



UAS Integration in the NAS Project Flight Test 6

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Flight Test 6 Overview

- Project and DAA for UAS Introduction
- 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
- Summary and Conclusions



UAS Integration in the NAS Project

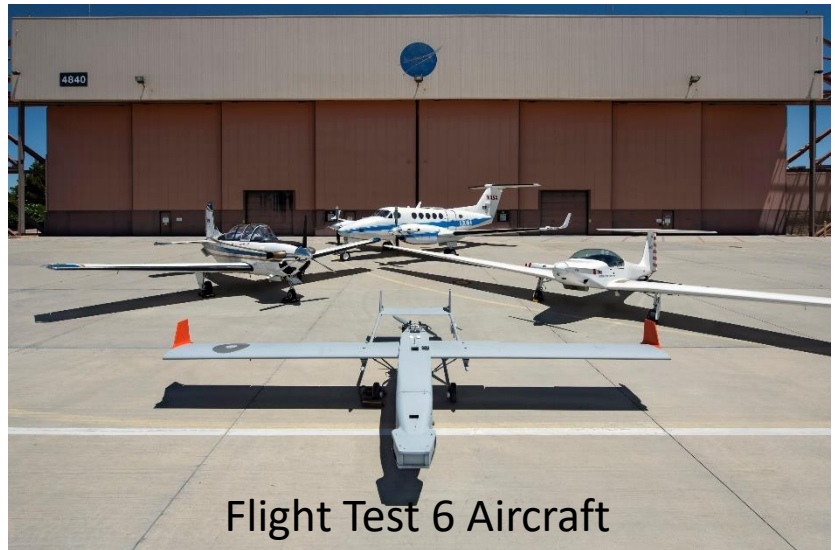
- NASA UAS Integration in the NAS Project
 - Part of NASA Integrated Aviation Systems Program
 - Supports RTCA Inc. SC-228 in defining DAA standards
 - Investigates and validates multiple facets of DAA for UAS
- Detect and Avoid (DAA)
 - Replaces “See and Avoid” for UAS
 - Automatic Dependent Surveillance-Broadcast (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
 - DAA and RADAR MOPS published 2017

Previous Flight Tests

- UAS Integration in the NAS Flight Tests 3 and 4
 - Phase 1 non-cooperative sensor (RADAR)
 - Detect-and-avoid well-clear (DWC) and alerting definition
 - Influenced design of FT6 test architecture and encounters
- Flight Test 6
 - Non-Cooperative DWC
 - Low Size, Weight and Power (Low SWAP) RADAR sensor
 - Low SWAP UAS operations below 10,000 ft.



