Operational Overview for Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project Flight Test Test Series 3

Steffi Valkov

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What is UAS-NAS?

• Increased urgency in the desire and ability to fly Unmanned Aerial Systems (UAS) in the National Airspace System (NAS)
  – National security
  – Defense
  – Scientific
  – Emergency management

• NASA project: “UAS Integration in the NAS”
  – Conducting research in the areas of:
    • Self Separation/Sense and Avoid Interoperability
    • Human Systems Integration (HSI)
    • Communication
  – Human-in-the-loop testing
  – Integrated flight-test activities

• Supporting the development of regulations governing the routine access of UAS to the NAS
Flight Test Series 3 (FT3)

• Flight Test Series 3 (FT3)
  – Integrated flight test part of the UAS-NAS campaign

• Goals of FT3 included development and evaluation of:
  1. Sense and Avoid (Detect and Avoid (DAA)) guidance algorithms in an end to end traffic encounter
     • Aircraft sensor to wind
     • TCAS II
     • Latency uncertainties to a Ground Control Station (GCS) display
  2. Prototype communication system
  3. Data collection to inform the preliminary draft of Minimum Operational Performance Standards (MOPS)
     • DAA
     • Command and Control (C2)
  4. Increased team’s capabilities and reduced risks to follow-on flight tests such as Flight Test 4 (FT4) and beyond.

• Two parts:
  – Configuration 1
  – Configuration 2
## FT3 Stakeholders

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>DAA Algorithm or SUT</th>
<th>Aircraft</th>
<th>Additional Information</th>
</tr>
</thead>
</table>
| NASA Ames Research Center (ARC)                   | • JADEM DAA Algorithm  
• CFG1: JADEM encounters  
• CFG2: HSI requirements  
• CFG2: “Virtual ATC”                            |                                                                          |                                          |
| NASA Armstrong Flight Research Center (AFRC)      | • Host of Live Virtual Constructive (LVC) – data distribution between ARC, GRC, and LaRC  
• CFG2: RGCS                                    | • CFG1: NASA870 “Ikhana”  
• CFG1 and CFG2: Intruder(s)                       | • Responsible test organization                              |
| NASA Glenn Research Center (GRC)                 | • CFG2: CNPC                                                                       | • CFG1: S-3B high-speed ownship (cancelled)                             |                                          |
| NASA Langley Research Center (LaRC)              | • Stratway+ DAA Algorithm  
• CFG1: Stratway+ encounters                     |                                                                          |                                          |
| General Atomics Aeronautical Systems, Inc. (GA-ASI) | • CPDS DAA Algorithm  
• CFG1: Due Regard Radar (DRR)  
• CFG1: CPDS encounters  
• CFG1: Radar encounters  
• CFG1: TCAS encounters                           |                                                                          |                                          |
| Honeywell International, Inc. (HON)              | • Honeywell Fusion Tracker                                                          | • CFG1 and CFG2: N3GC C90 King Air intruder                           |                                          |
• Configuration 1: Pairwise Scripted Encounters
  – Evaluated advisories generated by SS and CA algorithms
  – Ownship Ikhana vs. one (or two) manned intruders
    – Configuration 1a: Low-speed ownship
      • Participants: ARC (SSI), LaRC, AFRC, GA-ASI, HON
    – Configuration 1b: High-speed ownship (not attempted)
      • Participants: ARC, AFRC, GRC

• Configuration 2: Full Mission
  – Ownship NASA608 vs. manned intruders and virtual traffic
  – Real flight data to improve simulation (IHITL)
  – Pre-planned flight plan
    • Represents fictitious fireline flown in Oakland Airspace
  – Pilot in Research Ground Control Station (RGCS)
    • Lateral control. Safety pilot perform airspeed and altitude changes
  – Participants: ARC (HSI), AFRC, GRC, HON
## Terminology, Configuration, and Equipage

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<tr>
<th>Aircraft</th>
<th>EDM DRR</th>
<th>ADS-B</th>
<th>GPS</th>
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FT3 Flight Test Period

### Configuration 1

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| Total  |            | 56.2   | 212        |

*Flight hours based on Ownship

11 Data Collection Flights

3 Data Collection Flights

**Config 1:** 15 June 2015 through 24 July 2015

**Config 2:** 13 July 2015 through 12 August 2015

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5 June 2017

Operational Overview for UAS Integration in the NAS Project Flight Test Series 3
CONFIGURATION 1
Aircraft, Airspace, and Admin

Ownship

NASA 870
“ikhana”
MQ-9 Predator

Intruders

N3GC
King Air

NASA 865
T-34

High-Speed Intruder

NASA 850
F-18

Work Area:
- Edwards AFB R-2515 and Buckhorn MOA
- Primarily used Mercury Spin and Four Corners

Flights:
- Day Prior Brief
- Morning Brief
- Takeoff 0600L - Land 1100L
- Debrief
Stand Alone Facility (SAF) Mission Control Room

Test Conductor: Managed mission execution over voice communication on mission net (VHF radio) with Ikhana pilot, intruder pilots, and local ATC.

