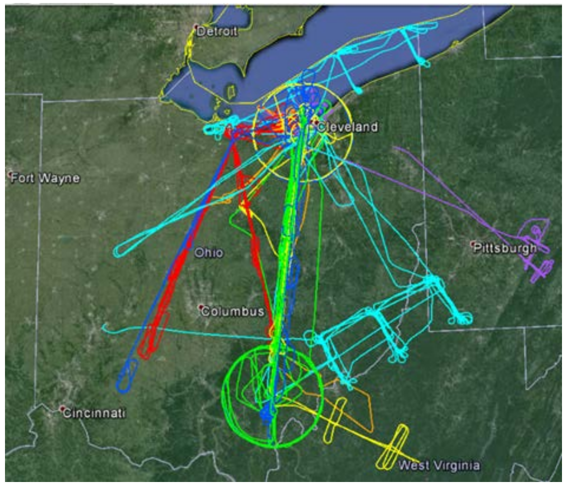


Gen-5 CNPC Validation Flight Testing

Demonstration and support of the development of an Unmanned Aircraft Control and Non-Payload Communications (CNPC) System in both L & C spectrum bands

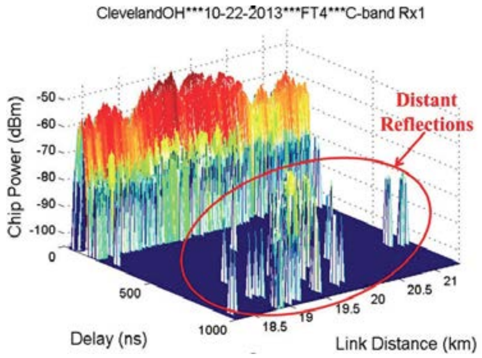
Flight Testing in Multiple Environments

Established ground station positions across U.S. and conducted air-ground measurement campaigns in multiple terrain settings



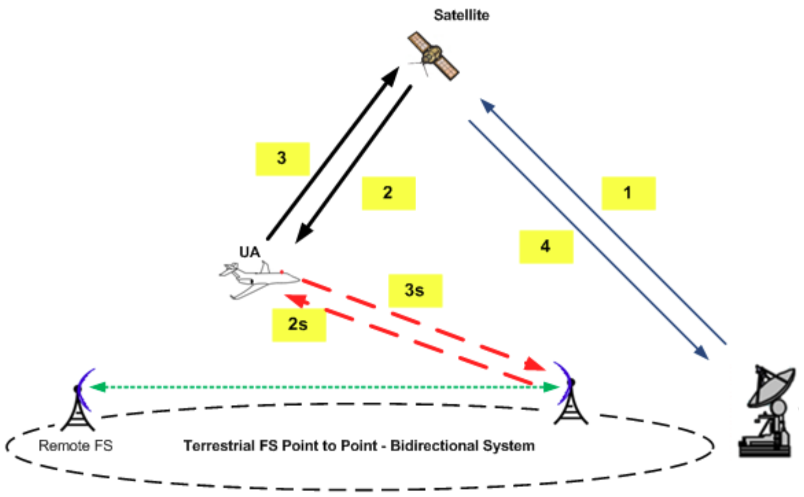
Channel Modeling

Conducted comprehensive L-Band and C-Band channel sounding to validate propagation models, supporting ICAO



UAS-NAS Command & Control (C2) Subproject—Phase I FY12-FY16

SatCom Studies



- C-Band SatCom: Supported obtaining C-Band Satcom frequency allocation at WRC-12
- Ku and Ka-Band Satcom: Performed sharing studies to obtain SatCom frequency allocations at WRC-15

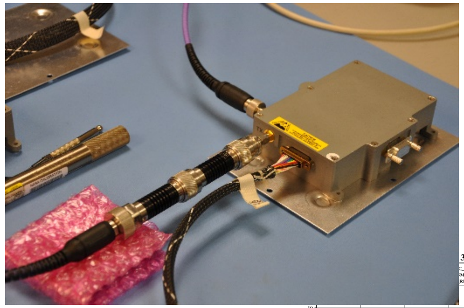
RTCA Support

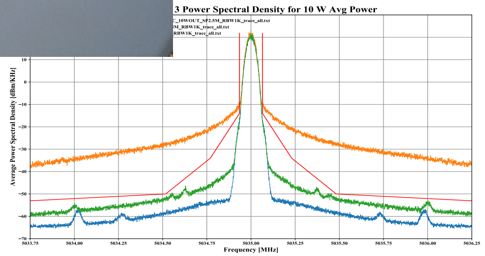
Supported RTCA SC-228 C2 WG MOPS for Terrestrial CNPC through establishing cooperative agreement, conducting lab/flight tests, leading subgroups and authoring multiple DO-362 sections

UAS-NAS Command & Control (C2) Subproject—Phase II FY17-FY20

Terrestrial Radio System Standards

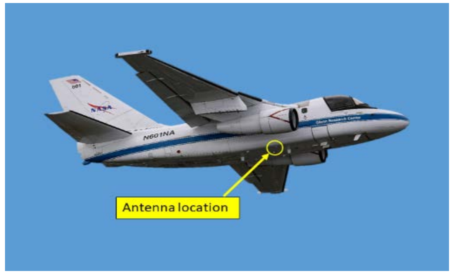
- Development of Low-SWaP CNPC radios for mid-size aircraft in higher-density flight environments.
- Support validation of C2 Terrestrial MOPS, DO-362 Rev A





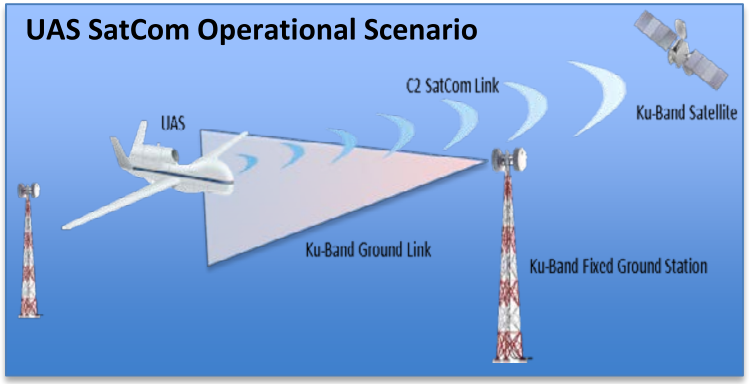
Terrestrial Radio System Validation

Conduct CNPC flight test campaigns that support the development and validation of C2 Terrestrial MOPS, DO-362 Rev A

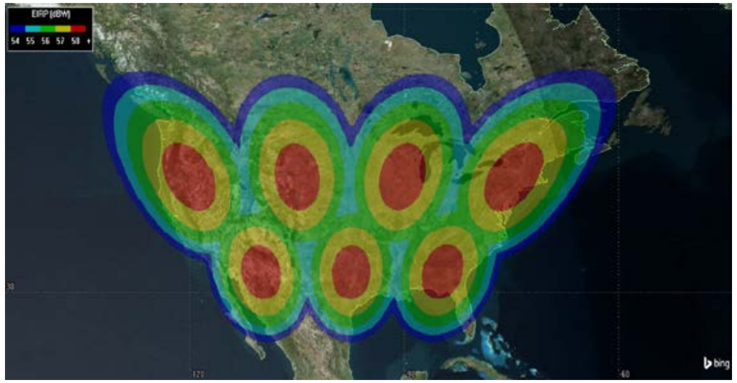


Ku Terrestrial/SatCom Interference Testing

Ku-Band flight testing of interference between fixed ground stations and satellite communication



C-Band SatCom Study and Designs



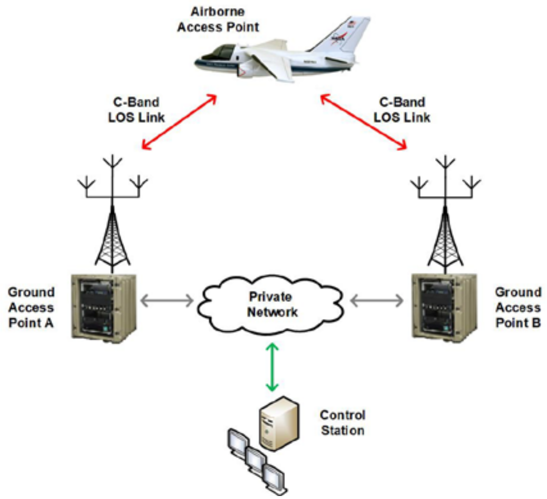
Study the feasibility of an operational satellite-based CNPC system in the approved C-Band spectrum

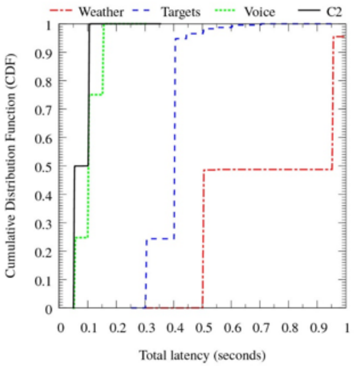
UAS-NAS Command & Control (C2) Subproject—Phase II FY17-FY20

Urban Air Mobility C3 Study

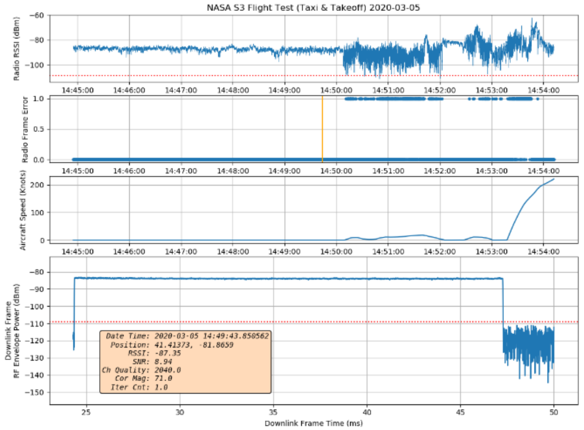
Study of UAS communications in the urban operational airspace and communications environment

Switchover Testing for C2 MASPS





Specialty Testing



RTCA Support

Supported RTCA SC-228 C2 WG Data Link MOPS (Terrestrial) DO-362 Rev A, and C2 Link System MASPS, DO-377

Results and Impact

- **All project milestones successfully completed**
- **All data deliveries completed to partner organizations**
- **Established an efficient, thorough, aeronautical communications flight and ground test competency for trusted, third-party investigations**
- **Assisted in publication of National Standards for C2 links leading to UAS in the NAS**
- **Over 60 study documents, data packages, conference publications, project summary reports completed**
  - Topics including initial concept development, frequency planning and advocacy, ground and air testing, propagation measurements, data compilations, UAM C3 studies, LTE cellular coverage tests, modeling, and simulations.

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

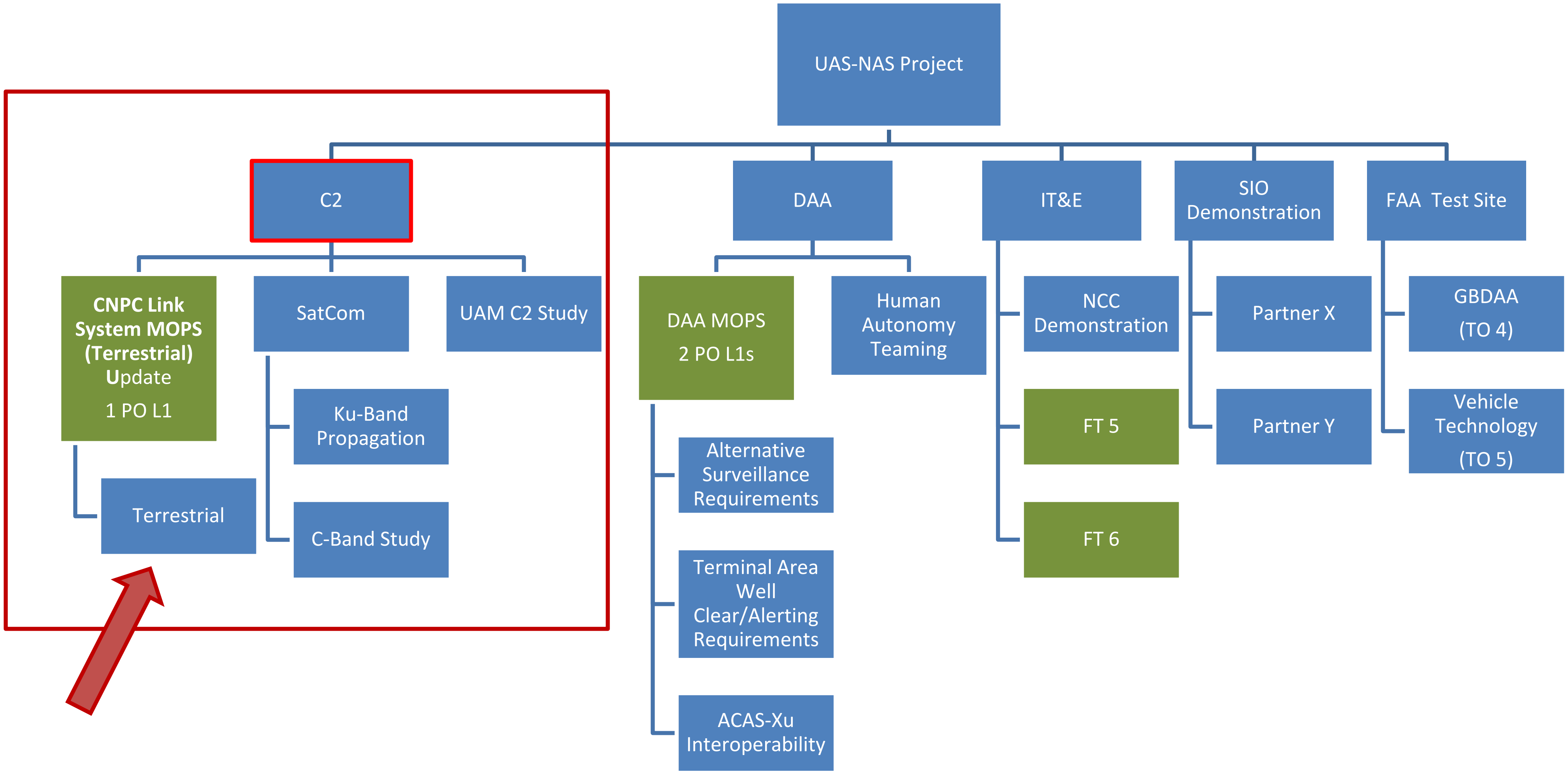
Command and Control Subproject

Terrestrial Based Command & Control

Kurt Shalkhauser

C2 Technical Lead, C2 Subproject

UAS-NAS Structure



Terrestrial-Based Command and Control Communications

Work Categories

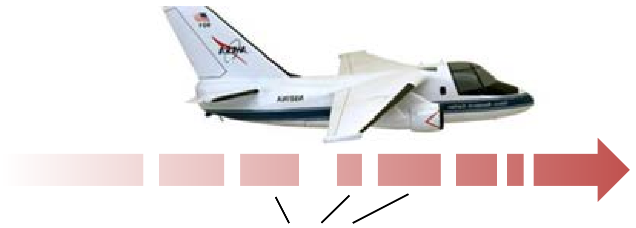
Modeling and Simulation

Hardware Development

System Studies

Spectrum Advocacy

Air-Ground Flight Testing



Flight Test Campaigns

Increasing Test Complexity

Work Components

Multi-year Cooperative Agreement with major aircraft avionics manufacturer:

Waveform and system trade studies, 7 “Generations” of CNPC radio waveforms, prototype radio hardware

Research Grant with a leading University:

Comprehensive L-Band and C-Band Air-Ground Channel Models based on flight tests in multiple terrain environments

Specialty Equipment developed under competitive procurements

COTS equipment purchased where possible to demonstrate readiness

Built up laboratory and ground test capability, including mobile systems and test-related “backhaul” infrastructure

Developed a flight test competency and flight assets (research aircraft) meeting a lengthy list of requirements

Terrestrial-Based Command and Control Communications

DO-362 C2 System Concept

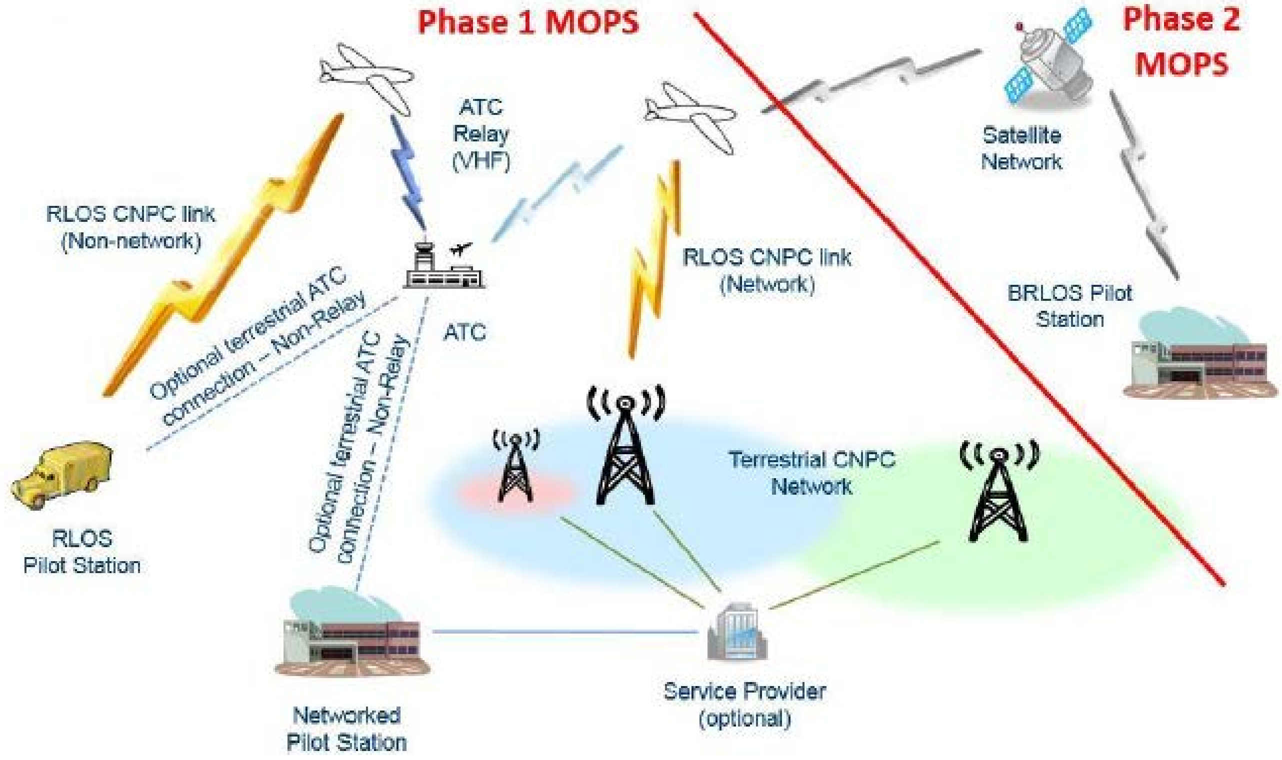
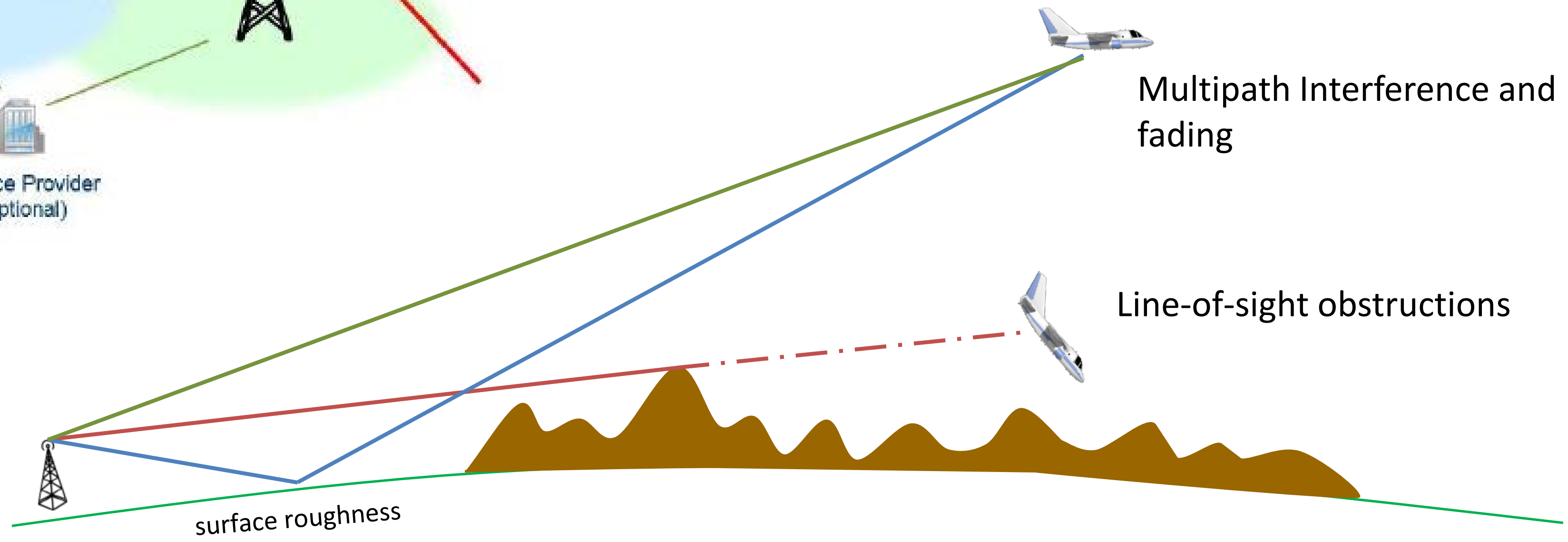


Image courtesy RTCA

CNPC Data

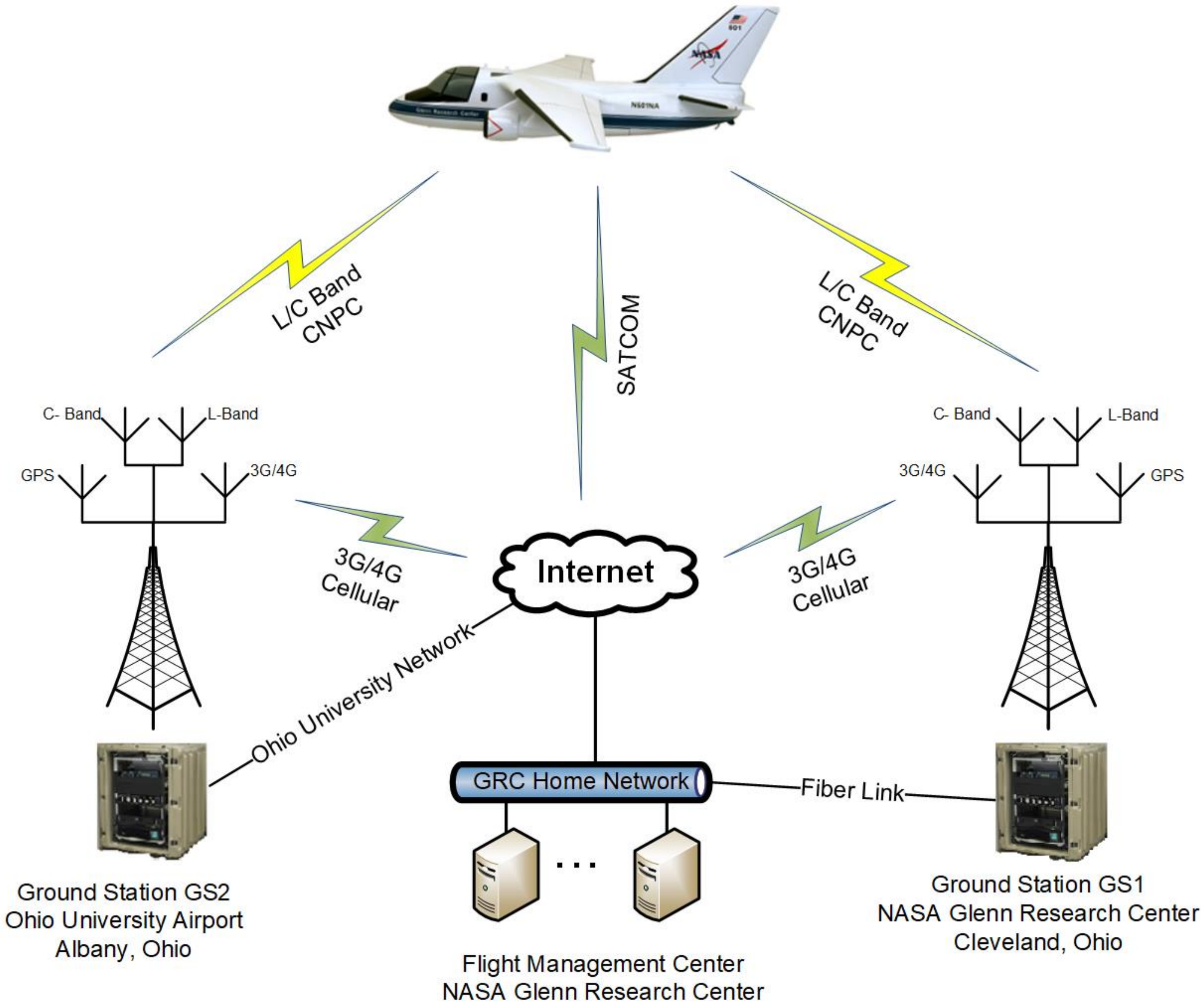
Latency
Bandwidth, Interference
Data throughput

Data flow issues

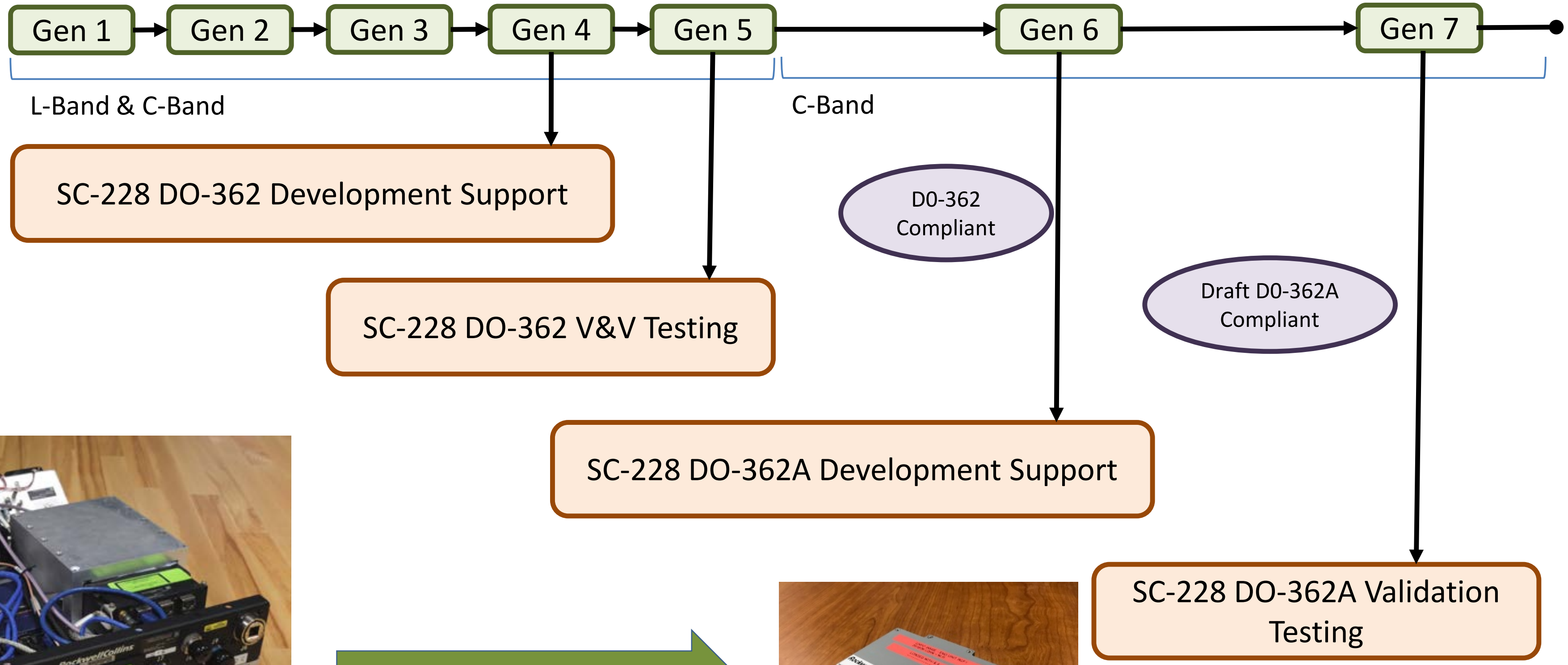


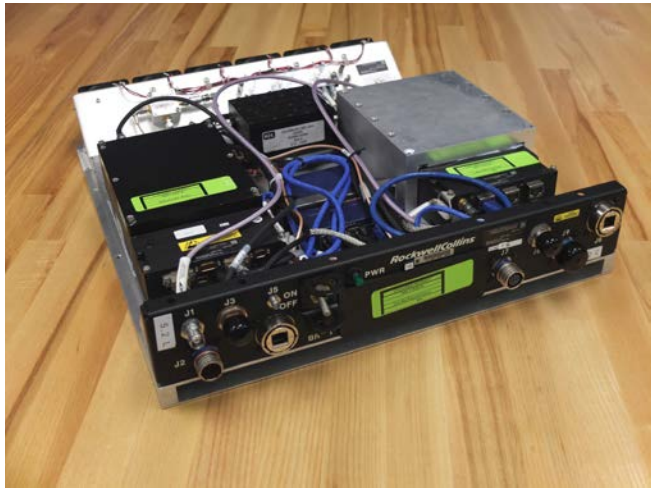
Radio frequency propagation issues

NASA UAS C2 Test System Arrangement



UAS Radio Hardware Progression





Military-based platform for large aircraft, ITAR restrictions on some elements of the radio, L&C bands

Small form factor, low size, weight and power for smaller aircraft at lower altitudes in higher-density environment. Improved waveforms, C-band frequencies, no ITAR restrictions

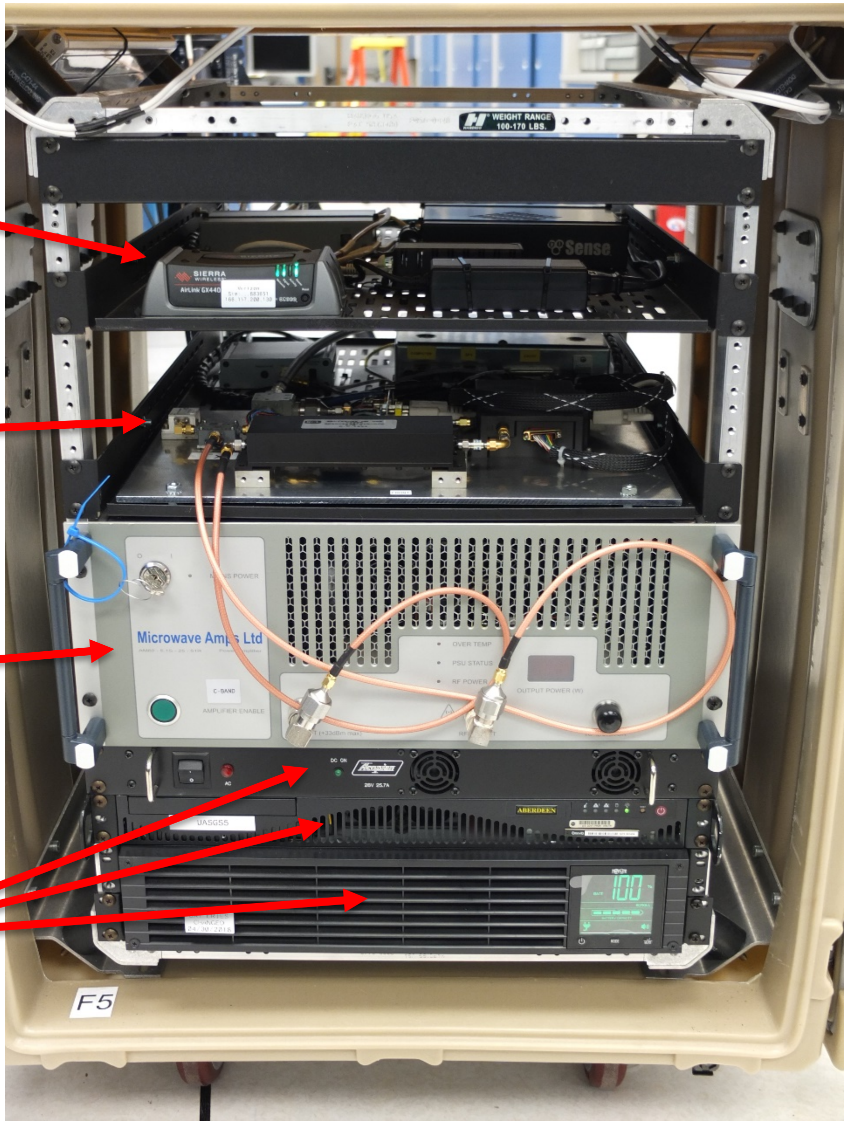
Transportable UAS C2 Ground Station

Networking equipment

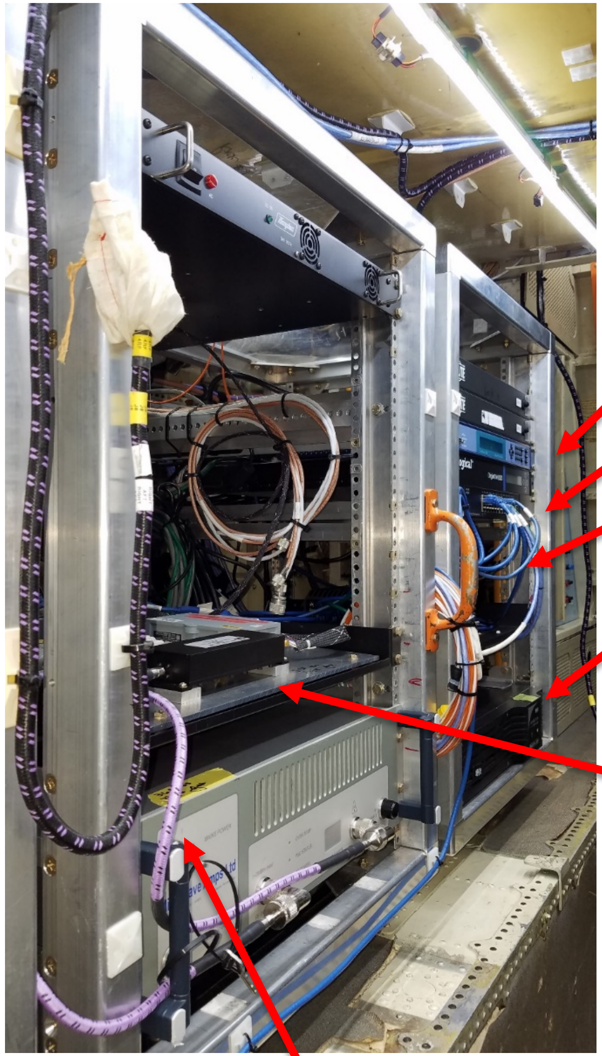
CNPC radio with support equipment

High-power fixed-gain amplifier

Computing and power equipment



Airborne UAS C2 Radio System



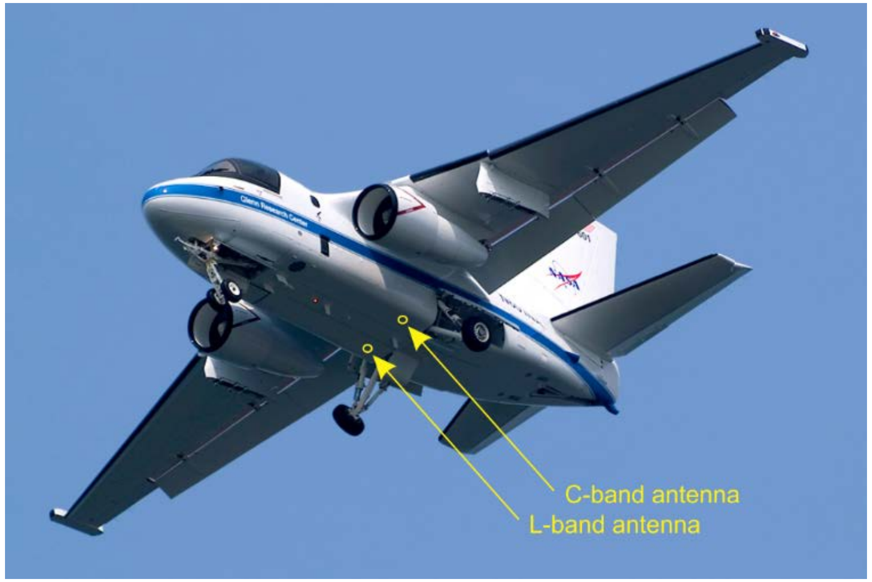
Timing equipment

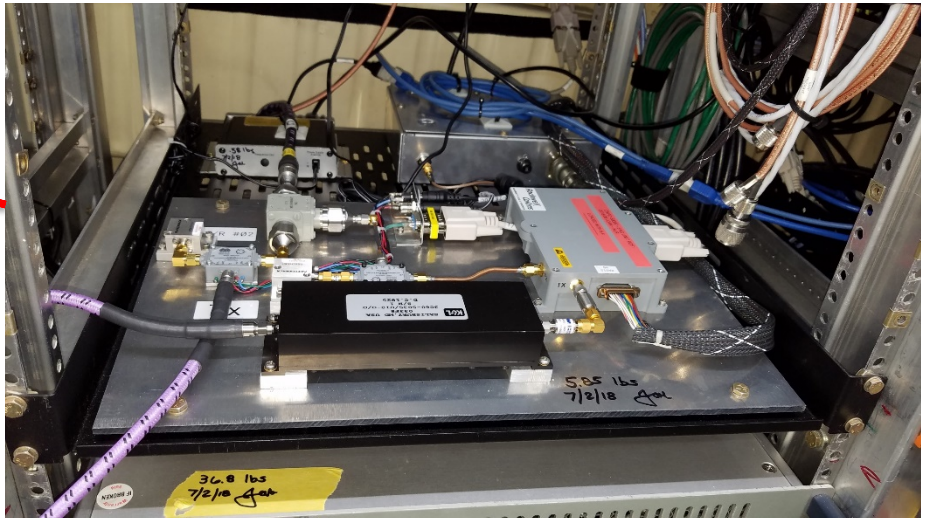
Networking equipment

Control computer

Power equipment

High-power Amplifier





Radio and support equipment

Terrestrial-Based Command and Control Communications

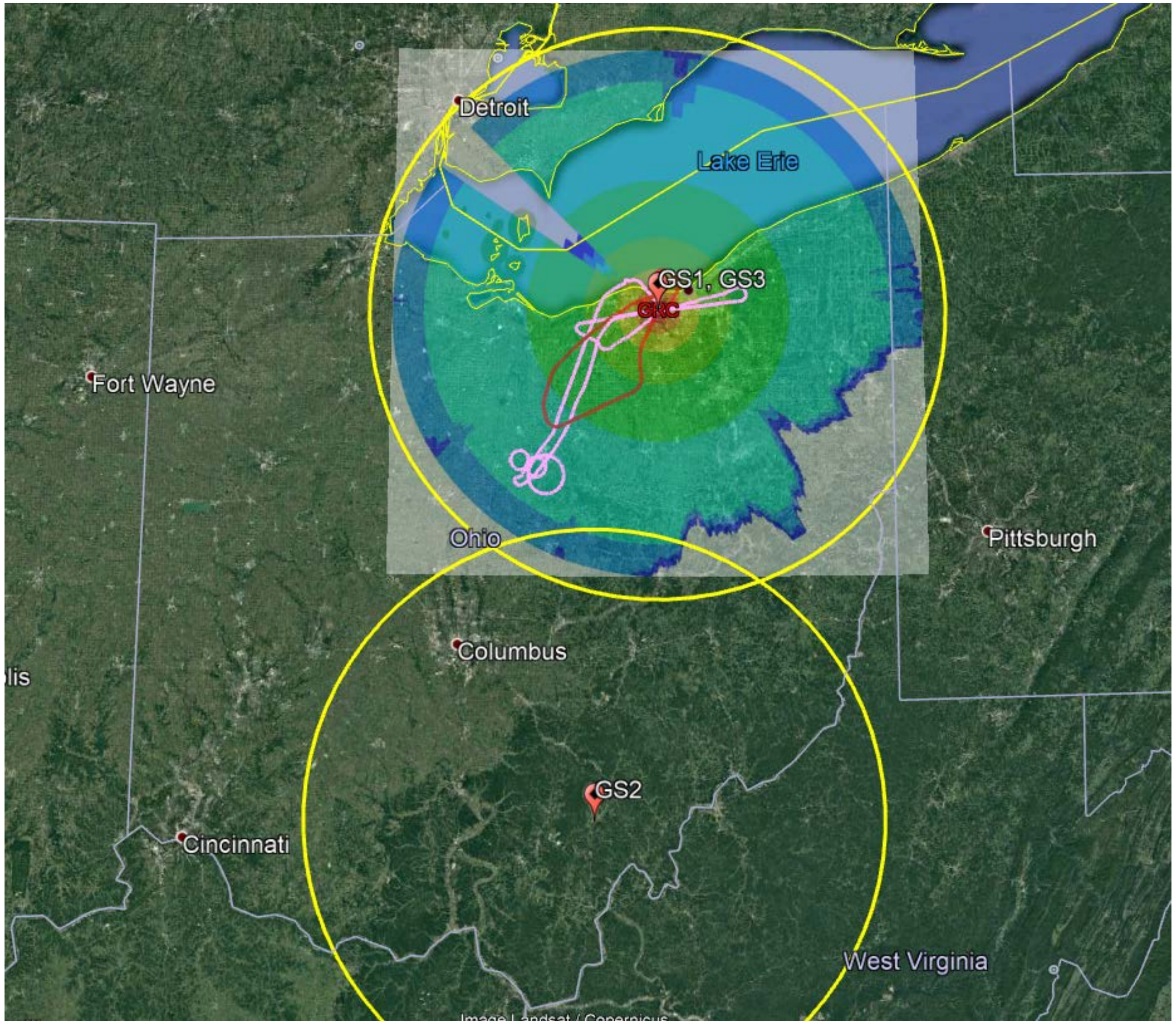
Sample ground test configuration

Sample airborne test configuration

Terrestrial-Based Command and Control Communications

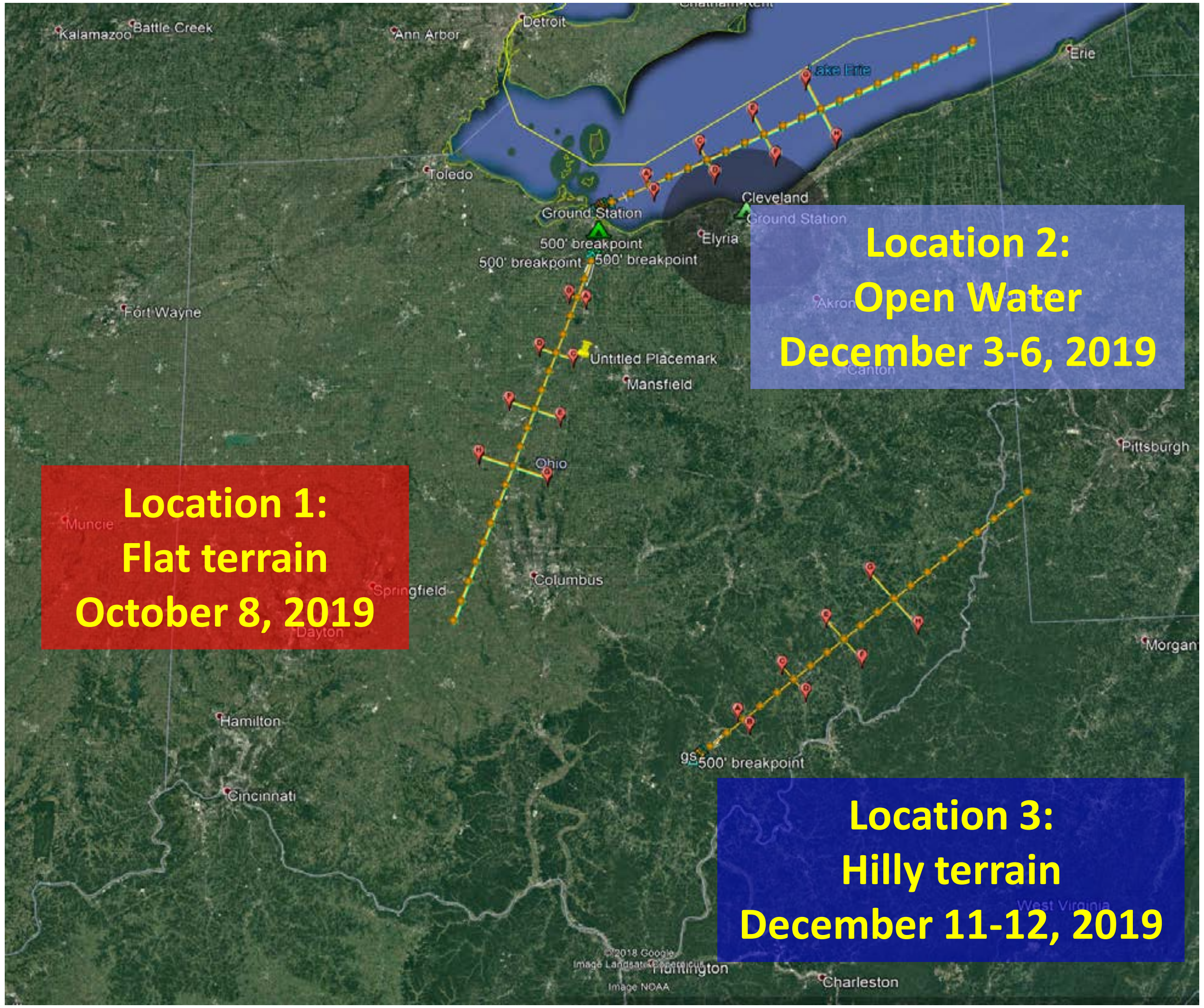
UAS Flight Test Control Room – Cleveland, Ohio

Terrestrial-Based Command and Control Communications



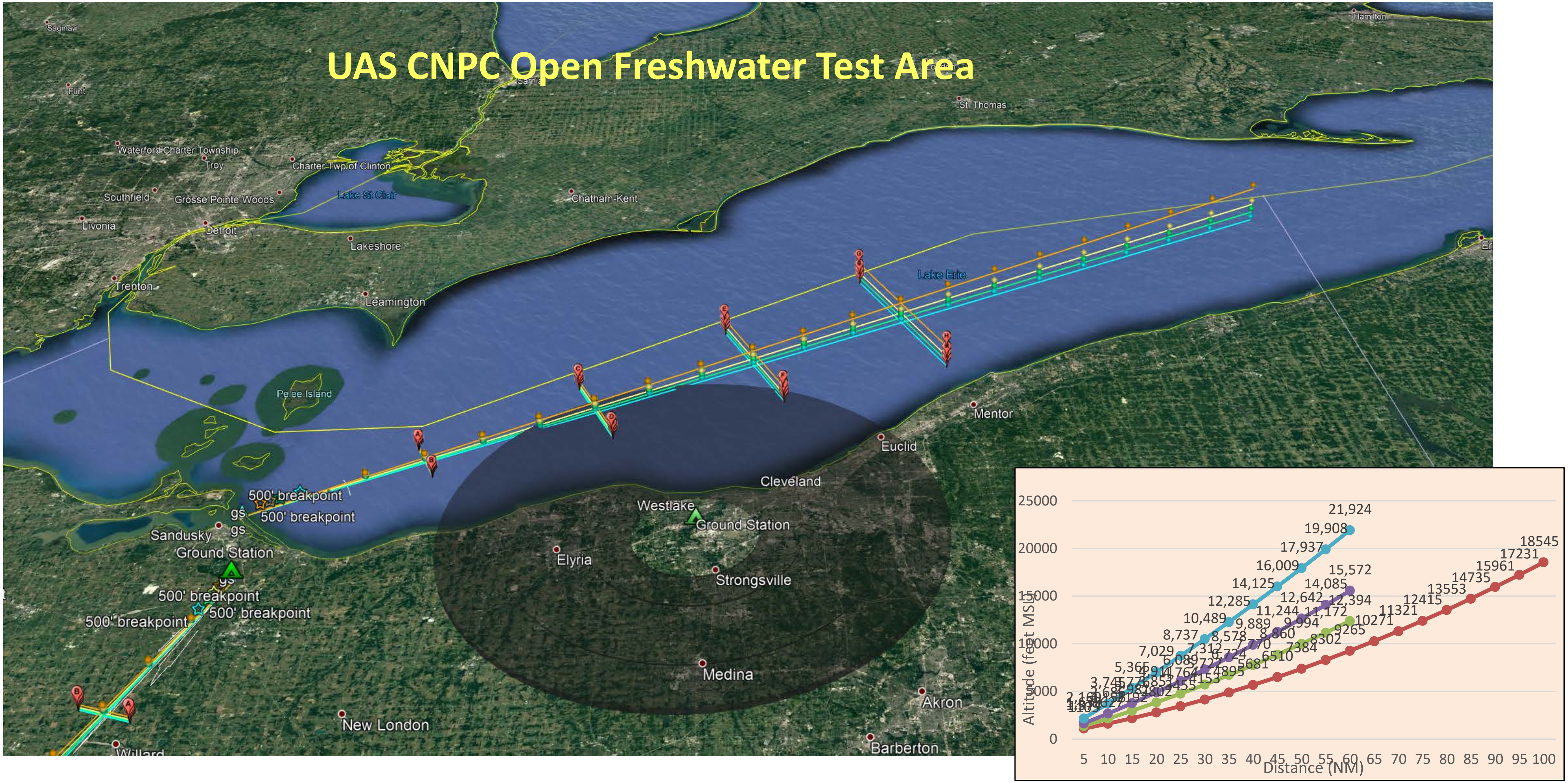
Simulations for flight planning and post flight data analysis

Terrestrial-Based Command and Control Communications

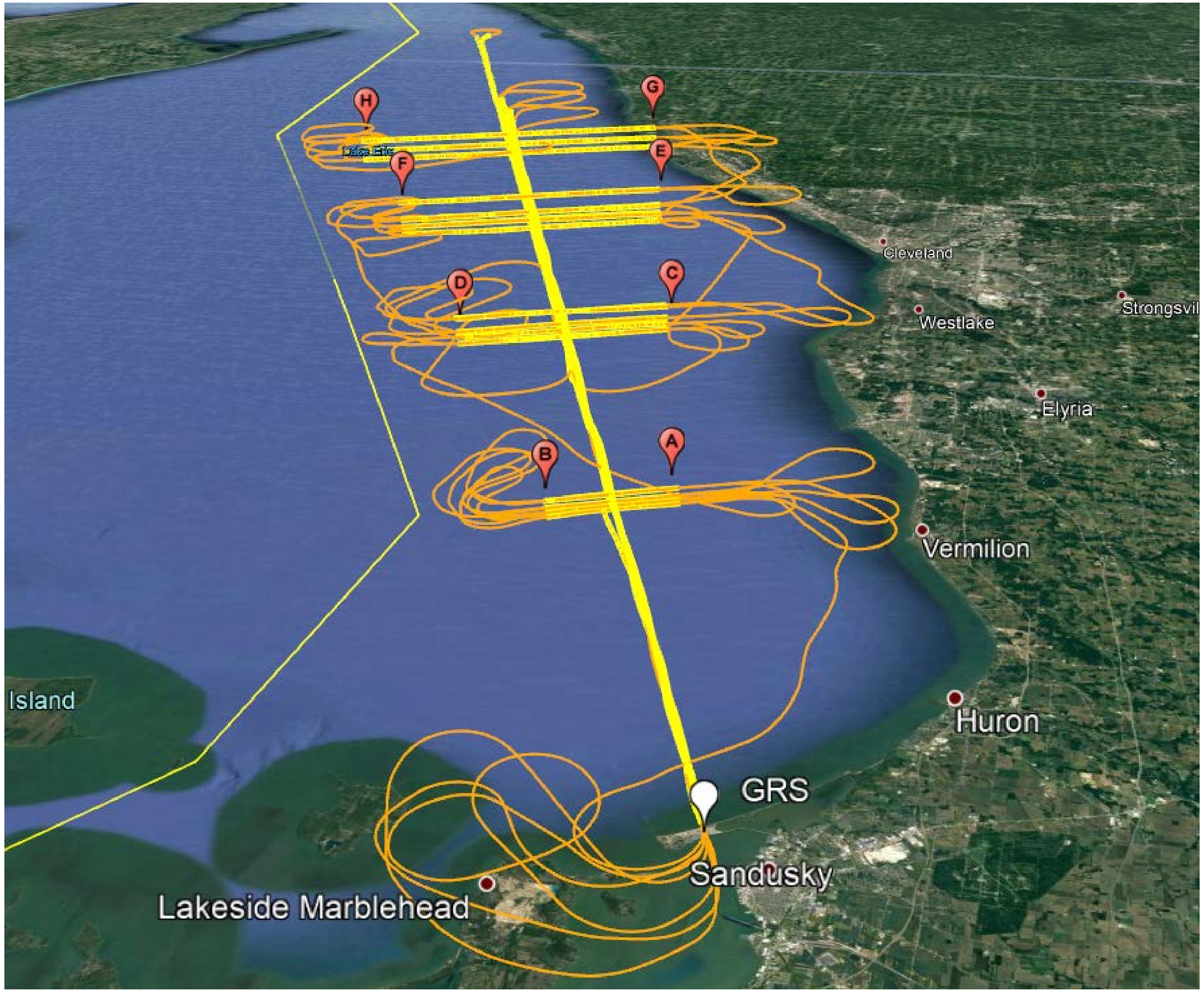


UAS CNPC Gen 7 Flight Test Areas

Terrestrial-Based Command and Control Communications

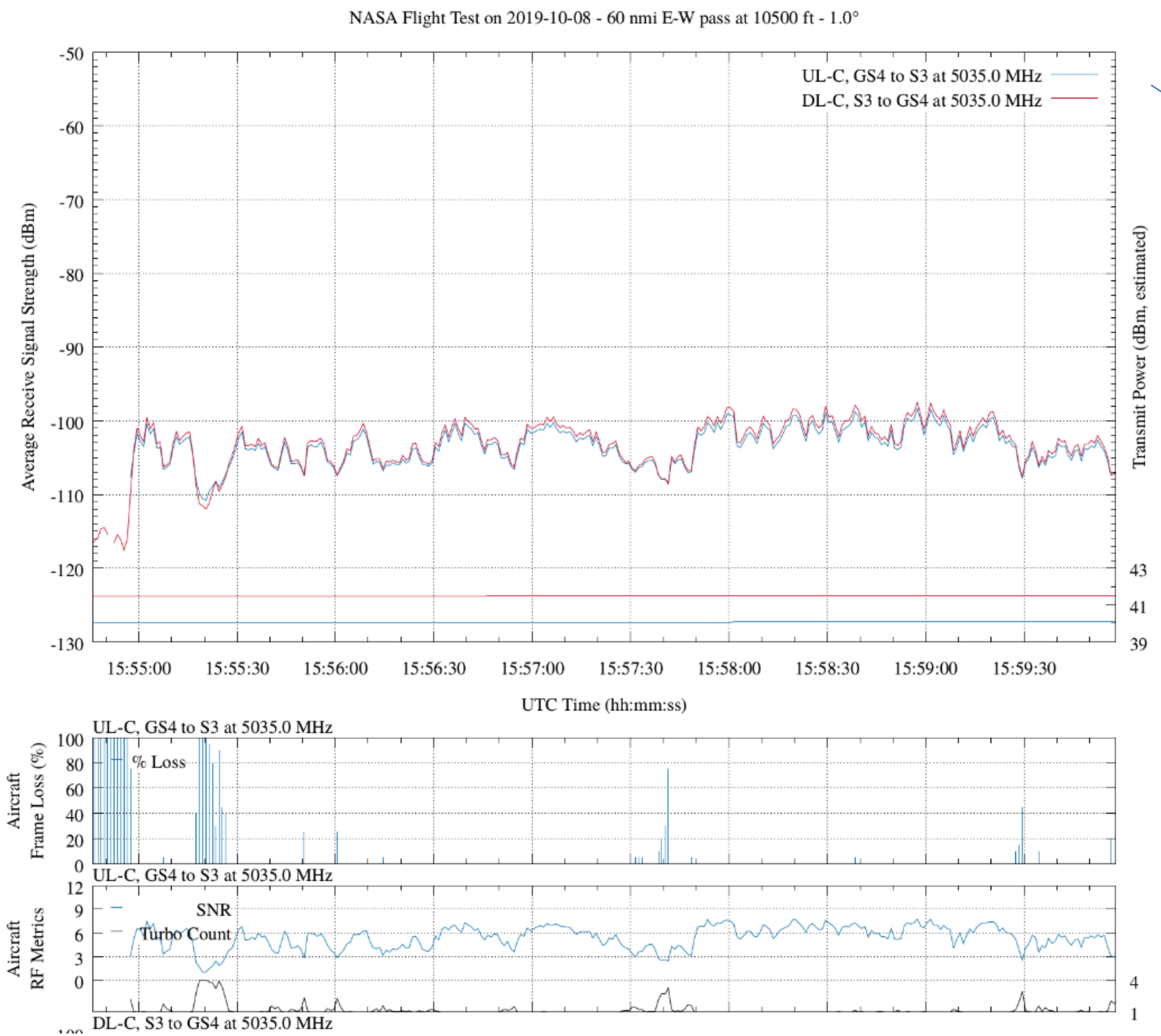


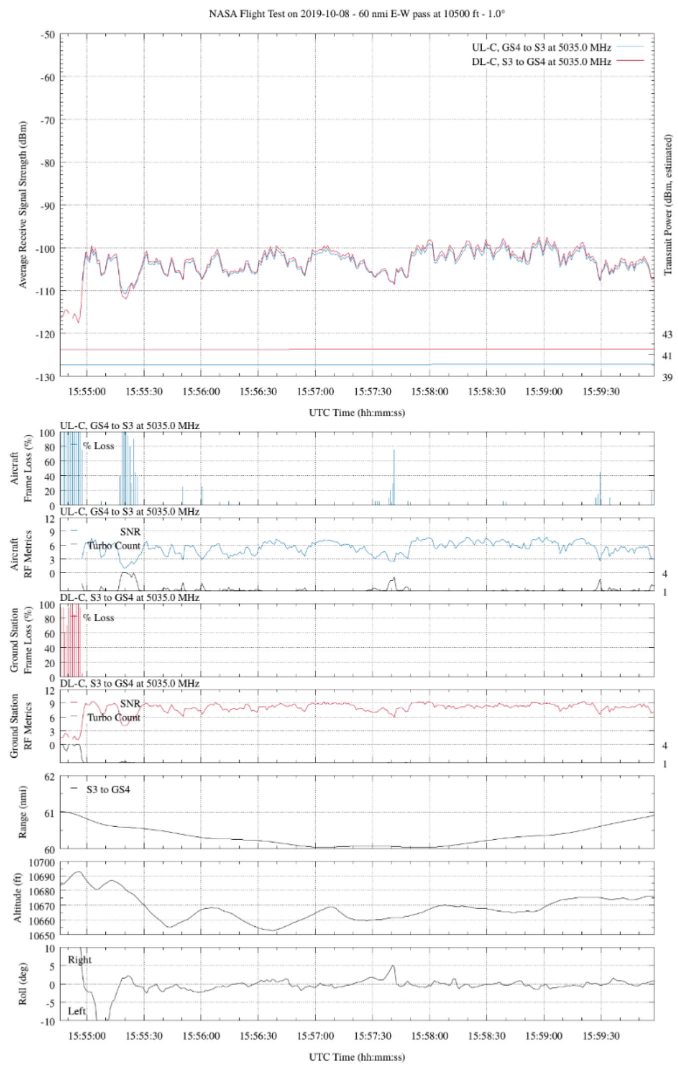
Terrestrial-Based Command and Control Communications



Gen 7 Fresh Water Flight Track and Segments

Typical Flight Test Measurement Data





CNPC Radio data

Aircraft data

Portion of Typical Radio Test Data File

Excess path loss uplink and downlink

(All others are calibration and correction factors)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
	Aircraft Position/Orientation							Uplink (GS to Aircraft)					Downlink (Aircraft to GS)						GS	Aircraft	GS to Aircraft		Terrain	GS Antenna		Aircraft Antenna	
Timestamp (seconds)	Latitude (degrees)	Longitude (degrees)	Altitude (meters)	Heading (degrees)	Pitch (degrees)	Roll (degrees)	Slant Range (km)	Transmit Power (dBm)	Received Power (dBm)	Samples	Path Loss (dB)	Excess Path Loss (dB)	Transmit Power (dBm)	Received Power (dBm)	Samples	Path Loss (dB)	Excess Path Loss (dB)	Free Space Path Loss (dB)	Antenna Gain (dB)	Antenna Gain (dB)	Azimuth Angle (degrees)	Elevation Angle (degrees)	Elevation Angle (degrees)	Phi Angle (degrees)	Theta Angles (degrees)	Phi Angle (degrees)	Theta Angles (degrees)
1570549554	40.679086	-83.15065	2338.151	110.2695	4.2409973	-1.978363	84.62894	40.10576	-104.326	20	146.8174	1.777066	41.37647	-104.005	20	147.7672	2.726847	145.0404	13.38169	-1.296131	210.03346	1.0574961	0.0131242	-10.03346	88.942504	-80.73128	89.444289
1570549555	40.678734	-83.14927	2337.717	110.43457	4.250885	-1.700409	84.60529	40.10568	-105.346	20	147.9565	2.918573	41.37664	-105.025	20	148.9065	3.868513	145.0379	13.40153	-1.196909	209.95178	1.0577096	0.0131242	-9.951781	88.94229	-80.97617	89.187516
1570549556	40.678366	-83.14792	2338.487	110.57437	4.2780762	-1.186523	84.58427	40.10561	-103.766	20	146.5919	1.556125	41.37682	-103.235	20	147.332	2.296223	145.0358	13.420351	-1.000354	209.87066	1.0586828	0.0117887	-9.870659	88.941317	-81.19524	88.691862
1570549557	40.678	-83.14655	2337.938	110.87814	4.284668	-0.476532	84.56273	40.10554	-102.296	20	145.3847	0.35109	41.37699	-101.725	20	146.0849	1.051348	145.0336	13.439357	-0.756625	209.78885	1.058774	0.014335	-9.788848	88.941226	-81.57601	88.018223
1570549558	40.677636	-83.14519	2338.029	111.14813	4.3222961	0.7402039	84.54131	40.10547	-102.656	20	146.1681	1.13673	41.37717	-102.275	20	147.0585	2.027147	145.0314	13.45829	-0.352135	209.7073	1.0592964	0.0287231	-9.707305	88.940704	-81.91964	86.834281
1570549559	40.677261	-83.14384	2338.624	111.48871	4.4296875	0.7976074	84.52194	40.1054	-102.257	20	145.742	0.712654	41.37735	-101.755	20	146.5126	1.48323	145.0294	13.477068	-0.396997	209.62639	1.0601162	0.0298333	-9.626394	88.939884	-82.34363	86.793091
1570549560	40.676887	-83.14249	2339.14	111.76996	4.3961792	0.6775818	84.50265	40.10533	-100.337	20	143.7396	-1.28781	41.37752	-99.6152	20	144.2903	-0.73707	145.0274	13.495892	-0.498284	209.5453	1.0608777	0.0266908	-9.545298	88.939122	-82.70395	86.942838
1570549561	40.67651	-83.14114	2338.342	112.10257	4.3000488	0.4108887	84.48335	40.10525	-102.997	20	146.2577	1.232261	41.3777	-102.635	20	147.1686	2.143155	145.0254	13.514878	-0.659201	209.4636	1.0607553	0.0266908	-9.4636	88.939245	-83.11428	87.250268
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1570549565	40.674966	-83.13579	2337.953	112.01633	4.4033203	-1.027222	84.41398	40.10497	-107.227	20	150.0174	4.999108	41.37841	-107.455	20	151.5189	6.500638	145.0183	13.590419	-1.205101	209.13838	1.0619858	0.0300459	-9.138377	88.938014	-83.35936	88.68348
1570549566	40.674574	-83.13445	2337.709	112.03638	4.4563293	-1.118134	84.3974	40.10489	-107.827	18	150.5935	5.576889	41.37858	-107.945	20	151.9851	6.968577	145.0166	13.609431	-1.248055	209.05654	1.0621776	0.0300459	-9.056543	88.937822	-83.46242	88.77563
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1570549568	40.673794	-83.13174	2336.551	112.0762	4.4200745	-0.423798	84.36365	40.10475	-103.947	20	146.9845	1.971448	41.37893	-103.525	20	147.8366	2.823454	145.0131	13.645007	-1.012581	208.89191	1.0621183	0.0241824	-8.891908	88.937882	-83.66084	88.105984
1570549569	40.673398	-83.1304	2335.682	111.38214	4.3967285	-0.924225	84.34802	40.10468	-103.367	20	146.3013	1.289812	41.37911	-102.945	20	147.1535	2.141977	145.0115	13.662052	-1.13289	208.80981	1.0618651	0.0198096	-8.809811	88.938135	-83.05059	88.558511
1570549570	40.672999	-83.12906	2335.766	111.25552	4.3937073	-2.094818	84.33321	40.10461	-105.448	20	147.9348	2.924825	41.37929	-105.255	20	149.0171	4.007149	145.01	13.679029	-1.596395	208.72798	1.0622412	0.0148889	-8.727981	88.937759	-83.00712	89.716953
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1570549572	40.672159	-83.1264	2339.066	111.69388	4.4154053	-1.592194	84.30865	40.10446	-107.188	20	149.8567	4.849243	41.37964	-107.445	20	151.3893	6.381884	145.0074	13.713165	-1.448679	208.56326	1.0650143	0.0181572	-8.563264	88.934986	-83.60681	89.260797
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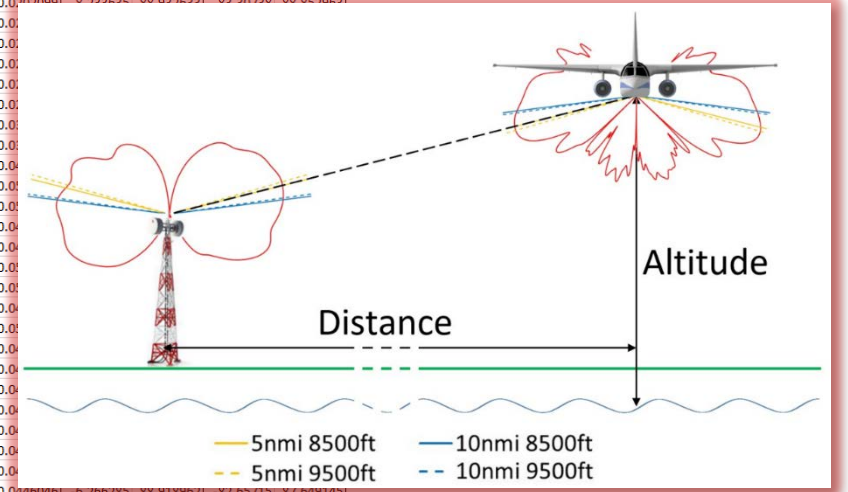
1570549575	40.670958	-83.12235	2339.988	111.24564	4.4068909	-1.232117	84.265	40.10425	-104.358	20	147.2415	2.238574	41.38017	-104.065	20	148.2246	3.221693	145.0029	13.764605	-1.285339	208.31533	1.0665848	0.0185748	-8.315331	88.933415	-83.40365	88.886735
1570549576	40.670579	-83.12101	2340.628	111.06903	4.3876648	-1.204102	84.24896	40.10418	-104.638	20	147.5588	2.557476	41.38035	-104.255	20	148.452	3.450754	145.0013	13.781553	-1.265054	208.23363	1.0673672	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549577	40.670192	-83.11966	2339.919	110.71143	4.348938	-1.501556	84.23357	40.10411	-103.948	20	146.7968	1.797078	41.38052	-103.495	20	147.6202	2.620514	144.9997	13.798648	-1.354153	208.1513	1.0672182	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549578	40.669782	-83.11833	2339.866	110.55597	4.379425	-1.234589	84.22149	40.10403	-102.238	20	145.2204	0.221974	41.3807	-101.625	20	145.884	0.885569	144.9984	13.815667	-1.237539	208.06931	1.0674432	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549579	40.669389	-83.11701	2340.346	110.50186	4.360199	-0.806396	84.20784	40.10396	-104.968	20	148.1247	3.127699	41.38087	-104.765	20	149.1985	4.201453	144.997	13.8323	-1.079871	207.98781	1.0680653	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549580	40.669001	-83.11566	2341.23	110.44913	4.3426208	-2.02478	84.19338	40.10389	-106.468	20	149.1515	4.155964	41.38105	-106.465	20	150.4254	5.429877	144.9955	13.847473	-1.568289	207.90562	1.0689803	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549581	40.66863	-83.11432	2341.748	110.31949	4.3253174	-2.38266	84.1775	40.10382	-105.249	20	147.8035	2.80958	41.38123	-104.985	20	148.8176	3.823652	144.9939	13.862489	-1.711344	207.8243	1.0696774	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549582	40.668243	-83.11298	2341.916	109.99677	4.316803	-2.138214	84.16304	40.10375	-104.959	20	147.661	2.66863	41.3814	-104.555	20	148.5353	3.542861	144.9924	13.877693	-1.579008	207.74198	1.0701051	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549583	40.667849	-83.11167	2343.166	109.75457	4.3693783	-2.610409	84.15099	40.10367	-104.799	20	147.3378	2.346582	41.38158	-104.315	20	148.1321	3.140972	144.9912	13.892593	-1.757217	207.66128	1.0712181	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549584	40.66748	-83.11035	2343.561	109.27963	4.4318848	-2.974274	84.13631	40.1036	-104.739	20	147.1845	2.194846	41.38176	-104.495	20	148.2191	3.229395	144.9897	13.907399	-1.865292	207.58112	1.0718062	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549585	40.667102	-83.10899	2343.904	108.80008	4.412384	-2.724335	84.12102	40.10353	-106.919	20	149.5309	4.54281	41.38193	-106.845	20	150.7356	5.747517	144.9881	13.922698	-1.714223	207.49831	1.0723718	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549586	40.666733	-83.10763	2344.278	108.30569	4.359375	-2.512299	84.10521	40.10346	-106.279	20	149.0374	4.050907	41.38211	-106.205	20	150.2422	5.255773	144.9864	13.937883	-1.582962	207.41611	1.0729698	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549587	40.666362	-83.10628	2344.346	108.41309	4.315979	-2.325806	84.08977	40.10339	-106.969	19	149.8043	4.819406	41.38229	-106.905	20	151.0193	6.034431	144.9849	13.95309	-1.521281	207.33381	1.0733521	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549588	40.666016	-83.10491	2344.697	108.6666	4.2816467	-1.789673	84.07155	40.10332	-104.989	20	148.0407	3.057737	41.38246	-104.625	20	148.9559	3.972921	144.983	13.96826	-1.32002	207.2517	1.0739873	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549589	40.665675	-83.10356	2345.162	108.54108	4.3096619	-1.471893	84.05359	40.10324	-104.999	20	148.2117	3.230596	41.38264	-104.535	20	149.0271	4.04594	144.9811	13.983284	-1.174058	207.17039	1.0746951	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549590	40.665329	-83.10219	2345.71	108.3436	4.3113098	-1.519684	84.03557	40.10317	-105.659	20	148.8782	3.898911	41.38281	-105.475	20	149.9737	4.994413	144.9793	13.998505	-1.182844	207.08802	1.0754616	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549591	40.664989	-83.10081	2345.185	108.23099	4.3231201	-1.734741	84.01685	40.1031	-105.719	20	148.8626	3.885268	41.38299	-105.535	20	149.9582	4.980929	144.9773	14.013751	-1.273686	207.00553	1.0755104	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549592	40.664646	-83.09943	2346.244	108.07416	4.3401489	-1.871521	83.99863	40.10303	-106.09	20	149.1949	4.219437	41.38317	-105.875	20	150.2607	5.285257	144.9754	14.027282	-1.324949	206.92284	1.0766302	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549593	40.664297	-83.09807	2347.12	107.8797	4.3242187	-2.03714	83.98177	40.10296	-106.12	20	149.1757	4.202029	41.38334	-106.035	20	150.3717	5.398008	144.9737	14.040595	-1.387431	206.84073	1.0775959	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549594	40.66394	-83.09672	2347.204	107.68414	4.3269653	-2.220337	83.96605	40.10288	-104.43	20	147.4296	2.457497	41.38352	-103.965	20	148.2457	3.273635	144.9721	14.053923	-1.456934	206.75854	1.0779959	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549595	40.663603	-83.09535	2346.891	107.52457	4.3005981	-2.337341	83.94837	40.10281	-104.79	20	147.757	2.786723	41.3837	-104.255	20	148.5033	3.53302	144.9702	14.067188	-1.502819	206.67675	1.0781683	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549596	40.663265	-83.094	2346.724	107.34686	4.2865906	-2.405457	83.93127	40.10274	-104.97	20	147.9284	2.959965	41.38387	-104.605	20	148.8449	3.876421	144.9685	14.080359	-1.524535	206.59554	1.078427	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549597	40.662933	-83.09265	2346.488	107.22079	4.2860413	-2.34201	83.91349	40.10267	-103.85	20	146.8542	1.88758	41.38405	-103.425	20	147.7108	2.744195	144.9666	14.093579	-1.491999	206.51403	1.0786538	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549598	40.662607	-83.09127	2346.914	107.26282	4.4307861	-1.207397	83.89461	40.1026	-103.78	20	147.2861	2.321421	41.38423	-103.205	20	147.9929	3.028194	144.9647	14.106936	-1.003487	206.43169	1.0793576	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549599	40.662278	-83.08989	2347.783	107.7822	4.4280396	-0.118927	83.87621	40.10253	-101.77	20	145.6457	0.682932	41.3844	-101.195	20	146.3526	1.389865	144.9628	14.120327	-0.647289	206.34917	1.0803534	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549600	40.661941	-83.08851	2348.225	108.47324	4.4143066	-0.055481	83.85869	40.10245	-100.72	20	144.5115	-0.44945	41.38458	-100.015	20	145.0886	0.127641	144.961	14.133777	-0.744953	206.26629	1.0810384	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1570549601	40.6616	-83.08714	2348.636	108.95856	4.381897	0.2738342	83.84197	40.10238	-102.1	20	145.9386	0.979426	41.38475	-101.605	20	146.7259	1.766676	144.9592	14.147196	-0.711245	206.1836	1.0816854	0.0394036	-6.183598	88.918315	-83.2198	87.368844
1570549602	40.661276	-83.08579	2348.58	109.20584	4.2733925	0.5195377	83.82483	40.10231	-102.57	20	146.4645	1.507034	41.38493	-102.055	20	147.2319	2.274443	144.9574	14.160286	-0.668521	206.10293	1.0820222	0.0288177	-6.102932	88.917978	-83.54043	87.161358
1570549603	40.660945	-83.08445	2347.448	109.48453	4.3313599	0.4735107	83.80844	40.10224	-102.42	20	146.27	1.314258	41.38511	-101.995	20	147.1276	2.171826	144.9557	14.173405	-0.726132	206.02203	1.0816064	0.0231444	-6.022033	88.918394	-83.90094	87.227737
1570549604	40.660599	-83.08308	2346.594	109.77155	4.4057922	0.3493652	83.79259	40.10217	-101.351	20	145.1672	0.21313	41.38528	-100.685	20	145.785	0.830857	144.9541	14.185688	-0.771202	205.93892	1.0813692	0.0167829	-5.938924	88.918631	-84.27287	87.371631
1570549605	40.660261	-83.08171	2345.421	110.00995	4.3722839	0.0458679	83.77653	40.10209	-102.441	20	146.1732	1.220773	41.38546	-101.925	20	146.9411	1.988659	144.9524	14.197419	-0.866973	205.85662	1.0809177	0.0167829	-5.856624	88.919082	-84.59179	87.701789
1570549606	40.659905	-83.08035	2345.185	110.28241	4.3667908	-0.411987	83.76274	40.10202	-103.821	20	147.4162	2.465233	41.38564	-103.025	20	147.9043	2.953278	144.951	14.209188	-1.01573	205.77412	1.0810578	0.0083407	-5.774118	88.918942	-84.94618	88.185184