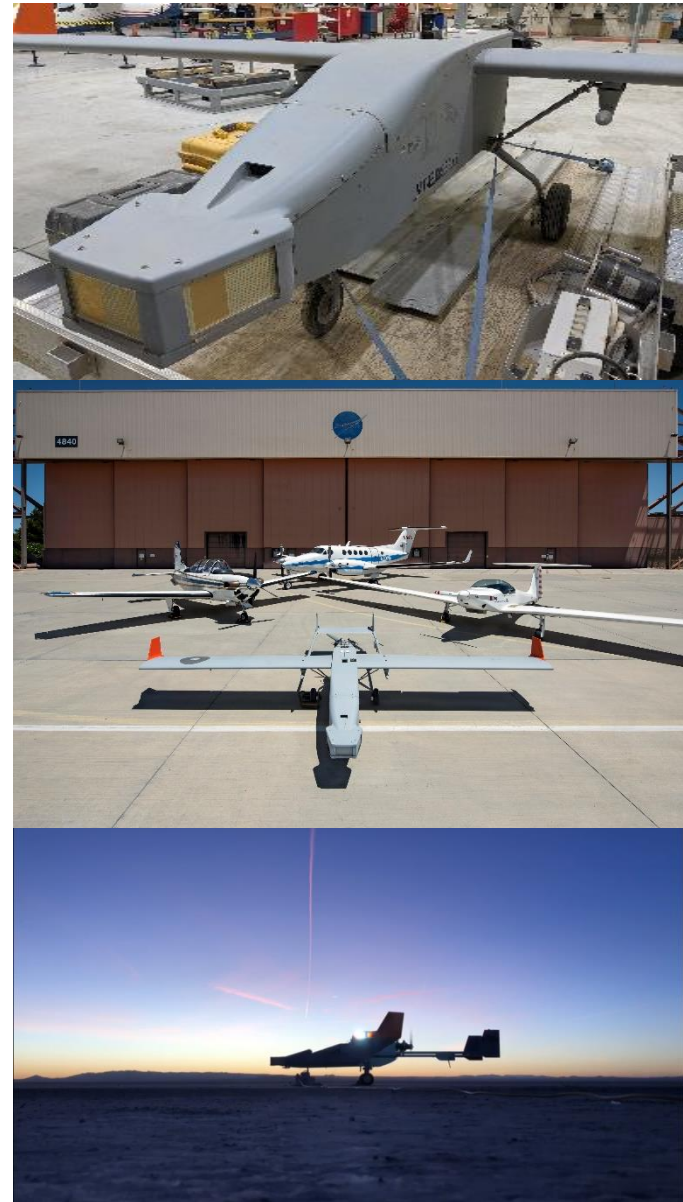
Flight Test 4 Aircraft



Flight Test 6 Aircraft

Flight Test 6

- Goal: Investigate Low Size, Weight, and Power (SWaP) UAS DAA operations below 10,000 ft
 - 3 Phases
 - **RADAR Characterization** – Measure the performance of a 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
 - Data collection conducted between July and November 2019





Detect and Avoid for UAS

- DAA Well-Clear (DWC) is lost when:
 - Horizontal separation is less than the horizontal threshold of the DWC definitionAnd
 - Vertical separation is less than the vertical threshold the separation of the DWC definitionAnd
 - The aircraft are projected to violate the horizontal and vertical thresholds within the time threshold of the DWC definition
- Candidate Non-Cooperative DWC:
 - Vertical (h^*) = 450 ft.
 - Horizontal (HMD^*) = 2200 ft.
 - Time (τ_{mod}^*) = 0 seconds
- A time to loss of DWC is calculated to trigger alerts and allow the human pilot to maneuver
 -  Corrective Alert: Pilot has time to contact Air Traffic Control (ATC) to negotiate DAA maneuver
 -  Warning Alert: Pilot must maneuver immediately to avoid losing well-clear
- DAA Guidance
 - Heading “bands” indicate which headings or altitudes will result in a loss of DWC
 - 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





