Unmanned Aircraft System Flight Test Approach Supporting the Development of Regulatory Recommendations for Integration with the National Airspace System

Michael Vincent

NASA Langley Research Center

Kevin Monk
Mauricio Rivas
Clint St John

Flight Test 6 Overview

- UAS Integration in the NAS Project
- Flight Test 3
- Flight Test 4
- Flight Test Series 6 Overview and Objectives
- RADAR Characterization and Scripted Encounters Overview
- Full Mission Overview
- RADAR Characterization Results
- Scripted Encounters Results
- Full Mission Data Analysis

FT6 Full Mission Research Team

- Conrad Rorie
- Garrett Sadler
- Casey Smith
- Jillian Keeler
- Gilbert Wu
- Wei-Ching Wang

UAS Integration in the NAS Project

- NASA UAS Integration in the NAS Project
  - Part of NASA Integrated Aviation Systems Program
  - Supports RTCA SC-228 in defining DAA standards
  - Investigates and validates multiple facets of DAA for UAS
- Detect and Avoid (DAA)
  - Replaces “See and Avoid” for UAS
  - ADS-B, RADAR, Active Surveillance instead of human eyes
  - Quantifiable definition of “Well-Clear”
- Phase 1 “En-Route” Minimum Operational Performance Standards (MOPS)
  - Large UAS
  - Transiting through Class E airspace
- Phase 2 Topics
  - DAA in the terminal area
  - **Low Size Weight and Power (Low SWaP) operations below 10,000ft**

Flight Test 3

- Objectives
  - Validate simulation results from DAA modeling
  - Investigate DAA/Collision Avoidance interoperability
  - Expand test architecture
- Approach
  - Scripted encounters between Ikhana and manned aircraft
  - Air-to-air RADAR (ATAR), ADS-B, Mode-C surveillance sensors
  - Sensor fusion tracker
  - DAA algorithms generate alerting and guidance
    - Stratway+
    - JADEM
    - CPDS

Flight Test 3

- Results
  - Unsteady alerting and guidance observed with non-cooperative sensors
    - Emphasized need for handling of uncertainty for non-cooperative sensors
    - Led to hysteresis, uncertainty, track generation requirements for RTCA DO-365
  - Alerting ranges for high-speed (400 kts) and maneuvering intruders
  - Refined systems under test
    - JADEM and CPDS improvements
    - Stratway+ developed into DAIDALUS
    - Honeywell sensor fusion tracker
    - State filtering for GA-ASI ATAR

Flight Test 4

- Objectives
  - Validate stressing cases for DAA MOPS – low speed, small RCS, high vertical closure rate, multiple intruders
  - Validate DAA/CA interoperability
  - Validate well-clear recovery guidance
  - Validate reference test vectors for DO-365
  - Validate alert timing
- Approach
  - Scripted encounters between Ikhana and KingAir, Gulfstream, T-34C, TG-14
  - JADEM, CPDS DAIDALUS as DAA systems
  - Test cards developed for NASA Ames & Langley, GA-ASI, Honeywell, RTCA

Flight Test 4

- Results
  - Candidate MOPS alert times sufficient for UAS to remain well-clear
  - Well-clear recovery guidance of limited utility with ATAR
  - Discovered cases where TCAS RA occurs before loss of DAA well-clear
  - Test vectors incorporated into DO-365, DO-366
  - DAIDALUS became reference DAA implementation for DO-365

Flight Test 6

- Investigate Low Size, Weight, and Power (SWaP) UAS DAA operations below 10,000 ft
  - 3 Phases
    - **RADAR Characterization** – Measure the performance of a Low SWaP non-cooperative sensor
      - Sensor accuracy, range, azimuth, elevation
    - **Scripted Encounters** – Validate the performance of the non-cooperative DWC
      - Alerting and guidance stability, maneuver effectiveness
    - **Full Mission** – Measure the human response data in a simulated National Airspace System (scenario)
      - Pilot response time, separation between aircraft, subjective acceptability
  - Conducted between July and November 2019

Detect and Avoid for UAS

- DAA Well-Clear (DWC) is lost when the separation between a UAS and another aircraft is within the vertical, horizontal, and time thresholds defined in the DAA MOPS
  - Candidate Non-Cooperative DWC:
    - Vertical (h^*) = 450 ft.
    - Horizontal (HMD^*) = 2200 ft.
    - Time (τ^*_{mod}) = 0 seconds
- An alert time to DWC is also calculated to allow the human pilot to maneuver
  - Corrective Alert: Pilot has time to contact ATC to negotiate DAA maneuver
  - Warning Alert: Pilot must maneuver immediately to avoid losing well-clear
- A DAA display provides the pilot with maneuver guidance in the form of heading and altitude “bands”
  - Pilot maneuvers so that the UAS heading or altitude is outside the bands

