UAS in the NAS
Flight Test Series 4
Overview

UAS Integration in the NAS Project
Jim Murphy: Project Engineer, Integrated Test and Evaluation

12 May 2016
Flight Test Series 4 Goals

• Conduct flight tests in a relevant environment to contribute to the validation of the final Phase 1 DAA MOPS

• Develop and maintain the infrastructure for a relevant test environment for UAS research
Flight Test Series 4 Research Objectives

• Validate DAA requirements in stressing cases that drive MOPS requirements, including: High-speed cooperative intruder, Low-speed non-cooperative intruder, high vertical closure rate encounter, and Mode C only intruder (i.e., without ADS-B)

• Validate TCAS/DAA alerting and guidance interoperability concept in the presence of realistic sensor, tracking and navigational errors and in multiple-intruder encounters against both cooperative and non-cooperative intruders

• Validate 'Well Clear Recovery' guidance in the presence of realistic sensor, tracking and navigational errors
Flight Test Series 4 Test Environment

- Support validation of final phase 1 DAA and Radar MOPS
  - Sensor noise, uncertainty
  - Navigation system errors, state data uncertainty
  - Wind compensation
  - Support SC-228 V&V activities

- Refine DAA alerting and maneuver guidance algorithms
  - Stressing encounters
  - More complex multi-intruder encounters
  - TCAS/DAA interoperability
  - Well clear recovery
  - Mixed intruder equipage
271 encounters planned for FT4 – 20% increase from FT3

Each encounter takes approximately 10 min and planning to complete ~20 encounters per flight day
Integration Roles & Responsibilities Summary

**NASA – AFRC (UAS-NAS / IT&E)**
- Provide LVC-DE Infrastructure
- Provide Intruder Aircraft (T-34, G-III, TG-14, King Air)
- Provide Ownship Aircraft (Ikhana)
- Test Conductor Station (SAF)

**NASA – ARC (UAS-NAS / IT&E)**
- Provide HLA infrastructure
- RUMS Server
- Video Distribution to LaRC

**SC-228**
- Devise Encounter matrix

**Honeywell**
- Provide instrumented TCAS II equipped intruder aircraft
- Fusion Tracker
- Post Flight Processing
- Devise Encounter matrix

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

**NASA - LaRC (UAS-NAS / SSI)**
- Provide DAIDALUS DAA
- Devise Encounter matrix

**GA-ASI**
- Provide proof of concept DAA system (EDM DRR, SAAP, etc.)
- CPDS Display and IO Server
- Devise Encounter matrix
Flight Test 4 Milestones/Key Activities

Timeline Not To Scale

FY16

(11/13) ERT Decision to delete FT4 Full Mission
FT4 Requirements TIM (F2F Peer Review)
12/16-17

FT4 Design TIM (F2F-Peer Review)
2/3-4

NASA808 ADS-B Modifications

NASA808 DGPS Modifications
4/12 4/15

NASA801 DGPS Modifications
4/11 4/15

NASA856 ADS-B Modifications
4/11 4/21

Ikhana FT4 Modifications
12/7

Ground Integration Tests/V&V
2/8 2/25

Integrated LVC/Ikhana Ground Testing (CST)
2/29 3/7

ARC & AFRC JADEM Regression Testing
3/7 3/18

Flight Test Plan Complete
2/19

Tech Brief 4/1

System Checkout Flights / Env. Expansion Flights
4/4 4/15

Support Aircraft Airworthiness / Tech Brief
4/7

Test Data Review 4/19

Scripted Encounters Flight Test
4/26 6/30

- Development Activities
- Scripted Encounters Flight Block
- Intruder Aircraft Mods
- Review / Tech Brief
### Aircraft Required Systems
- ADS-B Out
- Mode C or S Transponder
- GPS
- DGPS w/ Recording
- VHF Comm Radio (x2)

### FT4 Participating Aircraft

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Role</th>
<th>EDM DRR</th>
<th>ADS-B</th>
<th>DGPS</th>
<th>TCAS-II</th>
<th>TCAS-I</th>
<th>Mode S</th>
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**Ownship – Ikhana only**  
**New Intruders – Low Speed/RCS, High Speed, Mode C only**
Aircraft Performance

“Low Speed” Intruder
- AFRC TG-14 (NASA 856)
- 100 KGS
- Small RCS (radar specific)
- Low altitude flights (5000ft-10000ft)

“Mid Speed” Intruder
- HW King Air (N3GC)
- AFRC T-34C (NASA 865)
- AFRC King Air (NASA 7 & NASA 801)
- Up to 250 KGS
- Medium RCS (radar specific)