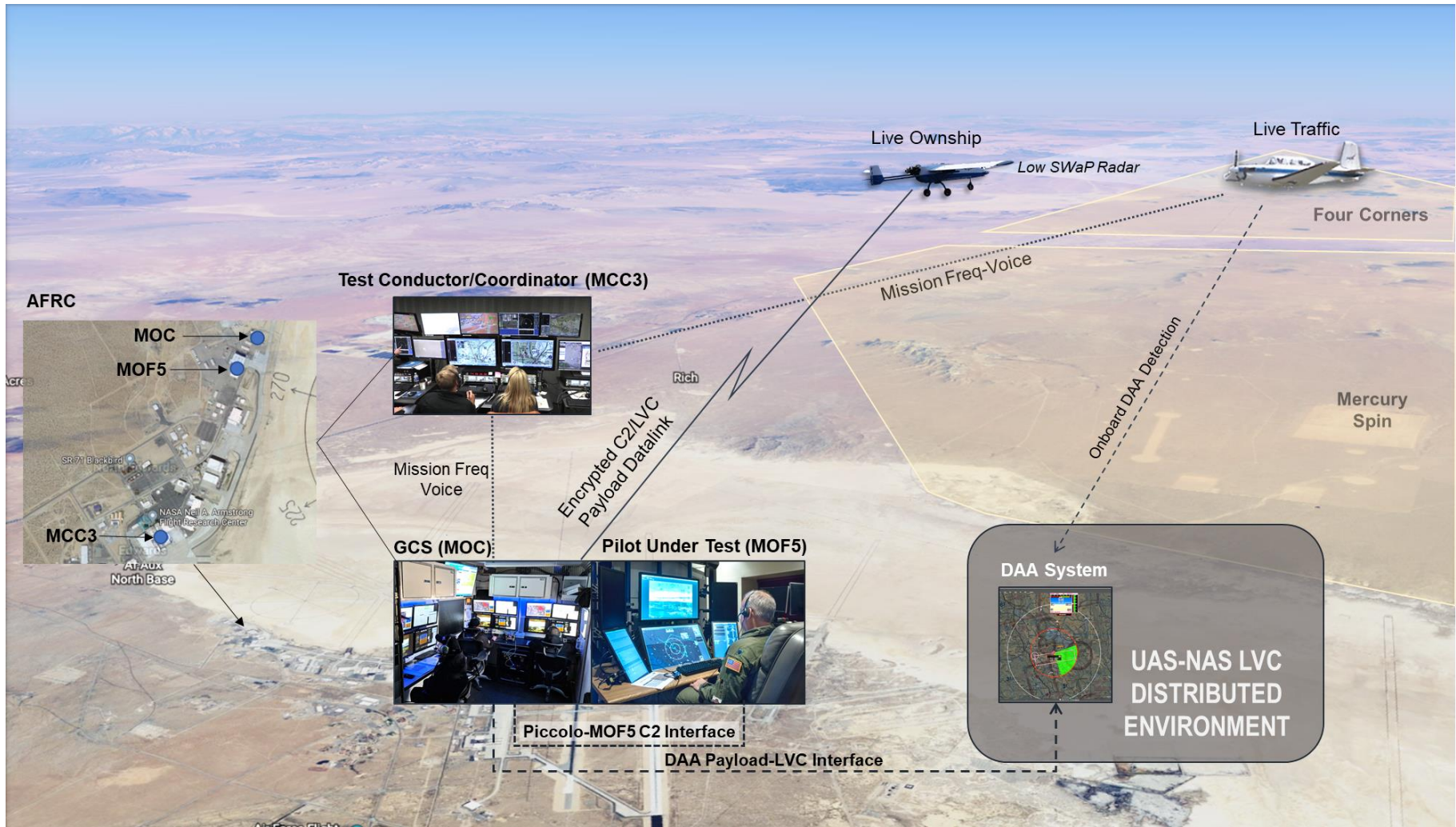
Vigilant Spirit Control Station (VSCS) and LVC-DE

- VSCS
 - Displays DAA alerting and guidance
 - Pilot user interface for control of vehicle
 - Developed by Air Force Research Lab (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

RADAR Characterization and Scripted Encounters CONOPS



- Pilot Under Test: NASA test pilot flying conditions on test card following DAA guidance



Scripted Encounters

- Goal: Execute preplanned encounters between UAS and manned aircraft to collect **DAA alerting and guidance data**
 - Observe behavior of DAA alerting and guidance from different approach angles and horizontal/vertical offsets
 - Alerting and guidance performance with cooperative and non-cooperative sensors
- UAS Performance
 - 60 KTAS, (40-100 kts ground speed)
 - 7°/Second turn rate target
- Variables
 - Geometry: 0° (head-on), 40°, 50°, 60°, 80°, 90°, 120°, 160°, 180°
 - Intruder horizontal maneuver, Intruder climb/descend
 - Vertical Offset: 200, 400, 500, 700, 1000 ft
 - Intruder Speed: 60, 100, 170 kts ground speed
 - Maneuver Initiation: Warning vs corrective
 - Maneuver delay: 3 seconds for warning, 8 seconds for corrective
 - Sensor Selection: **ADS-B cooperative** vs **non-cooperative sensor**
 - Mitigation: Unmitigated (fly-through) or mitigated



Scripted Encounters

- Procedure:

