NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Armstrong Flight Research Center

Pilot Perspective of UAS Flight Test at NASA

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Pilot Perspective - Overview

- Introduction
  - The UAS Problem, Importance, & NASA's Role
- Development
  - Objectives & Plan
- Test Approach
  - Tools: UAS & DAA System
  - Methods: Route and Mission Planning
- Training & Rehearsal
- Test Execution
- Pilot Lessons Learned
- Conclusions

NASC TigerShark UAS flying at NASA Armstrong 9 July 2019 (nasa.gov)

NASA 870 "Ikhana" UAS flying in the NAS on 24 May 2018

The UAS Problem: A Great Tool, But…

UAS = fantastic tool, yet lacks necessary access (integration) into public airspace

The Importance of UAS Integration:

- UAS = still huge market growth; increasing civil use & demand

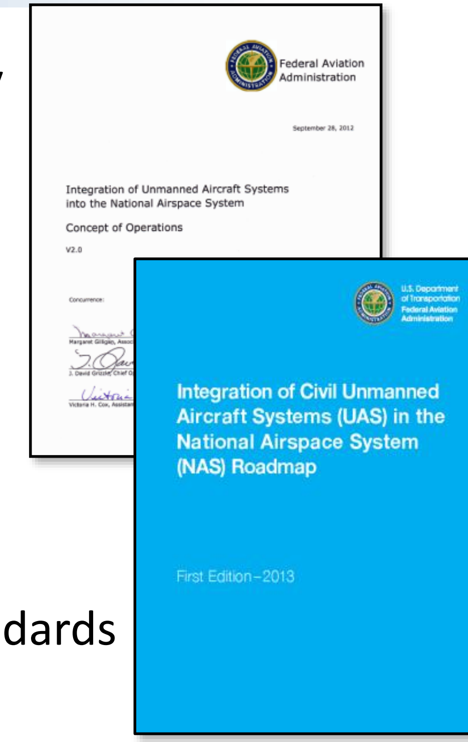
• Agriculture Monitoring	• Mail & Cargo Delivery	• News/Sports/Traffic
• Aerial Imaging/mapping	• Disaster & Wildfire	• Police & Border Security
• Environmental Monitoring	• Powerline/Pipeline/Rail	• Oil/Gas Exploration

- **Barriers & challenges** preventing full integration into public airspace *still exist:*
  - ❑ UAS Regulations/Policies/Procedures
  - ❑ Standards Development; NAS infrastructure
  - ❑ Enabling Technologies
  - ❑ Air Traffic Services; Public/Social considerations (trust)

1. World Civil UAS Market Profile & Forecast, Teal Group, 2016
2. The Economic Impact of UAS Integration in the United States, AUVSI, March 2013

Path to Integration Requires Developing Standards

- FAA's *UAS CONOPs* and *Roadmap* define **path forward** for safely integrating civil UAS operations into the NAS
  - Essential → development of Standards for DAA & C2
    - DAA Fundamental Challenge: **Detect-**&-Avoid to *satisfy* **See-**&-Avoid
    - C2 Fundamental Challenge: Pilot removed from the vehicle
- Standards = essential for multiple stakeholders:
  - **Regulators**: to certify/approve solutions in a consistent manner
  - **UAS Operators**: for operational use & new market applications
  - **UAS Manufacturers**: to develop compliant UAS platforms
  - **Industry**: to develop compliant HW/SW avionics, radios, sensors
- RTCA SC-228 - chartered by FAA to establish UAS DAA & C2 Standards


Federal Aviation Administration

September 28, 2012

Integration of Unmanned Aircraft Systems into the National Airspace System

Concept of Operations

V2.0

Concurrence:

U.S. Department of Transportation Federal Aviation Administration

Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap

First Edition–2013

So, the US Gov't partnered with NASA and aerospace industry to help solve the DAA & C2 challenges…

Acronymns: ***C2 –*** *Command & Control;* ***DAA*** *– Detect & Avoid;*
NAS – *National Airspace System;* ***RTCA –*** *Radio Technical Commission for Aeronautics*

NASA's Role in UAS Integration Flight Testing

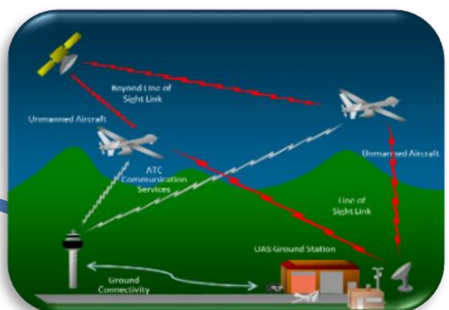
- UAS Problem - lacks "full" access to public airspace
- Access - requires Gov't regulations/standards
- Standards - require a flight test program
- **Flight test program** – requires concept of ops, test plan, & ultimately flight test data

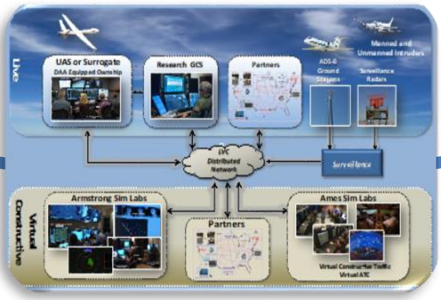
NASA's Objective: Provide research findings, use simulation & flight tests, support development & validation of DAA & C2 technologies necessary for integrating UAS into the NAS

- Develop ConOps & technologies to enable Comm/Nav/Surveillance (CNS)-equipped UAS to operate consistent with IFR ops.
- Accelerate routine UAS ops in the NAS.
- Demonstrate ≥1 commercial mission.

DAA Objectives

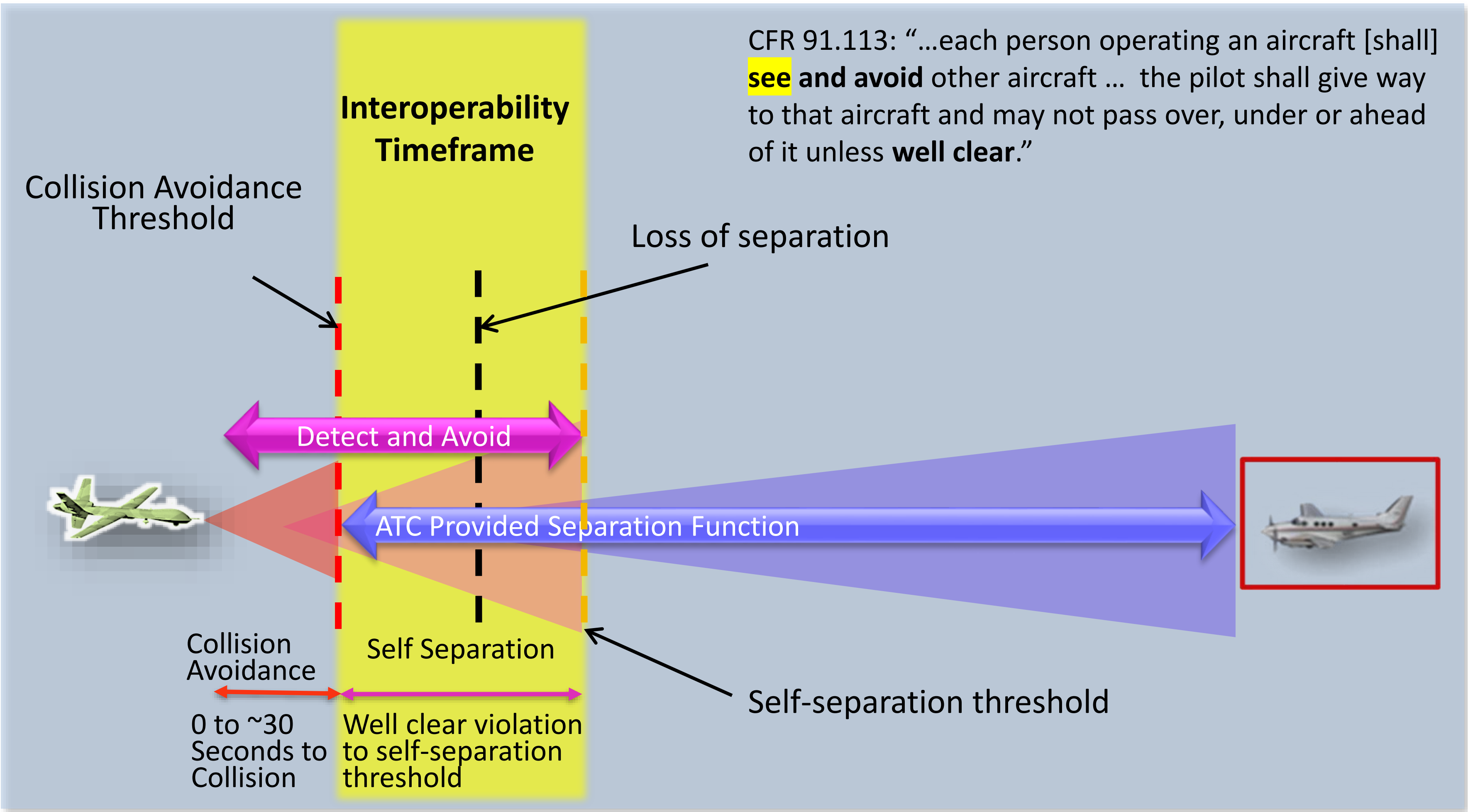
C2 Objectives





Systems Integration & Operationalization (SIO)

Focus of Research: Separation from Other Aircraft
Defining Detect-and-Avoid



***Time horizons of applicability are not to scale**

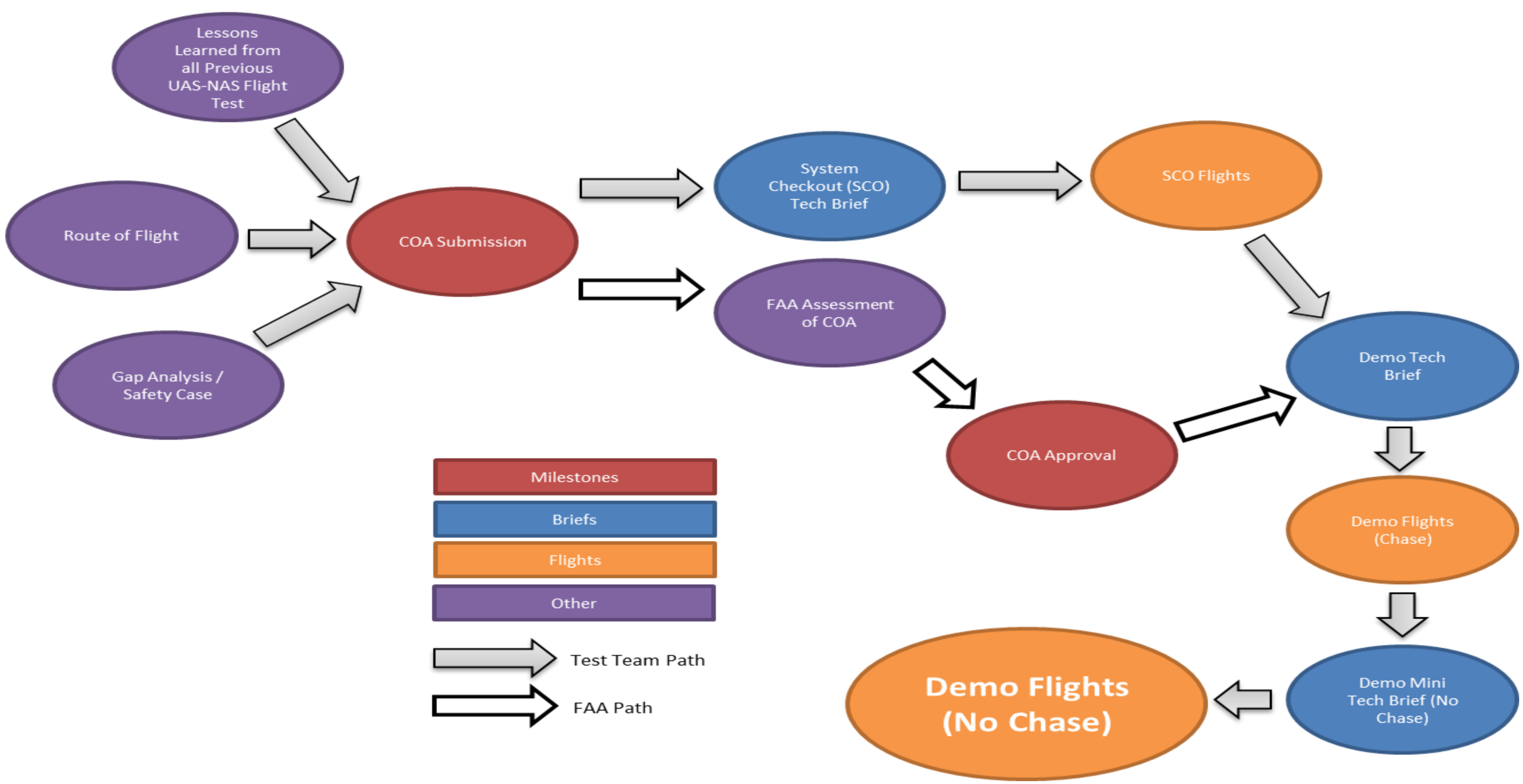
Typical NASA Flight Test Roadmap (NCC Example)

Test Planning
1. Previous Test Lessons Learned
2. Test Objective(s) & Approach
3. Gaps & Safety Analysis

Request Approval(s)
1. Airspace
2. Frequency Spectrum

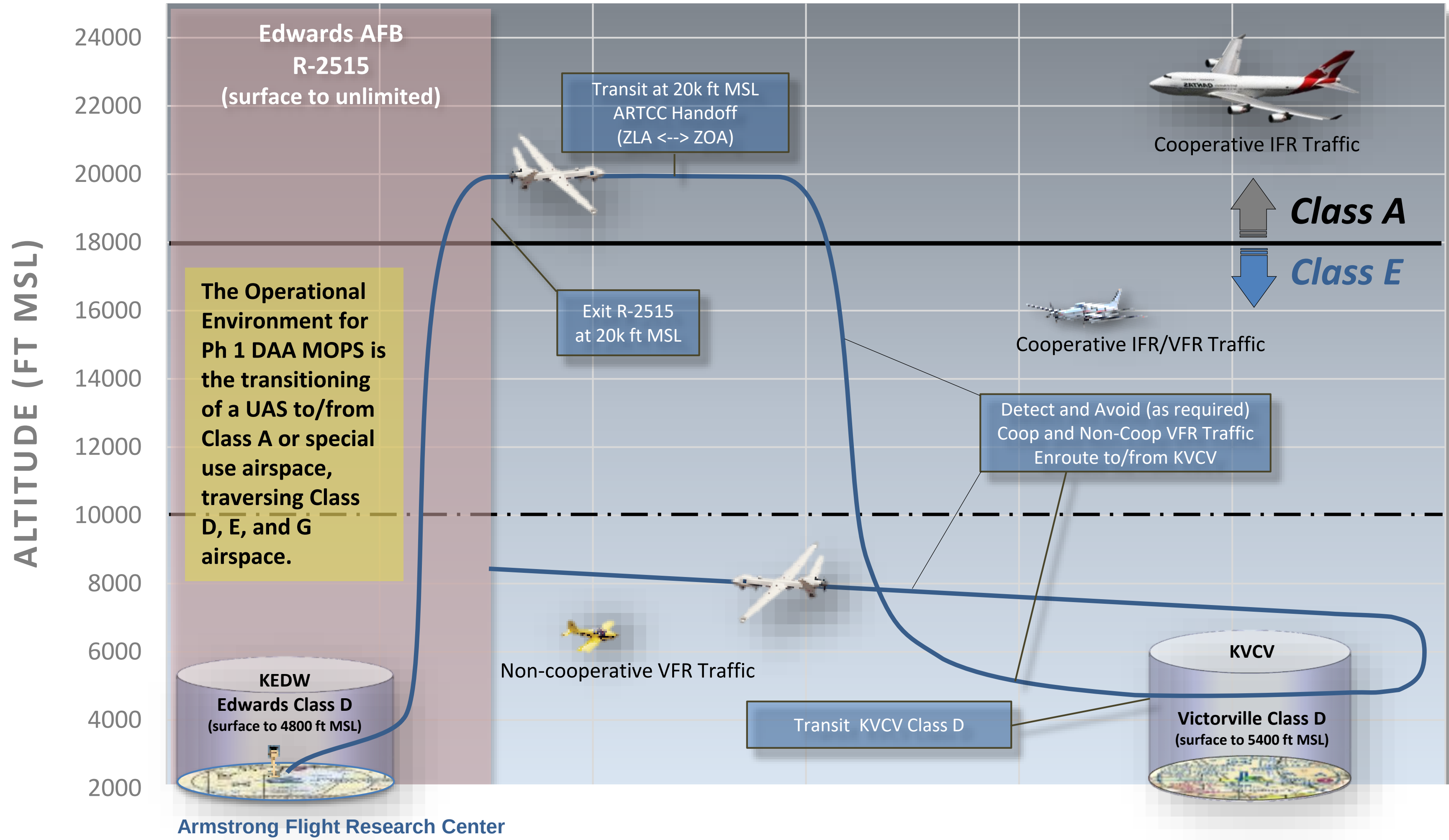
Technical & Safety Review Process

Training, Rehearsal, & Test Execution



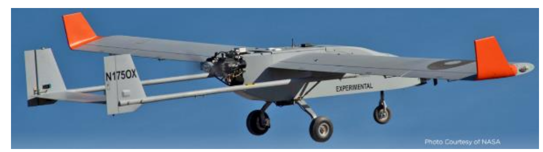
Goal: No Chase Aircraft COA Flight Demonstration

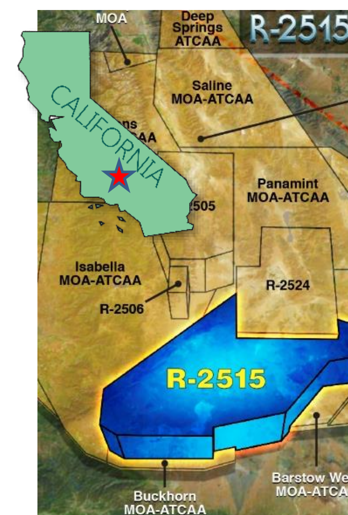
Objective: **Flight demonstration of a UAS transitioning to/from Class A (or SUA) to Class & D airspace, employing Phase 1 Detect and Avoid and Air-to-Air Radar MOPS Systems as alternate means of compliance to 14 CFR §91.111(a) & §91.113(b) "see and avoid/remain well clear" regulations.**