Measured loss

\- Predicted loss

= **Excess** path loss



Terrestrial-Based Command and Control Communications

UAS Phase 1 (Channel Characterization and CNPC radio generations 1-5)

- 65 mission flights
- Operated in 12 U.S. locations
- Over 12,000 miles on tower trailer and ground radio station (GRS)
- Over 200 hours of in-flight data collection

  300 million channel sounding impulse responses (147 GBytes)

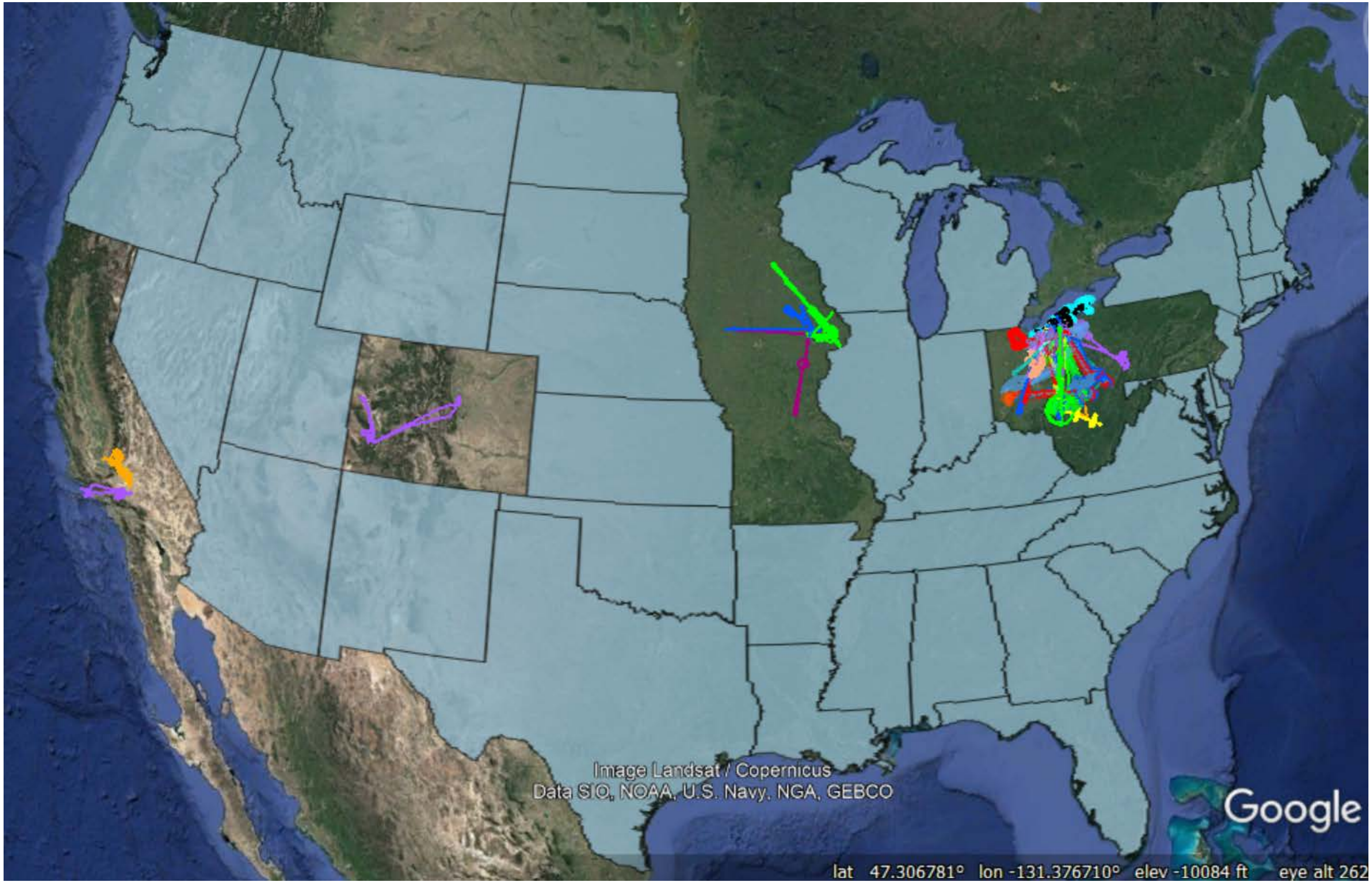
  200 hours x 3600 sec/hr x20 Hz x 2 radios =28.8 million radio data points (1.9 TBytes)

UAS Phase 2 (CNPC radio generations 6-7)

- 26 mission flights
- Operated in 6 U.S. locations
- 2,000 miles on tower trailer & GRS
- 70 hours of in-flight data collection

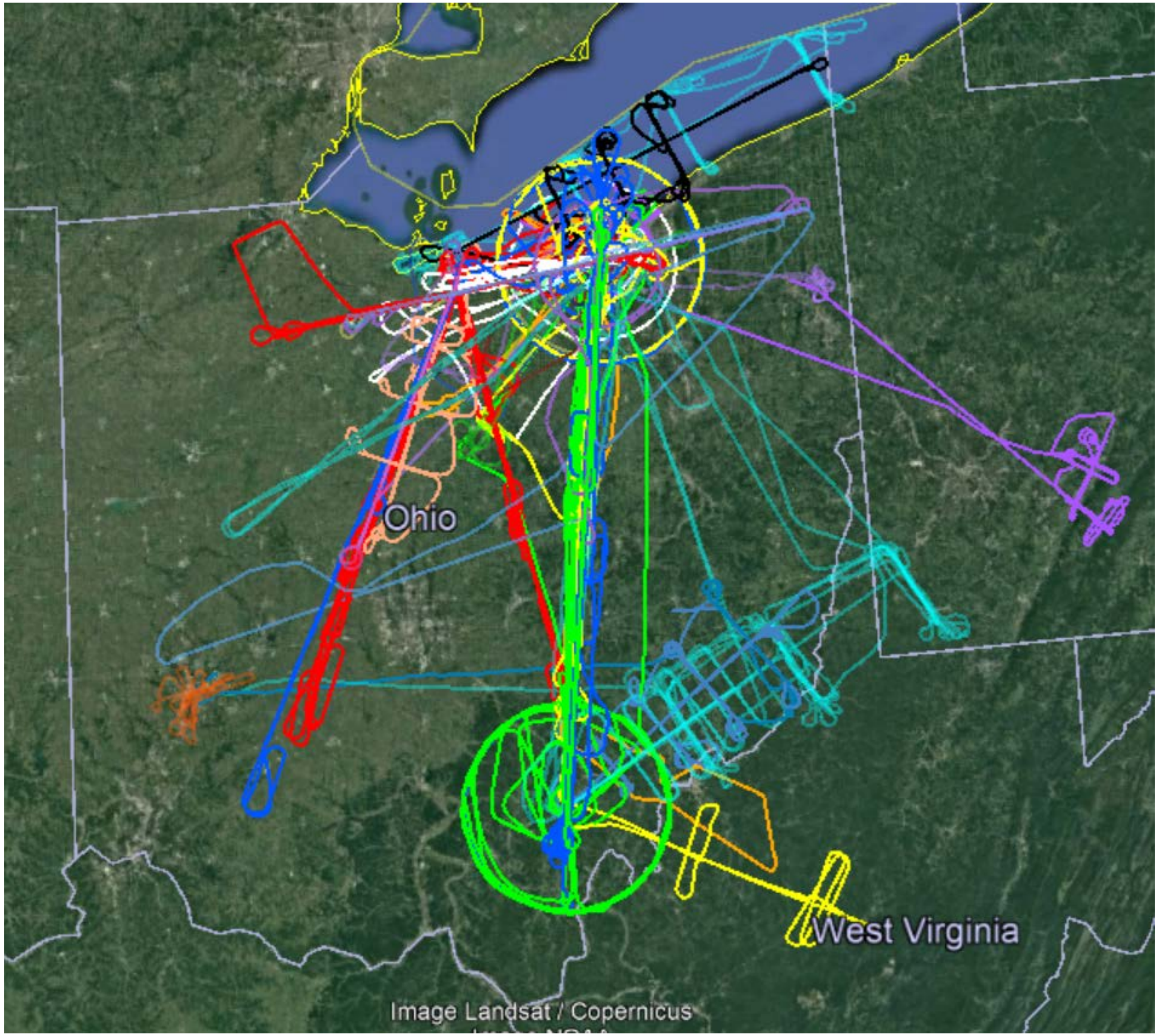
  70 hours x 3600 sec/hr x20 Hz x 2 radios =10.1 million radio data points (151 GBytes)

Terrestrial-Based Command and Control Communications



UAS C2 Flight Tracks Involving 8 States

Terrestrial-Based Command and Control Communications



UAS C2 Flight Tracks in Ohio Region

Terrestrial-Based C2 Research Impact

- Data from NASA laboratory, ground, and flight testing is used/referenced in RTCA *“Command and Control (C2) Data Link Minimum Operational Performance Standards (MOPS) (Terrestrial)”*
  - Impacted ≈500/700 pages of DO-362, 2016
  - Impacted 283/661 pages of DO-362 Rev A, (July, 2021)
- Data also supplied to RTCA DO-377 (C2 Data Link MASPS) and ICAO WG-F, and in preparation of International Telecommunications Union (ITU) recommendations for World Radio Conference WRC-15
- More than 44 project reports, technical articles, conference publications, and data submission packages

Lessons Learned—Terrestrial-Based C2 Communications

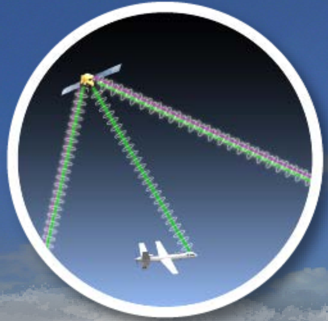
- Collaboration is vital to success
- Progressive testing with gradual increase in complexity produces best data
- Direct access to the test aircraft is essential

Leave-Behind Capabilities

Aeronautical Communications Competency

- State-of-the-art laboratory facilities, test ranges, flight test control facility, and test communications infrastructure that are highly-regarded as trusted, independent test entities.
- Proven experience in system modeling & simulation, satellite communications, ground station and airborne payload design, development, and off-site operations.
- Seasoned and well-integrated working relationship between researchers and flight operations organizations.
- Productive, open, and synergistic relationship with RTCA member organizations and UAS community.
- Well-known, multi-faceted flight test area in Ohio: flat and hilly terrain conditions; open freshwater test area within national boundary; urban, suburban, and rural conditions; and adjacent to an international airport (i.e. a broad range of realistic test conditions) -all within 10 minutes of GRC.
- Fully-trained, experienced workforce with all necessary skills for work in aeronautical and satellite communications; including modeling/simulation, analysis, hardware development, flight planning and operations, task management

UAS Integration in the NAS C2 Flight Test Personnel



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

Command and Control Subproject

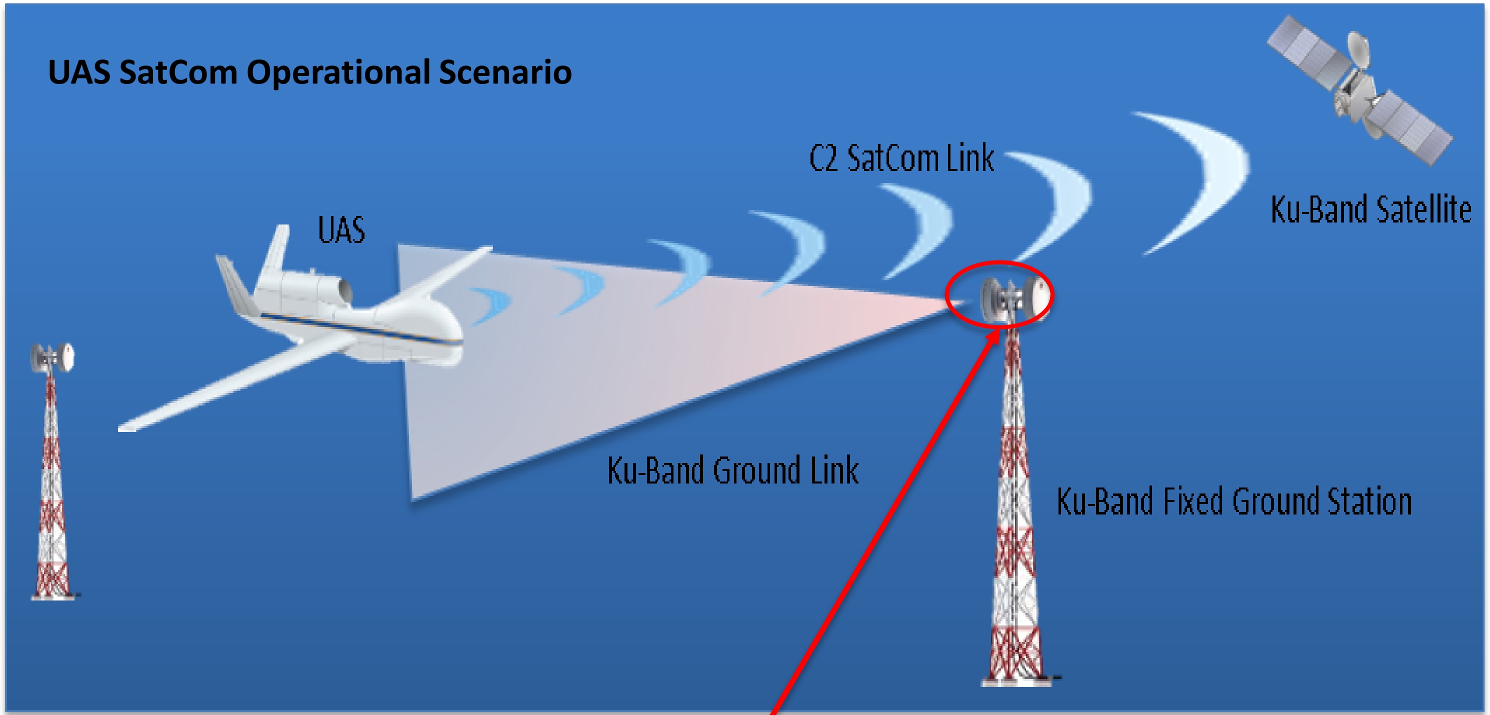
Satellite Based Command & Control

Dennis Iannicca

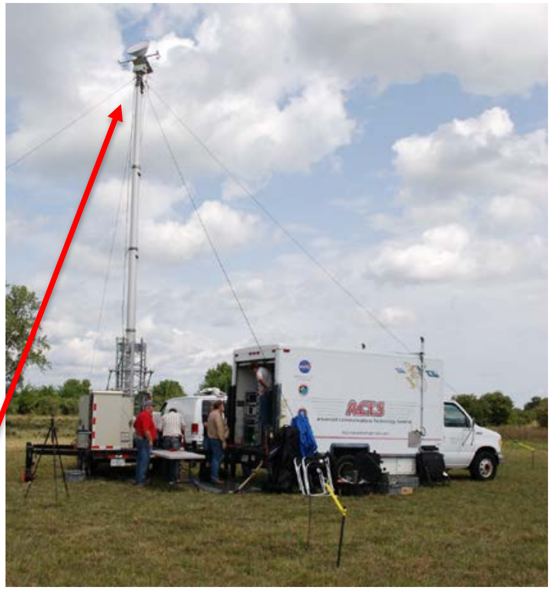
Satcom Lead, C2 Subproject

Ku-Band Spectrum Interference Testing

Objective: To support the FAA Spectrum Office and ITU to validate models and determine the extent of interference between a satellite-based Ku-Band C2 UAS system and fixed, point-to-point, Ku-Band earth stations still operating outside the United States.



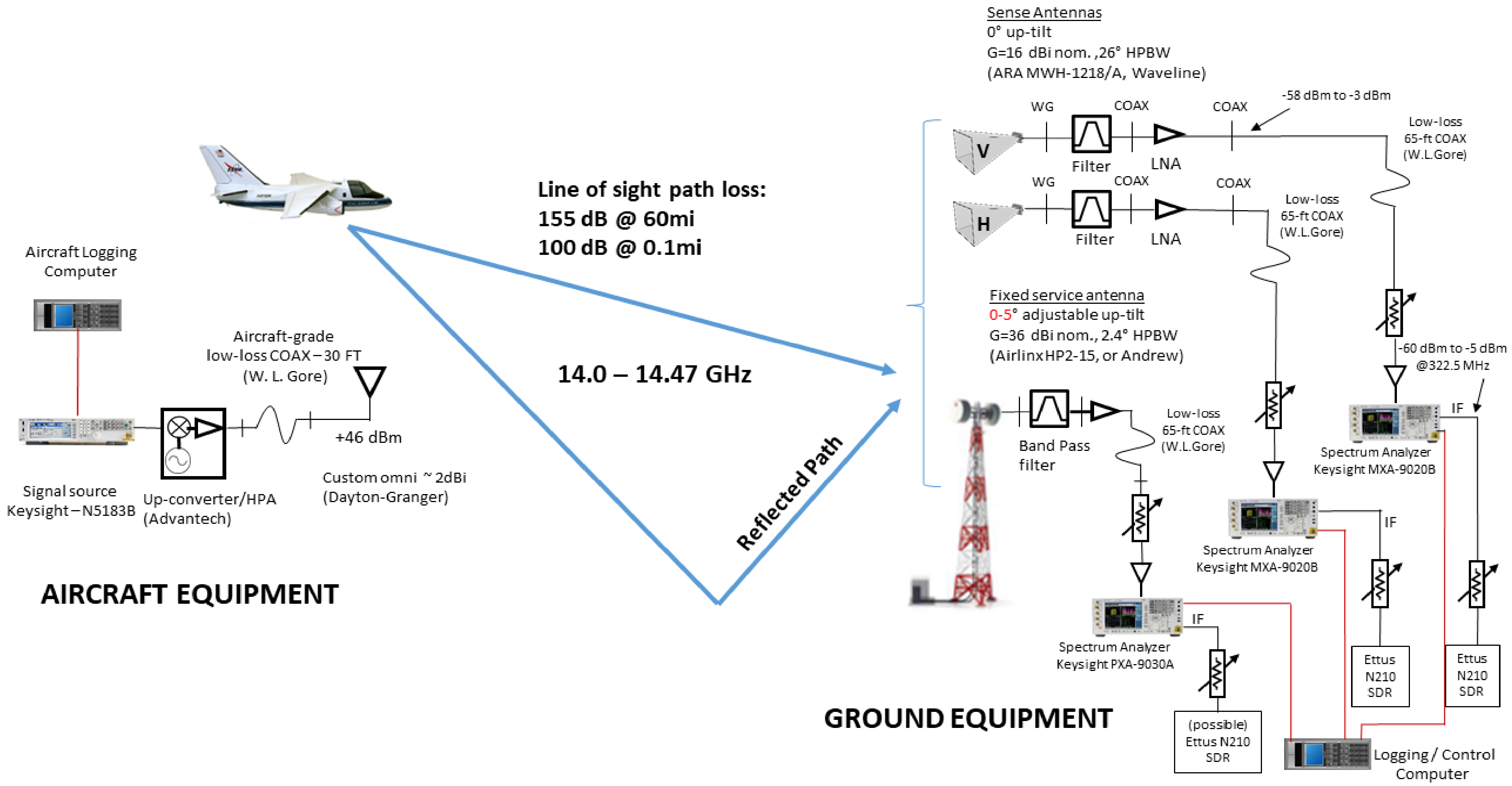
Interference Point



Ku Interference Ground Station at NASA Plum Brook Station

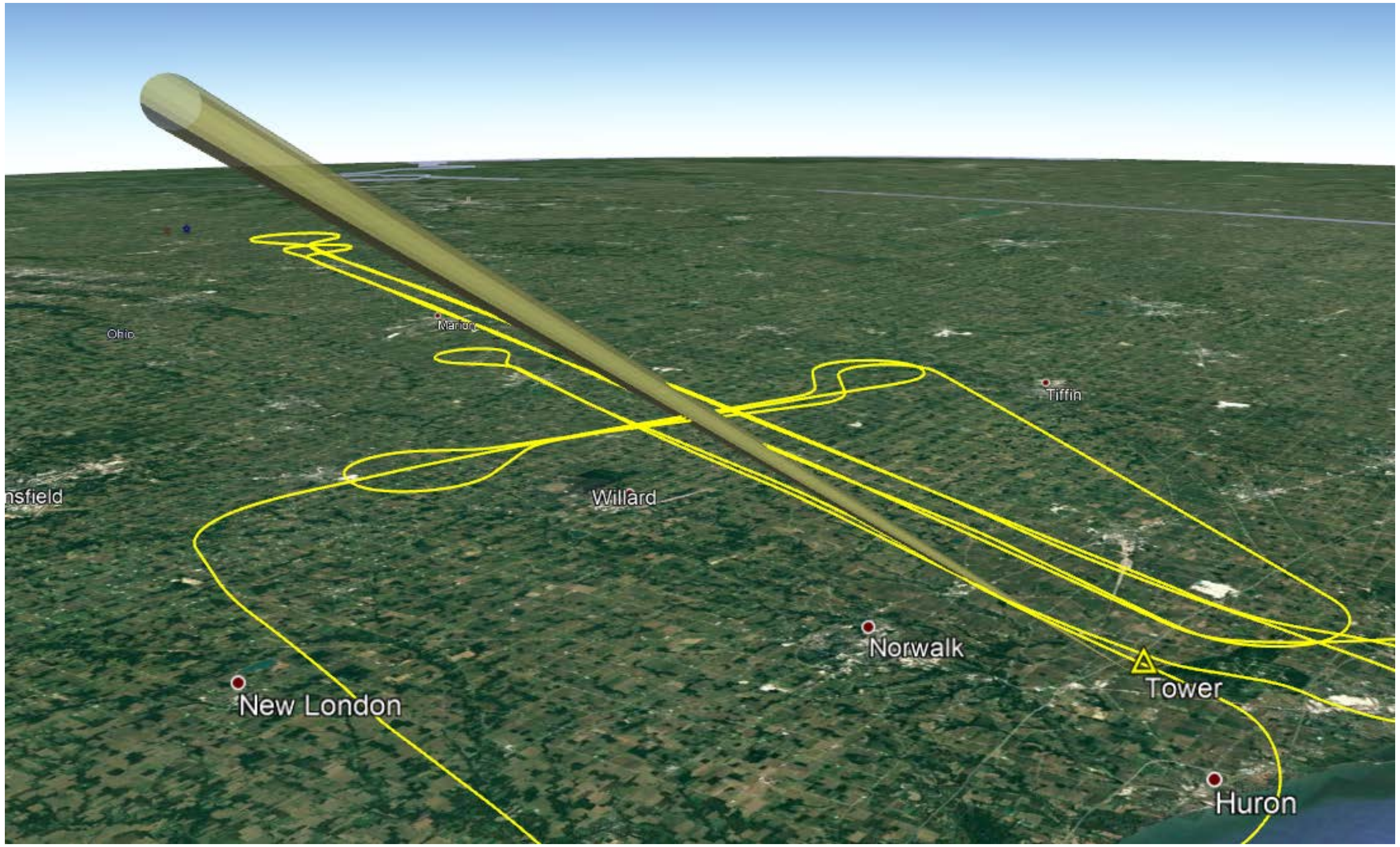
Ku-Band Multi-Polarization Receive Antennas

Ku-Band Spectrum Interference Flight Testing



Propagation test system primary components

Ku-Band Spectrum Interference Flight Testing



Perspective view of flight track, showing simulated main beam of 2' parabolic reflector antenna

Flight tests conducted August 30-31, 2017 in north central Ohio:

- 100 nautical mile flight corridor
- 14 individual flight segments
- 3 separate test altitudes
- 3 antenna elevation angles,
- 3+ hours of total data acquisition time

Calibrated, time-stamped, horizontally and vertically-polarized received signal strength measurements were compiled and provided to ITU analysts.

This flight data is one part of the comprehensive flight data package required by the World Radio Conference for the pending Ku/Ka-Band UAS C2 spectrum allocation decision.

C-Band SATCOM UAS C2 Design Study

Objective

Develop a conceptual system design of a C2 SATCOM System consistent with performance requirements specified in RTCA SC-228 documentation (DO-362). The system must operate within C-Band SATCOM frequencies allocated for UAS (5030-5091 MHz) and not interfere with terrestrial line-of-sight C2 systems operating within the same frequency range.

Problems

- No satellite systems operated within the AMS(R)S C-Band frequency allocation (5030-5091 MHz) that could be used to validate compatibility with terrestrial UAS C2 system.
- If the C-Band allocation for UAS C2 SATCOM continued to remain unexplored and unused a future World Radio Conference (WRC) could choose to repurpose the spectrum allocation for other uses.

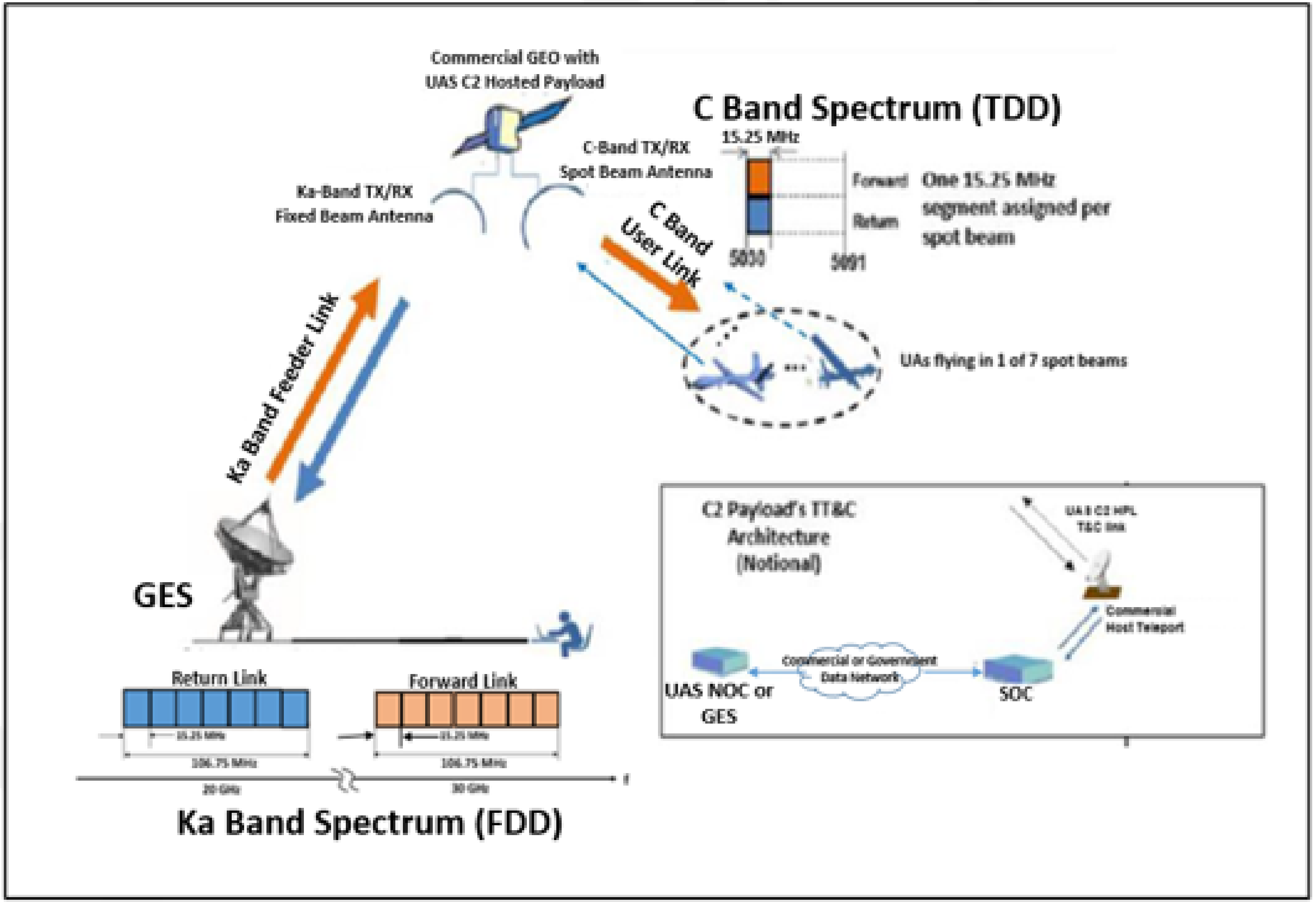
Goals

- Defend the allocation of C-Band frequencies for SATCOM C2 communications
- Assist RTCA SC-228 WG2 with MOPS and MASPS development

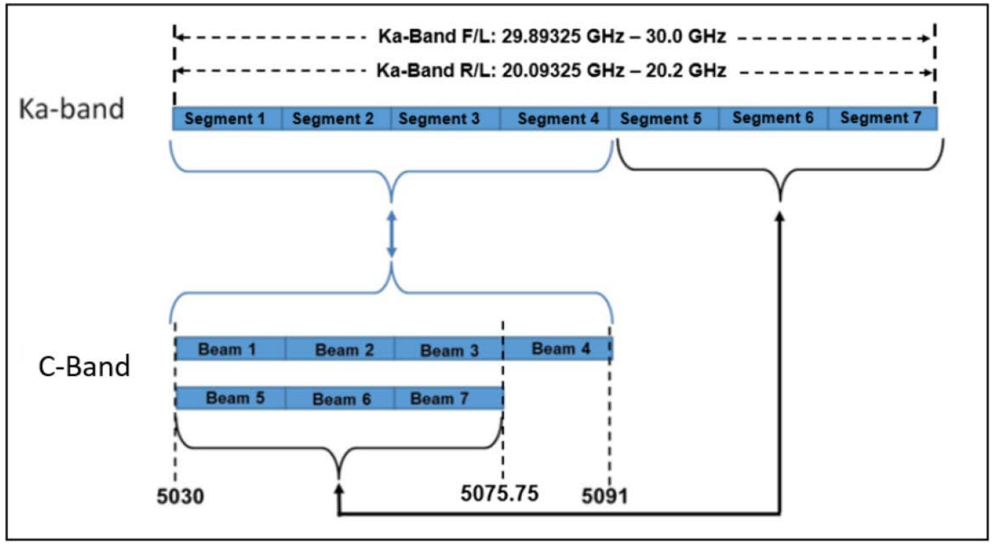
Approach

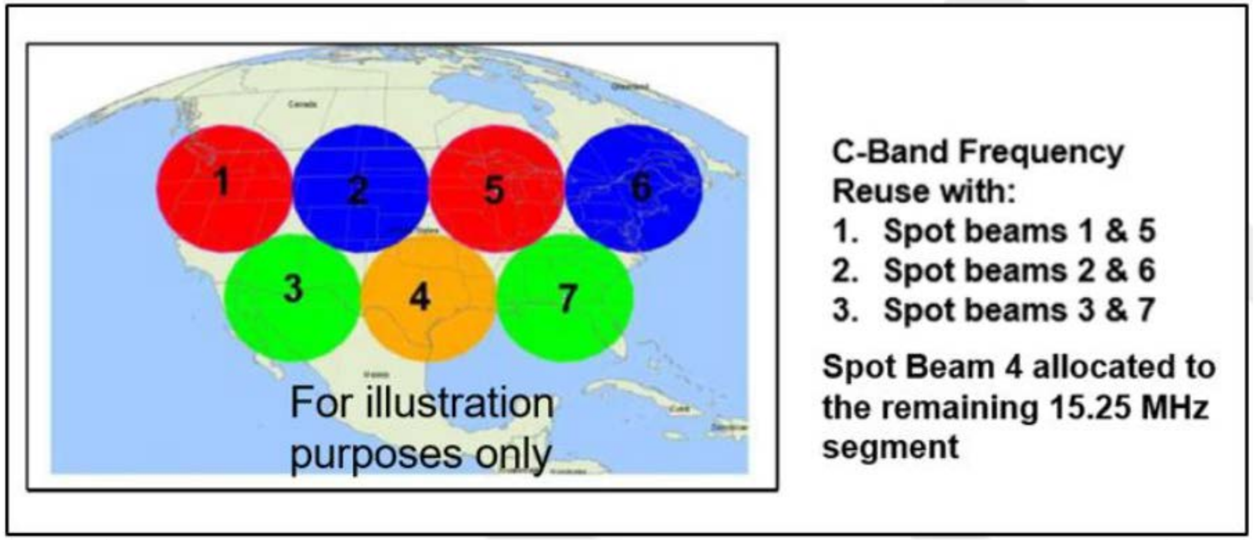
A series of studies was conducted under contract by LinQuest Corporation to iteratively develop a conceptual C2 SATCOM system utilizing the allocated C-band frequency range.

C-Band SATCOM UAS C2 Design Study

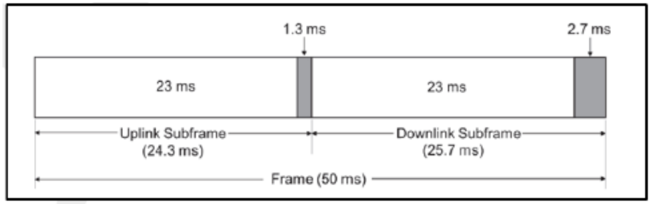


C-Band SATCOM UAS C2 Design Study

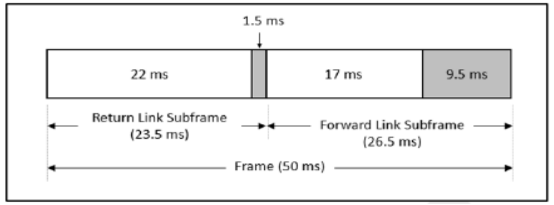




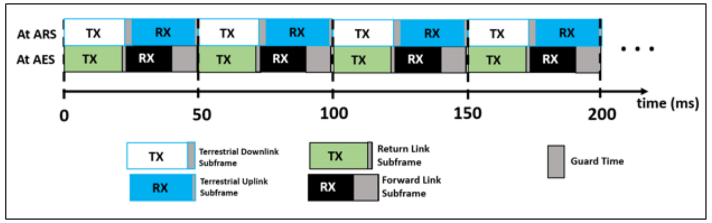
Terrestrial UAS C2 TDD Frame Structure

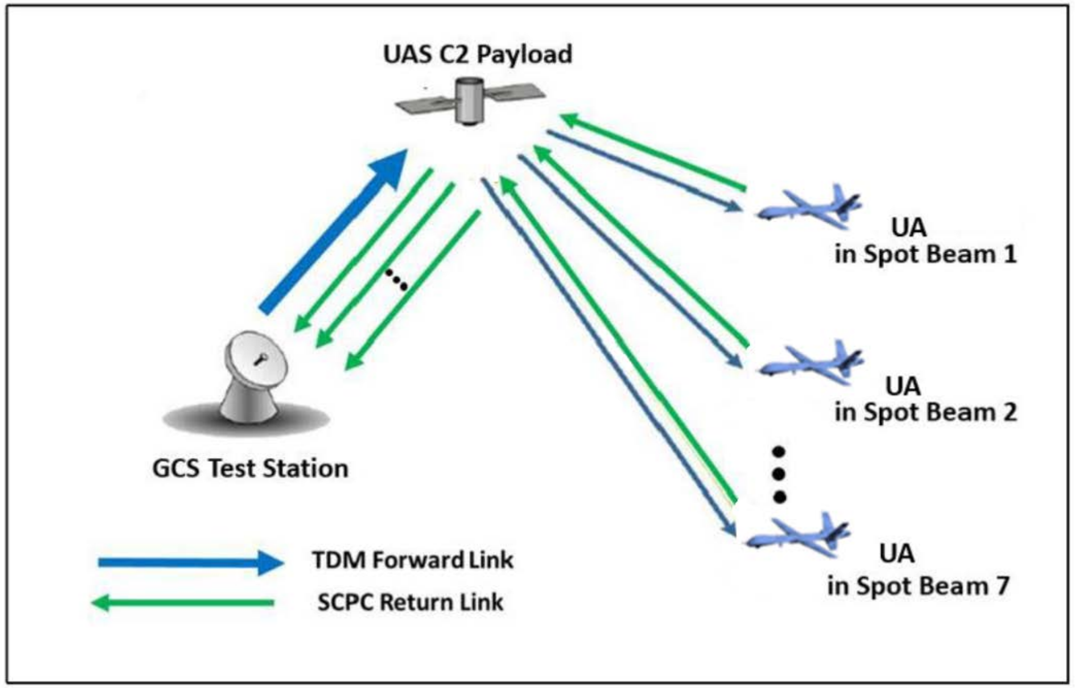


Satcom UAS C2 TDD Frame Structure

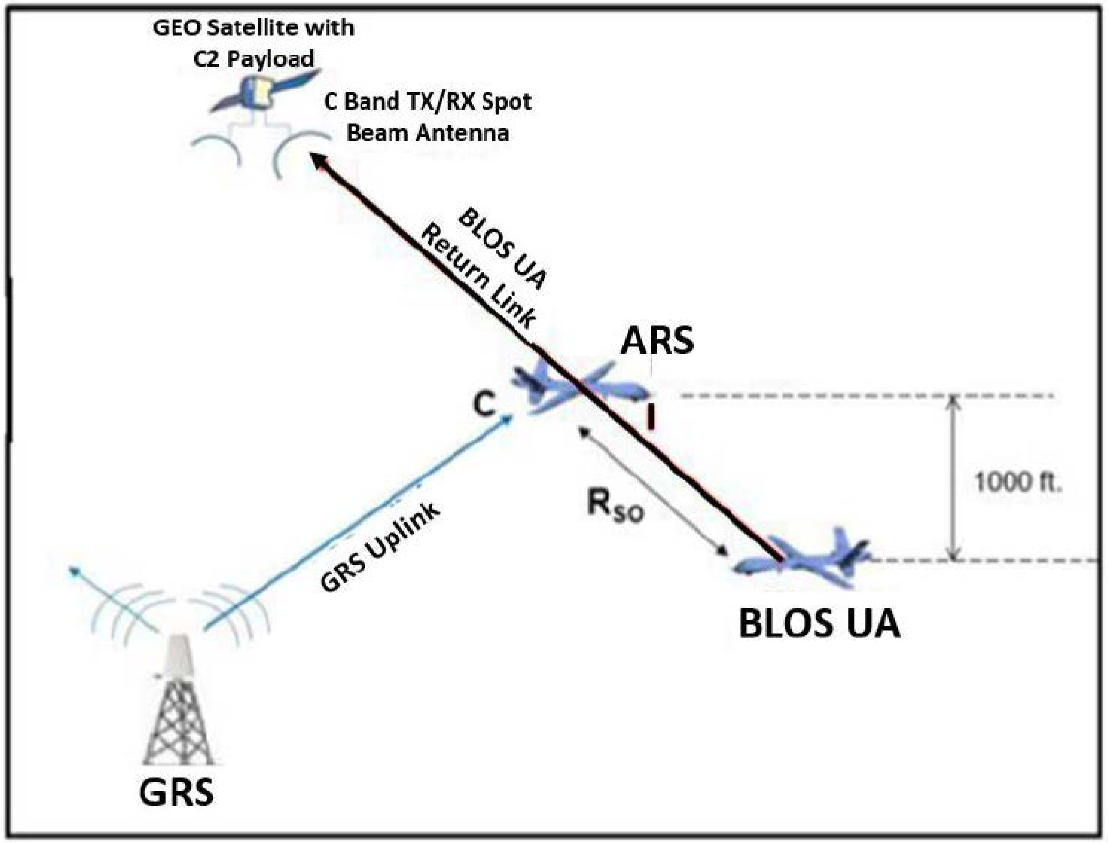


Synchronization between Terrestrial and Satcom Frames

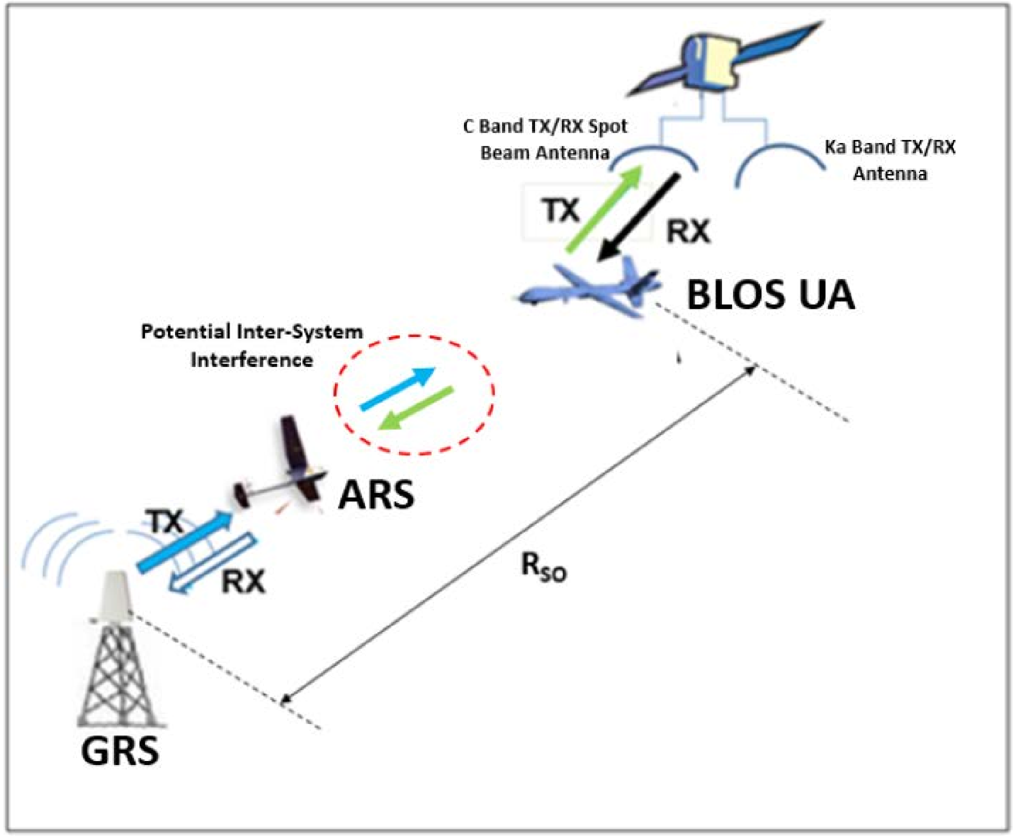




Satcom-Terrestrial Interference Analysis



Potential BLOS UA-to-ARS Interference Scenario



BLOS UA and GRS Potential Inter-System Interference Scenario

C-Band SATCOM UAS C2 Design Study

Output

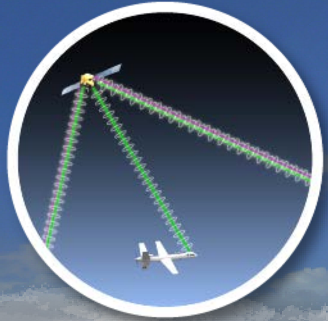
- C-Band SATCOM C2 Conceptual Design Report
- DO-362A Appendix G – C Band Satellite Link Compatibility

Leave Behind Capabilities

- Modeling and Simulation Tools for interference analysis

Lessons Learned

- Collaborate Early and Often



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

Command and Control Subproject

Urban Air Mobility Command, Control and Communications Study

Israel Greenfeld

UAM C3 Study Lead, C2 Subproject

UAM Overview 1

UAS Integration in the NAS

- Remotely piloted
- Beyond line of sight
- Above 400 feet
- Heavier than 55 pounds
- Open airspace

UAM

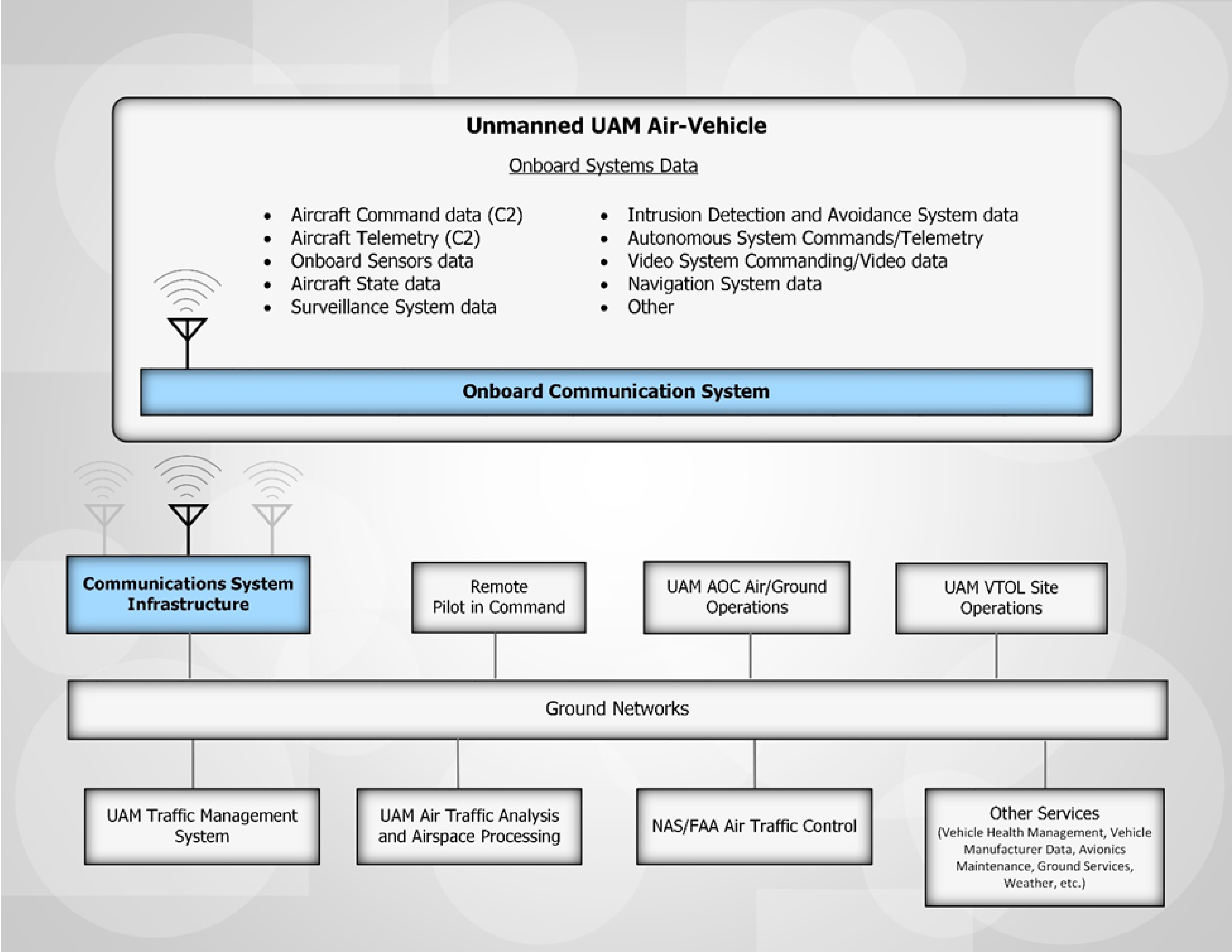
- Remotely piloted
- Beyond line of sight
- Above 400 feet
- *Much heavier than 55 pounds*
- *Urban airspace*
- Transport passengers

Safety

- People
- Hundreds of feet above the ground
- Flying over buildings and streets
- Reliable, robust, and secure command, control and communications (C3)

UAM Overview 2

UAM Overview 3



UAM Overview 4

	Manned		Unmanned	
	Phase 1	Phase 2	Phase 3	Phase 4
Pilot	Expert Pilot	Skilled Pilot	Ground Pilot	No Pilot
Autonomy	None	Limited	Partial	Full
C2	None	Low	Medium	High

Major Successes—Accomplishments 1

UAM C3 Task

Set of studies

Communications system tests

Modeling & Simulation

Planned Studies

Concept of Operations (C2)

Seed Requirements

Technology Assessment

Technology Gaps

LTE Cell Phone Tests

Receivers procured

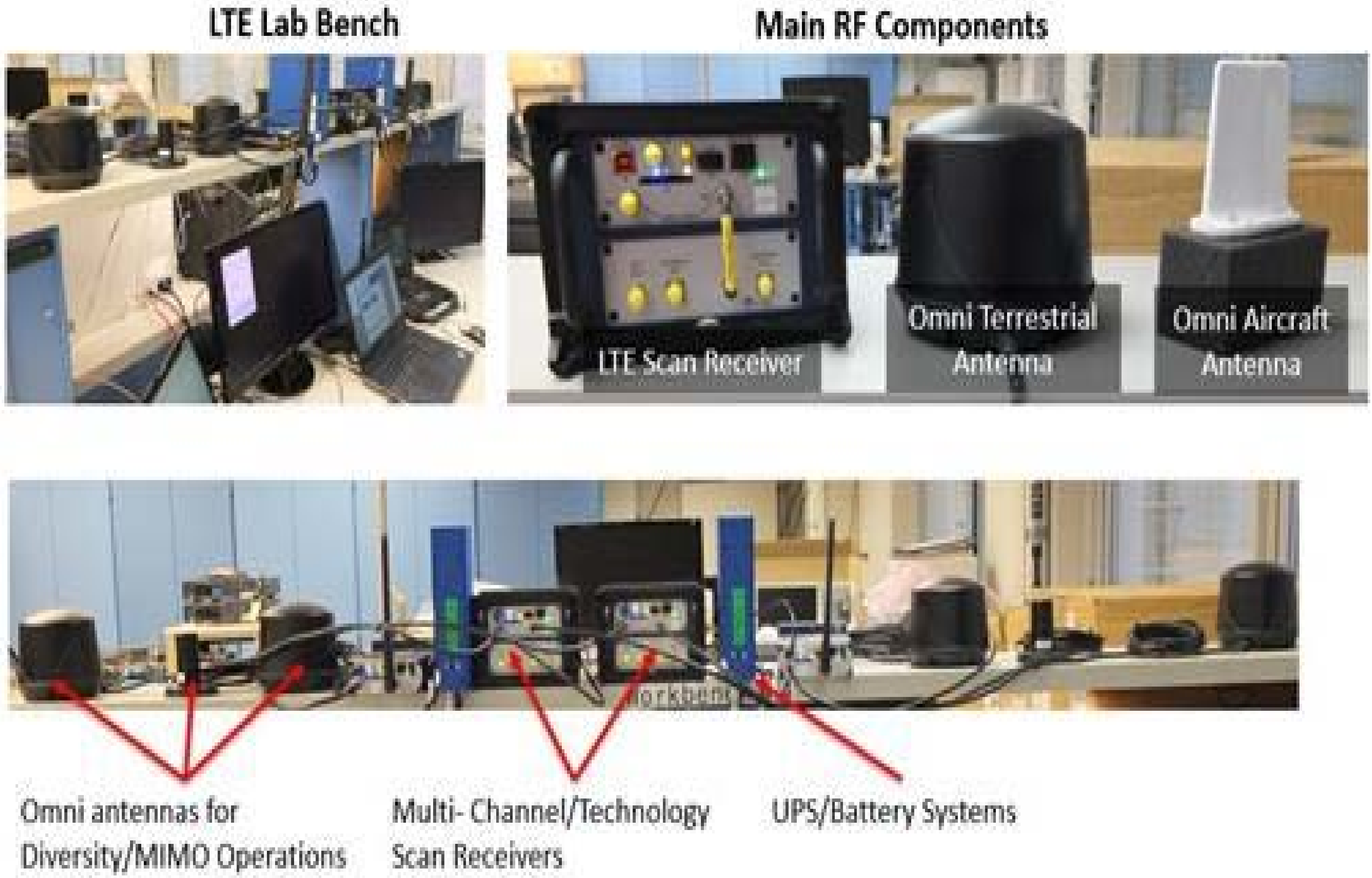
Tested in lab

Drive tests to discover existing channels

Plan flight tests.

A flight test is the only way to determine signal availability at altitude.

Major Successes—LTE 1



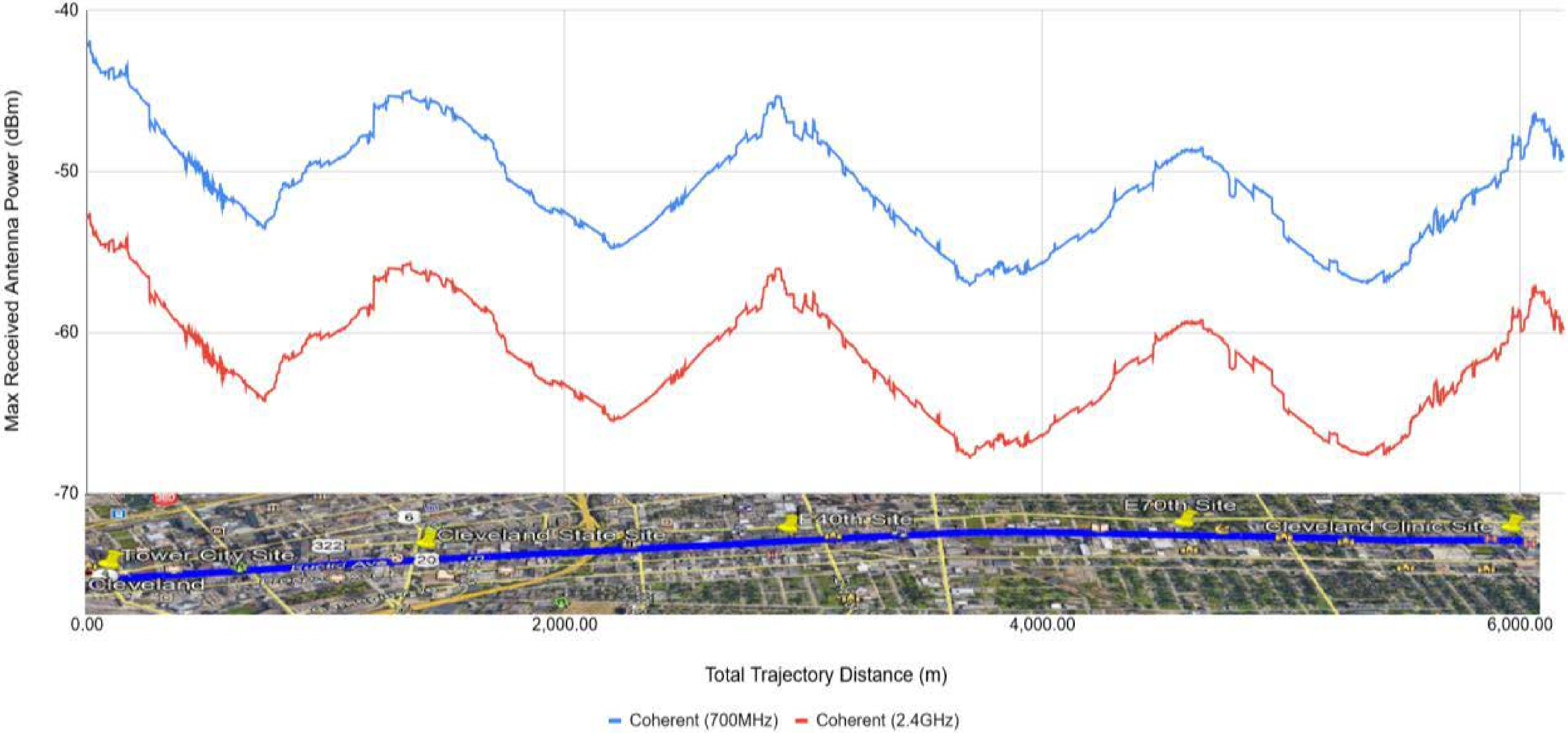
Major Successes—LTE 2

Major Successes—Accomplishments 2

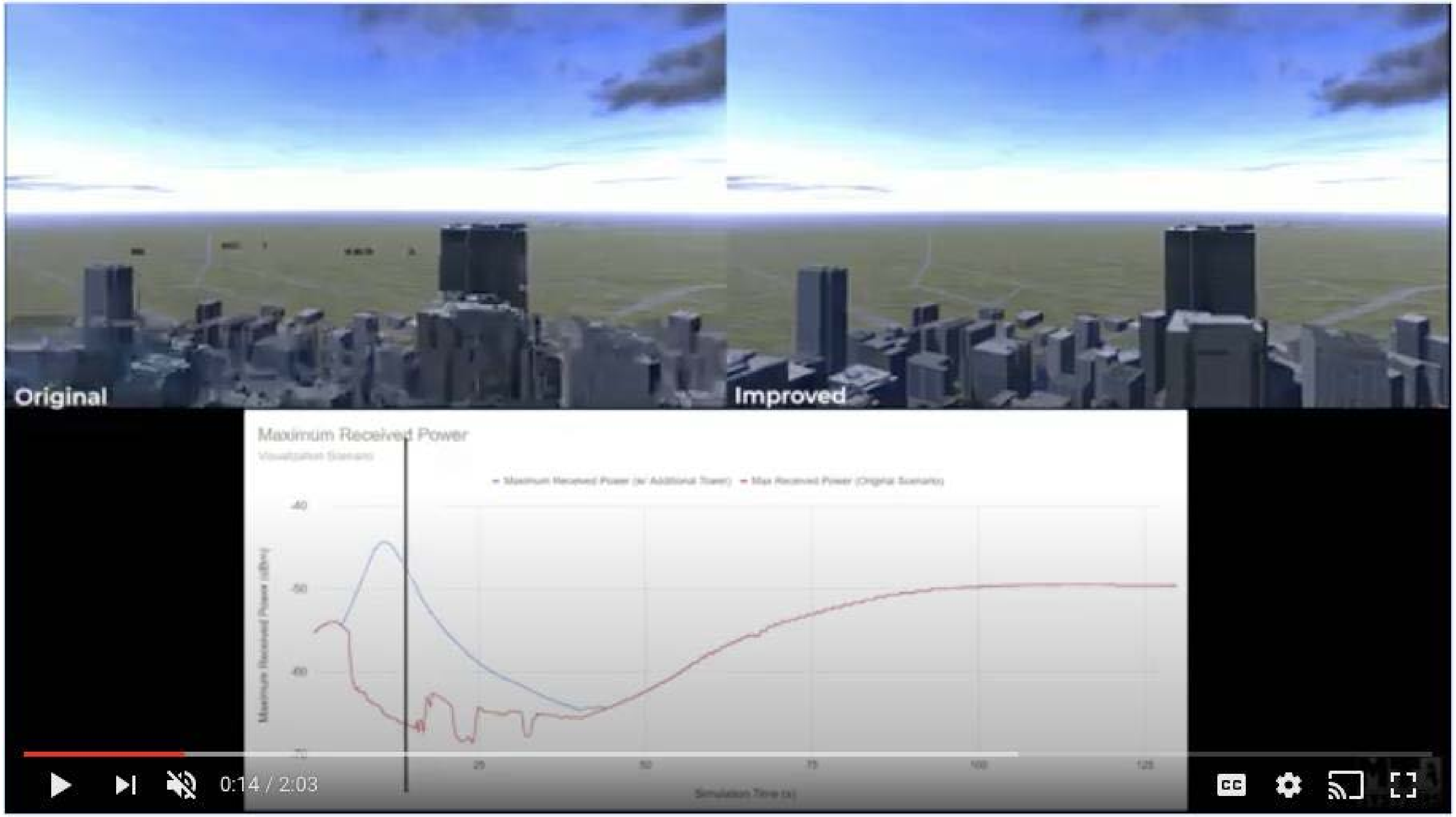
- **Modeling and Simulation**
  - Based on the Glenn UAM C2 Con Ops
  - Models and simulations and scripts were developed
  - Frequency, Altitude, Visualization
    - Test proposed technologies
    - Estimate future system performance
    - Analyze whether proposed technology meets operational needs

Interplay between Modeling and Testing

Major Successes—Modeling and Simulation 1



Major Successes—Modeling and Simulation 2



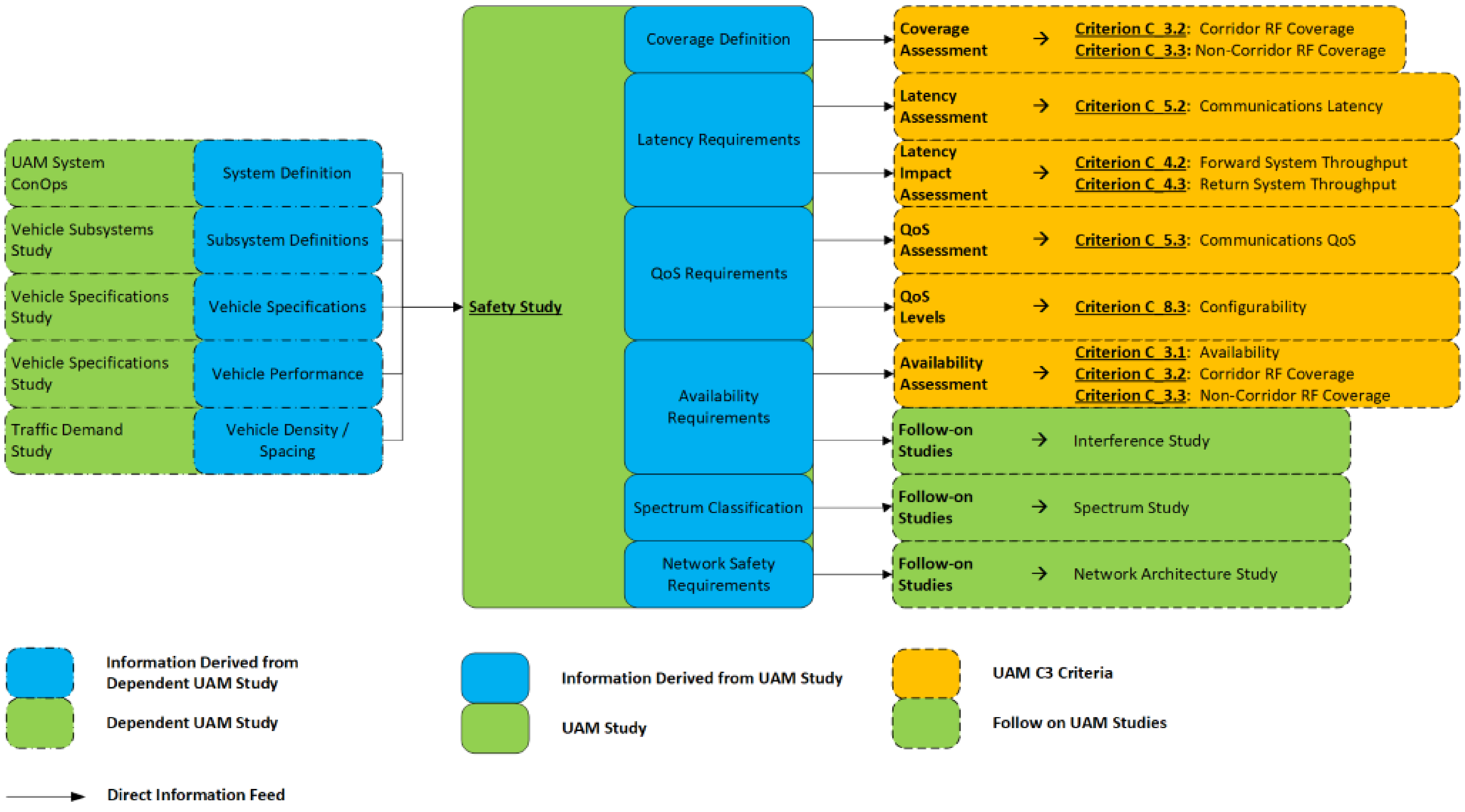
Major Successes—Impacts 1

- **UAM C3 Studies**
  - Technology assessment could not be completed
  - *Policies, requirements, and standards specific to UAM C3 operations have not been promulgated*
  - Identified missing information
  - Studies needed for generating information
  - Stakeholders likely qualified to produce information

- **Missing Information:**
  - Assigned spectrum, power allowed, vehicle specifications, vehicle subsystems, signal QoS, signal security, sufficient signal, ground radio requirements, traffic volume, traffic management, vertiport rules, height above ground/buildings, distance from buildings, speeds, separations, free path or corridors, weather limitations, emergency coverage

- **Studies Needed:**
  - UAM System Con Ops, Traffic Demand, Vehicle Specifications, Vehicle Subsystems, Safety, Network Architecture, Security, Throughput, Spectrum, Interference

Major Successes—Impacts 2



Major Successes—Impacts 3

- **LTE Cell Phone Tests**
  - Flight tests cancelled because COVID-19
  - LTE infrastructure in northeast Ohio region has changed
    - Redo ground drive tests
  - Restart Flight Operations preparations

LTE viable?