NASC TigerShark XP

- Manufacturer: Navmar Applied Sciences Corp
- UAS Type: DoD Group 3
- Wingspan: 22 ft.
- Endurance: 8-12 hour
- Max speed: 80 KTAS

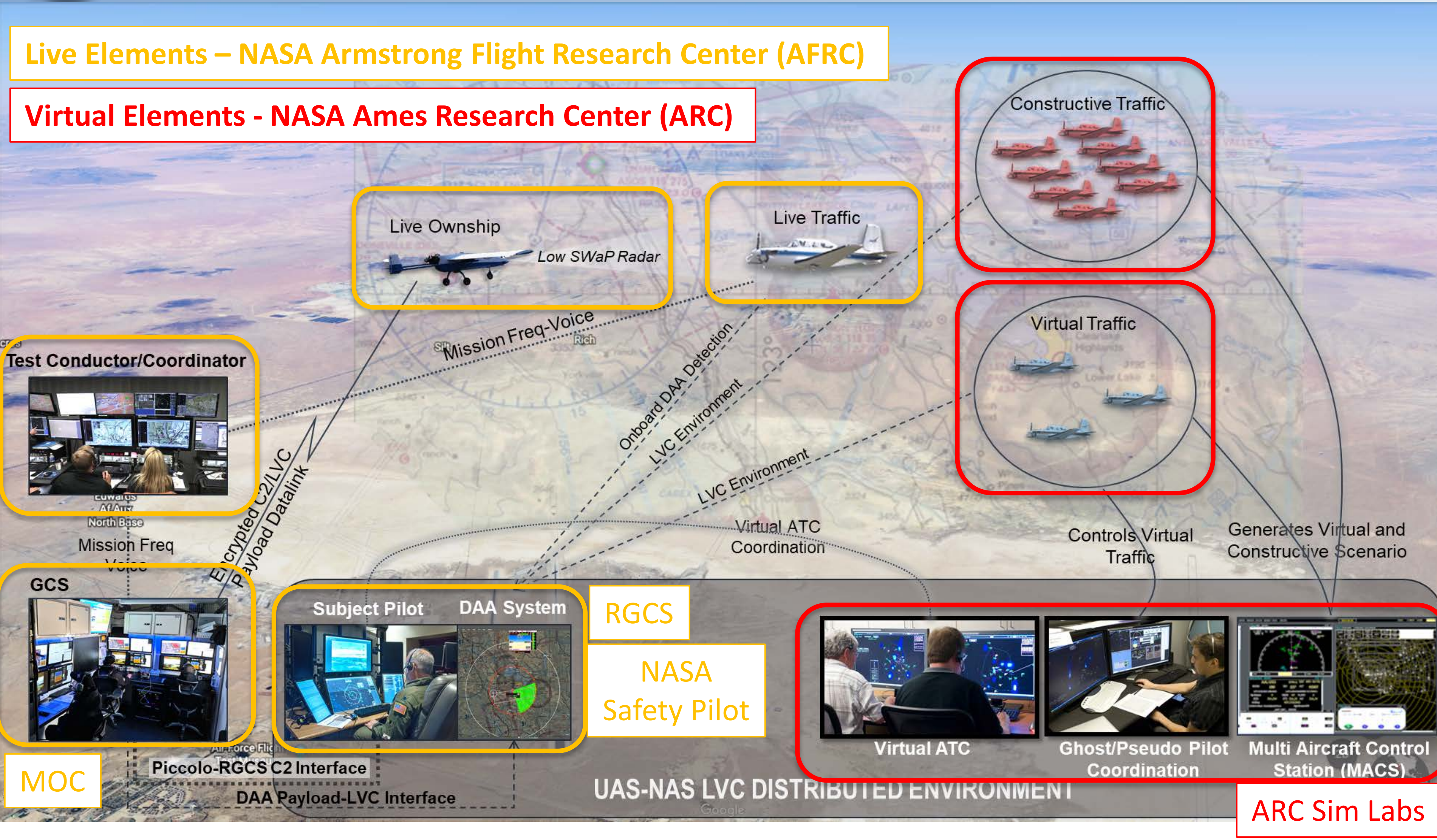
- Radome nose fabricated to house Low Size, Weight, and Power (SWaP) non-cooperative RADAR sensor – Honeywell "DAPA-Lite"
- Addition of exhaust injection smoke system for visual ID from manned aircraft
- Mobile Operations Center (MOC) houses internal pilot using Piccolo Control Center
- MOC linked to Research Ground Control Station (RGCS) where DAA system was housed