Test Approach – 1. Tools

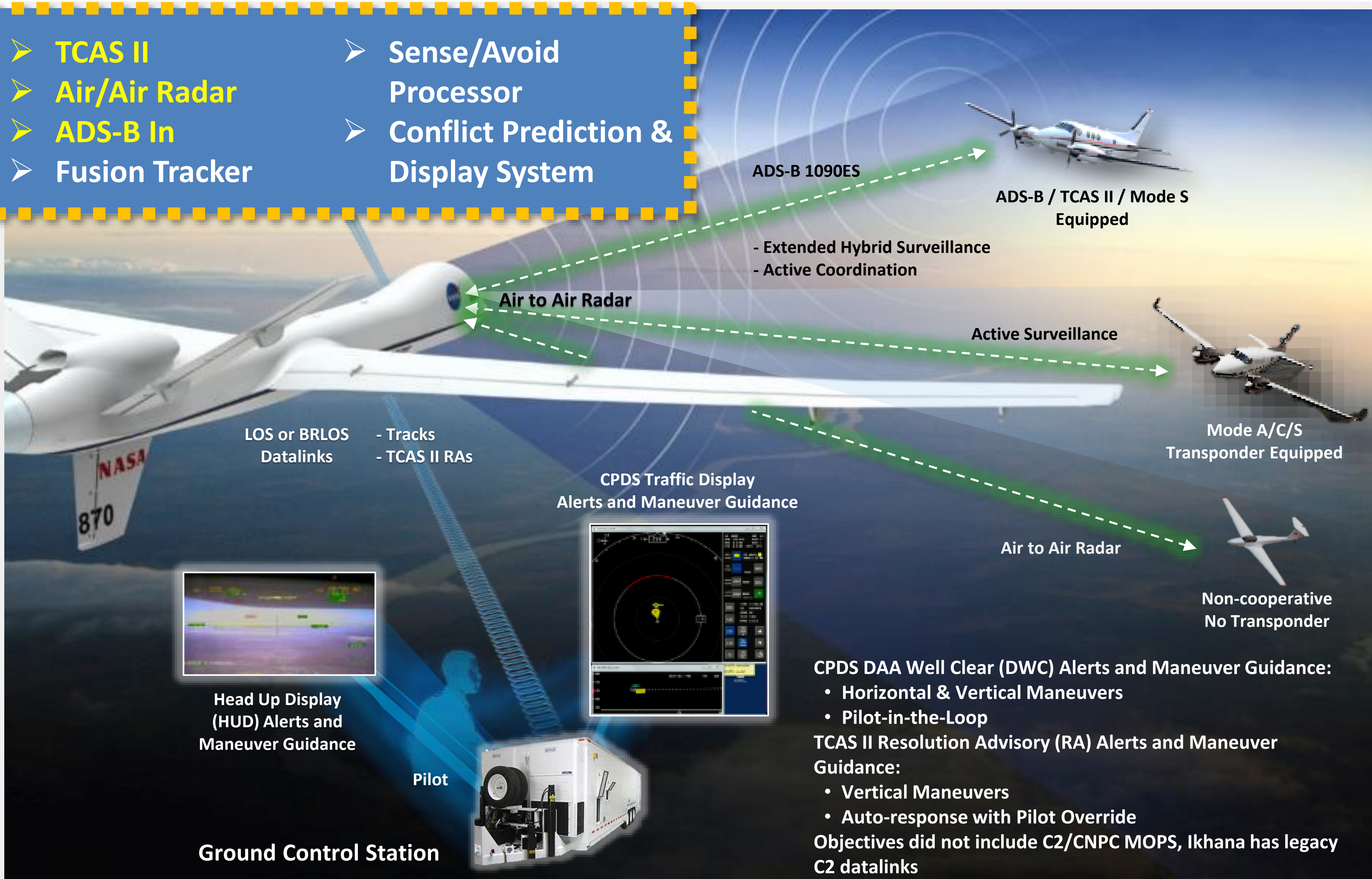
- **UAS** – able to carry payload; reliable aircraft and C2 system; able to modify for test
- **Ground System** – able to host test displays; test team communication network; adequate pilot interface to execute flight test objectives
- **Chase/Intruder Aircraft** – broad sample of speeds/sizes; experienced chase and/or test pilots
  - Know if aircraft **can fly** the speeds/altitudes expected!
- **Airspace** – restricted/protected to avoid non-player interference; size to accommodate flight profiles
- **DAA System Under Test (SUT)** - Air-to-Air Radar, ADS-B In, Tracker/Processor, Data Recorder…





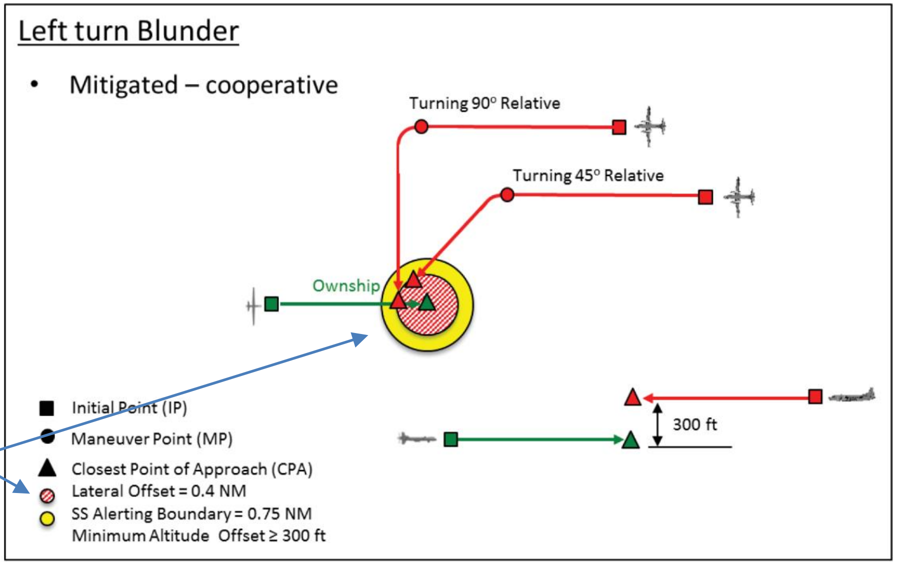
DAA System Architecture (NCC Example)

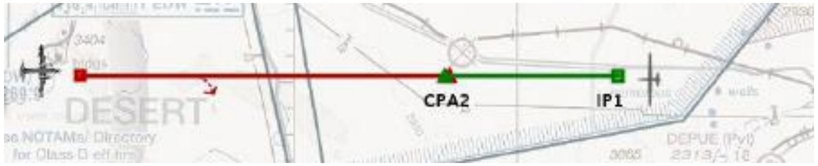
- TCAS II
- Air/Air Radar
- ADS-B In
- Fusion Tracker
- Sense/Avoid Processor
- Conflict Prediction & Display System



Test Approach – 2. Methods

- Methods – *to prove the DAA system avoids collisions in myriad cases*
  - **Stress the System Under Test…**
  - **Through many different flight encounter profiles (speed, altitude horizontal and vertical offset angles, prioritize multiple intruders**
    - Ownship (UAS) vs. Intruder (1 to multiples)
  - **Scripted Encounters (test matrix)**
    - Minimum Lateral Offset to avoid actual collision…
    - **Closest Point of Approach** for each Encounter
    - Start and End points for ownship & intruder(s)
    - Deconfliction altitudes to return to after encounter
    - Minimum visual range for <500 ft altitude difference
  - **Build-down Approach** (easy first)
    - >500 ft altitude separation*
      - *Visual not required < min range
    - Non-maneuvering
    - Non- or Early-reacting Ownship
    - Medium speed, medium altitude
  - **Disciplined Tech/Safety Review**
  - **Train, Rehearse, Brief, Fly, Debrief**



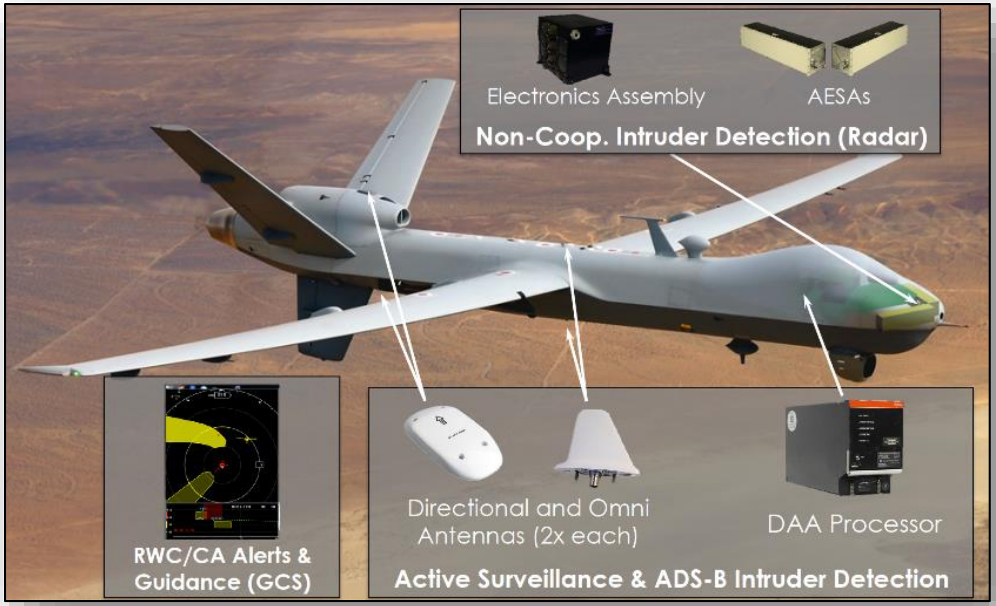


Pilot Test Training & Rehearsal

Goal: Train project aircrew on the important areas – to ensure effective, efficient, safe test execution

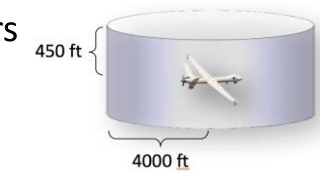
Creation: Test plan assessment by highly experienced UAS pilots

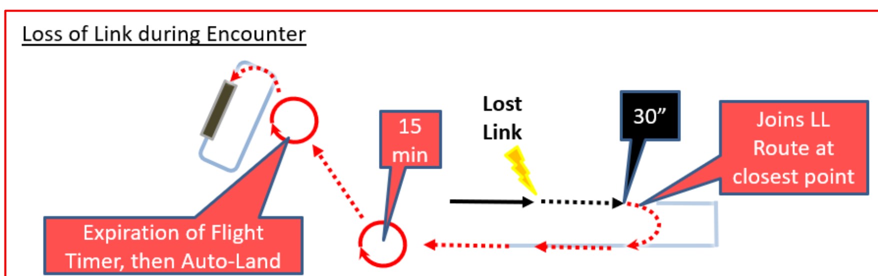
- First, know the baseline aircraft system & understand the “new” tech added
- Understand proper UAS flight test methods, and apply to the proposed test points

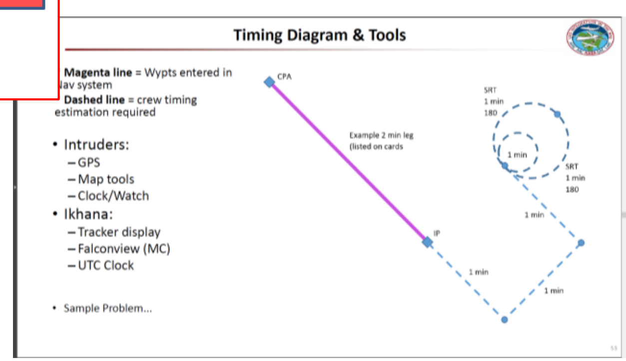


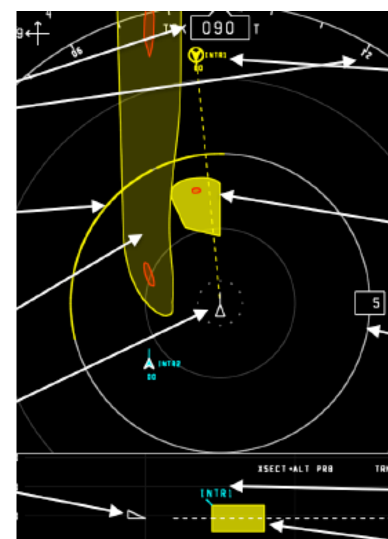
Training for Aircrew Team (multi-format)

- Hardware/Software familiarity including test displays
  - Simulation or Videos – displays, alerts, interactive functions in real-time scenarios
- Radio Calls – tabletop rehearsal; expected test flow and calls throughout
- Contingencies & Emergencies – brief expected calls, flight paths (deconfliction)
  - Engine failure, Radio failure, Chase support (escort) during an emergency
- Understand Lost Link programming and execution at any point during testing
- Brief/teach - properly execute the **challenging test points… HOW TO:**
  - Use the UAS system to perform complex maneuvers to meet desired test parameters
    - I.e. Maintain planned ground track, constant ground speed, while changing altitude, <u>then</u> maneuver according to an alert-driven avoidance cue.
  - Deconflict several aircraft if "Abort" call is made during a test encounter
  - Properly complete a test encounter if lost visual (if visual required)
  - Achieve precise timing constraints (techniques & equipment)









Scripted Encounter Video

<u>MQ-9 vs. C-90 King Air, head-on, slight offset</u>
At 1:24 -- Intruder turns toward ownship…
Ownship executes right-hand avoidance maneuver; note Alerts

CPDS Pilot Display Used for DAA

HUD

Test Timeline – Cycle of Plan-Train-Test-(Learn)

Coordination Meetings/Briefs

Flights/Flight Testing

(Well over 1000 Air-to-Air Encounters total)

Major Milestones

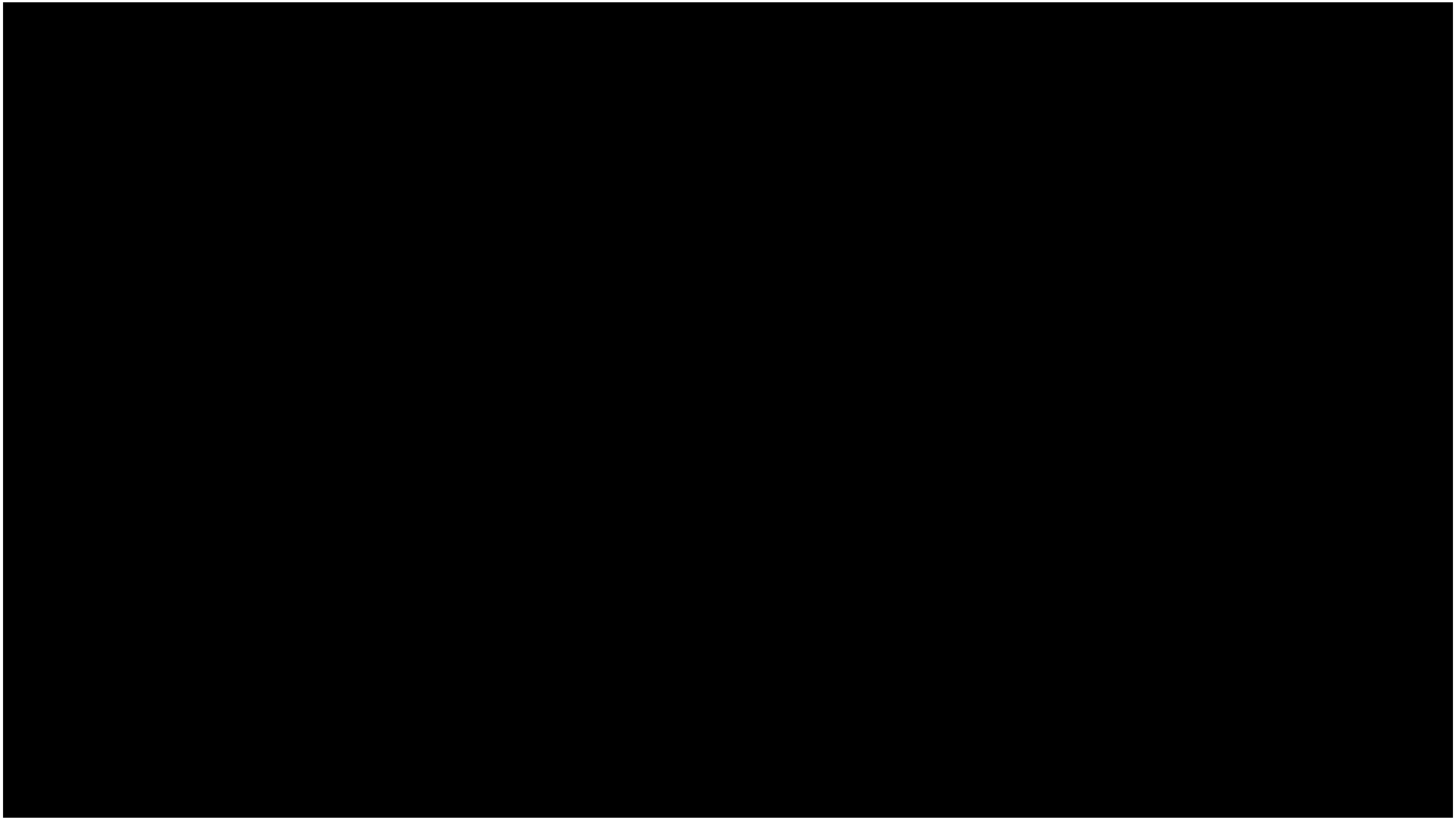
NASA UAS Integration In the NAS - Timeline

Date	Event
2013	NAC Aeronautics Committee, UAS Sub Committee recommend a bold demonstration in the NAS
2014	Kick-Off Meeting (NAS Demo)
Late 2014	**ACAS Xu SS Flight Test** – Tech Review, Train, Fly
Summer 2015	**Flight Test Series 3** – Tech Review, Train, Fly
Summer 2016	**Flight Test Series 4** – Tech Review, Train, Fly
Summer 2017	Phase I MOPS Released
Summer 2017	**ACAS Xu FT2 Flight Test** – Tech Review, Train, Fly
Early 2018	**NCC SCO Flight Test** – Tech Review, Train, Fly
Early 2018	FAA Review Board at NASA
Spring 2018	COA Approved; Followup Spectrum Clarifications
Summer 2018	**NCC Demo** – Tech Review, Train, Fly
Fall 2019	**Flight Test Series 6** – Tech Review, Train, Fly
2020-2021	**Resilient Autonomy** Sim Test & Virtual Live Demos

DAA Maturity

NASA Ikhana NCC COA Approval:
FAA FORM 7711-1 UAS COA Attachment, 2017-WSA-148-COA