- **Modeling and Simulations**
  - LTE (ground, flight) channel data
    - Verify models
    - Feedback/guidance for follow-on flights
  - Combine simulations with visual environment
    - Intuitive understanding of communications quality

Lessons Learned

- **UAM C3 Studies**
  - Crowded city, land/take off from buildings, newly designed vehicles, piloted remotely

    Safety challenges
  - New technology arena must have policies, requirements, and standards

    All playing to same sheet of music

- **LTE Cell Phone Tests**
  - Standard LTE receivers are not intended for full bandwidth sensing
    - Most parties want to check one or a few specific channels
  - NASA Glenn wanted to test the full range
    - Work with the vendor to obtain a more dynamic receiver

- **Modeling and Simulations**
  - Interplay between data collection, testing and system simulation, indispensable
    - Better understanding that either alone would generate

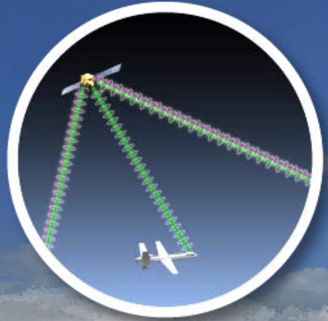
Leave Behind Capabilities

- **UAM C3 Studies**
  - Roadmap for UAM C3 policies and regulations
    - Recommended UAM C3 studies
    - Potential studies stakeholders
- **LTE Cell Phone Tests**
  - LTE receivers, ground/flight antennas, power supplies
  - Post processing of collected channel band data
  - Experience with LTE receivers and channel identification
  - Planning for a flight test
- **Modeling and Simulations**
  - Simulation scripts available for further analysis
  - Message that simulations need to go hand in hand with testing

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

Technical Interchange Meeting

Break for Lunch



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

Detect and Avoid Subproject Overview

Jay Shively
Subproject Manager, DAA Subproject

Outline

DAA overview of efforts across phases

- DAA technical challenge
- Initial state of the art
- Desired end state
- Stakeholders
- Focus of both phases
- Team structure
- Actual end state
- Leave Behind Assets

Initial State of the Art

- Industry demand
  - Military, civil ops, large UAS
- No certification pathway or standards
- No well accepted CONOPS
- COA's - hard to get, difficult to apply for, time consuming

NASA

- Access 5 (2004–2006)

RTCA

- SC-203 (2004–2012)

ICAO

- RPAS Study group (2008–2013)

Reaching Critical Mass about 2012

UAS Integration in the NAS

- 2012–2020

DAA, C2

- SC-228 (2013–present)

UAS Integration office (AUS)

- FAA (2012–present)

RPAS Panel

- ICAO (2014–present)

Detect And Avoid Technical Challenge

- Develop Detect and Avoid (DAA) operational concepts and technologies in support of standards to enable a broad range of Unmanned Aircraft System (UAS) that have Communication, Navigation, and Surveillance (CNS) capabilities consistent with Instrument Flight Rules (IFR) operations and are required to detect and avoid manned and unmanned air traffic

"Routine File and Fly Access"

- Community challenge
- On-going
- Technical, regulatory, community progress

See and Avoid: FAR Sec. 91.113

General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

Piloted “see and avoid” = UAS “detect and avoid”

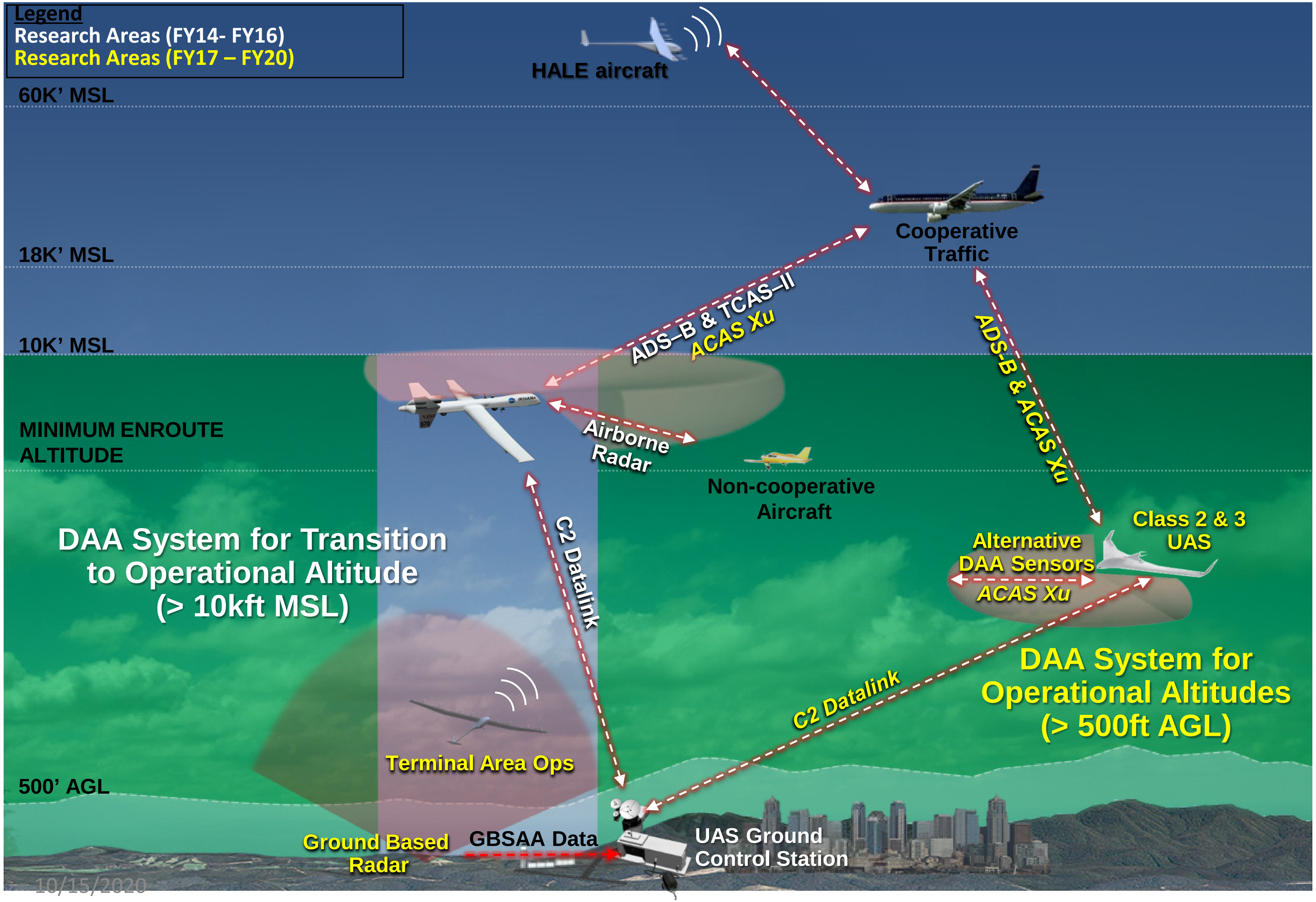
Pilots vision replaced by sensors (on- or off- board or both)

Pilot judgment of well clear = mathematical expression of well clear

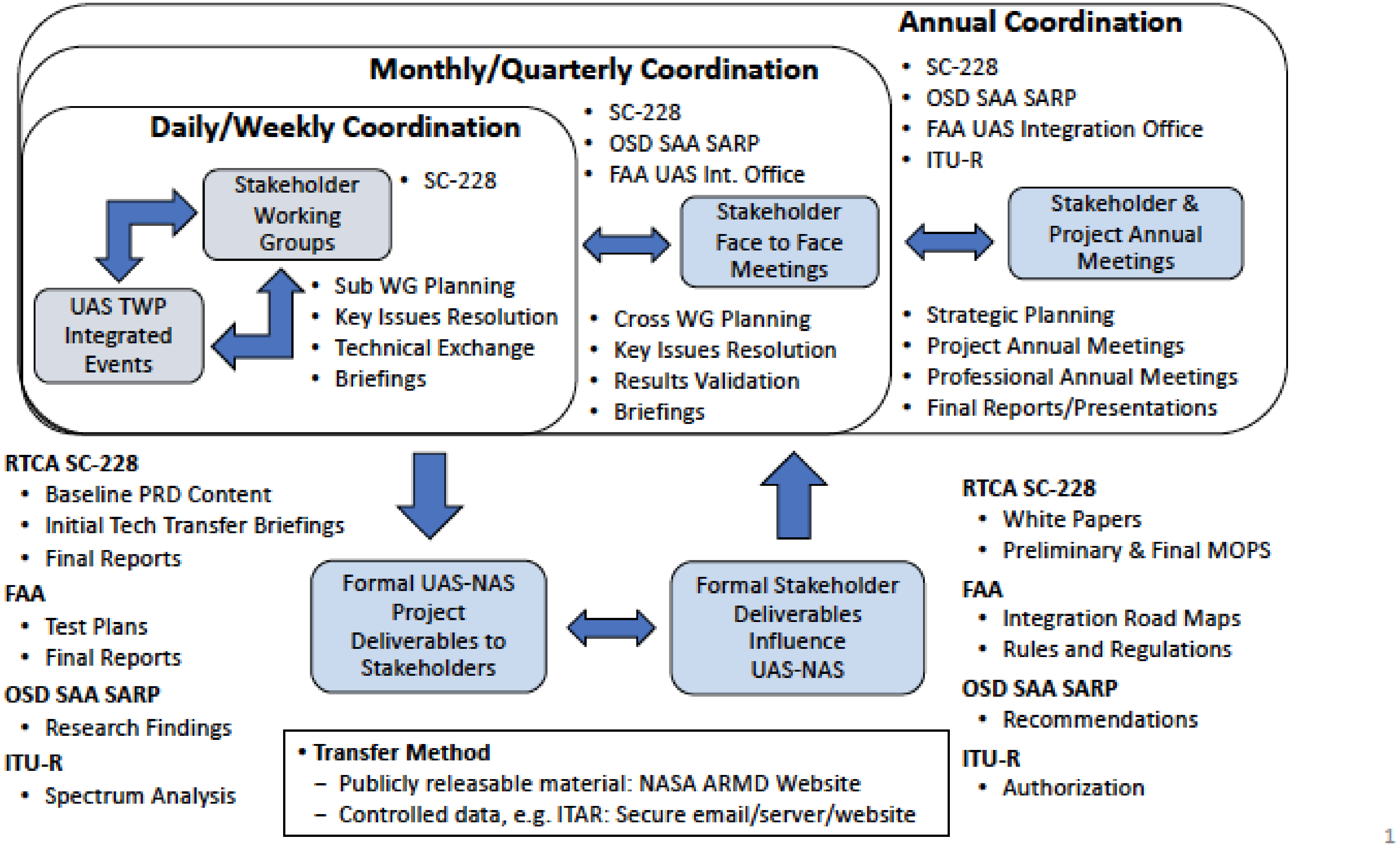
Phase 1:
Horz Miss Distance = 4000ft; Vert Miss Distance = 450ft; modTau = 35sec

Phase 2:
Non-coop horizontal = 2200, vertical = 450, no tau
Terminal horizontal = 1500, vertical = 450, no tau

DAA Operational Environments



Stakeholders



- FAA
- DoD
- Industry
  - OEMs
  - Operators
- RTCA
- Pilots' associations
- ATC
- Public

Phase 1

- Ikhana with large General Atomics RADAR
- TSO-C211 (DAA) and TSO-C212 (ATAR)
- No Chase COA

TC-SAA: SAA Performance Standards

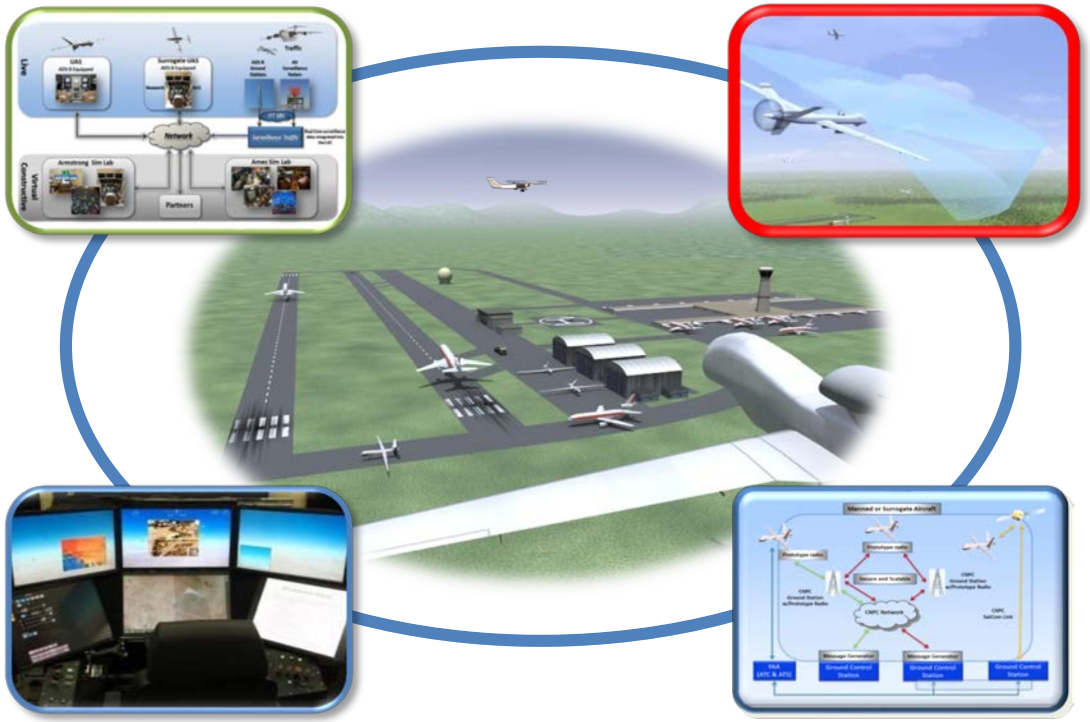
RT1 - UAS Integration

- Airspace integration procedures and performance standards to enable UAS integration in the air transportation system

TC-SAA - Provide research findings to develop and validate UAS Minimum Operational Performance Standards (MOPS) for sense and avoid (SAA) performance and interoperability

TC-ITE: Integrated Test & Evaluation

TC-SAA: Sense and Avoid Performance Standards

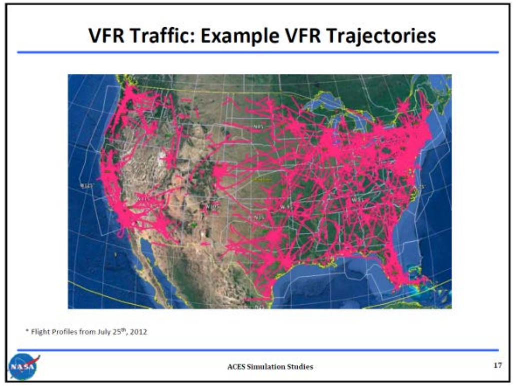


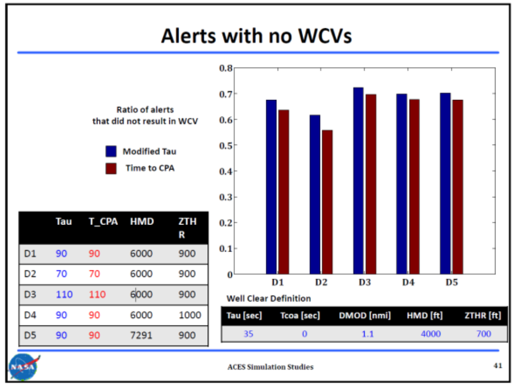
TC-HSI: Human Systems Integration

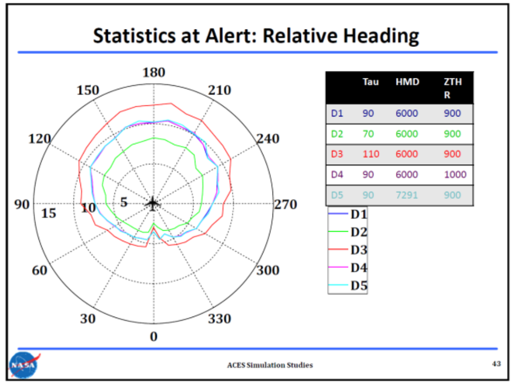
TC-C2: Command & Control Performance Standards

Well Clear Metric and Definition Study

- **Research Activity Objective:**
  - Gather data and develop recommendations for a quantified definition of Well Clear using cooperative Visual Flight Rule traffic that meets target level of safety requirements and NAS-interoperability considerations





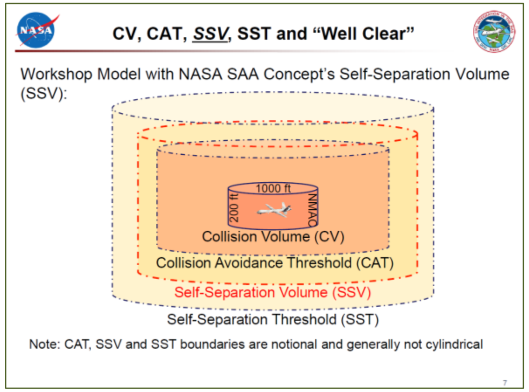


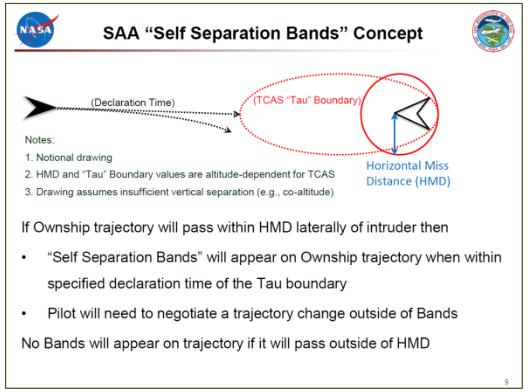
- **Significant Results, Conclusions, and Recommendations:**
  - A minimum 5 nmi range to avoid missed detections
  - 99% of the alerts lie within 10 nmi with a 90 second modified tau alerting threshold
  - Horizontal miss distance and vertical distance criteria will have the largest impact on encounter rates and the closer two aircraft are the more sensitive the encounter rate is to these parameters
  - ~70% of alerts generated using modified Tau or time to co-altitude criteria did not lead to a Well Clear violation

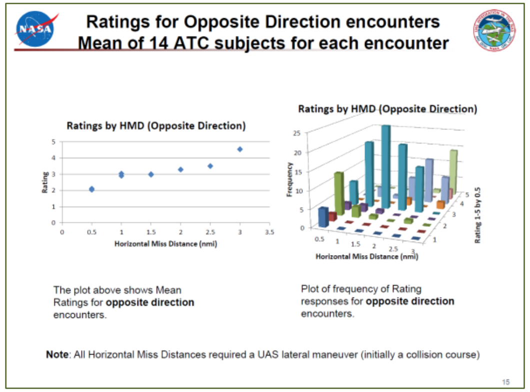
Results Contributed to Well Clear Separation Standard for DAA MOPS

UAS Controller Acceptability Study (CAS)1 HITL

- **Research Activity Objective:**
  - Evaluate the impact of UAS SAA self separation maneuvers resulting for different SAA Well Clear volumes on controller perceptions of safety and efficiency







- **Interim Significant Results, Conclusions, and Recommendations:**
  - A horizontal miss distance of ~1.5 nmi appears to be optimal for ATC acceptability (away from the airport vicinity)
  - Horizontal miss distance of 1.5 nmi is 150% larger than the TCAS resolution advisory horizontal miss distance for all airspace below Class A, and 136% larger in Class A
  - 500' IFR-VFR vertical separation (with no vertical closure rate) was universally acceptable during debrief sessions
  - Air traffic controllers thought the SAA integration concept as presented was viable

Results Contributed to Well Clear Separation Standard & ATC Interoperability for DAA MOPS

TC-HSI: Human Systems Integration

RT1 - UAS Integration

- Airspace integration procedures and performance standards to enable UAS integration in the air transportation system

TC-HSI - Provide research findings to develop and validate human systems integration (HSI) ground control station (GCS) guidelines enabling implementation of the SAA and C2 performance standards

TC-ITE: Integrated Test & Evaluation

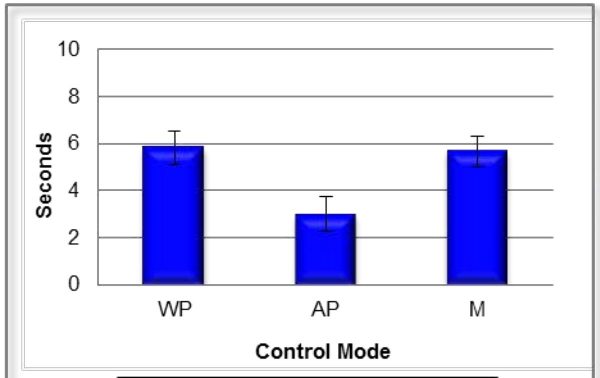
TC-SAA: Sense and Avoid Performance Standards

TC-HSI: Human Systems Integration

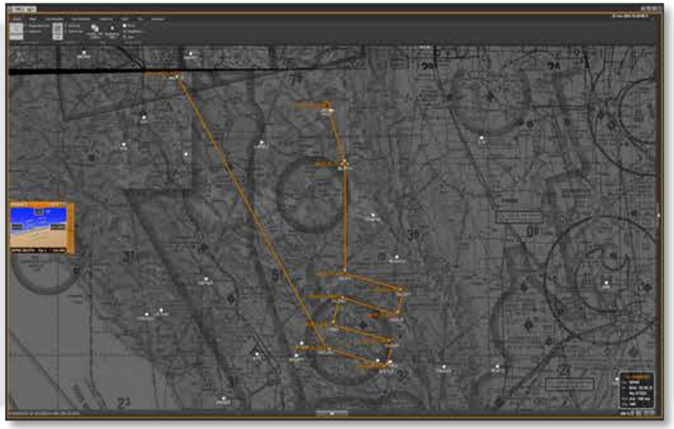
TC-C2: Command & Control Performance Standards

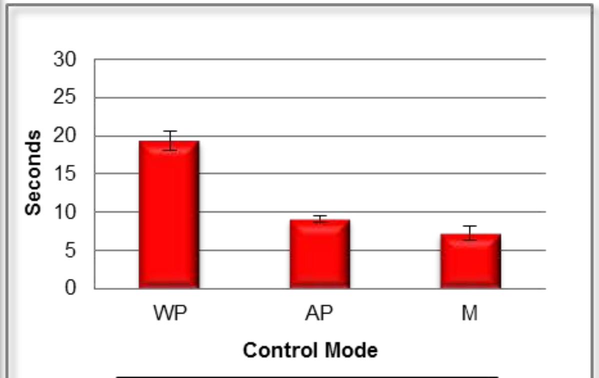
Full-Mission Simulation 1: Levels of Automation

- **Research Activity Objective:**
  - Evaluate pilot response to various events while operating under various levels of UAS automation



Pilot Response Time





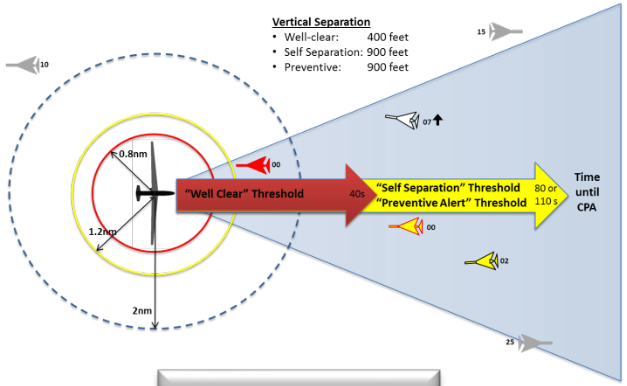
Pilot Edit Time

- **Significant Results, Conclusions, and Recommendations:**
  - Waypoint-to-waypoint control mode demonstrated significant deficits in all of the pilot measured response components compared to Autopilot and Manual control modes
  - Autopilot and Manual control modes had significantly shorter compliance times overall than Waypoint-to-waypoint control mode implying a potential need for a function or mode for quick input to respond the alerts or ATC instructions
  - Initial database of expected pilot response time distributions

Results Contributed to GCS Automation Guidelines/Requirements for DAA & C2 MOPS

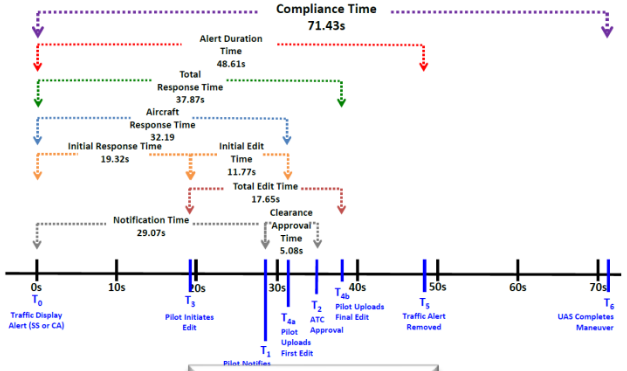
Part-task Simulation 4: SAA Pilot Guidance

- **Research Activity Objective:**
  - Evaluate efficacy of minimum information SAA displays, potential improvements for advanced information features and pilot guidance, and integrated vs stand-alone GCS SAA displays



SAA Thresholds

GCS Display



Timeline

- **Interim Significant Results, Conclusions, and Recommendations:**
  - Consistent advantage seen for Advanced over Basic displays
  - Overall, the Advanced displays had a faster Total Response Time compared to Basic
  - There were no significant differences between the Standalone and Integrated condition
  - Implications to Well Clear Violations and DAA Timeline need to be evaluated

Results Contributed to GCS Minimum Information Guidelines/Requirements for DAA MOPS

Phase 2

FOCI

- Low Space, Weight and Power (SWaP) Sensors
- Smaller UAS (class 2 & 3)
- Terminal Area Operations

Tiger Shark with Honeywell RADAR Panels

Flight Test 6

- **Goal: Investigate Low Size, Weight, and Power (SWaP) UAS DAA operations below 10,000 ft**
  - 3 Phases:
    - **RADAR Characterization** – Measure the performance of a prototype Low SWaP non-cooperative sensor developed by Honeywell
    - **Scripted Encounters** – Validate the performance of the non-cooperative DWC
    - **Full Mission** – Measure the human response data in a simulated National Airspace System scenario
- **RADAR Characterization**
  - Prototype RADAR system had insufficient range for DAA operations
- **Scripted Encounters**
  - 70% of encounters were effective with 3.5 nmi surveillance range (compared to about 50% at 2.0 nmi and 2.5 nmi)
  - Maneuvering beyond edge of heading bands increased maneuver effectiveness
- **Full Mission**
  - Zero losses of DAA well-clear logged
  - Slower response times, but more ATC-approved maneuvers
  - Pilots were often unable to respond to Corrective alerts due to limited surveillance range
  - Larger path deviations & more time spent off course
  - Low workload ratings overall
  - Sufficiency of DAA guidance bands rated favorably
  - More conservative on minimally-acceptable RDR during debrief

Contributions to the Community

Phase 1

DO-365
DO-366
Minimum Operating Performance Standards (MOPS) for Air-to Air Radar Detect and Avoid (DAA) Systems

Technical Standard Orders
TSO-C211, Detect and Avoid
TSO-C212, ATAR for Traffic Surveillance

NASA DAA Team Contributions:
- Well clear definition
- Alerting
- Guidance
- Displays
- Reference algorithm
- Significant modeling and simulation

Leave Behind Capabilities

- **Detect and Avoid Alerting Logic for Unmanned Systems (DAIDALUS)**
  - 228 Reference Algorithm
  - DAIDALUS software library is released under the NASA Open Source Agreement and is available in Java and C++ at https://github.com/nasa/daidalus.

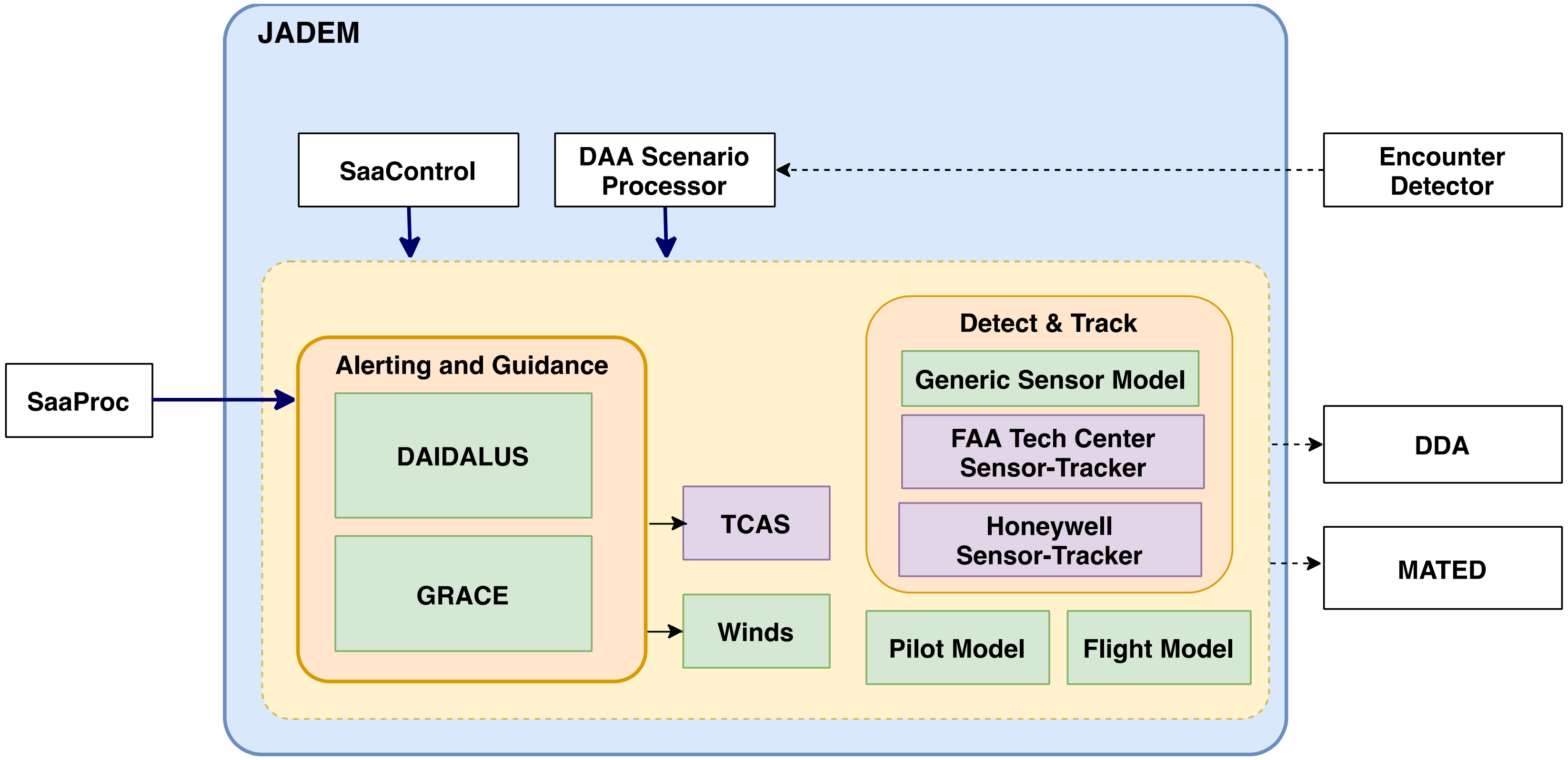
MACS STARS Display

- **NASA version of AFRL's Vigilant Spirit Control Station (VSCS)**
  - Integrated with DAIDALUS and alerting and guidance display features

- **Multi-Aircraft Control Simulation (MACS)**
  - Configurable as an ATC Stars or ARTCC display
  - UAS ground control station developed from modified MACS software

MACS UAS Ground Control Station

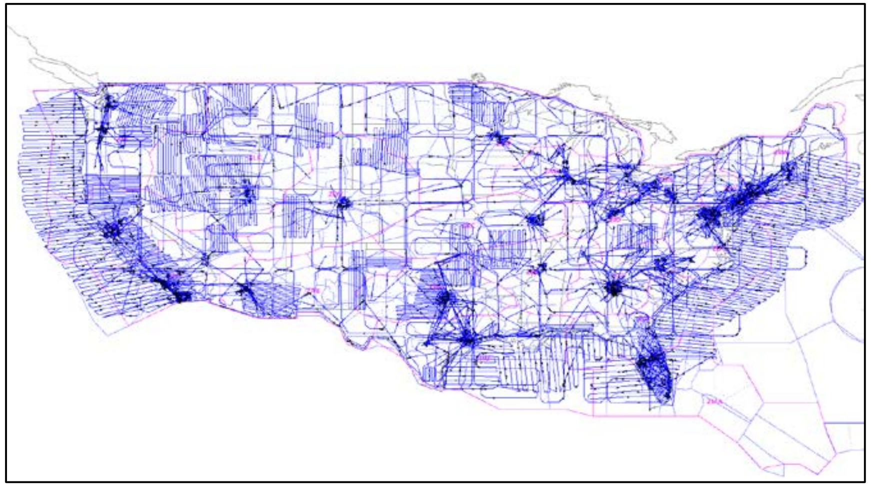
Java Architecture for DAA Extensibility and Modeling (JADEM)

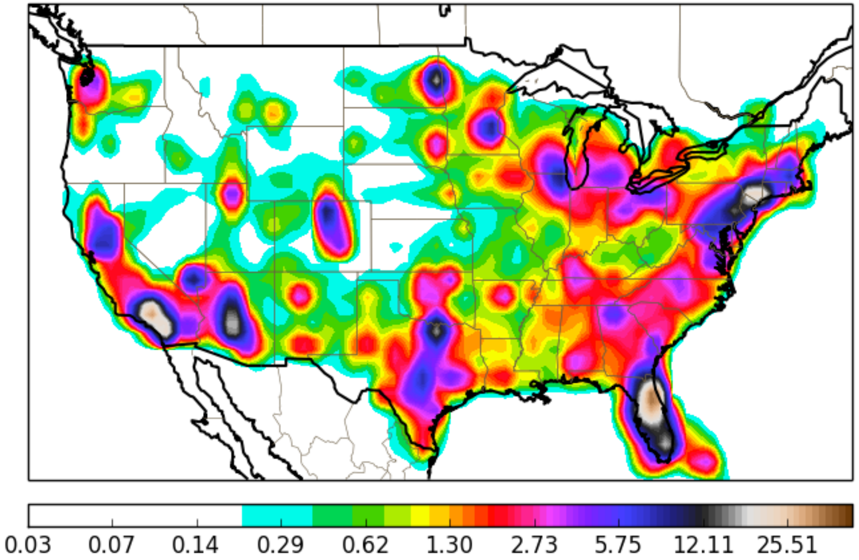


Solid White Box: tool
Solid Arrow: usage
Dashed Arrow: data flow
Green: in-house library
Purple: external

ACES/Encounter Set

- 100,000 representative pairwise DAA encounters between UAS and visual flight rules (VFR) traffic
- 20,000 hours of projected UAS missions in one day, simulated by Airspace Concept Evaluation System (ACES)
- UA speed range from 40 to 291 KTAS
- VFR traffic recorded by radar across continental U.S.

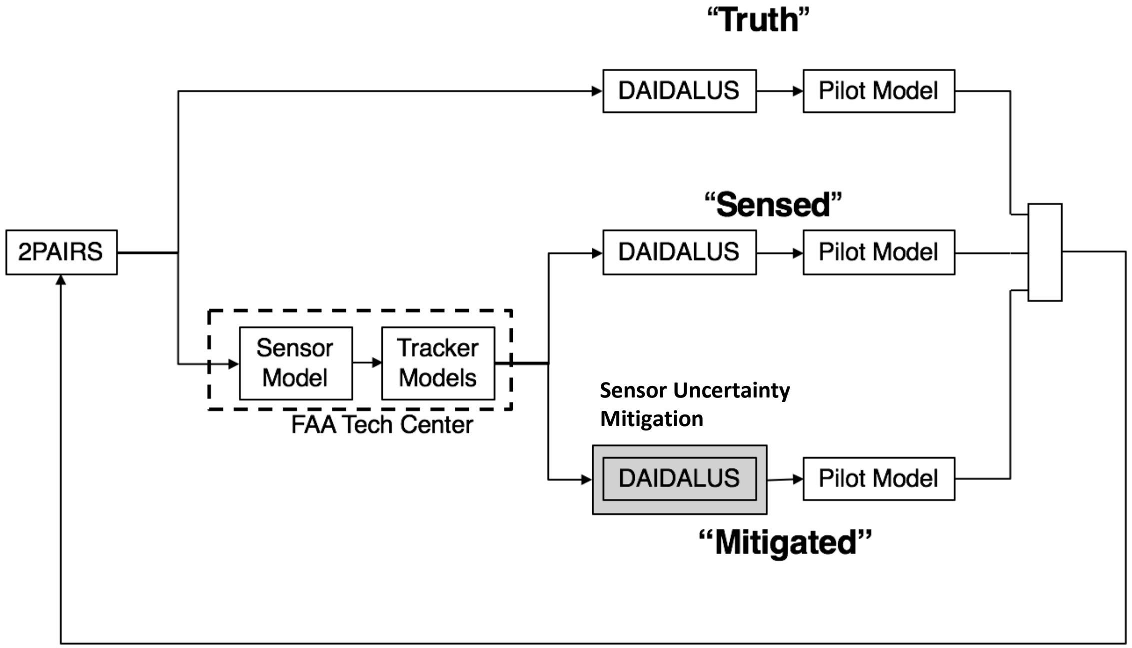




Average counts of VFR flights flying simultaneously within 1x1 degree blocks (latitude/longitude)

Unmanned Batch Simulation (UBS)

- NASA Langley's Unmanned Batch Simulation (UBS) is used to test and validate the behavior of the Detect and Avoid Alerting Logic for Unmanned Aircraft Systems (DAIDALUS) Algorithm
  – The system can generate or ingest truth vectors or generate vectors involving ADS-B, Mode S, or airborne radar sensor uncertainty
  – With a simple, rules-based pilot model, UBS can test the ability to follow maneuver guidance generated by DAIDALUS to avoid intruders



DAA (grossly over-simplified)

3 Technical Areas:

Guidance and Control

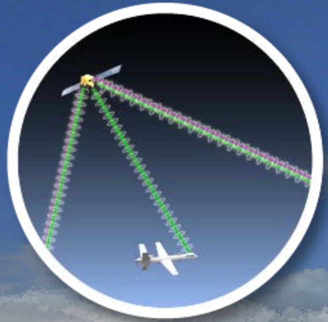
- Avoidance algorithm (DAIDULUS)
- Terminal area focus simulations

Modeling and Simulation

- Fast time simulations (ACES)
- Well clear definition(s) and analysis

Human Systems Integration

- Displays
- Guidance
- Alerting
- Human in the loop simulations



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

Detect and Avoid Subproject

Modeling & Simulation

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Acknowledgments

M&S team members 2012–2020

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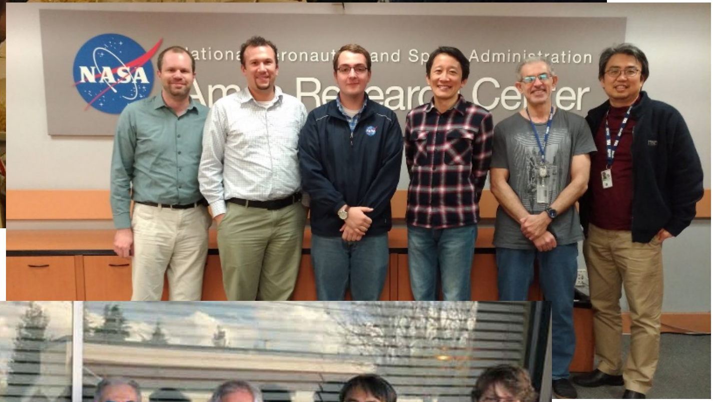
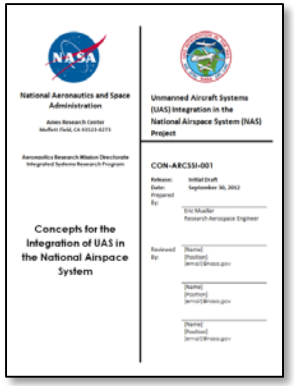


Detect-and-Avoid (DAA) Modeling and Simulation



UAS-NAS integration concepts

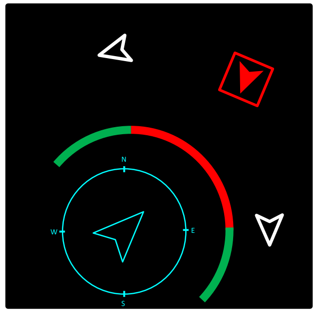
Modeling and Simulation Capabilities

UAS mission profiles

UAS types

VFR Traffic

alerting and guidance



sensor models

Flight Test

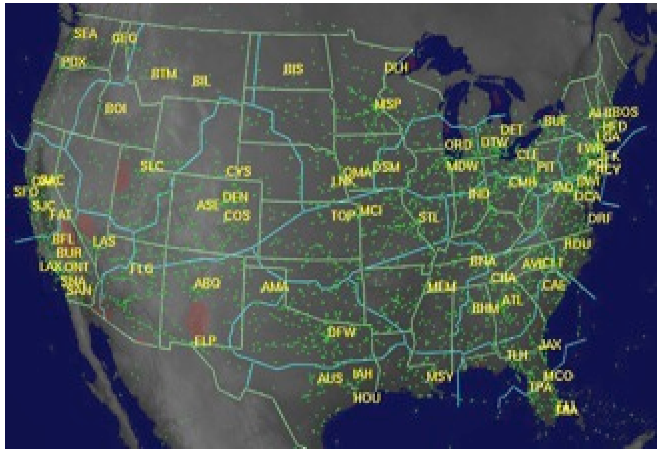
Human-in-the-Loop

Air Traffic Control

Pseudo pilots for manned traffic

UAS pilots

NAS-wide Simulation



ACES: Flight plan and NAS-agent modeling system

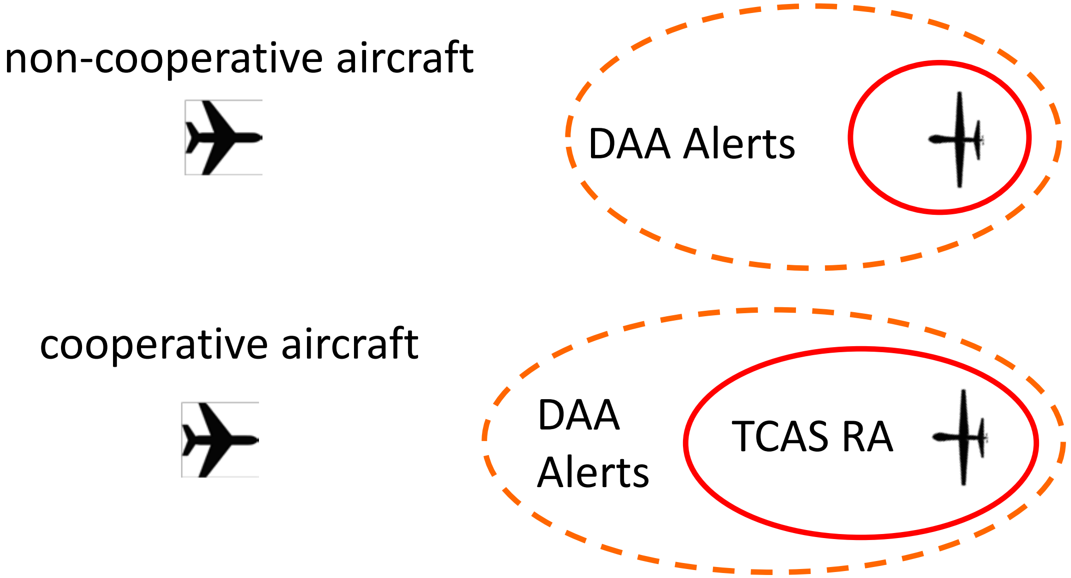
Major Research Topics

- **DAA well clear (DWC)**
- **Surveillance**
- **Alerting and guidance**
- **Safety and operational suitability**
- Display configuration and requirements
- DAA interoperability with Traffic Collision Avoidance System (TCAS)
- Integration and flight tests

Detect-and-Avoid (DAA) Well Clear (DWC)

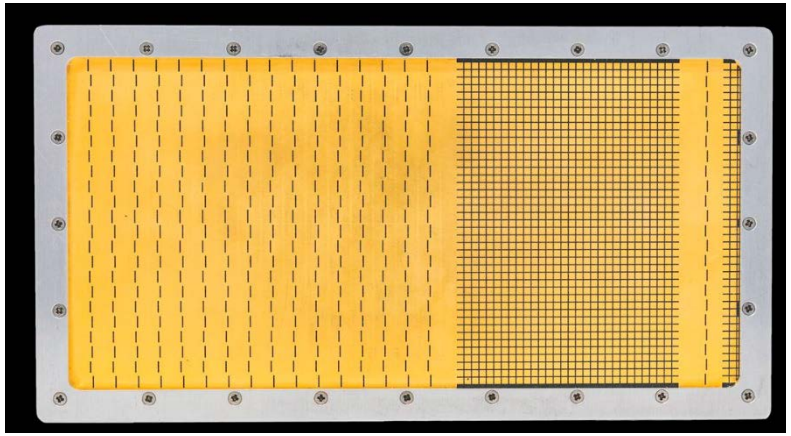
- DWC provides an objective separation standard between UAS and manned aircraft
- NASA contributed significantly to the Phase 1 DWC work
- NASA drove the development of Phase 2 DWC work

DWC	Horizontal Miss Distance (ft)	altitude separation (ft)	τ_{mod}
En route Cooperative	4000	450	35
En route Non-cooperative	2200	450	0
Terminal Area	1500	450	0



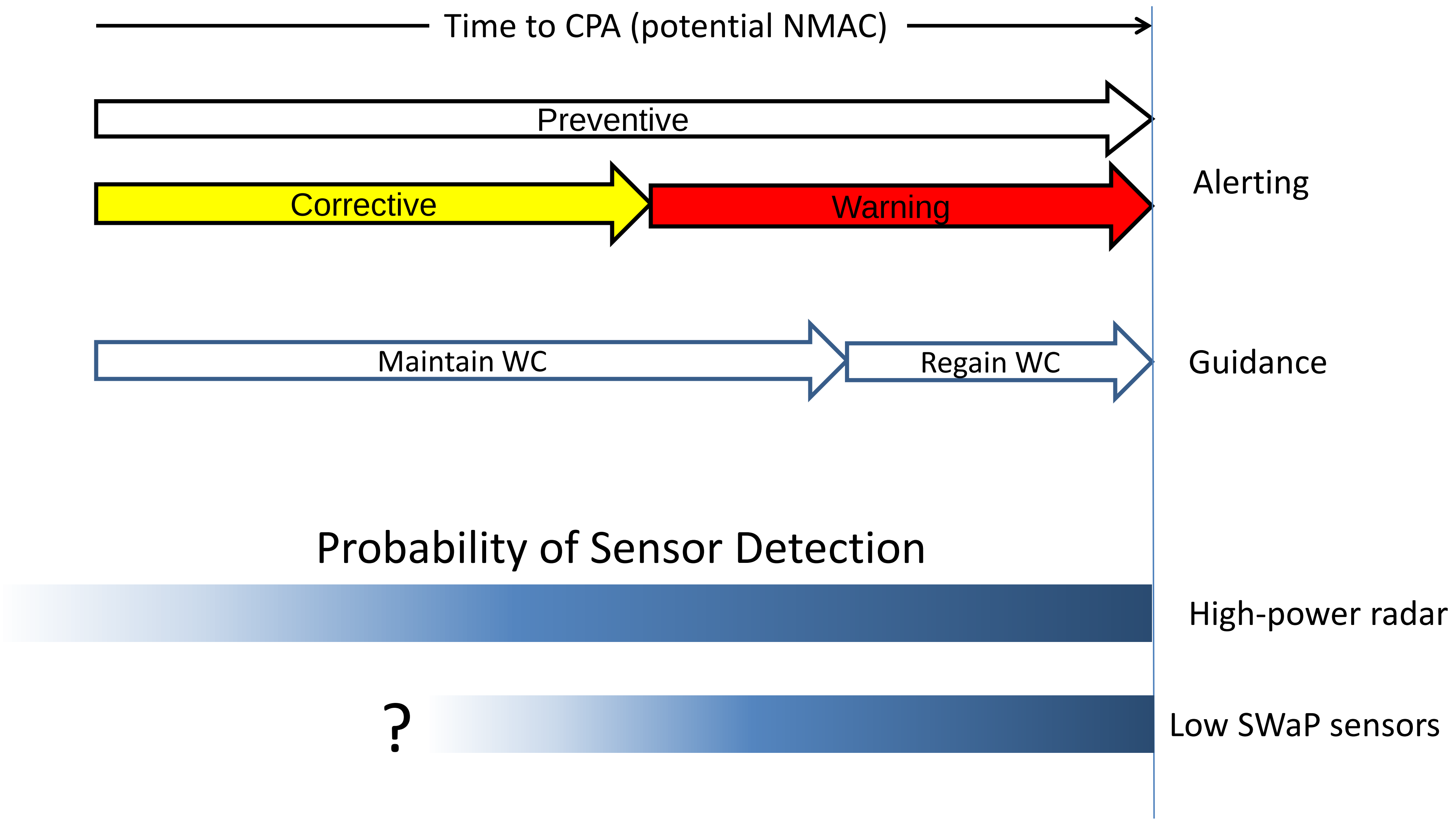
Low Size, Weight, and Power (SWaP) Sensor

- **Phase 1 air-to-air radar is high-power and high payload, not suitable for many UAS operations that have lower mission speeds and utilize smaller UAs**
- **NASA drives the development of surveillance volume requirements for Low SWaP sensor at SC-228:**
  - Air-to-air radar
  - Electro-Optico / Infrared (EO/IR)
- **DAA performance considerations**
  - Operational suitability metrics
  - Safety metrics
- **Honeywell International selected as partner**
  - Honeywell provides low SWaP radar and aircraft integration support
  - NASA conducts flight tests to demonstrate integration of technology and inform the MOPS development



Honeywell's DAPA Lite (RDR-84K)

DAA Alerting and Guidance



NMAC: near mid-air collision

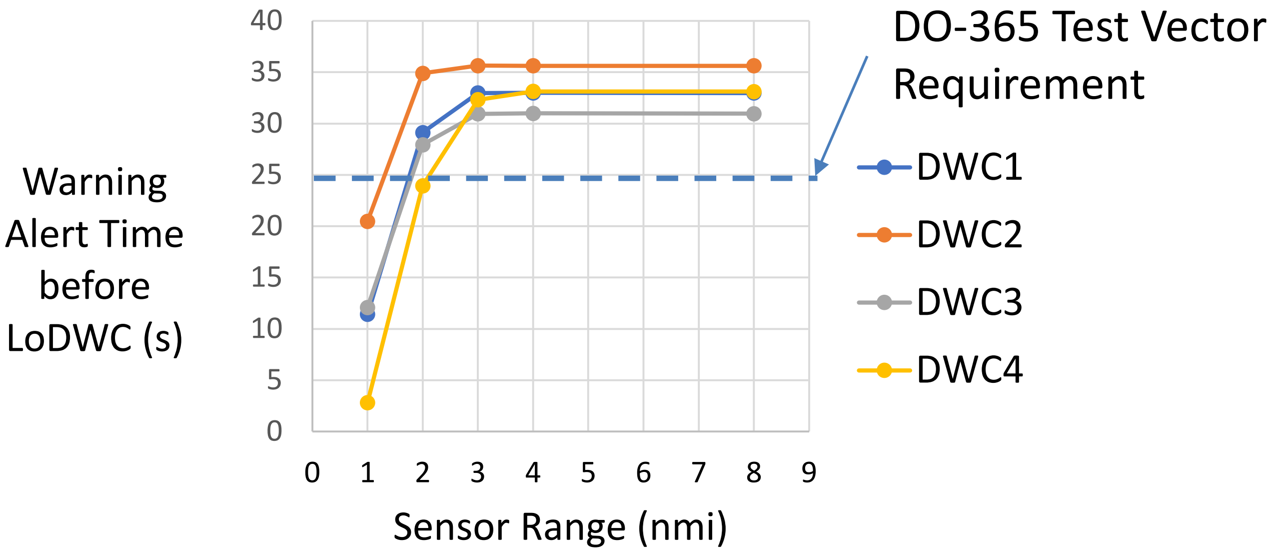
Surveillance Volume Development

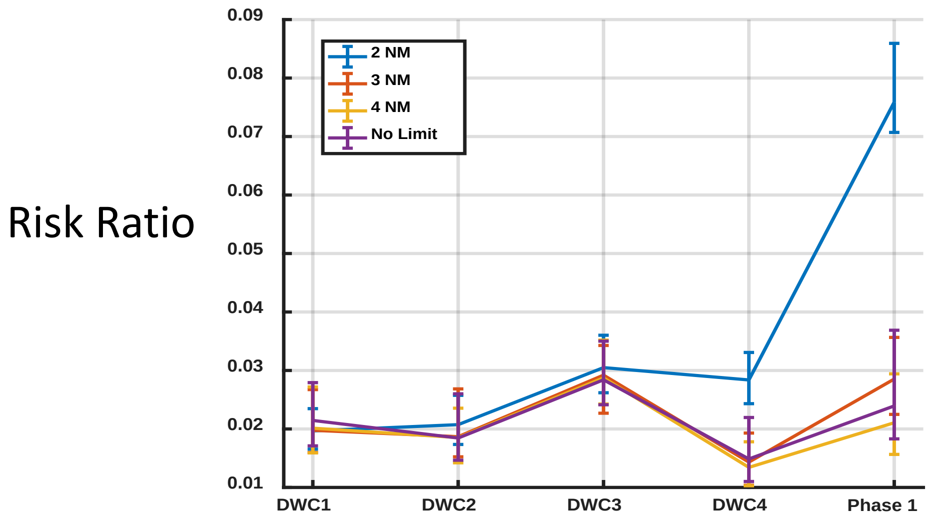
Operational Suitability

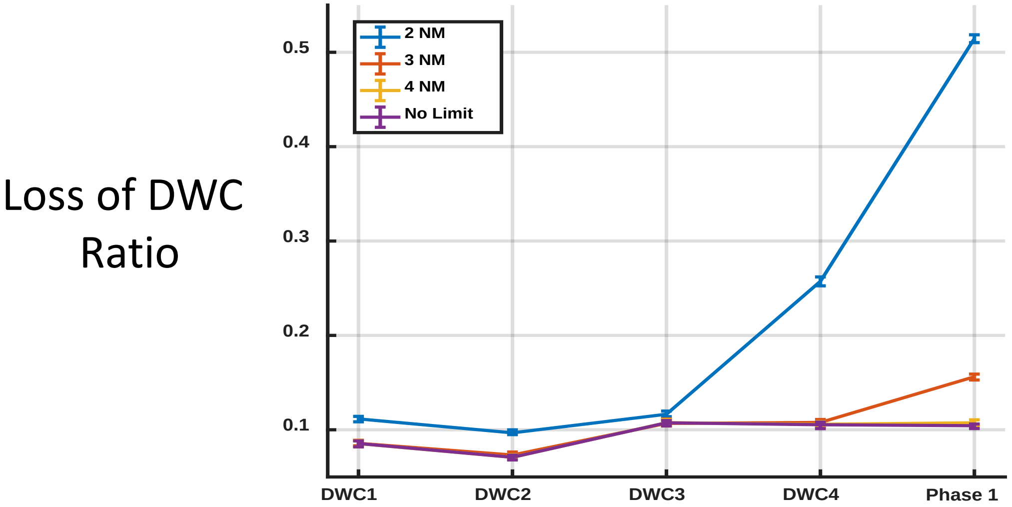
- Alerting performance
- Pilot performance and acceptance

Safety Metrics

- Near-mid-air-collision (NMAC) risk ratio
- LoDWC ratio







RTCA Contributions

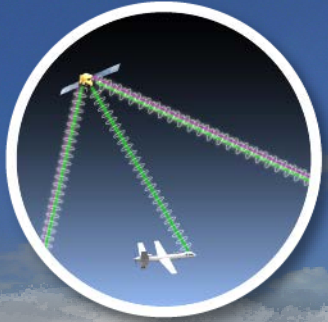
- **DAA MOPS**
  - Non-cooperative DAA Well Clear
  - Low SWaP operations
  - Extension of UAS speed under 10,000 ft MSL from 200 KTAS to 291 KTAS
  - Alerting and guidance
  - Test vectors

- **Air-to-Air Radar (ATAR) and Electro/Infrared (EO/IR) Sensors MOPS**
  - Drove work supporting field or regard requirements
  - Authored 4 ATAR appendices
  - Authored 2 EO/IR appendices

Lessons Learned

- **Technical:**
  - The smaller non-cooperative DWC preserves the same level of safety achieved by the larger Phase 1 DWC while reducing surveillance volume requirements for non-cooperative sensors such as radar and EO/IR
  - The surveillance range requirement derived based on the SC-228 ConOps remains a challenge for low SWaP radar technology

- **Best Practices:**
  - Development of encounter-based simulation capabilities facilitated the validation of various surveillance, alerting, and guidance criteria on a statistical basis
  - State-of-the-art software development tools and process, as well as people equipped with such skill sets, contributed significantly to the achievement of all the milestones involving fast-time, human-in-the-loop, and flight tests.



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

Detect and Avoid Subproject

Guidance & Control

Tod Lewis

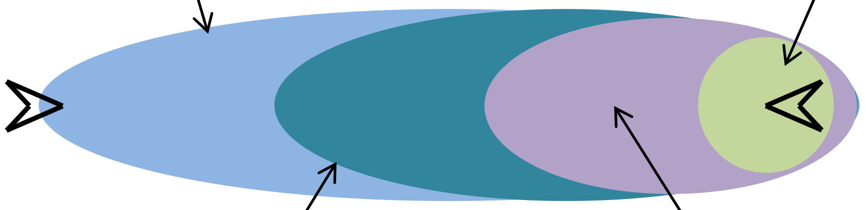
Guidance & Control Technical Lead, DAA Subproject

Outline

- Overview of G&C Focus Areas and Main Findings
  1. Development of a Detect and Avoid Algorithm (DAIDALUS)
  2. En Route DAA Well Clear (DWC) Definition
  3. Terminal DWC Definition
  4. Basis for Switching Between En Route and Terminal DWC
  5. Terminal DWC Alerting Times
- DAIDALUS updates
- Major Successes
- Lessons Learned

Background

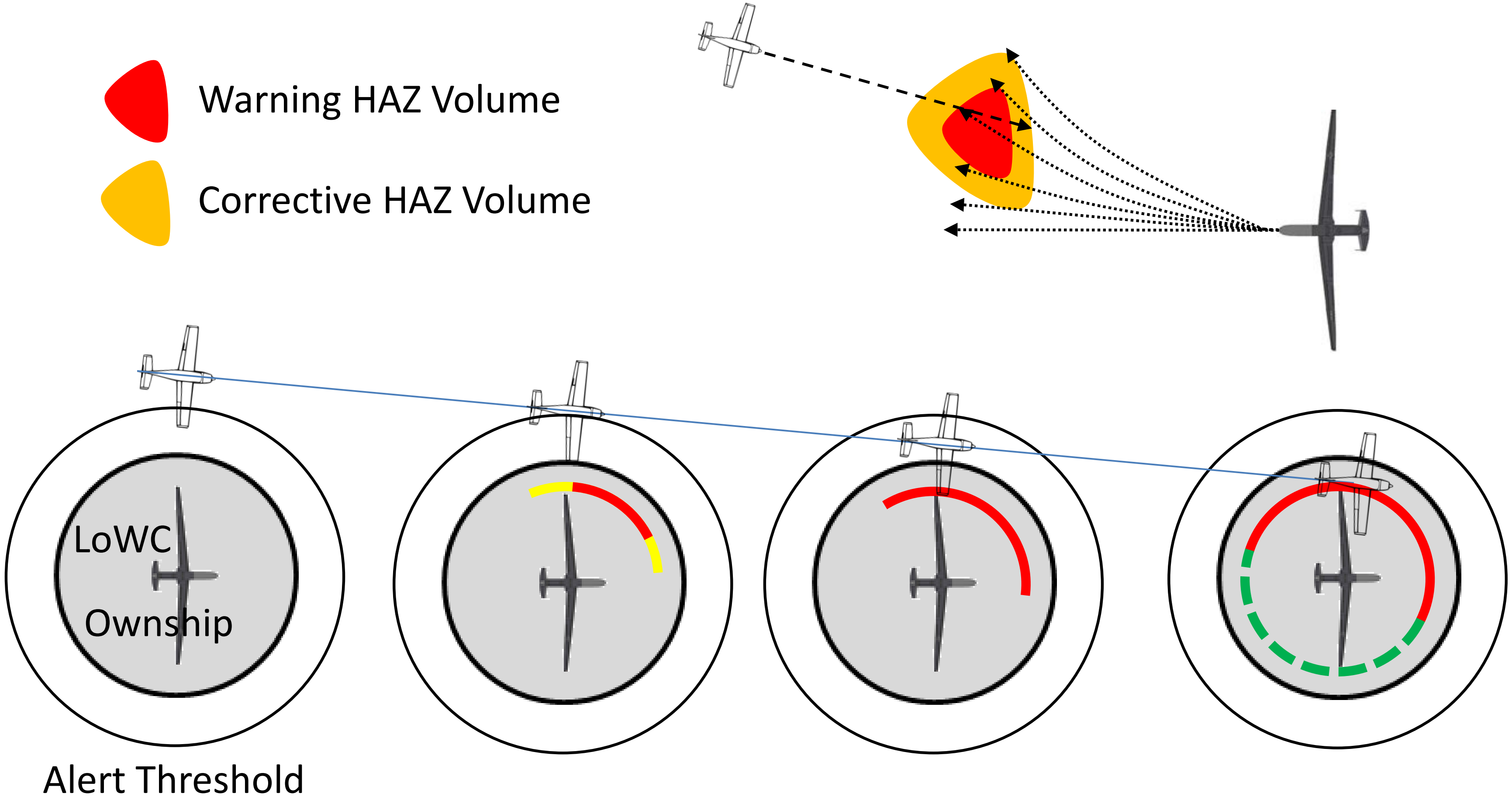
- **En Route DAA Well Clear (DWC)**
  - Hazard Zone (HAZ)
  - Taumod* = 35s
  - DMOD = 4000' = Horizontal Miss Distance (HMD*)
  - h* = 450'



Alert Type →		Preventive Alert	Corrective Alert	Warning Alert
Alert Level →		Caution	Caution	Warning
HAZ	τ^*_{mod} (Seconds)	35	35	35
	DMOD and **HMD***(Feet)	4,000	4,000	4,000
	h* (Feet)	700	450	450
Alert Times	Minimum Average Time of Alert (Seconds)	55 (prior to HAZ)	55 (prior to HAZ)	25 (prior to HAZ)
	Late Threshold (Seconds)	20 (prior to HAZ) or 5 (after HAZ)	20 (prior to HAZ) or 5 (after HAZ)	15 (prior to HAZ) or 5 (after HAZ)
	Early Threshold (Seconds)	75 (prior to HAZ) or 110 (prior to CPA)	75 (prior to HAZ) or 110 (prior to CPA)	55 (prior to HAZ) or 90 (prior to CPA)
NHZ	τ^*_{mod} (Seconds)	110	110	90
	DMOD and HMD*(NM)	1.5	1.5	1.2
	VMOD (Feet)	800	450	450

Phase 1 Overview

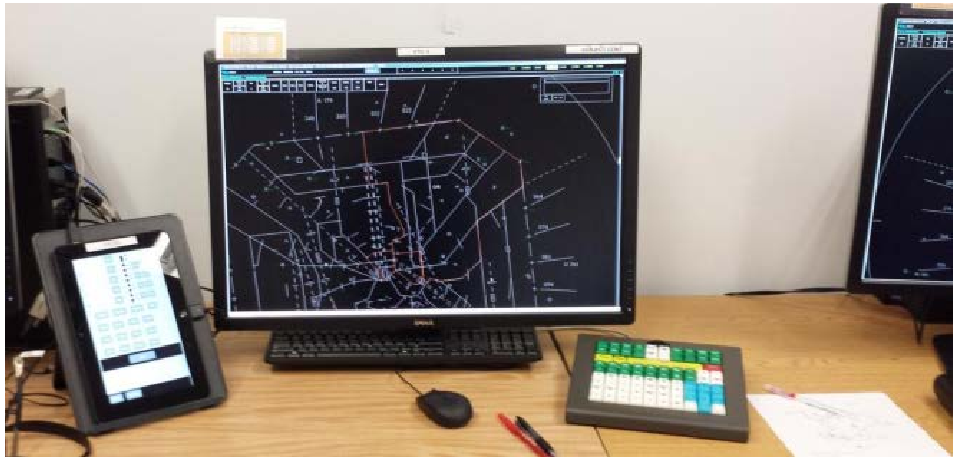
- **Focus Area 1 – Development of a Detect and Avoid Algorithm**
  - **D**etect and **A**vo**id** **A**lerting **L**ogic for **U**nmanned **S**ystems (DAIDALUS)
  - Formally proved algorithm for prediction of loss of DWC and generation of alerting and maneuver guidance



Phase 1 Overview

Focus Area 2—En Route DAA Well Clear (DWC) Definition

- **Three human-in-the-loop studies and an engineering analysis provided the basis for the Phase 1 En Route DWC Definition**
  – Goal was to inform the mathematical model for DAA Well Clear (DWC) to be used by the DAA algorithm to provide alerting and guidance
- **Research questions involved:**
  – Path deviation acceptable to controllers and pilots to remain well clear?
  – How do environmental and operational concerns affect acceptable path deviation?
  – What alert time is acceptable to pilots and controllers?

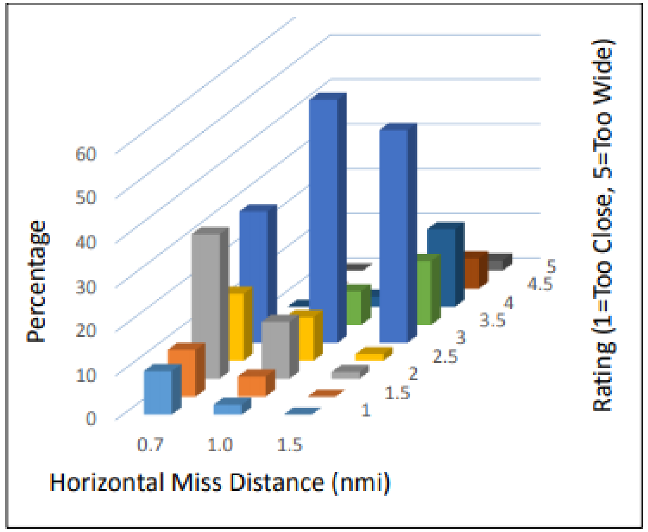


ATC Station

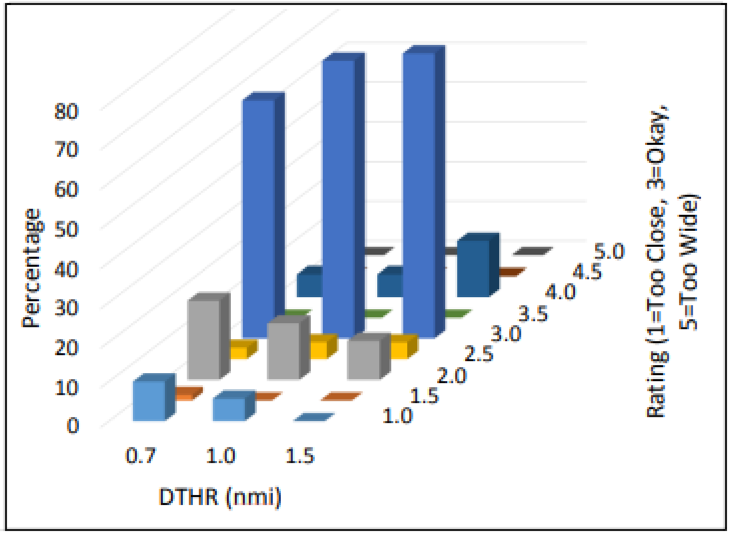
UA Pilot Station

Focus Area 2—En Route DAA Well Clear (DWC) Definition

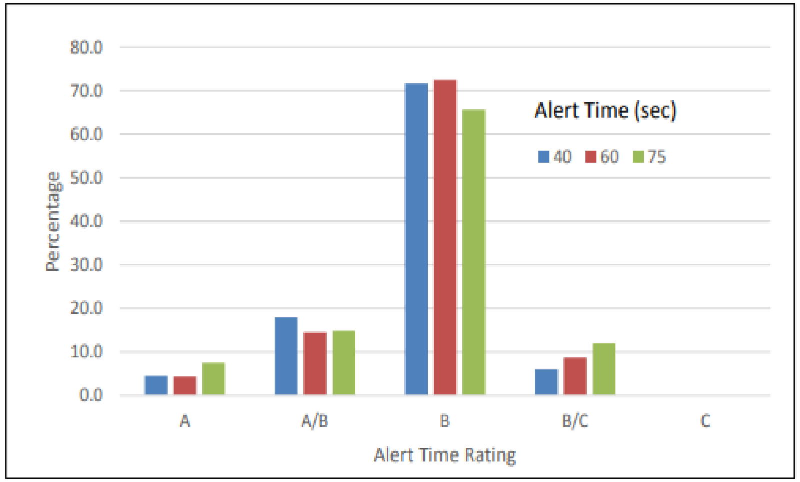
- **Selected Results:**
  - Horizontal miss distance (HMD) of 1.0 and 1.5 nmi optimal for both pilots and controllers
  - Winds of 7 and 22 knots did not impact HMD results
  - Communication delays had little performance or workload impact; however, controllers expressed irritation with longer delays (> 400ms), which would have been disruptive with higher traffic density
  - All alert times tested (40s, 60s, and 70s) were acceptable to pilots and controllers



Controller HMD Ratings for Crossings



UAS Pilot HMD Ratings for Crossings

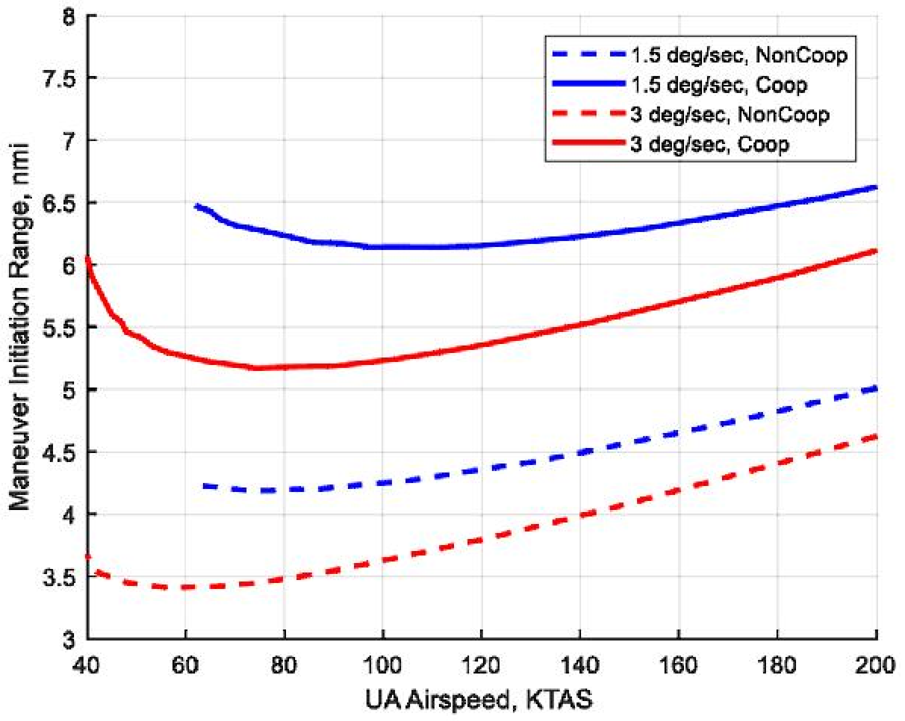


UAS Pilot Alert Time Ratings for Crossings (A = Too Early, B = Timing OK, C = Too Late)

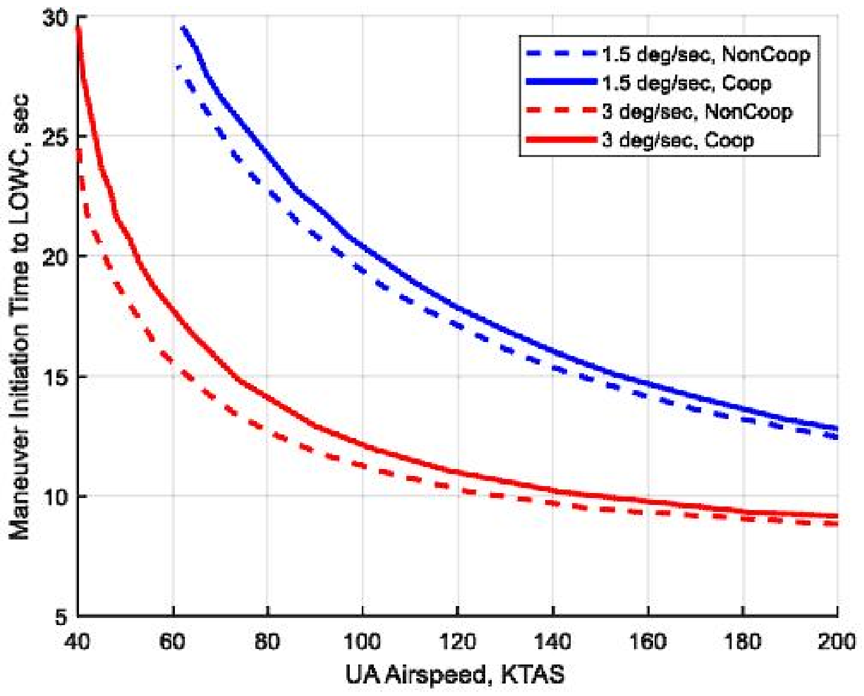
Phase 1 Overview

Focus Area 2—En Route DAA Well Clear (DWC) Definition

- An engineering analysis informed UA performance assumptions, surveillance requirements, and alert timing



Maneuver Initiation Range for Level-Turn Maneuvers; Altitude < 10000’



Maneuver Initiation Time for Level-Turn Maneuvers; Altitude < 10000’

Phase 1 Overview

- **Focus Area 2—En Route DAA Well Clear (DWC) Definition**
  - Analysis informed UA speed and other operational assumptions
  - Analysis supported alerting times
  - Analysis supported the radar declaration range (RDR) values published in RTCA DO-366

- **UA Performance Assumptions**
  - Sustainable turn rate of either 1.5 or 3 deg/s
  - Vertical acceleration of 0.25g
  - Minimum climb/descent rate of 500 fpm
  - Roll-in/out rate of 5 deg/s
  - Command-to-execute latency of ≤ 2s

Turn Capability (Deg/s)	Altitude < 10,000' MSL and Terminal		Altitude >= 10,000' MSL	
	Minimum Airspeed (KTAS)	Maximum Airspeed (KTAS)	Minimum Airspeed (KTAS)	Maximum Airspeed (KTAS)
1.5	60	200	60	600
3.0	40	200	40	600

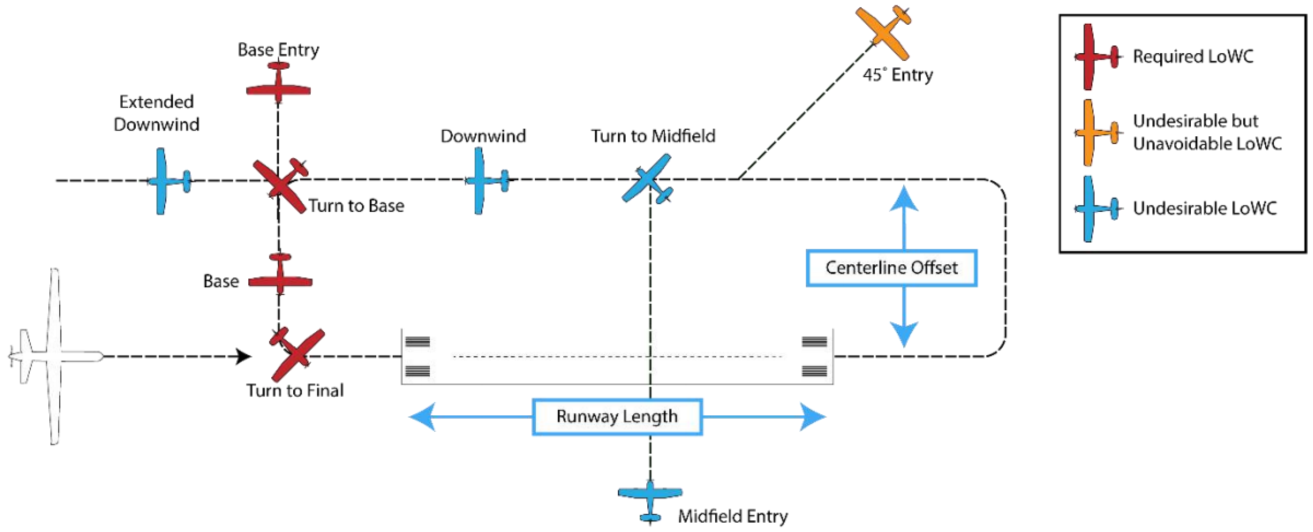
UA Speed Bounds per Altitude and Turn Capability

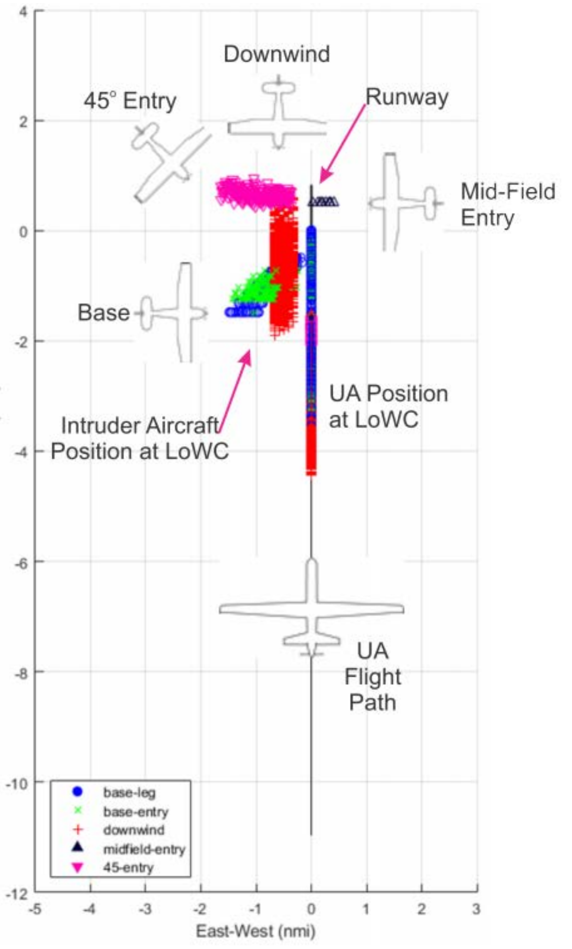
	Altitude < 10,000' MSL	Altitude >= 10,000' MSL
	Maximum Airspeed (KTAS)	Maximum Airspeed (KTAS)
Non-Cooperative	170	N/A
Cooperative	291	600

Intruder Speed Bounds per Altitude

Focus Area 3—Terminal DAA Well Clear (DWC) Definition

- **Three fast-time studies investigated the behavior of the Phase 1 En Route DWC and alternate DWCs involving intruders in the VFR traffic pattern**
  - Selected Results for Phase 1 En Route DWC applied in terminal area
    - Early Corrective alert threshold may be crossed while the UA is 8.55 nmi from the runway and Warning level alerts may be issued as far away as 7.5 nmi from the runway.
    - Loss of Well Clear (LoWC) possible with UA as far as 4.5 nmi from the runway





LoWC Geometry

Phase 2 Overview

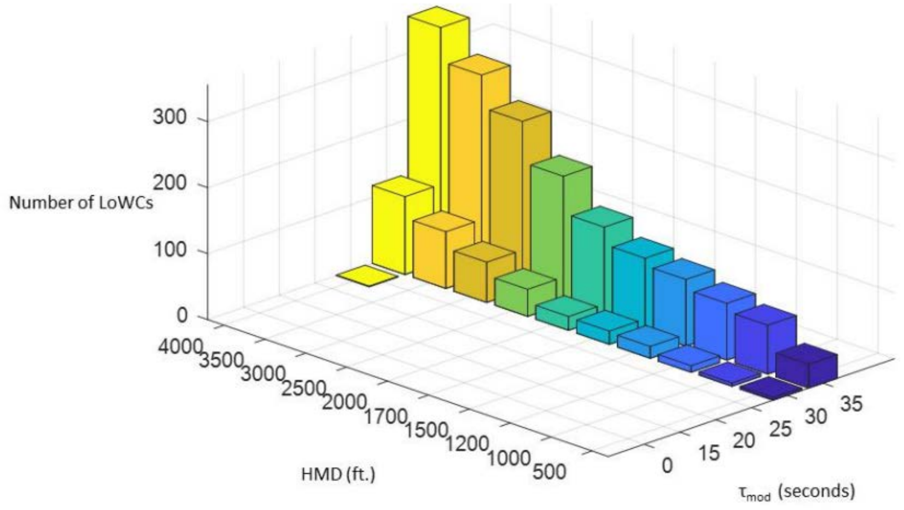
Focus Area 3—Terminal DAA Well Clear (DWC) Definition

- **Selected Results for alternate Terminal DWCs**
  - Smaller HMD eliminated undesired alerts caused by intruders on the downwind leg
  - Reduced τmod* eliminated undesired alerts caused by intruders on the 45 deg entry
  - Terminal DWC definition should include: h* = 450 ft., an HMD* between 1000 ft. and 2000 ft., and τmod* between 15 seconds and 25 seconds.
  - RTCA SC-228 defined the terminal hazard zone parameters:

    h* = 450 ft, HMD* = 1500 ft., and τmod* = 0s.