“High Speed” Intruder
- AFRC G-III (NASA 808)
- Up to ~500 KTAS at 20k ft

T-34
- Up to 250 KGS
- Medium RCS (radar specific)

King Airs
- Up to ~280 KGS
- Large RCS (radar specific)
Airspace Planning

- Primarily Mercury Spin, 4 Corners & Buckhorn MOA (red outline)
- 1,000 ft AGL (4.2K ft) to 20K ft MSL
- Extensions (west / north) may be requested real time for encounters that need the additional airspace
- Ops outside of test area (blue shaded areas) are planned to be performed early (before 0800) when airspace is relatively empty
- Operations between 0600 and 0700 are under Joshua control and have less geographical constraints

Airspace Extensions (Blue Shaded Areas)
- Conducted early 0600-0800 preferably
- Pre-coordinated 24-48 hours in advance
- Requested real-time with SPORT (after 0700)

Ikhana must remain within R-2515 at all times. Intruder aircraft can use Buckhorn MOA, plus areas shaded in blue.
FT4: NASA DAA Suite: JADEM/VSCS

• Java Architecture for DAA Extensibility and Modeling (JADEM) software:
  • Subscribes to LVC GW for ownship and intruder flight state data (flight state message).
  • Subscribes to LVC GW for TCAS RA messages.
  • Contains DAA algorithm for conflict detection and resolution.
  • Contains DAA/TCAS interoperability logic.
  • Publishes DAA conflict resolution as heading bands and altitude tape keep out zones.
  • Publishes Well Clear Recovery (WCR) as suggestive guidance.

• Vigilant Spirit Control Station (VSCS) software:
  • Developed by AFRL as an integrated ground control station for command and control of UAS.
  • VSCS Tactical Situation Display (TSD) augmented by AFRL with DAA display elements to support NASA Human Systems Integration (HSI) objectives.
  • VSCS TSD serves as the Cockpit Display for Traffic Information (CDTI) for SSI-West experiment.
  • VSCS TSD displays DAA and WCR guidance produced by JADEM.
  • VSCS TSD displays TCAS RA aural and visual alerts.
FT4: NASA DAA Suite: DAIDALUS/MACS

• **DAIDALUS:**
  - Subscribes to LVC GW for ownship and intruder flight state data (flight state message).
  - Subscribes to LVC GW for TCAS RA messages.
  - Contains DAA algorithm for conflict detection and resolution.
  - Contains DAA/TCAS interoperability logic.
  - Provides DAA avoidance and recovery bands.
  - Provides WCR band.

• **MACS:**
  - Adapted for use as a DAA test bed.
  - Displays DAA guidance from DAIDALUS on generic HSI, VSI, and altitude instruments.
  - VSI DAA bands replaced by TCAS guidance during RAs.
  - Displays WCR band.
FT4: GA-ASI CPDS

**CPDS:**

- Receives ownership and surveillance tracks from the SAAP.
- Displays Ownship and Surveillance track data on the CDTI display and VPD.
- Processes surveillance tracks through its DAA algorithm to create conflict probes displayed on CDTI and VPD.
- Provides engineering display (Winconverter) with additional data on ownship and intruder.
- Bridge module provides option to select adding UTC offset to the received A735B with readout to verify offset.
- Bridge module includes fractional seconds in the time put in to the GA_CPDS traffic topic. Allowing IOServer to forward time.
- Winconverter proxy panel to suppress certain data to CPDS domain.
- Winconverter capability to send DAA alerts to HUD (if connected to flight network).
- CDTI added North-up option.
FT4 leverages off a core system infrastructure used for ACAS-Xu and FT3 test missions. Major changes to FT4 occur at the software level.
Encounter Planning Process

**Encounter Set**
All encounters with same variables

**Configuration**
Geometries / Equipment

**Test Objectives**
Primary TOs

**Success Criteria**
What determines success in flight

**Test Methods**
Procedures to achieve success criteria

**Evaluation Criteria**
Post-flight analysis / data collection

**Researcher Evaluation**
Using local constraints (E.g., Lat/Long)
Simulate/Evaluate
- Mission success / original intent
- Expected results

**Initial Requirements**

**OWG & SSWG**
Safety compliance
- Specified maneuvers
- Required safety constraints
- Update hazards

Mission Success
- Test Objective Table
- Training material
- Simulation Video (as applicable)
Measurable and Achievable

**Specific SUT Working Group**
Ensure requirements are fully understood
Review encounter variables
- Test objective Tables
- Flight Cards
Ensure compliance with constraints and limitations