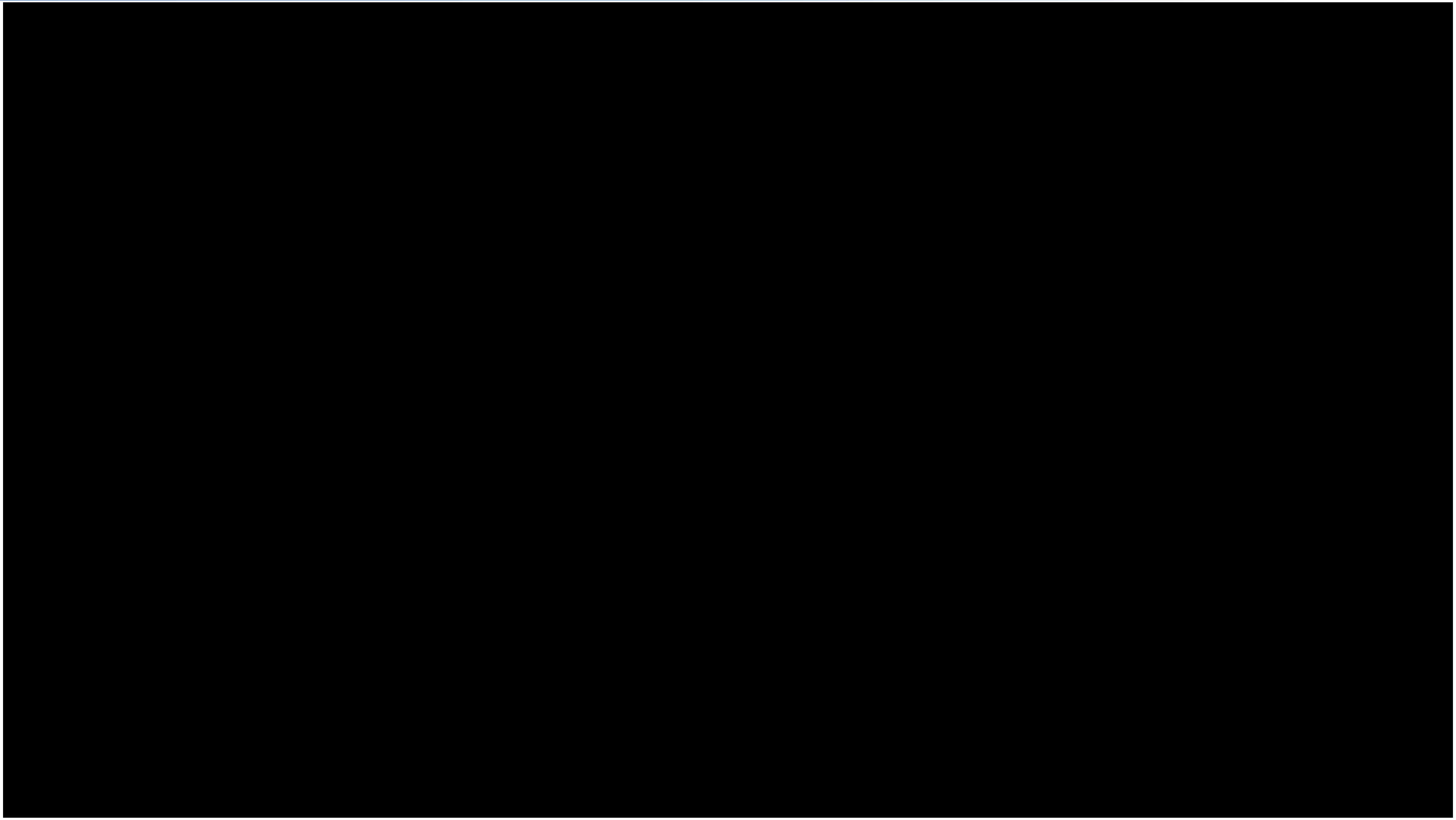
NASA Prepares to Fly a Large Unmanned Aircraft in Public Airspace without Chase Plane for First Time using DAA Technology



Ikhana Flight #250, 24 May 2018, Mission Rehearsal in the NAS with Chase

~2.5 hr flight, ~200 nm route, NAS Altitudes FL200 to 5,000' MSL

Sharing Air: Integrating Unmanned Aircraft with Manned Aircraft in the National Airspace System



NASA Ikhana Flight #251, 12 June 2018, No Chase Flight (Solo) Demonstration

~2.5 hr flight, ~200 nm route, NAS Altitudes FL200 to 5,000’ MSL

Lessons Learned Overview

NASA UAS Flight Test Top Lessons Learned

1. Project Planning Lessons
2. Training and Rehearsal Lessons
3. Flight Planning Lessons
4. General Execution Lessons
5. Timing Execution Lessons

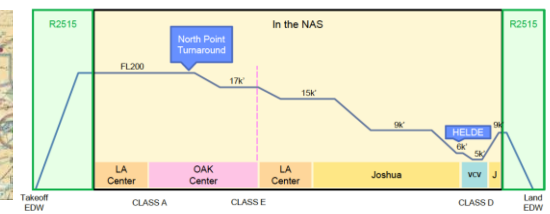
**See paper for full list of top lessons learned.*

1. Project Planning Lessons (1/3)

Early Coordination with Spectrum Management

Involve spectrum management during early planning regarding comm, datalinks, and frequencies in flight, to ensure national level approvals/certifications in time for testing.

- Test delayed: some frequencies approved for restricted airspace were not approved for NAS.
- FAA **operational approval** was independent of **spectrum approval**, which was independent of **COA approval**.



FAA Early Involvement in Mission Design

Involve FAA early in the formulation of the NAS mission profile, for time to consider, recommend and approve test flight route/profile.

- Test delayed: Involving FAA later required time to locate/inform the right FAA approvers.

Early Schedule Margin

Fly early envelope expansion flights separate from systems check flights, to allow proper basic flight testing without undue schedule pressure during flight.

- Also plan several pilot proficiency flights to ensure pilot readiness for the complex nature of flight test encounters/maneuvers.

1. Project Planning Lessons (2/3)

Chase Aircraft

If support aircraft have chase roles (photography, close formation, instrument verification, etc.), first identify the UAS airspeed (cruise & limits) to understand which aircraft can feasibly execute chase duties.

- Especially for smaller UAS such as TigerShark; besides the TG-14 motor glider, all other aircraft had to S-turn behind the TigerShark to maintain chase position without approaching stall.

UAS-NAS test aircraft. (Back, L-R) NASA King Air B200, NASA Gulfstream III, Honeywell King Air C90; (front, L-R) NASA TG-14, NASA T-34, & NASA Ikhana.

Limiting Many Waypoints

For large test point matrix (many waypoints), reuse same waypoints across many test profiles to keep the number of waypoints to a minimum, to ease pilot workload (efficient input of coordinates into manned and unmanned flight management/autopilot systems).

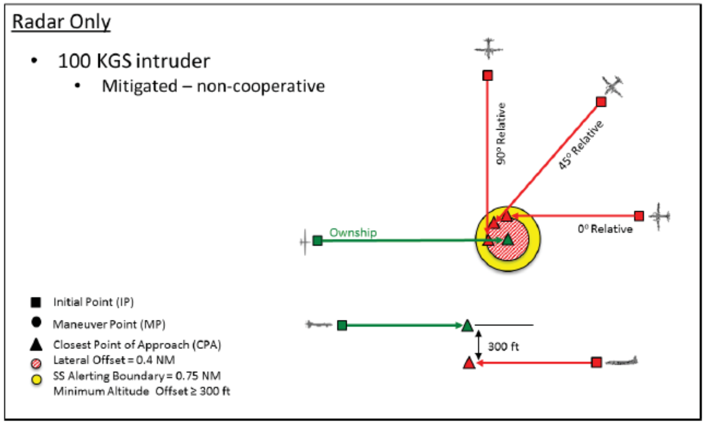
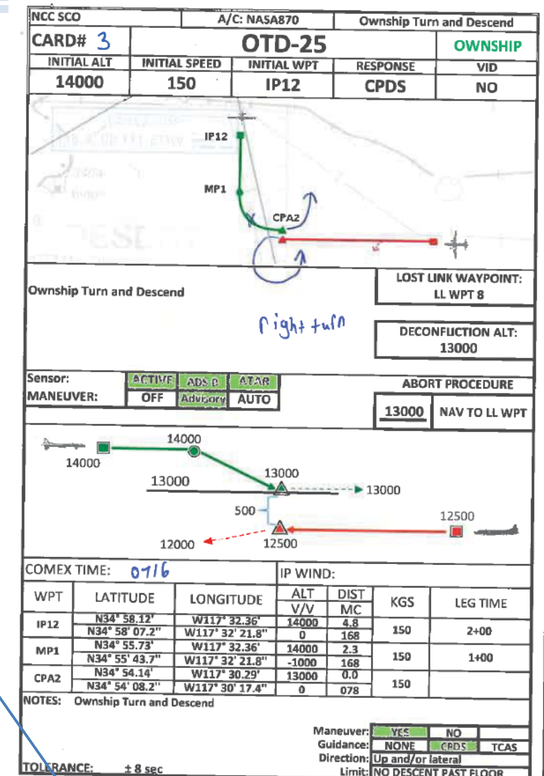


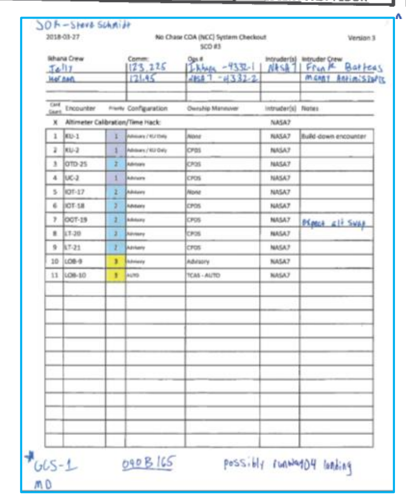
Figure 22. Radar Only Encounter. In order to simulate non-cooperative targets, the radar would be the only active sensor feeding the DAA algorithms. The intruder aircraft would turn their transponder off in this encounter.

Daily Test Card Usability

Cards should specifically list **essential** information for the test team:

- Information: efficiently organized and simply worded, to facilitate easy reference during busy execution of test. *No extra clutter!*
- Put specific maneuver desires/constraints (essential details) in the cards (e.g., “Traffic symbol turns yellow = single turn to first avoidance heading, maintain until end of run. Only turn toward the south”).
- Overview card (“dance card”): expected order and number-code of today’s deck of cards, with essential (one-line) parameters (e.g., altitude; system on/off; maneuver type, etc.)
- Easier to understand the test sequence (and locate info) if you don’t give the *entire* project’s catalog of cards at the mission brief!
- Involve project aircrew early in the card review process, well before the day of flight.





Extending the Flight Test Phase

If new discoveries drive expanded research: Increase the number of flights accordingly if the number of test points increases, instead of “packing” more test points into existing flights, which reduces margin for repeats and increases program pressure.

2. Training & Rehearsal Lessons (1/2)

Intentional Training and Rehearsal

Provide realistic & relevant aircrew training, familiarization and rehearsals

- Focus on the SUT and flight test execution
- Best format – sim, video, brief, discuss, flights
- Increased aircrew effectiveness/awareness during UAS test execution if thoroughly trained & rehearsed.
- Highlight important, unfamiliar SUT characteristics that might be confusing during test (i.e. auto-scaling of scope range; mag vs true heading; sequence of alert levels, and the correct response to each alert level.
- Airborne time-on-target execution is difficult; give special emphasis in training.

CPDS Traffic Display

Build-down, Simple to Complex

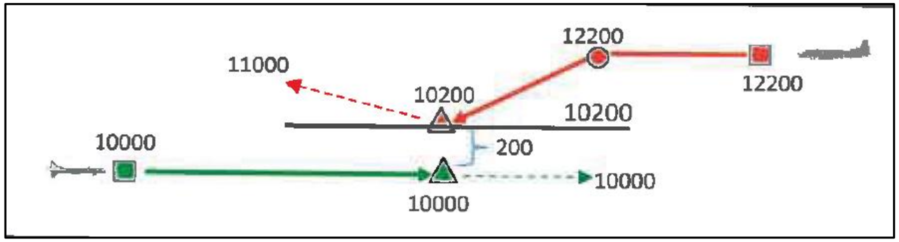
To gain familiarity & proficiency in test execution.

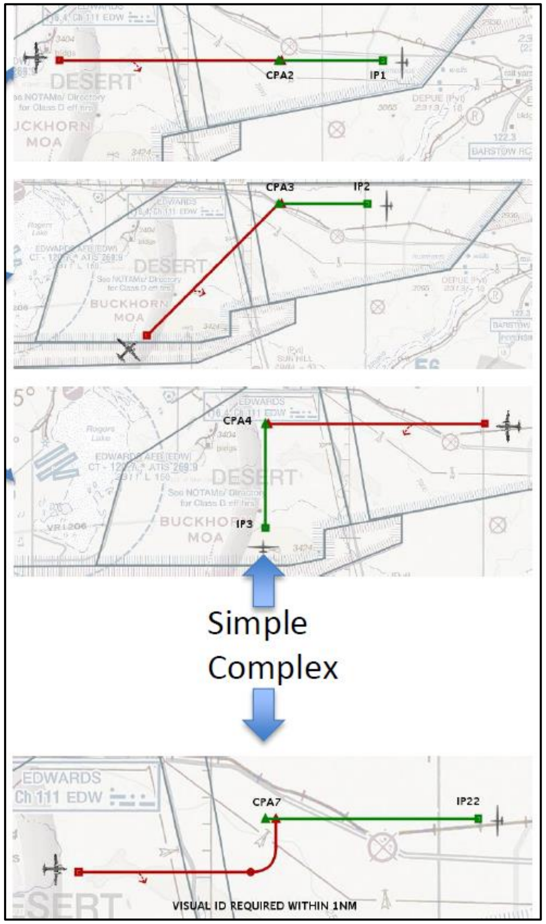
- After training/rehearsal, schedule aircrew for <u>flight observations</u> of the pilot & co-pilot during test
- Fly as co-pilot first to “acclimate” to the pace, radio calls, displays and SUT before flying as pilot in command.

Practice Complicated Tasks

Use simulator, tabletop, &/or proficiency flights to practice (rehearse) complex maneuvering of the UAS or intruder

- Goal: repeatable, accurate results - especially for combined vertical/horizontal (3D) maneuvers, timing, or any non-typical maneuvering.





3. Flight Planning Lessons (1/2)

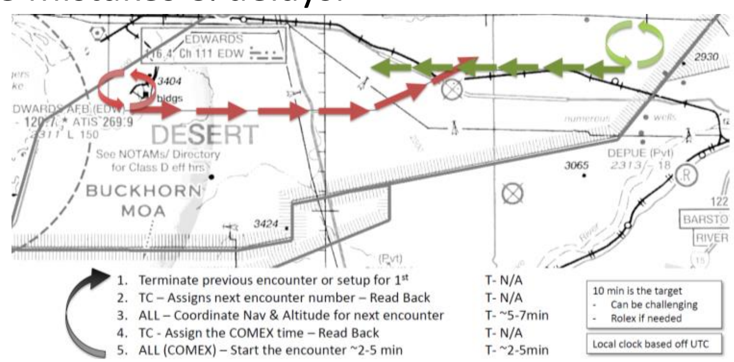
Maximize Pilot Performance

- Adequate manning of complex flights (high mental workload)
- Plan crew swaps/breaks periods – peak alertness; (≤ 2 hrs max active testing).
- Consider adjusting for consecutive days of flight test

Optimal Flight Test Pacing

Time between test points should allow normal (standard rate turn) maneuvering. Moderate test pacing <u>increases</u> likelihood of aircraft arriving at the start point <u>on-time</u> and <u>stabilized on-conditions</u> with adequate pilot <u>situational awareness</u> of the execution instructions.

- Avoid compressed (rushed) timing which creates more mistakes & delays.



Efficient Altitude Profile

Plan daily sequence (dance card) to group same-altitude points, and change altitudes in one direction.

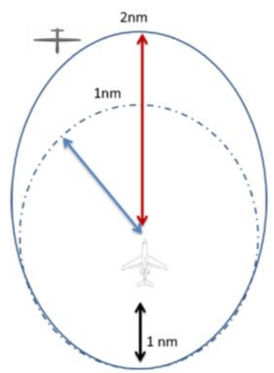
- Unnecessary altitude changes which wastes time and fuel.

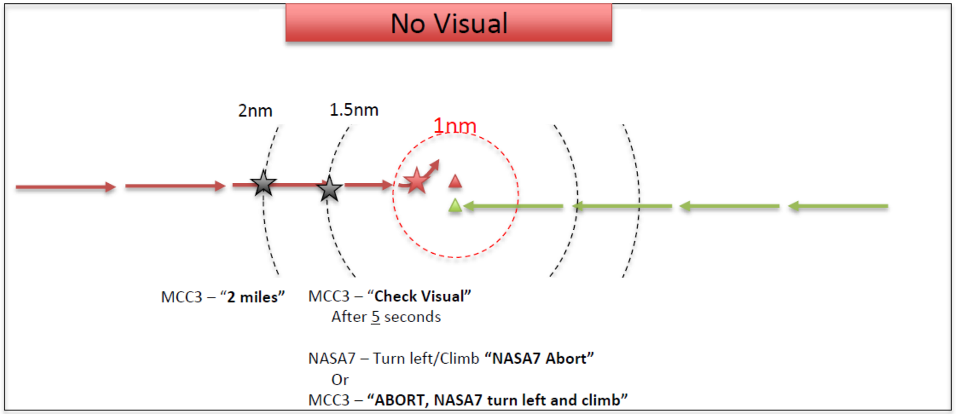
3. Flight Planning Lessons (2/2)

Visual Acquisition (of UAS by Intruder) during Encounters

If visual acquisition is a safety mitigation for aircraft deconfliction, timing &/or positional assumptions must account for relative closure speed between aircraft.

- Abort Criteria: Normal 1-mile visual acquisition minimum was increased to 2-miles for Gulfstream G-III (higher speed), to guarantee time for abort response, maneuver, and safe separation between aircraft.





KGS Closure	Seconds per mile	Vis Range
300	12s	1nm Vis Range
330	11s	
360	10s	
390	9s	
High Closure 2nm Vis required		
450	8s	2nm Vis Range

Backup Cards

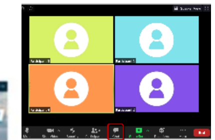
Include daily alternative card options in case of airspace changes, or interruptions.

- Early contact with airspace owners – best available times & limitations; and explain your test needs.
- Brief extra cards each day – test time is valuable! Never attempt ad-hoc, unbriefed flight testing.
- Brief alternate cards in case airspace changes (altitude &/or horizontal), that fit in a single airspace.

Schedule Enough Crews

Account for crew cancellations especially with guest help; know your minimum-required crew numbers.

4. General Execution Lessons




Pivot to Virtual Testing (COVID-19) – Adapt schedule and test methods to maintain research progress.

- Geographically distributed test team concept - live testing over teleconferencing; continued limited testing/simulation can be valuable to achieve project goals.

Shortcuts to Mitigate High Task Loads

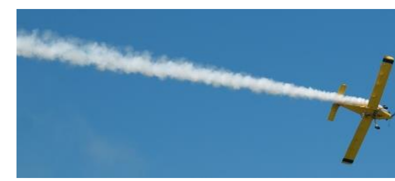
- Highlight areas to aid rapid eye focus (markers, stickers, tape)
- Consider switches, menus, buttons to ready for execution - “one button” command.
- Briefed division of duties - pilot & co-pilot (UAS and/or intruder). *Example:*
- Pilot Flying: fly (track, speed, altitude), determine timing/adjustments.
- Pilot Not Flying: radio, waypoints/flight management system, call visual, backup timing/maneuver.

Plan for Lost-Link – Know how the UAS will fly lost-link in different test scenarios. *It happened to us!*

- Intruder became safety chase; UAS crew used CRM + systems knowledge + checklist to resolve & land safely.

Visual Acquisition of Smaller UAS

- Later, closer-range acquisition, even with smoke trail (TigerShark) – faint vs. background.



Environmental Effects on Visual Acquisition

Ability to visually acquire a UAS varies greatly - many factors: color/glossiness of UAS; sun angle; background clutter, color/contrast; clouds, haze, smoke; windshield/canopy quality; and eyesight and scan technique. Sun reflection (glint) gives long range acquisition but is unpredictable & momentary. Train where to look (elevation angle).

- Always be ready to abort the encounter if safety conditions not met.

Intruder Maintain Altitude Separation During Rejoin to UAS

Maintain altitude separation (i.e. 500 feet below) when joining with UAS until visual and closure speed is manageable. Visual acquisition may occur much closer/later than expected. Typically ATC or Test Conductor provided a position “point out” to initiate the rejoin.

Optimize Displays for Test Accuracy

Know your Nav system - waypoints, graphics, guidance cueing – be on **time, speed, altitude & course**.

- Watch/digital clock (seconds) - briefed time-hack; GPS ETA/ETE to waypoint.
- Glass cockpit map display; precision Nav system desired. Backup tablet flight map very useful (Foreflight-type)
- Live ADS-B tracks on map = increases situational awareness
- Pre-load waypoints; Save “flight plans” for each test encounter (titles = card numbering)
- Know how to sequence waypoints (overfly vs lead-turn); avoid premature waypoint sequencing.