HAZ Parameter	Values
h*(ft)	250, 300, 350, 400, 450
HMD* (ft)	500, 1000, 1500, 2000, 3000, 4000
τmod*	0, 15, 20, 25, 30, 35

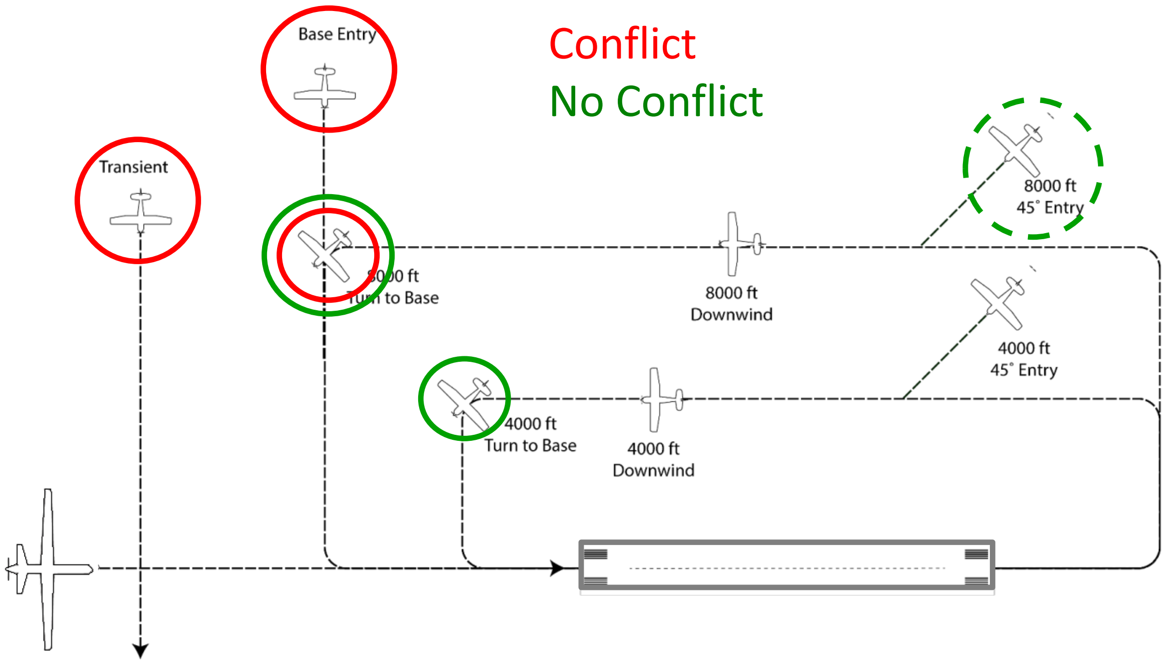
Well-Clear Volume Dimensions Investigated

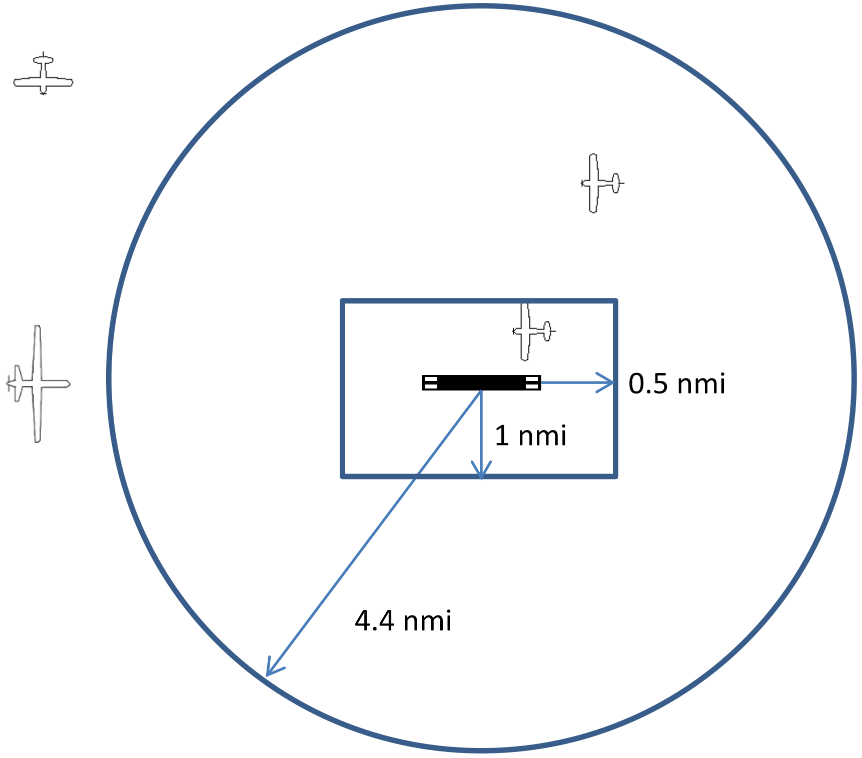


LoWC Excitation for 45 deg Entry Encounters

Focus Area 4—Basis for Switching Between the En Route and Terminal DWC

- **A human-in-the-loop study investigated pilot performance and acceptability of:**
  - Shape and size of the DAA Terminal Area (DTA)
  - DWC switch based on location of the UA or the intruders
- **Fast-time Engineering Analysis conducted to refine the size of the DTA**





Phase 2 Overview

Focus Area 4—Basis for Switching Between the En Route and Terminal DWC

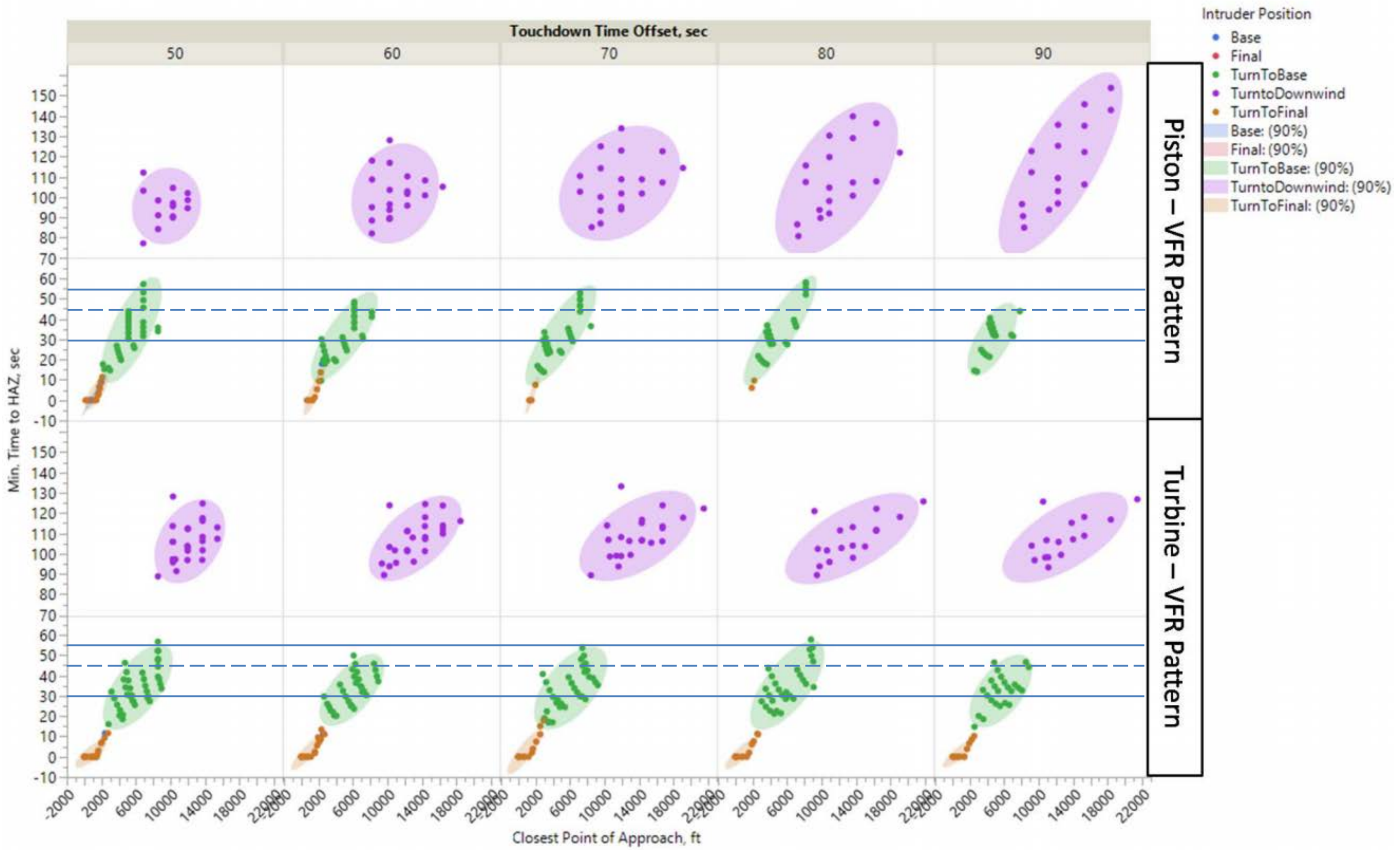
- **Results**

Feature	Intruder Cylinder	Intruder Prism	Ownship Cylinder
Alerting on 45 Entry	**No alerts issued ⇑**	**En Route Warning ⇓**	En Route Prev/Corr
Alerting on Extended Base	**LoWC due to insufficient Terminal Warning alert timing ⇓**	**En Route alerting with plenty of lead time ⇑**	
Alerting on Transit	Discrete En Route and Terminal alerting events	**Continuous En Route alerting ⇑**	**Continuous En Route alerting ⇑**
Alerting given Nominal Separation	**No alerts issued ⇑**	**En Route Warning alerts ⇓**	En Route Prev/Corr
Alerting on Downwind	**No alerts issued ⇑**	**No alerts issued ⇑**	**Alerts prior to entering DTA ⇓**
Alerting on Turn to Base	**Late Warning ⇓**	**Directly to Recovery ⇓**	**Late Warning ⇓**
Aircraft Response Time	Fastest due to preemptive maneuver setup	Align with En Route response times	
Maneuvering	Most maneuvers without alerts	Most speed commands due to earliest alerts	
Separation		Greatest separation at CPA	
Subjective: Alert Timing/Distance	**Too Late/Too Close ⇓**	**Just Right ⇑**	Greatest spread; a bit more 'Too Early/Too Wide'

Phase 2 Overview

Focus Area 5—Terminal DWC Alerting Times

- **A fast-time engineering analysis investigated candidate terminal alerting times**
  - SC-228 adopted the following alert times based on this and earlier studies:
    - Early warning alert time set to 55s
    - Minimum avg warning alert time set to 45s
    - Late warning alert time set to 30s
  - The time to HAZ for the intruders turning downwind (magenta) being much higher than the selected early alert time, prevents undesired alerts



Time to Hazard Zone by Intruder Position

DAIDALUS v2 updates

- **Multiple alerters, with the ability to switch dynamically**
  - Allows for En-route, Terminal Area, and low-SWAP DWC simultaneously
  - Supports switching to Terminal Area DWC
- **Integrated Sensor Uncertainty Mitigation (SUM) logic**
- **Hysteresis logic**
  - M of N for alerts and bands: reduce on/off jitter in alerts and guidance
  - Time-based persistence: keeps alerts and guidance visible long enough for action
  - Value-based persistence: reduces reversals and jitter in guidance
- **DAA Terminal Area (DTA) logic**
  - Allows for DTA area to be specified (position and size).
  - Includes modes for departing, en-route, and landing.
  - Supports automatic switching to Terminal Area DWC, including special guidance
- **Updates to alerting logic to maintain alerts through maneuvers**
  - Reduces disappearance then reappearance of alert in changing encounters
- **Available under NASA Open Source Agreement:** https://github.com/nasa/daidalus

DAIDALUS

Major Successes

- **Developed the DAA reference algorithm for RTCA DO-365**
- **Provided research and analysis to support DO-365 requirements:**
  - En Route and Terminal Hazard and Non-Hazard Zones
  - En Route and Terminal DWC Alerting Parameters
  - Information to support cooperative and non-cooperative radar declaration range
  - Size and shape of the DAA Terminal Area
  - En Route/Terminal DWC switching methodology
- **Supported test vector development and scoring**
- **Contributed to writing of DO-365**
  - DAA Alerting and Guidance Processing Requirements (2.2.4)
  - [Test Procedures for] DAA Alerting and Guidance Processing Requirements (2.4.4)
  - Appendix C, Development of Detect and Avoid Well Clear
  - Appendix D, UAS Maneuver Performance Requirements
  - Appendix G, DAA Alerting Logic and Maneuver Guidance for UAS Reference Implementation
  - Appendix Q, Sensor, Tracking, and Alerting Assessment

Lessons Learned

- **When providing research and analysis that supports standards jointly developed with external stakeholders, especially for a new technology:**
  - Share experiment designs with stakeholders during the design phase to ensure that the research questions and results will support the developing requirements to the greatest extent possible
  - Build flexibility into the research schedule, recognizing that new research questions and needs will arise as time goes on
  - Be willing to slip schedule in order to efficiently handle changing research requirements
  - Be willing to re-prioritize or rescope tasks
- **Having people on the team with the right skills was critical to accomplishing the research**
  - We were successful because of them and their work is greatly appreciated

Questions

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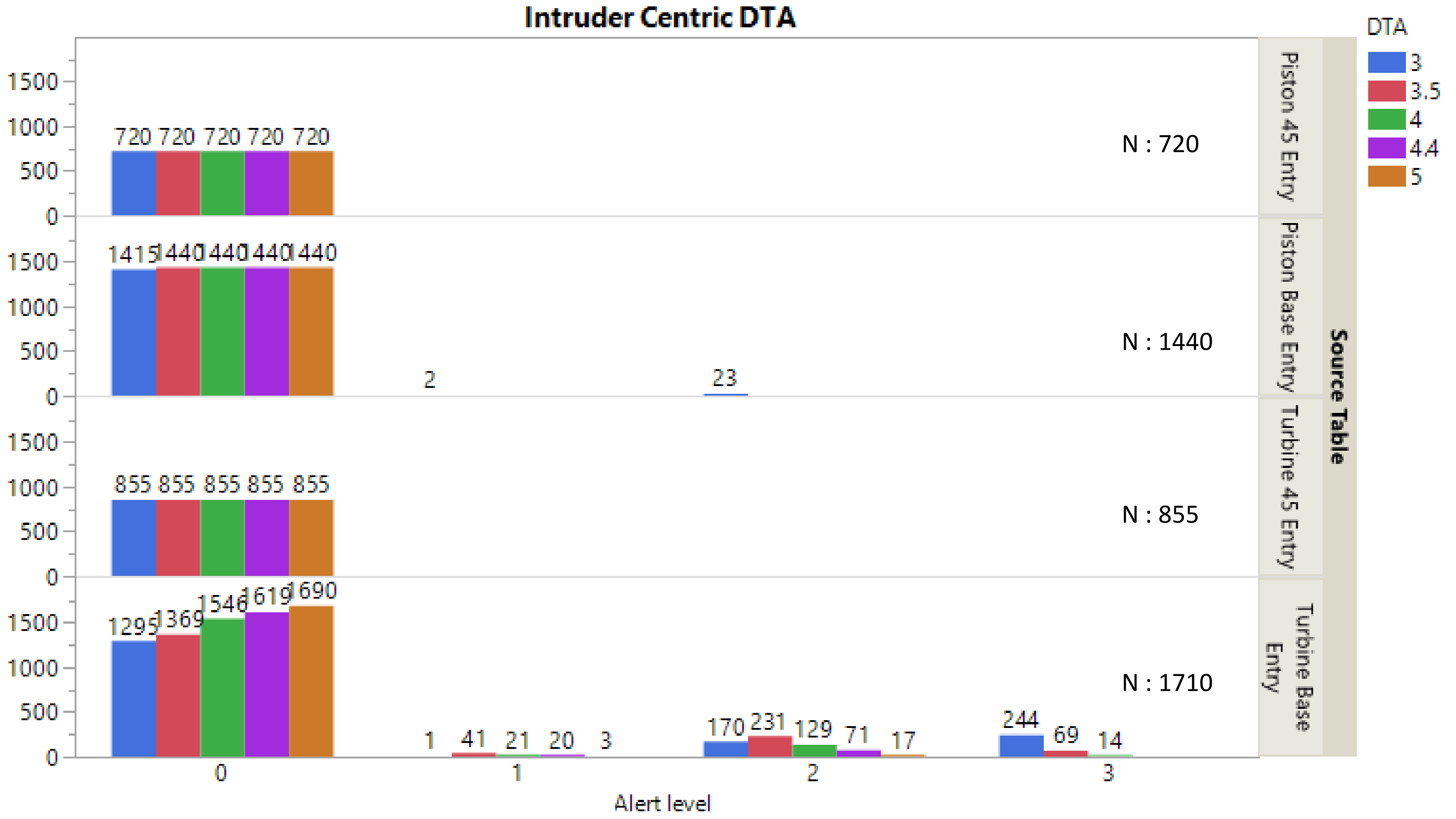
Backup

Phase 2 Overview

- **Focus Area 7—Refinement of the Size of the DAA Terminal Area**

- **Fast-time Engr Analysis to determine range of cylinder DTA radius**
  - Appropriate alerting behavior was observed for DTAs of radius 4 – 5 nmi.



Given the touchdown time offsets in this analysis, having no alerts at DTA entry point is desirable, especially warning alerts.

* N represents total number of encounters for each DTA size.

RTCA SC-228 Terminal Requirements

- **Terminal DWC and Alerting Times**
  - See Table.
- **DTA shape and size**
  - Cylinder
    - Radius 4 – 5 NM
    - Height 1800 – 2200 ft
    - Location: Centered on arrival and/or departure runway
- **DWC Switching Method**
  - Based on intruder being within an active DTA
    - A DTA is active only for runways to be used by the UA for takeoff/landing

Alert Type →		Warning Alert
Alert Level →		Warning
HAZ	τ^*_{mod} (Seconds)	0
	DMOD and $\mathbf{HMD}^*$(Feet)	1,500
	$\mathbf{h}^*$ (Feet)	450
Alert Times	Minimum Average Time of Alert (Seconds)	45 (prior to HAZ)
	Late Threshold (Seconds)	30 (prior to HAZ) or 10 (after HAZ)
	Early Threshold (Seconds)	55 (prior to HAZ) or 70 (prior to CPA)
NHZ	τ^*_{mod} (Seconds)	75
	$\mathbf{DMOD\ and\ HMD}^*$(Feet)	2,000
	VMOD (Feet)	450

DAIDALUS Availability:

The DAIDALUS software library is released under the NASA Open Source Agreement and is available in Java and C++ at https://github.com/nasa/daidalus. The code available is a reference implementation of DAA algorithms as described in DO-365 Appendix G. The DAIDALUS code is a research prototype intended to satisfy many of the DAA functional requirements, though it is not a fully functioning DAA system. System developers may use this resource as a basis of comparison for the behavior of their own DAA software. While this approach may help in the development process, DAA certification will ultimately depend on meeting the requirements of DO-365 and software certification requirements such as DO-178c.

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

Detect and Avoid Subproject

Human Systems Integration

Conrad Rorie

Human Systems Integration Technical Lead, DAA Subproject

Acknowledgements

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  - Jay Shively
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  - Conrad Rorie

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  - Dan Chiappe
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  - Garrett Sadler
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  - Jillian Keeler
  - Casey Smith
  - Terence Tyson
  - Vern Battiste
  - Joel Lachter
  - Alan Hobbs
  - Walter Johnson
  - Joe Ott
  - Ricky Russell
  - Caitlin Kenny

Outline

- Background
- Overview of HSI Focus Areas and Main Findings
    1. ATC Interoperability
    2. DAA: En Route Operations
    3. DAA: Terminal Area Operations
    4. DAA: Multi-UAS
    5. DAA: Low Size, Weight and Power (SWaP) Operations
    6. DAA: ACAS Xu
- Major Successes
- Lessons Learned

Background

Note on Methodology

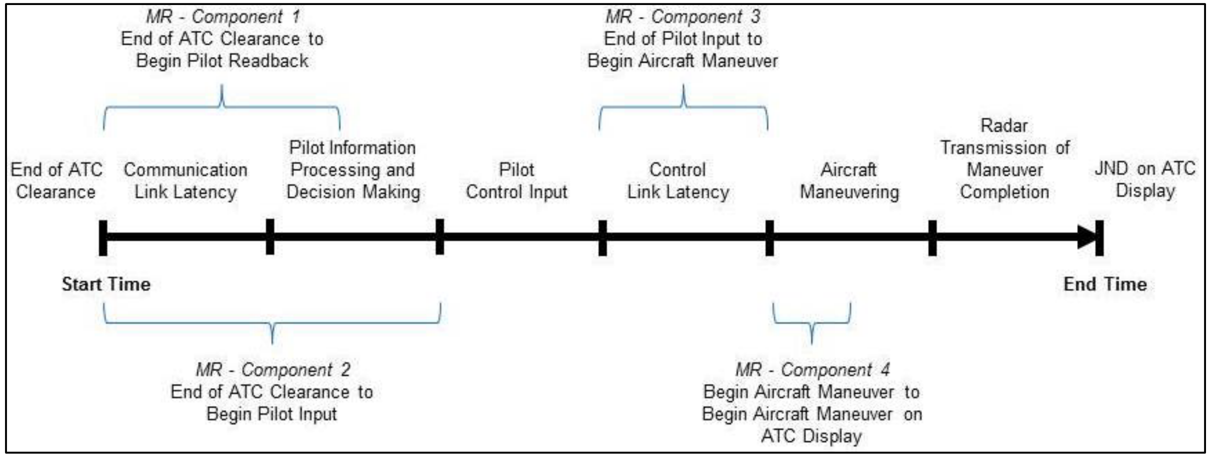
- **Focus was on the interaction between UAS pilots and the other agents in the system (e.g., ground station, ATC, manned traffic)**
- **Studies were typically human-in-the-loop (HITL) simulations:**
  - Active UAS pilots typically serving as participants, flying simulated (large) UAS under IFR
  - Retired ATC and active general aviation pilots serving as confederate controllers and confederate traffic, respectively
    - Allowed for communications & negotiations to occur in real-time
  - Vigilant Spirit Control Station (VSCS; Air Force Research Laboratory asset) served as research ground control station
  - Multi Aircraft Control Station (MACS) served as airspace environment
  - Detect and avoid (DAA) algorithms, and associated software, in-the-loop to provide alerting and guidance to the UAS pilot
- **Research performed in conjunction with RTCA SC-228's UAS Detect and Avoid (DAA) MOPS development (DO-365)**

UAS pilot participant at Vigilant Spirit Control Station (VSCS)

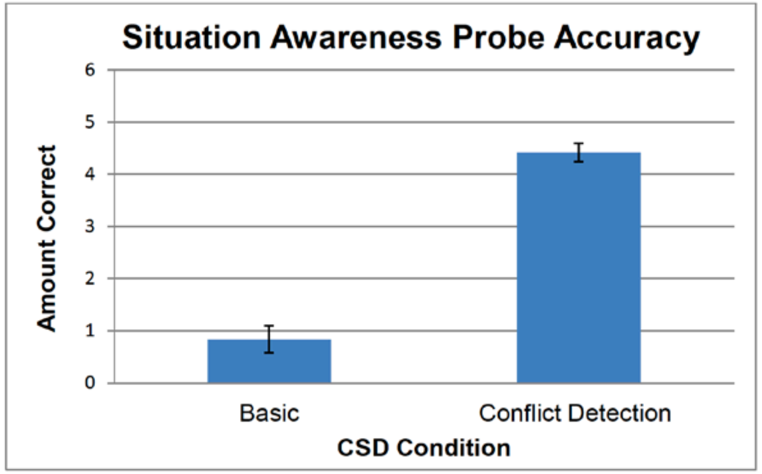
Confederate ATC at MACS displays

Phase 1 Overview

- **Focus Area 1—ATC Interoperability**
  - Six early studies (2 executed with support from CHAAT) specifically examined different aspects of pilot-ATC interaction
    - E.g., measured response, workload and situation awareness, contingency management, ground station control modes
  - These early studies built up HSI's simulation capabilities, methods of analysis, and established the efficacy of increased separation responsibilities to UAS pilots
  - Selection of Results:
    - "Measured response" timeline created to quantify each aspect of pilot-ATC interaction
    - UAS pilots were found to negotiate with ATC quickly and effectively, comparable to manned pilots
    - Ground station traffic displays w/ conflict detection tools improved UAS pilot situation awareness and workload

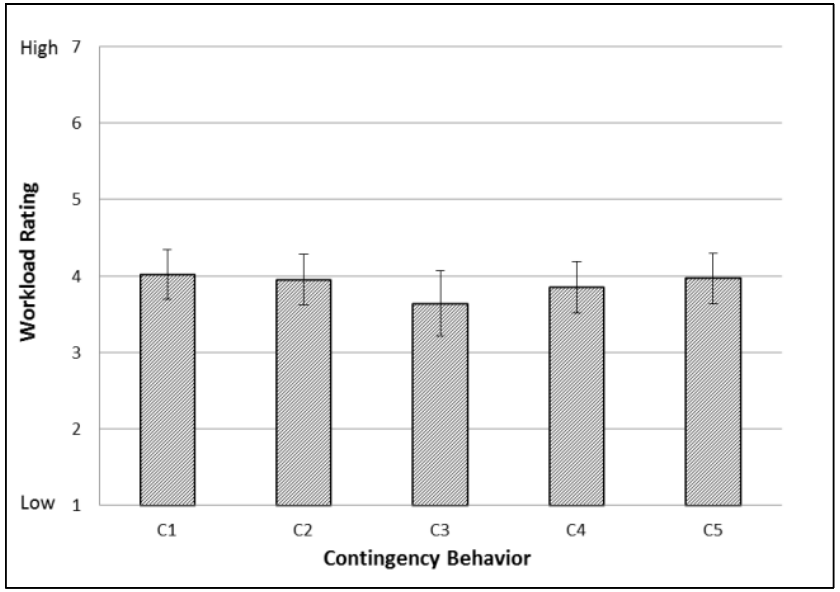


Measured Response (MR) components (Shively, Vu & Buker, 2013)

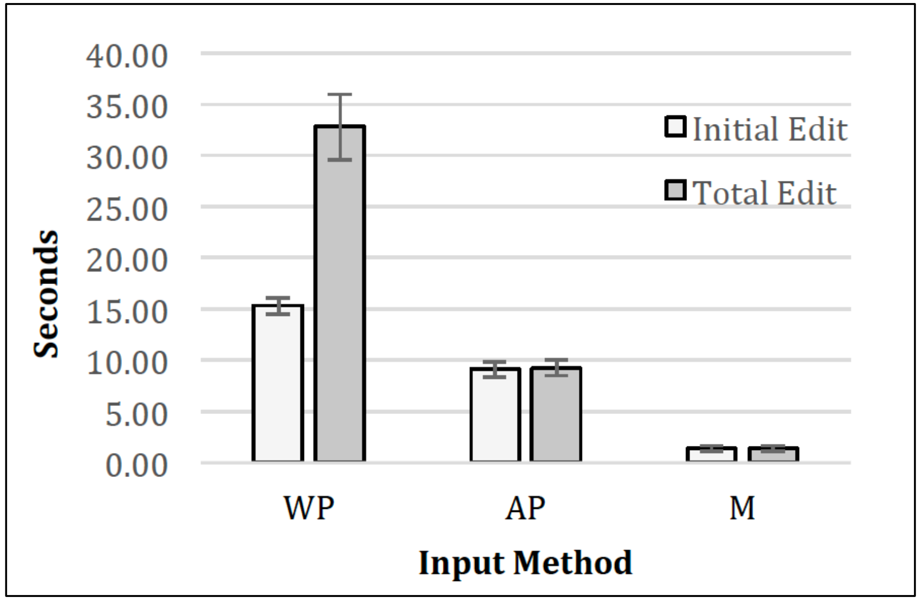


Situation Awareness ratings (Kenny, 2013)

- **Focus Area 1—ATC Interoperability**
  - Selection of Results (cont'd)
    - ATC were found to be remarkably resilient in handling various UAS contingency procedures
      - Workload and effectiveness practically unchanged
      - ATC reported that was UAS predictability was most important factor
    - Ground station control mode had a major impact on how quickly pilots could comply with ATC clearances
      - Manual (stick & throttle) input method allowed pilots to implement ATC clearances faster than auto-pilot or waypoint



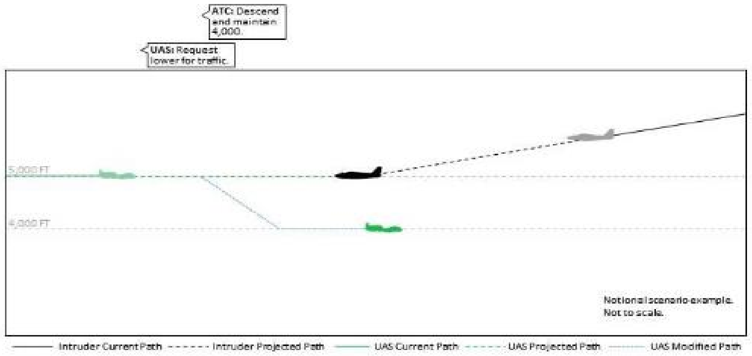
Mean workload rating (Fern, Rorie & Shively, 2014)

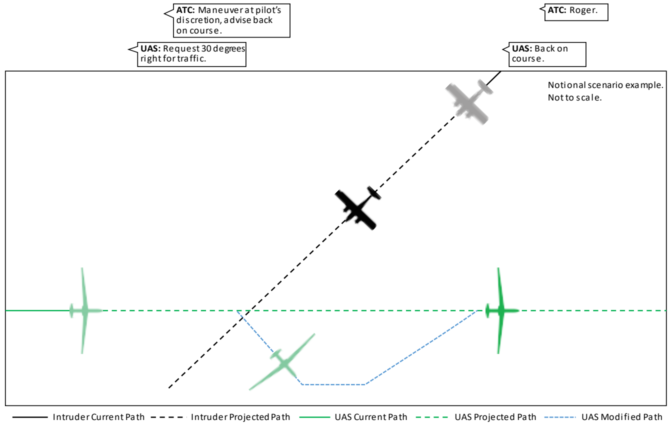


Mean "edit" time by control mode (Rorie & Fern, 2014)

Phase 1 Overview

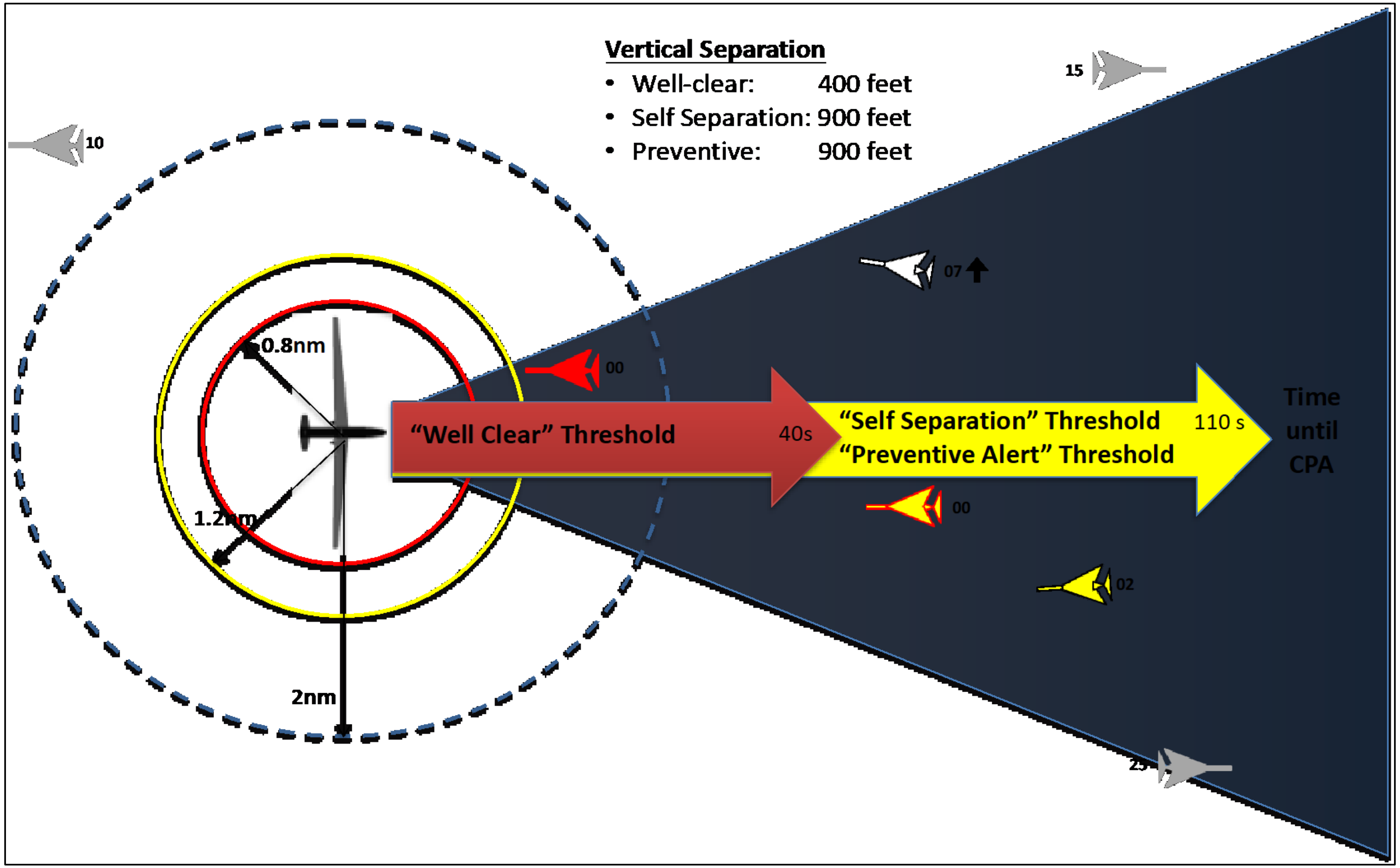
- **Focus Area 2—Detect and Avoid: En Route Operations**
  - Six studies ("full mission" HITLs & engineering analyses) investigated the minimum display requirements for DAA alerting and guidance
    - DAA system alerting and guidance assists pilots in maintaining 'DAA well clear' from nearby traffic
    - HSI focused on operations in Class E airspace to capture IFR-VFR traffic conflicts
  - Initial research questions included:
    - What is the pilot's contribution to the DAA timeline?
    - Should the DAA alerting structure include a warning-level alert in addition to a caution-level alert?
    - In what format should DAA maneuver guidance be presented?
      - **Informative** = traffic position & DAA alerting only; pilot responsible for determining how to maneuver
      - **Suggestive** = traffic position, DAA alerting & DAA "guidance" that depicts ranges of conflict trajectories
      - **Directive** = traffic position, DAA alerting & single DAA avoidance maneuver





Phase 1 Overview

- **Focus Area 2—Detect and Avoid: En Route Operations**
  - DAA alerting structure from study 1:



- **Focus Area 2—Detect and Avoid: En Route Operations**
  - Examples of different guidance types:

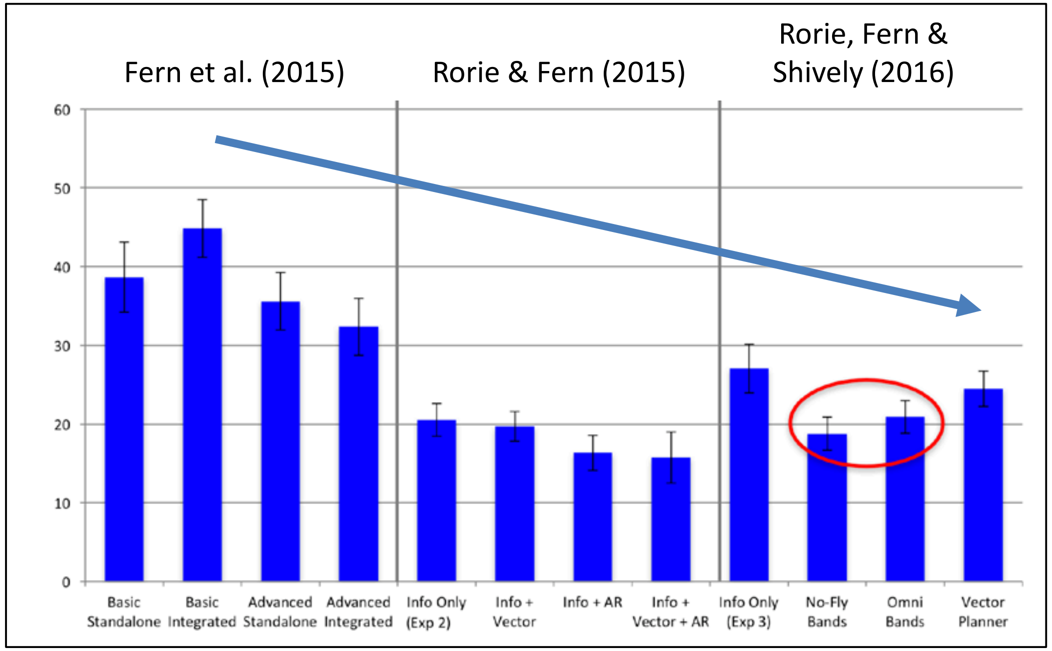
Informative

Suggestive

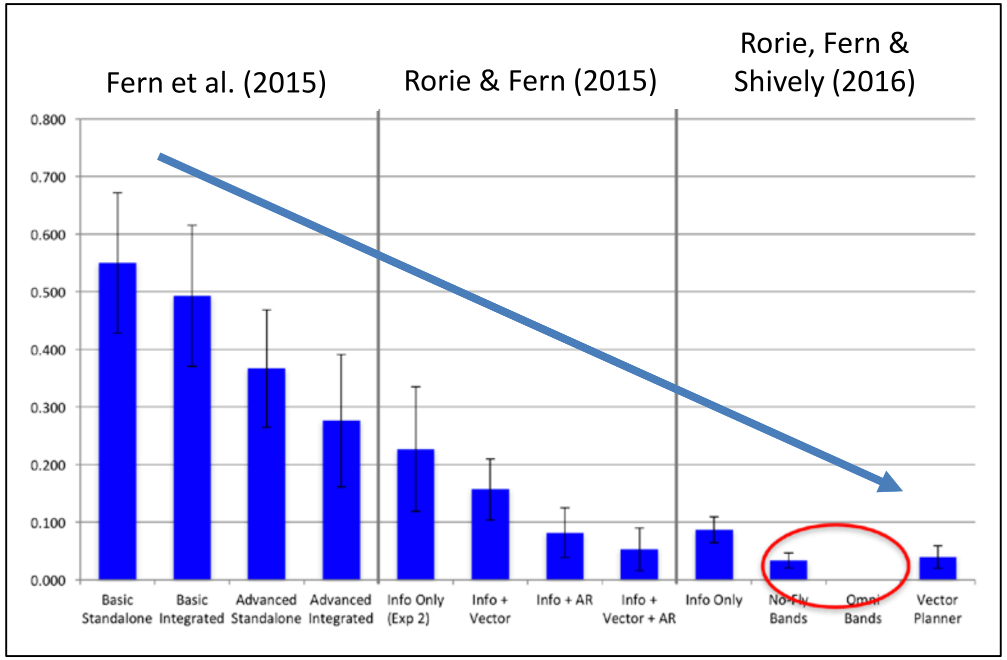
Directive

Phase 1 Overview

- **Focus Area 2—Detect and Avoid: En Route Operations**
  - Selection of Results:
    - Across the first 3 DAA studies, response times and losses of DAA well clear were drastically reduced
    - Improvements were the result of clearer visual and aural alerting and suggestive guidance formats
      - Simplified well clear and alerting thresholds led to more consistent pilot behavior
      - Use of DAA suggestive guidance reduced likelihood of losses of DAA well clear



Average pilot response times to Corrective alerts across 3 first DAA studies



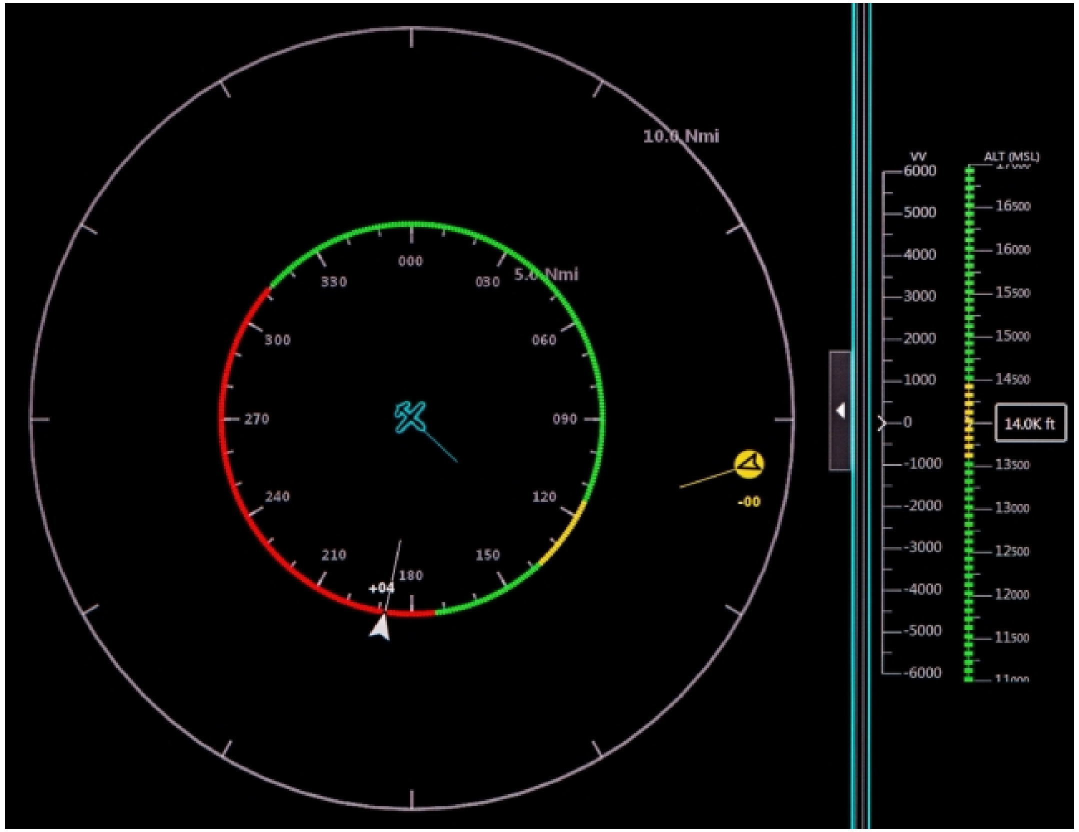
Average proportion of losses of DAA well clear across first 3 DAA studies

Phase 1 Overview

- **Focus Area 2—Detect and Avoid: En Route Operations**
  - The alerting and guidance structure was further tested and validated in follow-on studies
  - Resultant Phase 1 DAA alerting and suggestive guidance:

Symbol	Name	Pilot Action	Time to Loss of Well Clear	Aural Alert Verbiage
	DAA Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now"
	Corrective DAA Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
	Preventive DAA Alert	• On current course, corrective action **should not be required** • Monitor for intruder course changes • Talk with ATC if desired	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
	Guidance Traffic	• **No action required** • Traffic generating guidance bands outside of current course	X	N/A
	Remaining Traffic	• **No action required** • No coordination required	X	N/A

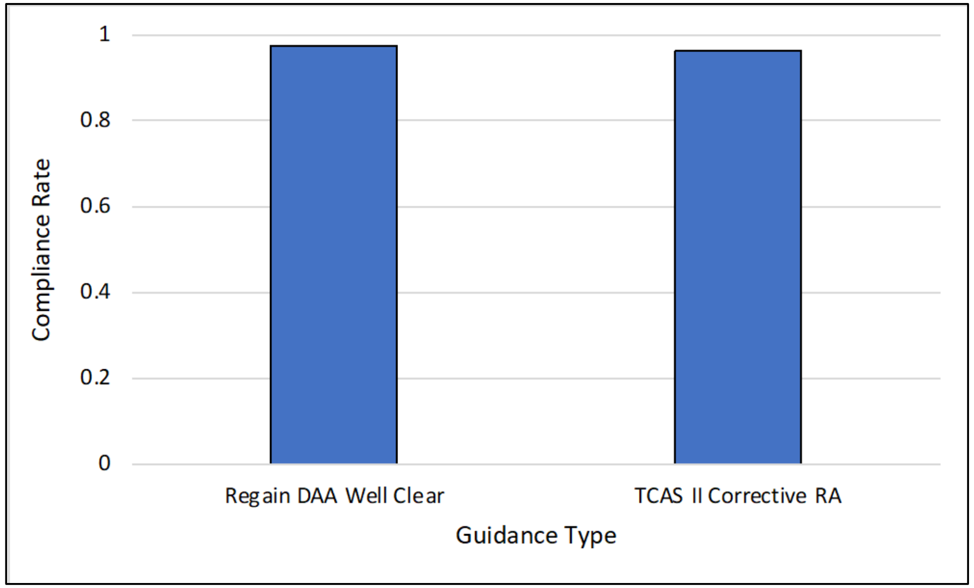
Phase 1 (Class 1) DAA alerting structure



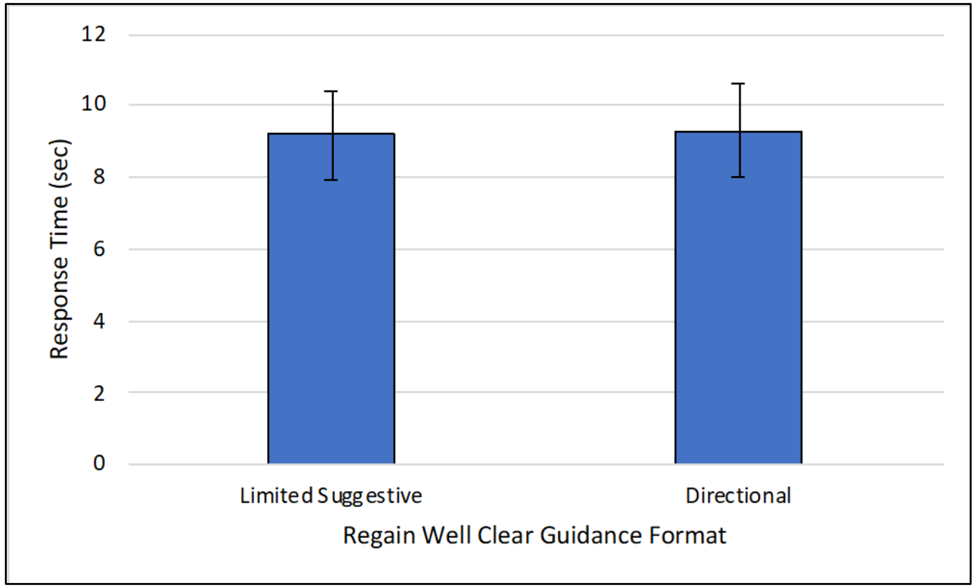
Phase 1 DAA suggestive guidance (heading and altitude "bands")

Phase 1 Overview

- **Focus Area 2—Detect and Avoid: En Route Operations**
  - Selection of Results (cont'd)
    - One study looked at integration of DAA & TCAS II found high rates of compliance with both guidance types
      - TCAS II Traffic Advisory (TA) replaced with DAA alerting
      - DAA guidance modified to not contradict TCAS II guidance
    - Separate study found that presentation of conflict-free trajectories and "regain" DAA well clear guidance had zero effect on pilot response times and loss of DAA well clear proportions



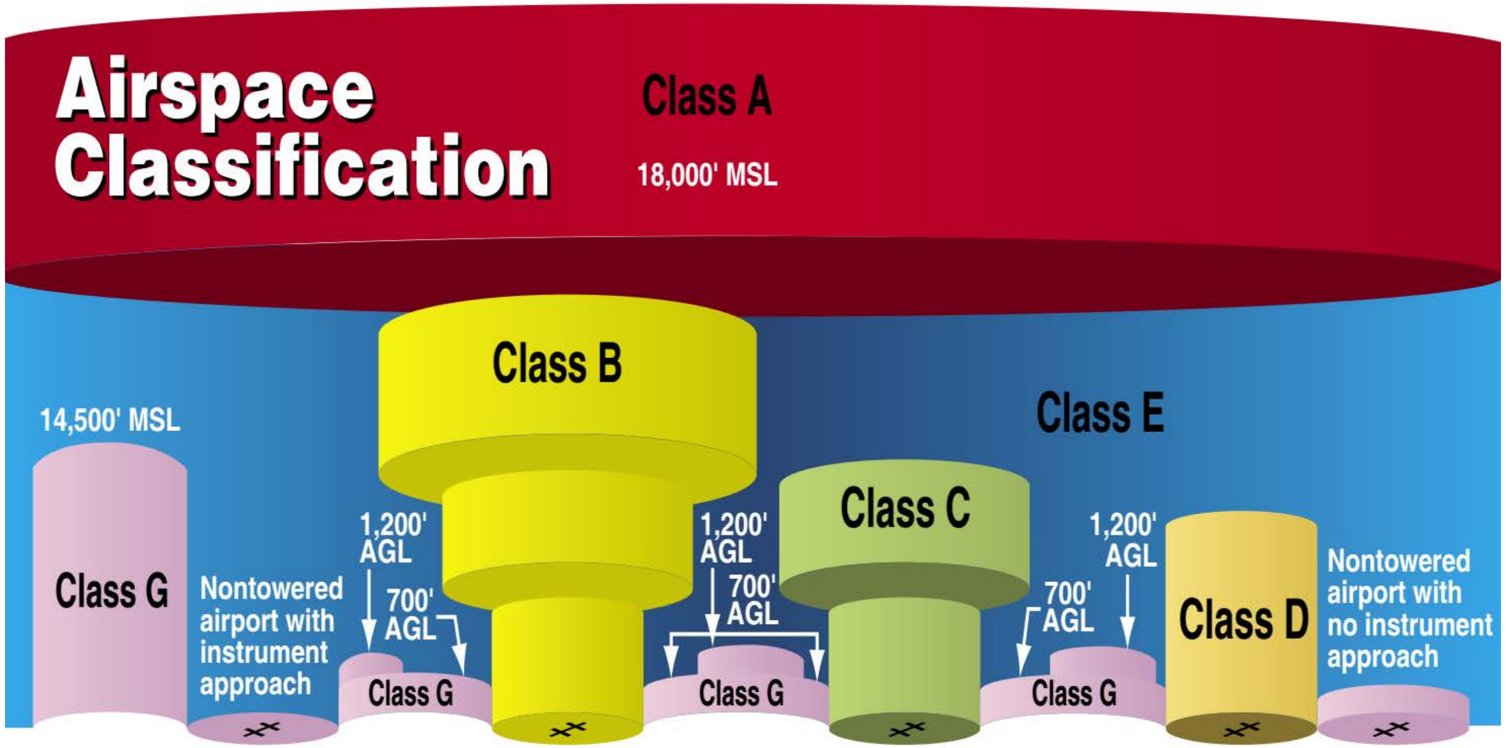
Compliance rate with regain vs. TCAS II guidance (Rorie & Fern, 2018)



Avg. response times to different regain well clear formats (Monk & Roberts, 2017)

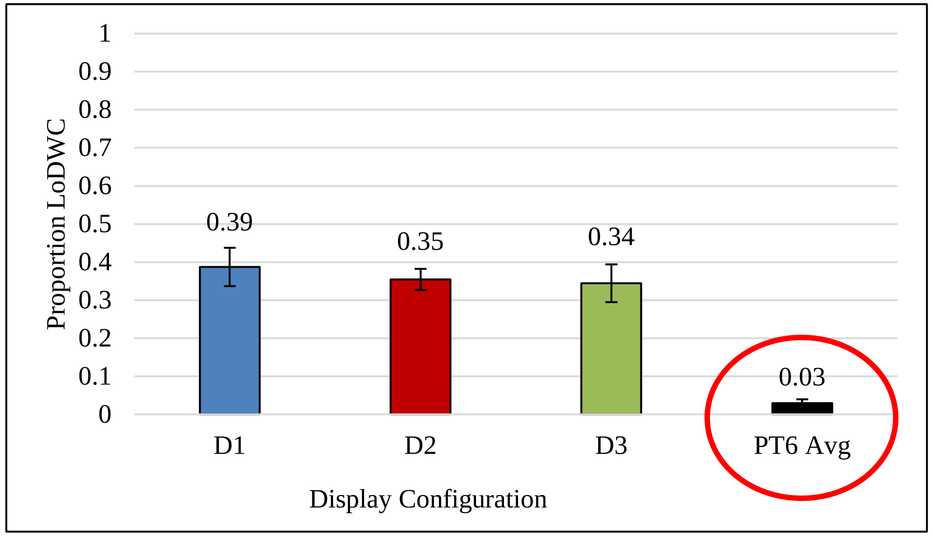
End of Phase 1

- **This wrapped up our Phase 1 work**
- **At the same time, RTCA SC-228's DAA MOPS transitioned into a new phase**
  - Phase 2 was designed to expand the scope to include a wider range of UAS operations
  - New operations included: terminal area operations, lower size, weight and power (SWaP) platforms and sensors, and more!

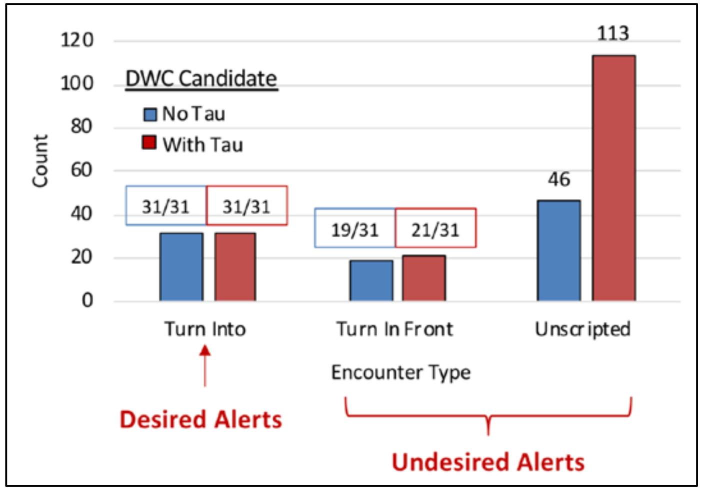


Phase 2 Overview

- **Focus Area 3—DAA: Terminal Area Operations**
  - HSI executed two studies to investigate DAA in the terminal area
    - Study 1 applied the en route DAA well clear definition and alerting while UAS flew into a Class D (towered) airport
    - Study 2 flew similar scenarios with terminal area-specific DAA well clear definitions
  - Selection of Results:
    - Study 1 found that UAS pilot response times and proportion/severity of losses of DAA well clear jumped up significantly
    - The terminal area-specific well clear definitions used in Study 2 led to far better performance
      - However, the definition that included a temporal component (i.e., modTau) led to more undesirable alerts
      - Also found strong evidence for adjusting the guidance structure (e.g., guidance should 'force' a missed approach)



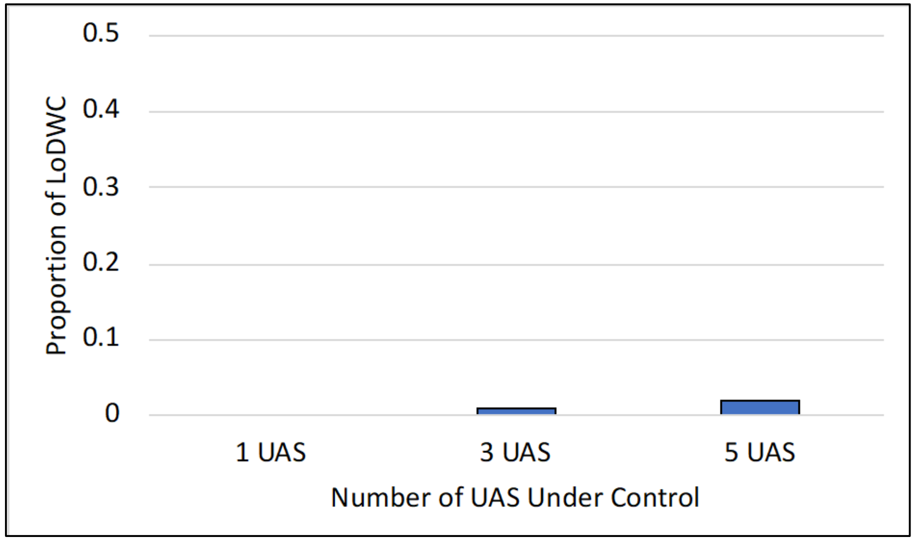
Proportion of losses of well clear in Study 1 (Fern et al., 2018)



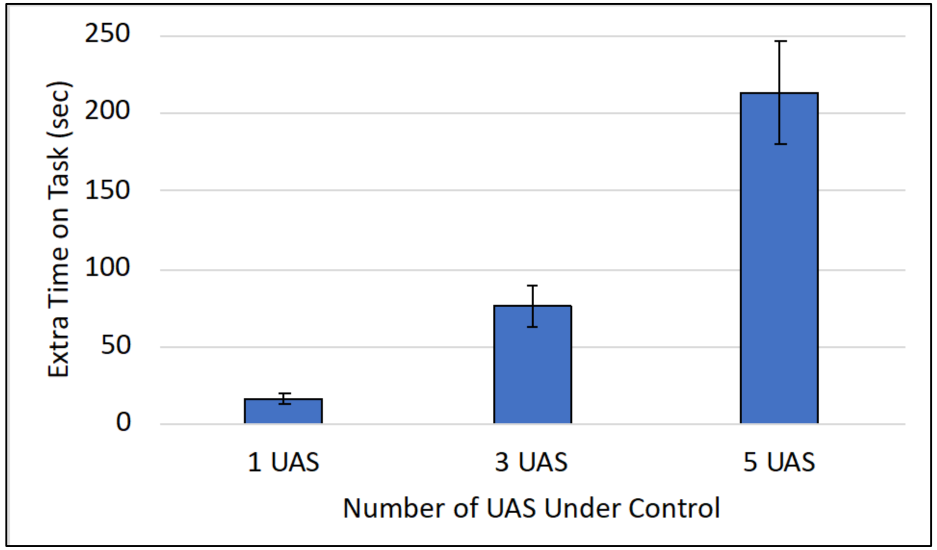
Number of desirable & undesirable alerts in Study 2 (Rorie et al., 2019)

Phase 2 Overview

- **Focus Area 4—DAA: Multiple UAS Operations**
  - One study was conducted that applied the en route DAA well clear definition and alerting/guidance requirements to a UAS operator controlling 1, 3, or 5 UAS
    - UAS pilot participants had to avoid DAA conflicts with one (or multiple) UAS while also executing search and rescue operations with each vehicle
  - Selection of Results:
    - Pilots proved surprisingly resilient to maintaining DAA well clear even when controlling 3 & 5 UAS
    - Task efficiency impacted severely by number of UAS



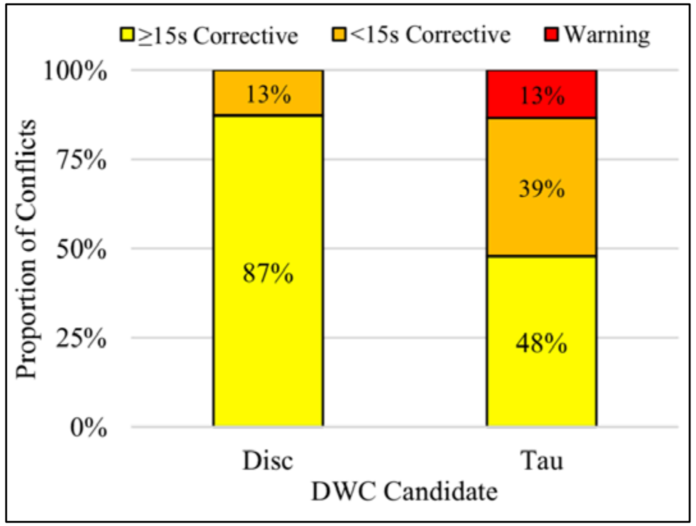
Proportion of losses of well clear by number of UAS (Monk et al., 2019)



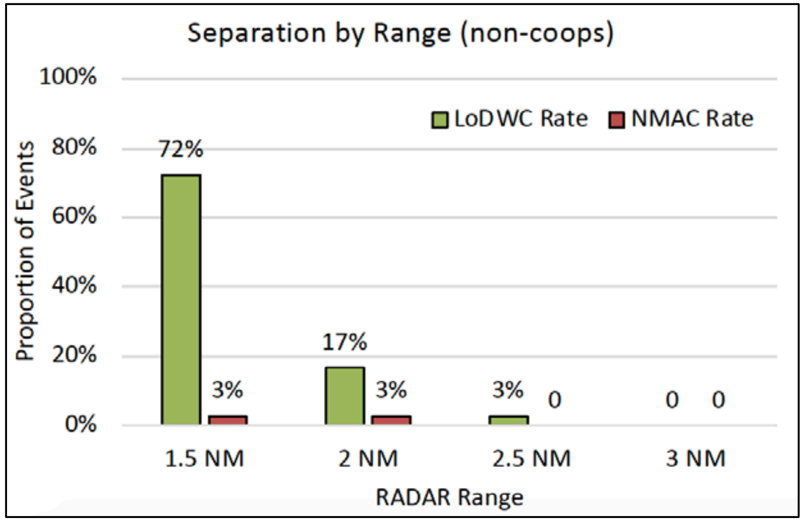
Average time over task by number of UAS (Monk et al., 2019)

Phase 2 Overview

- **Focus Area 5—DAA: Low Size, Weight and Power (Low SWaP) Operations**
  - Two simulations and one flight test were conducted that examined the impact of low SWaP sensor performance on the DAA system
    - Sim 1 looked at 2 different low SWaP-specific DAA well clear definitions
    - Sim 2 looked at 4 different low SWaP sensor declaration ranges
  - Selection of Results:
    - Sim 1 found that short-duration corrective alerts were more likely when modTau was included in definition
    - Sim 2 found that losses of DAA well clear increased significantly if declaration range dropped below 2.5nm
      - 2.5nm consistently provided the full warning alert time, which is associated with lower rates of losses of well clear

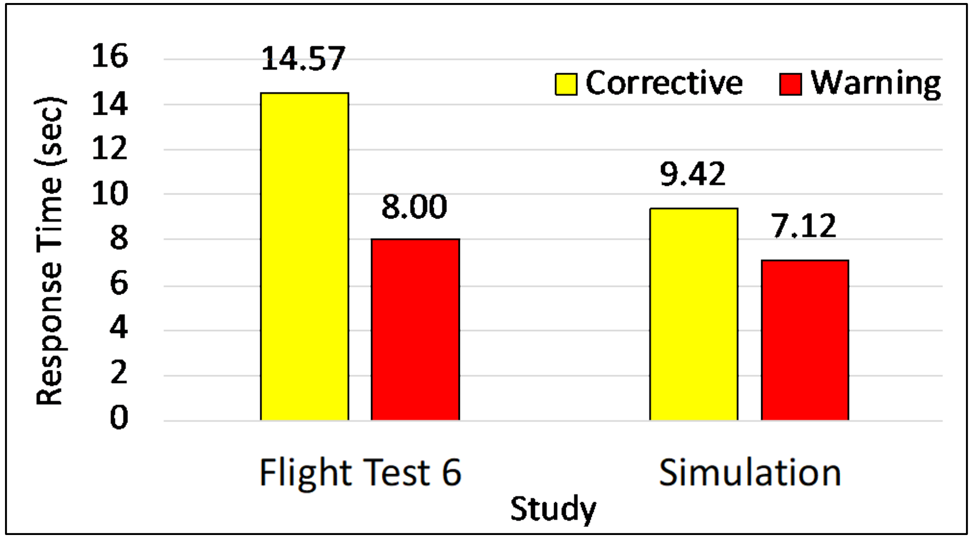


First alert type by DAA well clear definition (Monk et al., 2020a)

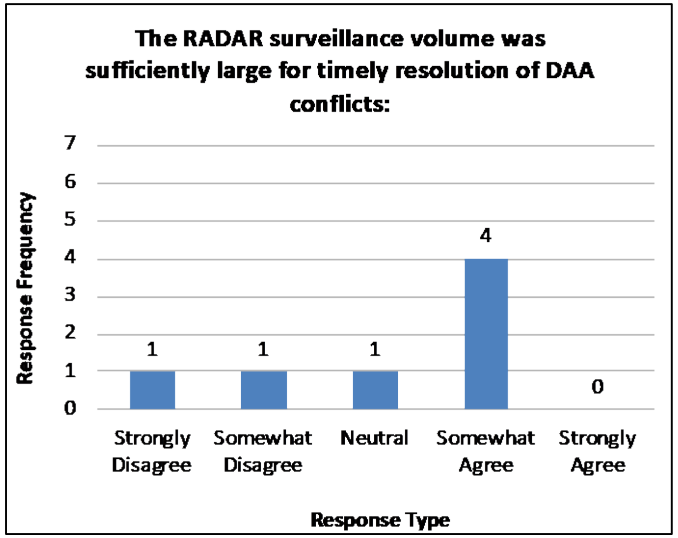


Proportion of losses of well clear by declaration range (Monk et al., 2020b)

- **Focus Area 5—DAA: Low Size, Weight and Power (Low SWaP) Operations**
  - Flight Test Series 6—Full Mission Configuration – emulated Low SWaP sensor onboard Tigershark XP
    - UAS pilot participants controlled the TigerShark while responding to live DAA conflicts using 2.5nm range
    - Same airspace environment used in HITL sims (virtual ATC & background traffic) was also in-the-loop
  - Selection of Results:
    - UAS pilot performance comparable between flight test and simulation (0 losses of well clear in flight test)
    - Flight test participants were accepting of 2.5nm declaration range but with considerable pushback



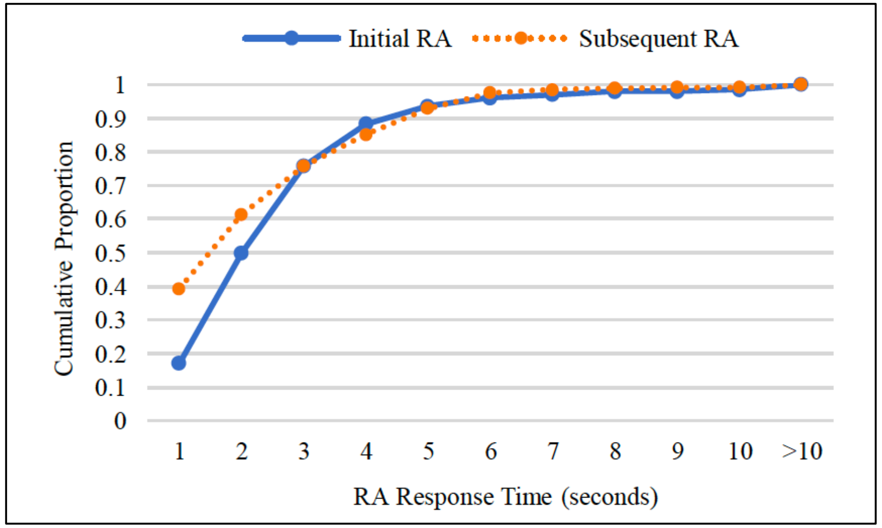
Average pilot response times in Low SWaP flight test vs simulation



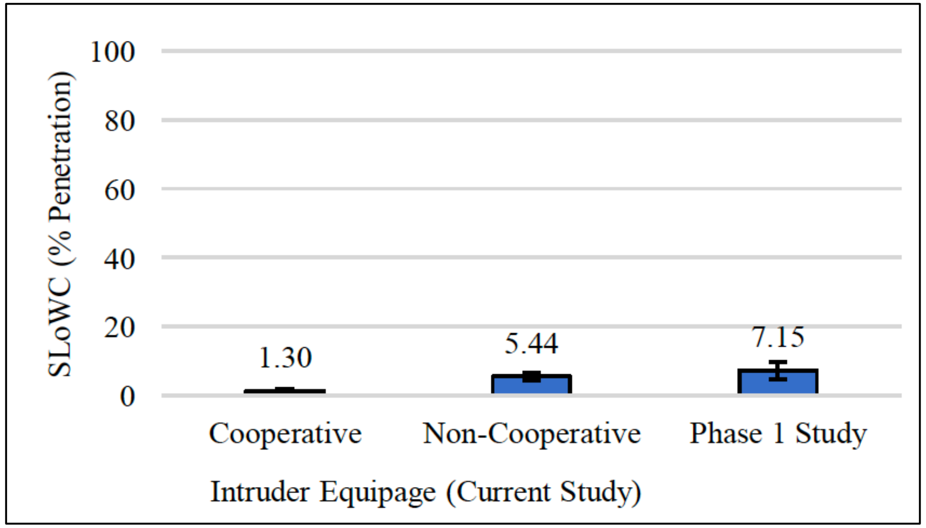
Subjective responses to acceptability of 2.5nm declaration range

Phase 2 Overview

- **Focus Area 6—DAA: Airborne Collision Avoidance System Xu**
  - One engineering analysis and one simulation investigated ACAS Xu
    - ACAS Xu issues both DAA alerts and Resolution Advisories (RAs)
    - ACAS Xu RAs can be vertical (same as TCAS II), horizontal, or blended (simultaneous horizontal and vertical)
  - Selection of Results:
    - The engineering analysis & HITL found that the visual and aural presentation used for depicting ACAS Xu RAs was intuitive and effective
    - The HITL demonstrated that with proper interface support tools, pilots could reliably meet the 5 second (and 2.5 second) RA response time requirements



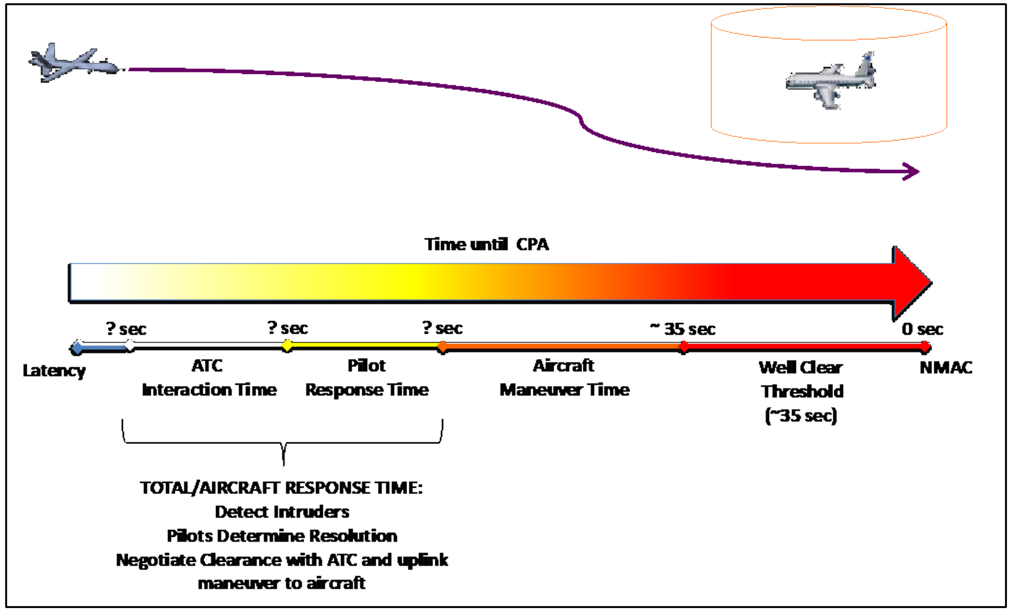
Average RA response times (Rorie et al., 2020)



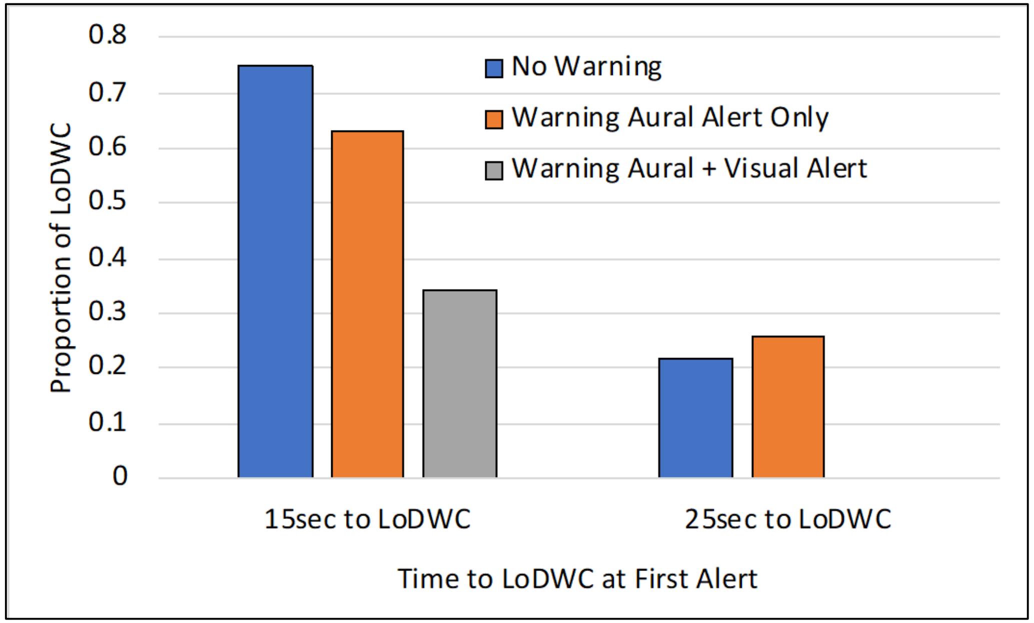
Average loss of well clear severity with ACAS Xu compared to Phase 1 (Rorie et al., 2020)

Major Successes

- **Phase 1 research established the need for capturing the 'measured response' for RTCA**
  – The pilot response & interaction timelines helped to inform the Phase 1 air-to-air RADAR declaration range requirements
    - ~10 seconds required for ATC coordination; ~10 seconds required for pilot to determine and execute appropriate response
- **Also helped designate suggestive DAA guidance and the DAA warning alert as minimum requirements**
  – Suggestive guidance led to strong performance and received high ratings from pilots
  – DAA warning alert reduced losses of DAA well clear by indicating ATC coordination was no longer appropriate

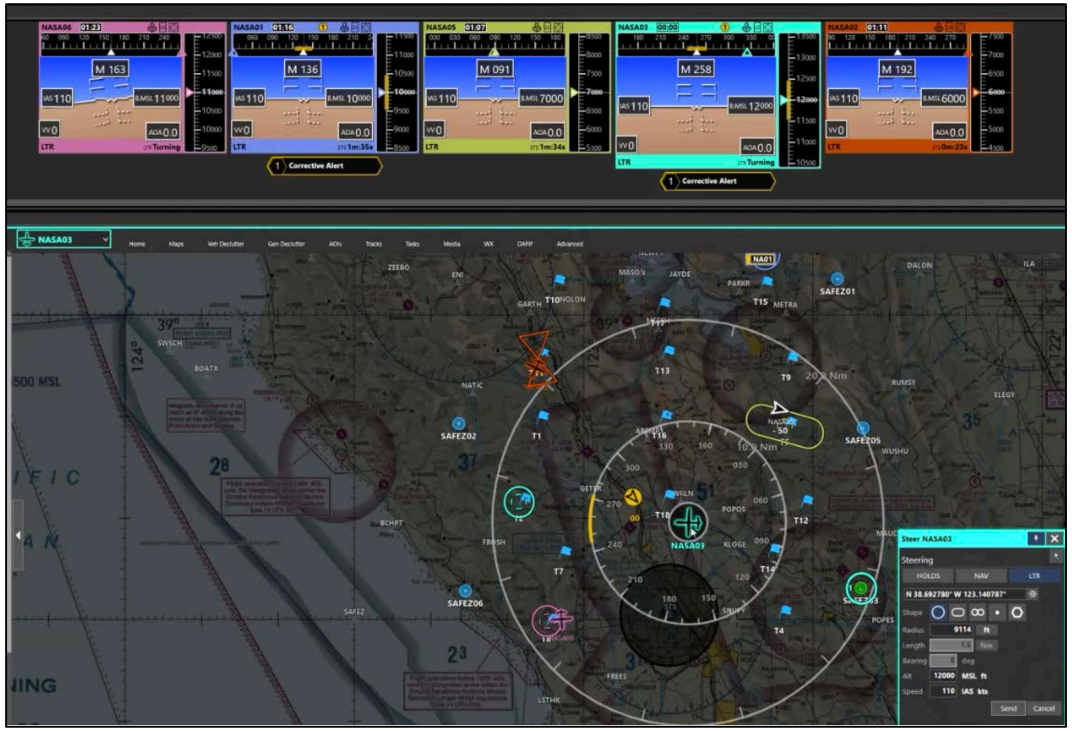


UAS pilot contribution to the intruder detection requirements

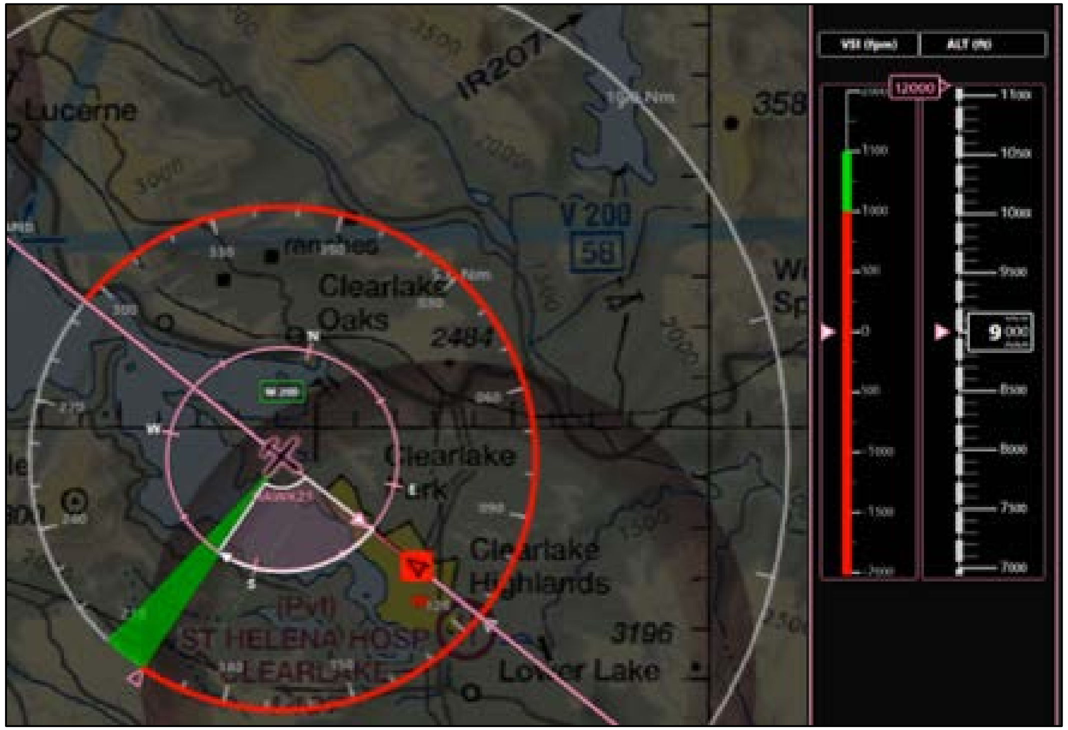


UAS pilot contribution to the intruder detection requirements (Monk et al., 2018)

- **Phase 2 research succeeded at extending the DAA system into new environments:**
  - HSI helped inform the development of 2 new DAA well clear definitions (i.e., non-cooperative and terminal area-specific definitions)
  - Work on multi-UAS control suggested that DAA supports 1:5 control paradigm (and potentially more)
  - Integration of ACAS Xu Run 5.0 demonstrated utility of real-time testing



Screenshot of multi-UAS control within Vigilant Spirit Control Station



Screenshot of ACAS Xu blended RA

Major Successes

- **HSI – with significant support CHAAT – helped contribute to the writing of DO-365**
  - SC-228 MOPS (Rev 0) Support
    - DAA Traffic Display Subsystem Requirements (2.2.5) section
    - DAA Traffic Display Subsystem Requirements test procedures section (2.4.5)
  - SC-228 MOPS (Rev’s A & B) Support
    - Rev A:
      - Updated test procedures for DAA Alerting and Guidance Processing Requirements (2.4.4)
      - Updated test procedures for DAA Traffic Display Subsystem Requirements (2.4.5)
    - Rev B:
      - Updated DAA Alerting and Guidance Processing Requirements (2.2.4) and DAA Traffic Display Subsystem Requirements (2.2.5) to incorporate Class 3 (ACAS Xu)

Lessons Learned

- **General**
  - Importance of incorporating human factors/HSI considerations early in development
    - Project and sub-project leads fought to play a role in RTCA
  - Higher fidelity simulation helps get “buy-in” from participants and stakeholders
    - Participants often complimented the quality of the training and background airspace environment
    - Resulted in more committed performance and robust feedback
  - Defining ‘minimum’ standards is hard – first impulse is to design a system that would perform ideally
    - Team had to get used to building up features and then paring them back
- **DAA specific**
  - Simplify alerting/guidance to the extent possible to aid in intuitiveness
    - Pilot behavior becomes more predictable
    - There are limits...over-simplifying can remove critical information (e.g., Is there time to contact ATC?)
  - Pilots benefit from suggestive guidance’s ability to indicate when it is safe to return to course
  - Top-down nature of ground station display makes horizontal maneuvers particularly compelling

Questions

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- **Focus Area 4—DAA: Multi-UAS**
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- **Focus Area 5—DAA: Low Size, Weight and Power (SWaP) Operations**
  - Monk, K. J., Rorie, R. C., Keeler, J. N., & Sadler, G. G. (2020). An examination of two non-cooperative detect and avoid well clear definitions. In *AIAA Aviation Forum 2020.* doi:10.2514/6.2020-3263
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- **Focus Area 5—DAA: Low Size, Weight and Power (SWaP) Operations (continued)**
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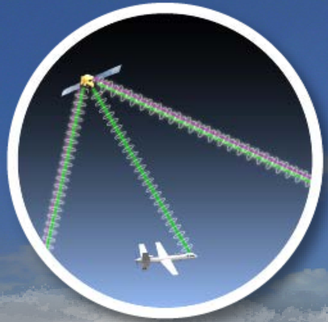
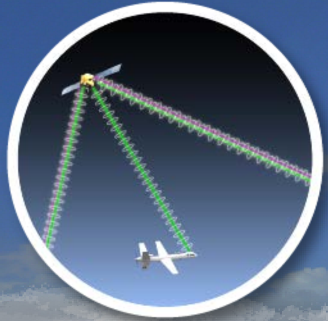


Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Technical Interchange Meeting

Break



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

Integrated Test & Evaluation Subproject Overview & Live Virtual Constructive (LVC) Environment

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Live Virtual Constructive Technical Lead, IT&E Subproject

ARC IT&E Team

Leadership Team
Ty Hoang
Estela Buchman
Jim Murphy
Neil Otto

LVC Developers
Srba Jovic
Jacob Pfeiffer
Jeffery Hernandez

System Engineer
John Connolly

Verification & Validation Developer
Aaron Lynch

Data Management
Jacob Pfeiffer

Subject Matter Experts
Wayne Bridges
Matthew Gregory
Zachary Roberts
Eric Sarbacker

ACAS Developers
Michael Roberts
David Shapiro
Marc Shaw-Lecerf

IT&E Roles and Responsibilities

Phase 1—Development

1. Develop a simulation architecture to support real-time human-in-the-loop (HITL) studies with support for UAV operations in the National Airspace System (NAS).
2. Develop a flight test infrastructure to conduct UAV flight in the NAS with communication and coordination with air traffic control and other traffic.
3. Develop the Live Virtual Constructive (LVC) software and network to combine HITL simulation and flight test capabilities to provide high-fidelity operations.