- UAS and intruder begin at specified entry criteria
- UAS pilot detects DAA alerting and guidance on Vigilant Spirit Control Station (VSCS)
- UAS pilot holds for prescribed interval of time
- UAS pilot initiates horizontal following guidance bands
- Increasing turn angle to keep up with bands necessary
- UAS pilot returns to course if able

Scripted Encounters Backup		N1750X		2.a.0.3	
Card #	DAAb-03			OWNSHIP	
INITIAL ALT	INITIAL SPEED	INITIAL WPT	RESPONSE	VID	
8000 FT	60 KGS	IP1E	Yes	YES	

Ownship

Intruder

INSTRUCTIONS:				LOST LINK WAYPOINT:	
- Maneuver 3 seconds after warning alert triggered - PUT toggle smoke on when TC calls "2 miles" - Once Intruder calls "Visual", PUT toggle smoke off - If Intruder calls "Blind", PUT toggle on and calls "Smoke On"				LL - 1	
DECONFLICTION ALT:					
8000					
ABORT PROCEDURE:					
8000				Continue on Mission Plan	

SENSOR:	Radar Only	ADS-B Only	Radar + ADS-B
SAAPROC:	NASA856	NASA865	NASA801

N1750X 8000
7000
200
8000
NASA 865 7800

COMEX TIME:			IP WIND:			
WPT	LATITUDE	LONGITUDE	ALT V/V	DIST MC	KGS	LEG TIME (TOTAL REM.)
IP1E	N34° 55.30'	W117° 28.31'	8000	2.0	60	2+00 (2+00)
	N34° 55' 17.8"	W117° 28' 18.5"	0	078		
CPA1E	N34° 55.30'	W117° 25.87'	8000	0.0	60	End
	N34° 55' 17.8"	W117° 25' 52.4"	0	078		

NOTES:

- CPA lateral offset is 0.3 nmi
- Visual Identification at greater than 0.8 nmi
- Validate Low SWAP DWC Warning Timeline
- Set SAAProc to 2.0nmi FOR

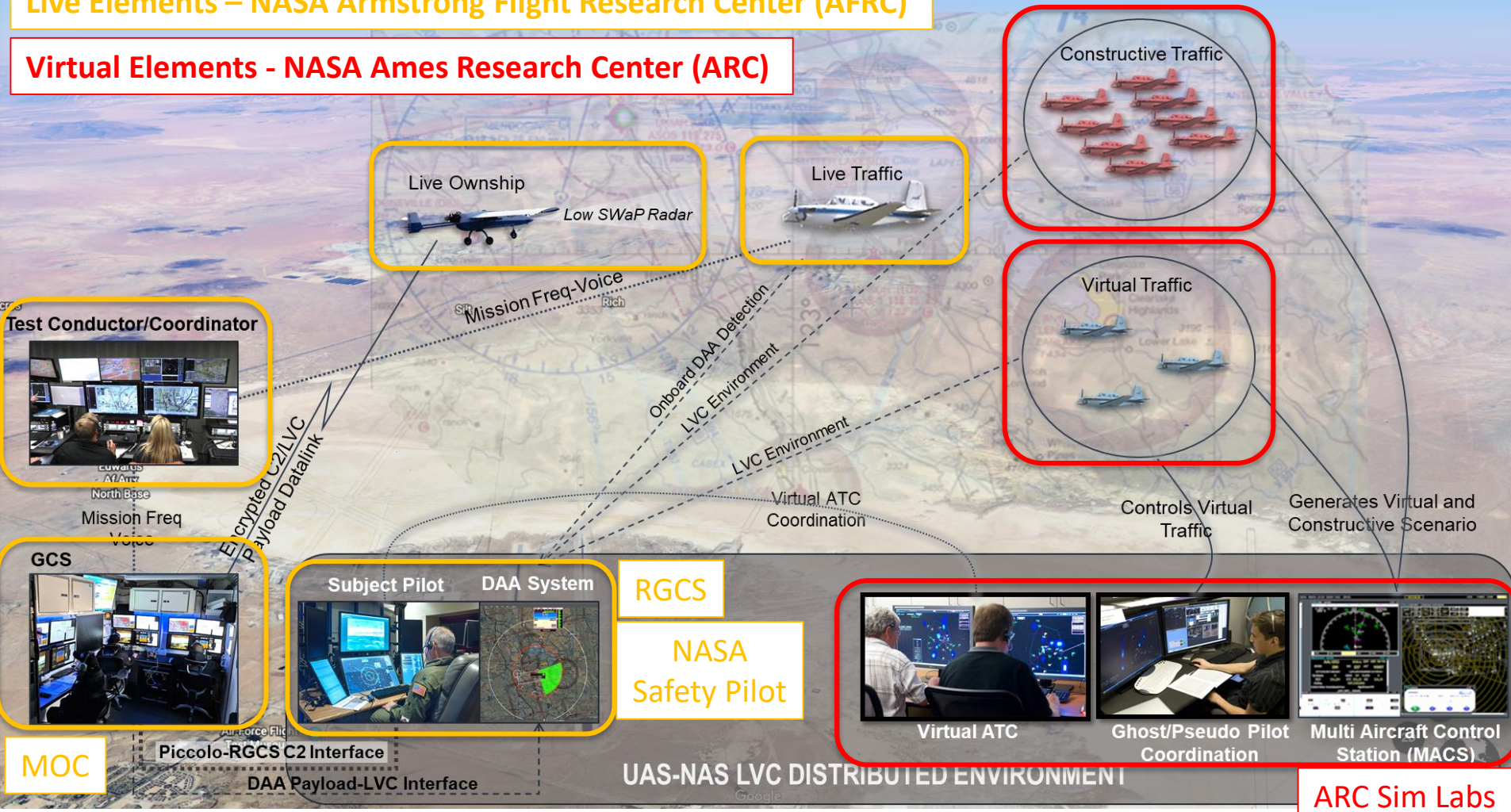
Maneuver:	Yes	No	
Guidance:	DAA	WCR	
Direction:	Lateral		
TOLERANCE:	±8 sec	±5 kts	Limit: NO DESCENT