Impact of Strong Winds on Timing

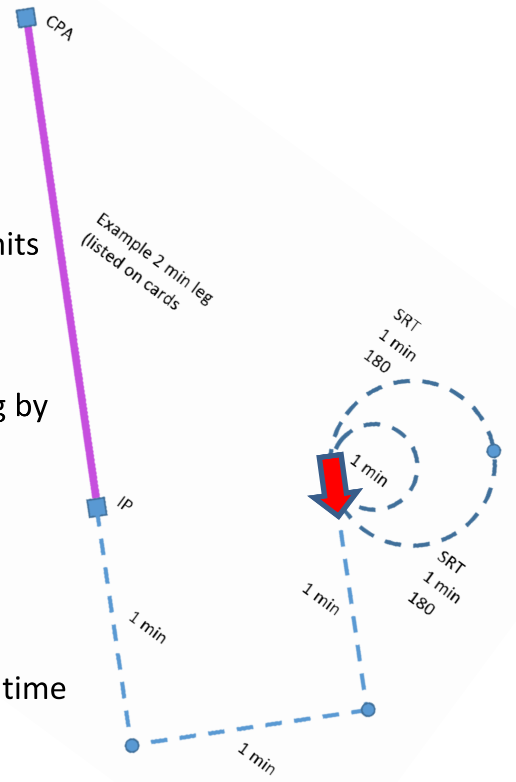
Limits small/slow UAS ability to adjust track & speed to fix timing errors; min/max speed limits may prevent achieving ground speed.

- Aircraft displays & Nav system - adjust for winds for accurate timing.

Loiter - racetrack pattern near start point; downwind leg: offset from the inbound (start) leg by one standard-rate-turn radius (180-degree turn), adjust for crosswinds. Stabilize early on parameters (altitude & speed).

Fix timing errors using the racetrack pattern: Given Start Time (i.e. 09:50:00)

- When abeam the start point (09:46:20); Subtract abeam time from start time (09:50 – 09:46:20 = 3m 40s), then subtract 1m for 180-deg SRT = 2m 40s
- Continue downwind leg **past** the abeam point the following amount: Half the computed time = 1m 20s
- Then 180-turn inbound and continue to make **small adjustments** as required…
- Speed fixes small errors up to ~10s; S-turns fix large timing errors (inbound leg)
- Otherwise abort if off conditions at the start point according to “abort criteria.”



Conclusions

Some keys to success in UAS flight testing:

- **Early Planning Team - Involve teammates & pilots (and regulators when necessary) in early planning**
- **Test Approach - Use (& keep refining) efficient/effective flight test approaches**
- **Lessons learned – Collect & add to your list (avoid re-learning them!)**

While these do not guarantee success, they certainly help achieve accurate, efficient, safe test execution and data.

- **For more information, please refer to the References in this paper, including these reports (https://ntrs.nasa.gov):**

  "UAS-NAS NASA 870 Ikhana No Chase COA (NCC) Flights, FTR," NASA ID **20180004861**
  "UAS Integration in the NAS Project: Overview of FT Series 6," NASA ID **20205004052**

Team photo after successful flight into NAS, 12 June 2018

REFERENCES

1. Flock, A., Marston, M., and Valkov, S., "UAS-NAS NASA 870 Ikhana No Chase COA (NCC) Flights, Flight Test Report," NASA ID 20180004861, August 2018.

2. Marston, M., Flock, A., Loera, V., Kim, S., Vincent, M., Wu, M., Rorie, C., Bridges, W., and Wang, W., "UAS Integration in the NAS Project: Overview of Flight Test Series 6," NASA ID 20205004052, July 2020.

3. RTCA DO-365, "Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems," RTCA, 31 May 2017.

4. RTCA DO-366, "Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance," RTCA, 31 May 2017.

5. FAA Technical Standard Order TSO-C211, "Detect and Avoid (DAA) Systems," FAA, 25 September 2017.

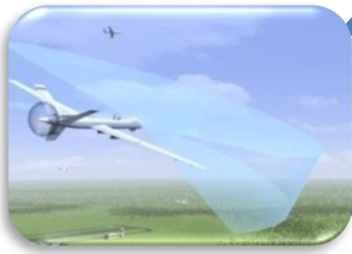
6. FAA Technical Standard Order TSO-C212, "Air-to-Air Radar (ATAR) for Traffic Surveillance," FAA, 22 September 2017

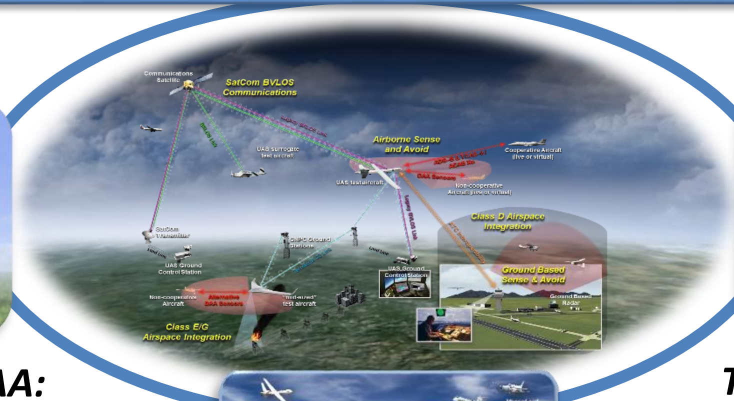
7. Whiting, Teresa, "Resilient Autonomy Ends, Autonomy Research Ongoing," NASA Armstrong Flight Research Center, 4 October 2021.

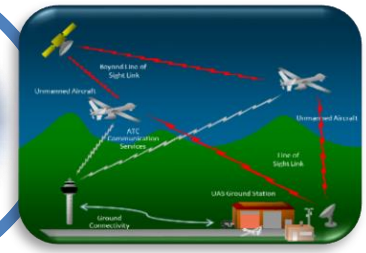
- BACKUP SLIDES

Unmanned Aircraft System (UAS) integration in the National Airspace System (NAS) Project Goal

Goal: Provide research findings, utilizing simulation and flight tests, to support the development and validation of DAA and C2 technologies necessary for integrating Unmanned Aircraft Systems into the National Airspace System

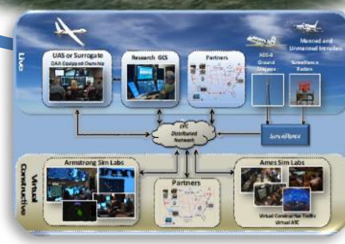






Technical Challenge-DAA: Detect and Avoid (DAA)

Develop DAA operational concepts and technologies in support of standards to enable a broad range of UAS that have Communication, Navigation, and Surveillance (CNS) capabilities **consistent with IFR operations** and are required to detect and avoid manned and unmanned air traffic



System Integration and Operationalization (SIO)

Accelerate routine UAS operations in the NAS. Industry will provide a UAS to support one or more commercial missions with NASA as a consulting partner

Technical Challenge-C2: Command and Control (C2)

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

Stakeholders and Participants

- **NASA Ames Research Center (ARC)**
  - ATC expertise on route development
  - Present at Oakland (ZOA) Air Route Traffic Control Center (ARTCC) during NAS flights
- **NASA Armstrong Flight Research Center (AFRC)**
  - Responsible Test Organization
  - Hosted ownship platform NASA 870 “Ikhana” UAS
  - Provided live intruders for system checkout flights
  - Hosted Live Virtual Constructive (LVC) environment for data collection
- **General Atomics Aeronautical Systems, Inc. (GA-ASI)**
  - Hardware, software, and integration support for Ikhana UAS
  - GA-ASI designed Detect and Avoid (DAA) system
    - Conflict Prediction and Display System (CPDS)
    - Air-to-Air Radar (ATAR)
- **Honeywell International, Inc.**
  - Hardware, software, and integration support for Surveillance and Tracking Module (STM)/ACAS prototype processor (containing Fusion Tracker and TCAS II)
- **Federal Aviation Administration (FAA)**
  - Guidance through development of COA application and final approval
  - Held Safety Risk Management Panel (SRMP) at NASA AFRC
  - Coordination to ensure resolution of spectrum management issues

Overview of NCC

Coordination Meetings/Briefs

Flights/Flight Testing

(Over 1000 Air-to-Air Encounters in 5 Campaigns)

Major Milestones

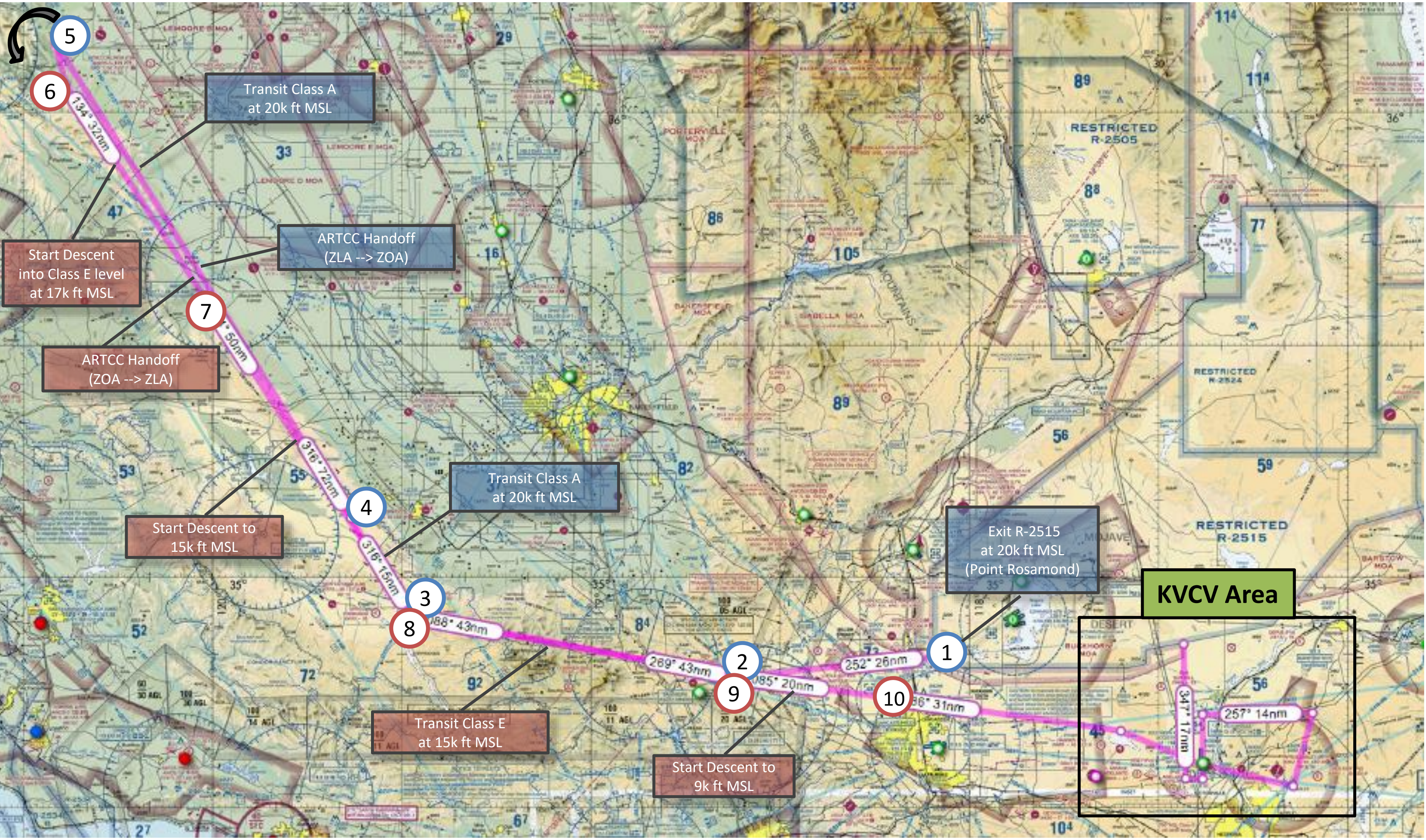
No Chase COA Summary

Date	Event	Description
2/25/2013	NAC Aeronautics Committee, UAS Sub Committee recommendation to conduct a bold demonstration in the NAS	NAC recommendation to do more than just conduct research and collect data but to employ its unique capabilities to conduct a "Bold Flight Demonstration".
6/2/2014	Demonstration Kick-Off Meeting	Initial planning activities; develop goals and objectives
Dec. 2014	ACAS Xu SS	ACAS Xu Flight Testing
Summer 2015	Flight Test Series 3	FT3 Flight Testing
Summer 2016	Flight Test Series 4	FT4 Flight Testing
12/15/2016	NCC Strategy Meeting	Meeting at GA-ASI to discuss planning for NCC
2/2/2017	NCC Coordination WG	Earliest meeting on record with NCC name
5/31/2017	Phase I MOPS Released	DAA and ATAR Phase I MOPS
Summer 2017	ACAS Xu FT2	ACAS Xu FT2 Flight Testing
10/27/2017	AFRC COA Brief to Management	Brief to AFRC upper management
10/30/2017	COA Submission	Old system for COAs
12/20/2017	COA Re-submission into CAPS	Added "CONOPS" section, route modified
2/1/2018	NCC SCO Tabletop	Team training
2/8/2018	NCC SCO Tech Brief	Brief to AFRC upper management
2/14/2018	NCC SCO Flight 1	Ikhana only
2/15/2018	NCC SCO Flight 2	With intruder
2/21/2018	FAA SRMP Day 1	AFRC hosted FAA event, day 1
2/22/2018	FAA SRMP Day 2	AFRC hosted FAA event, day 2
2/28/2018	NCC SCO Flight 3	With intruder, attempt 1
3/21/2018	NCC Flight 3 Follow-up Tech Brief	Brief to AFRC upper management
3/28/2018	NCC SCO Flight 3	With intruder, attempt 2
3/30/2018	COA Approved	FAA FORM 7711-1 UAS COA Attachment, 2017-WSA-148-COA
4/5/2018	C-Band C2 STA Not Approved	STA to approve use of C-Band LOS C2 outside of SUA was denied due to the FAA Spectrum Office requiring clarification on the NCC operations and risk mitigations. Multiple FAA Spectrum Office and UAS Integration Office coordination meetings followed.
5/10/2018	NCC Demo Tech Brief	Brief to AFRC upper management
5/10/2018	NCC Demo Tabletop	Team training
5/23/2018	STAs for Operations <u>with</u> Chase Approved	STAs included C-Band C2, DPX-7 Transponder, TPA-100 TCAS, ARC-210 VHF Radio
5/24/2018	NCC Demo With Chase	Mission execution (photo chase)
6/6/2018	STAs for Operations <u>without</u> Chase Approved	STAs included C-Band C2, DPX-7 Transponder, TPA-100 TCAS, ARC-210 VHF Radio, ATAR
6/12/2018	NCC Demo Without Chase	Mission execution (no chase)

Ikhana Predator B (NASA 870) DAA System

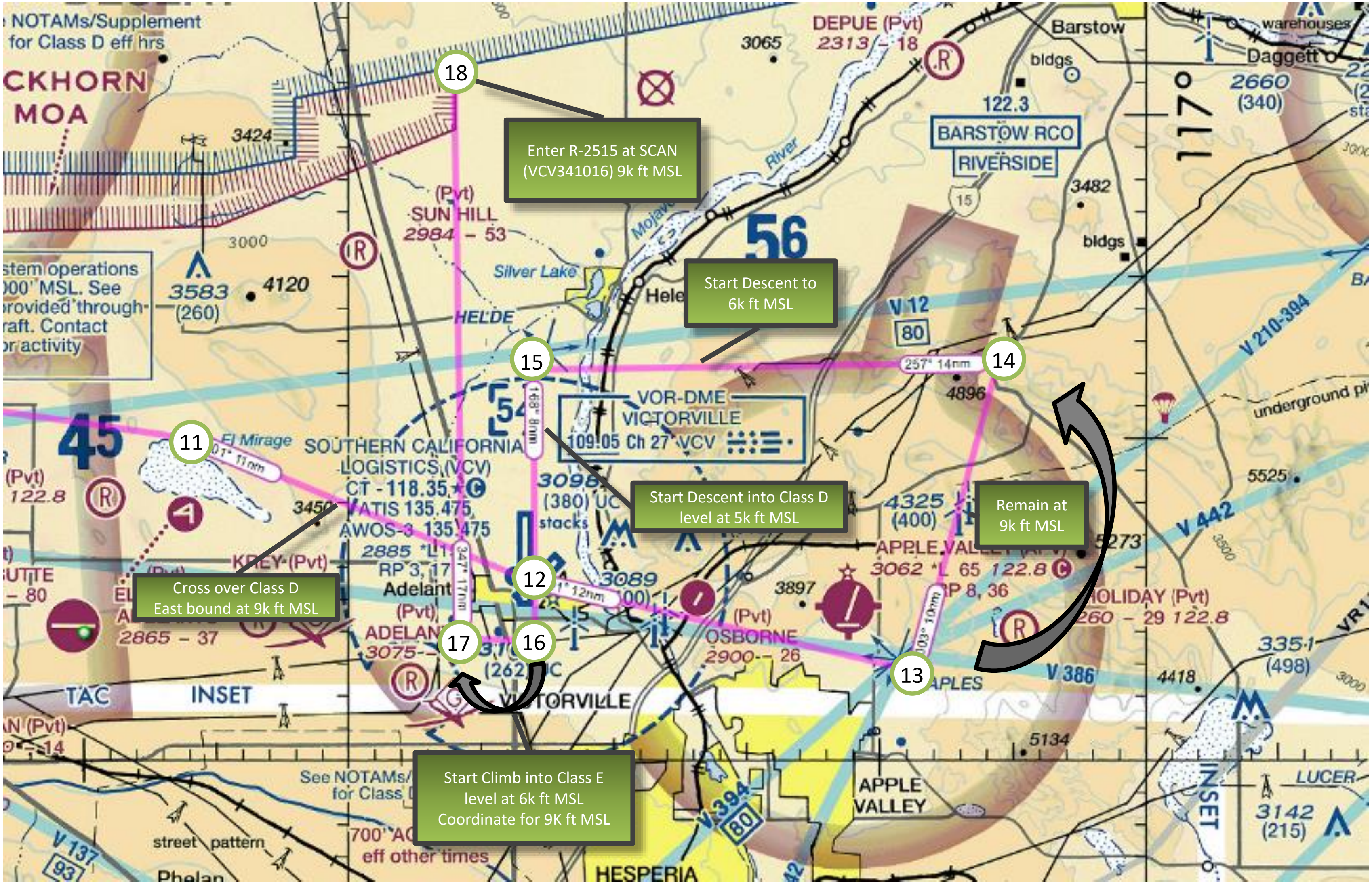
- **Active Surveillance / TCAS II**
  - TCAS II v7.1 hosted in the Honeywell TPA-100 ACAS Processor
  - During the NCC flight demonstrations, Ikhana was configured to respond automatically to TCAS II RAs
  - Cooperative aircraft
- **Air-to-Air Radar**
  - GA-ASI manufactured X-Band ATAR field of regard (±15° elevation and 110° azimuth)
  - Non-cooperative aircraft
- **ADS-B In**
  - ADS-B surveillance was provided by the Honeywell TPA-100 ACAS Processor
  - Receives 1090ES signals and provides track data to the fusion tracker for correlation with other sensor data
  - Employed in an extended hybrid surveillance mode to reduce 1030/1090 MHz band transmissions
  - Cooperative aircraft
- **Fusion Tracker**
  - Hosted in Honeywell TPA-100 ACAS Processor, correlates intruder tracks from multiple surveillance sensors (i.e., Active Surveillance/TCAS II, ADS-B In and ATAR) into a fused track
- **Sense and Avoid Processor**
  - Sense and Avoid Processor (SAAP) served to interface DAA systems, condition track data for downlink to the GCS, and archive data for post-flight processing
- **Conflict Prediction and Display System (CPDS)**
  - Hosted GA-ASI algorithm that predicts DAA loss of well clear
  - CPDS parsed the track data received from the Ikhana downlink and probed estimated trajectories for possible losses of well clear as DAA alerts and maneuver guidance information