Derived from AFTC Test Planning Guide
Encounter Tolerance Development

ACAS Xu

- Probabilistic approach 99.7%
- Min offsets:
  - 200' vertical
  - 0.5 nmi lateral
  - ±5, 8, 10 sec
- Altimeter & navigation calibration
- Mission Rules

FT3

- Deterministic approach
  - Leveraged off of ACAS Xu
- Min offsets:
  - 200’ vertical
  - 0.5 nmi lateral
  - ±5, 8, 10 sec
- Altimeter calibration
- Mission Rules

FT4

- Deterministic approach
  - Leveraged off of FT3
- Min offsets:
  - 200’ vertical
  - 0.4 nmi lateral
  - ±5, 8, 10 sec (DAA Real Time)
- Altimeter calibration
- Mission Rules

Decreased to 0.4 nm horizontal separation. Required to achieve TCAS alerting below 10K

ACAS – FT3

- High Confidence with ACAS-Xu offsets
- Mission Success criteria closely approximated ACAS-Xu
- Nav/Cal- not measureable, no added value or increase safety margins

FT3 – FT4

- High Confidence with previous test planning criteria
- Decrease from 0.5 to 0.4 nm horizontal offset for mission success and;
  - Engineering & crew judgment – min acceptable levels of safety are maintained
Ikhana FT-4 Mission Flights

- **15 Flights Planned**
  - Tuesdays and Thursdays, late April through June
- **Up to 6.5 hour flights planned**
- **Single and Multiple Intruders**
  - 1, 2, or 4 manned aircraft
    - Honeywell, NASA AFRC, and/or AF aircraft
- **Objectives**
  - Using various geometries, closing airspeeds, and altitudes
    - Demonstrate FT-4 system performance
      - Within approved FT-4 test envelope
    - Demonstrate various Self-Separation display systems
      - GA-ASI: Conflict Prediction and Display System (CPDS)
      - NASA: JADEM and DAIDALUS
Multiship (7) Four Intruders

- Mixed speeds
  - Unmitigated

New for FT4
- 4 intruders, but simple fly-through encounter
Medium Speed Intruder (4)

Ownship Maneuver and Climb

- Mitigated

Intruder Blunder and Level Off

- Unmitigated

New for FT4
-Ikhana turning and climbing

Same encounter variables as FT3

Initial Point (IP)
- Maneuver Point (MP)
- Closest Point of Approach (CPA)
- Lateral Offset = 0.4 NM
- SS Alerting Boundary = 0.75 NM
- Minimum Altitude Offset ≥ 500 ft
Single Intruder Test Card

**FT4 DAA Scripted**
- A/C: NASA 870
- S/N: 001
- VERSION 4

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<th>OWNSHIP</th>
<th>LOST LINK MISSION: TBD</th>
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**DISPLAY:**
- JDAM
- DADA
- CPDS

**MANEUVER:**
- OFF
- Advisory
- AUTO

**SENSOR SELECT:**
- Tracker
- Radar
- ADS-B
- TCAS

**ABORT PROCEDURE:**
- 15500 MAINTAIN HEADING

**COMEX TIME:**
- WPT
  - LATITUDE
  - LONGITUDE
  - ALT V/V
  - DIST MC
  - KGS
  - LEG TIME

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<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>ALT V/V</th>
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**NOTES:**
- Ownership maneuver. Follow JDAM Guidance.
- TOLERANCE: ± 8 sec ± 5 kts

**DECONFLICTION ALT:**
- 14500

**IP WIND:**
- WPT
  - LATITUDE
  - LONGITUDE
  - ALT V/V
  - DIST MC
  - KGS
  - LEG TIME

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**NOTES:**
- Expect Ownship maneuver.
- TOLERANCE: ± 8 sec ± 5 kts

**ABORT PROCEDURE:**
- 14500
- 123
Multiship Intruder Test Card (1)

### CARD# 047-Am-M3M

**OWNSHIP**

1. TC announces COMEX time.
2. Announce "<Callsign>, IP inbound, altitude & special procedure review" crossing IP.
3. On condition at IP.
4. TC calls "terminate" when run complete.
5. TC announces next Card Number.

**DISPLAY:**
- IADEM
- DAIDA
- CPDS

**MANEUVER:**
- OFF
- Advisory
- AUTO

**SENSOR SELECT:**
- Tracker
- Radar
- ADS-B
- TCAS

**COMEX TIME:**

<table>
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<tr>
<th>WPT</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
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**NOTES:**

**TOLERANCE:** ± 8 sec ± 5 kts

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**INTRUDER 1**

**LOST LINK MISSION:** TBD

**DECONFLICT ALT:** 11000

**ABORT PROCEDURE**

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**ABORT PROCEDURE**

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**COMEX TIME:**

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**NOTES:** Expect Ownship maneuver.