Full Mission Concept of Operations

Live Elements – NASA Armstrong Flight Research Center (AFRC)

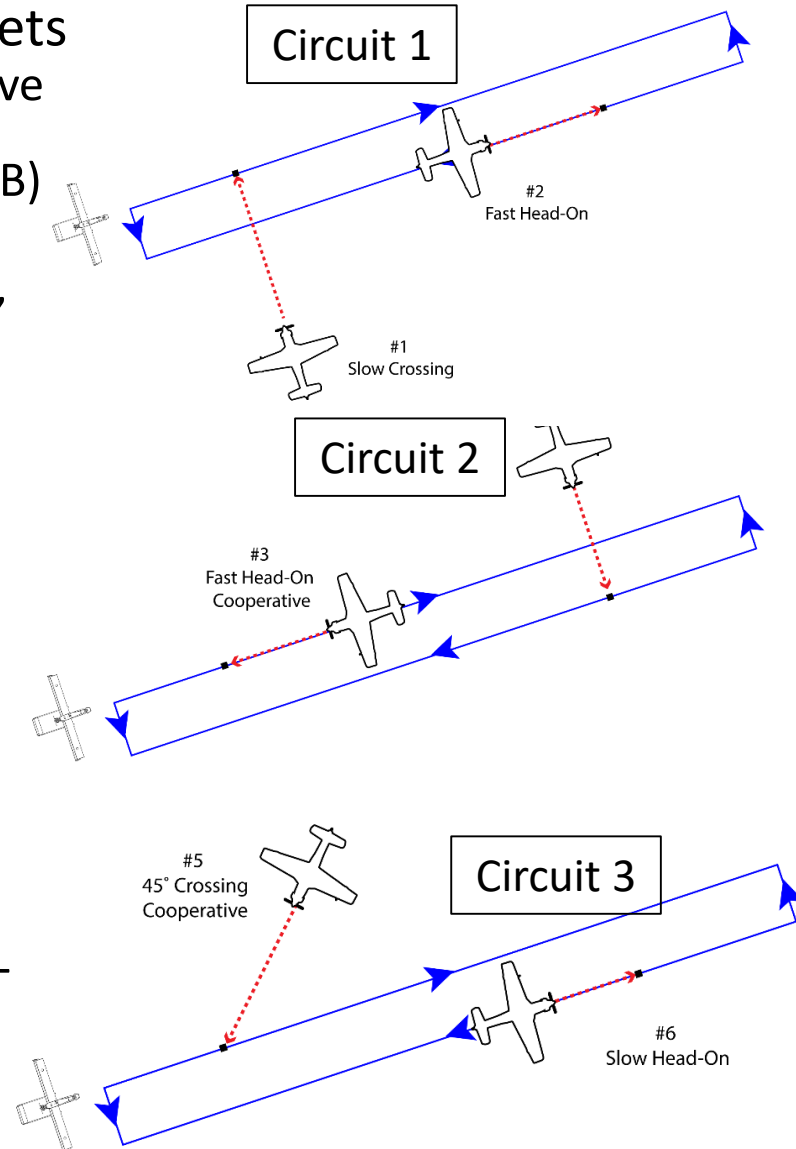
Virtual Elements - NASA Ames Research Center (ARC)