Vigilant Spirit Control Station (VSCS) and LVC-DE

- VSCS
  - Displays DAA alerting and guidance
  - Pilot GUI for control of vehicle
  - Developed by AFRL
- Live, Virtual and Constructive Distributed Environment (LVC-DE)
  - Connects geographically distant assets
  - Connects live assets with virtual and constructive elements
  - Combines environmental flight with simulated environment
  - FT6 simulated a sector within Oakland airspace

- **Constructive Traffic**: Simulated traffic on scripted route, no human intervention
- **Virtual Traffic**: Simulated traffic controlled by pseudo pilots
- **Live Traffic:** UAS and manned “intruder” aircraft

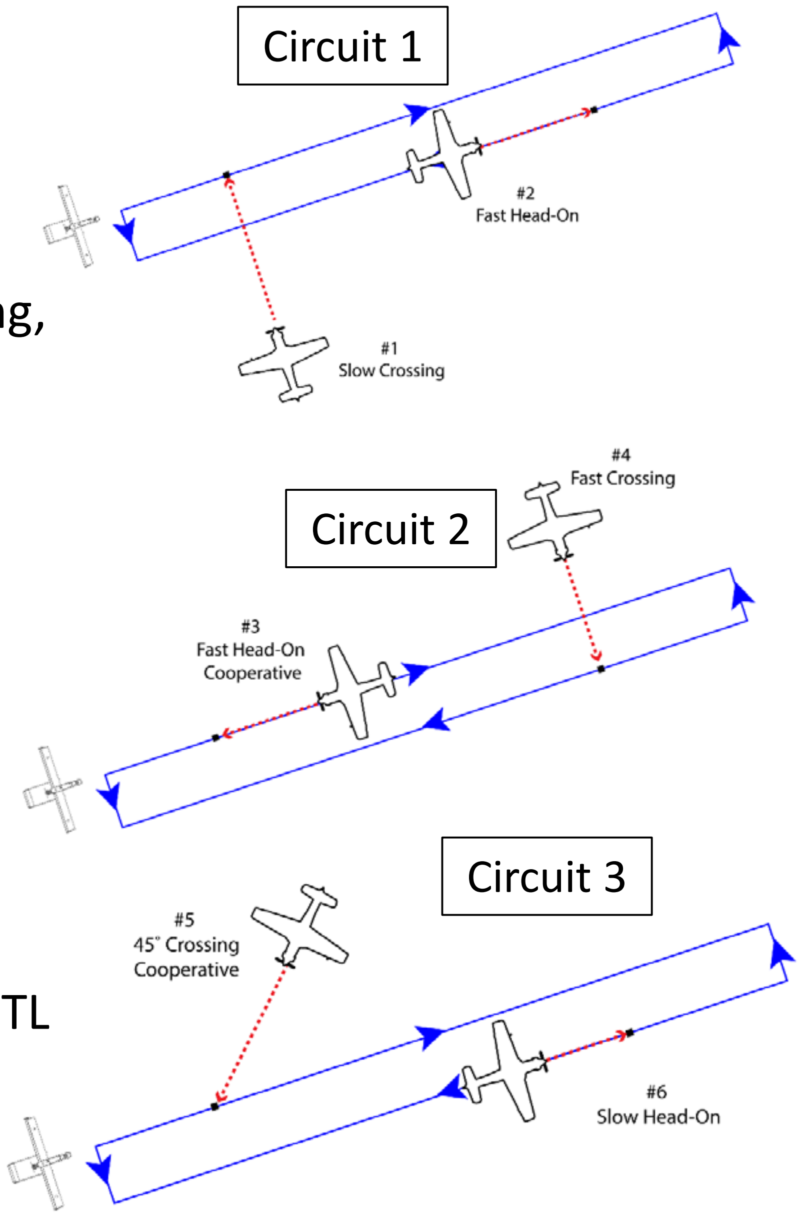
Full Mission Concept of Operations



- **Subject Pilot**: Non-NASA UAS pilot who is naïve to conditions of test encounters
- **Virtual ATC:** Trained controller managing the UAS and all cooperative traffic in the simulated sector