No Chase Aircraft COA Flight Demonstration Route

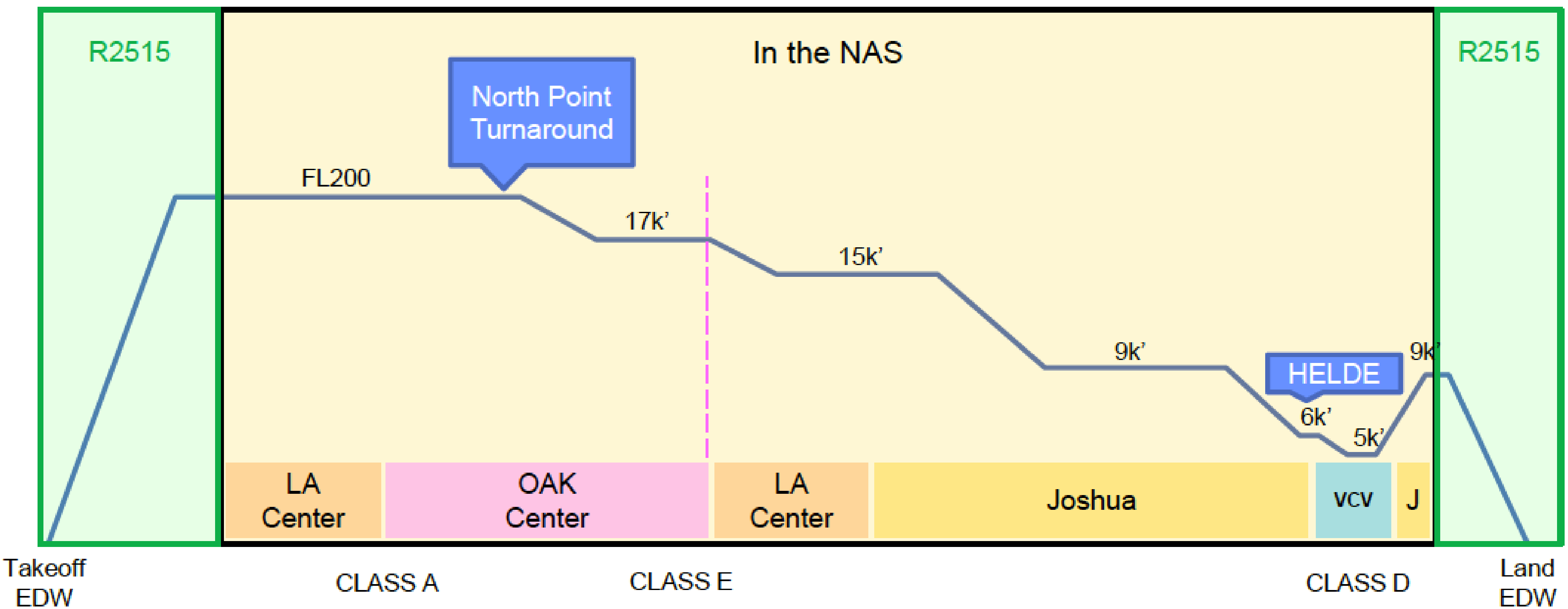


No Chase Aircraft COA Flight Demonstration Route

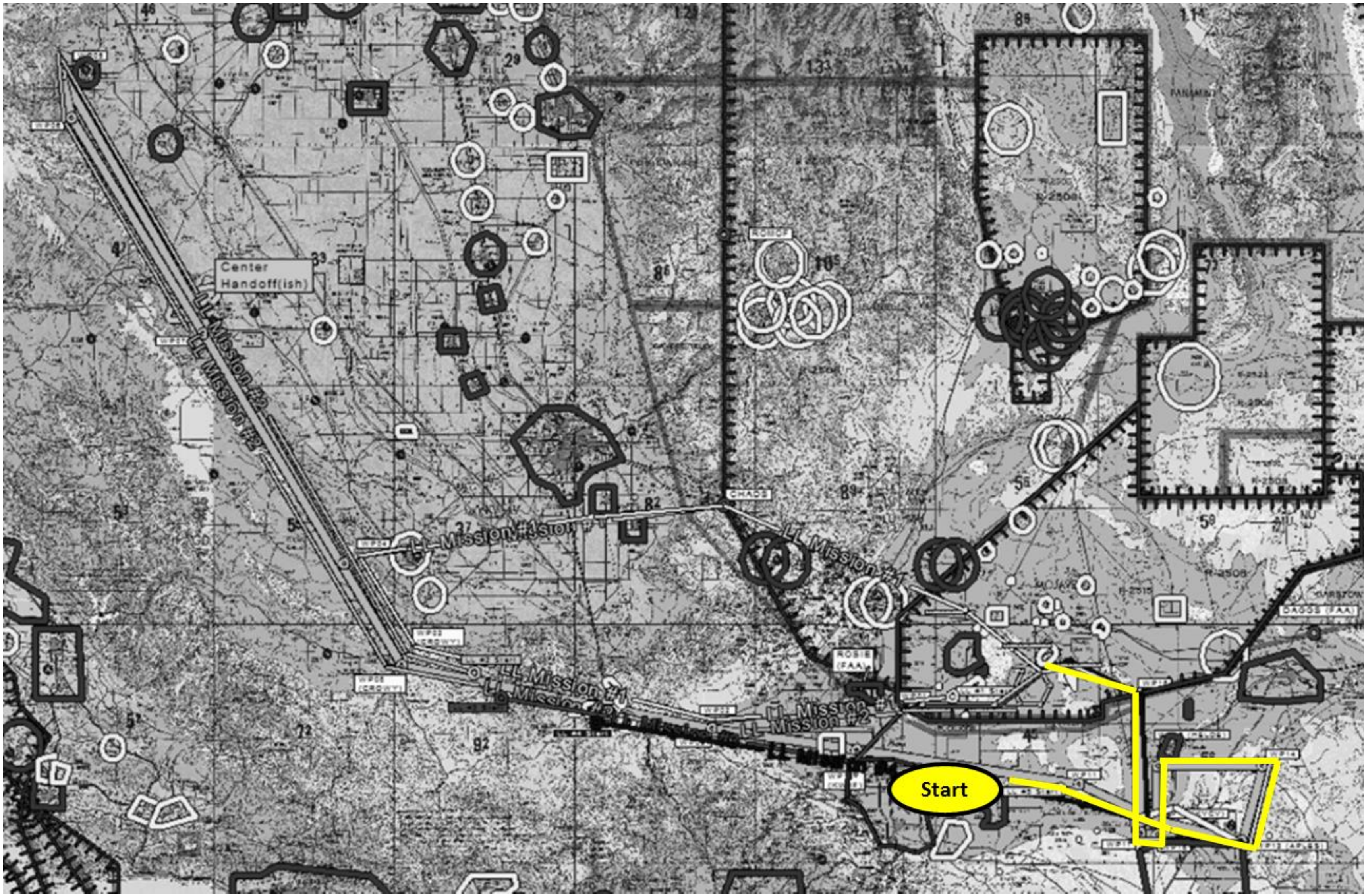
Zoom in of KVCV Area. At or above Min. Vectoring Altitude (MVA) at all times, WPT 11-18.



Mission Altitude Profile



Lost Link



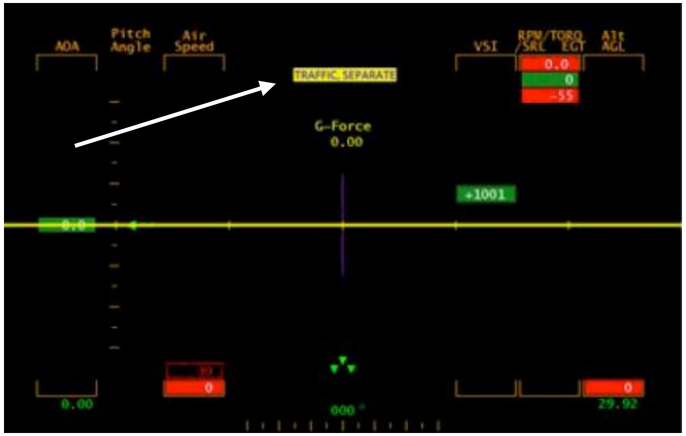
Mission Summary

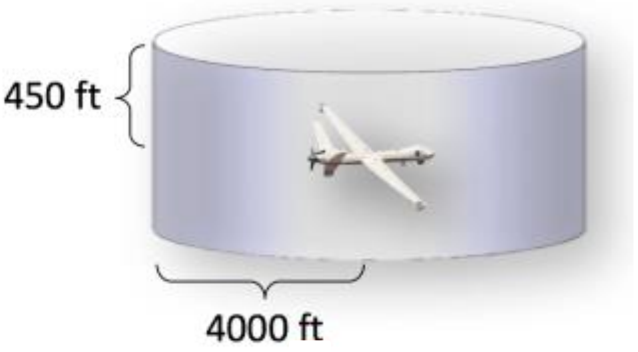
- NCC Flight Demo successfully completed
- DAA Systems worked as expected
  - Extended hybrid surveillance on ADS-B equipped aircraft
  - Sensor fusion
  - ATAR track on VFR traffic with an intermittent transponder
  - DAA Alerting and Guidance
- Some Ku downlink dropouts
- First ever "Traffic Detected" interchange with ATC
- Comments from ZLA, ZOA, JCF
  - Minimum impact to operations – controllers had been provided brief on route, lost link
  - Operation no different than manned aircraft

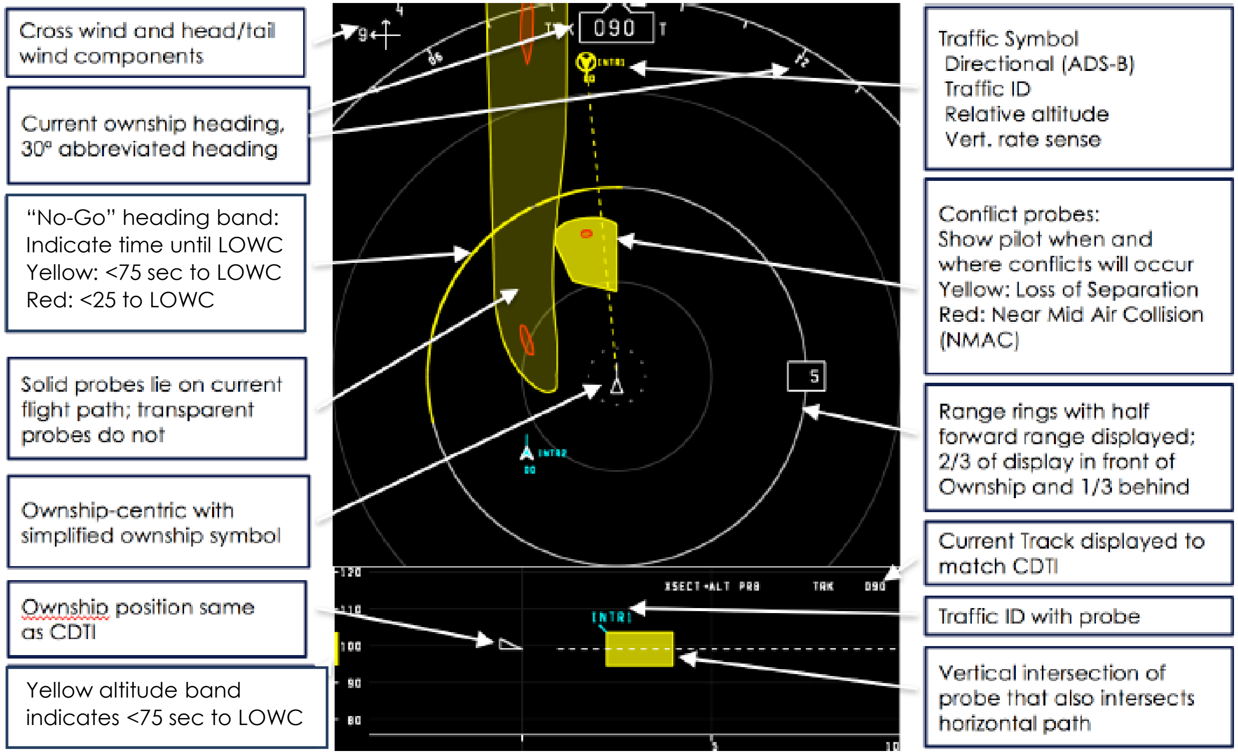
Backup:
DAA System Overview

DAA Equipment

Pilot's Test Displays







COA Process

2017	• Safety case, route, hardware/software specifications, mission planning
30 Oct 2017	• COA Online System – draft application with FAA agreement • UAS, route, safety case, mission
20 Dec 2017	• COA Application Processing System (CAPS) • Added requested CONOPS document
21-22 Feb 2018	• FAA SRMP at AFRC • Hazards discussed, route updated
30 Mar 2018	• COA released • FAA FORM 7711-1 UAS COA Attachment, 2017-WSA-148-COA
5 April 2018	• Additional questions from FAA Spectrum Office • Equipment that meets intent of MOPS/Technical Standard Orders (TSOs) but not certified to those standards
23 May 2018	• Special Temporary Authorization (STA) • Included C-Band C2, DPX-7 Transponder, TPA-100 TCAS, ARC-210 VHF Radio • Flight with chase, 24 May 2018
6 June 2018	• STA plus ATAR • Results from flight with chase reported to FAA • Flight without chase, 12 June 2018

Backup:
Standards Compliance
and
Safety Case Approach

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 Minimum Operational Performance Standards (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.
  - The majority of the gaps were related to the display of DAA and ATAR system health and status information to the UAS pilot.
    - It was 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 where system health and status telemetry data is downlinked to the Ikhana GCS and displayed not only to Ikhana’s DAA system experienced pilots, but also available to test engineers with subject matter expertise to accurately assess system status.

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 for all DAA related software can be 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 will be tested to DAL C rigor requiring full code structural coverage.**
  - **The only software component of the DAA System not being tested to DAL C full code statement coverage is the Honeywell sensor fusion tracker hosted in the TPA-100 ACAS processor.**
    - **To address this gap, Honeywell has implemented an I/O crosscheck algorithm, to DAL C standards, that will validate the fusion tracker's output with TCAS/Extended Hybrid Surveillance.**
    - **This feature will ensure 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 <10kft 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 <10kft MSL until the UAS is within C-Band DLOS range. This is expected to occur prior to WPT 9 before initiating the descent from 15kft MSL to 9,000ft MSL.
  - Route of Flight:
    - The NCC mission plan has been carefully developed to remain off of published airways and away from known flight activity associated with gliders and other small aircraft that NASA has not fully tested the ATAR system against.
    - Flight tests were utilized to validate ATAR performance predictions using RCS modeling and simulations for medium and large aircraft. Modeling and simulation results show sufficient detection and track performance against small RCS aircraft such as gliders; however, to further reduce risk, this flight demonstration is planned to remain clear of areas with known glider activity.

Backup:
Mission Information

Mission Waypoints (GPS & VOR Cuts)

WP	LATITUDE (N)	LONGITUDE (W)	VOR	Fix (DD175)	ALT	Remark
1	34° 49' 40.00"	118° 05' 48.00"	Edwards	**EDW 233/12**	**FL200**	Exit R2515
2	34° 47' 00.00"	118° 37' 00.00"	Lake Hughes	**LHS 330/06**	**FL200**	
3 (CROWY)	34° 54' 54.00"	119° 28' 34.00"	CROWY	**CROWY**	**FL200**	Turn North
4	35° 07' 41.38"	119° 38' 09.42"	Fellows	**FLW 067/12**	**FL200**	5 min to OAK
5	36° 09' 00.00"	120° 25' 0.00"	Priest	**ROM 075/12**	**FL200**	Turnaround/Overfly
6	36° 03' 35.73"	120° 23' 25.22"	Priest	**ROM 098/14**	**FL200**	Begin Descend to 17
7	35° 36' 31.31"	120° 01' 36.78"	Avenal	**AVE 214/3**	**17,000**	Begin Descend to 15
8 (CROWY)	34° 54' 54.00"	119° 28' 34.00"	CROWY	**CROWY**	**15,000**	Turn East
9	34° 47' 00.00"	118° 37' 00.00"	Lake Hughes	**LHS 330/06**	**15,000**	Begin Descend to 9
10 (GWF)	34°44'19.00"	118° 13' 0.00"	Wm J Fox NDB	**GWF**	**9,000**	(PMD 299/10)
11	34° 40' 00.00"	117° 36' 00.00"	Victorville	**VCV 282/11**	**9,000**	
12 (VCV)	34° 35' 39.00"	117° 23' 24.00"	Victorville VOR	**VCV**	**9,000**	
13 (APLES)	34° 32' 54.48"	117° 08' 58.14"	APLES	**APLES**	**9,000**	Turn North
14	34° 42' 20.35"	117° 05' 34.95"	Victorville	**VCV 054/16**	**9,000**	Turn W, Descend
15 (HELDE)	34° 42' 16.29"	117° 22' 57.18"	HELDE	**HELDE**	**6,000**	Turn S, Descend
16	34° 33' 43.03"	117°23' 00.88"	Victorville	**VCV 159/2**	**5,000**	Turn W, Climb to 6
17	34° 33' 47.96"	117° 25' 43.42"	Victorville	**VCV 215/3**	**6,000**	Turn N, Climb to 9
18 ~~(VEGAS)~~	34°51' 19.00"	117° 26' 03.00"	Victorville	**VCV 341/16**	**9,000**	Enter R2515

Sample NCC SCO Test Profile

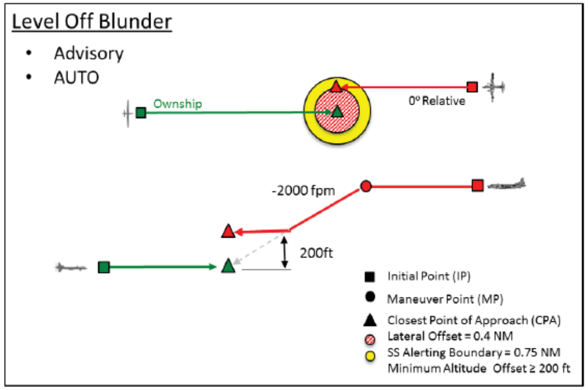


Figure 25. Intruder Level-Off Blunder.

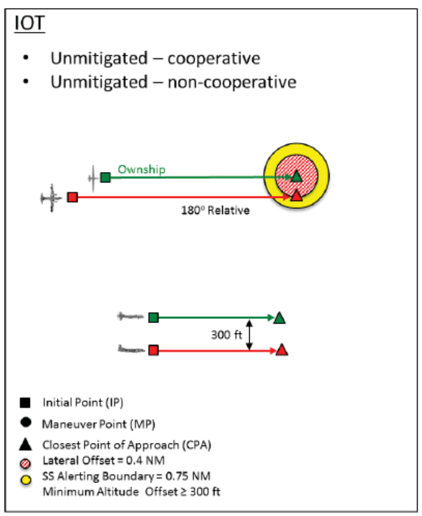


Figure 26. Overtaking Intruder. This encounter would be used to represent an encounter that may occur in the NAS due to the slower speed of Ikhana.