- **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 encounters with Low SWaP non-cooperative sensor
 - 2 encounters with cooperative sensor (ADS-B)
 - Intruder speeds: 170kts or 100kts
 - Encounter geometry: Head-on, 90° crossing, 45° crossing
 - Encounter locations can shift along route
- 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

- UAS/intruder separation
- ATC coordination time
- Response time
- Subjective workload
- System acceptability
- Questionnaires:
 - After encounter
 - After circuit
 - After simulation
- Debriefing interview





RADAR CHARACTERIZATION



RADAR Characterization

- Results show range not sufficient for UAS detect-and-avoid operations
 - Human-in-the-loop (HiTL and fast time simulation investigated minimum acceptable range (Wu, Wang, 2019; Monk, Rorie, Smith, Keeler & Sadler 2019)
 - 2.0 nmi identified as minimum range for DAA operations
 - RADAR detections and declared tracks were generally below 1.5 nmi
- RADAR Emulation
 - Software solution developed to emulate a RADAR field-of-regard
 - ADS-B tracks outside of specified range, azimuth and elevation limits filtered out
 - Azimuth +/- 110°
 - Elevation +/- 15°
 - Range was variable in scripted encounter and set to 2.5 nmi in full mission
 - Sensor noise not simulated - ADS-B uncertainty used
 - Previous research investigated the effects of sensor uncertainty*

*Rorie, Shively, Fern, Santiago, Consiglio, Mueller. 2015. *UAS Integration in the NAS Project Part Task 5 DAA Display Evaluation Primary Results*.