FT6 Full Mission

- Each subject pilot encountered 6 live targets
  - 4 with Low SWaP non-cooperative sensor
  - 2 with cooperative sensor (ADS-B)
  - Intruder speeds: 170kts or 100kts
  - Encounter geometry: Head-on, 90° crossing, 45° crossing
  - Encounter locations can shift
- 7 Subject pilots
  - Active military
  - UAV type certification
    - Fixed wing
    - Previous year experience
  - Current FAA medical or equivalent
    - Corrected to normal vision
  - Full color perception
  - Private Pilot Certificate
  - No previous UAS Integration in the NAS HITL activities



Full Mission Subject Training and Metrics

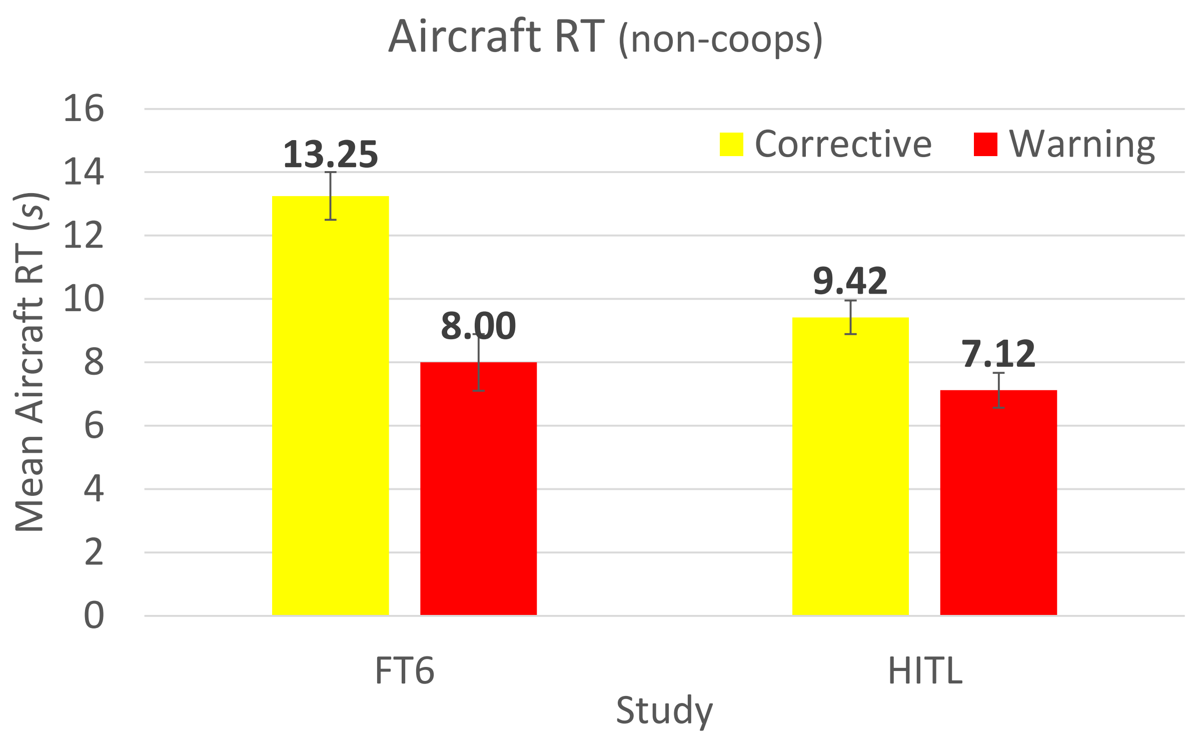
- Training
  - Day before flight
    - Intro to FT6, responsibilities, vehicle overview
    - VSCS Interface: information display, sending commands, vehicle behavior
    - DAA System: alert meaning, guidance, surveillance system
    - Mission: airspace, ATC, secondary tasks
    - Simulation practice
  - Morning of flight
    - Refresher practice of simulated encounters
- Data Collected
  - Separation between UAS and live traffic
  - Pilot response: ATC coordination and alert reaction times
  - Pilot subjective workload and system acceptability
  - Questionnaires:
    - After encounter
    - After circuit
    - After simulation
  - Debriefing interview

FULL MISSION RESULTS

Aircraft Response Time

- Slower responses to Correctives compared to HITL results
  - Higher proportion of Corrective alerts in FT6, longer average alert duration
  - More pilots on common voice frequency