**TOLERANCE:** ± 8 sec ± 5 kts

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FT4 DAA Scripted | A/C: N3GC | S/N: 47 | VERSION 4

FT4 DAA Scripted | A/C: N3GC | S/N: 47 | VERSION 4
Multiship Intruder Test Card (2)

**FT4 DAA Scripted**

**A/C:** NASA 856  
**S/N:** 47  
**VERSION 4**

**CARD#** 047-Am-M3M  
**INTRUDER 2**

1. TC announces COMEX time.
2. Announce “<Callsign>, IP Inbound, altitude & special procedure review” crossing IP.
3. On condition at IP.
4. TC calls “terminate” when run complete.
5. TC announces next Card Number.

**DECONFLICTION ALT:** 10000

**ABORT PROCEDURE**

9000  
033

**COMEX TIME:**

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**NOTES:** Expect Ownship maneuver.

**TOLERANCE:** ± 8 sec  ± 5 kts
Minimum Separation

• The minimum geospatial offsets planned are 200 feet vertical and 0 foot horizontal (although not simultaneously during any test run)

• Test encounters with a minimum vertical separation of less than 500 feet will include a lateral offset of at least 2430 feet (0.4 nmi)
  – Allows for some built-in safety margin that still meets well-clear volume requirements and test data collection objectives

• Test encounters more than or equal to 500 feet vertical offset may have a 0 foot horizontal offset.

• All participating aircraft will ensure the aircraft altimeter system meets manufacturer calibration specifications and requirements for normal operation in the NAS.

• A maximum of 608 feet (0.1 nmi) navigation error (GPS derived position) is allowed for each aircraft based on the system’s built-in navigation accuracy readout.
Ikhana FT-4 Nominal Encounter Mission Flow

- **T-1: Day before detailed brief**
  - Protect crew rest for back-to-back flights possible if back up dates are utilized
- **T-0 All: All crew pre-flight delta brief**
- **T-0 Ikhana: Individual aircraft crew brief, as required**
- Each aircraft take-off to arrive within R2515 at required time
  - 0600 ish for Ikhana
- Ikhana and manned aircraft perform altitude calibration, as required
- Prior to each encounter verify encounter, configuration, visual ID requirement, expected behavior, and abort procedures per UAS-NAS encounter cards and Ikhana flight cards
• Execute Encounter

• Between Encounters
  – Maneuver Mode: Advisory/Off
  – Maintain previous encounter deconfliction altitude until laterally separated and as directed by TD for upcoming encounter
  – Configure for next encounter set up

• Execute additional encounters per flight cards

• RTB, as appropriate

• Land

• De-brief
FT4 Mission Management Responsibilities

• **Test Conductor**
  – Manages mission execution over voice communication on mission net (VHF radio) with Ikhana pilot, intruder pilots, and SPORT

• **Test Director**
  – Primary liaison with test conductor
  – Manages voice communication on test team net with Ikhana mission director, SOR, LVC, local agencies, and non-local agencies (as required)

• **Mission Directors**
  – Communicates directly with co-located pilots within GCS, test director, and other agencies (as required)

• **LVC**
  – Communicates with test director on test team net to provide real-time discussions on live virtual constructive performance (as required)

• **Senior Operations Representative (SOR)**
  – Independent representative of the Code O director with authority to stop a test if it is deemed that the test team is making unauthorized changes to the briefed test cards, is confronted with unanticipated events that should be addressed on the ground, or other issues that might arise that warrant a test to be stopped and reevaluated in a less dynamic environment than in the middle of a test mission

• **Range Control Officer**
  – RCO monitors and makes coordination calls with Armstrong COMM and the SAF DATR mission system ops folks (as required)
Zeus
• Thales ADS-B receiver integrated

Quicklook 2
• MITLL product in development
• Operates using a stand alone computer
• May be installed prior to FT4
• Will not be used as a SA display for FT4
Ikhana UAS Communication – FT-4 Flights

IGLOO GCS (See Seating Arrangement Slide)
• DAA Display’s are located to the left of PPO-1 Station
• HUD will display TCAS alerting. HDD’s display TCAS WCA
• When specifically configured HUD will display DAA and TCAS alerting (Only 1 flight)
• Aural Alerts (Commands and Tone)
  - GCS will annunciate a TCAS alert tone
  - JADEM SUT will annunciate a TCAS alert commands
## FT4 Displays Under Test

(Pilot/User centric)