Test Director: Primary liaison with test conductor and managed voice communication on test team net with Ikhana mission director, safety, engineering, local agencies, and non-local agencies (as required).

Test Coordinator: Acted as a scribe and managed secondary SAF tasks.
• Planned: 3 flights per week
  – About 4 hrs of data collection
  – 10 min per encounter

• Briefs
  – Roll call
  – Mission summary
  – Mission timeline
  – Weather/NOTAM
  – UAS status
  – Mission information
  – GCS status
  – Airspace/airfield
  – Support assets
  – Contingencies
  – Miscellaneous
  – Flight card review

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<tr>
<th>Time of day</th>
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<th>NASA850 F-18</th>
<th>NASA865 T-34</th>
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<td>0430</td>
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<td>Individual unit briefs</td>
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<td>0500</td>
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<td>0600</td>
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<td>0620</td>
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Safety and Mission Rules

Safety working groups analyzed and discussed flight test hazards to create mission rules.

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<tr>
<th>Admin</th>
<th>Procedural</th>
<th>Execution</th>
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</thead>
<tbody>
<tr>
<td>• System Under Test (SUT) not used for safe separation of aircraft&lt;br&gt;• Weather&lt;br&gt;  ▪ 3 or greater miles of visibility&lt;br&gt;  ▪ Clear of clouds 1000’ above and below planned maneuvers, including aborts</td>
<td>• Time hack for all participants&lt;br&gt; • Altimeter calibration (for flight days with encounters &lt; 500 ft vertical)&lt;br&gt; • Update, and Ikhana Lost Link verified&lt;br&gt; • Check aircraft navigation quality&lt;br&gt; • Between encounters, mode set to advisory or OFF&lt;br&gt; • Between encounters, stay at deconfliction altitude</td>
<td>• Visual required within 1 NM for encounters &lt; 500 ft vertical separation&lt;br&gt; • TCAS (other than test card) followed only if from non-participating aircraft and have SA on participants&lt;br&gt; • Operations outside approved FT3 envelope prohibited during encounters&lt;br&gt; • Aborts for reasons that cause unsafe conditions&lt;br&gt; • Encounter aborted if TCAS opposite of expected&lt;br&gt; • When within 1 NM, minimum vertical separation 200’&lt;br&gt; • Timing constraint resets</td>
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</table>
To the extent possible, encounter order was designed with a “build-down” philosophy.

**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
- Single intruder encounters followed by multiship
- Encounters with same intruders grouped
- Advisory prior to auto maneuvers
- Once encounter type is cleared, continue through deck next day

Simple

Complex
**Nomenclature**

**Configuration 1 nomenclature**

<table>
<thead>
<tr>
<th>[Series]</th>
<th>[Min altitude offset]</th>
<th>[Vertical profile]</th>
<th>[Encounter angle]</th>
</tr>
</thead>
</table>

- **Series**
  - L = Low speed
  - H = High speed
  - M = Multiship

- **Minimum altitude offset**
  - 1 = 1000 ft
  - 2 = 200 ft / 700 ft
  - 3 = 300 ft
  - 4 = 400 ft
  - 5 = 500 ft
  - 6 = 300 ft / 700 ft
  - 7 = 400 ft / 500 ft
  - 8 = 2500 ft
  - 9 = 4000 ft

- **Vertical profile (ownship/intruder)**
  - 1 = H-level/level
  - 2 = Level/H-level
  - 3 = Level/climb
  - 4 = Level/descent
  - 5 = Climb/level
  - 6 = Descent/level
  - 7 = Climb/descent
  - 8 = Descent/climb
  - 9 = Level/H-level/L-level