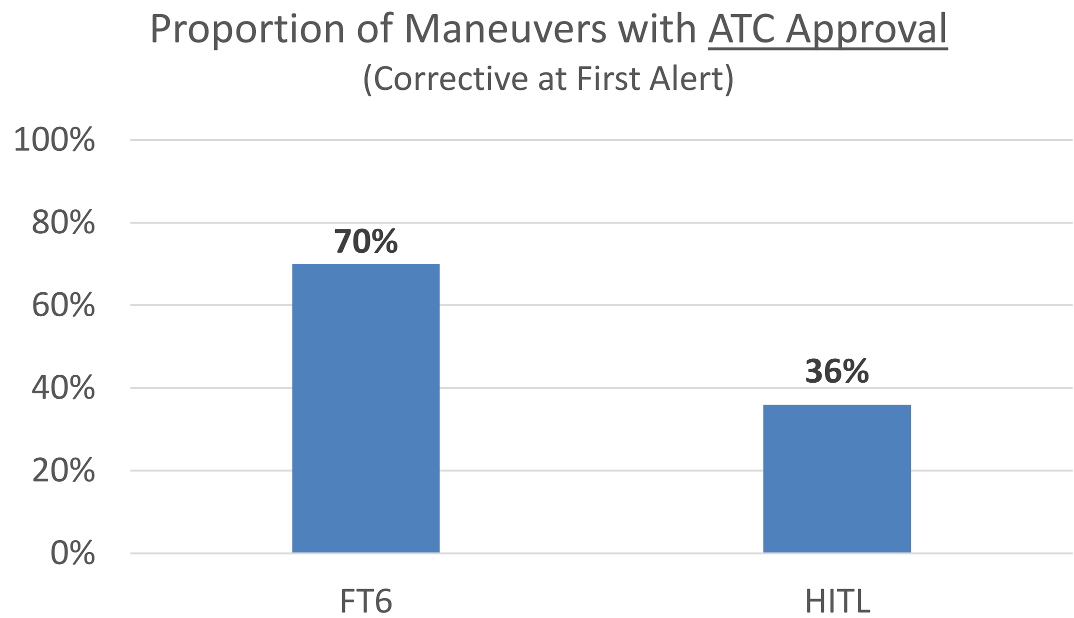
- RT distribution (non-cooperative traffic)
  - Corrective at First Alert: 80% of RTs within 15sec (Max = 20sec)
  - Warning at First Alert: 80% of RTs within 10sec (Max = 11sec)