<table>
<thead>
<tr>
<th>DAA Alerts (VSCS)</th>
<th>DAA Alerts (VSCS / DAIDALUS Display)</th>
<th>DAA Alerts</th>
<th>TCAS Alerting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heading Bands</strong></td>
<td><strong>Heading Bands</strong></td>
<td><strong>Descriptive</strong></td>
<td><strong>Directive</strong></td>
</tr>
<tr>
<td>“Turn Heading ###”</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### FT3 Capabilities

- Lateral & Vertical
- Vertical
- GCS Tone

### FT4 Similarities

- Lateral & Vertical
- Vertical
- GCS Alerts

### FT4 Differences

- Aural Alerts (May be muted)
- DAA alerts displayed on HUD for 1 flight.

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**GA System**

**JADEM**

- DAA Alerts (VSCS)
- Heading Bands
- “Turn Heading ###”

**DAIDALUS**

- DAA Alerts (VSCS / DAIDALUS Display)
- Heading Bands

**CPDS**

- DAA Alerts
- TCAS Alerting
- Lateral & Vertical
- Vertical

**HUD**

- DAA Alerts
- TCAS Alerting
- Vertical
- GCS Alerts

### Additional commands available

- Descriptive
- Directive

---

**FT4 Displays Under Test**

(Pilot/User centric)

- GA System
- JADEM
- DAIDALUS
- CPDS
- HUD
Winconverter with DCPA* plot enabled

*DCPA: Distance at Closest Point of Approach
Configuration: RUMS

ARC

- RUMS client (Internet Browser)
- RUMS messaging
- Traffic
- Ownership
- DAA Alerts
- WCR
- TCAS RA

RUMS Server uasgw2

AFRC

- RUMS client (Internet Browser)
- RUMS messaging

LVC GW gateway4

VPN

Flight Data
- DAA, TCAS RA
- RUMS messaging
- Web client/server
Configuration: Video Streaming

LaRC

RTP video client (IP Address)

VPN

VSCS video stream

DAIDALUS video stream

ARC

Epiphan Appliance

Video client (Internet Browser)

Video Server

VIDS uasvsvr

VSCS Stream

DAIDALUS Stream

DAIDALUS Stream

VSCS Stream

AFPAC

DAIDALUS Computer

Epiphan Appliance

Monitor

VSCS Stream

DAIDALUS Stream

Epiphan Appliance

Monitor

AFRC
Data Collection Archiving

Reference: Flight Test Series 4 Data Management Plan, FT4 IT&E DMP-001
Flight Test 4 Flight Schedule

- Seeking approval from Tech Brief Board to fly FT4 Flight Test Series using current available integrated and tested version of LaRC provided DAIDALUS software.

<table>
<thead>
<tr>
<th>FT4 Plan A (Baseline Version of DAIDALUS only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
</tr>
<tr>
<td>4-8</td>
</tr>
<tr>
<td>Sys Check Flts</td>
</tr>
</tbody>
</table>

- LaRC working to update DAIDALUS software (final version) to be able to flight test with final version.
- Project approach:
  - Software needs to be delivered by 5/23 in order to meet FT4 completion milestone (L1) of 6/30/16.
  - 2-3 weeks of regression testing
  - Mini-tech updates
  - Complete DAIDALUS flights at the end of June
Backup Charts
During the FT3 Data Review, the IT&E co-PE from Ames identified a timing discrepancy in the ownship 1 Hz message containing position data (latitude, longitude) from Ikhana when compared to:

- 10 Hz & 50 Hz ownship messages on Ikhana
- Independent GPS data from Ikhana

Graphs from Jim Murphy presentation ‘FT3_data_analysis_v7.pptx’
Representation of Timing Discrepancy

Range perceived by DAA Algorithm

Actual range

- Intruder position at ~90 seconds
- Intruder extrapolated to this position by the DAA algorithm since it’s using the DTIF ownship time as reference: ~(90 - ~2 Seconds)

Timeline 90 Seconds (Corrective Self Separation Alert)

- Ownship position at T₀
- DTIF reports this position with time T₀ - ~2 seconds

0.5 nmi Actual range

- Range perceived by DAA Algorithm
Data Collection Archiving

Reference: Flight Test Series 4 Data Management Plan, FT4 IT&E DMP-001
Data Collection Archiving

AFRC LVC

Honeywell

DAPTIV

Encrypted file transfer through https protocol

Quad Video

Intruder On-Board

DGPS

Ikhana On-Board

SAAP

DGPS

Reference: Flight Test Series 4 Data Management Plan, FT4 IT&E DMP-001