Phase 2—Execute simulations and flight tests

1. Work with researchers from other subprojects to design and execute research concepts via simulation or flight test activities.
2. Integrate Detect and Avoid (DAA) technologies.
3. Provide system integration testing, Verification & Validation (V&V) testing.
4. Collection, dissemination , and archival of simulation and flight test data (audio, video, aircraft state, messaging).

The Live Virtual Constructive – Distributed Environment (LVC-DE)

The LVC-DE software and framework was developed to support simulation and flight test activities at NASA Ames and Armstrong

Constructive – Simulated vehicle executing predefined route and trajectory

Virtual – Human controlling simulated vehicle

Live – Human controlling real vehicle

Distributed Environment – Apply LVC capabilities across test sites and participants

The Live Virtual Constructive (LVC) Attributes

Distributed

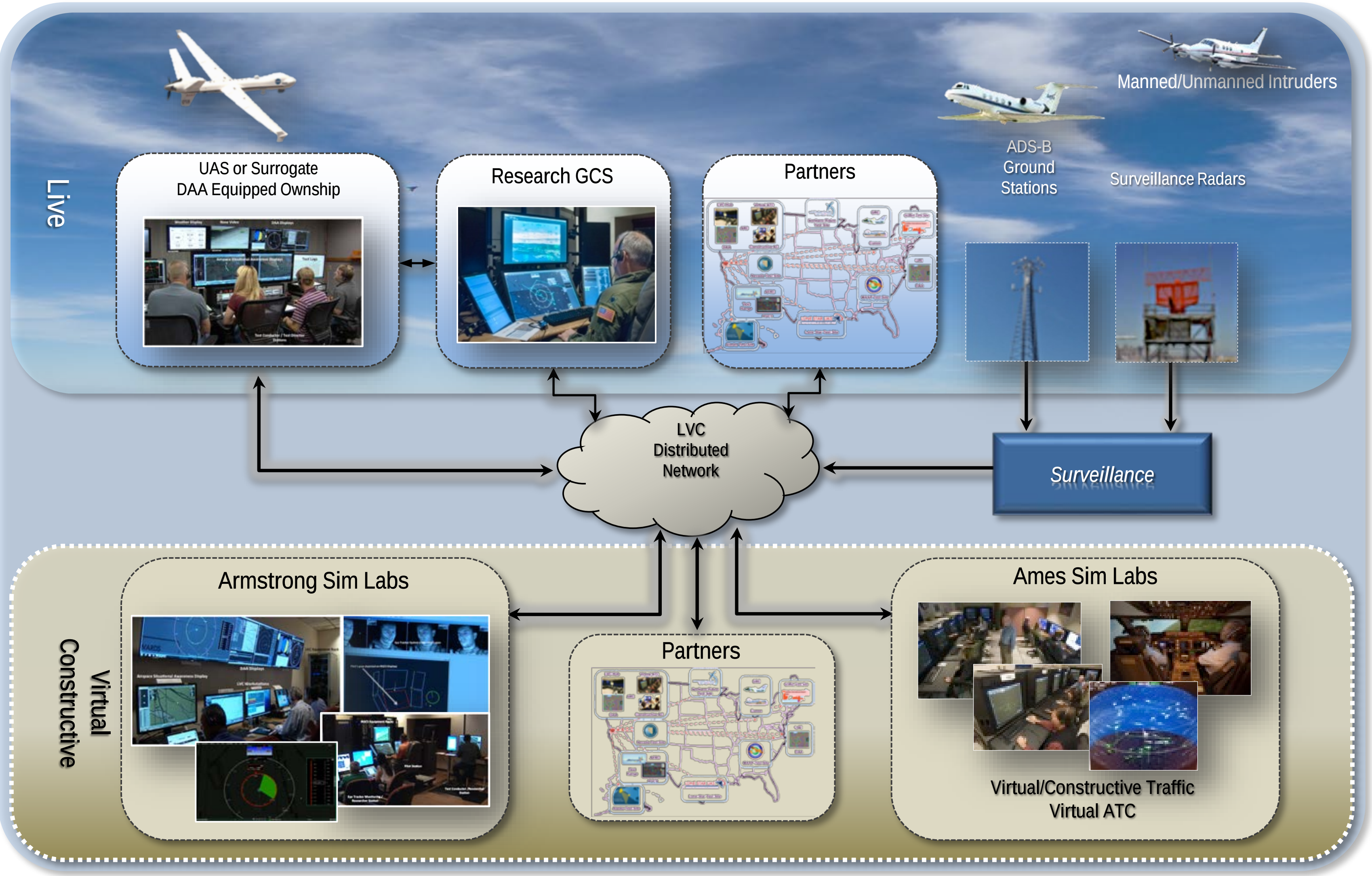
- To support asset usage where they exist
- External partner support

Adaptable

- Support for dynamic research requirements
- Utilize inputs from multiple surveillance sources (air and ground)
- Emulate data sources and features

Extensible

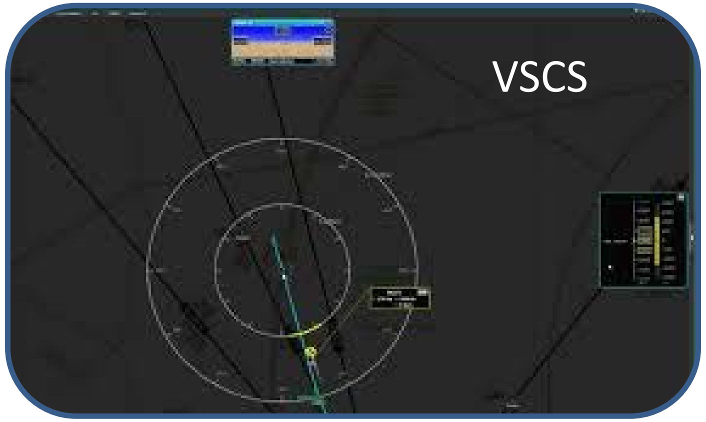
- Use for simulation and live flight testing
  - Reduces risk moving between simulation and flight test
- Across NASA centers
- Tie in UAS partners

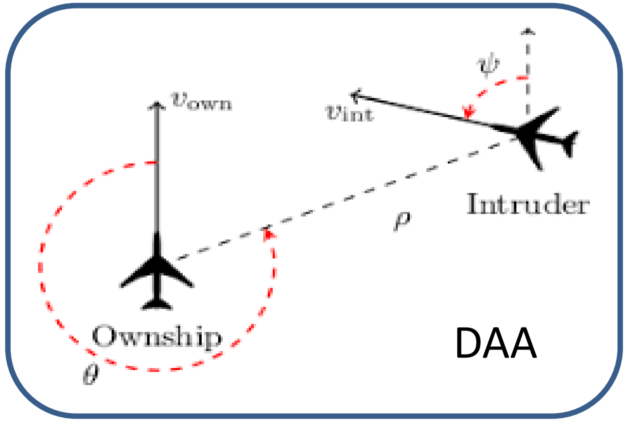


IT&E Simulation Environment

Software Components

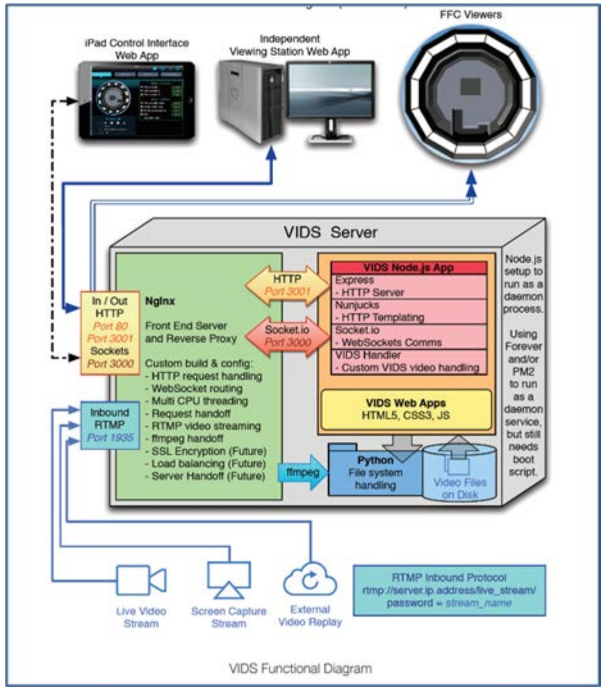
- **LVC** and gateway installed at Ames and Armstrong
- Multi-Aircraft Control System (**MACS**)
- Integration of software components
  - Vigilant Spirit Control Station (VSCS) (HSI team)
  - Detect and Avoid (DAA) algorithm (M&S team)
  - ACAS-Xu algorithm (FAA/MIT-LL)
  - Sense and Avoid processor (SaaProc)



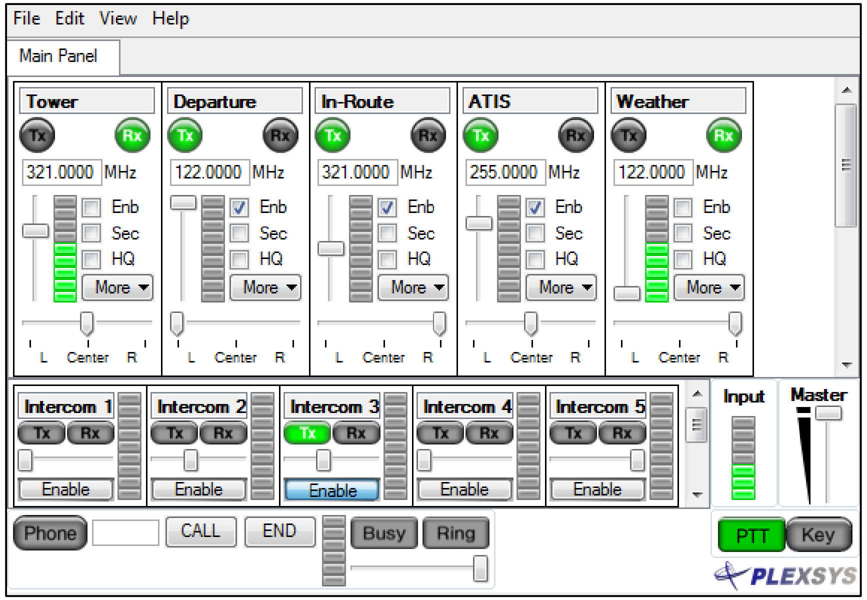


MACS

VIDS



Plexsys



Hardware Components

- LVC & MACS workstations (Linux, Windows)
- Video Ingest and Distribution System (VIDS)
- Plexsys and Simphonics audio system

IT&E Simulation Environment (continued)

Facilities

- Distributed Simulation Research Lab (DSRL)
- Software Development Laboratory (SDL)
- FutureFlight Central (FFC)

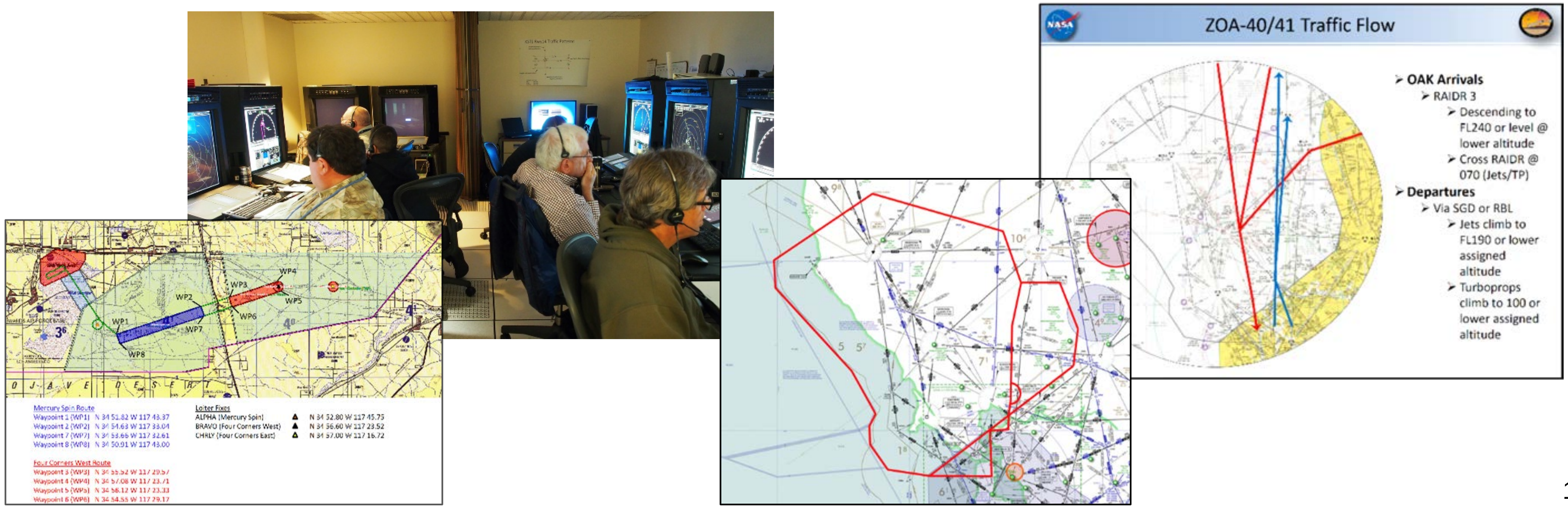
Staffing Support

- Pseudo-pilots
- ATC knowledge
  - Domain application
  - Scenario development
- Test subject pilot recruitment
- Training all staff

DSRL

SDL

FFC



Summary of Ames IT&E Supported Activities

Throughout the span of the UAS-NAS project, IT&E supported:

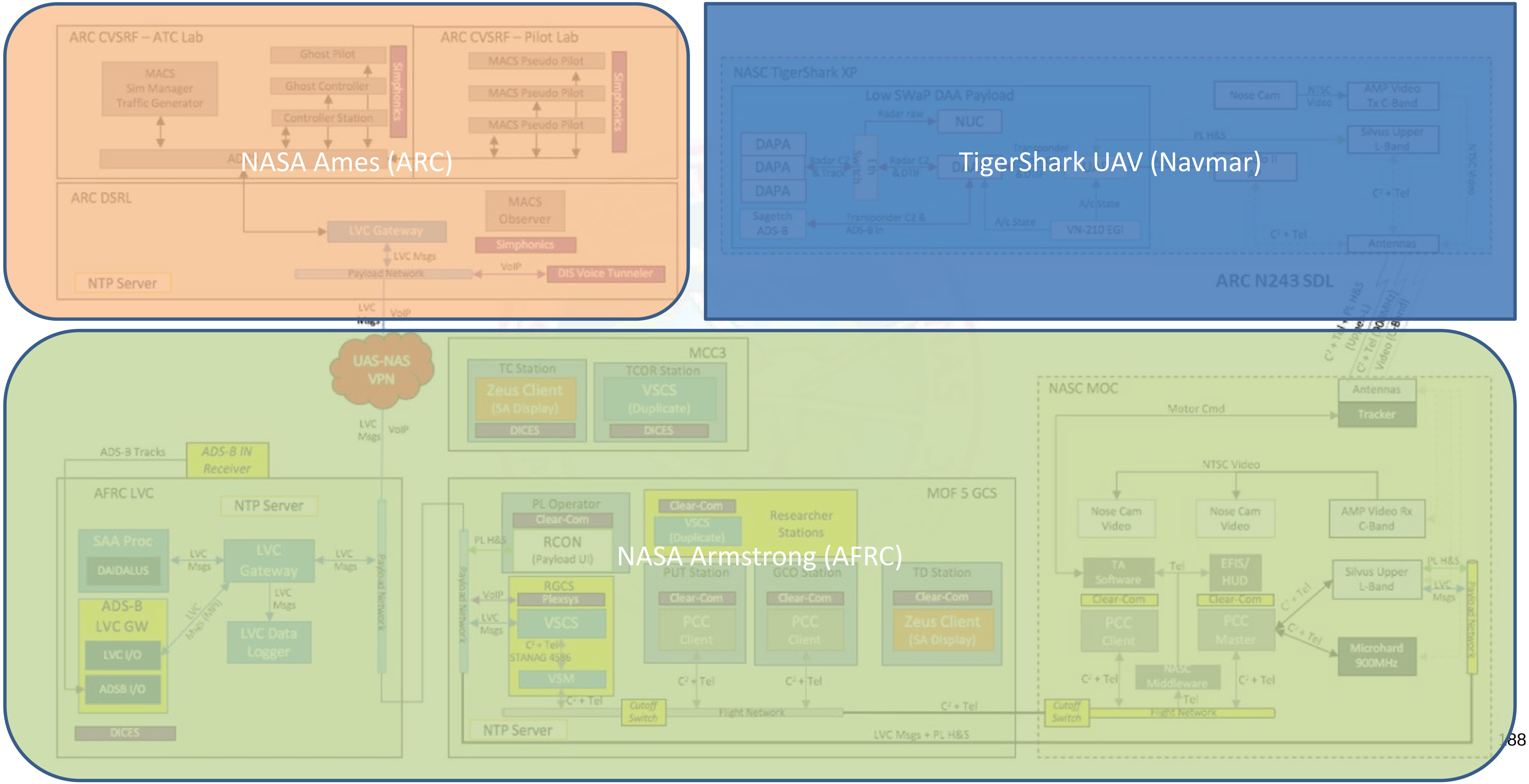
- 2 – **Proof-of-concept demonstrations**
  - Fort Hood Demonstration
  - No Chase COA Flight Demonstration
- 13 – **Human-in-the-Loop (HITL) simulations**
  - Airborne Collision Avoidance System Xu (ACAS-Xu), Full Mission, Integrated HITL (I-HITL),
  - Low Size, Weight, and Power (Low SWaP), Multi-UAS,
  - Part Task 3, Part Task 4, Part Task 4B, Part Task 5, Part Task 6,
  - TASATS, Terminal Operations (TOPS 1), and TOPS 1b
- 5 – **Flight Test (FT) activities**
  - ACAS-Xu Flight Test 1, Flight Test 2, Flight Test 3, Flight Test 4, and ***Flight Test 6***
- 4 – **Outreach events**
  - (2) Association for Unmanned Vehicle Systems International (AUVSI)
  - (1) EAA AirVenture Oshkosh
  - (1) InterDrone

IT&E Support of FT-6

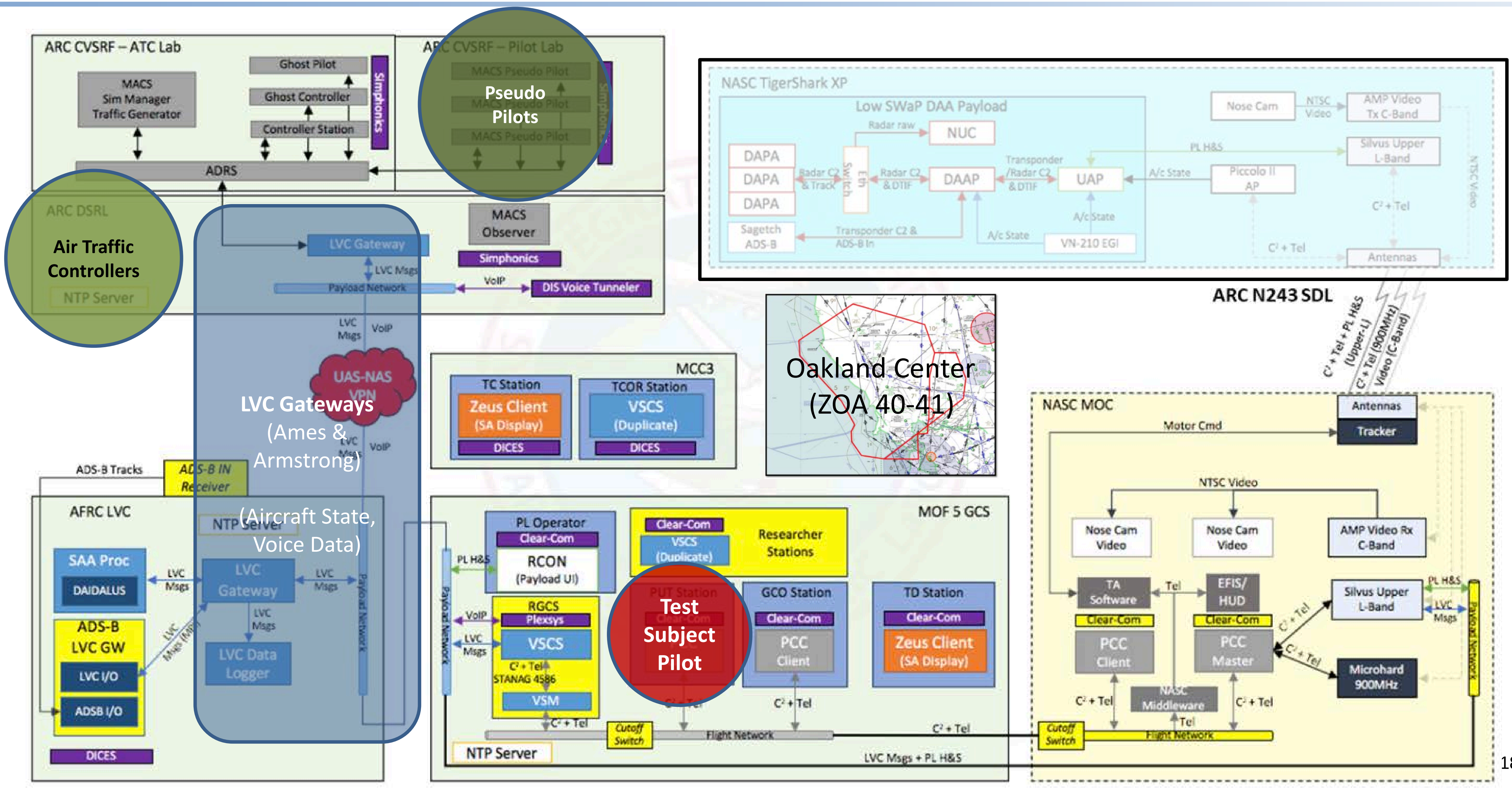
Objective

FT6 required a pilot to execute a UAS mission in the NAS designed to validate human-systems integration performance and DAA requirements. To conduct the flight test, the UAS-NAS Project utilized a Navmar Applied Sciences Corporation TigerShark XP UAS, which was integrated into the LVC-DE network. This allowed live flight and simulation assets from multiple NASA centers to construct a simulated NAS environment.

FT-6 Connectivity Diagram



FT-6 Communication and Data ‘Walk-Through’ Sequence



IT&E Simulation Facilities

Distributed Simulation Research Lab (DSRL) Layout

Ames Research Center, Distributed Simulation Research Laboratory, N-243, Room 240

Software Development Laboratory (SDL) Layout

Ames Research Center, Software Development Laboratory, N-243, Room 261

Existing and Former LVC Connected Partners

The NASA Ames team has worked with the following parties to establish an LVC connection:

NASA

- Armstrong
- Langley
- Glenn

FAA Test Site Partners

- North Dakota Department of Commerce, ND
- Virginia Polytechnic Institute & State University, VA
- Griffiss International Airport, NY
- University of Alaska Fairbanks, AK
- Nevada Institute of UAV, NV
- Texas A&M University Corpus Christi, TX

Leave Behind Capability of LVC

Ames still retains the following capabilities including status as indicated.

- **Software**
  - LVC – Utility is currently in stand-by mode but can quickly be put back in circulation if other projects needs it. Functionality is frozen with current configuration.
  - MACS – Actively being supported by the Ames community. Functionality is frozen with current configuration.
  - UAS-NAS related software and configuration files have been preserved in a demonstration ‘sandbox’.
- **Hardware**
  - All MACS and LVC workstations are in stand-by mode but remains fully functional.
  - Video Ingest and Distribution System (VIDS) – Fully functional in DSRL facility.
  - Plexsys and Simphonics audio system – Fully functional in SDL and DSRL facilities.
- **Facilities**
  - Distributed Simulation Research Lab (DSRL) – Stand-by mode but anticipated to be repurpose for other project.
  - Software Development Laboratory (SDL) – Stand-by mode but anticipated to be repurpose for other project.
  - FutureFlight Central (FFC) – Stand-by mode.
- **Staffing**
  - Majority of contractor members are still on-site but have been reassigned to other projects.
  - Civil servant members are in process of migrating to other projects.

Lessons Learned

- Work closely with researchers to obtain requirements early in development cycle and maintain constant contact to ensure accurate system development.
- Ensure system integration testing and subsystem checkout procedures are strictly adhere to, promoting system integrity and functionality. Useful when doing parallel development with multiple stakeholders.
- To the extend possible, ensure that pilot training on simulated Ground Control Station (GCS) should match as much as possible to the operational GCS system. Can be challenging when training system is not configured exactly as the operational system.
- Ensure testing schedule includes more-than-planned system checkout and data collection flights. Due to small UAV size and less robust performance characteristics, windy conditions and shared range-usage can affect planned flight runs.

Q & A

Backup Slides

Roles and Responsibility of the Integrated Test and Evaluation (IT&E) Subproject

- **Develop infrastructure to support and conduct Human Factors research**
  - Laboratory facilities, ground control station, test subject recruitment
  - Simulation environment (virtual air traffic control environment, and communication)
- **Develop infrastructure to support and conduct Detect and Avoid (DAA) research**
  - Laboratory facilities, simulation environment, scenario conditions
  - Detection distance, Closing rate, DAA applicability in en-route and terminal airspace
  - Remain Well Clear definition, Low Size Weight and Power requirements
  - Help define Minimum Operational Performance Standards requirements (MOPS) with RTCA
- **Develop infrastructure to support and conduct Flight Test activities**
  - Scenario development, Flight test Range, telemetry, surveillance, communication at NASA Armstrong
  - Provide flight test vehicles (UAV, chase plane, live intruder aircraft)
  - Integrate UAS DAA technologies with UAV in flight tests
- **Develop Live Virtual Constructive (LVC) system to support HITL simulations and flight tests**
- **Develop and Provide Verification and Validation (V&V) support**
- **Develop and Provide Voice, Video, and Data Recording, Dissemination, and Archival support**

Summary of IT&E Activities

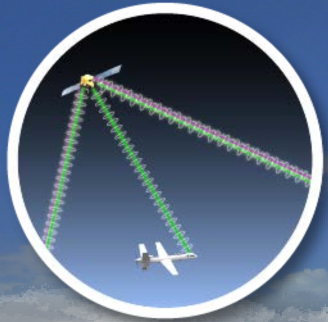
Activities	Date	HITL (15)	Flight Test (with LVC) (3)	External / Outreach (3)
Part Task 3	Feb 2012 – April 2012	VSCS / ZLA	-	-
Fort Hood Demonstration	June 2012 – Aug 2012	MACS / Robert Gray Army Airfield / FFC	-	Army
Full Mission	Feb 2013 – July 2013	VSCS / DAA / ZOA	-	-
TASATS	Feb 2013 – July 2013	MACS / ATC / DAA	-	-
Part Task 4	Aug 2013 – Feb 2015	VSCS / DAA Displays	-	-
Integrated HITL	Sept 2013 – Aug 2014	Integrate AFRC, ARC, & LaRC Sim	-	-
Part Task 4B	July 2014 – Oct 2014	GA's CPDS / DAA / Display Evaluation	-	RTCA
Part Task 5	Sept 2014 – April 2015	DAA / HSI / Inform RTCA SC-228 MOPS	-	RTCA
Flight Test 3	Jan 2015 – Sept 2015	LVC / ATC / Confederated Pilots	4-NASAs / DAA-A&G, C2 / SC-228 MOPS	RTCA
Part Task 6	Aug 2015 – Feb 2016	DAA MOPS DAG / HSI / TCAS II RA, VSCS	-	RTCA
Flight Test 4	Feb 2016 – April 2016	-	JADEM, DAIDALUS / CPDS, TCAS, radar / Ikhana	GA / Honeywell / RTCA
Terminal Operations (TOPS) 1	Jan 2017 – Nov 2017	SaaProc / VSCS / STARS, Class-D, KSTS	-	RTCA
ACAS-Xu Flight Test 2	June 2017 – Oct 2017	LVC / ATC / Confederated Pilots	ACAS-Xu, CPDS / RIG viz. to DSRL-FFC	GA
No Chase COA Flight Demo	Aug 2017 – June 2018	LVC / ATC / Confederated Pilots	DAA / ZOA-ZLA / Ikhana	-
Terminal Operations (TOPS) 1B	Dec 2017 – June 2018	Phase 1 DAG / Multi-UAS selection / SSA	-	AFRL

Summary of IT&E Activities (continued)

Activities	Date	HITL (15)	Flight Test (with LVC) (3)	External / Outreach (3)
Multi-UAS Simulation	Fed 2018 – Sept 2018	1-5 ac per VSGS with DAG	-	-
Low Size Weight & Power (Low SWaP)	Apr 2018 – Dec 2018	Evaluate DAA Well Clear / Pilot Perf.	-	RTCA
AUVSI	*April 2018*	-	-	*Portable LVC & VSCS*
EAA AirVenture, Oshkosh	*July 2018*	-	-	*Portable LVC & VSCS*
InterDrone	*Sept 2018*	-	-	*Portable LVC & VSCS*
ACAS Xu HITL	Oct 2018 – June 2019	ACAS Xu / Sensor Noise / DAA / Pilot Perf.	-	MIT-LL / Honeywell
Flight Test 6	Oct 2018 – Dec 2019	LVC / ATC / Confederated Pilots	DWC / Low SWaP / Display Req	RTCA
AUVSI	*April 2019*	-	-	*Portable LVC & VSCS*

In Summary:

- 2 – Proof-of-concept demonstration
- Fort Hood Demonstration, No Chase COA Flight Demonstration
- 13 – HITL simulations
- ACAS-Xu, Full Mission, I-HITL, Low SWaP, Multi-UAS, Part Task 3, Part Task 4, Part Task 4B, Part Task 5, Part Task 6, TASATS, TOPS 1, and TOPS 1b
- 5 – Flight Test (FT) activities
- ACAS-Xu FT2, FT3, FT4, and FT6
- 4 – Outreach activities
- AUVSI, EAA AirVenture Oshkosk, InterDrone



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

Integrated Test & Evaluation Subproject

Flight Test

Sam Kim

IT&E Technical Lead, IT&E Subproject

AFRC IT&E Team

Project Management
- Heather Maliska
- Mauricio Rivas
- Robert Navarro
- Peggy Hayes

Operations Eng
- Mike Marston
- Alex Flock
- Steffi Valkov
- Doug Wada
- Dan Sternberg
- Gabe Baca

Flight Systems
- Victor Loera
- Rashmi Vidyasagar
- Kassidy McLaughlin
- Jamie Willhite
- Ed Koshimoto
- Martin Hoffman
- Mike Dandachy
- Kurt Sanner
- Ricardo Arteaga
- Sky Yarbrough

Simulation Eng
- Gayle Patterson

Systems Eng
- Daniel Eng
- Mike Scardello

System Safety
- Ken Cross
- Barbara Labarge
- Phil Burkhardt

Software Assurance
- Duc Tran

Project Pilots
- Scott Howe
- Hernan Posada
- Mark Pestana

UAS in the NAS IT&E Flight Test Summary

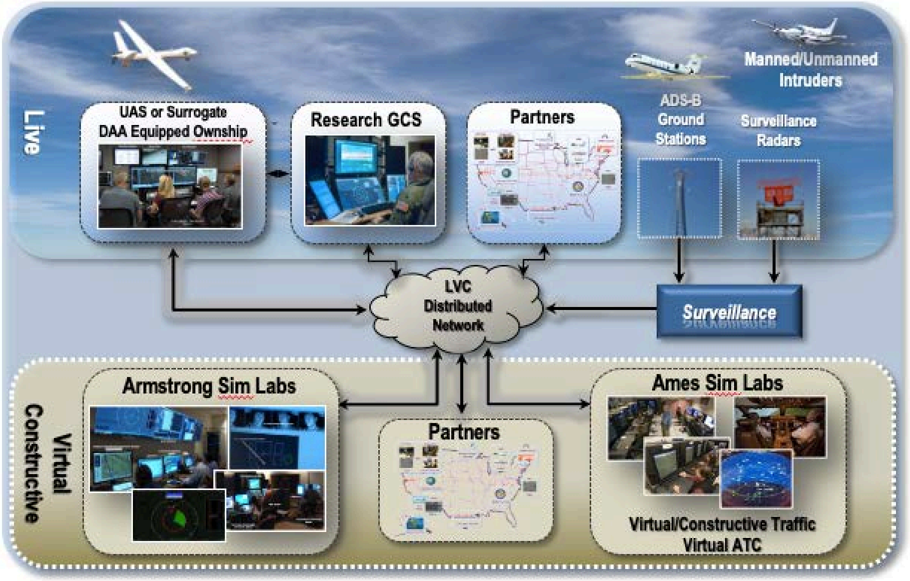
	Foundational Build-up of IT&E Infrastructure and Capabilities		Inform Phase 1 DAA Systems and Air-to-Air Radar (ATAR) MOPS				Validate Phase 1 DAA Systems and ATAR MOPS	Inform ACAS Xu MOPS	Capstone Demo	Inform Phase 2 Low SWaP DAA Systems and ATAR MOPS	
Flight Test Campaign	**Flight Test 1**	**Flight Test 2**	**ACAS Xu Flight Test 1**	**Initial DAA Flight Test**	**Flight Test 3**		**Flight Test 4**	**ACAS Xu Flight Test 2**	**NCC Flight Demo**	**Flight Test 5**	**Flight Test 6**
					Config 1	**Config 2**					
Project Phase	Phase 1							Phase 2			
Duration	05/15/2012 – 08/11/2012	05/23/2013	11/17/2014 – 12/10/2014	12/15/2014 – 12/19/2014	06/17/2015 – 07/24/2015	07/13/2015 – 08/12/2015	04/12/2016 – 06/30/2016	06/13/2017 – 08/01/2017	02/14/2018 – 06/12/2018	10/24/2018 – 10/25/2018	07/09/2019 – 11/21/2019
Sorties	4	1	6	3	11	15	21	12	5[1]	3	23
Flight Hours	9.6	Tagalong	27.8	13.5	56.2	36.4	98.1	56.0	17.9	4.5	67.6
Encounters	N/A	N/A	114	56	212	38	321	241	N/A	58	245
Ownship	NASA Ikhana UAS	NASA T-34C	NASA Ikhana UAS	NASA Ikhana UAS	NASA Ikhana UAS	NASA T-34C UAS Surrogate	NASA Ikhana UAS	NASA Ikhana UAS	NASA Ikhana UAS	Honeywell AStar Helicopter	NASC TigerShark B3 XP UAS

Note:
1 – Flight #5 was the NCC flight demo without a safety chase aircraft (flight hours: 2.7 hrs with 1.8 hrs in the NAS outside of SUA)

IT&E Flight Test Overview—Flight Test 1

Phase 1

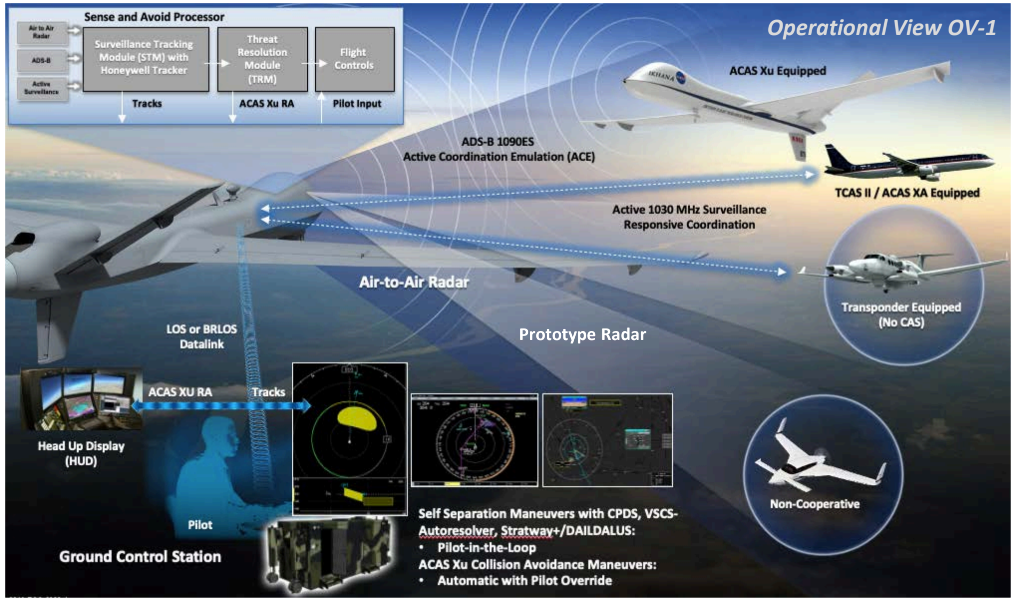
- **IT&E was a Technical Challenge chartered to**
  - Develop a distributed and scalable flight test environment for UAS DAA research
    - Incorporate NextGen technologies into the flight test infrastructure
    - Develop an LVC environment
    - Leverage existing and/or modify test aircraft
    - Leverage special use airspace
  - Plan and execute UAS DAA flight tests
- **Flight Test Series 1 Objectives**
  - Equip NASA Ikhana UAS with a COTS ADS-B Out/In system
  - Validate ADS-B Out performance
  - Collect ADS-B In data
  - Conduct initial LVC testing



IT&E Flight Test Overview—Flight Test 1 and 2

- **Flight Test 1 Results**
  - Confirmed Ikhana's ADS-B Out system met FAA Advisory Circular AC 20-165 for ADS-B Out equipage
  - Documented ADS-B In integration challenges unique to UAS
  - Established collaboration with the FAA Tech Center for support with validated data analysis tools
  - Verified data exchange of live, virtual, and constructive traffic data
- **Flight Test 2 Objectives**
  - Continue to evolve the LVC-DE
  - Establish LVC connectivity to GRC
  - Exchange ownship state data during T-34C CNPC flight test
- **Flight Test 2 Results**
  - Expanded LVC connectivity
  - Collected LVC latency data

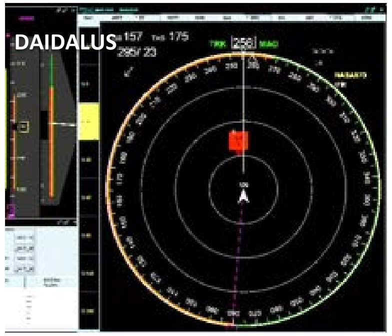
- **ACAS Xu Flight Test 1 Objectives**
  - Establish partnership with GA-ASI to equip NASA Ikhana UAS with critical prototype DAA capabilities for future flight tests
  - Collaborate with the FAA TCAS Program Office to mature the ACAS Xu proof-of-concept software (Run 1) in support of ACAS Xu MOPS development
  - Validate modeling and simulation tools and results
  - Demonstrate system behavior integrated on prototype avionics and UAS



- **ACAS Xu Flight Test 1 Results**
  - First time a CA system for UAS was tested without artificial horizontal or vertical offsets
  - First CA flight test employing UAS vs. UAS encounters
  - Sensor fusion successfully tracked multiple intruder aircraft
  - Successfully demonstrated performance of Run 1 proof-of-concept functionality

IT&E Flight Test Overview—Initial DAA Flight Test

- **Initial DAA Flight Test Objectives**
  - Assess DAA algorithm performance in the presence of sensor uncertainty and winds aloft
  - Collect data to develop realistic surveillance, alerting, and maneuver guidance models for simulations
  - Obtain pilot feedback on operational utility of the pilot guidance concepts
    - Vigilant Spirit Control Station (VSCS) - Autoresolver: Directive guidance, NASA/AFRL
    - Stratway+/DAIDALUS: Suggestive guidance, NASA
    - Conflict Prediction and Display System (CPDS): Suggestive guidance, GA-ASI
  - Continue to evolve the LVD-DE
  - Conduct risk reduction activities for Flight Test 3

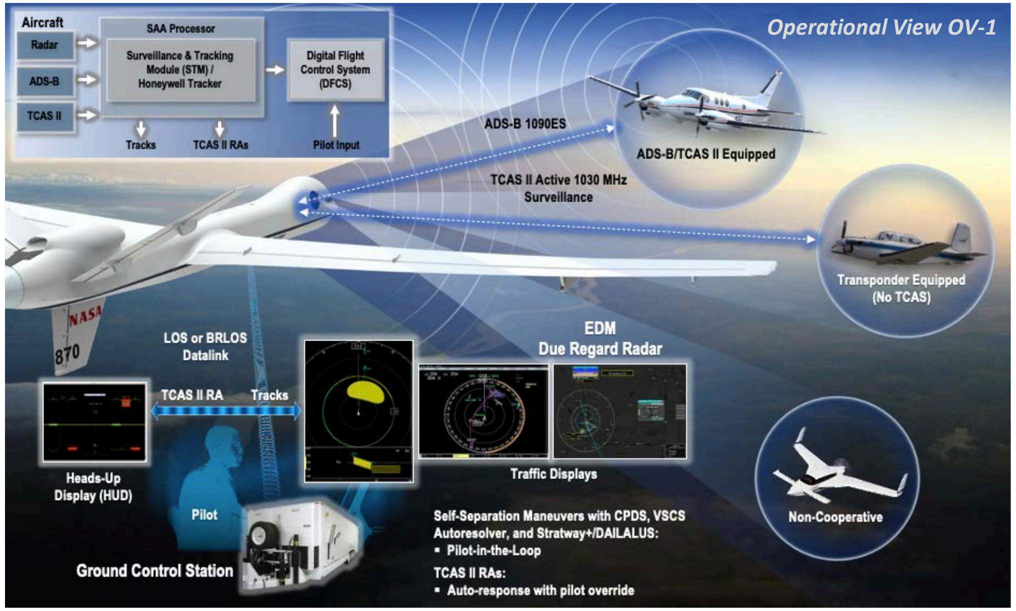


- **Initial DAA Flight Test Results**
  - Noisy or variation in aircraft state data resulted in intermittent threat detection and inconsistent maneuvers
  - UAS pilots were able to use the DAA alerting and guidance to maneuver
  - Valuable lessons learned and effective risk reduction for follow-on Flight Test 3
    - Data transfer inefficiencies encountered with large data files
    - Develop better data transfer methods and common analysis tools

IT&E Flight Test Overview—Flight Test 3

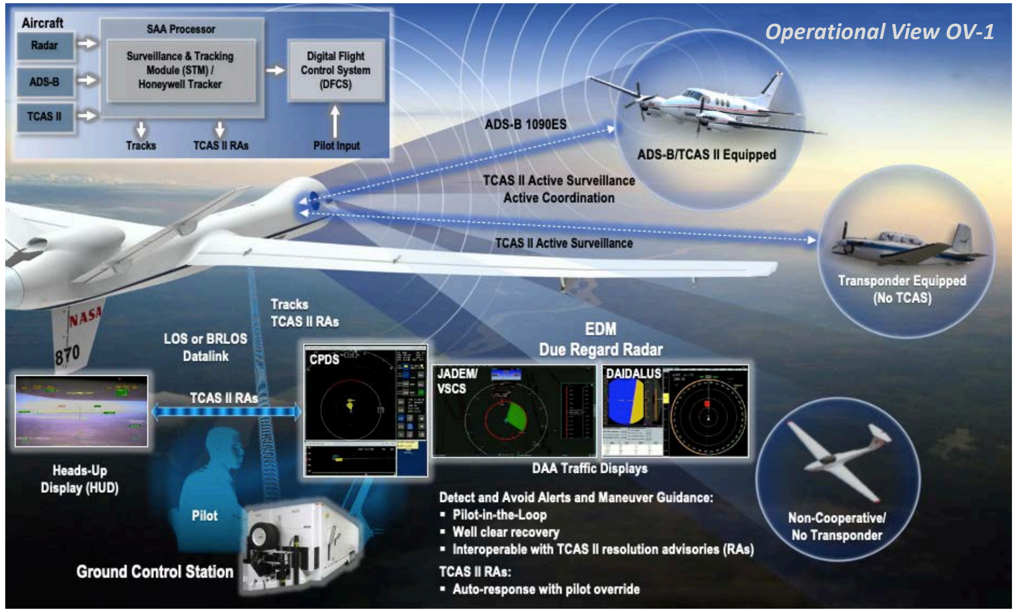
- **Flight Test 3 Objectives**
  - Collect data to inform draft Phase 1 MOPS for DAA and Command and Control (C2) including HSI alerting and guidance display standards
  - Continue partnership with GA-ASI to equip NASA Ikhana UAS with improved DAA capabilities for future flight tests
    - EDM Radar
    - TCAS II Auto-response and interoperability
  - Conduct risk reduction activities for Flight Test 4

- **Flight Test 3 Results**
  - Good data collection to update simulation models
    - Sensor noise and uncertainty
    - Wind compensation
  - EDM radar performance data collected against various RCS intruders
  - Stressing multi-intruder encounters completed to tax DAA algorithms



IT&E Flight Test Overview—Flight Test 4

- **Flight Test 4 Objectives**
  - Collect data to validate Phase 1 MOPS for DAA and ATAR Systems
  - Execute complex encounters to stress the DAA algorithms
    - Multi-intruder encounters
    - Well clear recovery
    - Mixed intruder equipage (ADS-B, Mode S, Mode C)
  - Document the performance of the test infrastructure in meeting the flight test requirements



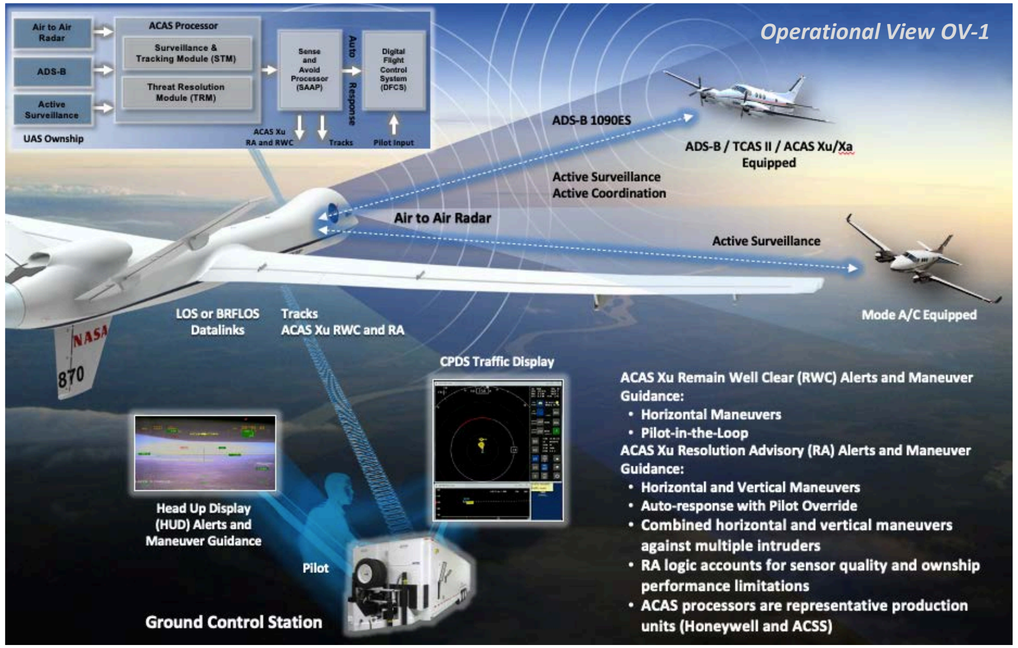
- **Flight Test 4 Results**
  - FT4 significantly contributed to the validation of Phase 1 DAA and ATAR MOPS
  - Identified some keys performance requirements that need additional refinement
    - Well Clear Recovery noise sensitivity
    - Time to co-altitude considerations

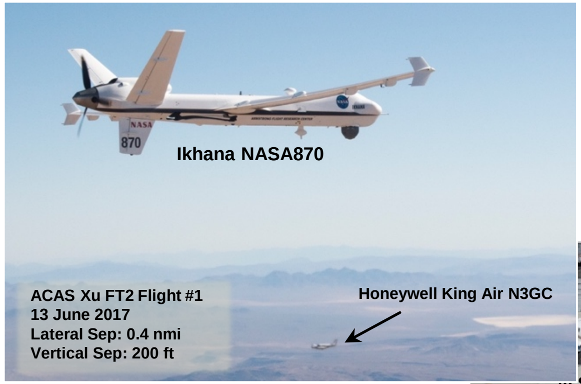
Intruder in a maneuver as seen by the Ikhana MTS-B

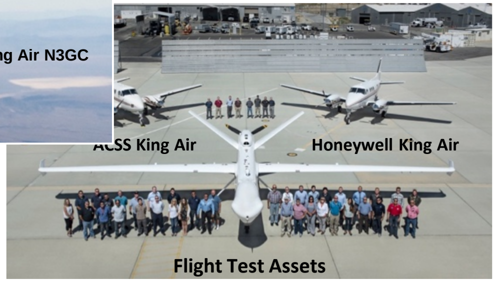
IT&E Flight Test Overview—ACAS Xu Flight Test 2

- **ACAS Xu Flight Test 2 Objectives**
  - Continue collaboration with the FAA TCAS Program Office-led partnership to mature the ACAS Xu software (Run 3) in support of ACAS Xu MOPS development
  - Validate modeling and simulations
  - Demonstrate system behavior integrated on production representative avionics

- **ACAS Xu Flight Test 2 Results**
  - Run 3 ACAS Xu features were demonstrated in the real flight environment, supporting the development of subsequent versions of the system logic
  - Valuable data was collected, enabling system performance evaluation and supporting ongoing research and development
  - Demonstrated ACAS Xu logic integrated into production representative ACAS processors

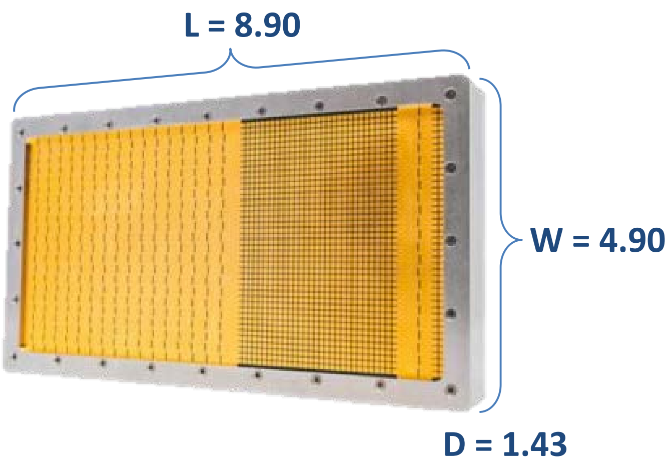






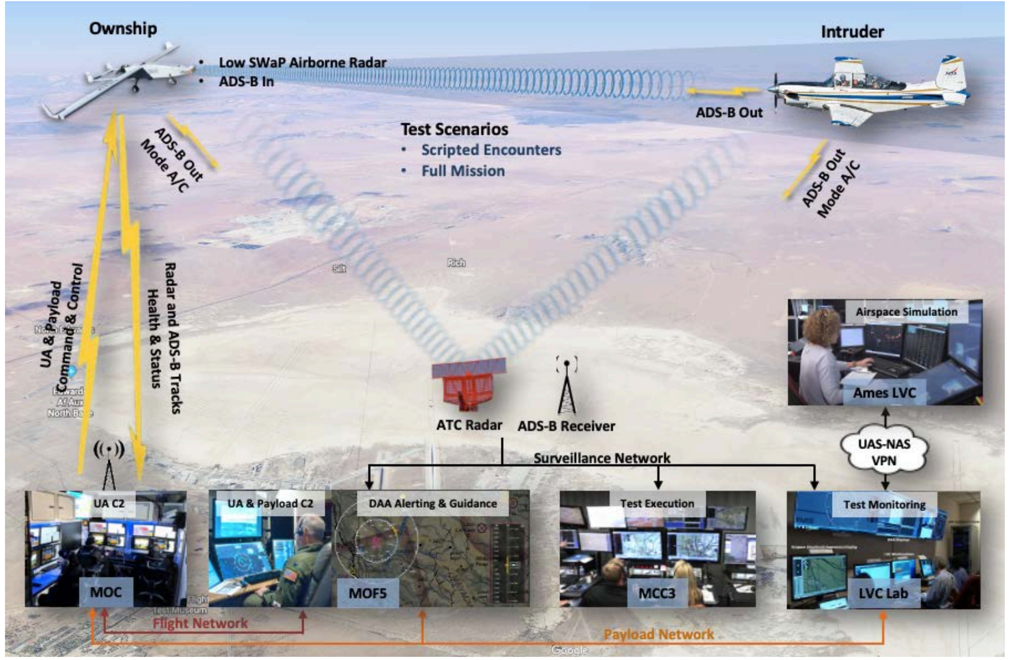
IT&E Flight Test Overview—Flight Test 5

- **Flight Test 5 Objectives**
  - Collect low SWaP ATAR data in preparation for Flight Test 6 via contracted “data buy”
- **Flight Test 5 Results**
  - Lack of elevation scan presented challenges in conducting air-to-air encounters
  - Successful flight test demonstration of the Raspberry Pi based DAA Processor
  - Identified refinements required to improve detection and track performance



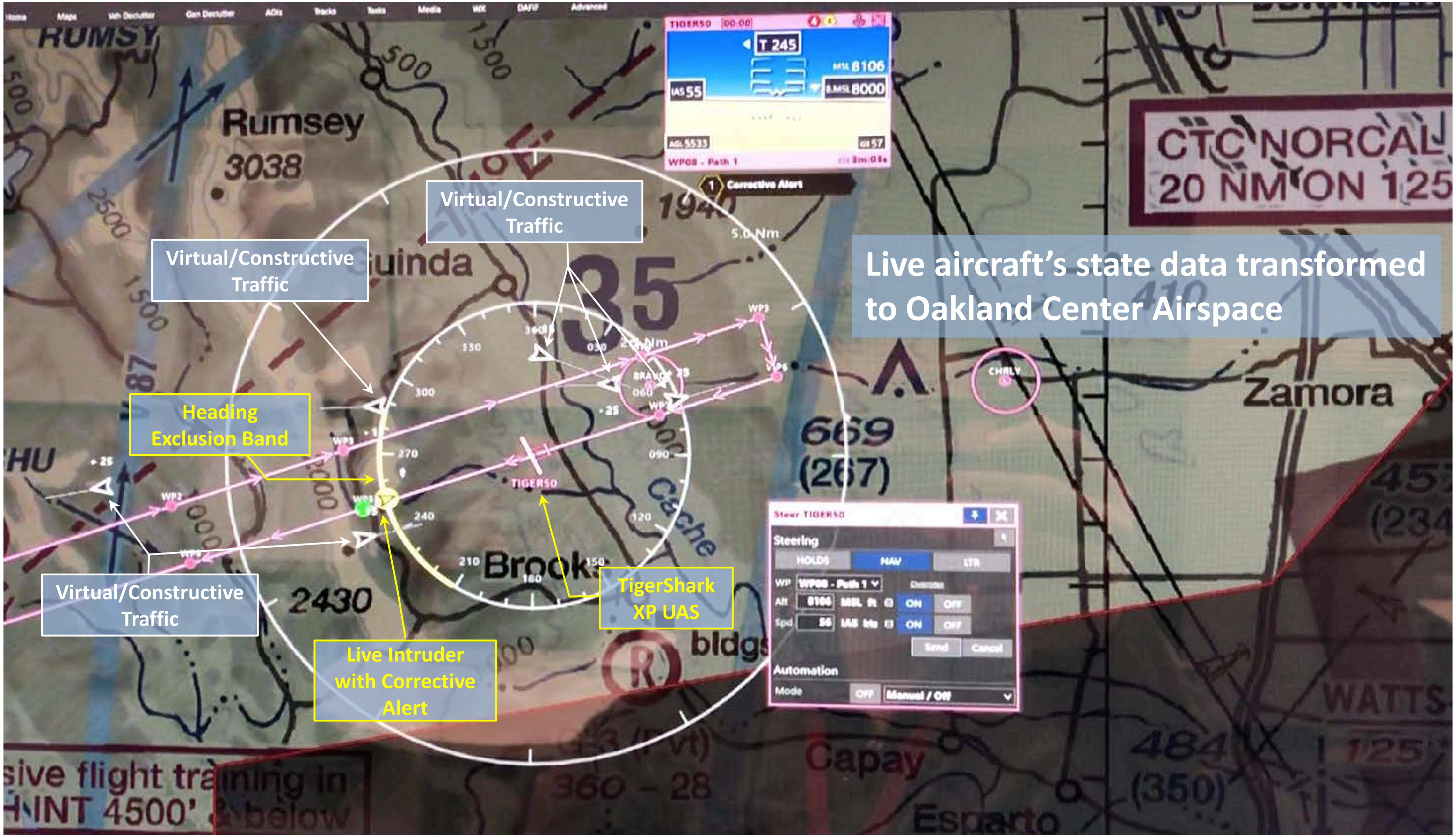
IT&E Flight Test Overview—Flight Test 6

- **Flight Test 6 Objectives**
  - Inform Phase 2 MOPS development of requirements for low SWaP airborne non-cooperative surveillance system
  - Inform Phase 2 MOPS development of DAA Well Clear (DWC) alerting and guidance requirements for low SWaP surveillance system equipped UAS
  - Characterize pilot response in a full mission environment to validate Human Systems Integration (HSI) simulation work for low SWaP surveillance system equipped UAS



- **Flight Test 6 Results**
  - Radar lacked target detection consistency and was unable to maintain track to support DWC evaluations. Low SWaP radar state of the art systems have performance challenges and require additional maturation.
  - Team adapted target aircraft ADS-B data to simulate the radar. The workaround enabled meaningful data collection to support other test objectives for defining low SWaP DWC alerting and guidance.
  - Determined that effective alerting, guidance, and well clear maneuvers can be achieved with a low SWaP radar declaration range of 3.5 nmi
  - Full Mission data collected validated modeling and simulation results

IT&E Flight Test Overview—Flight Test 6 Full Mission

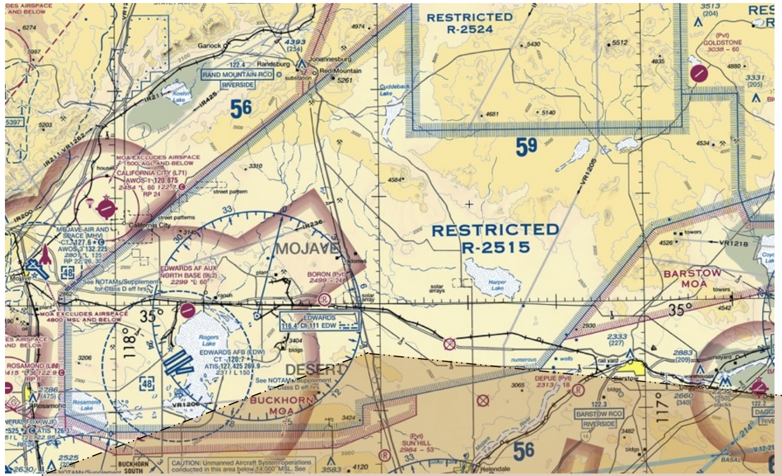


Lessons Learned

- Early CONOPS and airspace coordination is critical to convey project test requirements and ensure mission success. Continuously solicit feedback from airspace management, invite them to relevant project meetings, and treat them as a valued project team member.
- When flight testing with an unproven UAS, it's imperative that a robust UAS maturation plan be developed and coordinated with airspace management and airworthiness and flight safety approval authorities early in the project. Methodology for determining system reliability figures is an important consideration.
- Low SWaP ATA radar state of the art systems have performance challenges and require additional maturation for DAA use.
- Projects should consider conducting Operations Working Group & Integration Working Group meetings, as a minimum, to fully vet test objectives and maintain transparency of what is occurring in the project. These working groups serve to verify system requirements, solve problems, ask questions, and ensure team members have the latest status updates.
- Projects should strongly consider exercising mission rehearsals prior to conducting flight test or any complex ground tests. Rehearsals should include contingencies that are practiced by the team to a satisfactory stop point. Whenever possible, projects should perform rehearsals using the facilities where the actual missions will be conducted and employ the communication systems to be used during test.

Backup Slides

R2515 Airspace



ACAS Xu Flight Test 1

- **Objectives**
  - Collaborate with the FAA TCAS Program Office to mature the ACAS Xu software in support of ACAS Xu MOPS development
  - Validate modeling and simulations
  - Demonstrate system behavior integrated on prototype avionics and UAS
  - Collect flight test data for performance evaluations and future R&D

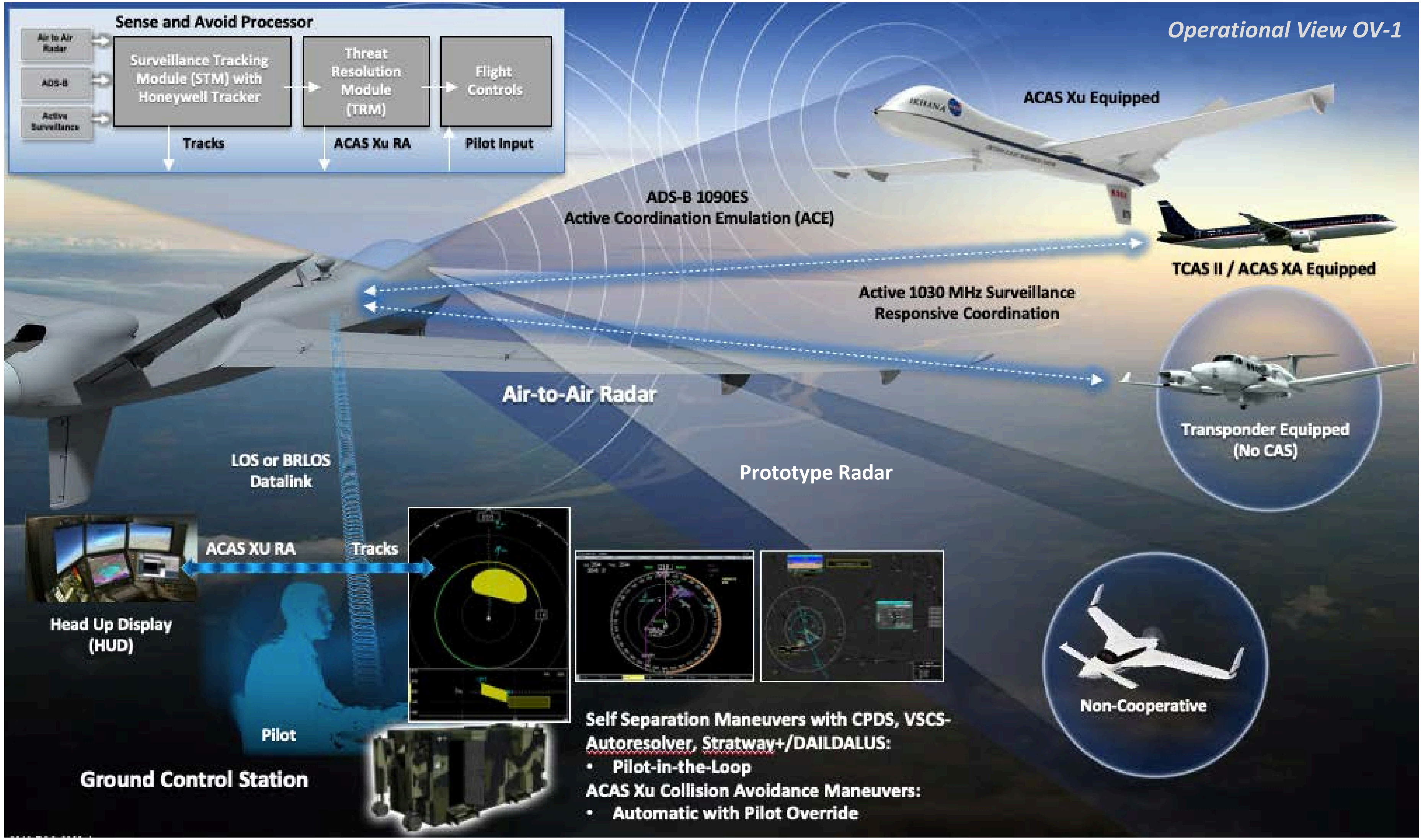
- **Approach**
  - Execute flight testing in partnership with FAA TCAS Program Office, MIT-Lincoln Lab, Johns Hopkins University Applied Physics Laboratory (JHU-APL), General Atomics - Aeronautical Systems, Inc., and Honeywell International, Inc.
  - Equip NASA's Ikhana UAS with prototype ACAS logic (Run 1) and proof-of-concept DAA avionics, specifically protype air-to-air radar (no elevation scan)
  - Evaluate the features of ACAS Xu Run 1 during scripted encounters:
    - Horizontal and vertical threat resolution logic
    - ADS-B surveillance for collision avoidance (vertical logic)
    - Airborne radar surveillance for collision avoidance (horizontal logic)
    - Interoperability with TCAS II
    - Active coordination emulation
    - Automatic response to TCAS II resolution advisories
    - Manned and unmanned intruders

Initial Detect and Avoid Flight Test

- **Objectives**
  - Assess DAA algorithm performance in the presence of sensor uncertainty and winds
  - Collect data to develop realistic surveillance, alerting, and maneuver guidance models for simulations used to inform DAA MOPS
  - Obtain pilot feedback on operational utility of the pilot guidance concepts
  - Integrate live data into the Live, Virtual, Constructive distributed environment
  - Collect flight test data to inform draft Phase 1 DAA MOPS
  - Conduct risk reduction activities for Flight Test Series 3 and 4

- **Approach**
  - Evaluate three DAA algorithms during scripted encounters with onboard surveillance data
    - Vigilant Spirit Control Station (VSCS) - Autoresolver: Directive guidance, NASA/AFRL
    - Stratway+/DAIDALUS: Suggestive guidance, NASA
    - Conflict Prediction and Display System (CPDS): Suggestive guidance, GA-ASI

System Overview—ACAS Xu FT1 and Initial Detect and Avoid Flight Test



ACAS Xu Flight Test 1

- **Test Duration**
  - ACAS Xu FT1: 11/17/2014 – 12/10/2014
    - NASA Ikhana UAS
    - 4 flights (manned intruder)
    - 2 flights (unmanned intruder)
    - 27.8 flight hours
    - 114 air-to-air encounters

- **Test Results**
  - First time a CA system for UAS was tested without artificial horizontal or vertical offsets
    - Flight test encounters flown in exact conflict conditions
  - First CA flight test employing UAS vs. UAS encounters
  - Sensor fusion successfully tracked multiple intruder aircraft
    - Association
    - Track manager
    - Tracking filters
  - Successfully demonstrated performance of Run 1 proof-of-concept functionality:
    - Horizontal and vertical threat resolution logic
    - ADS-B surveillance for collision avoidance (vertical logic)
    - Airborne radar surveillance for collision avoidance (horizontal logic)
    - Interoperability with TCAS II
    - Active coordination emulation
    - Automatic response to TCAS II resolution advisories

Initial Detect and Avoid Flight Test

- **Test Duration**
  - Initial DAA Flight Tests : 12/15/2014 – 12/19/2014
  - NASA NASA Ikhana UAS
  - 3 flights
  - 13.5 flight hours
  - 56 air-to-air encounters

- **Test Results**
  - Noisy or variation in aircraft state data resulted in intermittent threat detection and inconsistent maneuvers
    - Implemented Kalman filter for state data
    - Updated Autoresolver resolution logic to provide more consistent DAA maneuvers
  - Sensor Test
    - DAA guidance from DAIDALUS was effective
    - DAIDALUS was stable with real sensor data
    - Sensors performed as expected – no outstanding or new issues
  - Operator feedback
    - Operator was able to use the DAIDALUS guidance to maneuver
    - Display was usable, understandable
  - Risk Reduction
    - Lessons learned have driven decisions for Flight Test 3 and modeling and simulations
    - Allowed Team to mature data collection capability

Lessons Learned—Initial Detect and Avoid Flight Test

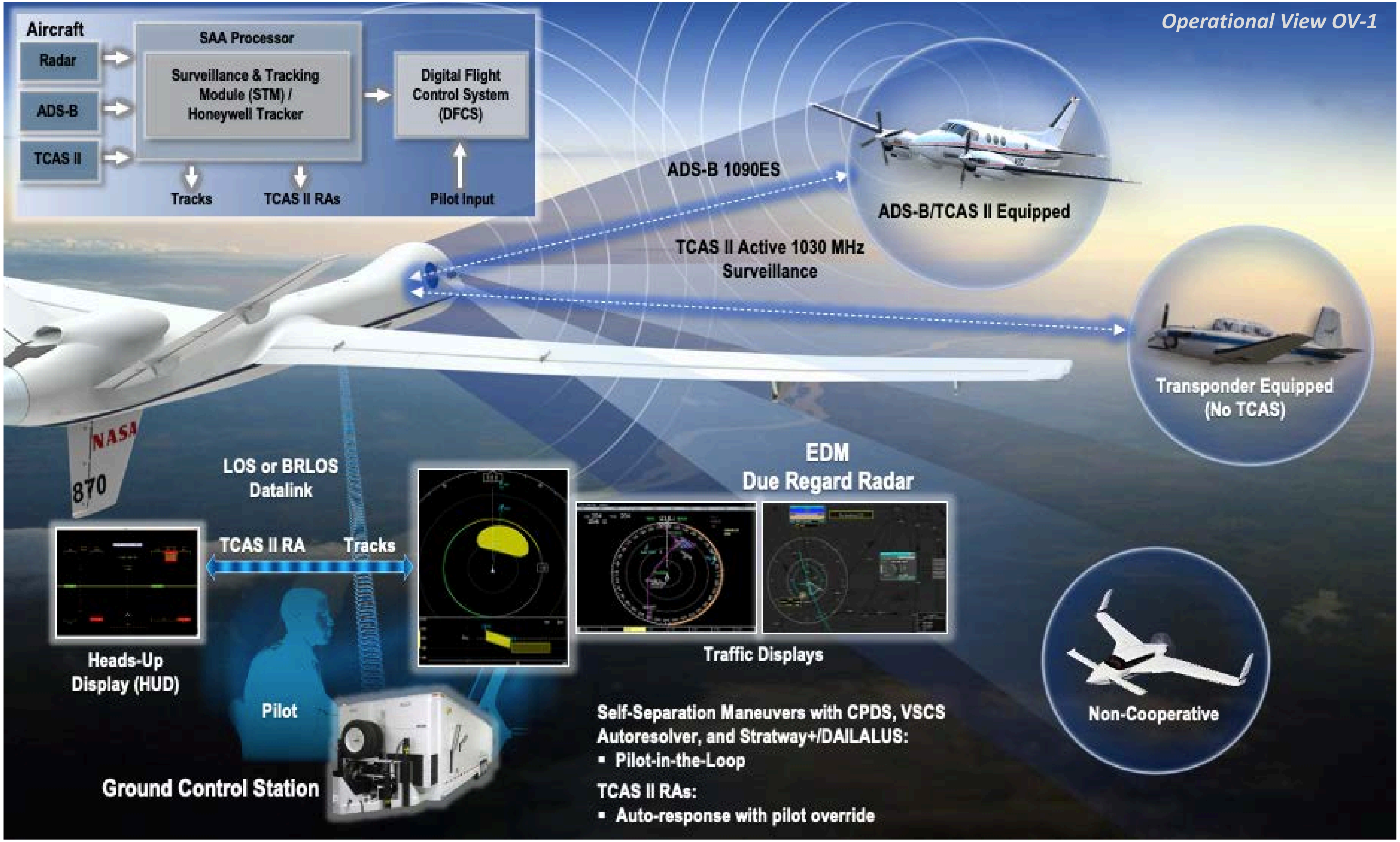
- **Noisy or variation in aircraft state data resulted in intermittent threat detection and inconsistent maneuvers**
  - Implemented Kalman filter for state data
  - Updated Autoresolver resolution logic to provide more consistent DAA maneuvers
- **Airspace Coordination**
  - Over 6 months coordinating airspace requirements
  - Developed excellent working relationship with Airspace Management (SPORT)
  - Continuing partnership into FT3
- **Surveillance Data and Mission Success**
  - Local ADS-B system installed as part of the ACAS Xu data collection effort proved to be invaluable to the Test Conductor in ensuring proper encounter setup and mission success
  - System carried into FT3 with NASA procured ADS-B receiver
- **Operational Tempo**
  - Flying a UAS is more demanding than a manned aircraft
  - Three flights a week (normal full week), and two flights a week (RDO weeks)
- **Pilot Training**
  - Additional time required to train pilots on new displays and operational concepts
  - Enhanced training for FT3
- **Data Collection, Storage, and Dissemination**
  - Data transfer inefficiencies encountered with large data files
  - Developing better data transfer methods and common analysis tools for FT3

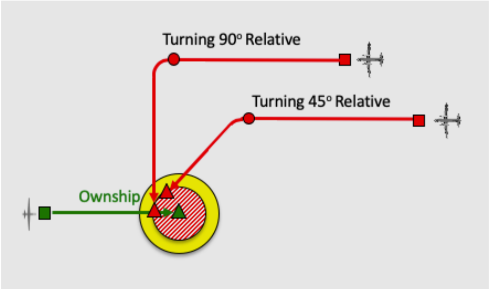
Flight Test 3

- **Objectives**
  - Collect data to inform draft MOPS for DAA and Command and Control (C2) including HSI alerting and guidance display standards
  - Increase test team experience and reduce risks associated with executing more complex operations in support of follow-on FT4 and Capstone activities

- **Approach**
  - Execute flight testing in partnership with General Atomics - Aeronautical Systems, Inc. and Honeywell International, Inc.
  - Equip NASA Ikhana UAS with DAA avionics, specifically the EDM air-to-air radar
  - Conduct scripted encounters with FT3 DAA algorithms accounting for
    - Sensor noise uncertainty
    - Navigation system errors and uncertainties
    - Wind compensation
  - Evaluate DAA functionality
    - Auto TCAS II maneuvers
    - EDM radar performance near scan volume limits
    - EDM radar low altitude performance tests
    - Higher closure rate encounters with an F/A-18 intruder
    - Stressing multi-intruder encounters
  - Conduct Full Mission operational scenarios with subject UAS pilots to validate modeling and simulations
    - Employ the NASA T-34C UAS surrogate equipped with prototype CNPC radios

System Overview—Flight Test 3





Flight Test 3

- **Test Duration**
  - Configuration 1: 06/17/2015 – 07/24/2015
    - NASA Ikhana UAS
    - 11 flights
    - 56.2 flight hours
    - 212 air-to-air encounters
  - Configuration 2: 07/13/2015 – 08/12/2015
    - NASA T-34C UAS Surrogate
    - 12 system checkout flights
    - 3 full mission data collection flights
    - 36.4 flight hours
    - 38 air-to-air encounters
- **Test Results**
  - ARC team members collected good data that will be used to update their simulation model and support future test efforts including PT6 (Part Task 6, V&V of MOPS) and FT4.
  - LaRC team members collected more data in one flight test event than had been collected in past simulated events. The data used to update their simulation model and help inform Phase I MOPS. Additionally, FT3 was the first time a multi-intruder encounter was conducted for these purposes.
  - CPDS team collected data on several corner case scenarios that challenged both the algorithm and aircrew judgment and decision making based off the CPDS alerting and guidance.
  - The TCAS and Radar stakeholders from GA-ASI both reported good data collected for their systems and intend to implement system enhancements. The TCAS alerts presented to the crews were within TCAS specifications, but aircrews recommended some user interface changes that better help them get instant SA once a TCAS RA is displayed.
  - Configuration 2 flights were cancelled after 3 data collection flights due to multiple problems that resulted in unreliable data. Valuable lessons were learned related to establishing clear functional and performance requirements especially when dealing with a complicated full mission test environment with a UAS surrogate aircraft.