Aircraft response time **– time elapsed from alert to first maneuver upload**

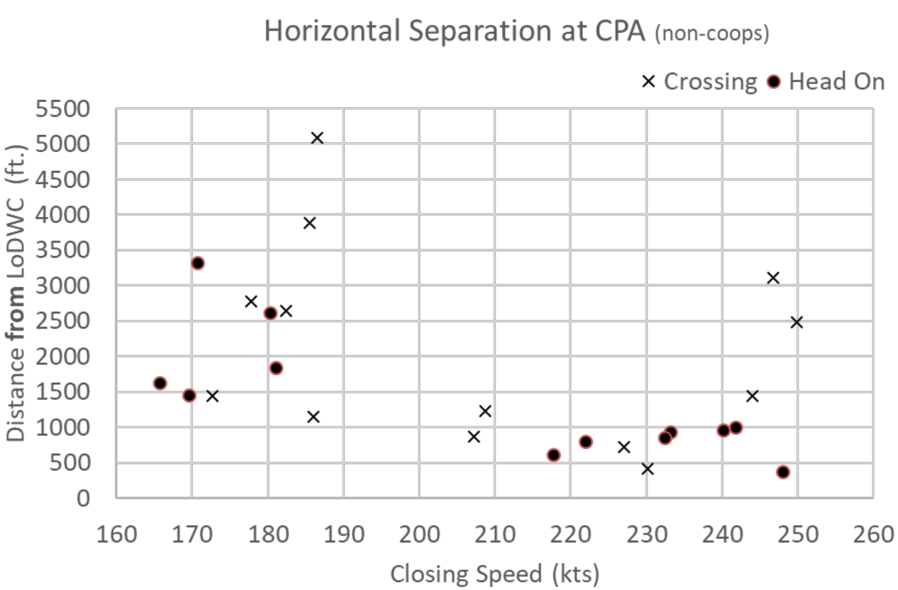
ATC Coordination

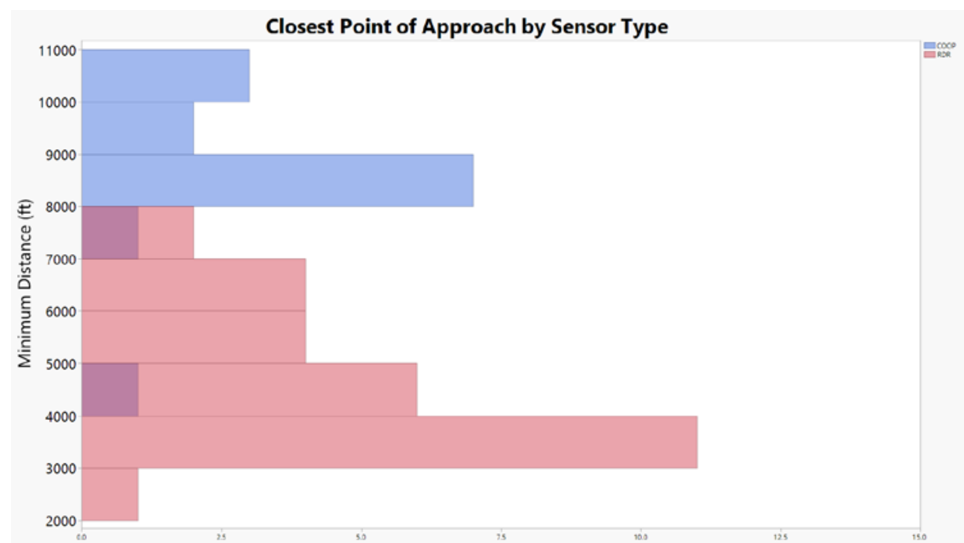
- ATC coordination rates nearly doubled in FT6 compared to HITL
  - More time to receive ATC approval before Warning onset (~12 sec)
    - Variability in closure rates due to changing atmospheric conditions
  - Warning onset typically occurred during transmission
    - On average, pre-approved maneuver uploads came 14 seconds after first alert



Separation Performance

- Zero Losses of DWC with either equipage
  - ‘Fast’ intruders accounted for the lowest closest points of approach
    - Closest call: 2577ft. Horz. CPA (Fast Head On, 27sec-to-LoDWC @ 1st alert)
      - Unintentional button click delayed pilot’s response
  - Encounters with the cooperative sensor predictably had higher closest points of approach
    - Due to unrestricted detection range



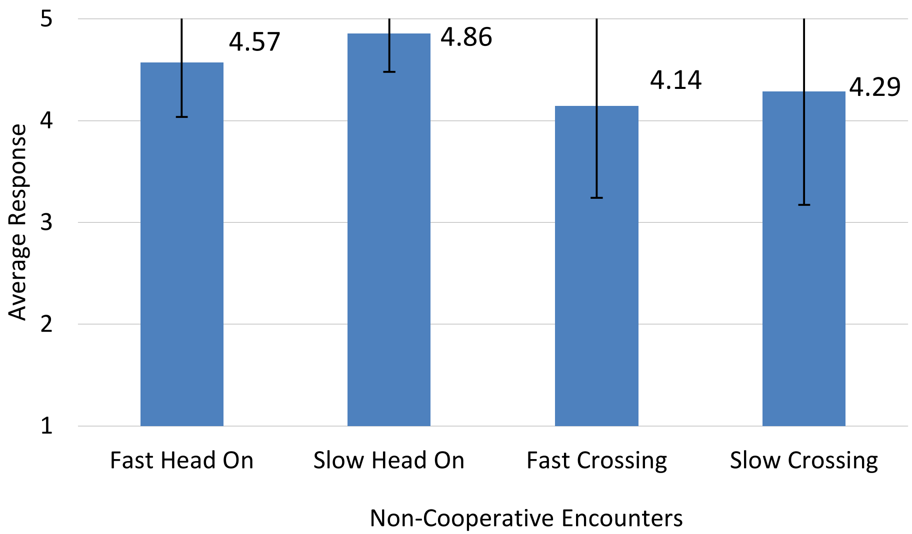


Post-Encounter

- Pilots felt that they were able to achieve sufficient separation in all four non-cooperative encounters, and found the DAA guidance bands useful