SCRIPTED ENCOUNTERS RESULTS

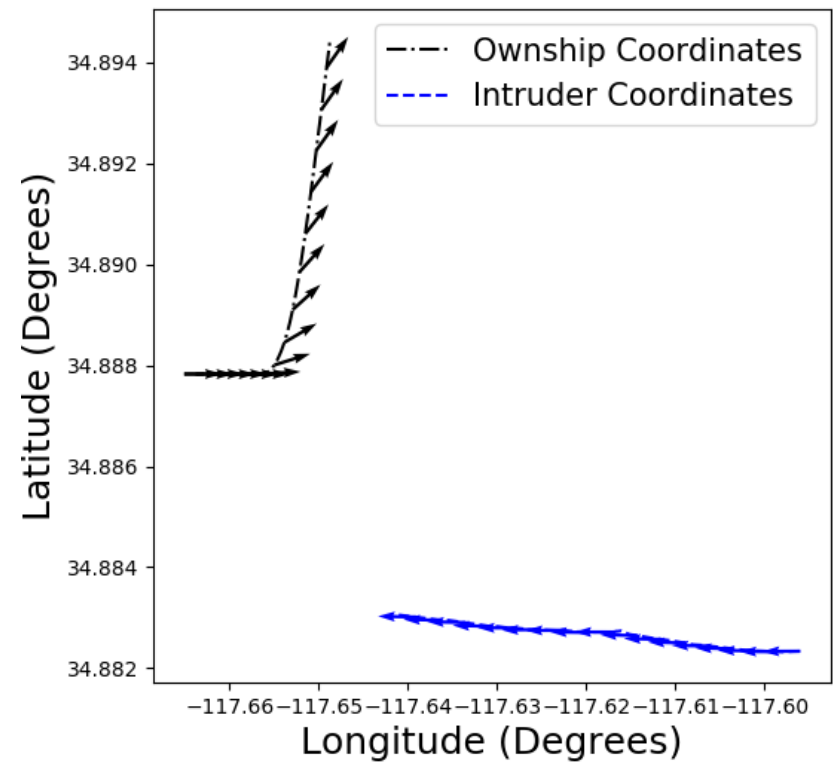
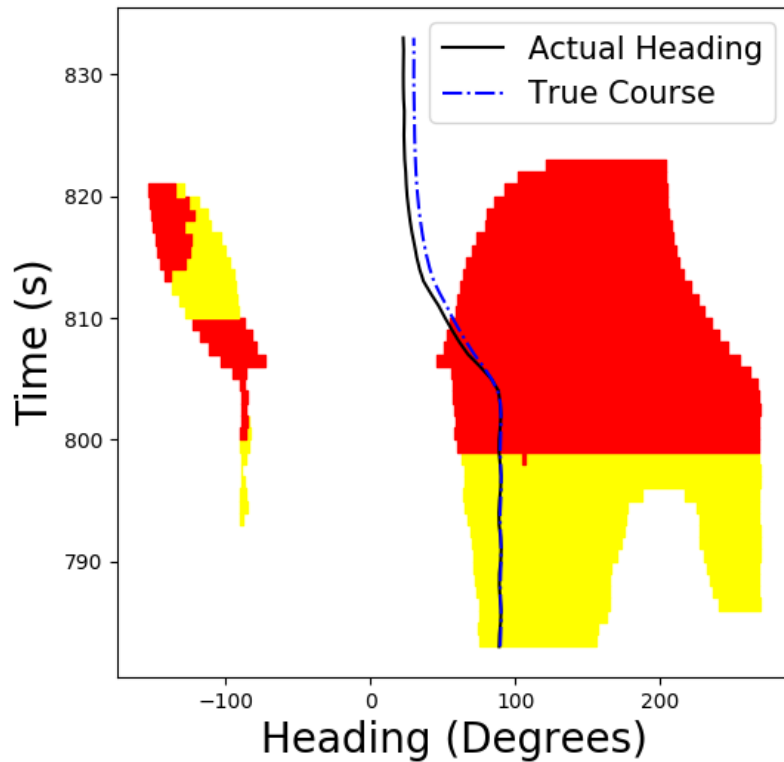


Scripted Encounters Flight Cards Summary

- Breakdown by simulated surveillance range (ADS-B)
 - 2.0 nmi surveillance range: 19 flight cards
 - 2.5 nmi surveillance range: 36 flight cards
 - 3.5 nmi surveillance range: 35 flight cards
- Encounter Categorization
 - Pilot induced maneuver effectiveness: Whether pilot was able to extinguish DAA alert with maneuver
 - Wind error: Wind direction and magnitude changed during maneuver
 - Turn rate error: Vehicle turn rate did not meet 7°/second turn rate assumption
- Exclusion Criteria:
 - Inadequate alerts and guidance due to encounter setup or software issues
 - Timing is off
 - Unstable alerts due to unplanned maneuvers