Lessons Learned—Flight Test 3

- A separate truth source for positional data (TSPI) from each aircraft was not available for post flight analysis. A truth data source should be considered standard equipment for any flight test operation. Incorporate DGPS or suitable TSPI data source on each intruder and ownship aircraft. Ensure all data being collected is time synced

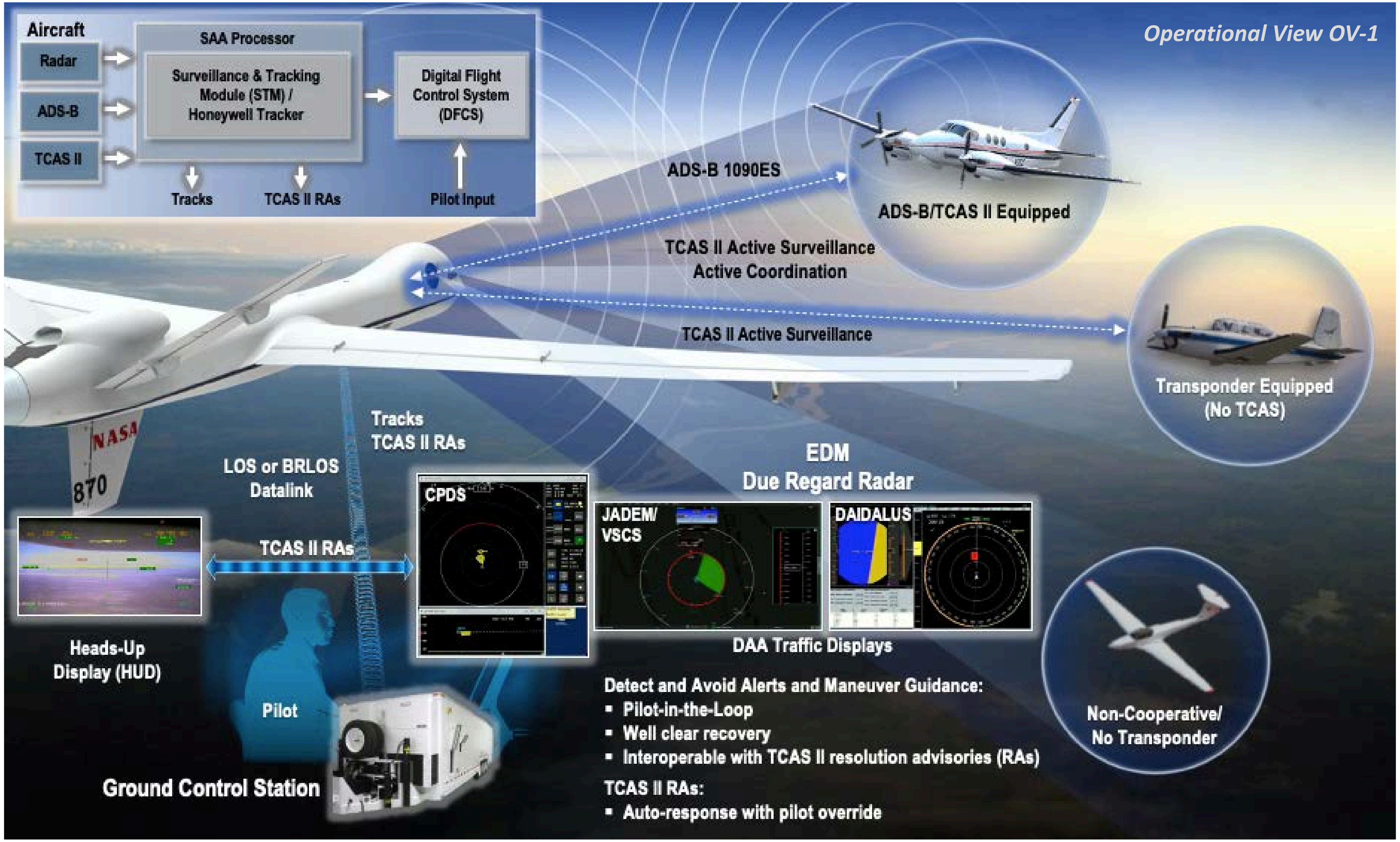
- Multiple operating/staging locations decreased efficiency in test execution. Operating from KEDW, KVNY, KPMD, and KBFL was a challenge to ensure efficient test execution. On multiple occasions, supporting aircraft were held at their staging locations for ATC clearances. Additionally, the offsite aircraft needed a higher bingo fuel in order to return to their staging location. Co-locate test aircraft to the greatest extent possible.

- Low priority within R-2515 resulted in missed flight test opportunities. Frequent communications with airspace management will help them understand test requirements and provide more effective deconfliction and improve mission success.

Flight Test 4

- **Objectives**
  - Conduct FT4 integrating DAA algorithms, Human Systems Integration (HSI) displays, and LVC test environment to support validation of Phase 1 DAA MOPS
  - Document the performance of the test infrastructure in meeting the flight test requirements
- **Approach**
  - Execute flight testing in partnership with General Atomics - Aeronautical Systems, Inc. and Honeywell International, Inc.
  - Conduct scripted encounters with FT4 DAA algorithms accounting for
    - Sensor noise uncertainty
    - Navigation system errors and uncertainties
    - Wind compensation
  - Refine Detect and Avoid (DAA) alerting and maneuver guidance algorithms to enable
    - Stressing encounters
    - More complex multi-intruder encounters
    - Well clear recovery
    - Mixed intruder equipage (ADS-B, Mode S, Mode C)

System Overview—Flight Test 4



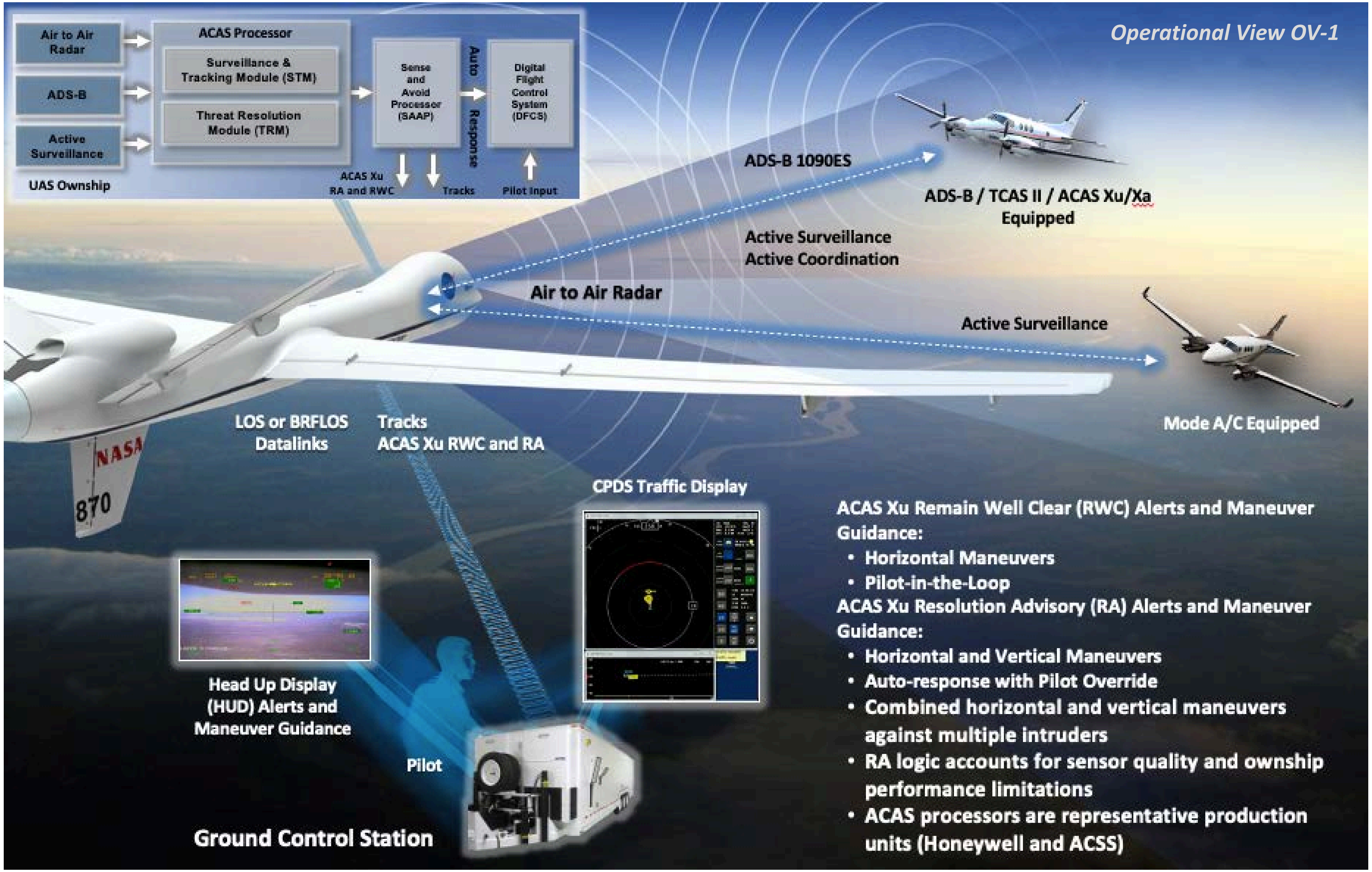
Flight Test 4

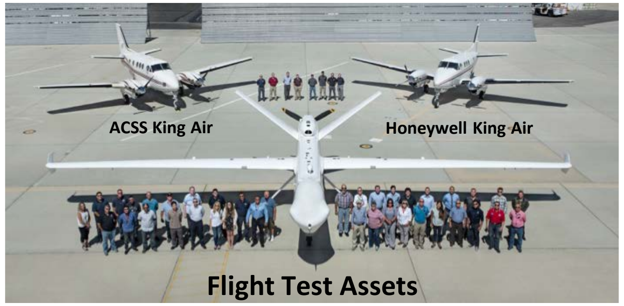
- **Test Duration**
  - 04/12/2016 – 06/30/2016
    - NASA Ikhana UAS
    - 21 flights
    - 98.1 flight hours
    - 321 air-to-air encounters
- **Test Results**
  - In concert with simulation activities, FT4 has significantly contributed to the validation of DAA MOPS
  - FT4 has identified some keys performance requirements that need additional refinement
    - Well Clear Recovery
      - Addresses “directive” alerting and guidance when well clear is lost
      - Sensor noise and uncertainty resulting in very dynamic and non-optimal guidance
    - DAA/TCAS Interoperability
      - Time to Co-Altitude requirement
        - » Addresses alerting on aircraft with high vertical closure rate
      - Well Clear definition above 10 kft MSL
        - » Addresses condition where TCAS RAs were experienced while DAA was not alerting

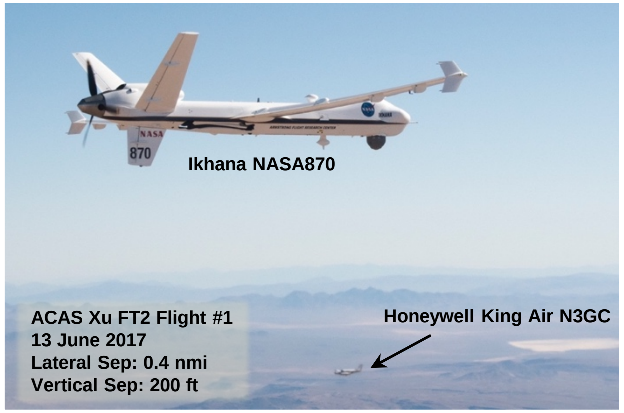
ACAS Xu Flight Test 2

- **Objectives**
  - Continue collaboration with the FAA TCAS Program Office-led partnership to mature the ACAS Xu software in support of ACAS Xu MOPS development
  - Validate modeling and simulations
  - Demonstrate system behavior integrated on prototype avionics and UAS
  - Collect flight test data for performance evaluations and future R&D
- **Approach**
  - Execute flight testing in partnership with FAA TCAS Program Office, MIT-Lincoln Lab, Johns Hopkins University Applied Physics Laboratory (JHU-APL), General Atomics - Aeronautical Systems, Inc., Aviation Communications & Surveillance Systems (ACSS), LLC., and Honeywell International, Inc.
  - Equip NASA’s Ikhana UAS with an evolved ACAS logic (Run 3) and updated DAA avionics
  - Conduct new and challenging encounters (geometries, maneuvers, and execution) and multiple intruder aircraft with various equipage combinations.
  - Evaluate the features of ACAS Xu Run 3:
    - A Surveillance and Tracking Module (STM) performing track correlation and a best source selection using the three surveillance inputs fed to ACAS Xu: 1090ES ADS-B, active surveillance (1030/1090 MHz interrogation/response), and airborne radar. Test a separate STM performing track fusion and developed by Honeywell.
    - A Threat Resolution Module (TRM) capable of issuing advisories in line with DAA requirements based on the surveillance provided by the STM, including intelligent selection of horizontal or vertical warning advisories based on ownship performance, surveillance source, and encounter geometry
    - Coordination of vertical advisories with intruder advisory systems using the same scheme employed by TCAS II and ACAS Xa (targeted to replace TCAS II)
    - Validation of ADS-B tracks using active surveillance (i.e. hybrid surveillance)
    - Issuance of combined vertical and horizontal warning advisories in multi-threat encounters

System Overview—ACAS Xu FT2







ACAS Xu FT2

- **Test Duration**
  - 06/13/2017 – 08/01/2017
    - NASA Ikhana UAS
    - 12 flights
    - 56.0 flight hours
    - 241 air-to-air encounters

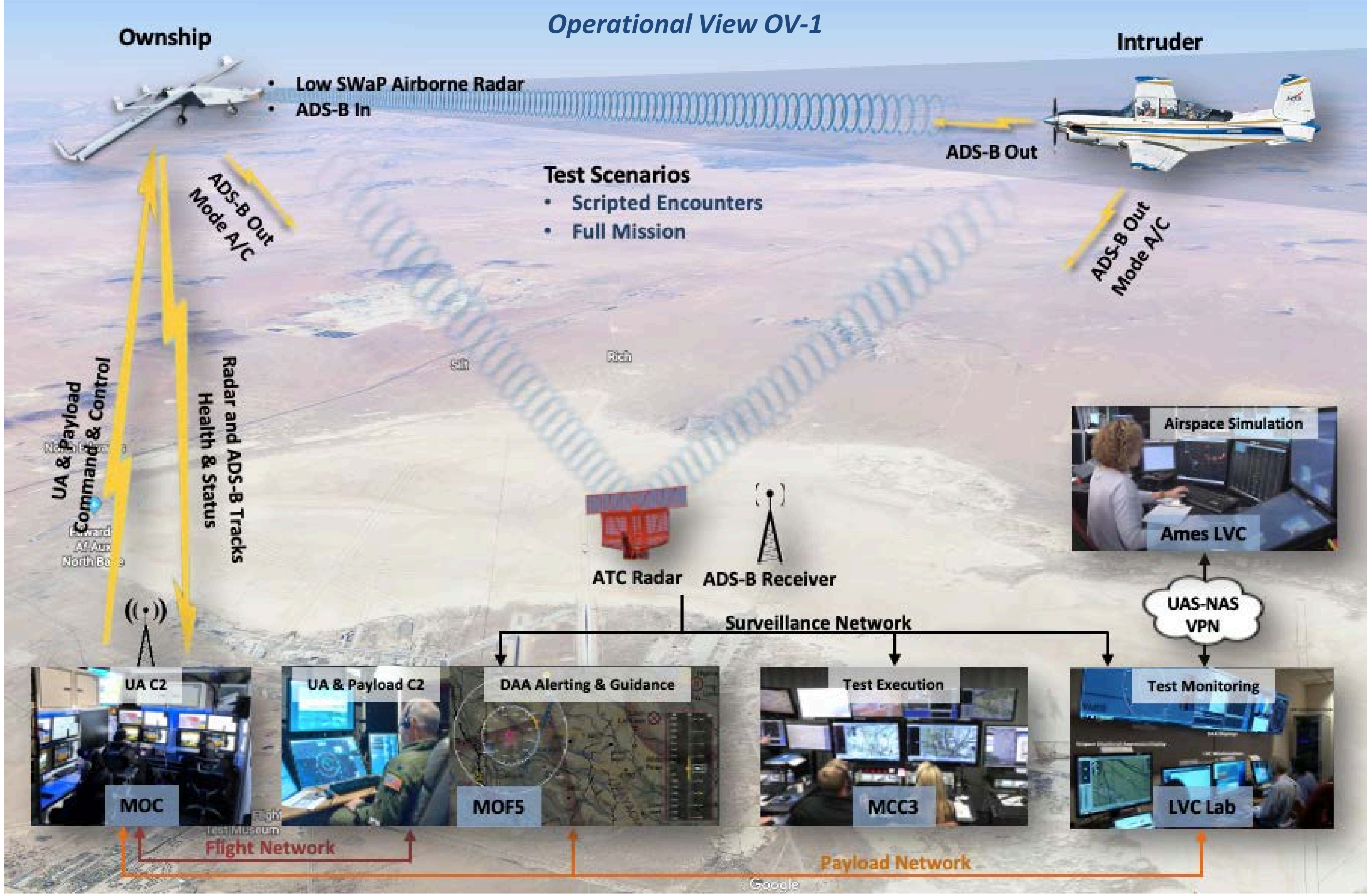
- **Test Results**
  - ACAS Xu Flight Test 2 gathered excellent data towards maturing the ACAS Xu algorithm and met all flight test objectives.
  - The flight test positively impacted the development of ACAS Xu in several ways:
    - New ACAS Xu features were demonstrated in the real flight environment, supporting the development of subsequent versions of the system logic
    - Undesired behaviors were observed, analyzed, and resolved
    - Valuable data was collected, enabling system performance evaluation and supporting ongoing research and development
    - Integration of the ACAS Xu logic into production representative ACAS processors and refinement of interface control documents (ICD's)
  - Assets were gained, including a mature flight test card design, new analysis tools, ACAS X team experience, and lessons learned

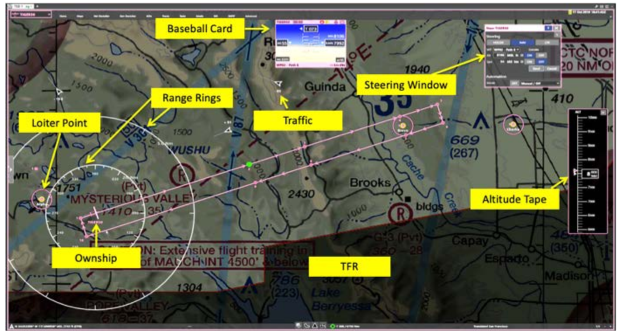
Flight Test 6

- **Objectives**
  - Inform Phase 2 MOPS development of requirements for low SWaP airborne non-cooperative surveillance system
  - Inform Phase 2 MOPS development of DAA Well Clear (DWC) alerting and guidance requirements for low SWaP surveillance system equipped UAS
  - Characterize pilot response in a full mission environment to validate Human Systems Integration (HSI) simulation work for low SWaP surveillance system equipped UAS

- **Approach**
  - Equip medium-sized group 3 NASC TigerShark Block 3 XP UAS with low SWaP sensors and research payload
  - Characterize representative low SWaP sensor in flight with unmitigated scripted encounters against various radar cross section intruder aircraft
  - Characterize low SWaP DAA system performance with scripted mitigated encounters
  - Characterize performance of low SWaP DAA system in simulated full mission operational scenarios with UAS subject pilots

System Overview—Flight Test 6





Flight Test 6

- **Test Duration**
  - 07/09/2019 – 11/21/2019
    - NASC TigerShark B3 XP UAS
    - 23 flights
      - 10 System Checkout flights
      - 3 Scripted Encounters flights
      - 3 Full Mission Shakedown/Mission Rehearsal flights
      - 7 Full Mission data collection flights
    - 67.6 flight hours
    - 245 air-to-air encounters

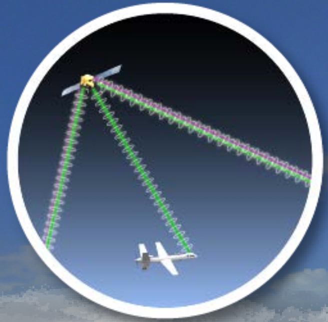
- **Test Results / Lessons Learned**
  - Radar lacked target aircraft detection consistency and was unable to maintain track to support DWC evaluations
  - Team adapted target aircraft ADS-B data to simulate the radar by constraining the ADS-B field of regard and reducing detection range for the target of interest. The workaround enabled meaningful data collection to support other test objectives related to defining low SWaP DWC alerting and guidance.
  - Determined that effective alerting, guidance, and well clear maneuvers can be achieved with a low SWaP radar declaration range of 3.5 nmi
  - Reference **NASA/TM-2020-220515** for a detailed analysis of the FT6 Scripted Encounters flight test phase
  - Full Mission subject pilots rated the virtual ATC simulation as realistic
  - Full Mission test results validated low SWaP DWC modeling and simulations

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

Wrap Up

Mauricio Rivas

Manager, UAS Integration in the NAS Project



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

Technical Interchange Meeting

End of Day 1

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

Technical Interchange Meeting

Day 2

October 1, 2020

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

Welcome

Clint St. John

Chief Engineer, UAS Integration in the NAS Project

Platforms and Discussion

- **MS Teams Participants** ***(includes speakers, presenters, and invited guests)***
  - Platform: MS Teams
  - Discussion: MS Teams microphone and chat functions
    - Unless speaking, please leave your cameras/webcams off to preserve WiFi bandwidth
    - Use your mute/unmute button (e.g. remain on mute unless you are speaking)
    - Enter comments/questions in the MS Teams chat
    - Raise your hand if you wish to speak
    - Say your name and affiliation before you begin speaking

- **YouTube Participants** ***(includes the remainder of the participants / UAS-NAS Project stakeholders)***
  - Platform: YouTube Live Stream *(go to* https://nari.arc.nasa.gov/uas-nastim *for the link!)*
  - Discussion: Conferences.io
    - Enter https://arc.cnf.io/ into your browser
    - Select the UAS Integration in the NAS Virtual Technical Interchange Meetings

Need Help?

If you need logistical or technological assistance throughout the meetings, you can reach out to the NARI hosts through the following platforms:

- Email us directly at arc-cal-nari@mail.nasa.gov
- Enter your comment or question in the **conferences.io** platform
- Enter your comment or question in the **MS Teams** chat

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Wednesday, September 30, 2020

9:00 – 9:10	Welcome & Logistics, Clint St. John, Chief Engineer, UAS Integration in the NAS Project
9:10 – 9:20	Mission Director's Introduction, Bob Pearce, Associate Administrator, ARMD
9:20 – 9:50	Program Director's Introduction & NASA's Cohesive UAS Strategy, Lee Noble, Program Director, IASP
9:50 – 10:10	NASA's UAS Integration in the NAS Project Overview, Mauricio Rivas, Project Manager, UAS Integration in the NAS Project
10:10 – 10:40	UAS-NAS Command & Control Subproject Overview, Kurt Shalkhauser, C2 Technical Lead, C2 Subproject
10:40 – 11:10	Terrestrial Based UAS Command and Control, Kurt Shalkhauser, C2 Technical Lead, C2 Subproject
11:10 – 11:40	Satellite Based UAS Command and Control, Dennis Iannicca, Satcom Lead, C2 Subproject
11:40 – 12:20	UAM Command Control and Communications Study, Israel Greenfeld, UAM C3 Study Lead, C2 Subproject

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Wednesday, September 30, 2020

12:20 – 1:05	Lunch
1:05 – 1:35	UAS-NAS Detect and Avoid Subproject Overview, Jay Shively, Subproject Manager, DAA Subproject
1:35 – 2:05	Modeling and Simulation, Gilbert Wu, Modeling & Simulation Technical Lead, DAA Subproject
2:05 – 2:55	Guidance and Control, Tod Lewis, Guidance & Control Technical Lead, DAA Subproject
2:55 – 3:45	Human Systems Integration, Conrad Rorie, Human Systems Integration Technical Lead, DAA Subproject
3:45 – 4:00	Break
4:00 – 4:30	UAS-NAS Integrated Test & Evaluation Subproject - Overview & Live Virtual Constructive (LVC), Ty Hoang, Live Virtual Constructive Technical Lead, IT&E Subproject
4:30 – 5:00	UAS-NAS Integrated Test & Evaluation Subproject Flight Test, Sam Kim, IT&E Technical Lead, IT&E Subproject

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Wednesday, September 30, 2020

5:00 – 5:15	Day 1 Wrap Up, Mauricio Rivas, Manager, UAS Integration in the NAS Project
5:15	End of Day 1

Thursday, October 1, 2020

9:00 – 9:10	Welcome & Logistics, Clint St. John, Chief Engineer, UAS Integration in the NAS Project
9:10 – 9:40	FAA Research Transition Team Overview, Laurie Grindle, Director for Programs and Projects, NASA Armstrong Flight Research Center, and Nick Lento, Division Manager, ANG-C2 New Entrants Division, Portfolio Management and Technology Development Office, FAA
9:40 – 10:10	No Chase COA Demonstration, Sam Kim, IT&E Technical Lead, IT&E Subproject
10:10 – 10:40	Systems Integration and Operationalization (SIO) Overview, Kurt Swieringa, SIO Technical Manager, UAS Integration in the NAS Project
10:40 – 11:00	Systems Integration & Operationalization - Partner Briefing: Bell, Jennifer Andrews, Bell APT70 SIO Project Lead

UAS-NAS Technical Interchange Meeting Agenda—Day 1

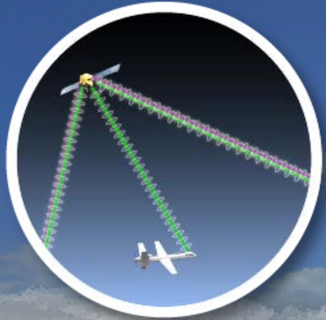
Thursday, October 1, 2020

11:00 – 11:20	Systems Integration & Operationalization - Partner Briefing: General Atomics Aeronautical Systems Inc, John Choi, Director, Special Purpose UAS
11:20 – 11:40	Systems Integration & Operationalization - Partner Briefing: American Aerospace ISR, David Yoel, CEO, American Aerospace Technologies Inc., & Ali Etebari, Vice President of Engineering, American Aerospace Technologies Inc.
11:40 – 11:55	Systems Integration & Operationalization – Questions & Answers
11:55 – 12:45	Lunch
12:45 – 1:15	Systems Integration & Operationalization FAA Perspective, Sabrina Saunders-Hodge, Director, Research, Engineering & Analysis Division (AUS-300) & Bill Stanton, Manager, UAS and Commercial Space Operational Integration, (AJT-3)
1:15 – 2:45	Stakeholder Panel Discussion: Technology and Community Benefits of the UAS-NAS Project, Moderated by Ed Waggoner, Deputy Associate Administrator for Programs, NASA ARMD (UAS Integration RTT Executive Co-Lead)
2:45 – 3:00	Break

UAS-NAS Technical Interchange Meeting Agenda—Day 1

Thursday, October 1, 2020

3:00 – 3:30	RTCA SC-228 Status and Next Steps, John Moore, SC-228 Co-Chair, Associate Director of Systems Engineering, Collins Aerospace, Brandon Suarez, SC-228 Co-Chair, Technical Director for UAS Integration at General Atomics Aeronautical, & Steve Van Trees, (Former SC-228 DFO), Aircraft Certification Service, FAA
3:30 – 4:15	Panel Session: Remaining Gaps, Kurt Shalkhauser, C2 Technical Lead, C2 Subproject, Jay Shively, Subproject Manager, DAA Subproject, & Kurt Swieringa, SIO Technical Manager, UAS Integration in the NAS Project
4:15 – 4:45	Transition of Efforts Within NASA: Advanced Air Mobility (AAM) Mission, Davis Hackenberg, Advanced Air Mobility Mission Integration Manager, NASA ARMD
4:45 – 5:15	Transition of Efforts Within NASA: ATM-X Increasingly Automated Air Cargo Operations Subproject, Kurt Swieringa, Technical Lead, ATM-X Increasingly Automated Air Cargo Operations Subproject, Robert Fong, Subproject Manager, ATM-X Increasingly Automated Air Cargo Operations Subproject
5:15 – 5:30	Day 2 Wrap Up, Mauricio Rivas, Project Manager, UAS Integration in the NAS Project
5:30	End of Day 2



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

FAA Research Transition Team (RTT) Overview

Laurie Grindle

Director for Programs and Projects, NASA Armstrong Flight Research Center

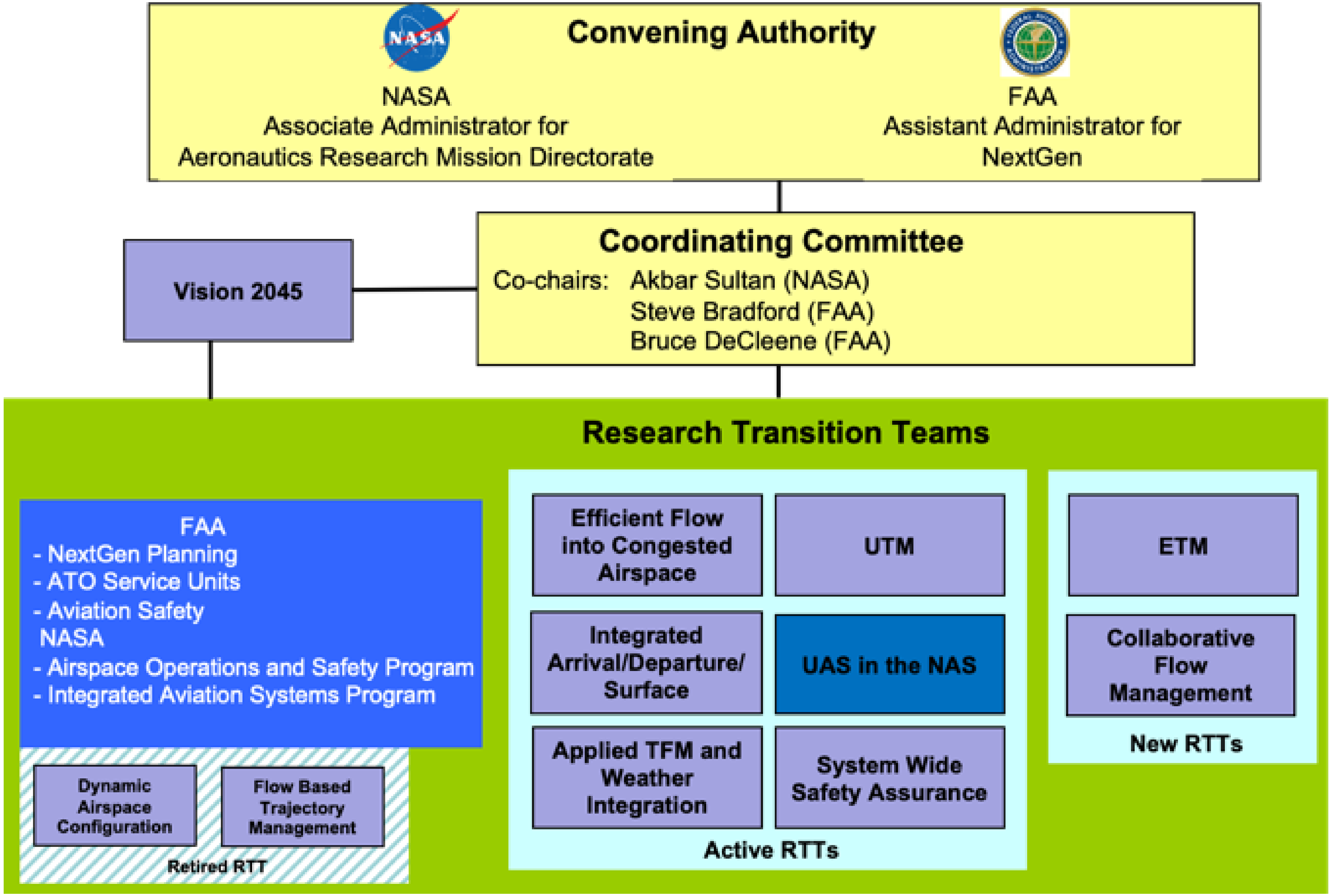
Steve Bradford

Chief Scientist, Architectureand NextGen Development, FAA

Historical Overview of RTTs

- The FAA and NASA RTTs to ensure that research and development needed for the Next Generation Air Transportation System (NextGen) implementation is identified, quantified, conducted, and effectively transferred to the implementing agency. This is accomplished primarily through collaboration among researchers, system planners, and implementers within the RTT.
- The proposal to establish RTTs and a Coordinating Committee to guide them was approved on October 22, 2007 by the FAA's Air Traffic Organization (ATO) Senior Vice President for NextGen and Operations Planning and by NASA's Associate Administrator for the Aeronautics Research Mission Directorate.
- The objectives of the RTTs are to: (1) provide a structured forum for researchers and implementers to constructively work together on a continuing basis; (2) ensure that planned research results will be fully utilized and will be sufficient to enable implementation of NextGen air navigation services concepts; and (3) provide a forum for the inclusion of NASA and FAA stakeholders who would be involved in the planning, conducting, receiving, and utilizing the research conducted by the RTTs.

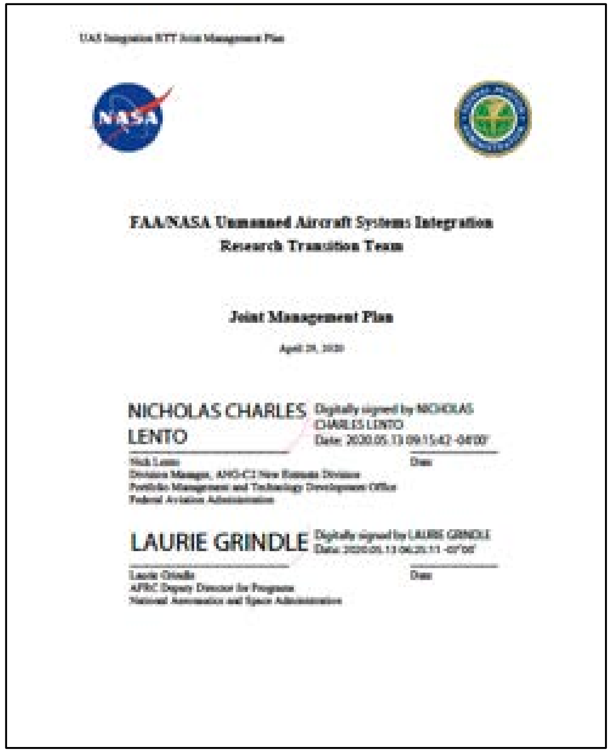
RTT Administrative Framework



UAS Integration RTT Responsibilities

- The UAS Integration RTT Co-Leads will develop and oversee the execution of the overall UAS Integration RTT through managing the formal Joint Management Plan (JMP)
- The UAS Integration RTT Working Group (WG) Co-Leads will coordinate Research Transition Products (RTPs) between NASA and the FAA, facilitate overall execution of the RTT, ensure appropriate interfaces between WGs are defined, and keep the RTT Co-Leads and agency Executives aware of critical issues and concerns
- The UAS Integration RTT WG members will coordinate and collaborate relevant UAS Integration in the NAS Project research and technology development findings across agencies in support of the RTPs identified in the JMP

UAS Integration RTT JMP


UAS Integration RTT Joint Management Plan

FAA/NASA Unmanned Aircraft Systems Integration
Research Transition Team

Joint Management Plan

NICHOLAS CHARLES LENTO

Nick Lento
Division Manager, ANG-C1 New Entrants Division
Portfolio Management and Technology Development Office
Federal Aviation Administration

LAURIE GRINDLE

Laurie Grindle
AFRC Deputy Director for Programs
National Aeronautics and Space Administration

UAS Integration RTT Initiated January 2017

UAS Integration RTT Working Groups

Detect and Avoid (DAA) WG

NASA Co-Lead Jay Shively **FAA Co-Lead Paul Campbell**

- Develop research findings to support RTCA SC-228 DAA Minimum Operational Performance Standards (MOPS)

Command and Control (C2) WG

NASA Co-Lead Mike Jarrell **FAA Co-Lead Francisco Capristan**

- Develop research findings to support RTCA SC-228 Minimum Aviation System Performance Standards (MASPS) and MOPS for terrestrial and satellite C2

Systems Integration and Operationalization (SIO) WG

NASA Co-Lead Kurt Swieringa **FAA Co-Lead Peter White**

- Conduct a series of demonstrations in partnership with industry to advance the state-of-the-art for operationalizing DAA, C2, and vehicle type certification

No Chase COA (NCC) WG (Sunset Nov 2018)

NASA Co-Leads Mauricio Rivas **FAA Co-Lead Randy Willis**

- Conduct a demonstration of the RTCA SC-228 Phase 1 MOPS to operate to/from and within Class A Airspace under a Certificates of Waiver or Authorization (COA) without the requirement for a chase aircraft

Concepts and Transversal Activities (C&TA) WG (Sunset Jan 2020)

NASA Co-Leads Will Johnson **FAA Co-Lead Sherri Magyarits**

- Jointly develop and vet a cohesive integration strategy for UAS integration for civil/commercial operations within the NAS by ~2025

RTT Facilitation Team:
Chuck Johnson, GIUAS, LLC
Lexie Brown, Media Fusion, Inc.

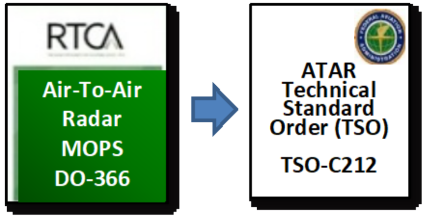
Objectives/RTPs/Outcomes of the DAA WG

Objective:

To ensure that research findings, developed primarily by NASA, will support the development of MOPS for DAA systems necessary to safely integrate UAS into the NAS during operations in controlled airspace in compliance with Part 91.113

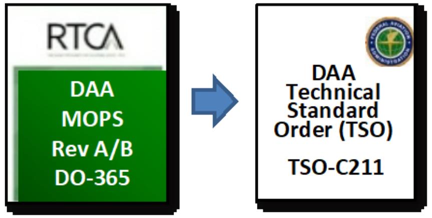
RTPs:

- Share DAA sensors and models to be used in testing in order to develop performance standards for alternative surveillance sensors
- Develop well clear ConOps, recommendations, low SWaP UAS performance characteristics, and Alerting/Guidance timelines to support RTCA SC-228
- Develop the requirements and modifications necessary to ensure that ACAS-Xu can accommodate operations supported by Phase 2 MOPS
- Develop research findings to inform RTCA MOPS decisions



Outcomes:

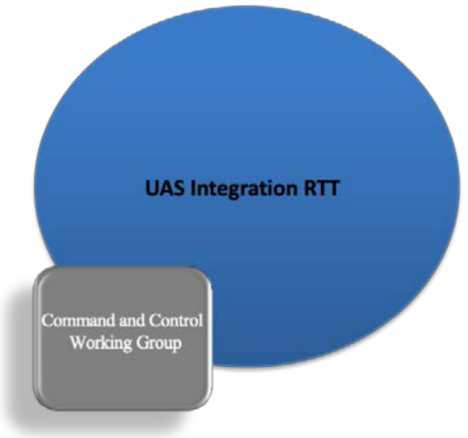
- RTCA MOPS for DAA Rev A/B (DO-365) and DAA Air-To-Air Radar (DO-366)
- Led to the development of complimentary Technical Standard Orders (TSO-C211 and C-212)



Objectives/RTPs/Outcomes of the C2 WG

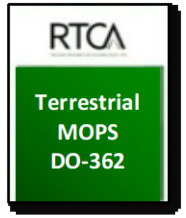
Objective:

To ensure that research findings, developed primarily by NASA, will support the development of MASPS and MOPS for Terrestrial C2 and provide limited Ku-Band SatCom propagation data and C-band SatCom Study information



RTPs:

- Conduct limited SatCom studies and analysis to inform the FAA Spectrum Office and RTCA SC-228 MASPS/MOPS
- Develop, test, and evaluate a representative UAS radio system that will provide research data for the development and validation of standards for Terrestrial C2 links between the UAS and ground radios in support of the RTCA SC-228 MOPS (Terrestrial) Rev A
- Conduct external coordination to jointly promote international harmonization through the International Civil Aviation Organization (ICAO), and the European Organisation for Civil Aviation Equipment (EUROCAE) working groups



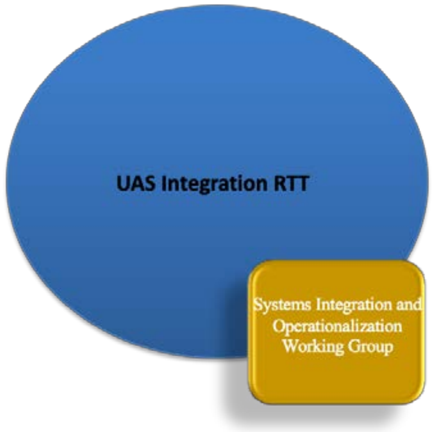
Outcomes:

- RTCA MOPS for Terrestrial C2 (DO-362)
- Coordination of C2 MOPS to inform EUROCAE MASPS and ICAO Standards and Recommended Practices

Objectives/RTPs/Outcomes of the SIO WG

Objective:

Conduct a series of demonstrations leveraging integrated DAA, C2, and state-of-the-art UAS vehicle technologies with industry partners in order to compile necessary artifacts for flight demonstrations in the NAS, and compile publicly available documentation of best practices learned from the partners' UAS development efforts, the process of obtaining approvals for the flight demonstrations, and initial efforts to form the foundation for ongoing/future type certification programs



RTPs:

- Share concepts of operations and operational risk assessment documentation from selected partners in support of SIO demonstrations
- Collaborate on what is required to obtain operational approvals for the SIO demonstrations and provide joint guidance to the SIO partners
- Document and publicly release best practices from the SIO effort

Outcomes:

- Approvals for two SIO partners to fly various aspects of their use cases in the NAS
- Documentation that describes a compilation of best practices, which are in the process of being published

Bell

Mission: Medical supply transportation in urban areas at altitudes between approximately 500 feet to 1,000 feet AGL

Vehicle: Autonomous Pod Transport - 70 (APT-70) (~300 Pounds)

SIO Demonstration Locations: Dallas Fort Worth area in Texas

SIO Demonstration Date: Late July or August

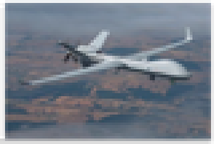
General Atomics Aeronautical Systems, Inc.

Mission: Infrastructure inspection at altitudes above 10,000 feet MSL

Vehicle: SkyGuardian (~12,000 Pounds)

SIO Demonstration Location: Southern California

SIO Demonstration Date: Early April



American Aerospace (formerly PAE ISR)

Mission: Infrastructure inspection at altitudes between approximately 1,000 feet to 3,000 feet AGL

Vehicle: Resolute Eagle (~180 pounds)

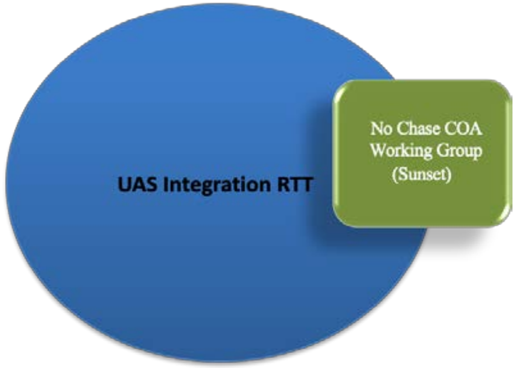
SIO Demonstration Location: The San Joaquin Valley (NASA is determining)

SIO Demonstration Date: Waiting for revised schedule and list of approvals that will be required

Objectives/RTPs/Outcomes of the NCC WG

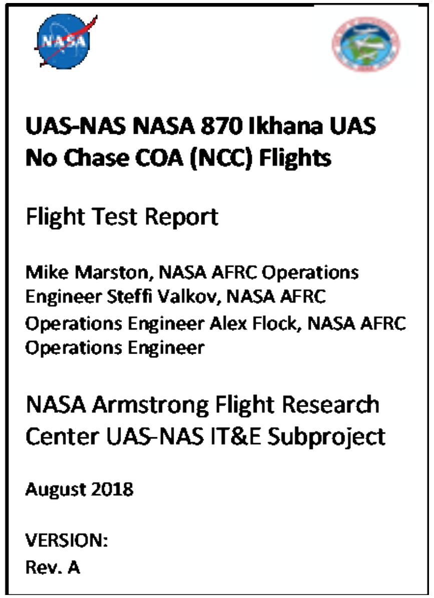
Objective:

To develop a concept of operations, objectives, partnerships, and approvals for a COA which demonstrates requirements of the RTCA SC-228 Phase 1 MOPS to operate to/from and within Class A Airspace without the requirement for a chase aircraft



RTPs:

- Obtain an approved COA to demonstrate a UA transitioning to/from Class A or SUA to Class E and Class D employing a DAA and Air-to-Air Radar Systems as alternate means of compliance for 14CFR 91.113b without the use of a chase aircraft
- Conduct flight (or series of flights) to demonstrate a UA transitioning to/from Class A or SUA to Class E and Class D employing a DAA and Air-to-Air Radar Systems as alternate means of compliance for 14CFR 91.113b without the use of a chase aircraft in order to inform potential changes to procedures/rules/regulations



UAS-NAS NASA 870 Ikhana UAS No Chase COA (NCC) Flights

Flight Test Report

Mike Marston, NASA AFRC Operations Engineer Steffi Valkov, NASA AFRC Operations Engineer Alex Flock, NASA AFRC Operations Engineer

NASA Armstrong Flight Research Center UAS-NAS IT&E Subproject

August 2018

VERSION:
Rev. A

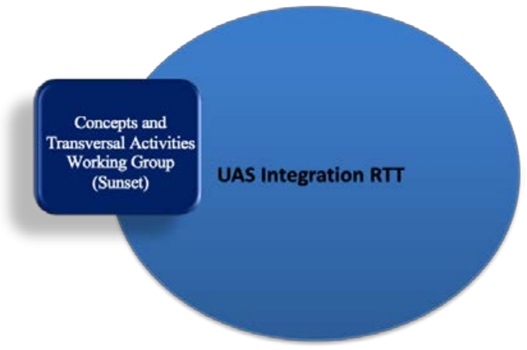
Outcomes:

- A flight test report (available to the public) documenting the operational concept of operations, flight test results, for the No Chase COA flights including comparing the equipage and other requirements of the operation to the RTCA SC-228 Phase 1 MOPS

Objectives/RTPs/Outcomes of the C&TA WG

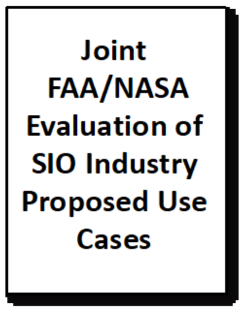
Objective:

To jointly develop and vet a cohesive integration strategy for UAS integration for civil/commercial operations within the NAS by ~2025 including the review of mature products from NASA, industry, and/or FAA for consistency with the vision for integration, assessing gaps, and developing use cases, as needed, for civil/commercial UAS missions



RTPs:

- Assess concepts of operation and use consistent with a cohesive strategy for UAS integration by ~ 2025, including specific use cases proposed by potential NASA partners for the SIO demonstrations planned for 2020

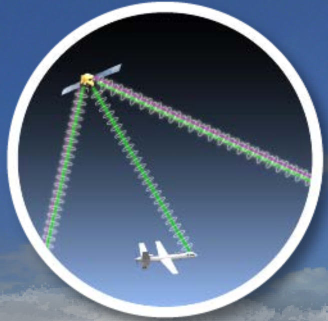


Outcomes:

- Recommendations from the C&TA WG members after evaluation of all industry proposals in support of the 2020 SIO demonstrations
- The C&TA WG was also a forum to discuss initial operational concepts and use cases for Advanced Air Mobility (AAM)

Next Steps

- The UAS Integration RTT will be sunset on December 31, 2020
- Unaddressed gaps for UAS integration will be documented as part of the closeout of this RTT
- Discussions across FAA and NASA leadership are occurring regarding the disposition of UAS integration gaps and whether/how to address them in the future
- Approaches to address these gaps may be included in other RTT-like activities such as the AAM Working Group



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

Integrated Test & Evaluation Subproject

No Chase Certificate of Waiver or Authorization (COA)

Flight Demonstration Overview

Sam Kim

IT&E Technical Lead, IT&E Subproject

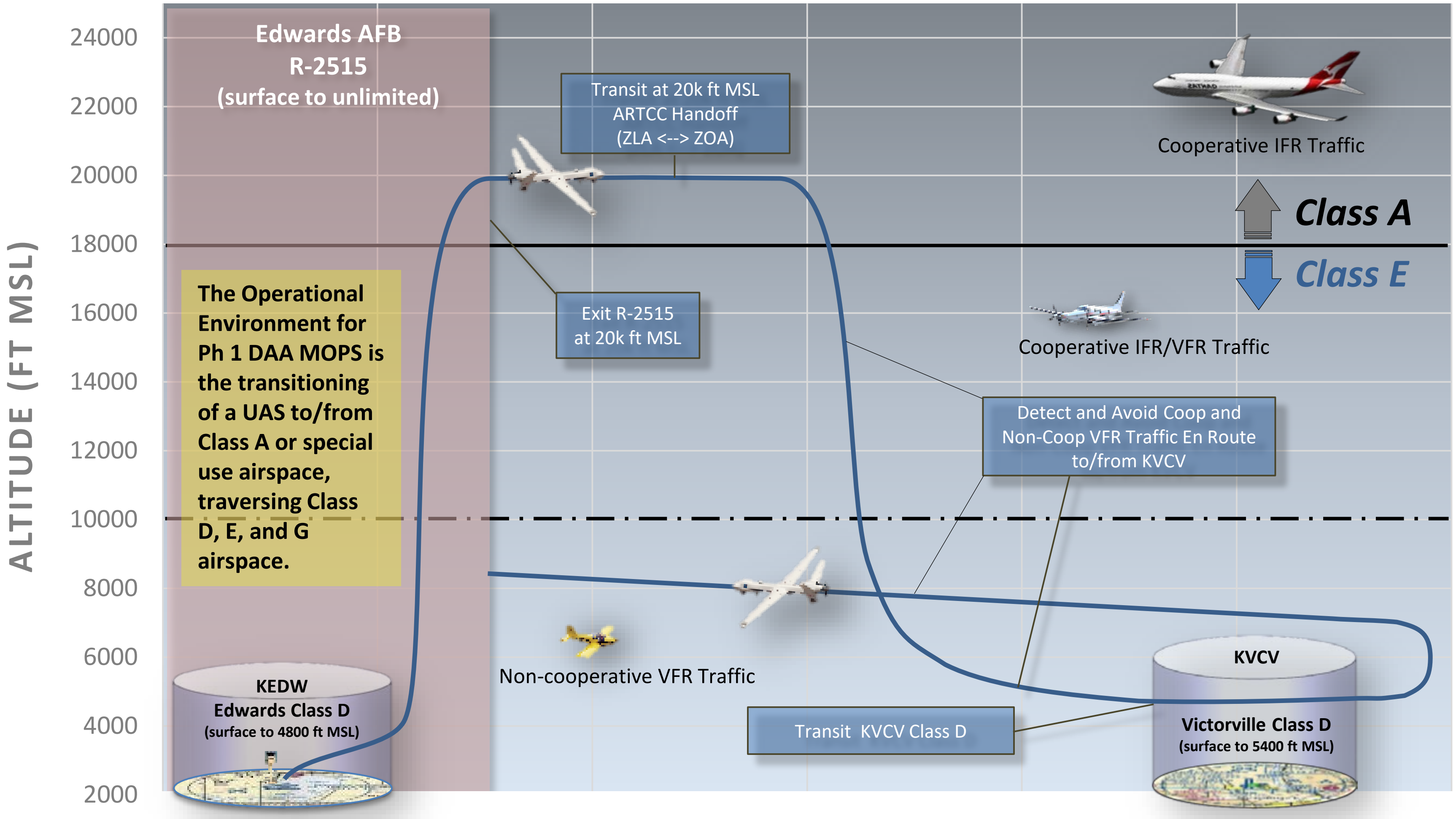
No Chase COA (NCC) Flight Demonstration Overview

- **Need/Goal:**
  - Less restrictive NAS access for UAS (routine file and fly)

- **Objectives:**
  - Demonstrate UA transitioning to/from Class A or SUA through Class E and Class D employing the Phase 1 DAA Systems and Air-to-Air Radar MOPS as alternate means of compliance for 14 CFR 91.111(a) and 14 CFR 91.113(b) to “see and avoid/remain well clear” of other traffic during an operationally representative mission
  - Obtain FAA COA permitting UAS flight demonstration in the NAS without the requirement for a safety chase aircraft to provide see and avoid functionality
  - Engage the FAA certification, safety, and operational approval organizations and in the process, inform policy development and the processing of similar COAs to enable less restrictive UAS access to the NAS
  - Serve as a “capstone” flight demonstration highlighting the UAS-NAS Phase 1 research activities

No Chase Aircraft COA Flight Demonstration

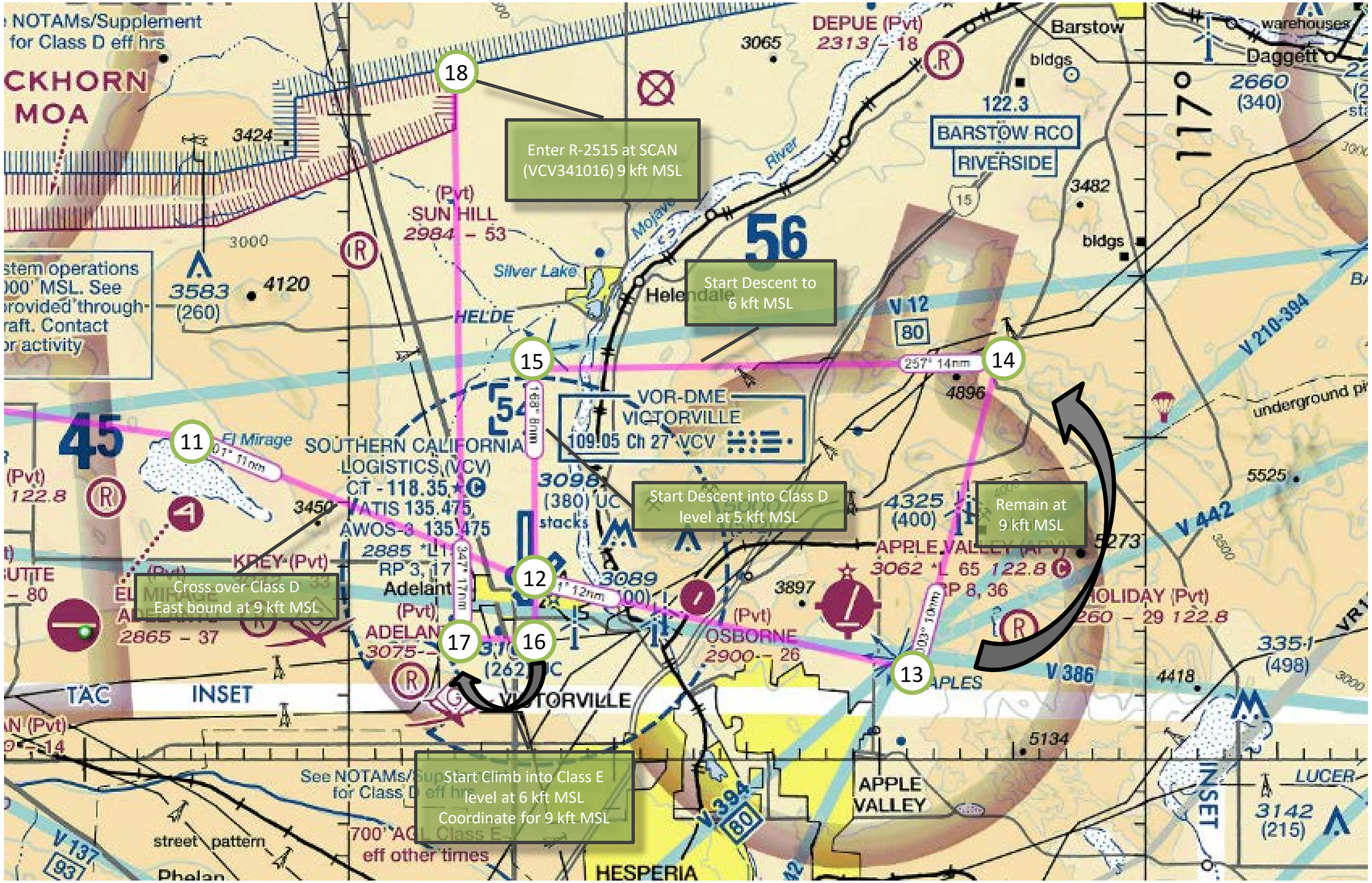
Objective: Execute a flight demonstration of a UAS transitioning to/from Class A or SUA to Class E and Class D employing the Phase 1 Detect and Avoid and Air-to-Air Radar MOPS Systems as alternate means of compliance to 14 CFR §91.111(a) and 14 CFR §91.113(b) "see and avoid/remain well clear" regulations



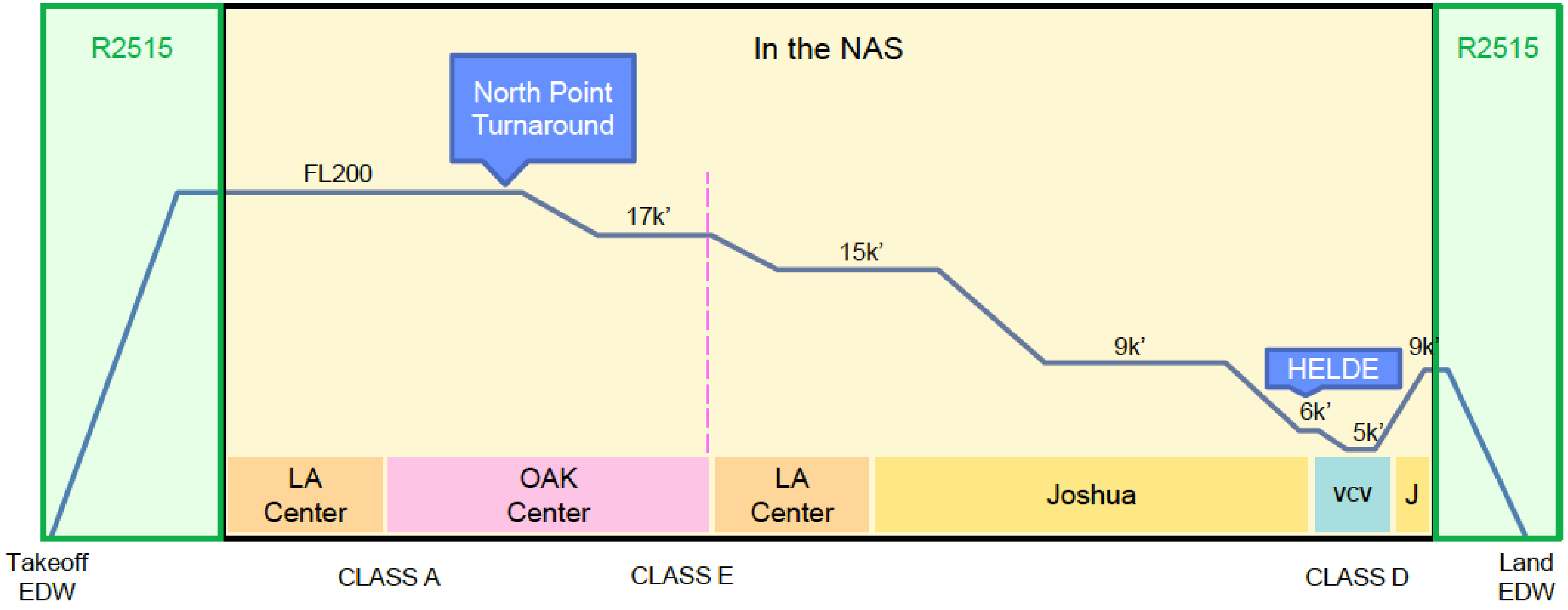
NCC Flight Demonstration Route of Flight

NCC Flight Demonstration Route of Flight

Zoom in of KVCV area. At or above MVA at all times, WPT 11-18



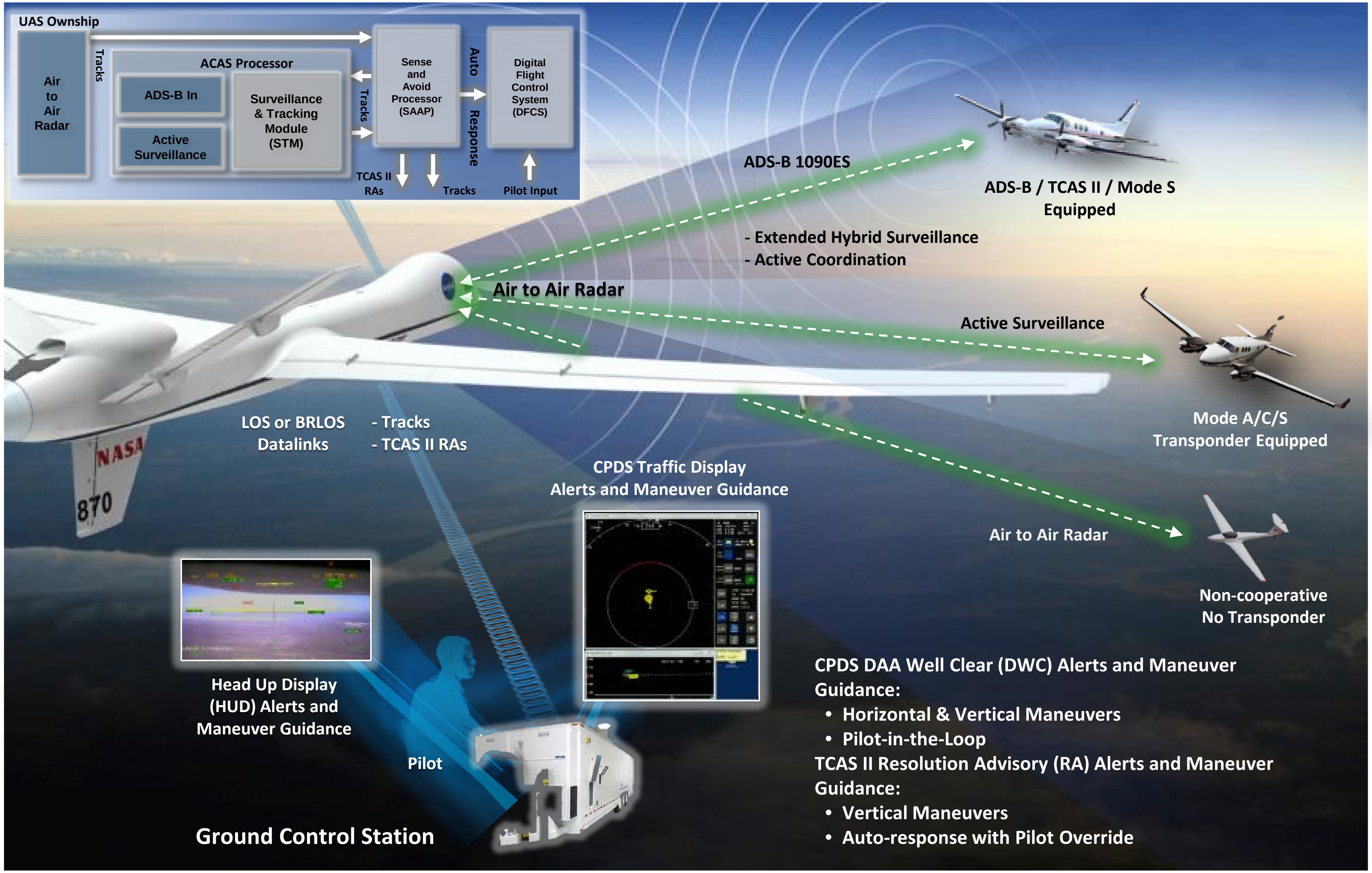
NCC Flight Demonstration Altitude Profile

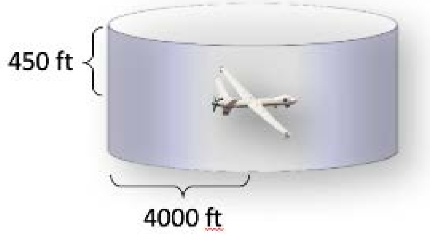


Route of Flight outside R2515: 415 nm

Time outside of R2515: 1.8 hrs

NCC Flight Demo DAA System Architecture





DAA Well Clear Volume

Safety Case Approach and Rationale

- **In order to safety operate UAS in the NAS, it must be shown that the Phase 1 Detect and Avoid (DAA) and Air-to-Air Radar (ATAR) Systems are an alternate means of compliance to 14 CFR §91.111(a) and 14 CFR §91.113(b) "see and avoid/remain well clear" regulations.**

- **The approach taken for this safety case entailed the following:**
  - Performed gap/compliance analysis of the DAA and ATAR systems "as installed" on the Ikhana UAS against published Phase 1 MOPS and Technical Standard Order (TSO) for the DAA and ATAR systems.
    - DO-365 MOPS (dated 31 May 2017) and TSO-C211 (dated 25 Sep 2017) for DAA Systems.
    - DO-366 MOPS (dated 31 May 2017) and TSO-C212 (dated 22 Sep 2017) for ATAR for Traffic Surveillance.
    - Most of the gaps were related to the display of DAA and ATAR system health and status information to the UAS pilot.
      - Determined that updates to the system software to display this information were not required for this demonstration due to Ikhana's architecture and flight test operations concept
        - » System health and status telemetry data is downlinked to the Ikhana GCS and displayed to pilots and engineers

Safety Case Approach and Rationale

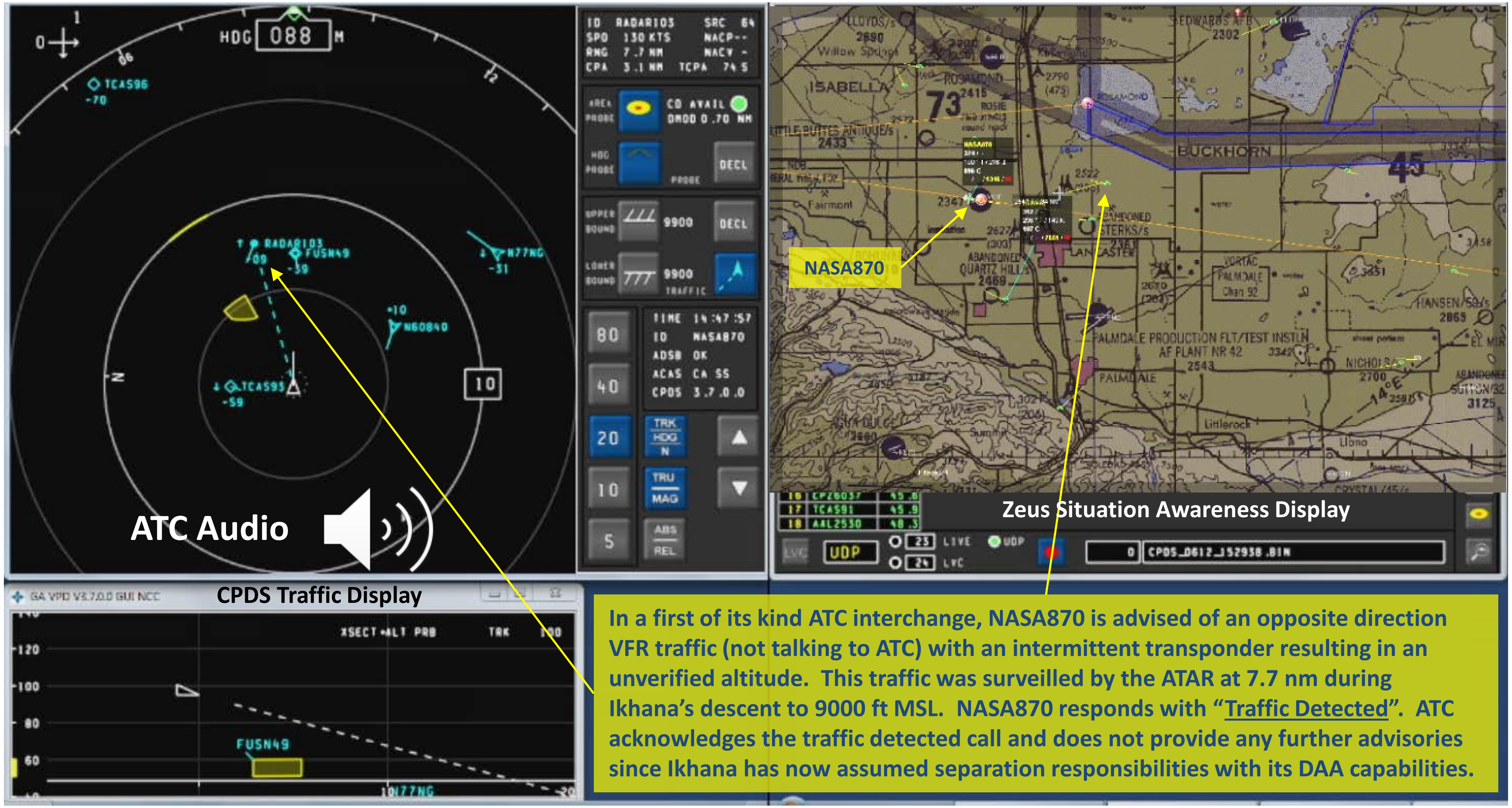
- **Performed gap/compliance analysis of the DAA and ATAR systems "as installed" on the Ikhana UAS against DO-178C software certification guidance (dated 13 Dec 2011)**
  - Design Assurance Level (DAL) for all DAA related software is Level D for overall process/documentation
  - Level C for software testing per DO-178C (full code statement coverage)
  - DAA and ATAR Systems critical DAA functionality is tested to DAL C rigor requiring full code structural coverage
  - The only software component of the DAA System not tested to DAL C full code statement coverage is the Honeywell sensor fusion tracker hosted in the TPA-100B ACAS processor.
    - To address this gap, Honeywell implemented an I/O crosscheck algorithm, to DAL C standards, that validates the fusion tracker's output with TCAS/Extended Hybrid Surveillance data.
    - This feature ensures that the tracker's output is accurate by validating the fusion tracker output tracks with DO-185B and DO-300A compliant passive and active surveillance techniques

Safety Case Approach and Rationale

- **Leveraged the FAA Safety Risk Management Document (SRMD) for UAS DAA System Safety Assessment (SSA) rev 0.5 dated 4 May 2017. Its fault tree influenced NASA's hazard report development and risk mitigation strategy.**

- **Developed operational mitigations to reduce risk and address performance gaps.**
  - ATM Services:
    - The NCC route of flight ensures its mission stays above MVA to leverage the legacy ATM safety systems (primary and secondary surveillance radar coverage)
  - Datalink Management: C2 datalink redundancy during Class E segment <10 kft MSL
    - Although the Ku SatCom BRLOS link has been very reliable on the NASA Ikhana UAS, the NCC route of flight was tailored to minimize operations in Class E <10 kft MSL until the UAS is within C-Band DLOS range. This is expected to occur prior to WPT 9 before initiating the descent from 15 kft MSL to 9 kft MSL.
  - Route of Flight:
    - NCC mission plan was carefully developed to remain off published airways and away from known flight activity associated with gliders and other small aircraft that NASA has not fully tested with the ATAR system
    - Flight tests utilized to validate ATAR performance predictions using RCS modeling and simulations for medium and large aircraft. Modeling and simulation results showed sufficient detection and track performance against small RCS aircraft such as gliders; however, to further reduce risk, the flight demo planned to remain clear of areas with known glider activity.