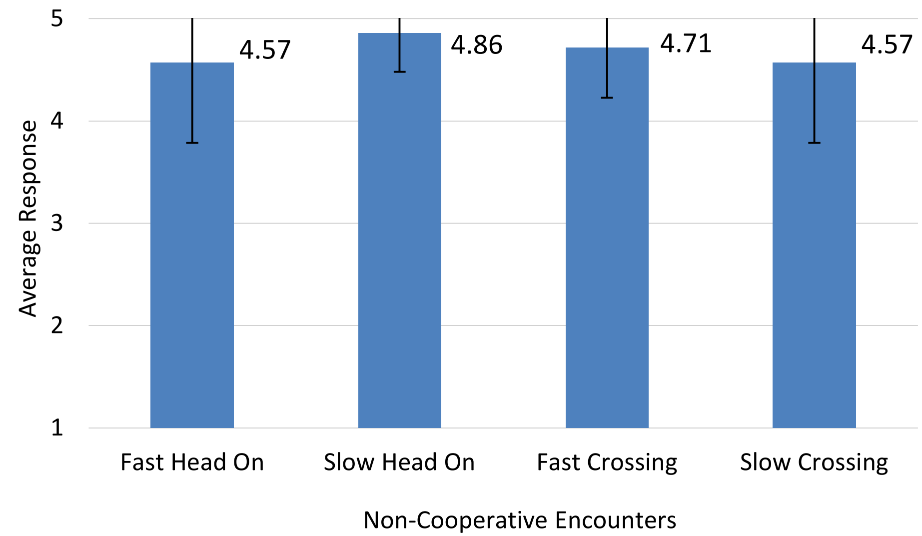
I was able to achieve sufficient separation from the intruder aircraft(s) using the alerting and guidance in this encounter:

1 = Strongly Disagree, 5 = Strongly Agree



The DAA guidance bands were useful for solving this encounter:

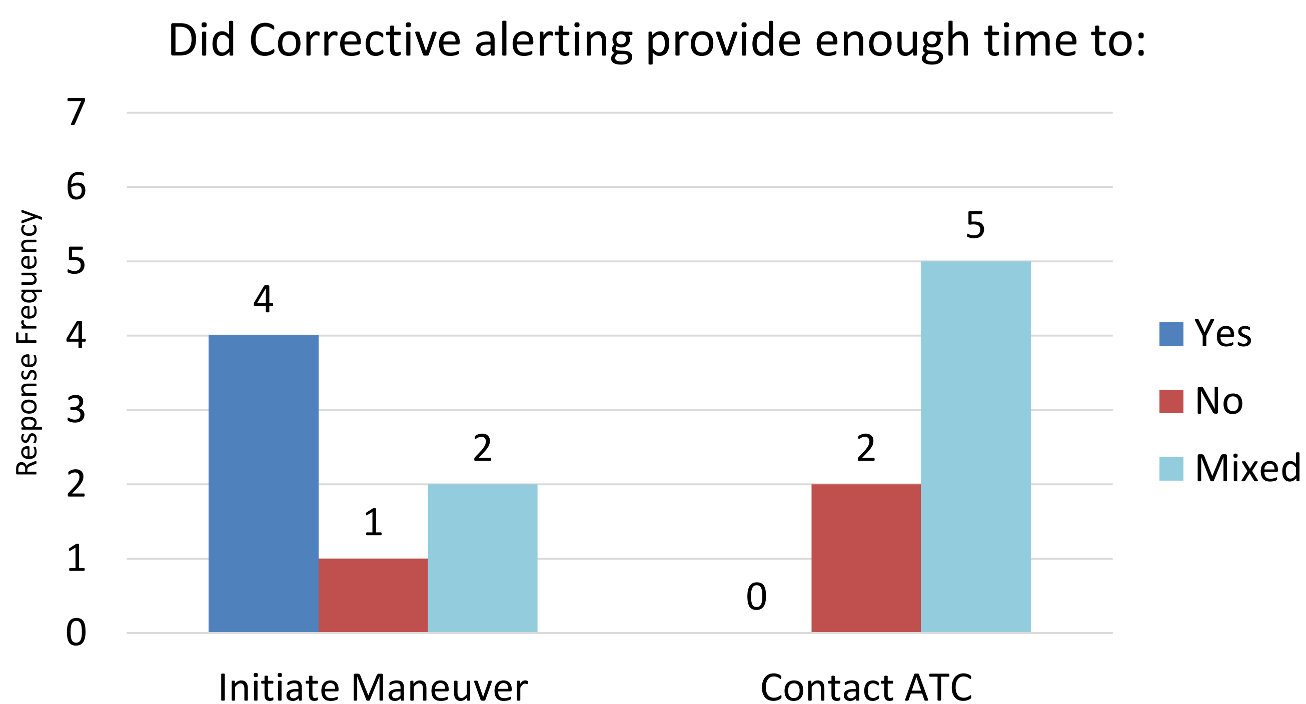
1 = Strongly Disagree, 5 = Strongly Agree