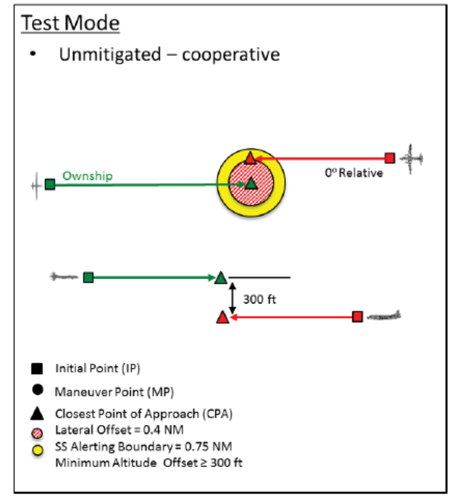


Figure 21. Test Mode Encounter. The DAA system test mode would be set to 253, which forced the system to drop fused targets.

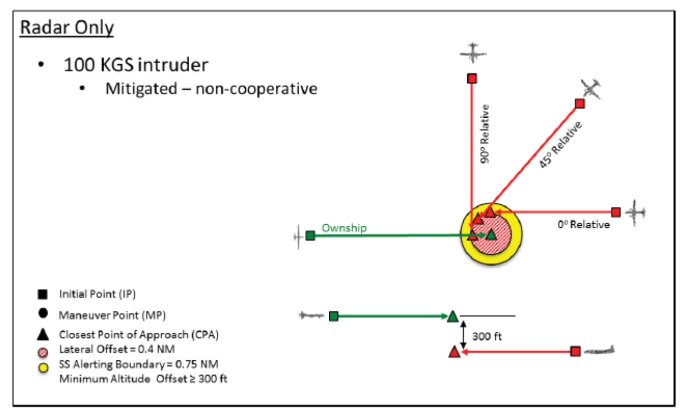


Figure 22. Radar Only Encounter. In order to simulate non-cooperative targets, the radar would be the only active sensor feeding the DAA algorithms. The intruder aircraft would turn their transponder off in this encounter.

Sample Dance Card

- Extra cards briefed
  - "Priority 3"

SOF – Steve Schmidt

2018-03-27 | No Chase COA (NCC) System Checkout | Version 3

SCO #3

Ikhana Crew	Comm:	Ops #	Intruder(s)	Intruder Crew
Jelly	123.225	Ikhana -4332-1	NASA 7	Frank Batteas
Hernan	121.95	NASA 7 -4332-2		Manny Antimisiaris

Card Count	Encounter	Priority	Configuration	Ownship Maneuver	Intruder(s)	Notes
X	Altimeter Calibration/Time Hack:				NASA7	
1	KU-1	1	Advisory / KU Only	*None*	NASA7	Build-down encounter
2	KU-2	1	Advisory / KU Only	CPDS	NASA7	
3	OTD-25	2	Advisory	CPDS	NASA7	
4	UC-2	1	Advisory	CPDS	NASA7	
5	IOT-17	2	Advisory	*None*	NASA7	
6	IOT-18	2	Advisory	CPDS	NASA7	
7	OOT-19	2	Advisory	CPDS	NASA7	expect alt swap
8	LT-20	2	Advisory	CPDS	NASA7	
9	LT-21	2	Advisory	CPDS	NASA7	
10	LOB-9	3	Advisory	Advisory	NASA7	
11	LOB-10	3	AUTO	TCAS - AUTO	NASA7	

*GCS-1 090B165 possibly runway 04 landing

MD

Lost Link Planning Example (NCC)

- Multiple routes depending on active route leg/direction

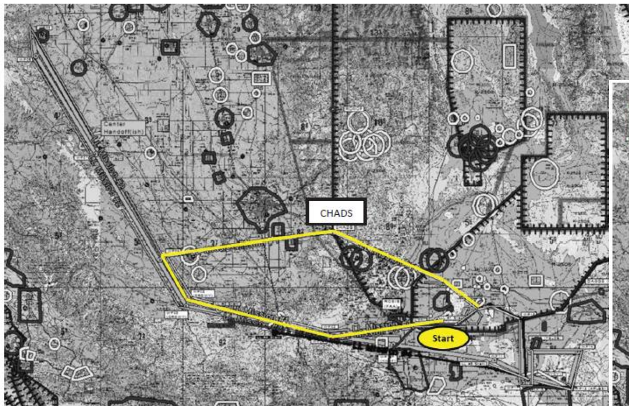


Figure 16. Lost Link Route 1.

Figure 17. Lost Link Route 2.

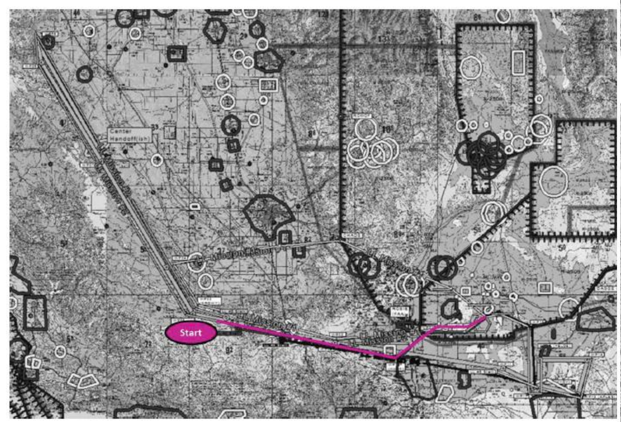


Figure 18. Lost Link Route 3.

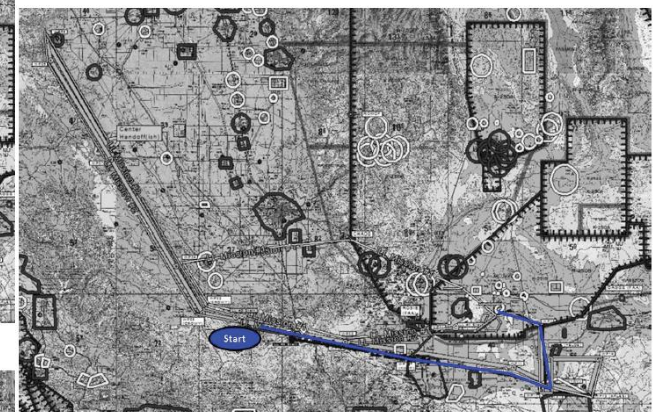


Figure 19. Lost Link Route 4.

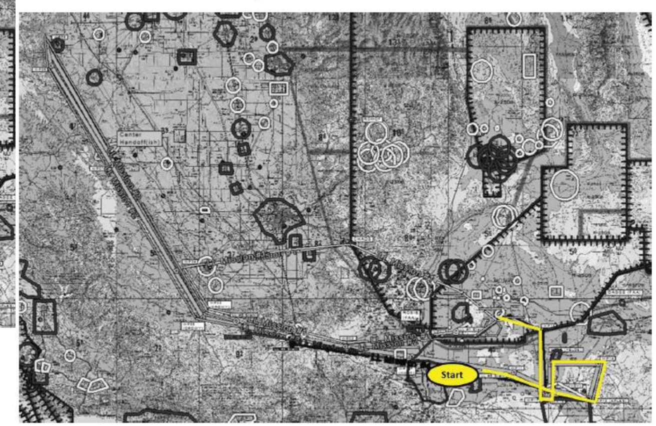


Figure 20. Lost Link Route 5.

Table 7. Summarized No Chase COA System Checkout Matrix.

2	3	4	7	9	11	13	15	16	21	22	23	24	25	27	28	29	30	031
PE Name/Type	Priority (1-high, 2-medium, 3-	Name	Leg Time (min)	Angle Into Int 1	Vertical Offset Int 1 (ft)	Lateral Offset INT1 (ft)	GS OWN	GS INT1	Altitude Regime	Ownship Initial Altitude	Ownship Vertical Velocity	Ownship Final Altitude	Ownship Abort Alt	Intruder 1 Initial Altitude	Intruder 1 Vertical Velocity	Intruder 1 Final Altitude	Intruder 1 Abort Alt	Intruder 1 Abort Hdng
High Speed	3	HS-11	2.0	0	500	0	180	300	<10K MSL	9000	0	9000	9000	8500	0	8500	8000	123
	3	HS-12	2.0	0	500	0	180	300	<10K MSL	9000	0	9000	9000	8500	0	8500	8000	123
Squawk Off	1	SQK-6	2.0	0	300	0	120	150	<10k MSL	9000	0	9000	9000	8700	0	8700	8000	348
	1	SQK-7	2.0	45	300	0	120	150	<10k MSL	9000	0	9000	9000	8700	0	8700	8000	258
	1	SQK-8	2.0	90	300	0	120	150	<10k MSL	9000	0	9000	9000	8700	0	8700	8000	213
Auto TCAS	3	ATCAS-22	1.0	0	300	2430	150	210	>10K MSL	21000	0	21000	21000	20700	0	20700	20000	123
	3	ATCAS-23	1.0	0	300	2430	150	210	>10K MSL	21000	0	21000	21000	20700	0	20700	20000	123
Test Mode	1	TM-1	2.0	0	300	0	160	180	>10k MSL	12000	0	12000	12000	11700	0	11700	11000	348
Use Case	1	UC-1-NOTUSED	2.0	0	200	0	150	180	>10k MSL	12000	0	12000	12000	11800	0	11800	11000	348
	1	UC-2	2.0	0	800	0	150	180	<10k MSL	9000	0	9000	9000	8200	0	8200	8000	348
	1	UC-4-NOTUSED	2.0	90	200	0	150	180	<10k MSL	9000	0	9000	9000	8800	0	8800	8000	348
	1	UC-5-NOTUSED	2.0	0	200	0	150	180	>10k MSL	12000	0	12000	12000	11800	0	11800	11000	348
Intruder Overtake	2	IOT-17	3.0	180	300	2430	160	180	>10K MSL	12000	0	12000	12000	11700	0	11700	11000	033
	2	IOT-18	3.0	180	300	2430	160	180	>10K MSL	12000	0	12000	12000	11700	0	11700	11000	033
Left Turn	2	LT-20	3.0	45	300	2430	160	180	>10k MSL	12000	0	12000	12000	12300	0	12300	13000	123
	2	LT-21	3.0	90	300	2430	160	180	>10k MSL	12000	0	12000	12000	12300	0	12300	13000	123
Ownship Overtake	2	OOT-19	3.0	180	300	2430	180	160	>10K MSL	12000	0	12000	12000	11700	0	11700	11000	123
High Descent Rate	2	HDR-16	3.0	0	500	2430	160	180	>10K MSL	10500	0	10500	10500	18000	-3000	11000	11500	123
Low Alt 3k AGL	1	LALT-24	3.0	0	200	2430	150	180	3000 AGL	6200	0	6200	6200	6000	0	6000	5200	348
	1	LALT-25	3.0	0	200	2430	150	180	3000 AGL	6200	0	6200	6200	6000	0	6000	5200	348
Double Blunder	2	DB-15	2.0	0	500	0	150	180	<10k MSL	7000	1000	9000	9000	12500	-1500	9500	10000	123
Level Off Blunder	3	LOB-9	2.0	0	200	0	150	180	>10k MSL	10000	0	10000	10000	12200	-2000	10200	11000	303
	3	LOB-10	2.0	0	500	0	150	180	>10k MSL	10000	0	10000	10000	12200	-2000	10200	11000	303
Ownship Turn & Descend	2	OTD-25	2.0	0	500	2430	150	180	<10k MSL	15000	-1000	13000	13000	12500	0	12500	12000	213
Nuisance	2	NUIS-13	2.0	0	1000	0	150	180	<10k MSL	9000	0	9000	9000	12000	-1500	10000	10000	123
	2	NUIS-14	2.0	0	500	0	150	180	<10k MSL	9000	0	9000	9000	12000	-1500	9500	10000	123

Training – Separation/Deconfliction (FT6 example)

Encounters: Ensuring Separation via Layers

- Altitude Separation
  - Scripted vertical separation
    - Side-by-Side altimeter calibration (required on sorties w/ <500' vertical sep)
- Horizontal Separation
  - Monitor GPS nav accuracy (Nav Quality); maintain GPS courseline IP to CPA;
  - Timing requirement at IP; Ground Speed requirement IP to CPA
- Visual – *surpasses other means (in close)*
  - Visually ensure deconfliction "end-game" if acquired
  - "Intruder" support aircraft: visually monitor setup; maintain visual/formation if required

- "Build-down" approach - start with simple / larger margins, such as…
  - ✓ Smoke Check and Altimeter Calibration
    - ✓ – start of each sortie; is "warmup" for formation, visual, & comm pacing
  - ✓ Straight-through non-maneuvering encounters
  - ✓ A limited number of geometries
  - ✓ >500' vert separation runs (visual not required)
  - ✓ UAS is non-maneuvering (racetrack)

- **Intruder pilot required to obtain visual by 0.4 nmi or abort (for closure of ~120 KGS)**
- **Intruder pilot required to obtain visual by 0.7 nmi or abort (for closure of ~230 KGS)**

Build-Down Philosophy

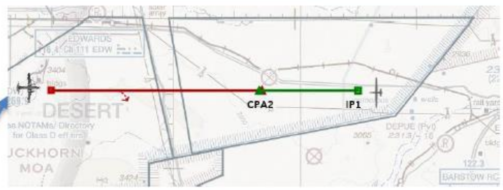
Build-Down Philosophy

To the extent possible, encounter order was designed with a "build-down" philosophy.

500 ft Sep

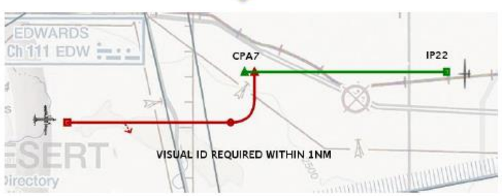
001-Am-S5H
004-Am-S5H
002-Am-S5H
005-Am-S5H
003-Am-S5H
006-Am-S5H

Example Only



Simple

Complex



Per Test Day:

- Encounters flown ≥500 ft vertical separation are considered to have 'standard separation' (NAS) and do not require a visual to execute
- Perform encounters with standard separation and transition to visual required encounters (500 ft, to 300 ft, to 200 ft)
- Perform "simple" geometries first
- Group together similar encounters
- Altitude blocks grouped together
- Encounters with same intruders grouped
- Advisory prior to auto maneuvers
- Once encounter type is cleared, continue through deck next day

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Test Execution Standards

- **All participating aircraft are expected to follow applicable test card instructions**
- **Test cards are designed to have a common format with unique components according to the role (ownship or intruder), specific tasks (display under test, encounter maneuvering, etc.), and other guidance**

General: Test Conductor will <u>actively</u> manage participants supporting the flight test

On Condition: Use normal piloting techniques and tools to arrive at the test encounter IP

- On course – As close as possible to planned route heading and zero cross track error
- On time – Within tolerance on the card (as req)
- On speed – Capture and maintain +/- 5 kts of planned airspeed (KGS)

When NOT ABLE to achieve start conditions:

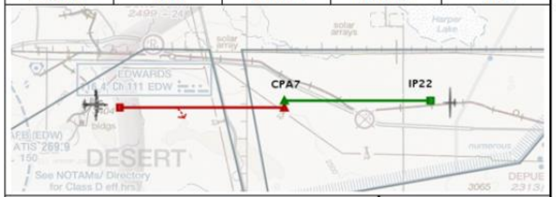
- Prior to run start inform TC if unable to make COMEX time. Expect ROLEX.
- REPORT and CONTINUE – Report the error (timing). Standby for instruction.
- Altitude/Airspeed/Track – Capture the planned condition if able. Report gross errors.
- TC will manage the encounter – Terminate or Reset, if required

Winds Aloft:

- Record actual wind data (heading and velocity) at the IP for every test encounter performed. Report over the radio if requested. Provide Wind data to TCOR in debrief.

Turns: Standard rate turns

NCC SCO	A/C: NASA870		High Descent Rate	
CARD#	HDR-16			OWNSHIP
INITIAL ALT	INITIAL SPEED	INITIAL WPT	RESPONSE	VID
10500	160	IPA22	None	NO



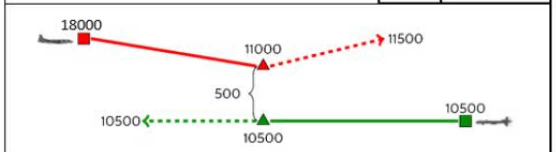
High Descent Rate (intruder) 3000fpm
Demonstrate representative NAS encounter

LOST LINK MISSION: TBD

DECONFLICTION ALT: 10500

ADS-B IN:	TBD	TBD	TBD
MANEUVER:	OFF	Advisory	AUTO

ABORT PROCEDURE: 10500 | NAV TO LL WPT



COMEX TIME: IP WIND:

WPT	LATITUDE	LONGITUDE	ALT / V/V	DIST / MC	KGS	LEG TIME
IP22	N34° 57.09'	W117° 17.86'	10500	8.0	160	3+00
	N34° 57' 05.4"	W117° 17' 51.6"	0	258		
CPA7	N34° 57.09'	W117° 27.62'	10500	0.0	160	
	N34° 57' 05.4"	W117° 27' 37.2"	0	258		

NOTES: Ownship maneuver. Follow CPDS Guidance.