ATC Interaction—"NASA 870, Traffic Detected," 0747L



In a first of its kind ATC interchange, NASA870 is advised of an opposite direction VFR traffic (not talking to ATC) with an intermittent transponder resulting in an unverified altitude. This traffic was surveilled by the ATAR at 7.7 nm during Ikhana's descent to 9000 ft MSL. NASA870 responds with "Traffic Detected". ATC acknowledges the traffic detected call and does not provide any further advisories since Ikhana has now assumed separation responsibilities with its DAA capabilities.

NCC Flight Demo Mission Summary

- **No Chase Flight Demo successfully completed**
- **DAA Systems worked as expected**
  - Extended hybrid surveillance on ADS-B equipped aircraft to provide better traffic surveillance with minimal RF impact
  - Sensor fusion provided improved track stability and accuracy
  - ATAR-only track on VFR non-cooperative traffic with an intermittent transponder
  - DAA Alerting and Guidance provided the PIC with excellent situational awareness
- **First ever "Traffic Detected" interchange with ATC**
- **Some Ku downlink dropouts**
  - Short durations, likely due to co-channel interference, did not result in loss of situational awareness
  - Highlighted need for DO-362 compliant CNPC datalink

- **FAA Comments:**

"Overall, it was a successful event from the ATC and UAS advancement perspectives. In nominal state and following normal ATC/PIC protocols, this was no different than a manned flight under the same conditions."

Lessons Learned—NCC Flight Demo

- **There is more to obtaining an operational approval to fly in the NAS than just getting a COA approved**

- **Frequency Spectrum Approval and Equipment Certification**
  - Issue:
    - The Project and the AFRC Radio Frequency Spectrum Management Office (RFSMO) did not have a good understanding of the Frequency Spectrum allocation/assignment/approval process for operations outside of SUA when developmental/experimental equipment interfaces with the operational NAS
    - Due to the majority of the DAA and ATAR systems being classified as developmental/experimental, NASA's strategy/safety case development for the NCC flight demos was founded upon demonstrating that the systems to be employed met the "intent" of the Phase 1 MOPS/TSOs. Performance standards gaps would be identified, risks assessed, and mitigations developed.
    - This plan and its implications for obtaining frequency spectrum approval were not fully understood by the NCC Team. NAS operations required NTIA or FCC certified transmitters.
    - Although the COA was approved on March 30, 2018, addressing the frequency spectrum issues resulted in delays that pushed the flights into May/June

Lessons Learned—NCC Flight Demo

- **Recommendation:**
  - Involve the FAA Frequency Spectrum Office early in formulation and ensure inclusion in the SRM process so that all frequency spectrum requirements are understood and accounted for in project planning and coordination
  - Involve the RFSMO early in the Project to initiate National Telecommunications and Information Administration (NTIA) certification process (Federal Agency) or FCC licensing (non-Federal Agency). These processes have long timelines.
  - When hardware/software certifications are not achievable in project timeline, must coordinate project intentions with the FAA early in the COA application and SRM process
  - Vet performance standards gaps and mitigations with the FAA and ensure clear understanding of system limitations
  - The Special Temporary Authorization (STA) process was a work-around that sufficed for this COA, but is not recommended

- **Moving forward:**
  - The FAA will continue to pursue better integration between the operational approval orgs and spectrum management in processing future COAs. Additionally ATC terminology and training will incorporate UAS operations with DAA capabilities.

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

Systems Integration & Operationalization Overview

Kurt Swieringa

SIO Technical Manager, UAS Integration in the NAS Project

Outline

- Current State of the Art of UAS Operations (above 400 feet)
- Overview and Benefits of SIO
- Overview of SIO Partners
- SIO Accomplishments
- Best Practice Highlights
- Summary

Historical Involvement in UAS Research & Applications

Remote piloting with a Piper PA-30 Twin Comanche

Remote piloted supersonic highly maneuverable aircraft technology research

Environmental Research & Sensor Technology (ERAST) Project on high altitude UAS

X-48 Hybrid / Blended Wing Body Research

GL-10 Greased Lightning Prototype electric propulsion research

Sierra B Science Sensor Platform

Prandtl tailless flight research

X-56 aerodynamics flight research

Invention

From remotely piloted to pre-programmed to semi-autonomous flight
From flight in sterile airspace to the National Airspace
From research missions to civilian applications (science/commercial/emergency)

Adoption

1970's | 1980's | 1990's | 2000's | 2010's | 2020's

Remote piloted DAST aeroelastic research

F-15A Remotely Piloted Research Vehicle Project

Federal Aviation Administration (FAA) teamed with NASA on Controlled Impact Demonstration (CID) employing a remotely piloted Boeing 720

X-36 Tailless Fighter Agility Research

Aerosonde science platform for hurricane research

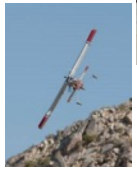
X-43 hypersonic propulsion flight research

X-45A Flight Test Program

Ikhana UAS-NAS Research

Global Hawk Science Platform

DROID Automatic Ground Collision Avoidance flight testing



NASC Tigershark DAA flight testing

Current State of the Art of UAS Operations (above 400 feet)

- **Approval for beyond visual line of sight operations remain a challenge, particularly for operations above 400 feet**
  - Lack of ”certified” DAA and C2 systems and lack of certified UAS

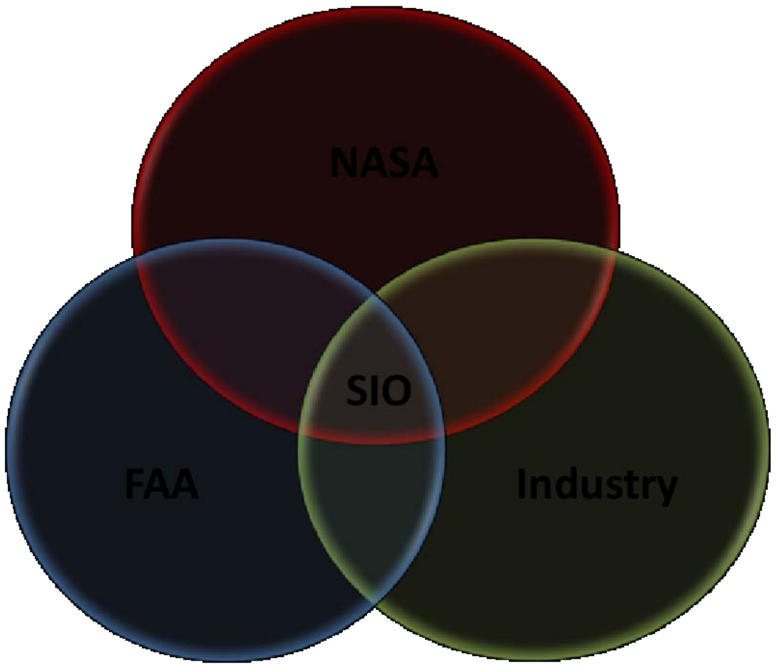
- **Non-Part 107 UAS operations require special approvals**
  - No defined certification path for larger UAS yet
  - Special approvals include Certificate of Waiver or Authorization (COA), 91.113 waiver for beyond line of sight operations, spectrum approvals, etc.
  - Special approvals enable the FAA to assess safety of operations and determine any special mitigations or accommodations
  - Special approvals enable coordination of lost link and other contingency procedures

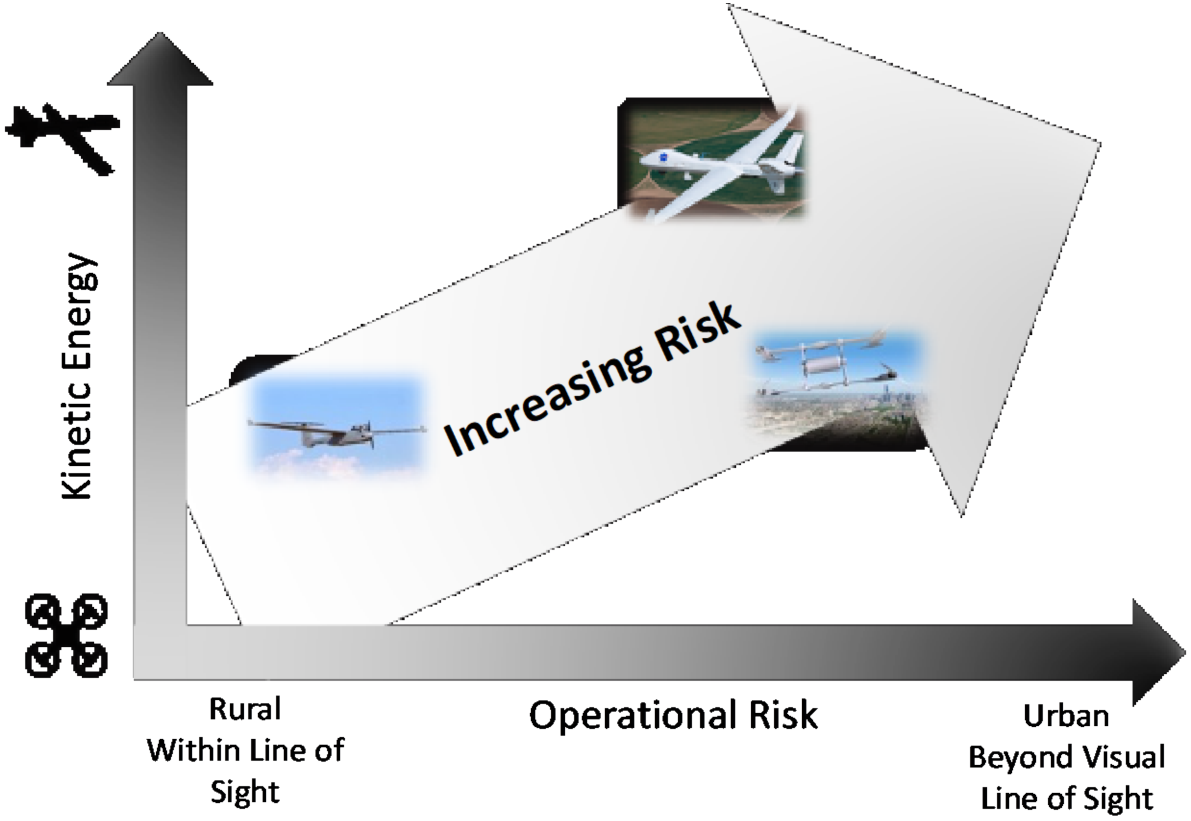
- **Operational mitigations are often required to compensate for risk associated with non-certified or non-proven systems**
  - Visual observers on the ground or in a chase aircraft to see and avoid traffic
  - Avoid operations over people and/or populated areas
  - Low altitude operations (e.g., below 400 feet)
  - Special ATC coordination

SIO Overview

Goal: Work toward routine commercial UAS operations in the National Airspace System (NAS)

- Integrate prototype Detect and Avoid (DAA) and Command and Control (C2) technologies
- Conduct flight demonstrations in the NAS
- Work toward UAS type certification
- Share best practices with the UAS community

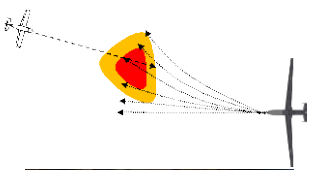




Operational Environments:

- Operations in controlled airspace above 500 feet
- Partners span a range of different operating environments and types of UAS
  - Different operational environments and missions
  - Different UAS weights and characteristics

SIO Overview



Integration of Prototype DAA and C2 systems

- DAA and C2 are key technologies for the integration of UAS into the NAS
- Integrate and evaluate prototype DAA and C2 systems to determine gaps that must be addressed for certified systems

Flight demonstration in 2020

- Emulate commercial concepts of operations
- Obtain approval to fly in the National Airspace System
- Help inform industry if certain concepts of operation are viable in the current NAS, or whether a more limited operation may be needed in the interim as air traffic infrastructure and technology evolve

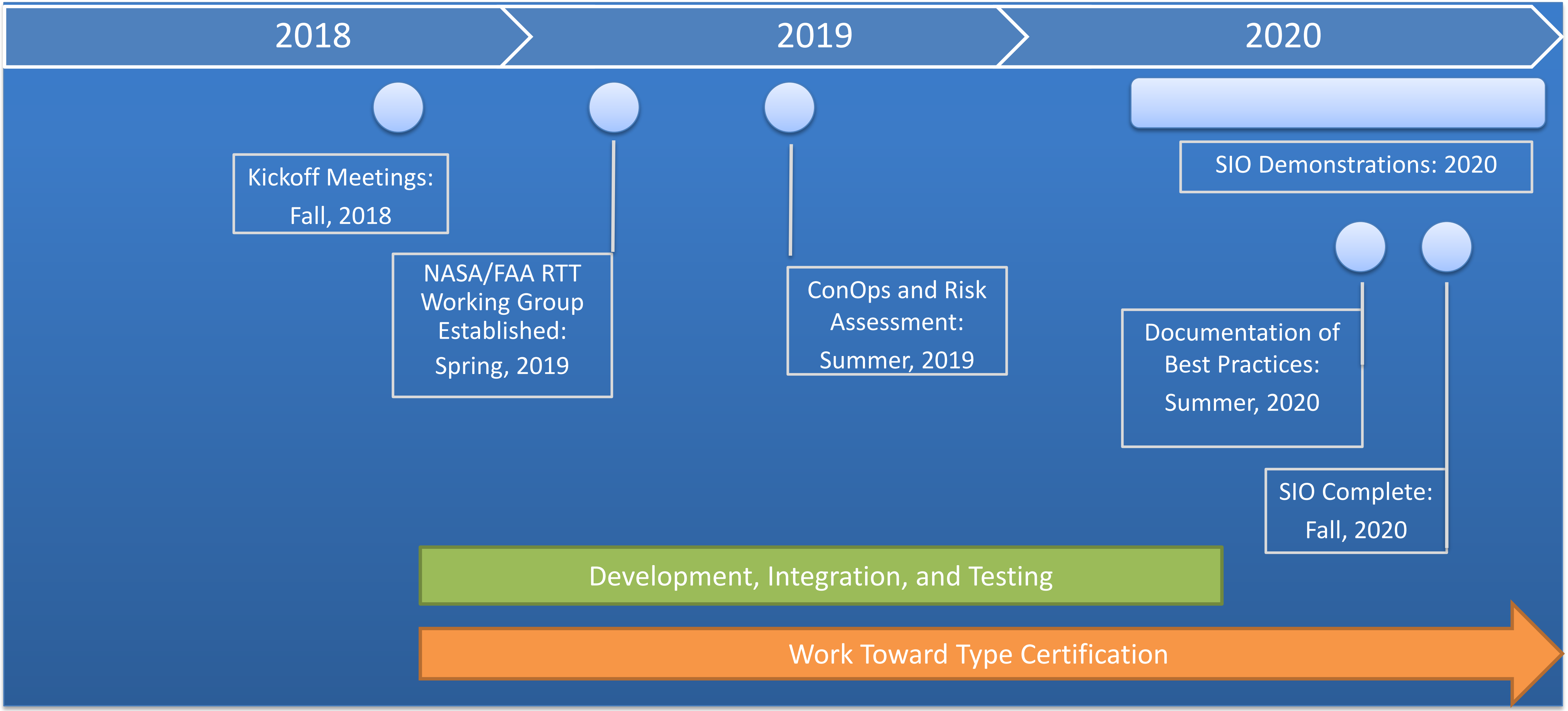
Progress toward UAS certification

- Certification will be necessary to enable routine commercial UAS operations in the NAS
- The SIO partners are all pursuing or plan to pursue certified UAS
- SIO projects will help inform certification strategies for new technology, based on the flight lessons learned from the flight demonstrations in 2020

Documentation of best practices

- Description of concept of operations for SIO missions
- Best practices and lessons learned from SIO certification efforts
- Identify gaps in current UAS technology solutions and current barriers

Schedule


2018
2019
2020
Kickoff Meetings: Fall, 2018
NASA/FAA RTT Working Group Established: Spring, 2019
ConOps and Risk Assessment: Summer, 2019
SIO Demonstrations: 2020
Documentation of Best Practices: Summer, 2020
SIO Complete: Fall, 2020
Development, Integration, and Testing
Work Toward Type Certification

Summary of SIO Partners

Bell

Mission: Medical supply transportation in urban areas at altitudes between approximately 500 feet to 1,000 feet AGL

Vehicle: Autonomous Pod Transport - 70 (APT-70) (~300 Pounds)

SIO Demonstration Location: Urban area in Texas

General Atomics Aeronautical Systems, Inc. (GA-ASI)

Mission: Infrastructure inspection at altitudes above 10,000 feet MSL

Vehicle: SkyGuardian (~12,000 Pounds)

SIO Demonstration Location: Southern California and Southern Arizona

American Aerospace Technologies, Inc. (AATI)

Mission: Infrastructure inspection at altitudes between approximately 1,000 feet to 5,000 feet AGL

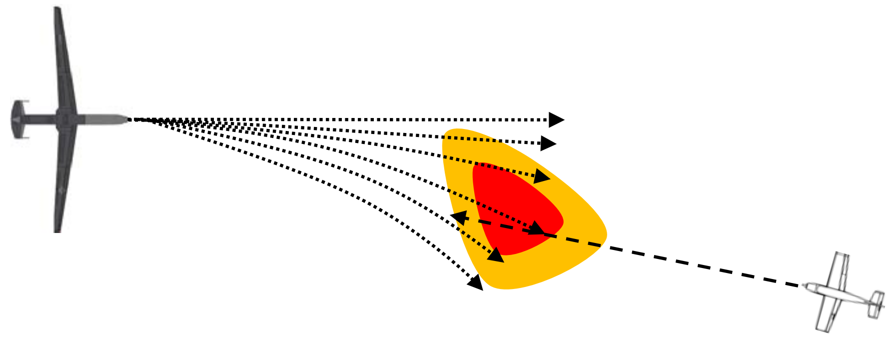
Vehicle: Resolute Eagle (~180 pounds)

SIO Demonstration Location: Central California

The Challenge

DAA Accomplishments

- Design and integration of an experimental Low SWaP DAA system
- Experimental DAA system evaluated by FAA AIR and appropriate operating limitations determined
- DAA system flight testing and data collection
- Creation of open source MIT LL DAA modeling and simulation tools



C2 Accomplishments

- Partial integration of prototype C2 system aligned with DO-362
- Creation of a prototype low SWaP C2 system that uses multiple redundant links
- Obtaining temporary spectrum authorizations for SIO demonstrations

SIO Accomplishments: UAS Flight Demonstrations

Bell

- Flight demonstration in the DFW area
- Flight through Class E and B airspace between 500 and 1,000 feet AGL
- Flight tests leading up to demonstration examined prototype DAA and C2 systems, which were also used during the SIO demonstration
- Key Risk mitigations: visual observers, no flight over people, emergency landing sites

General Atomics Aeronautical Systems, Inc. (GA-ASI)

- Flight demonstration in the southern California area completed on April 3, 2020
- Approximately 9-hour flight through Class E, A , and restricted airspace on a route from Grey Butte to Yuma proving grounds
- Flight tests leading up to demonstration examined prototype DAA and C2 systems, which were also used during the SIO demonstration
- Key Risk mitigations: chase aircraft in Class E airspace, ground observers for surface operations
- After the demonstration, a new experimental airworthiness certificate was pursued that included revised DAA operating limitations, potentially paving the way for future flights without a chase aircraft

American Aerospace Technologies, Inc. (AATI)

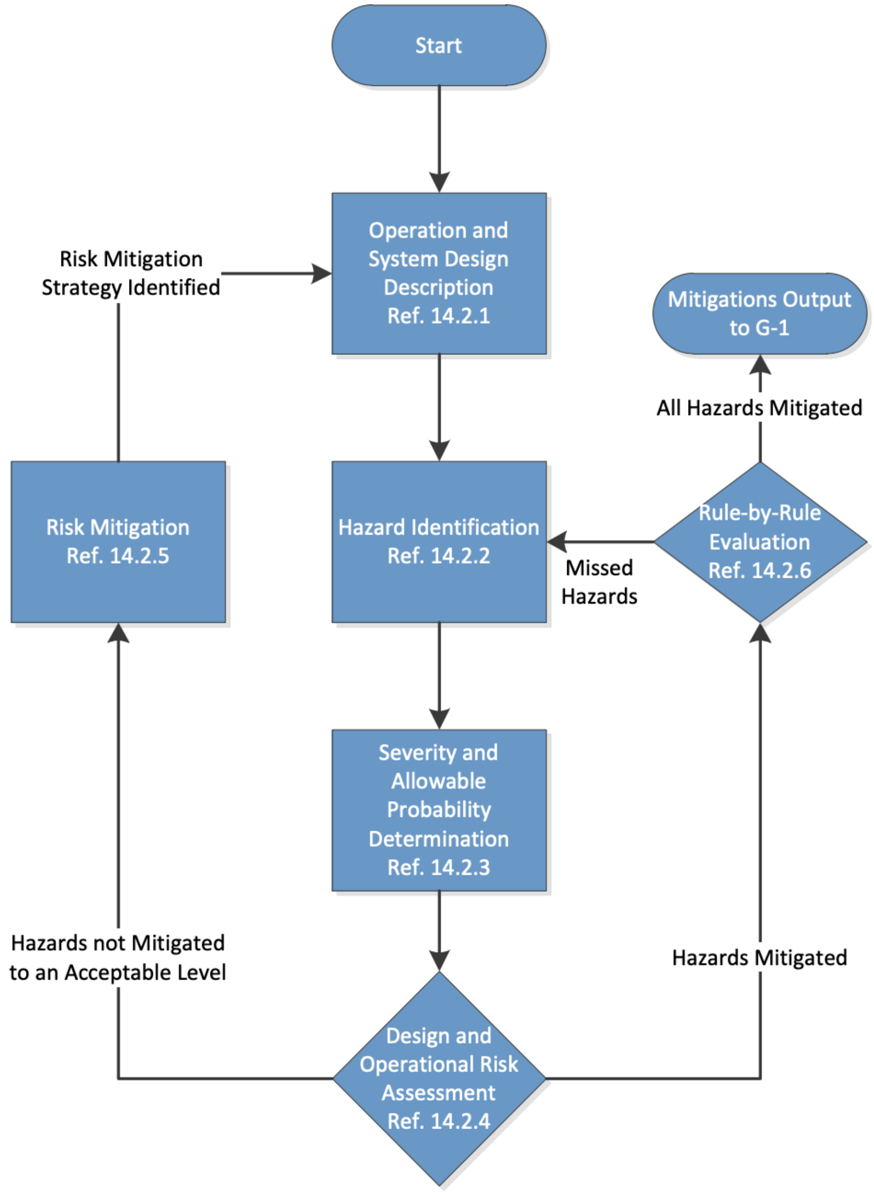
- Flight demonstration expected to occur late 2020 or early 2021

SIO Accomplishments: Type Certification Progress

Overall, NASA learned that further work was needed to finalize the configurations of our Partners' UAS prior to submitting key document for type certification

Type Certification Progress:

- Completed concept of operations documents for different missions (one submitted to LA ACO)
- Completed operational risk assessment documents (one submitted to LA ACO)
- Completed draft project specific certification plans
- Additional applicable documentation
  - UAS Flight Operations and User's Manuals
  - Systems design documentations
  - Test and evaluation reports



SIO Accomplishments: Sharing Best Practices

- **Best practices will be documented in a NASA publication that will be publicly available**
  - Maddalon Jeffrey, *Best Practices Identified Through the Completion of UAS Flight Demonstrations,* NASA/TM-2020-XXXXXX
  - Publication pending
- **Describes best practices identified throughout the SIO effort**
  - Overview of SIO and objectives
  - Overview of safety and certification
  - Current state of UAS standards
  - UAS through the process
  - Best practices
  - Best practices for demonstration approval

NASA/TM–2020-000000

Best Practices Identified Through the Completion of UAS Flight Demonstrations

Jeffrey Maddalon, Kurt Swieringa
Langley Research Center, Hampton, Virginia

Israel Greenfeld
Glenn Research Center, Cleveland, Ohio

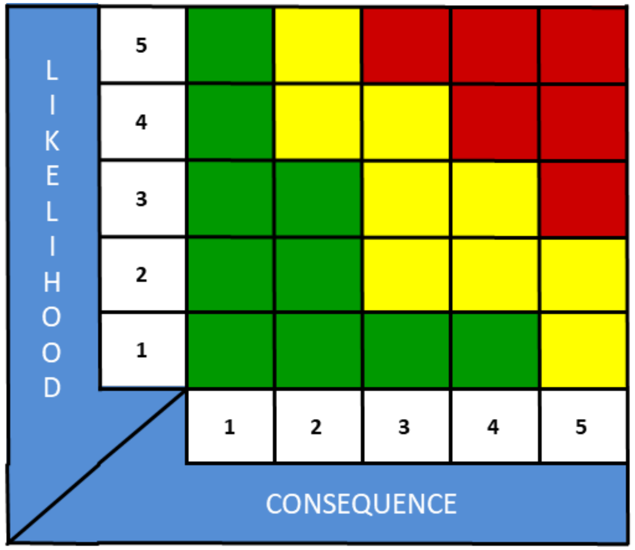
Summer L. Brandt, Peter Robinson, M. Gilbert Wu, Seungman Lee
Ames Research Center, Moffett Field, California

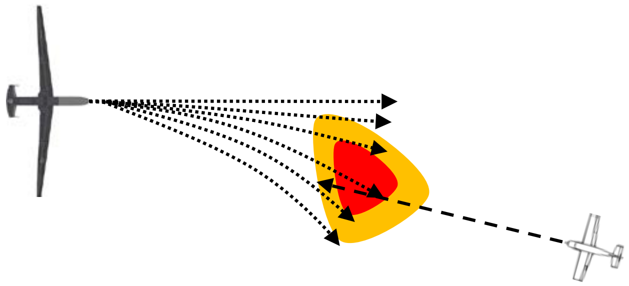
Paul Volk
Adaptive Aerospace Group, Inc., Hampton, Virginia

John Del Frate
The Aerospace Corporation, Edwards, California

Best Practice Highlights

- **General:**
  - Define a clear concept of operations
  - Identify all hazards and sufficient mitigations to those hazards
  - Rely on conventional engineering practices
  - Demonstrate capability in a low risk environment before moving to higher risk environments
- **DAA:**
  - Following current standards or standards being developed will result in a DAA system that is easier to certify
  - The ability of low Size Weight and Power (SWaP) DAA sensor technology to meet safety goals is still being investigated
  - When developing contingency procedures for lost link, UAS operators should consider how air traffic will be detected and avoided





Best Practice Highlights

- **C2 and Spectrum:**
  - Spectrum is finite and valuable
  - Spectrum approvals are needed for all systems that RF signals
  - The risk of interference must be considered and sufficiently mitigated
  - The risk of lost or degraded link may be mitigated via a robust C2 link, autonomy, and/or robust lost link procedures
    - Unlicensed bands are not viable for safety critical applications
    - Licensed bands (e.g., LTE and SATCOM) may be viable for certain operations, but need additional testing and standards development
    - C-band (5030-5091 MHz) Control and Non-Payload Communications (CNPC) spectrum is currently the most viable option for C2
  - If C-band CNPC spectrum is used, data classes described in RTCA DO-362 and supported data rates should be carefully considered during UAS design

Summary

- The Systems Integration and Operationalization (SIO) activity is a NASA partnership with industry, with close FAA coordination, to work toward commercial UAS operations in the National Airspace System

- SIO is focused on UAS larger than 55 pounds operating above 400 feet

- The three industry partners are integrating DAA and C2 systems into unmanned aircraft system and conducting flight demonstrations in the National Airspace System

- Overall, the SIO activity was highly illuminating — a great deal was learned by our Partners, the FAA, and NASA which has been captured through the best practices document that will be available to the UAS industry and research community

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

Systems Integration & Operationalization Partner Briefing: Bell

Jennifer Andrews

Bell APT70 SIO Project Lead

Bell APT 70 System Integration and Operationalization (SIO)

Jennifer D. Andrews

Bell SIO Project Lead

NASA Systems Integration and Operationalization (SIO)

Furthering certification & BVLOS technology

Demonstrating Urban, Critical Medical Transport Mission

Flight demo Q3 2020

Engaging medical community support

Increasing BVLOS Tech TRL from 4 to 6

Detect & Avoid (DAA) with Xwing

Command & Control (C2), Internal

Pushing boundaries of Urban UAS Ops

Operating >55 lb UAS

Flying with GA & Heli traffic

Transiting in & out of DFW, Class B Airspace

Overcoming urban environment challenges

Building certification pathways for medium UAS

Capturing required approvals & process for air logistics missions

Contributing to standard committees on BVLOS tech

Navigating challenges with guidance and strong support from NASA

National and Local Stakeholders

Government, community and industry collaboration for furthering UAS routine UAS operations

Federal Aviation Administration (FAA)

North Central Texas Council of Government (NCTCOG)

Local Medical Community

Nation-wide Suppliers

NASA

SIO Sponsor

Bell

Vehicle, Datalink, Ground Station, System Integrator, Certification

Xwing

Detect and Avoid (DAA)

University of Massachusetts, Amherst's Center for Collaborative Adaptive Sensing of Atmosphere

Weather Avoidance Technology

Bell Autonomous Pod Transport (APT) 70

APT is an all-electric, tail sitting Vertical Take off and Landing (VTOL) unmanned aircraft, which uniquely transitions to fixed wing flight

Objective:

Using the Bell APT70, demonstrate a commercial mission in the NAS and advance the technologies required for autonomous BVLOS flight operations over people in urban environments through uncontrolled and controlled airspace.

Beyond Visual Line of Sight Technologies

Command and Control (C2)

2 RF Line of Sight (LOS) links on separate frequencies

Airborne Detect and Avoid (DAA)

ADS-B Transponder

Two aircraft radars

Visual DAA

Ground Control Station

Weather Avoidance / Monitoring

Integrated DAA Displays

Leveraging established validation methods to advance UAS operations

Component & System Testing

C2, DAA, GCS with DAA interface, and Weather Application testing in lab, simulation environments and component ground testing

C2 Mission environment Validation

Bell 407 test bed of subsystems and C2 system along flight path

EMI System Compatibility

Ground based, on vehicle testing of components

Airborne DAA Testing

DAA system testing on Bell 407 for tuning and flight encounters

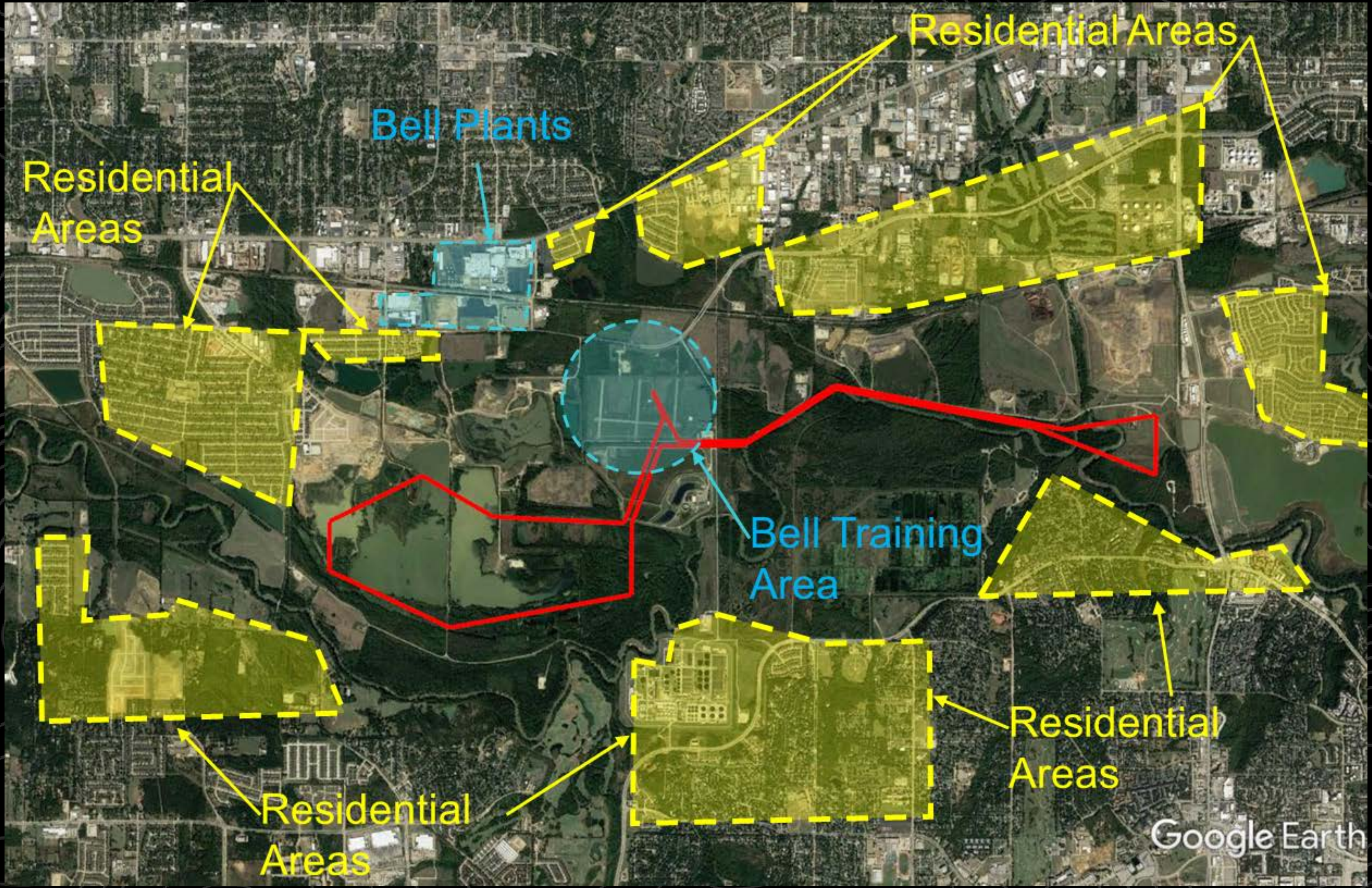
Spectral Survey of Operating Area

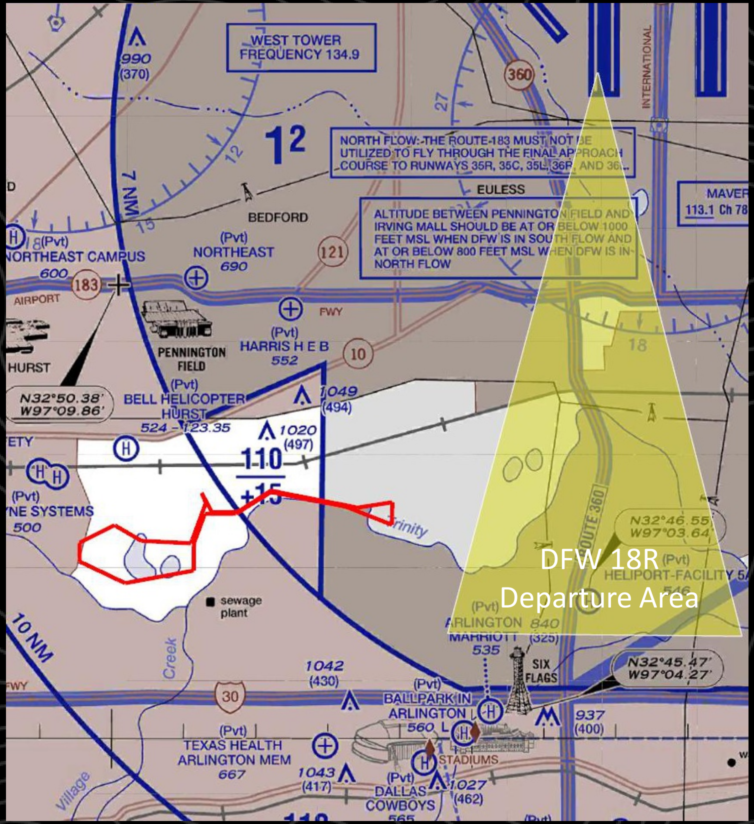
Airborne and Ground based testing

Bell APT 70 Flight Testing

Step-by-step remote site testing of integrated systems prior to demonstration

Mission Concept of Operations





9.4 nmi round trip

Flight altitudes: 500 to 1000 ft AGL

Mission Iteration

Safety is Primary

Focused on safety, Bell iterated with the FAA and NASA on mission operations and flight path over 10 months prior to submittal of paperwork for COA application.

FAA Organizations included

- Aircraft Certification Service (AIR)
- Air Traffic Organization (ATO)
- Spectrum Engineering (AJW-1C3)
- Flight Standards (AFS)
- Fort Worth MIDO, Fort Worth FSDO

Air Safety

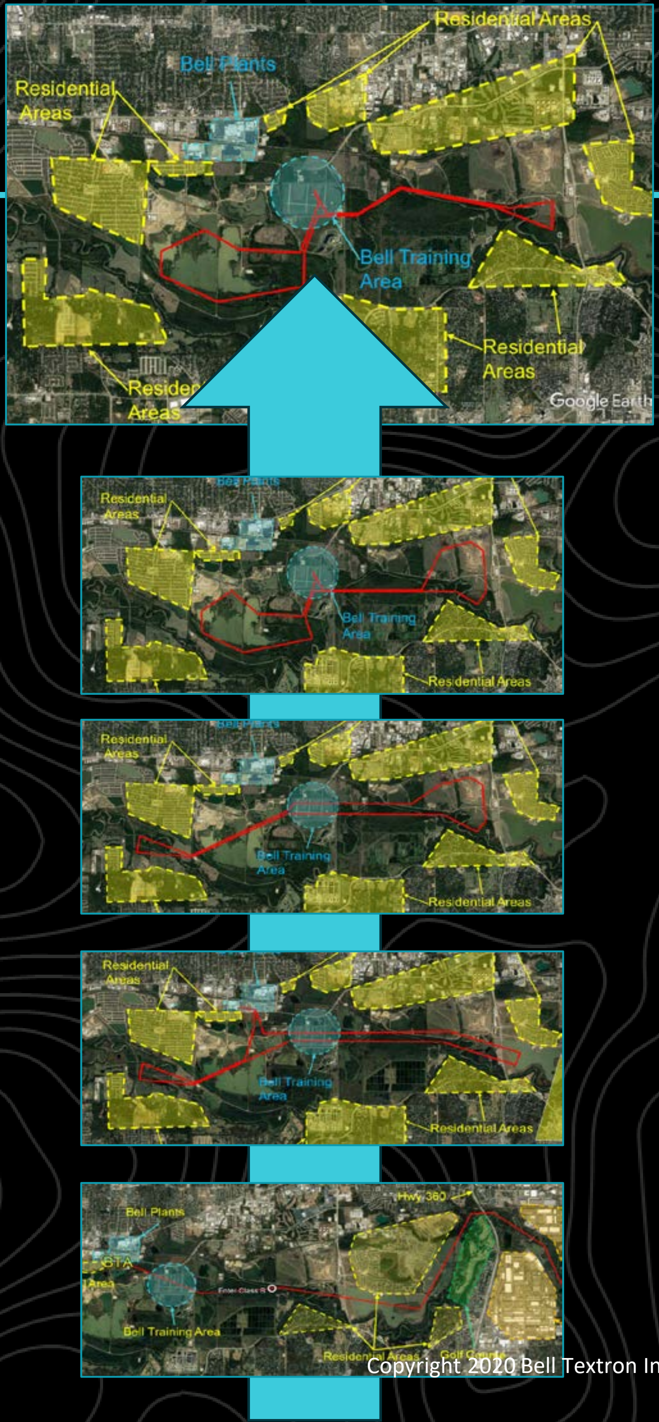
Proximity to DFW traffic, Non-cooperative traffic, BVLOS operations

Ground Safety

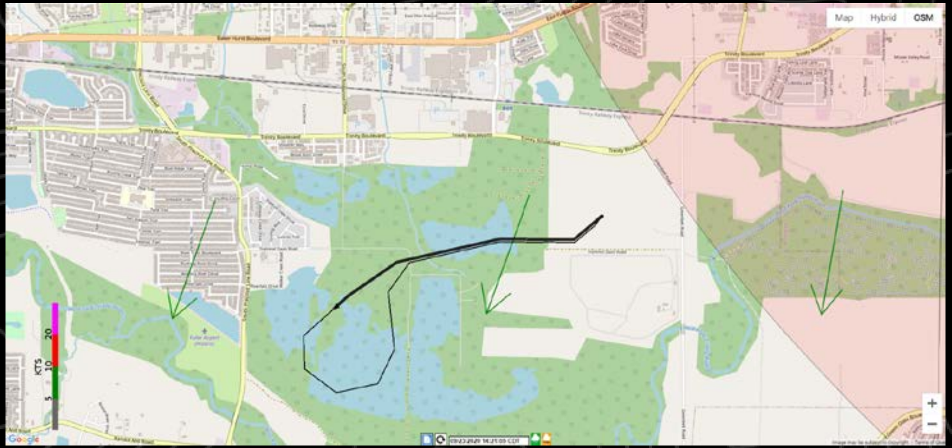
No flights over people, road crossing, land owner permissions, emergency landing zone evaluations

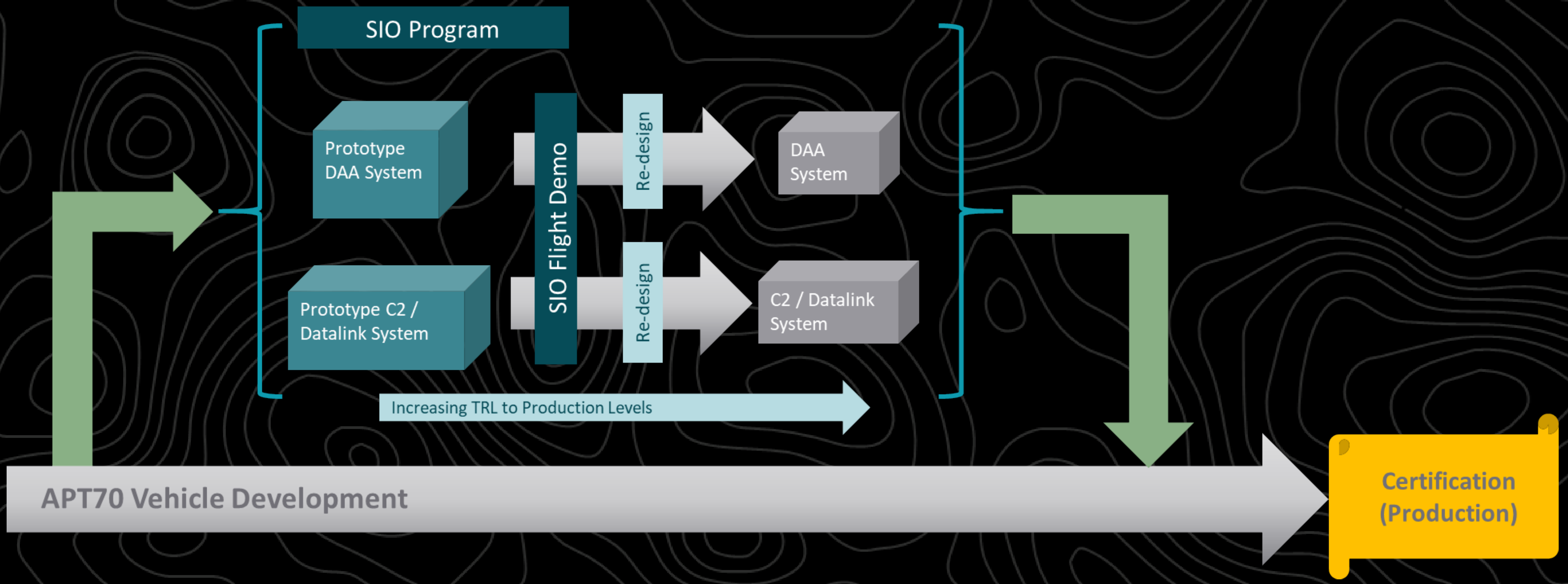
Mission Objectives

Controlled & Uncontrolled airspace, altitude 500 + ft AGL, representative of commercial operations



Bell APT70 SIO Flight Operations & Demonstration





Building the pathway for Medium UAS authorization & approvals

Capturing required approvals & processes for air logistics missions

Risk-based Safety Assessment

Mission Concept of Operations

Exemptions/Waiver applications

Navigating challenges with guidance and strong support from NASA & FAA

Controlled Airspace

Spectrum

Foundation for more robust and optimized (SWaP) solutions

Test Data & Analysis

Lessons Learned

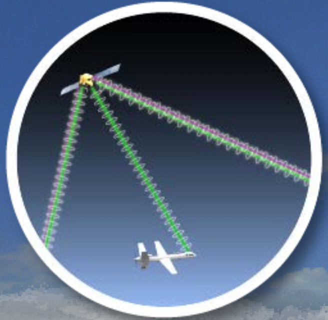
Standards Requirements

Production design & airworthiness considerations

- BVLOS technologies
- Advanced automation / Autonomy
- Durability & reliability requirements
- Productionization of COTS parts
- Use of additive manufacturing
- Regulations & standards definition

SIO Flight Test Team at Choctaw Nation of Oklahoma's Emerging Aviation Technology Test Center (EATTC)
Photo used with permission from Dr. Robert Huck

THANK YOU



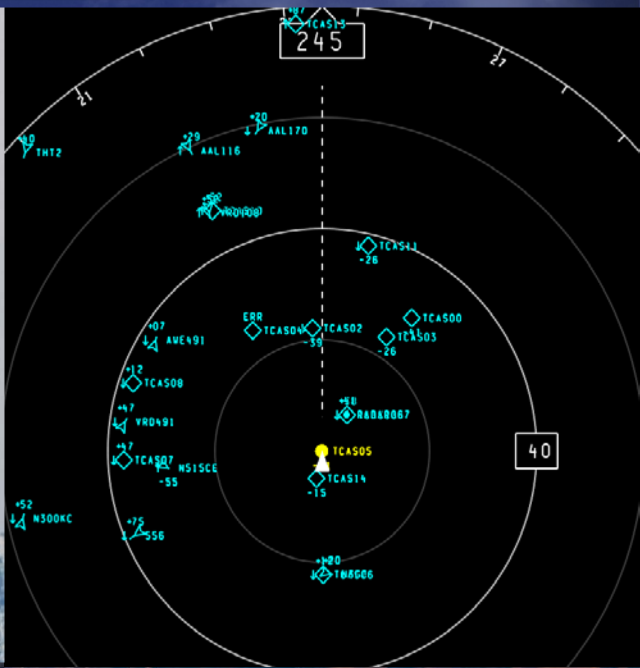
Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Systems Integration & Operationalization Partner Briefing: General Atomics Aeronautical Systems Inc.

John Choi

Director, Special Purpose UAS, General Atomics Aeronautical Systems Inc

GA-ASI Systems Integration Operationalization (SIO) Demonstration



UAS-NAS Project Closeout Technical Interchange Meeting

September 30 – October 1, 2020

GENERAL ATOMICS AERONAUTICAL

The SIO Demonstration was Truly a Collaborative Effort!

GENERAL ATOMICS AERONAUTICAL

Honeywell Aerospace

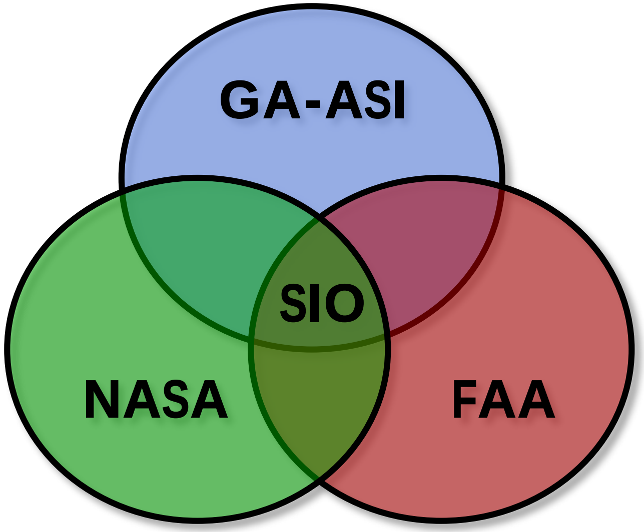
Collins Aerospace
A United Technologies Company

NASA

GA-ASI SIO Demonstration Objective and Scope

SIO Demonstration Achievements:

- Development of a CONOPS with high commercialization potential;
  - COMPLETE
- Integration of systems and technologies necessary to support CONOPS (Detect and Avoid, CNPC)
  - COMPLETE
- Generation of safety and airworthiness data, identification of operational requirements and restrictions, and obtaining approval to operate in the NAS;
  - COMPLETE
- Flight Demonstration that emulates the commercializable CONOPS
  - COMPLETE
- Progress toward obtaining a type certification for the SkyGuardian UAS
  - COMPLETE



GENERAL ATOMICS AERONAUTICAL

GA-ASI SIO Concept of Operations (CONOPS) Overview

Commercial CONOPS: Multi-phase infrastructure survey plus public safety support

Operation Setting: Southern California

- Flight in Class A, E and G airspace
- Routing avoids Class B airspace

Time: Long endurance, day into night mission

Sensors: Physical sensors + virtual Sensors

- Physical: EO/IR turret and Lynx® multi-mode radar
- Virtual: Hyperspectral, LiDAR, etc.

CONOPS Output: Survey data for customer dissemination

	Surveying Mission	Commercial Capability
1	Railroad Inspection	Track Alignment, Obstructions, Landslide
2	Agricultural Survey	Crop Health Monitoring and Assessment
3	Aqueduct/Canal Inspection	Damage Survey, Leak Detection
4	Land Survey	Topographical Mapping, Photogrammetry
5	Power Line Inspection	Vegetation Encroachment, Line Sag Analysis
6	Oil/Natural Gas Pipeline Inspection	Leak Detection, Change Detection
8a	Street Light Survey	Map Functioning/Non-Functioning Lights
8b	Public Safety Support	Vehicle Speed Enforcement, On-call Incident Support

GA-ASI SIO Demonstration UAS Platform: General Atomics ASI SkyGuardian UAS

- **GOAL: Create a UAS Capable of Being Certified by Civil Agencies for National Airspace Integration**
  - Nov 2016: Prototype aircraft first flight (N190TC)
  - May 2017: N190TC sets new company endurance record of 48.2 hours
  - July 2018: First transatlantic flight of a MALE UAS
  - April 2020: SIO Demonstration Flight

Aircraft Characteristics

Wing Span/Length:	79 ft/38 ft.
Max Gross Takeoff Weight:	12,500 lb.
Payload Capacity:	800 lb. internal/5,550 lb.
Payloads:	EO/IR, Lynx Multi-mode Radar
Max Altitude:	40,000+ ft.
Max Endurance:	40+ hr

Fault Tolerant Redundant Electrical Power Generation

Capabilities

- Remotely piloted, supports fully-preprogrammed mission
- Automatic Takeoff and Landing Capability
- Nine external stores stations
- C-band Line-of-Sight data link
- Ku-band SATCOM data link; interchangeable to X Band
- Detect and Avoid
- Maritime Mission Kit

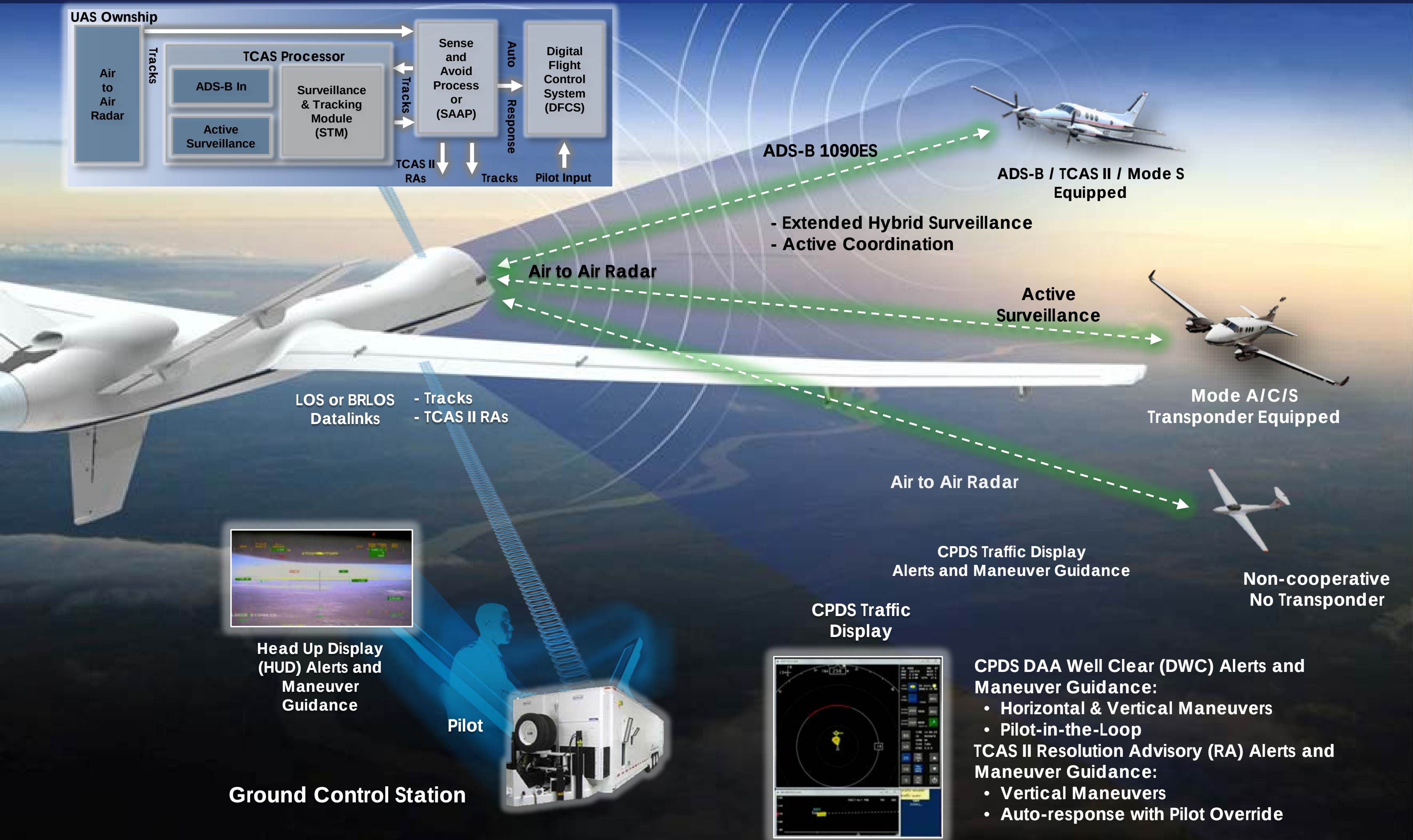
Certifiable Ground Control Station, CGCS

DO-254 Avionics Design Assurance

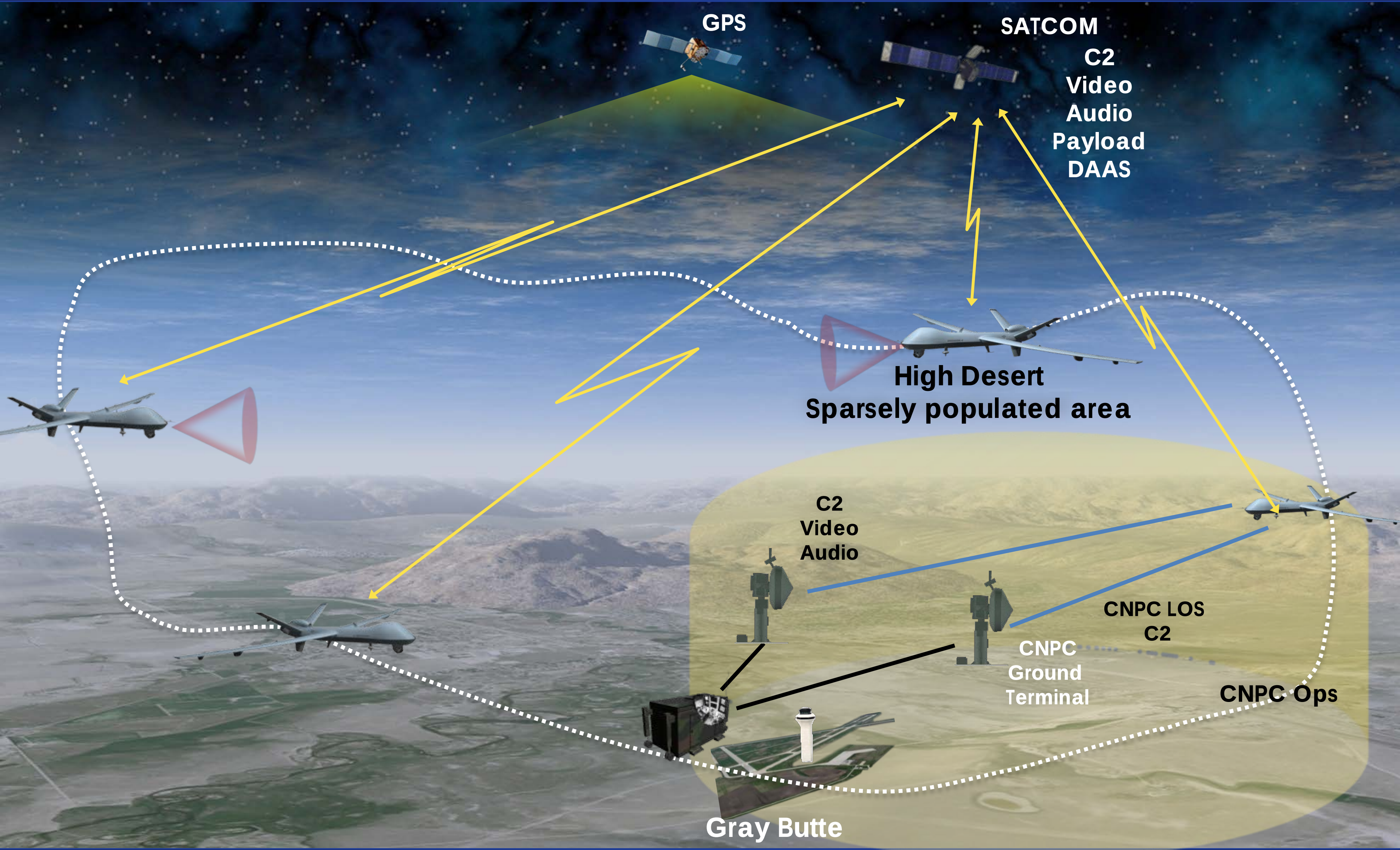
DO-178 Software Design Assurance

Certified displays and full payload separation

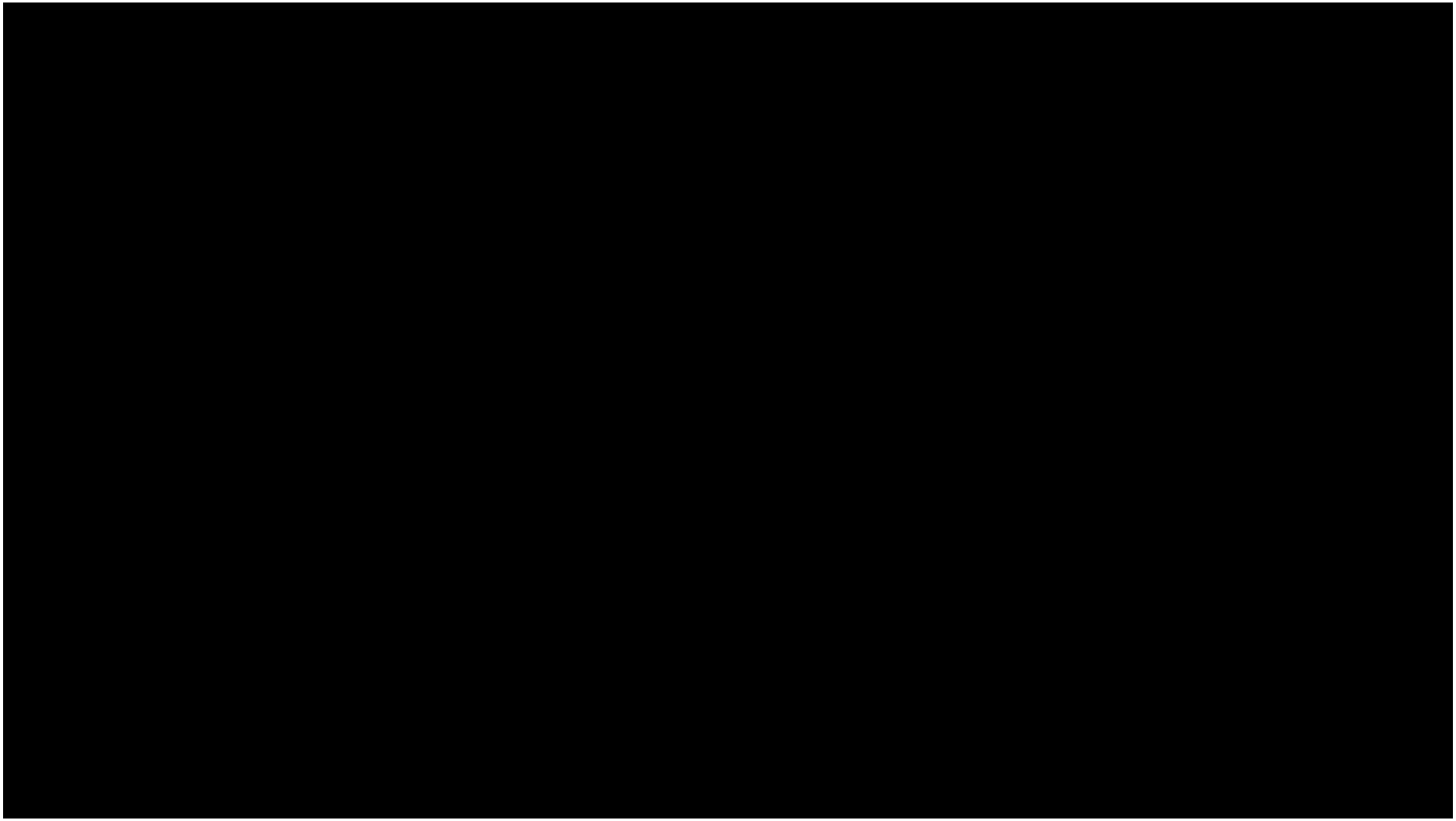
SIO Key Enabling Technology: Detect and Avoid



SIO Key Enabling Technology: Control Non-Payload Communication (CNPC) Datalink

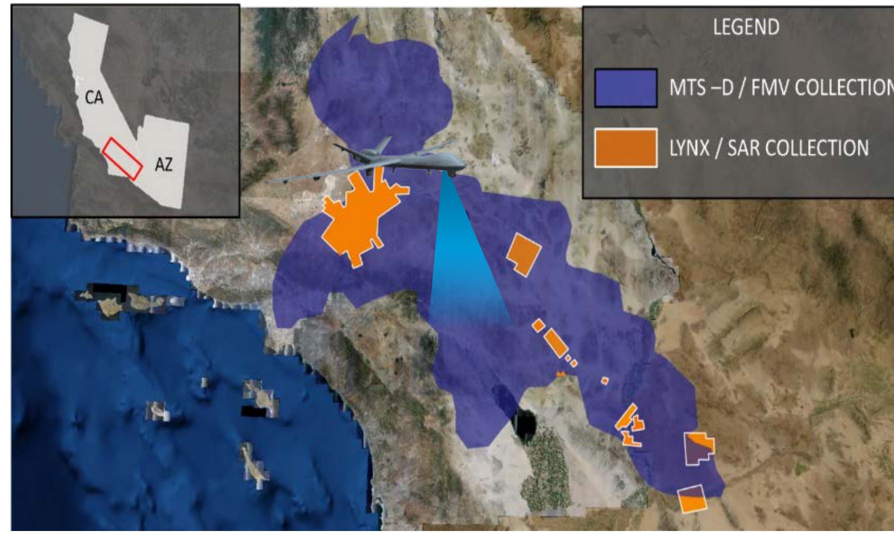


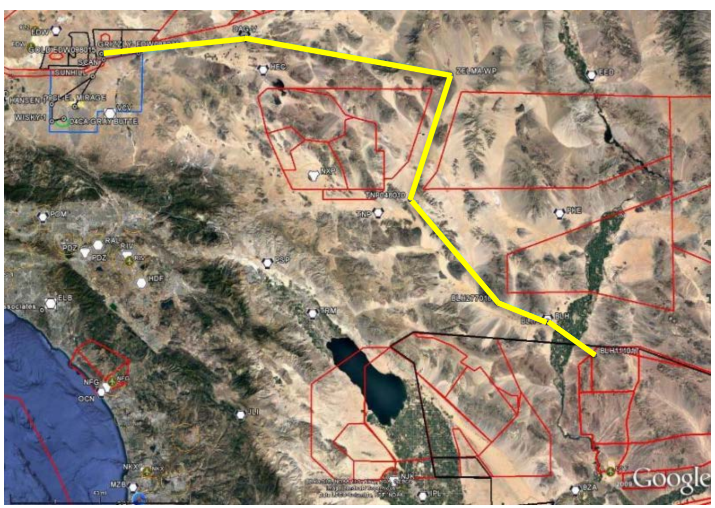
SIO Demonstration Event



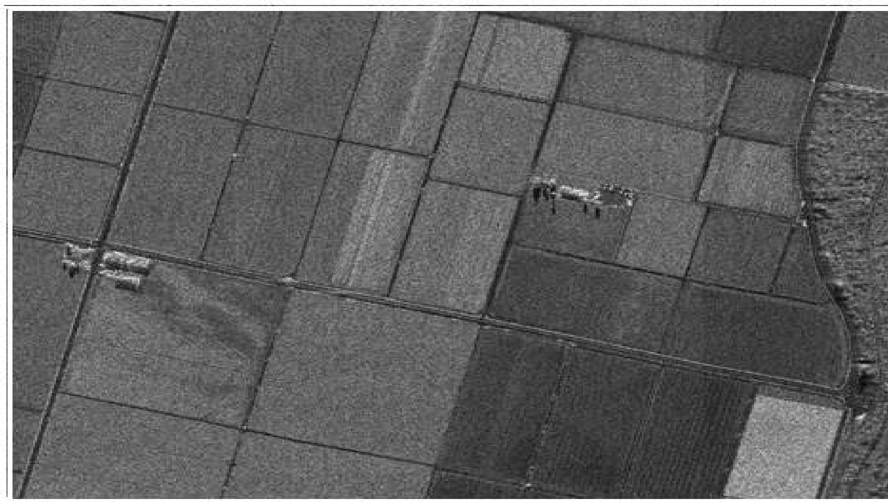
SIO Demonstration Event:
Flight Route and Infrastructure Inspection Capability

Area Surveyed During SIO Demo Flight





Route of Flight



Lessons Learned and Best Practices

- **Lessons Learned**
  - C2 bandwidth optimization is needed for full CNPC link capability
  - FAA Operational Approval process for BVLOS No Chase UAS operations requires routine use to mature approval processes and increase FAA staff familiarity
  - Route optimization + advanced surveying techniques to maximize commercial potential

- **Best Practices**
  - Early FAA engagement across all lines of business
  - Joint FCC and FAA Spectrum Office coordination
  - Partnerships with industry leaders on key emerging technology development

Next Steps After SIO and Beyond

- Continue to pursue FAA type certification of SkyGuardian UAS.
- Continue to pursue FAA TSO certification of GA-ASI's DAA system.
- Continue testing of CNPC Radios including use in terminal environments, and hand-offs/transitions between multiple CNPC ground nodes.
- Fly a No-Chase COA route when operationally approved and resources allow.
- Continue working the FAA on UAS flight approvals towards the end goal of large-scale, routine, commercial UAS operations performed with safety, efficiency, and security.
- Coordinate with the entities identified by the FCC to understand and solve any outstanding frequency authorization items.
- Investigate cooperative research opportunities with universities on the use of SAR for crop health monitoring.

Thank You

GENERAL ATOMICS
AERONAUTICAL



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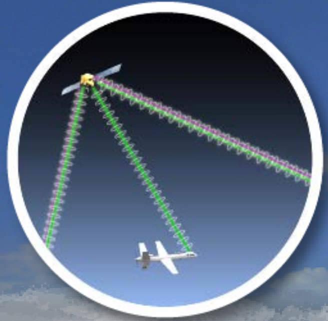


Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Systems Integration & Operationalization Partner Briefing: American Aerospace Technologies Inc.

David Yoel

CEO, American Aerospace Technologies Inc.

Ali Etebari

Vice President of Engineering, American Aerospace Technologies Inc.

AMERICAN AEROSPACE TECHNOLOGIES INC.

UAS-NAS
Technical Interchange Meeting

September 30 – October 1, 2020

NASA System Integration and Operationalization (SIO) Goals

- Collaboration between UAS Industry and Government Aviators towards UAS operations in the NAS
- Goals:
  - Commercial UAS operations in the NAS for larger UAS
  - Increase public acceptance
  - Exercise FAA safety and risk mitigation process
  - Leverage NASA expertise in NAS
- Establish Flight CONOP demonstrations that have commercial applicability with public benefit
- Integrated DAA and C2
- In parallel – SIO partners seek type certification with the FAA.