Post-Test

- Majority thought alerting provided enough time to **initiate maneuver** in most cases
  - Slower aircraft intruding were okay, faster ones were "pushing it"

- Mixed responses on **timing to contact ATC** at corrective alert level
  - Pilots reported instances where encounter immediately elevated to Warning while attempting coordination
  - "Sometimes frequency congestion didn't allow time to coordinate"



Field of Regard (FOR) Considerations

- Intruder A/C fell out of FOR during <u>26 of 27 avoidance events</u>
  - Smaller detection range -> larger turns required for resolution
    - Stresses 110° azimuth limit, especially at fast closure rates
    - Wider turns observed in live flight compared to HITL
      - Pilots added buffer to target headings to account for crosswinds
  - DAA information remained absent for at least 13 seconds (max = 87sec)
    - Half never re-appeared on display
    - Occasionally, symbology disappeared before Clear-of-Conflict
  - 59% of intruders reached CPA while outside of FOR
    - Lost more separation without conflicting traffic in sight
    - Always diverged in time to avoid LoDWC or early return to course
      - Pilots spent more time off course than previous HITLs (63sec)

Study	Azimuth Drops before CoC	Avg. Turn Size (Fast Intruders)
FT6	11/27 **(41%)**	128deg
HITL	9/36 **(25%)**	90 deg

Summary

- Scripted Encounters
  - For maneuvers executed in a timely fashion more than half of these maneuvers effectively resolved conflicts
    - A 3.5 nmi surveillance range achieved a higher success rate (~70%) than 2.5 and 2.0 nmi (50%)
  - For ineffective encounters, the lead contributing factors are
    - Pilots' decision
    - Change of Intruder's velocity
  - It may be beneficial for pilots to add more maneuver "buffer" beyond the heading bands to the target heading
    - Maneuvers are more effective when buffers are larger
- Full Mission
  - Pilot Performance (compared to HITL)
    - Zero Losses of DAA Well Clear
      - HITL: 1 LoDWC due to Early Return to Course
    - Slower response times, but more ATC-approved maneuvers
      - More caution alerting due to slower ownship speeds
  - Pilots were still often unable to respond to Corrective alerts
    - All but two encounters reached warning-level status
  - Pilot Feedback
    - Low workload ratings overall
      - Moderate increases for fast-closure encounters
    - Sufficiency of DAA guidance bands rated favorably
      - Corrective alert timing inadequate for ATC coordination

FT6 Conclusions and Lessons Learned

- High winds impacted flight operations with the Tigershark
  - Low ground speeds – difficult to set up encounters
  - Challenging launch and recovery
  - Survey multiple launch and recovery sites as best practice – cross winds
- Multiple flight plans provided flexibility
  - Allowed test to continue when part of airspace was unavailable
  - Allowed multiple encounter attempts during full mission
- Rehearsal for full mission a necessity
  - Full mission procedures needed practice from the entire team to lock down
- Visual conspicuity an issue for vehicle of this size
  - Smoke system for visual identification was of limited utility
  - Visibility of smoke depended on weather – overcast skies and haze hampered visual ID

Special Thanks To….

- AFRC
  - Mike Marston
  - Alex Flock
  - Sam Kim
  - Robert Navarro
  - Doug Wada
  - Arya Abrego
  - Jamie Turner
  - Rashmi Vidyasagar
  - Eleonor Barron
  - Scott Howe
  - Derek Abramson
  - Kassidy Mclaughlin
  - Daniel Surgeon
  - Rocky Garcia
  - Hernon Posada
  - Victor Loera
  - Justin Hall
  - Duc Tran
- ARC
  - Mohamad Refai
  - Ty Hoang
  - Wayne Bridges
  - Zach Roberts
  - Andrew Cone
  - Elvia Valenzuela
  - Jay Shivlely
- LaRC
  - Ivan Clarke
- NASC
  - Stephen Hamilton
  - Charles Zera
  - Bryan Hazlett
  - Tia Williams
  - Emily Fox
- Honeywell
  - Jamal Haque
  - Marc Pos
  - John Ihlen
  - Eric Euteneuer

End

Questions?

XP-002 Unpack / Assembly

XP-002 Getting the “Rock Star” Treatment

TMOC operations during Lakebed Tow Test

TMOC established at B4864

XP-002 and NASC Team

Lakebed Tow Test Configuration

BACKUP