- **Encounter angle**
  - A = 0 degrees
  - B = 20 degrees
  - C = 45 degrees
  - D = 90 degrees
  - E = 110 degrees
  - F = 135 degrees
  - G = 160 degrees
  - H = 180 degrees
  - J = -45 degrees
  - K = -90 degrees
  - L = -135 degrees
  - M = Turning 45 degrees
  - N = Turning 90 degrees
  - P = Zig-zag
  - Q = 0 / 0
  - R = 0 / 45
  - S = 0 / 90
  - T = 0 / 135
  - U = 20 / -20
  - V = 45 / 90
  - W = 90 / 135
  - X = Turning 45 degrees / 180 degrees

Test card nomenclature: Quick, easy way to gain SA and identify properties of the specific encounter

Example: L42A

- Low-speed ownship
- 400 ft vertical separation
- Ownship below intruder
- 0 degree angle offset between ownship and intruder
Operational Overview for UAS Integration in the NAS Project Flight Test Series 3

- Comprehensive matrix built to track over 300 unique encounter scenarios
- Tracked information such as scenario name, aircraft involved, groundspeeds, altitudes, and waypoints
- Part of mission planning and ensuring encounters fit in allotted airspace
- Used look-up tables to automatically generate and populate the flight test cards
Ownship and Intruder Example Cards

Operational Overview for UAS Integration in the NAS Project Flight Test Series 3

5 June 2017
### FT3 CONFIGURATION 1

**Operational Overview for UAS Integration in the NAS Project Flight Test Series 3**

**Schedule**

#### FT3 CONFIGURATION 1

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**5 June 2017**

**~20 encounters/day**
Execution
Execution – Quad Video
CONFIGURATION 2
Aircraft, Airspace, and Admin

**Ownship**
- NASA 608
  - T-34
- N3GC
  - King Air
- NASA 865
  - T-34
- NASA 7
  - King Air

**Intruders**
- N3GC
  - King Air

**Work Area:**
- R-2508
- R-2515, Isabella MOA

**Flights:**
- Brief 1200L (Performed once)
- Takeoff 1430L
- Land 1730L
- Debrief
Configuration 2 Concept of Operations

Routine UAS Operations
- UAS transitioning Class E airspace to/from Class A, D, G airspace
- UAS equipped to detect and avoid traffic
  - IFR
    - ADS-B
    - Transponder
  - VFR
    - Cooperative
      - ADS-B
      - Transponder
    - Non-cooperative

Live Intruder(s)
- ADS-B

Virtual/Constructive Intruders

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

Research GCS

LVC Distributed Network
- SAA/DAA Algorithms
- Display of Proximal Traffic

Virtual ATC

VPN

Multi-Aircraft Control System

Virtual Intruder(s)
(Pseudo Pilots)
Fireline Route

All live aircraft were manned and responsible for See and Avoid.
**Mission Information**

- Only one pre-brief required (static nature of fireline)

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<td>N3GC King Air</td>
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<td>Mass briefing</td>
<td>Human systems integration training (2.0 hours)</td>
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<td></td>
<td></td>
<td></td>
<td>System under test ready</td>
</tr>
<tr>
<td>Takeoff LSP</td>
<td>1430 KBFL</td>
<td>1430 KEDW</td>
<td>1430 KEDW</td>
<td>DSRL/LVC/RGCS up and running</td>
<td>In the loop</td>
</tr>
<tr>
<td>1445</td>
<td></td>
<td></td>
<td></td>
<td>Establish data flow (system check)</td>
<td>Begin test</td>
</tr>
<tr>
<td>1515</td>
<td></td>
<td></td>
<td></td>
<td>Commence exercise run 1 (40 min + 20 min setup)</td>
<td>End test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Commence exercise run 2</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>Commence exercise run 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Finish exercise - return to base (data archiving)</td>
<td></td>
</tr>
<tr>
<td>Recover</td>
<td>1730 KBFL</td>
<td>1770 KEDW</td>
<td>1745 KVNY</td>
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<td>Attend</td>
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<tr>
<td>1845</td>
<td></td>
<td></td>
<td></td>
<td>Flight debrief</td>
<td></td>
</tr>
<tr>
<td>1945</td>
<td></td>
<td></td>
<td></td>
<td>End of test day</td>
<td></td>
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## Schedule

<table>
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<tr>
<th>Flight</th>
<th>Date</th>
<th>Day of Week</th>
<th>System Under Test</th>
<th>Encounter Types</th>
<th>Planned LIVE Encounters</th>
<th>Flown LIVE Encounters</th>
<th>LIVE Points Achieved</th>
<th>Virtual Points Flown</th>
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<tbody>
<tr>
<td>GRC 1</td>
<td>13-Jul-15</td>
<td>M</td>
<td>CNPC</td>
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<td>CST 1</td>
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<td>CST 2</td>
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<td>CST 5</td>
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<td>CNPC</td>
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<td>CNPC</td>
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<td>HSI/RGCS</td>
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<td>F</td>
<td>HSI/RGCS</td>
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<td>Data 10</td>
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<td>HSI/RGCS</td>
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<td>CANCELLED</td>
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</tr>
</tbody>
</table>