AATI is working to demonstrate commercial UAS operations in the NAS for larger UAS beyond §107

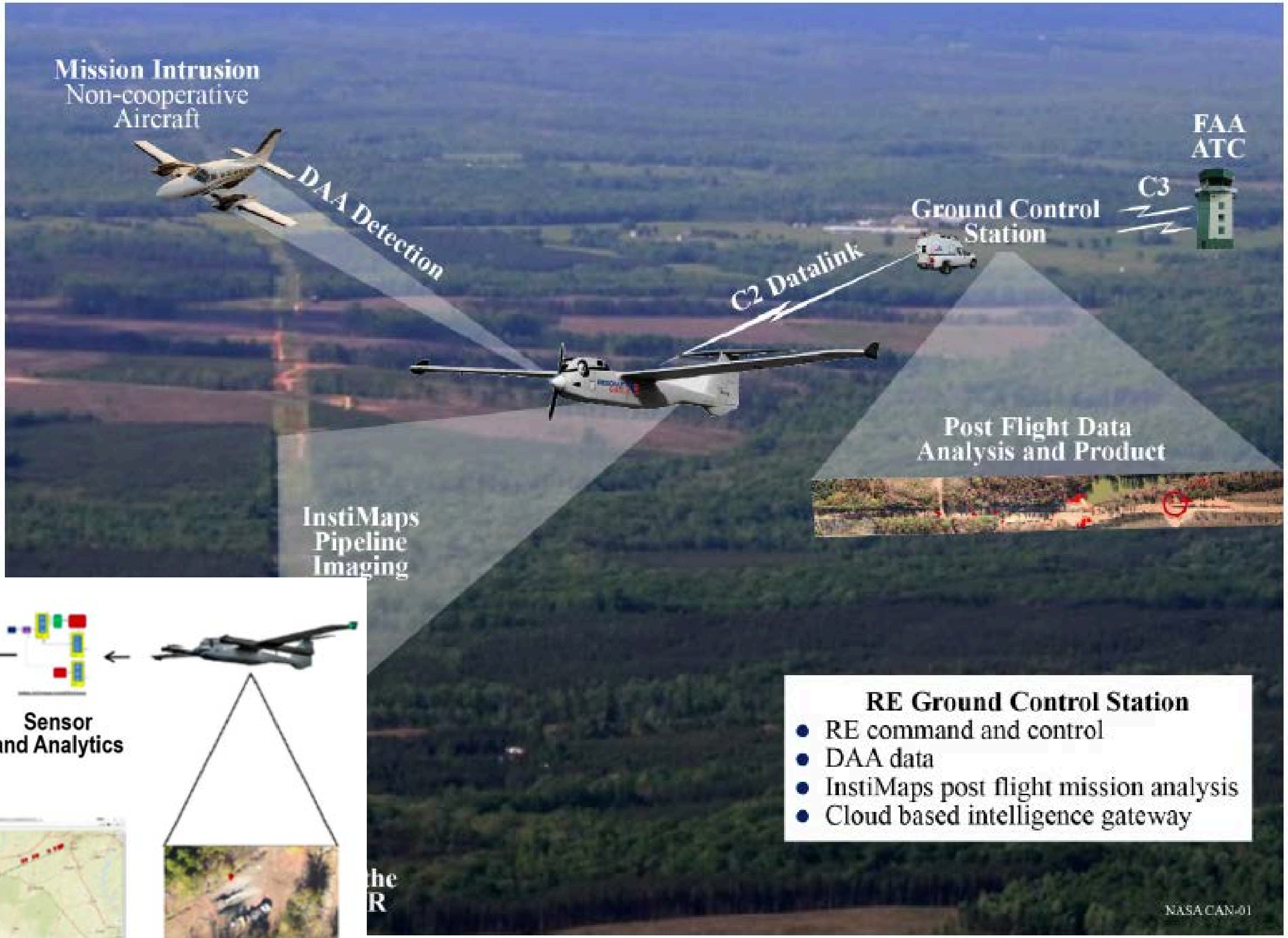
Objectives

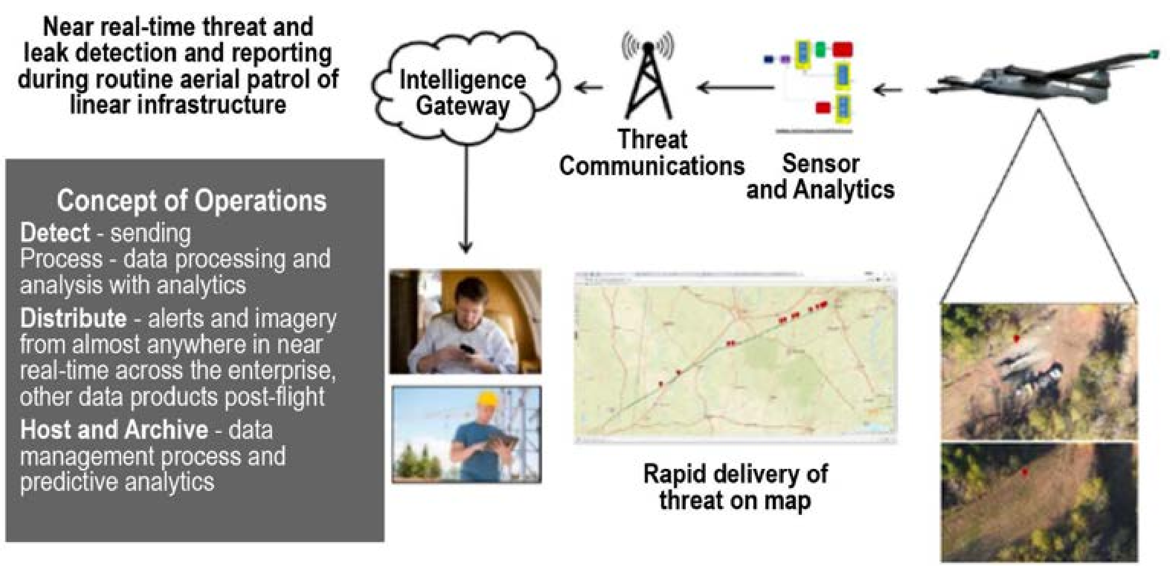
- Develop UAS and systems to support commercial operations in the NAS through demonstration and work towards FAA type certification
- Leverage developing standards and technologies
- Collaborating with the FAA, NASA, and PHMSA/PRCI on type certification basis for larger UAS
  - Determining Deltas with Current Regulation and finding a new basis for UAS going forward
- AATI Requirement: Leverage existing programs to accumulate flight hours

AATI is working to demonstrate commercial UAS operations in the NAS for larger UAS beyond §107

AATI NASA SIO – Commercial Infrastructure Inspection

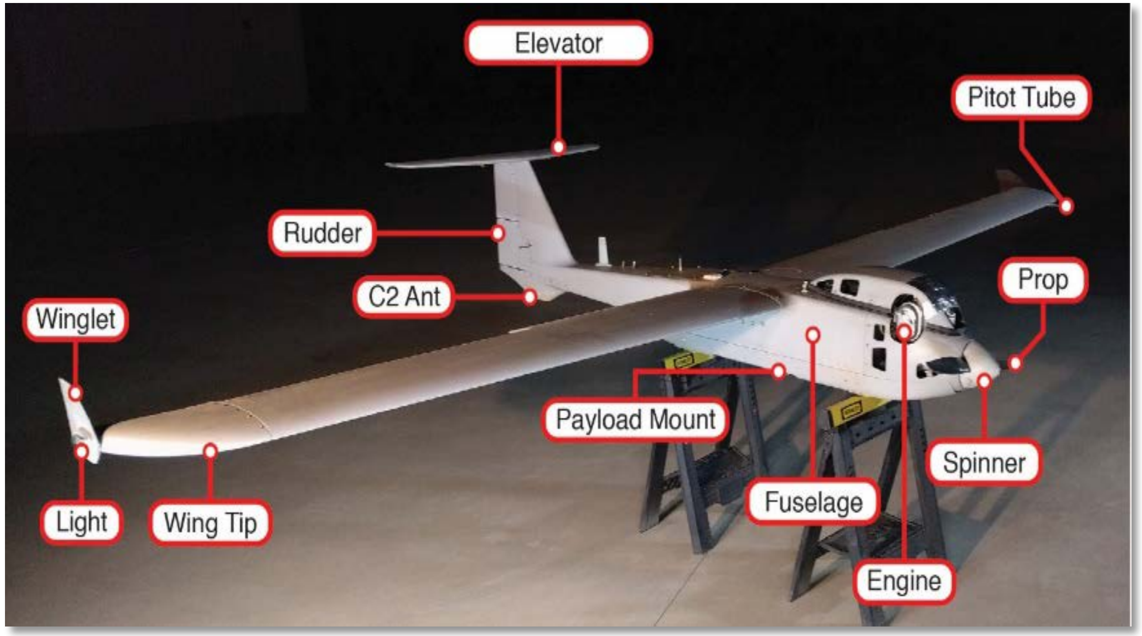
- Infrastructure Inspection and Automatic Threat Detection Payload
- Implementation of Detect and Avoid
- Serve the needs of the public
- Approximately 500,000 miles of pipeline in US
- Inspections are required 2 times a month but are often done more frequently
- Pipeline incidents are costly to the Customer when problems arise





AATI Solution – AiRanger™ formerly Resolute Eagle

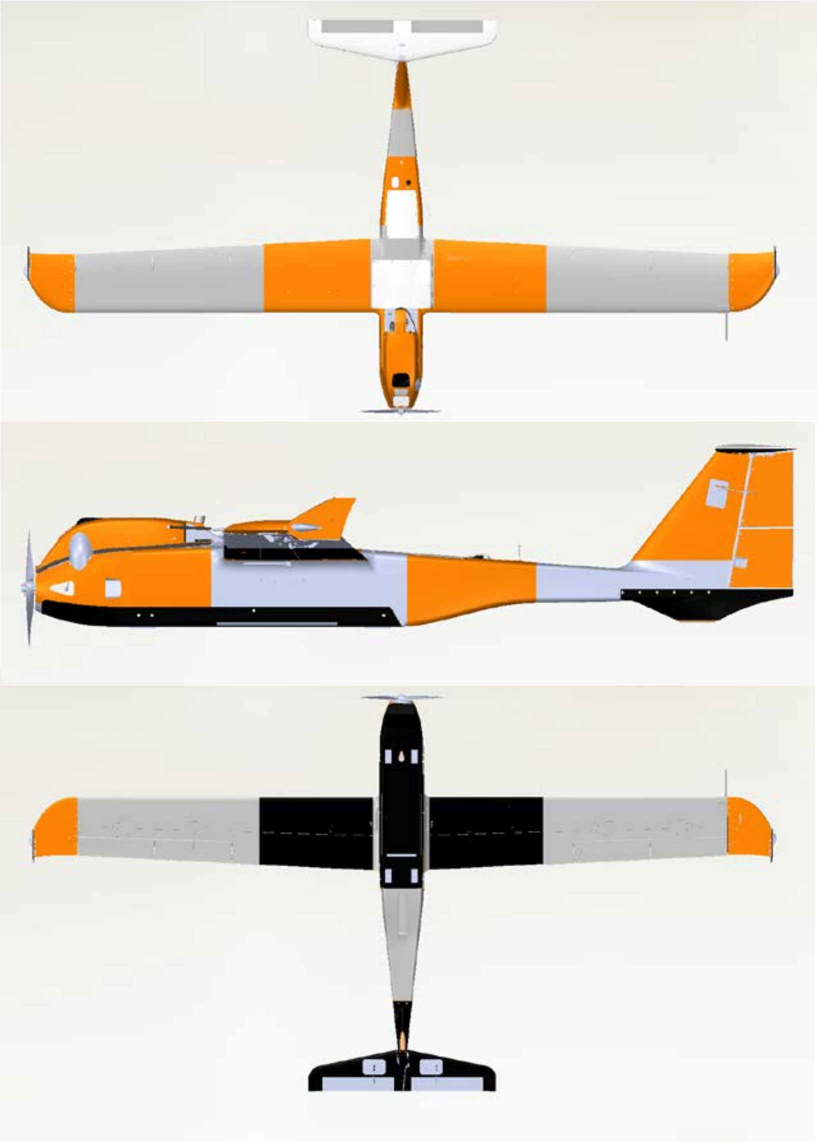
Wing Span:	*18.2 ft*
Length:	*9.5 ft*
Endurance:	*18 + hours (configuration dependent)*
Service Ceiling:	*15,000 ft*
Speed (dash/cruise):	*100 kts / 50 kts*
Engine Power:	*8.2 hp*
Maximum Takeoff Weight:	*220 lbs*
Empty Weight:	*140 lbs*
Max. Payload Weight:	*65 lbs*
Payload Bays:	*Fuselage and underwing bays*
Launch/Recovery:	*Lightweight catapult / belly skid landing*
Onboard Power:	*1,150 + watts (900 watts available for payloads)*
Communications:	*Line of sight (LOS), beyond-line-of-sight (BLOS), and relay beyond visual line of sight (BVLOS)*



- Take off and landing – non traditional fields
- Detect and Avoid paint scheme, lighting and visibility

AiRanger^{TM} is a CTOL UAS w/significant payload and fuel capabilities, allowing long-range commercial missions

Enhanced Visibility Features



Increasing Visibility to Manned Aircraft

- Applying polyurethane paint to critical body features will allow improved visibility to manned aircraft.
  - Certain colors (fluorescent orange) were visible at distances of 2.3 miles vs 1 mile unpainted
- Fluorescent colors are most visible in areas of light; tops of wings, wingtips, and fuselage.
- Dark colors are most visible in shaded areas; underside of both wings and fuselage.

Enhanced Visibility Features provide additional safety benefits by enhancing visibility to other vehicles

AATI Leveraging - NASA / Industry SIO Related Work

- Development
  - RTCA
    - SC228 – Minimum Operations Performance Standards (MOPS) for UAS
      - DO 365 - Detect And Avoid
      - DO 366 – Air to Air Radar for Traffic Surveillance
      - DO 362 – Command and Control (C2) Data Link
      - DO 381 – Ground Based Surveillance System (GBSS)
    - SC147 – Traffic Alert & Collision Avoidance System (TCAS)
  - ASTM F38 – Unmanned Aircraft Systems
    - F38.01 Airworthiness
    - F38.02 Flight Operations
    - F38.03 Personnel Training, Qualifications and Certification
  - UAS Detect and Avoid Concepts and Technologies
    - Simulators with MIT LL
    - DAIDALUS Detect and Avoid Alerting Logic for Unmanned Systems
    - ACAS sXU - Collision Avoidance Alert and Guidance
  - UAS Command and Control Concepts and Technologies
    - Certification of UAS C2 Data Link – CNPC-5000 – 5040-5050 MHz
    - UTM Use of CNPC-1000 for sUAS – 960-977 MHz

AATI is leveraging the efforts of NASA, FAA, and working groups to follow a thorough Type Certification process

Shared Programs Phases

Phase I Campaign	Proof of Concept - Flight Ops in the field with Customers
Phase II Campaign	Sensor Improvement and Customer Operations and Communications progression Towards BVLOS / SIO
Phase III Campaign	Customer flights and Type/Cert Flight Ops
Phase IV Operations	Customer flights and Type/Cert Flight Ops Routine Patrol for Customer / AiRanger UAS
Phase V Operations	Routine Patrol Nationwide – Multiple Commercial Operations with Type Certification

AATI is leveraging multiple commercial efforts to maximize Airworthiness data

Available Certification Basis

D&R – Based on functional test, to accumulate successful flight hours to substantiate overall UAS reliability

- Controllability, Maneuverability, and Stability
- Containment
- Powerplant and Supporting Systems

Small UAS up to 100 lbs.

Not enough

Population Density (people per square mile)	Baseline Configuration (flight hours)	Reduced probability of injury configuration <30% AIS 3 of greater injury (flight hours)
Up to 100 (rural)	375	150
Up to 3,000	1,100	540
Up to 7,000	2,500	1,300
Up to 10,000	3,000	1,800
Up to 14,000	5,000	2,500
Up to 20,000	7,200	3,600

- GCS
- Detect and Avoid
- C2
- Powerplant

Traditional - Based on design requirements verified by inspection, analysis, demonstration, or test

- Structural Integrity
- Command and Control Data Links

Manned Aviation

- Light Sport ASTM compliance
- General Aviation
  - 14 CFR 23-64

Too Much

Part 23 with Means of Compliance

AATI is using a modified certification basis approach to address the niche space of the AiRanger™ sUAS

Approach to Type Certification

Operational Risk Assessment

- Loss or Degradation of Command and Control Link
- Loss or Inability to Control Aircraft
- Loss or Aerodynamic Performance
- Loss or Degradation of Aircraft Controls
- Loss of Structural Integrity
- Loss of Crew Situational Awareness
- Inability to Accommodate Payload:
  - Aerodynamic Performance
  - Weight and Balance
- Departing the Controlled Area
  - Loss of Navigation Performance
  - Improper Flight Plan Information
  - Improper Command Input
  - Loss of C2 Link

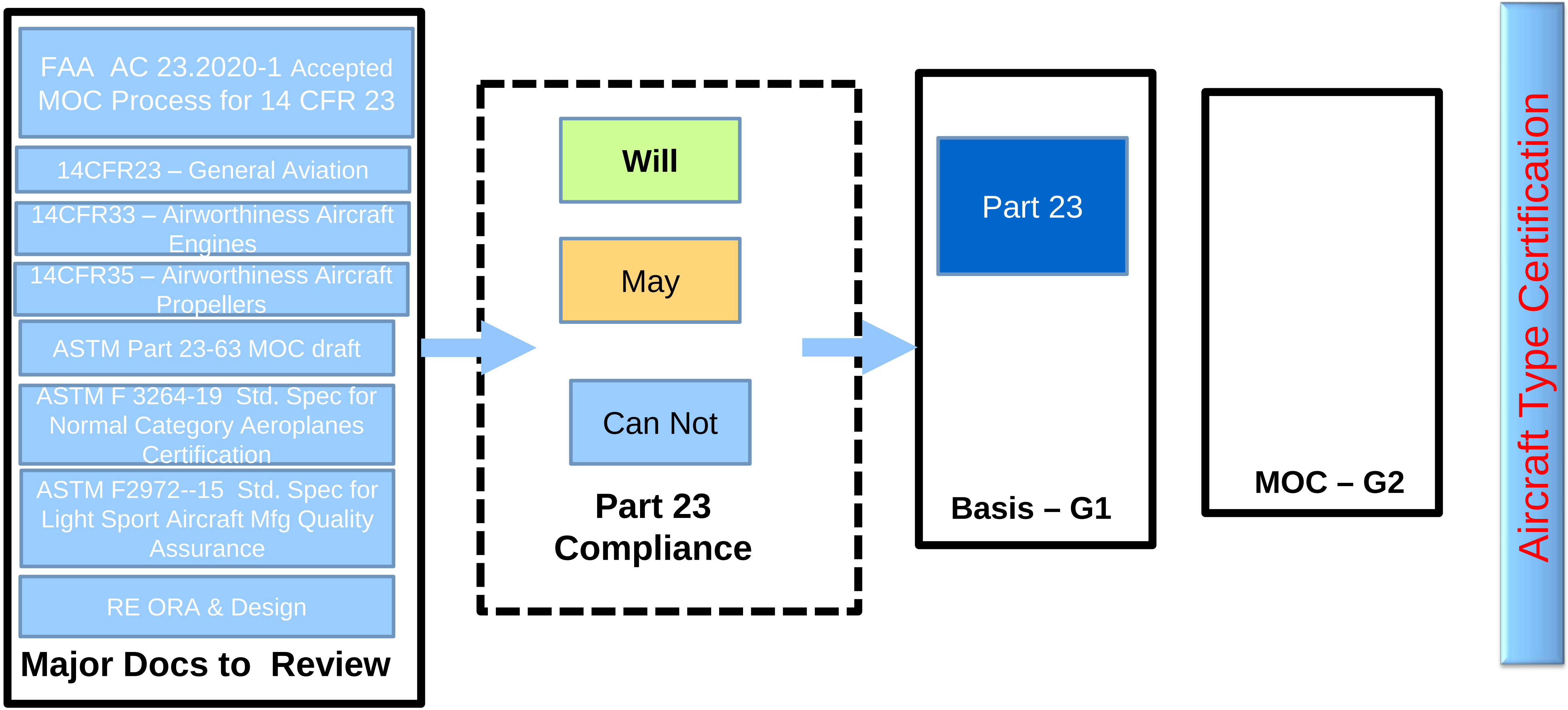
- Updated CONOPS and ORA – Submitted to FAA
- 14CFR23-64 start with ASTM Part 23-63 MOC draft, select a few items that:

Will Comply
May Comply
Cannot Comply

- Develop G1 – Basis in parallel with G2 – Means of Compliance

AATI's approach to Type Certification includes an Operational Risk Assessment that has been accepted by the FAA

FAA Certification Approach Process



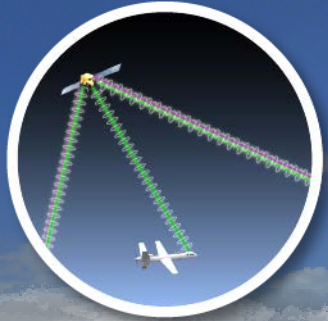
AATI is following a modified Certification Approach Process based on Part 23 compliance

Status

- Weekly meetings with FAA / NASA on type certification
- Drafting G1
- Developing G2
- Demo Flight – Dec2020/Jan2021

AATI is rapidly approaching its SIO demo on the way to Type Certification in this new vehicle class

Questions



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

Systems Integration & Operationalization Questions & Answers Session

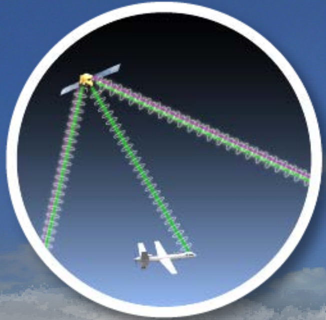
Kurt Swieringa

SIO Technical Manager, UAS Integration in the NAS Project

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

Technical Interchange Meeting

Break for Lunch



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

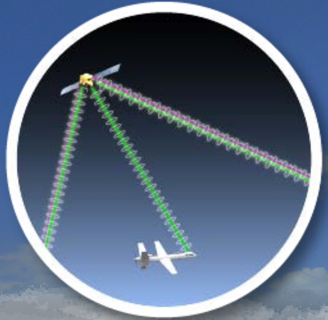
Systems Integration & Operationalization FAA Perspective

Sabrina Saunders-Hodge

Director, Research, Engineering & Analysis Division

Bill Stanton

Manager, UAS and Commercial Space Operational Integration



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

Stakeholder Panel Discussion: Technology & Community Benefits

Moderator: Ed Waggoner

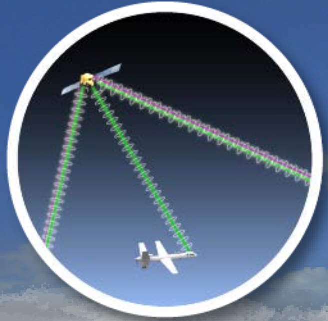
Deputy Associate Administrator for Programs,

NASA ARMD

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

Technical Interchange Meeting

Break



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

RTCA Status and Next Steps (Phase III)

John Moore

Associate Director of Systems Engineering, Collins Aerospace

Brandon Suarez

Technical Director for UAS Integration, General Atomics

Steve Van Trees

Aircraft Certification Service, FAA

SC-228 “Phase III”

John R. Moore & Brandon Suarez, Co-Chairs

Steve Van Trees, FAA

October 1, 2020

SC-228 Standards Development Overview

RTCA
THE GOLD STANDARD FOR AVIATION SINCE 1935

Phase I

Complete

- Detect and Avoid (DAA) for civil UAS equipped to operate into Class A airspace under instrument flight rules (IFR).
- Transitioning of a UAS to and from Class A traversing Class D, E, and G airspace.
- Command and Control (C2) using L-Band Terrestrial and C-Band Terrestrial data links.

Phase II

Ongoing

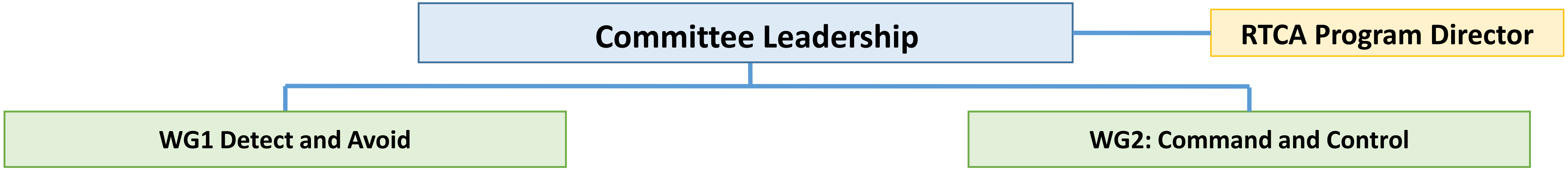
- Extends DAA: 1) extended UAS operations in Class D, E, and G, airspace, 2) take-off and landing operations in Class C, D, E, and G airspace, and 3) transit through Class B airspace
- C2 expanded to address 1) service level agreements and UAS design and operational considerations for SATCOM, and 2) a unified methodology for link budget to support certification and/or operational approval.

Phase III

Initiated

- Phase I & II scope had been shaped by FAA while RTCA was FACA
- Phase III moves to more self-identified scope rather than external directed

SC-228 – Phase I Standards Completed



DO-365 Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems

- Issued 05-31-17

DO-366 Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance

- Issued 05-31-17

DO-362 Command and Control (C2) Data Link Minimum Operational Performance Standards (MOPS) (Terrestrial)

- Issued 09-22-16

SC-228 – Phase II Standards Status

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Committee Leadership — **RTCA Program Director**

WG1 Detect and Avoid

DO-365A MOPS for DAA Systems
- Issued 03-26-20

DO-381 MOPS for Ground Based Surveillance Systems (GBSS) for Traffic Surveillance
- Issued 03-26-20

DO-366A MOPS for Air-to-Air Radar for Traffic Surveillance
- Committee Plenary Approved 09-10-20

DO-365B Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems
- In Final Review and Comment Period

DO-XXX Minimum Operational Performance Standards (MOPS) Airborne EO/IR Sensor

WG2: Command and Control

DO-377 Minimum Aviation System Performance Standards (MASPS) for C2 Link Systems Supporting Operations of Unmanned Aircraft Systems in U.S. Airspace
- Issued 03-21-19

DO-362A Command and Control (C2) Data Link Minimum Operational Performance Standards (MOPS) (Terrestrial)
- In Final Review and Comment Period

DO-377A Minimum Aviation System Performance Standards for C2 Link Systems Supporting Operations of Unmanned Aircraft Systems in U.S. Airspace

Phase 3 TOR Roadmap

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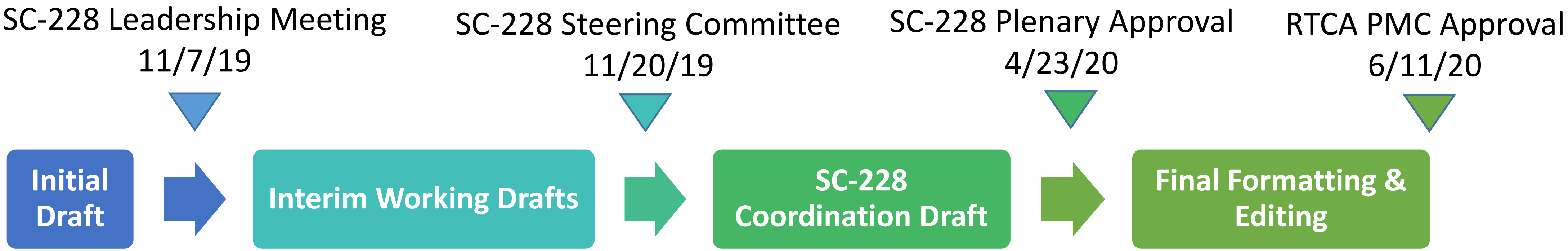
- There was a series of stakeholder telecons held in late 2019 / early 2020 to identify and prioritize potential working topics for Phase 3
- Two new topics based on recommendations from the FAA's UAS in Controlled Airspace ARC.
  - Guidance and behavior to follow when a UA enters a Lost C2 Link State.
  - Navigation performance requirements that would enable (augmented) GNSS based systems for all phases of flight.
- Related Terms of Reference (TOR) Update Schedule / Process



SC-228 Leadership Team

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Committee Leadership

Co-Chair: **John R. Moore**, Collins Aerospace
Co-Chair: **Brandon Suarez,** GA-ASI
Gvt. Auth. Rep: **Steve Van Trees**, FAA
Secretary: **Christina Westover,** Boeing

RTCA Program Director

Al Secen
Vice President,
Aviation Tech and Stds
RTCA, Inc.

658 Registered Members
as of 8/28/20

139 Organizations
Represented

And growing,
~ 120 active participants

Ad Hoc
DO-304A Update

Co-Chair: **John R. Moore**, Collins
Co-Chair: **Brandon Suarez,** GA-ASI
Secretary: **Christina Westover,** Boeing

Operations
Fabrice Kunzi, GA-ASI
Erin Roesler, NPUTS
Systems
Will Johnson, NASA

WG1
Detect and Avoid

Co-Chair: **Don Walker**, Airbus SV
Co-Chair: **Fabrice Kunzi** , GA-ASI
Secretary: **Matt Spanos**,
Transport Canada

WG2
Command & Control

Co-Chair: **Jim Williams**, JHWUS
Co-Chair: **Steve Van Trees**, FAA
Secretary: **Lee Nguyen**, FAA

WG3
Lost Link

Co-Chair: **Randy Willis**, NG
Co-Chair: **TBD**
Secretary: **TBD**

Anticipate 2020 Q4 standup

WG4
Navigation

Co-Chair: **Joel Wichgers**, Collins
Co-Chair: **Matt Harris,** Boeing
Secretary: **TBD**

Anticipate 2021 Q1 standup

Ad Hoc Working Group

- To initiate the Phase Three activities SC-228 will stand up an ad hoc working group of stakeholders with a focus on the operational framework for setting the foundation for all working groups. Some key characteristics of this group:
  - Will be chaired by the SC-228 Plenary Co-Chairs
  - Will include representatives from current and future UAS Operators, FAA Air Traffic Organization, air traffic controllers, airspace user community, research organizations, and UAS OEMs
  - Will include some members across the current standing working groups to seed the initial Phase Three activity
- Create a normalized set of use cases for use across the Special Committee in Phase Three. These are expected to include (but are not limited to):
  - High Altitude Pseudo-Satellite (HAPS) UAS
  - Linear Infrastructure Survey / Low Altitude Controlled Airspace
  - UAS Cargo Operations Under Part 135
  - Advanced Air Mobility (AAM) / Vertical Takeoff and Landing (VTOL) UAS
- Use Cases will serve to:
  - Clearly link Operation to standardized Technology/Capabilities
  - Create common Operational Services & Environment Description (OSED) components to align work of SC-228 WG's
  - Identify Operators and OEM's willing to support development, data collection, and operational trials

Phase III Deliverables

Product	Description	FRAC Complete	WG
Guidance Material & Considerations for UAS (DO-304A)	This guidance material summarizes the operational use case / scenarios to be used by all the standing working groups in conducting Phase Three. This would a major update to DO-304 Guidance Material and Considerations for Unmanned Aircraft Systems.	April 2021	AH
GBSS MOPS (DO-381A)	Revision to include a class of reduced performance consistent with enroute DWC requirements.	April 2021	WG1
GM for Lost C2 Link UAS Behavior	Prepare guidance material that will regularize the lost link behavior of UAS operating in controlled airspace.	April 2022	WG3
GM for UAS Navigation Systems	Create standard equivalent level of safety guidance material for Part 91 operations under IFR.	April 2022	WG4
C2 Link MOPS (Terrestrial) (DO-362B)	Incorporate any changes required to harmonize SATCOM compatibility with EUROCAE Standard. Updates required as a result on initial implementation of the A revision.	July 2022	WG2
DAA MOPS (DO-365C)	Future revision of the DAA MOPS to accommodate new functionality from completed SPR and/or OSED material.	October 2022	WG1
C2 Link MOPS for LTE Networks	Create standard for use of LTE commercial networks for C2 Links used for type certificated UAS.	January 2023	WG2
C2 Link Systems MASPS (DO-377B)	Incorporate needed revisions from DAA system changes/additions. Address safety risk requirements for operations in Class E above A airspace.	April 2023	WG2

Coordination / Joint Work

- RTCA SC-147
  - DO-382 MASPS for Collision Avoidance System Interoperability,
    - Approved 09-10-20 (EUROCAE ED-264)
  - DO-386 Minimum Operational Performance Standards for Airborne Collision Avoidance System X (ACAS X) (ACAS Xu)
- EUROCAE Working Group 105
  - Intent to jointly develop LTE performance standard for UAS C2
- ASTM F38
  - Open to discussions of potential joint efforts

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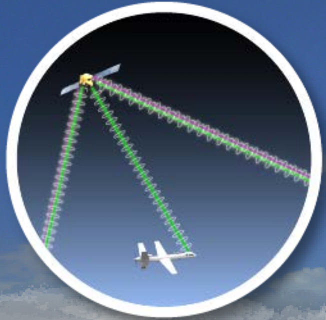
Thank you
Please Join SC-228!

John R. Moore & Brandon Suarez, Co-Chairs

Steve Van Trees, FAA

October 1, 2020



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

Panel Session: Remaining Gaps

Kurt Shalkhauser

C2 Technical Lead, C2 Subproject

Jay Shively

Subproject Manager, DAA Subproject

Kurt Swieringa

SIO Technical Manager, UAS Integration in the NAS Project

CNPC Waveform Validation Gap

Remaining Gap

- No CNPC system testing has been performed with multiple aircraft radios operating with a single ground radio station to validate multi-user waveforms, nor to investigate magnitude of near/far signal interference problems.
- Multipath signal reflections from airport-area structures produce “fast fade” conditions, found to be highly destructive to CNPC signals. Previous surface testing discovered this effect, but testing was forced to stop prior to resolution. Waveform adjustments have not been verified.

Recommended Approach to Close

- Flight test campaign using existing radio hardware with adjusted waveforms.
- Perform instrumented, taxi-through-takeoff demonstration flights using high-speed I-Q sampling system.
- Results from this testing would directly impact DO-362 MOPS by enhancing simulation work allowing improved performance margins for commercial developers.

Impact of Gap

- Severe loss of signal during aircraft taxi operations.
- All waveform operating modes and all phases of flight have not been tested. Without the full data suite, certain DO-362A sections will be recommendation; not a proven capability.

Access to Allocated C-Band Spectrum for Satellite Communications

Remaining Gap

- Satellite-based CNPC systems for UAS have not been demonstrated or characterized due to risk and cost to commercial developer. No beyond-line-of-sight UAS-NAS systems exist.
- Few measurements have been made to confirm levels of interference between satellite-based and terrestrial-based CNPC links.
- Satcom would provide additional pilot-to-aircraft CNPC options

Recommended Approach to Close

- Leverage recent work in C-band satcom interference studies and system design to develop experiment concept.
- Prepare and operate radio test systems to measure and evaluate satcom and terrestrial CNPC interference and compatibility.
- Provide data to confirm analysis of satellite/terrestrial interference and compatibility, provide results to user community and standards organizations

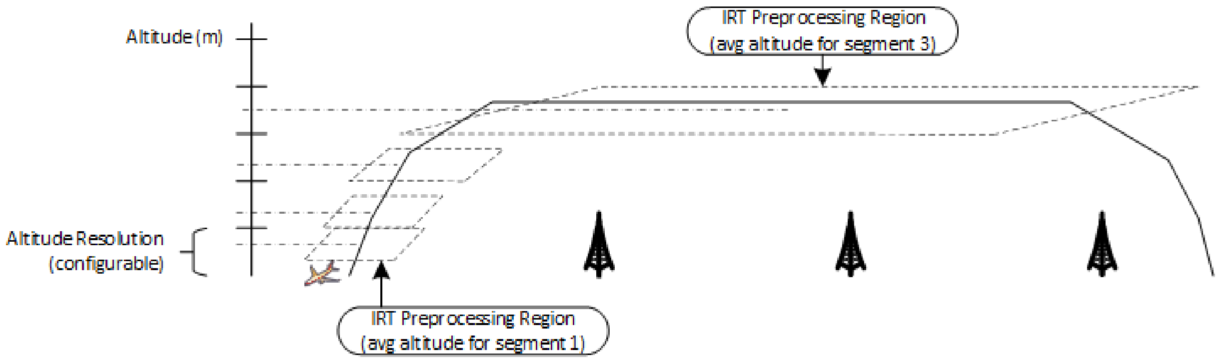
Impact of Gap

- Much time being spent by standards organizations and industry on modeling and simulation of satcom/terrestrial systems, but little test progress has been made.
- Long-range UAS operations over water and in remote areas is not possible.
- Integration of UAS in the NAS is slowed
- Potential for loss of allocated spectrum if it is not utilized.

Characterization of C-Band CNPC in Urban Flight Environment

Remaining Gap

- Limited data exists to characterize bi-directional C-band CNPC radio link performance in urban environment.
- Current data set for over-land and over-water propagation only; little data exists for urban settings



Recommended Approach to Close

- Utilize existing equipment for single-aircraft test campaign with multiple strategically-placed ground-level and elevated ground radio stations.
- Urban results can be contrasted with, and added to, existing C-band database.
- Work closely with RTCA and other standards organizations to establish test conditions and data parameters.

Impact of Gap

- The suite of terrestrial test environments for C-Band CNPC is not complete. (Further NASA testing would build more complete data set and yield improved standards.)
- No means for independent comparison of LTE or other radio technologies to a baseline.

Verification of LTE Performance at Altitude

Remaining Gap

- Viability of LTE technology for urban UAV communications is unproven
- Need to independently verify LTE performance at altitude

Recommended Approach to Close

- Perform ground and flight tests to fully characterize LTE signal performance in urban environments
- Leverage existing laboratory tests, ground tests, flight and route plans to expand identification of local LTE channels
- Utilize existing equipment to conduct comprehensive aircraft test campaign
- Work closely with other Government Agencies and standards organizations to establish test conditions and data parameters
- Reduce data and run simulation/analysis to support standards development.

Impact of Gap

- Lack of LTE performance data impedes further development of a potential C3 communications system

Integrated Threat Warning

Remaining Gap

- Integrate existing DAA systems with:
  - Obstacles
  - Terrain
  - Weather

Recommended Approach to Close

- Prioritized alert system
- Integrate:
  - Wx RADAR
  - GPWS
  - Terrain databases

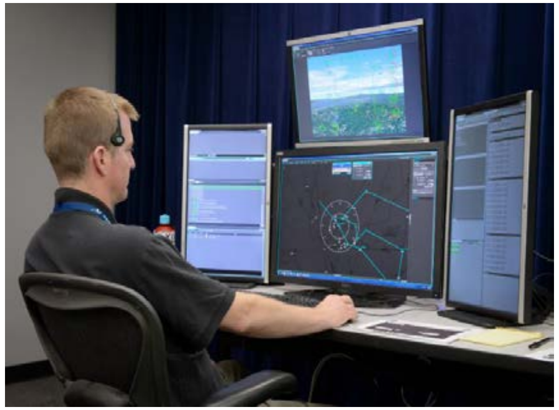
Impact of Gap

- Complete operational envelope not realized
- Lost Link procedures not NAS safety compliant

Auto Execution

Remaining Gap

- Autonomous Execution of:
  - Collision Avoidance
  - Maintain Well Clear



Recommended Approach to Close

- Integrate directive guidance with aircraft control systems
- Clear enunciation
- Mode awareness

Impact of Gap

- Increased sensor range requirement
- Limited lost link functionality

Operational Certification Standards

Remaining Gap

- Address certification of UAS operations:
- UAM
- Auto Cargo
- Infrastructure inspection
- High altitude long endurance

Recommended Approach to Close

- Develop specific use cases
- Contingency management
- With FAA – develop safety cases

Impact of Gap

- Lack of ability for a type certified aircraft to perform routine operations

Sensor Requirements for Low SWaP Operations

Remaining Gap

- ATAR MOPS (DO-366A) requires a 3.5 NM declaration range for a manned aircraft in the class of a KingAir. This is challenging for current radar technology
- Difficulty of visual acquisition of a medium-sized UA (~500 lb) has not been taken into account in the low SWaP sensor azimuth range requirements.

Recommended Approach to Close

- Sensor development
- Multiple sensor integration
- Extend the DAA ConOps to more VFR-like operations or even auto-execution
- Re-evaluate the applicability of right-of-way rules to mid-sized UA, and reconsider the azimuth range coverage of the low SWaP sensors.

Impact of Gap

- Inability of OEMs to meet standards for certification
- Safety concerns

Scalable and Robust Lost Link Procedures

Remaining Gap

- Lost link procedures are currently not scalable to full-scale file-and-fly commercial UAS operations
- Currently, lost link procedures are defined in the COA and are specific to the UAS and its operating environment
- There is a need to develop procedures and/or automation to support robust and scalable lost link procedures

Recommended Approach to Close

- Industry and government participation in the RTCA SC-228 lost link working group
- Development of robust and scalable procedures and unmanned aircraft technology validated through simulations and flight tests
- Consider both smaller UAS flying at lower altitudes and large UAS

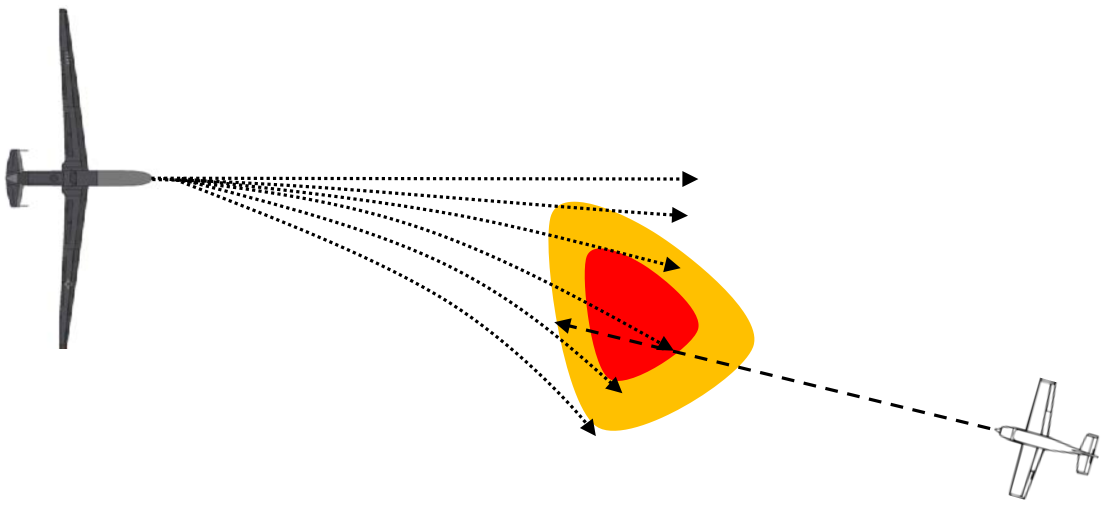
Impact of Gap

- The lack of scalable lost link procedures prevent full integration of file-and-fly UAS operations in the NAS

UAS Operations Without IFR Flight Plan

Remaining Gap

- UAS operators desire the flexibility to fly certain missions without the need to follow an IFR flight plan (similar to VFR operations for conventional aircraft)
  - Provide greater operational flexibility, particularly for vehicles that can access the NAS from non-traditional locations
  - Prevent the need for ATC resources to support certain UAS operations in airspaces where VFR flight is allowed



Recommended Approach to Close

- Assess current regulations and standards to determine any modifications that are needed to remove the assumption of IFR operations
- Identify hazards associated with non-IFR flight and procedural or technological mitigations to those hazards.
- Validate procedures and technologies through simulations and flight tests

Impact of Gap

- The need for an IFR flight plan for UAS operations can prevent operational flexibility and unnecessarily tie up ATC resources
- If successful, addressing this gap will help enable UAS operations in certain airspaces without the need for an IFR flight plan, resulting in increased scalability

Ability to Use Commercial LTE/SATCOM Services for C2

Remaining Gap

- UAS operators desire the ability to use existing commercial LTE and SATCOM services for C2 and other safety related functions
  - Reduce the amount of special infrastructure that needs to be built
  - Reduce the need for separate communication systems for C2 and payload (save weight and power)
  - Allow higher transmission of information that requires higher bandwidth
- Since C2 is considered to be part of the UAS, there may be challenges to certifying the use of existing commercial infrastructure not specifically designed for aviation

Recommended Approach to Close

- Create industry standards for the use of LTE, SATCOM, and other applicable communication methods (e.g., RTCA SC-228)
- Identify hazards associated with the use of SATCOM/LTE and develop technological and/or procedural mitigations
- Use simulation and flight tests to validate performance, including worse-case network usage (including the risk of all UAS in a region losing service at the same time)

Impact of Gap

- The lack of data driven standards for commercial LTE/SATCOM C2 links prevent the use of existing commercial infrastructure, which may be able to provide low cost and scalable communications for certain operations

Type Certification of ”Smaller” UAS

Remaining Gap

- There is a need for additional certification policy and standards for “smaller” UAS (e.g., 200 to 300 lbs.) that are too large for the FAA’s durability and reliability approach, but pose a lower risk than larger manned aircraft

Recommended Approach to Close

- Establish an industry led group (with government participation) to examine current UAS industry standards that may serve as methods and means of compliance for ”smaller” UAS and identify gaps
- Develop new standards or modify existing standards to address those gaps

Impact of Gap

- The lack of a a clear certification approach for “smaller” UAS is a barrier to using those vehicles for commercial operations

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

Transition of Efforts Within NASA: Advanced Air Mobility (AAM) Mission

Davis Hackenberg

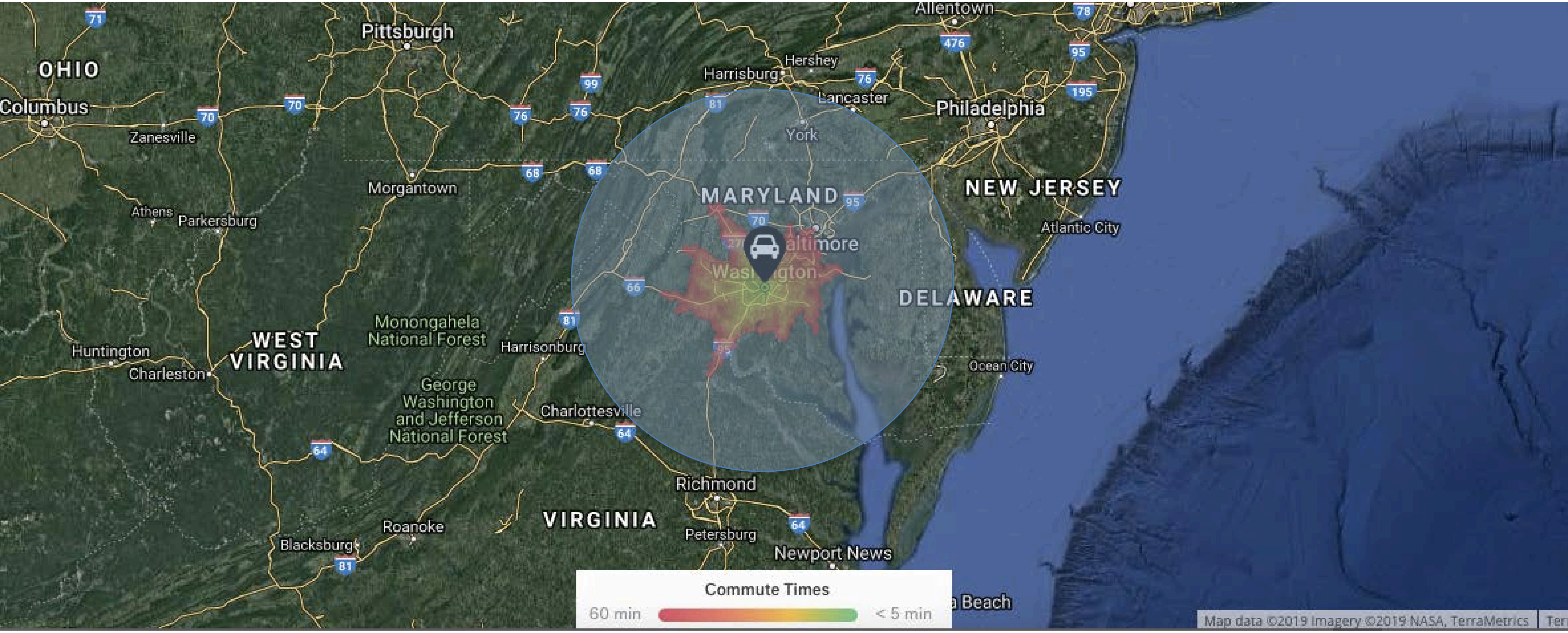
Advanced Air Mobility Mission Integration Manager, NASA ARMD

National Aeronautics and Space Administration

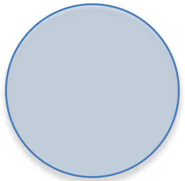
ARMD Advanced Air Mobility (AAM) Mission

October 1, 2020

Aerial Reach – 30 Minute Journey

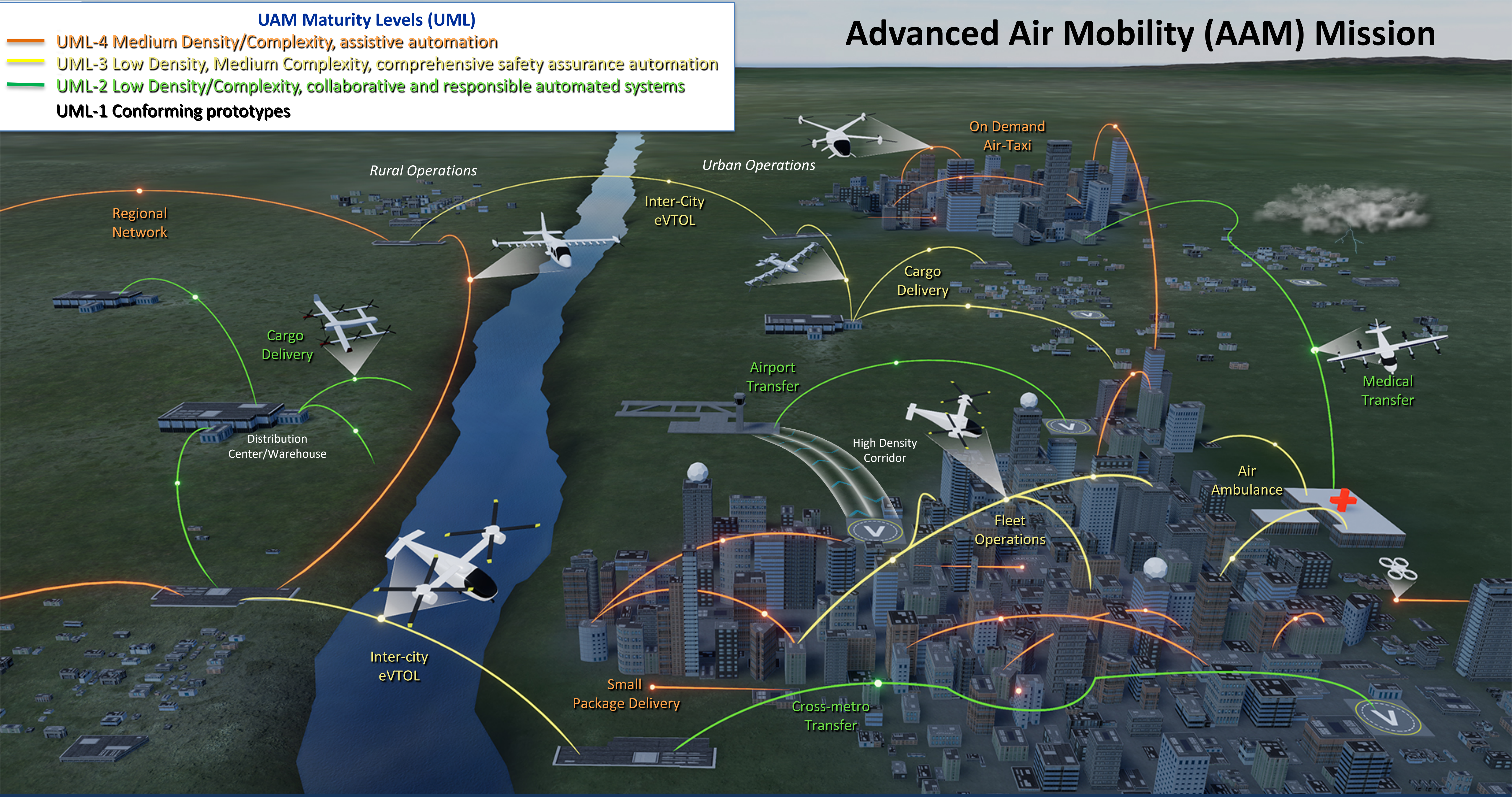


24 hr weighted average
60 minute driving commute
Washington, DC.



Any time of day
~30 minute (~75mi radius) Aerial Commute
Washington, DC.

Advanced Air Mobility (AAM) Mission



Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions

AAM Mission Critical Commitment

Vehicle Development and Operations Develop concepts and technologies to define requirements and standards addressing key challenges such as safety, affordability, passenger acceptability, noise, automation, etc.

Airspace Design and Operations Develop UTM-inspired concepts and technologies to define requirements and standards addressing key challenges such as safety, access, scalability, efficiency, predictability, etc.

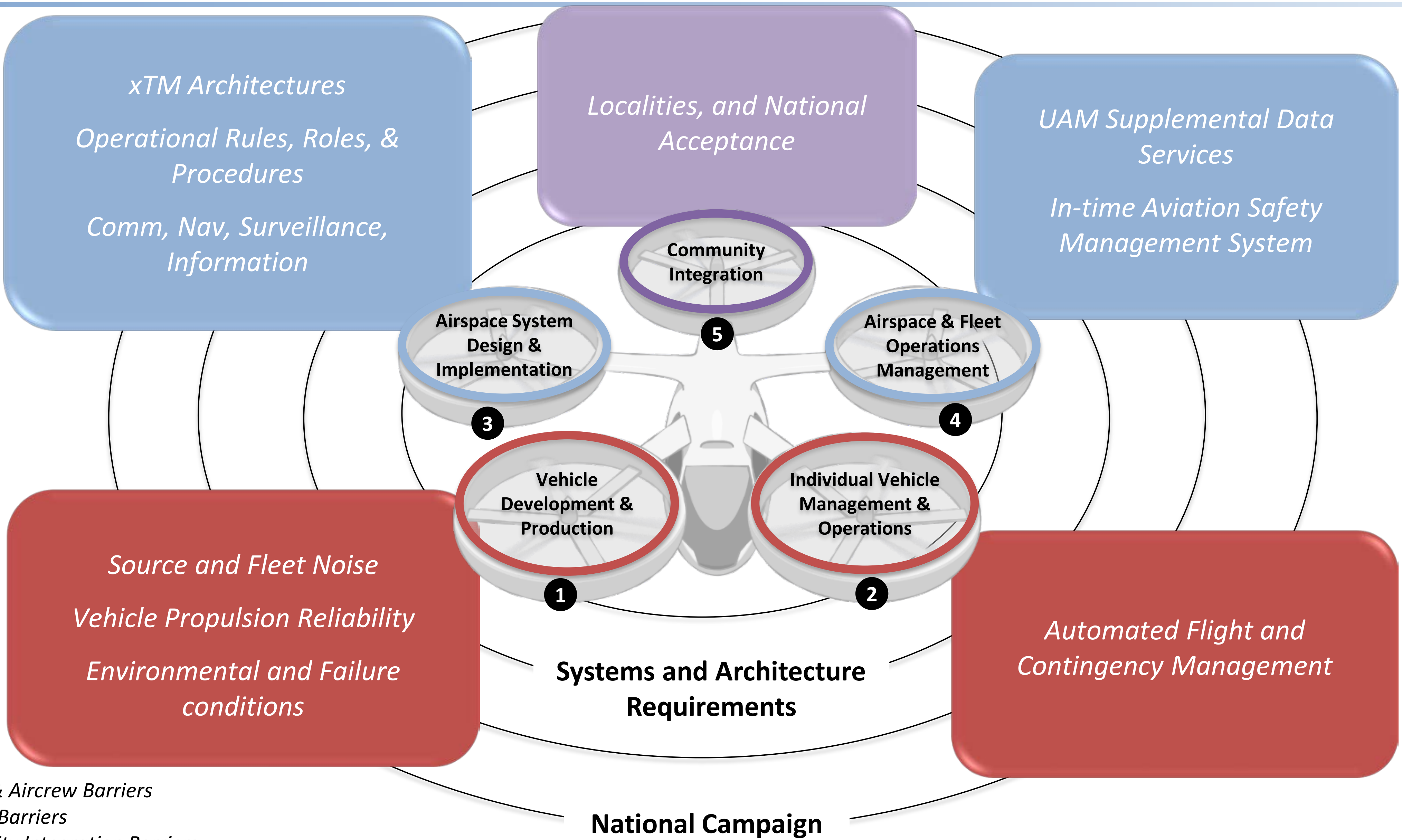
Community Integration Create robust implementation strategies that provide significant public benefits and catalyze public acceptance, local regulation, infrastructure development, insurance and legal frameworks, etc.

Critical Commitment:

Based on validated operational concepts, simulations, analyses, and results from National Campaign demonstrations, the AAM Mission will deliver <u>aircraft, airspace, and infrastructure system and architecture requirements</u> to enable sustainable and scalable medium density advanced air mobility operations

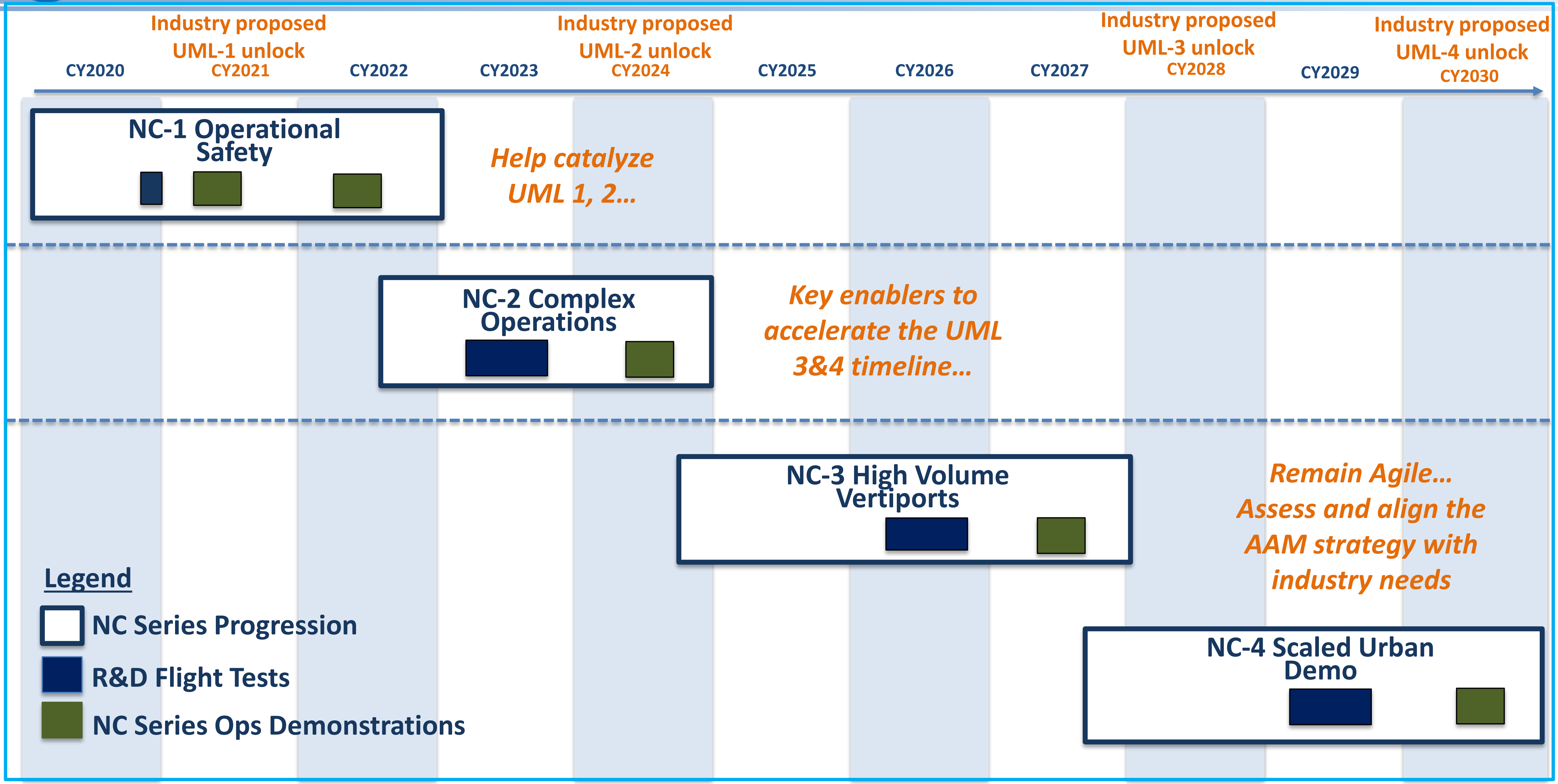
Achieving "systems and architecture requirements" will require *<u>enabling activities</u>* such as 1) the AAM National Campaign Series 2) a robust Ecosystem Partnership model and 3) NASA ARMD Portfolio Execution.

NASA AAM Mission Priorities

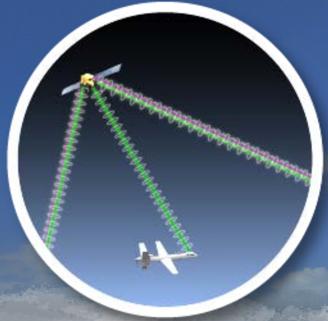


Aircraft & Aircrew Barriers
Airspace Barriers
Community Integration Barriers
Pillar number

National Campaigns Support of the Industry Timeline



UML "unlocks" based on a range of publicly available industry projections and conversations with partners; not a consensus view



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

Transition of Efforts Within NASA:

ATM-X Increasingly Automated Air Cargo Operations Subproject

Kurt Swieringa

Technical Lead, ATM-X Increasingly Automated Air Cargo Operations Subproject

Rob Fong

Subproject Manager, ATM-X Increasingly Automated Air Cargo Operations Subproject

ATM-X

Increasingly Autonomous Air Cargo Operations (Auto-Cargo)

October 1, 2020

Subproject Manager: Rob Fong
Technical Lead: Kurt Swieringa

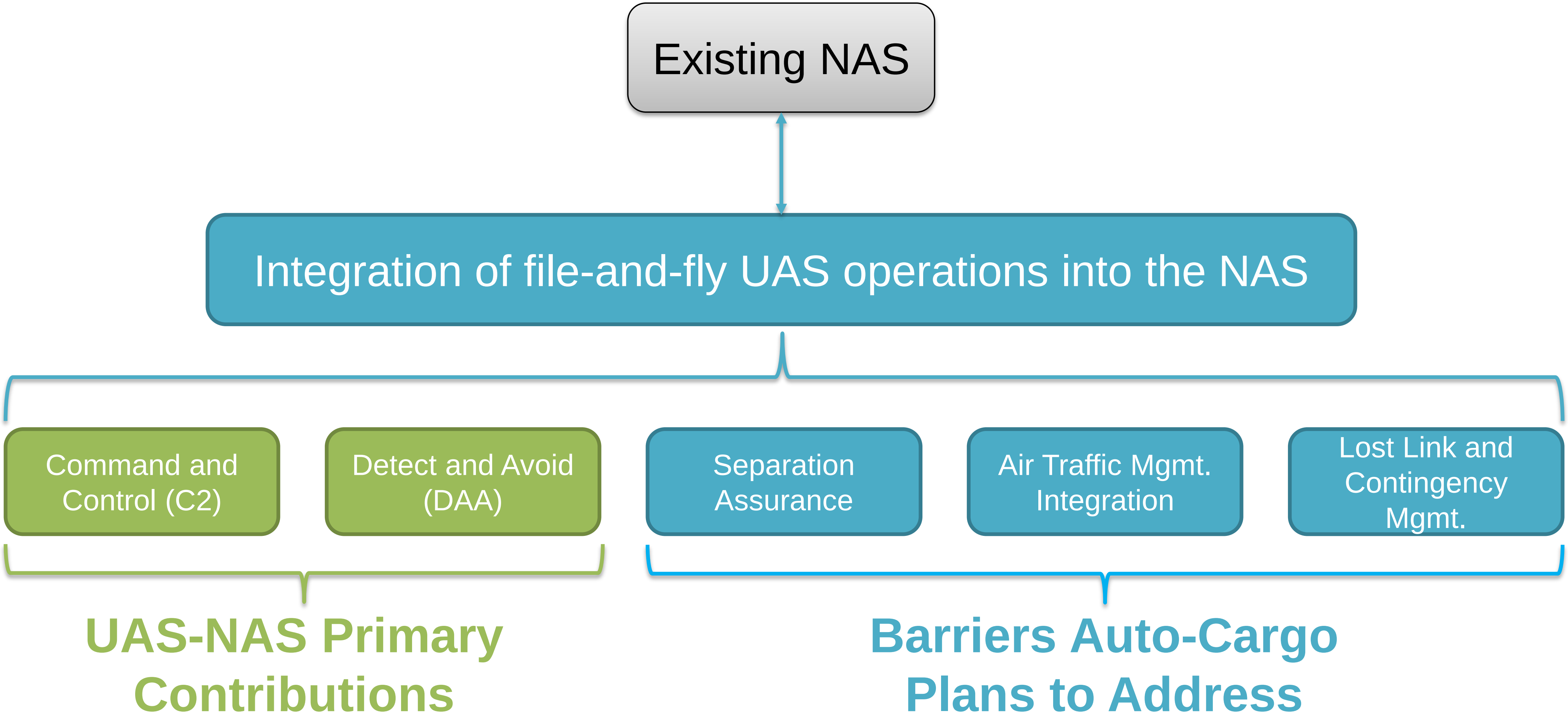
Outline

- Motivation
- Transition from UAS-NAS to Auto-Cargo
- Auto-Cargo Overview
- Approach
- High-Level Plan
- Stakeholders and Partnerships
- Status
- Summary

Motivation

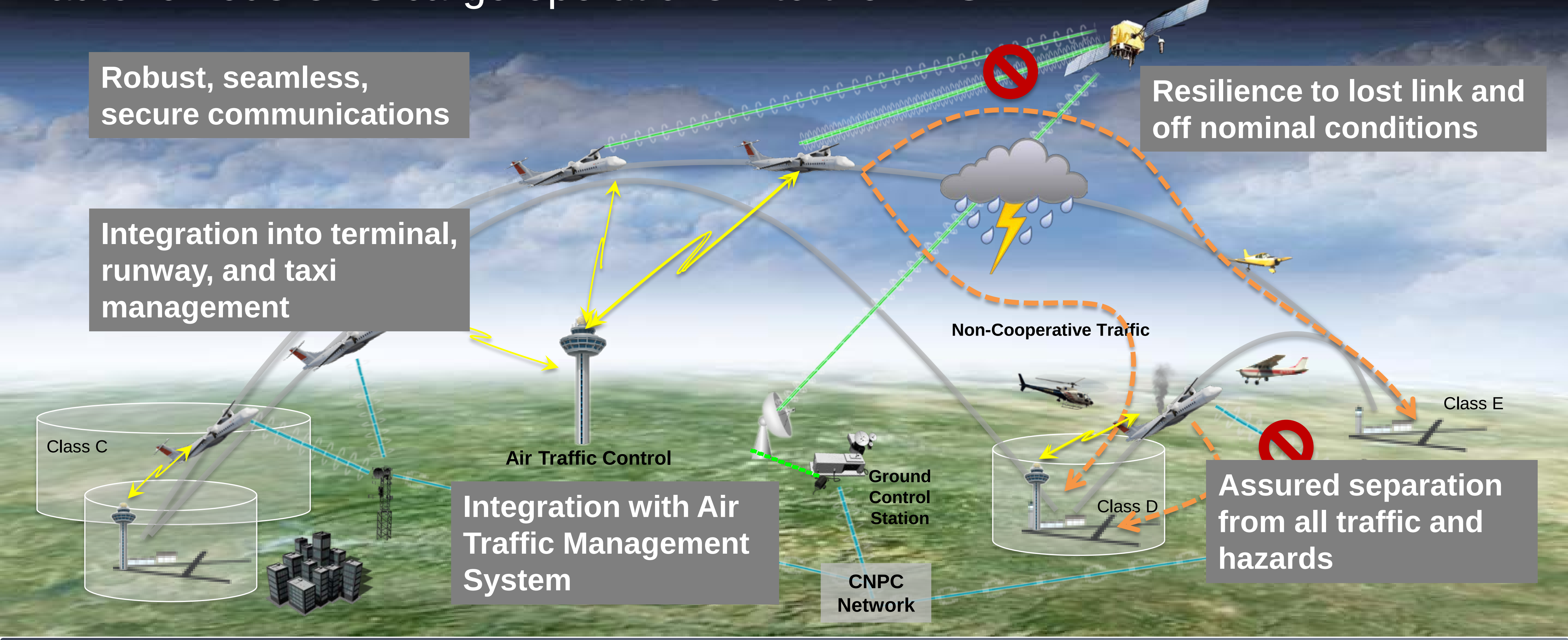
- The use of large unmanned aircraft systems (UAS) for cargo delivery has the potential to revolutionize how cargo is transported across the United States.
  - Industry has shown interest in utilizing UAS for cargo operations.
  - RTCA is developing a UAS Cargo concept of operations as part of Special Committee 228 (SC-228).
- NASA can help pave the way for this new industry.
  - Conduct research to support development of performance and integration requirements.
  - Collaborate with industry to align research with commercially viable use cases.
  - Collaborate with the FAA to ensure alignment with their vision.
- Auto-Cargo is an ATM-X subproject with the task of addressing remaining barriers to UAS integration.
  - The focus on cargo transportation is a viable commercial use case that will be used to clarify barriers and prioritize research for integration into the existing National Airspace system (NAS).
  - The research conducted is expected to be applicable to a broader set of use cases.
  - Auto-Cargo will serve as a pathfinder for the integration of increasing levels of automation in the NAS.

Contributions toward Integration of UAS into the NAS



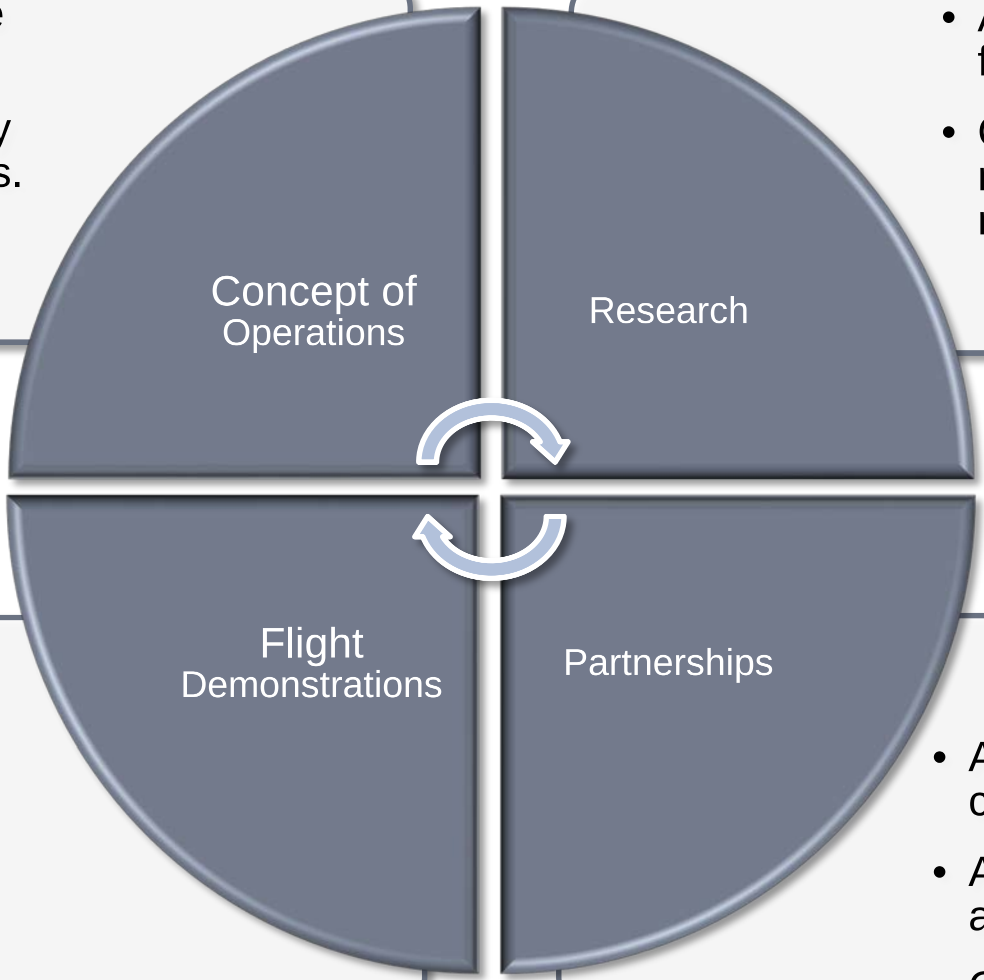
Auto-Cargo Overview

Goal: Seamless, scalable, and robust integration of increasingly autonomous UAS cargo operations into the NAS



Auto-Cargo Approach

- Use industry partnerships to motivate a commercially viable ConOps.
- Include increasing levels of autonomy to address airspace integration needs.

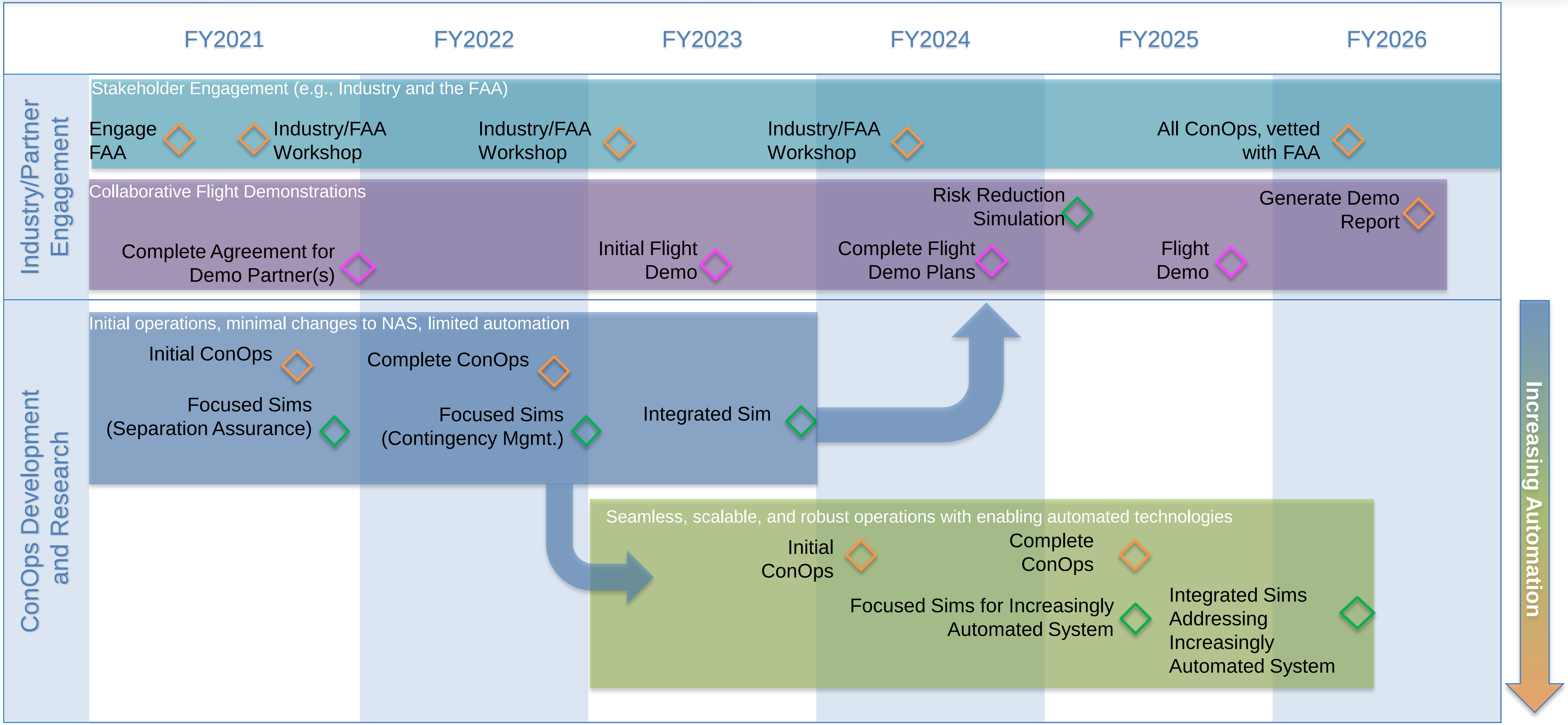


- Address research questions derived from the ConOps.
- Conduct studies to define data-driven recommendations to the FAA and relevant standards organizations.

- Conduct collaborative flight demonstrations with industry.
- Validate ConOps.

- Align NASA research with commercially viable use cases.
- Align NASA research with FAA plans and policy.
- Collaborate with industry and the FAA.

Auto-Cargo High-Level Plan



Stakeholders and Partnerships

The subproject plans a multi-faceted industry partnership and stakeholder engagement to bring broader resources and participation to fully achieve the project objectives.

Stakeholders

- The FAA
- Industry standards organizations (e.g., ICAO, RTCA, ASTM)
- UAS manufacturers
- UAS avionics manufacturers
- Cargo transportation companies

Partnerships

- Industry Partnerships
  - Collect input for ConOps development which will influence NASA's research.
  - Conduct collaborative flight demonstrations.
- FAA Partnerships
  - Collaborative ConOps development.
  - Coordinate research via research transition team.
- Standards organizations support
  - Provide research to influence standards.
  - Support RTCA SC-228 and other key standards organizations.

Status

- Auto-Cargo is a newly approved subproject within NASA's Air Traffic Management - eXploration (ATM-X) Project.
- A market survey has been commissioned to assess industry and market interest in UAS cargo operations which will be used to refine the scope of our investigations.
- Auto-Cargo will release a Request for Information (RFI) later this year to learn about industry plans to invest in UAS cargo operations, understand the challenges that must be addressed, and help NASA determine a comprehensive partnership strategy to engage industry.
- A detailed Auto-Cargo subproject plan is currently in review.

Summary

- Auto-Cargo will extend the work of the UAS-NAS project by addressing remaining barriers that prevent commercial UAS operations in the NAS.

- Research will be focused on separation assurance, air traffic management integration, and contingency management.

- Auto-Cargo will collaborate with industry, the FAA, and relevant standards organizations to progress toward file-and-fly UAS cargo operations in the National Airspace System.

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

Wrap Up

Mauricio Rivas

Project Manager, UAS Integration in the NAS Project

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

Technical Interchange Meeting

End of Day 2

NASA