Maneuver:	YES	NO	
Guidance:	NONE	CPDS	TCAS
Direction:	Down and/or lateral		
Limit:	NO CLIMB		

TOLERANCE: ± 8 sec ± 100 fpm

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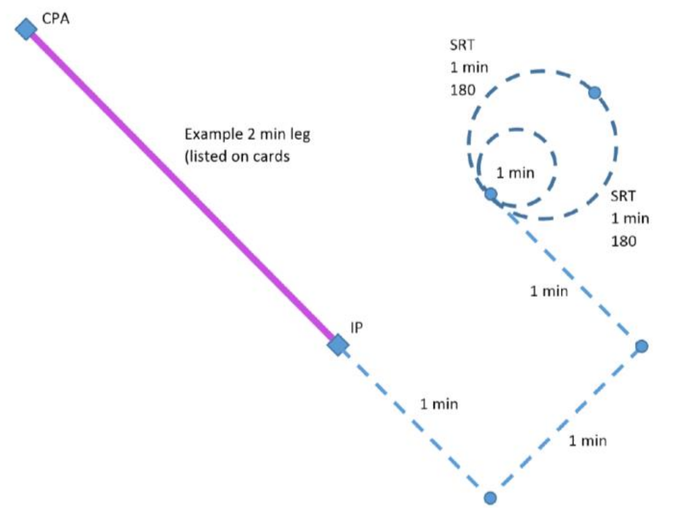
Timing Execution Training

Timing Diagram & Tools

* **Magenta line** = Wypts entered in Nav system
* **Dashed line** = crew timing estimation required

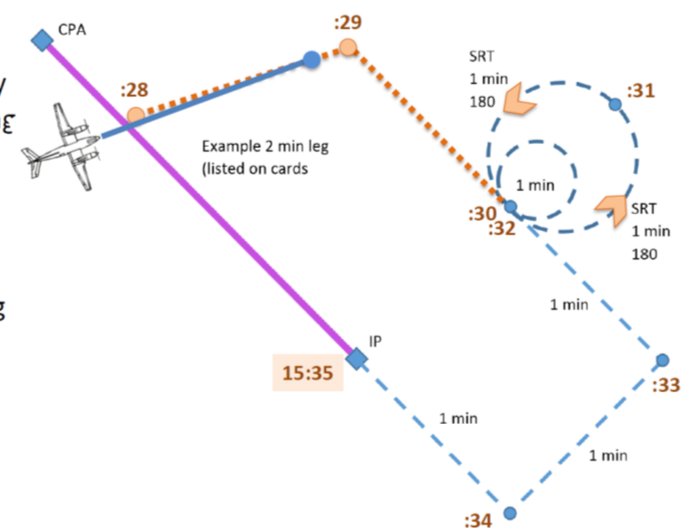
- Intruders:
  - GPS
  - Map tools
  - Clock/Watch
- Ikhana:
  - Tracker display
  - Falconview (MC)
  - UTC Clock

- Sample Problem…

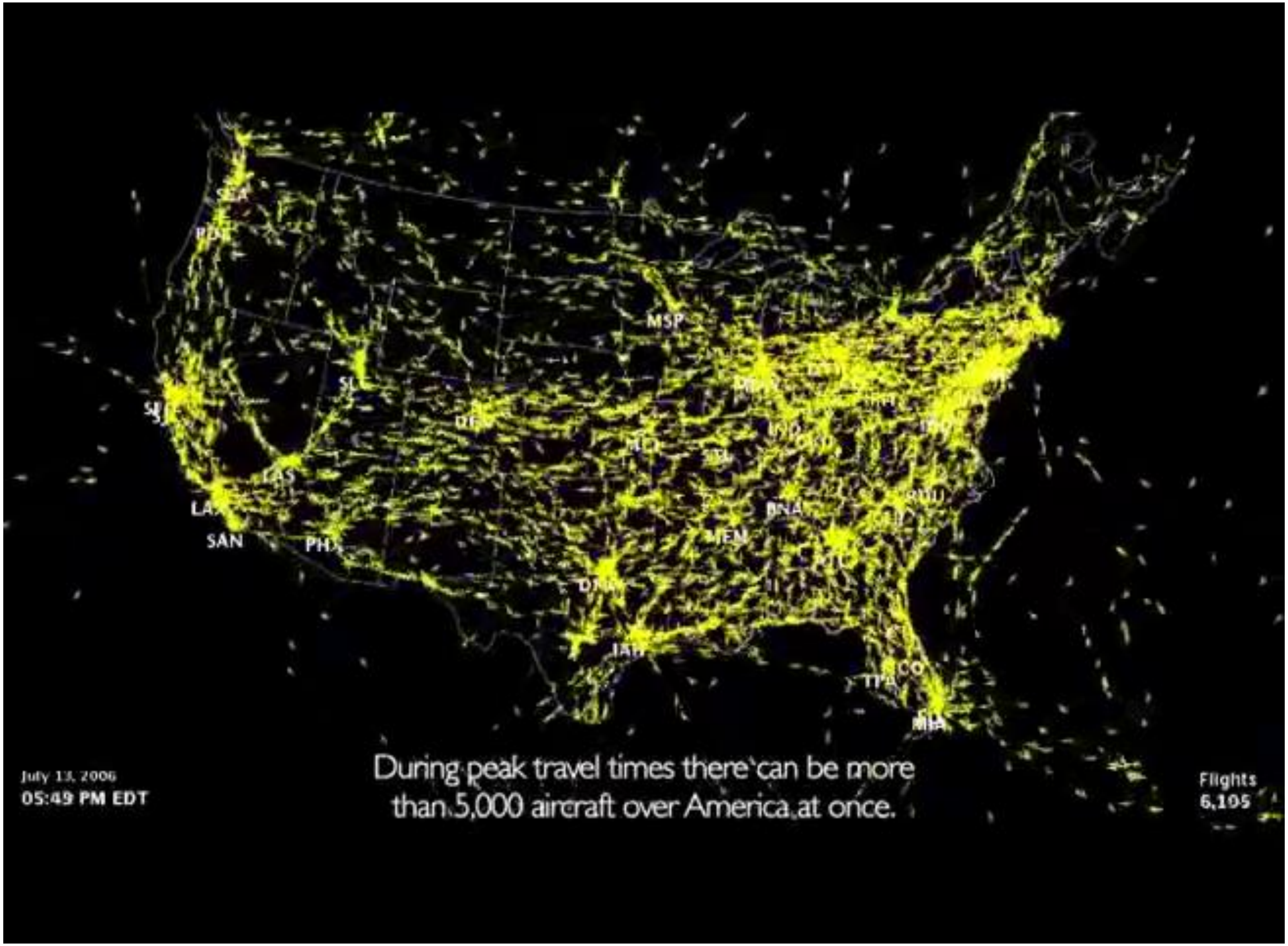


Example Timing Problem (Con't)

- (Time Now: 1527:45)
- Visualize/Adjust geometry to arrive at a known timing point on whole minute if able
- Work backward from IP (COMEX 1535) to determine timing, holding turns, extensions etc.



A Typical Day in America's Airspace



Resilient Autonomy Virtual Testing & Live Demos

- Autonomous vertical (AGL) path following; Auto-Ground Collision Avoidance System & Airborne Collisions Avoidance System (simulation testing)
- DoD Live Demo
- Alaska Bush Pilots Association Live Demo

Xplane Flight Sim; NASA autonomy resolver (HW & SW); Sim testing live over telecom; Hosted at Pilot's home desk.

Mission Timeline

- **Mission Events: 05-24-2018**
  - **0624L Ikhana Takeoff and climb to FL200 within R-2515**
  - **0654L Enter NAS Class A at Point Rosamond (WP01) FL200**
  - **0707L Brief DAA Corrective Alert on SWA462 (Southwest Airlines 737 descending out of FL350 to FL210)**
  - **0721L Check-in with ZOA-11**
  - **0735L Descent to 17,000 ft MSL**
  - **0736L Check-in with ZLA-15**
  - **0742L Start of descent to 15,000 ft MSL**
  - **0809L Start of descent to 9,000 ft MSL**
  - **0832L Start of descent to 6,000 ft MSL**
  - **0836L Start of descent to 5,000 ft MSL and cleared transit through KVCV Class D**
  - **0845L Entry into R-2515 9,000 ft MSL (WP18)**
  - **0900L Ikhana landing**

Brief DAA Corrective Alert
Southwest Airlines 462

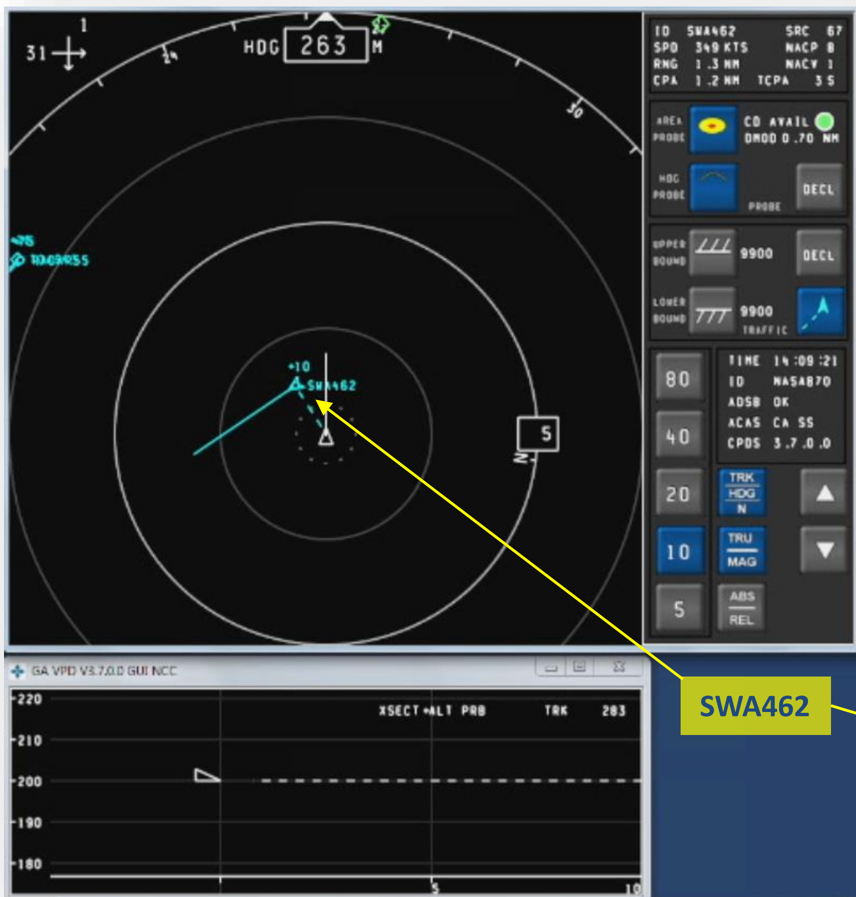
- Ikhana NASA 870 cruising at FL200
- 0707L, DAA corrective alert on SWA462 B737 descending out of FL310 to FL220 headed to Burbank. SW462 was 14.7 nmi away at time of alert
- SWA462 surveilled by ATAR and ADS-B with sensor fused target report. TCAS was using extended hybrid surveillance mode and was not actively interrogating
- DAA corrective alert cleared as SWA462 leveled off at FL220 11.7 nmi away

CPDS Traffic Display

Zeus Situation Awareness Display

Brief DAA Corrective Alert (con't)

Southwest Airlines 462



CPDS Traffic Display

- Subsequent descent and level-off at FL210 by SWA462 at 5 nmi triggered TCAS TA and "Traffic Traffic" alert (audio and head-up display)
- SWA462 surveilled by ATAR, ADS-B, and TCAS with sensor fused target report
- SWA462 CPA = 1.3 nmi with 1000 ft altitude separation

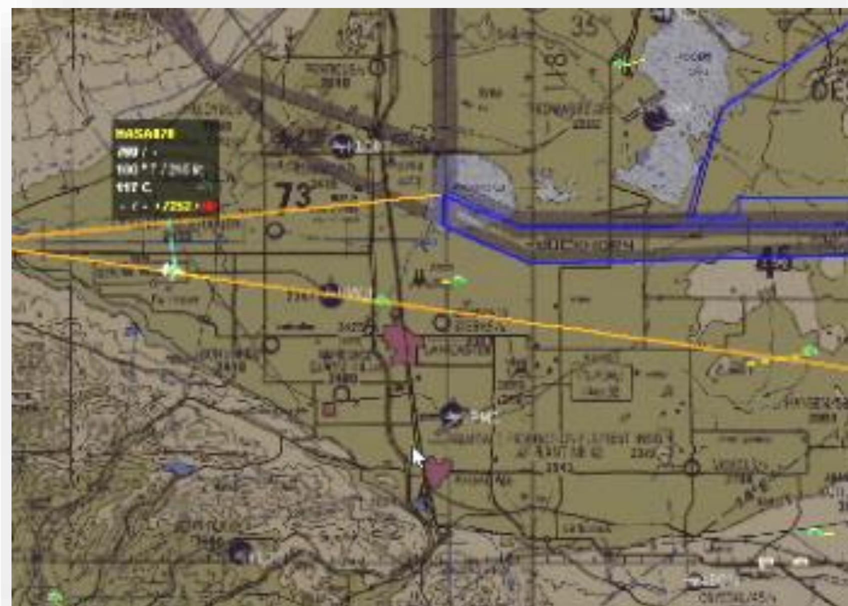
Zeus Situation Awareness Display

Traffic Enroute to KVCV

CPDS Traffic Display

Conflict space depicted on Vertical Profile Display of VFR traffic

- TCAS surveillance on VFR aircraft landing at Fox Field (8.7 nmi, 75 KGS, 2,300 ft MSL)
- TCAS surveillance on VFR aircraft at 12.3 nmi, 5,500 ft MSL later becoming sensor fused (TCAS and ATAR) surveillance (6.1 nmi, 5,500 ft MSL)



Zeus Situation Awareness Display

Traffic Around Apple Valley Airport

CPDS Traffic Display

- TCAS surveillance on VFR aircraft in the traffic pattern (3.2 - 4.8 nmi, 57- 60 KGS, 2,800 - 3,800 ft MSL)

Zeus Situation Awareness Display

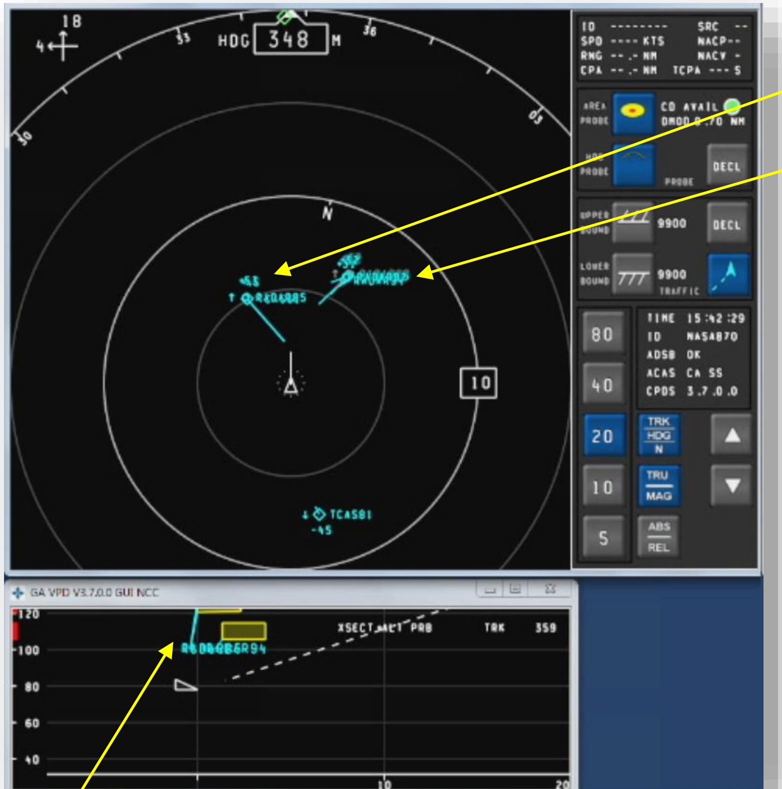
Traffic at KVCV

- Ikhana level at 5,000 ft MSL, inside the KVCV Class D
- TCAS surveillance on VFR aircraft in the traffic pattern (3.2 nmi, 59 KGS, 3,400 ft MSL and climbing at ~500 fpm)

CPDS Traffic Display

Zeus Situation Awareness Display

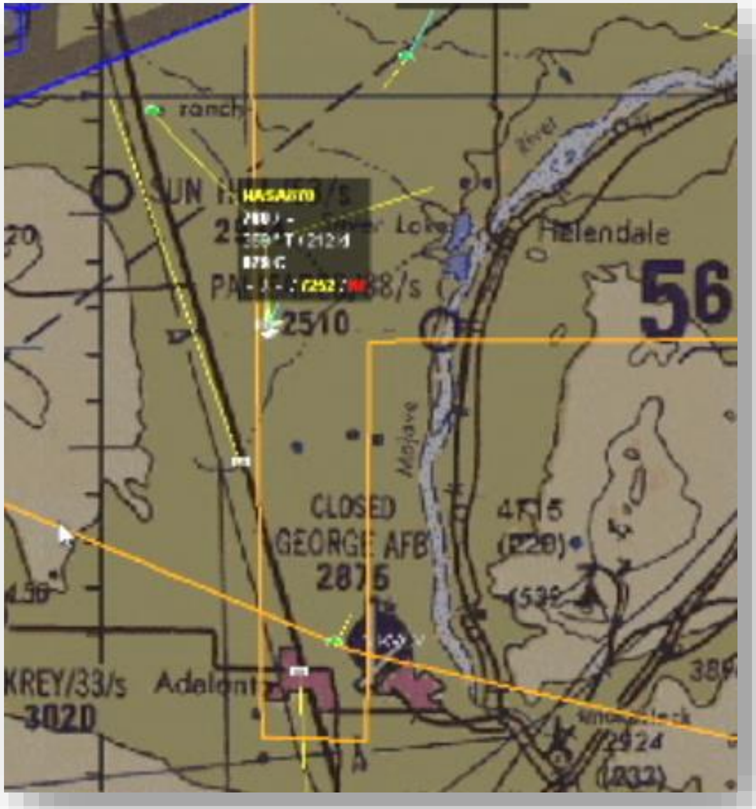
Traffic Enroute to R-2515



CPDS Traffic Display

Conflict space depicted on Vertical Profile Display of VFR traffic

- TCAS and ATAR surveillance on fast mover leaving R-2515 (5.1 nmi, 361 KGS, 12,400 ft MSL)
- Sensor Fused surveillance on MQ-9 orbiting south of R-2515 (6.5 nmi, 11,000 ft MSL)