**Totals** | 62 | 38 | 18 | 41
Example Flight Card

**Configuration**
- Aircraft
- Aircraft role
- Deconfliction altitude
- Live encounter #
- Ownership ENC altitude

**Virtual ENC**
- Live ENC
- Visual identification notice

**Abort procedure**

**Waypoints**
- Distance
- Magnetic course
- Temporary flight restriction
- Holding pattern
- Fly-to waypoint
- Live ENC waypoint

**Example Flight Card**

5 June 2017

Operational Overview for UAS Integration in the NAS Project Flight Test Series 3
Data Collection 1, Run 2: August 10, 2015

1: Maneuver
2: Maneuver
3: Maneuver
4: Maneuver

- Incorrect alerting on encounter 4
1: Maneuver
2: NO maneuver – timing
3: Maneuver
4: Maneuver

• NEW heading for Intruder 2 into encounter 4
LESSONS LEARNED
Operational Observations

1. Configuration 1 and 2 flight tests were distinct and separate
2. Configuration 2 flights were cancelled after 3 of 10 data collection flights and Configuration 1b was not attempted
3. Multiple operating/staging locations decreased efficiency in test execution
4. Low priority within R-2515 resulted in missed flight-test opportunities
5. An intruder was within 1 nmi and less than 500 ft vertical separation without being visual on Ikhana
6. Haze, clouds, and wind aloft affecting encounters
7. Understanding success criteria and training operators was critical to mission success
CONCLUDING NOTES
Operational Overview for UAS Integration in the NAS Project Flight Test Series 3

5 June 2017

• FT3 Configuration 1 successful
  – All researchers reached main objectives for their SUT
  – For many researchers, first time receiving real flight data
  – Flew milestone encounters:
    • Live UAS multi-ship encounter
    • TCAS Auto
    • TCAS sequential advisory

• FT3 Configuration 2 cancelled after 3 data collection flights
  – Gathered many lessons learned to improve FT4 and beyond

• Flight Test Series 4 (FT4) was successfully flown in 2016
  – Similar to FT3 Configuration 1
  – Even more intruders, sensors, and configurations
  – Operational successful built heavily on lessons learned from FT3

• ACAS Xu FT2 will begin next week!
  – NASA Armstrong acting as responsible test organization once again
**Altimeter Calibration Card**

**FT3 ALTIMETER CALIBRATION**

**Rejoin and Altitude Calibration:**
1. All aircraft set with 29.62” altimeter setting.
2. IKHANA loads appropriate Lost Link Mission. (IKHANA Only)
3. OWNSHIP holds at CP6, LEFT HAND TURNS.
4. CHASE arrives for rejoin at an initial altitude of 11,000’ then climbs to maintain 500 feet separation until visual, then completes rejoin at 12,000’
5. OWNSHIP calls altitude in feet MSL.
6. CHASE adjusts altimeter setting to match OWNSHIP altitude.
7. CHASE calls altitude in feet MSL. Maintain new altitude setting for duration.
8. For multi-ship missions intruders (CHASE) cycle sequentially according to prebrief.
9. CHASE maintain new altitude setting for test runs.

“ALT cal complete, NDGC cleared off <dir> <alt>”
Perform visual calibration if required.

<table>
<thead>
<tr>
<th>PT</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>OWNSHIP ALTITUDE</th>
<th>CHASE ALTITUDE</th>
<th>A/S</th>
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<tbody>
<tr>
<td>IP 20</td>
<td>34° 57.89'</td>
<td>117° 33.62'</td>
<td>12000</td>
<td>11000</td>
<td></td>
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<tr>
<td></td>
<td>34° 57.53.4”</td>
<td>117° 33° 37.3”</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CPA6</td>
<td>N34° 57.89’</td>
<td>W117° 24.47’</td>
<td></td>
<td>12000</td>
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</tr>
<tr>
<td></td>
<td>N34° 57.53.4”</td>
<td>W117° 24° 28.2’</td>
<td></td>
<td></td>
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Operational Overview for UAS Integration in the NAS Project Flight Test Test Series 3