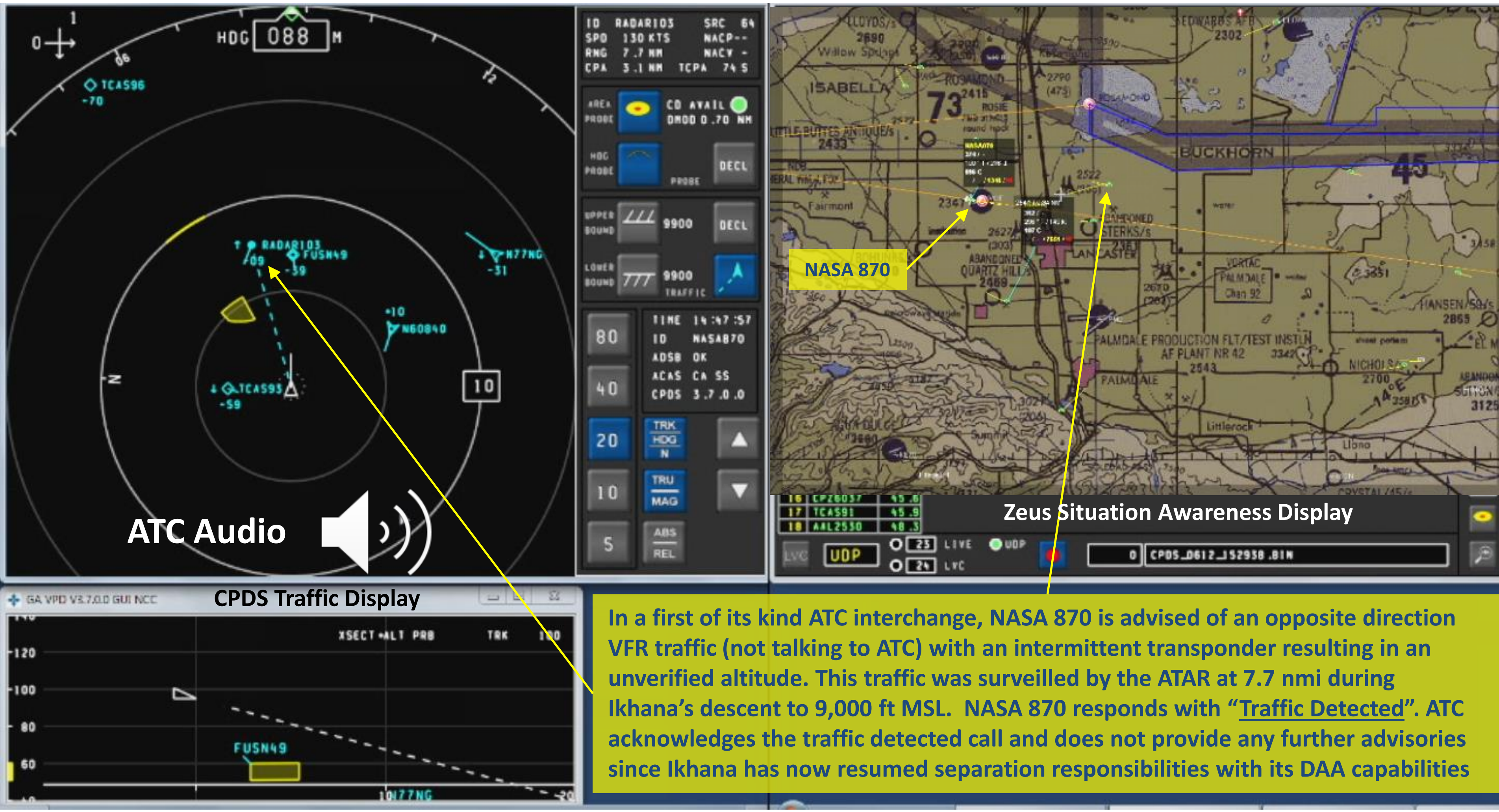


Zeus Situation Awareness Display

Mission Timeline

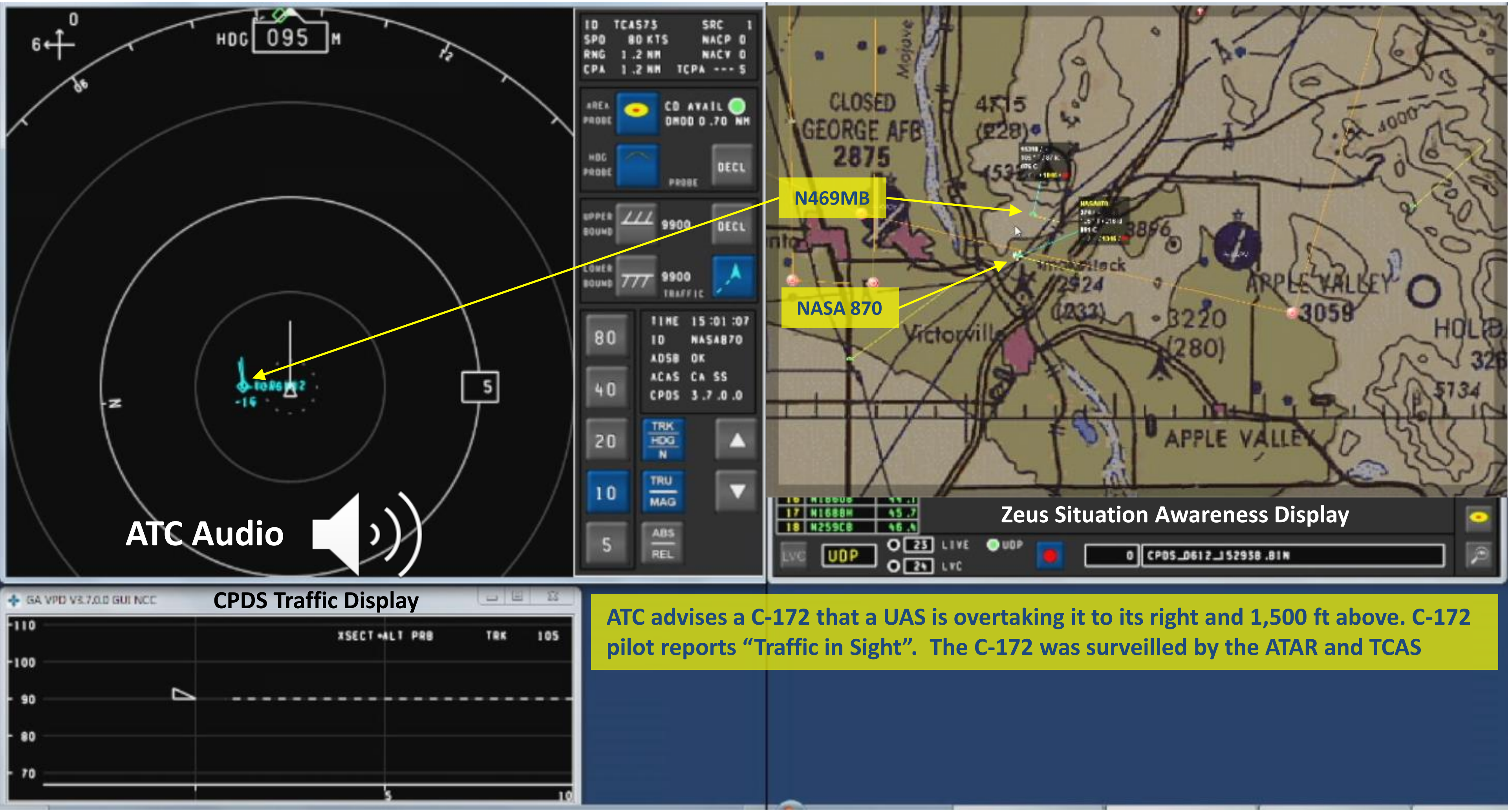
- **Mission Events: 06-12-2018**
  - **0604L** Ikhana Takeoff and climb to FL200 within R-2515
  - **0628L** Enter NAS Class A at Point Rosamond (WP01) FL200
  - **0659L** Check-in with ZOA-11
  - **0711L** Descent to 17,000 ft MSL
  - **0715L** Check-in with ZLA-15
  - **0718L** Start of descent to 15,000 ft MSL
  - **0743L** Start of descent to 9,000 ft MSL
  - **0747L** ATC interaction (first of its kind) where ATC provides traffic advisory on an opposite direction VFR traffic with an intermittent transponder and unverified altitude. Ikhana responds with "Traffic Detected" and ATC acknowledges. No further traffic advisories are provided on that VFR traffic since Ikhana has the traffic detected
  - **0801L** ATC/Pilot interaction where a C-172 is provided an advisory of a UAS overtaking it to the right and 1,500 ft above. C-172 pilot reports "Traffic in Sight"
  - **0806L** Start of descent to 6,000 ft MSL
  - **0810L** Start of descent to 5,000 ft MSL and cleared transit through KVCV Class D
  - **0818L** Entry into R-2515 9,000 ft MSL (WP18)
  - **0846L** Ikhana landing
- **Route of Flight outside R-2515:** 415 nm
- **Time outside of R-2515:** 1.8 hrs

ATC Interaction
"NASA 870, Traffic Detected"



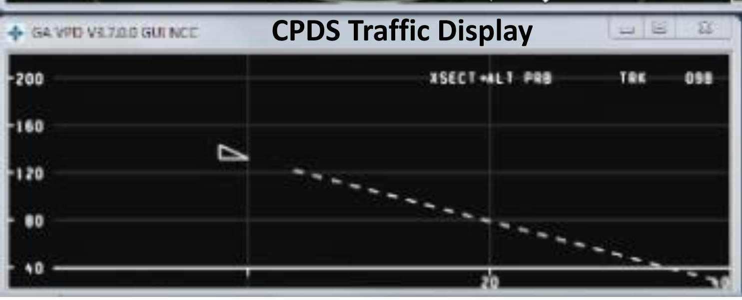
In a first of its kind ATC interchange, NASA 870 is advised of an opposite direction VFR traffic (not talking to ATC) with an intermittent transponder resulting in an unverified altitude. This traffic was surveilled by the ATAR at 7.7 nmi during Ikhana's descent to 9,000 ft MSL. NASA 870 responds with "Traffic Detected". ATC acknowledges the traffic detected call and does not provide any further advisories since Ikhana has now resumed separation responsibilities with its DAA capabilities

ATC Advisory to C-172 of Overtaking UAS (Ikhana) Traffic



ATC advises a C-172 that a UAS is overtaking it to its right and 1,500 ft above. C-172 pilot reports “Traffic in Sight”. The C-172 was surveilled by the ATAR and TCAS

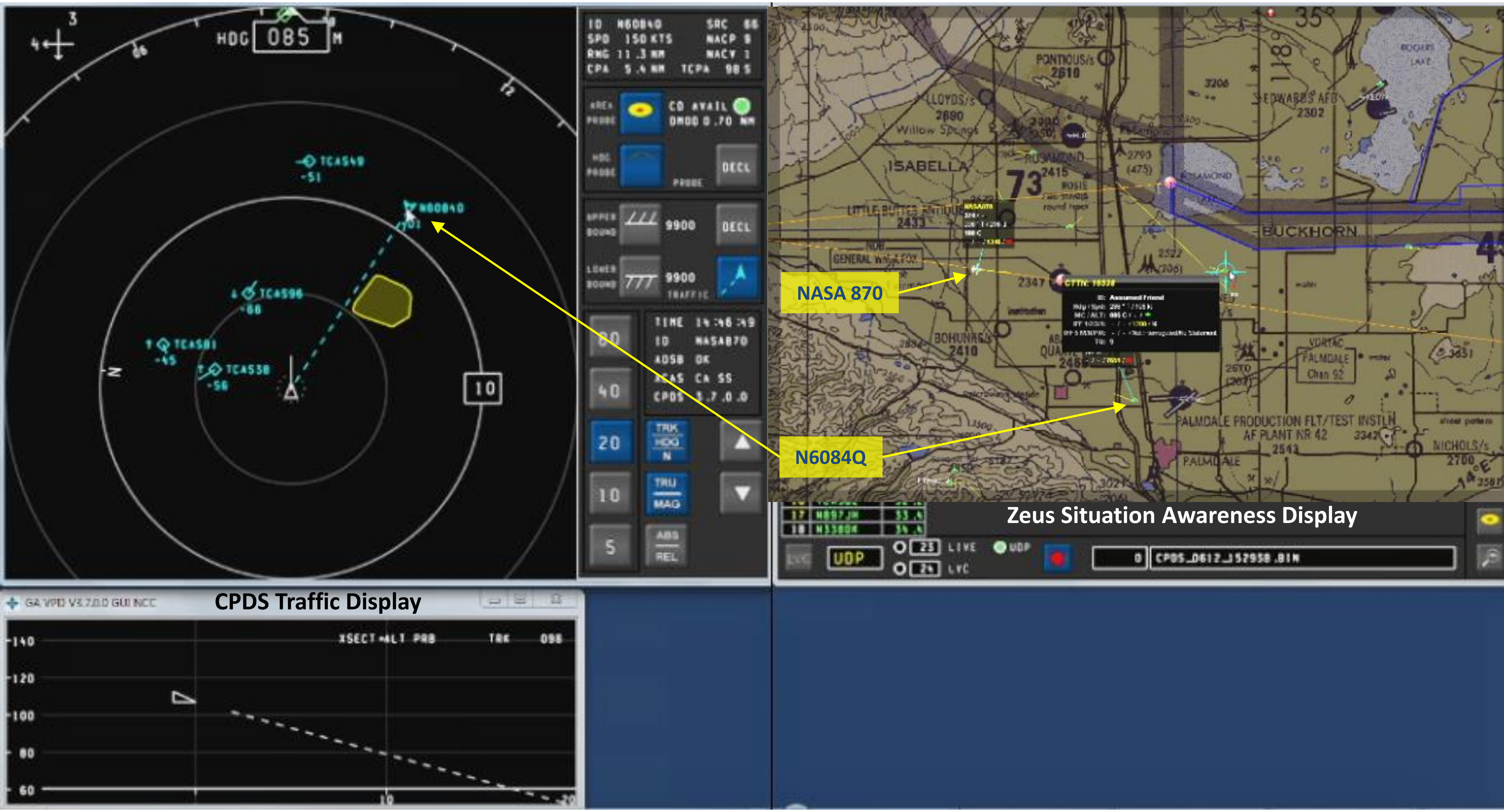
ATC Interaction
Mooney N6084Q



ATC is overly cautious and directs heading change to a Mooney that is over 25 nmi away of descending UAS traffic. Ikhana is descending to 9,000 ft MSL with the Mooney level at 10,500 ft MSL. The Mooney was surveilled by ATAR and ADS-B. TCAS was using extended hybrid surveillance mode and was not actively interrogating the Mooney

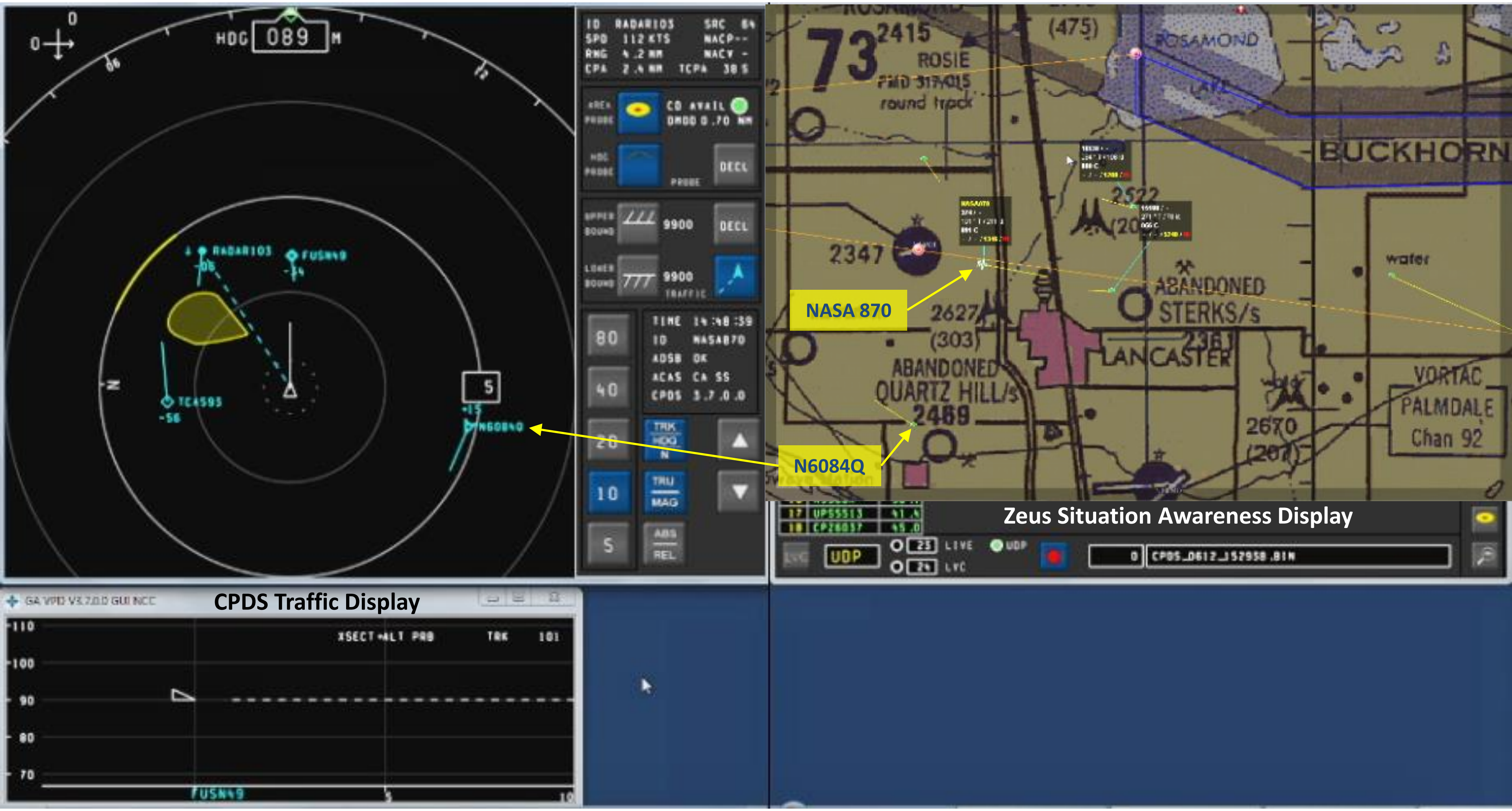
ATC Interaction (con't)

Mooney N6084Q



ATC Interaction (con't)

Mooney N6084Q



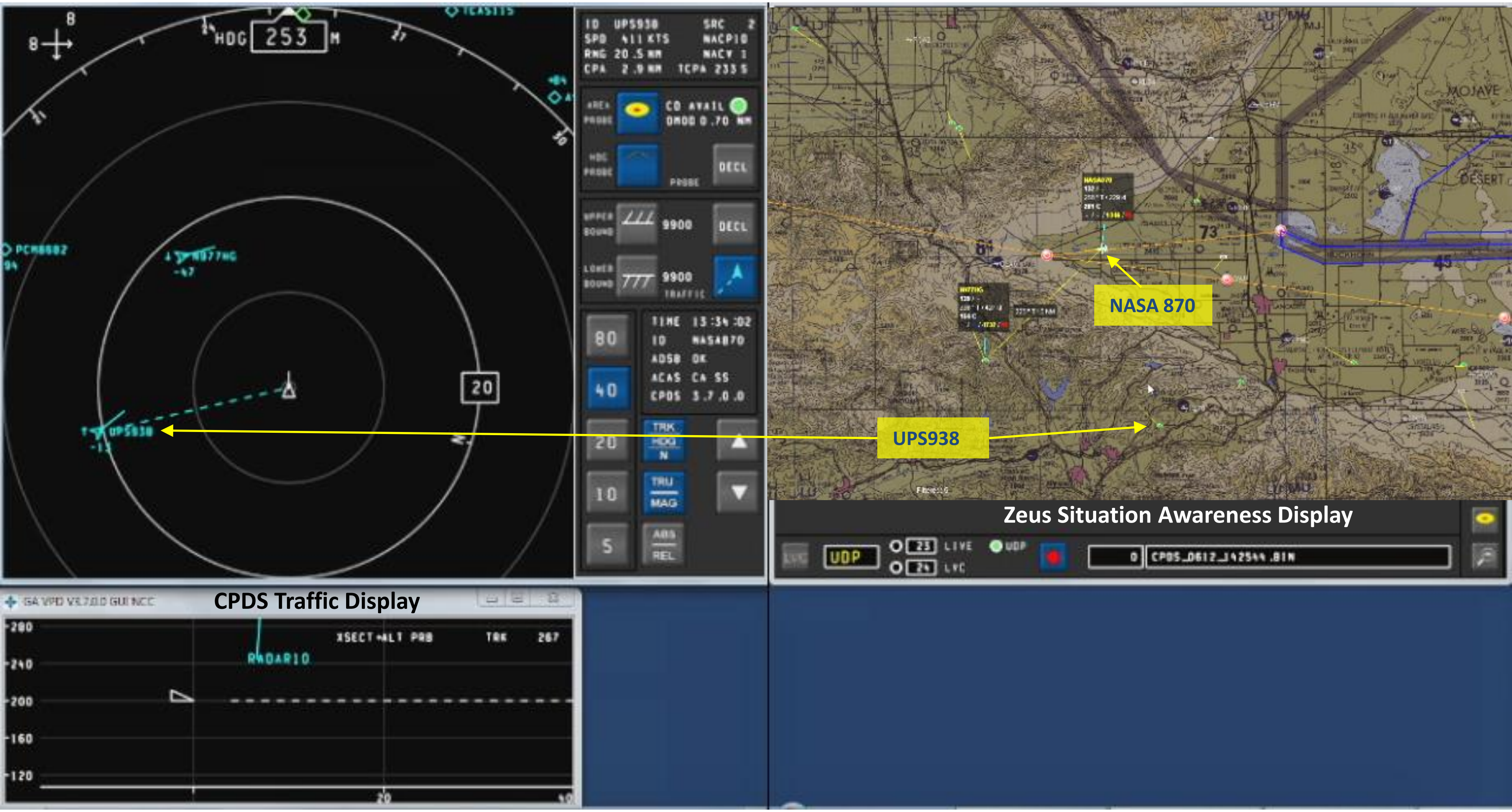
ATC Interaction

UPS938

ATC is overly cautious and directs a UPS B757 to climb at or above 1,500 fpm through FL210 for traffic (Ikhana). Ikhana is level at FL200. The UPS B757 was surveilled by ADS-B. Traffic was outside ATAR FOR and TCAS was using extended hybrid surveillance mode and was not actively interrogating the B757

ATC Interaction (con’t)

UPS938



ATC Interaction (con't)
UPS938