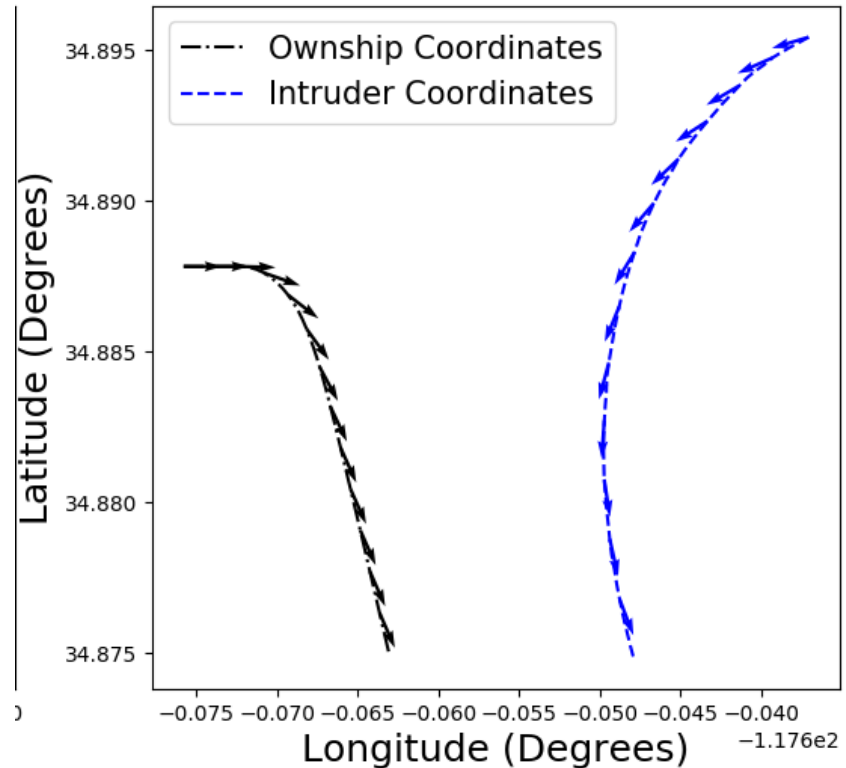
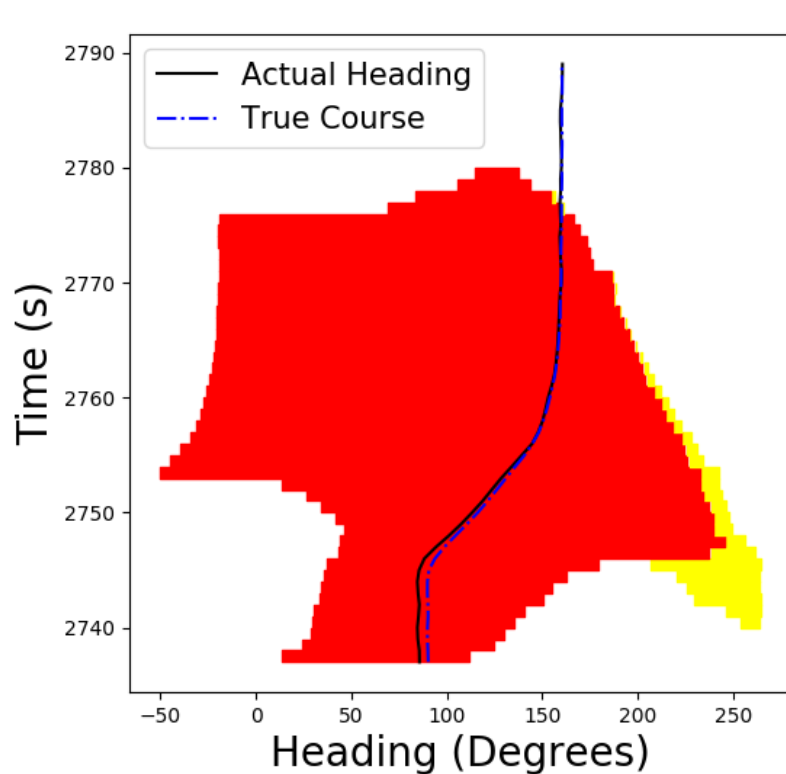
Pilot Induced Effective Maneuver



- Corrective initially displayed
- Pilot waited until warning alert was displayed to maneuver
- Selected a maneuver that required least amount of heading change
- Approximately 90° heading change
- Remained well-clear



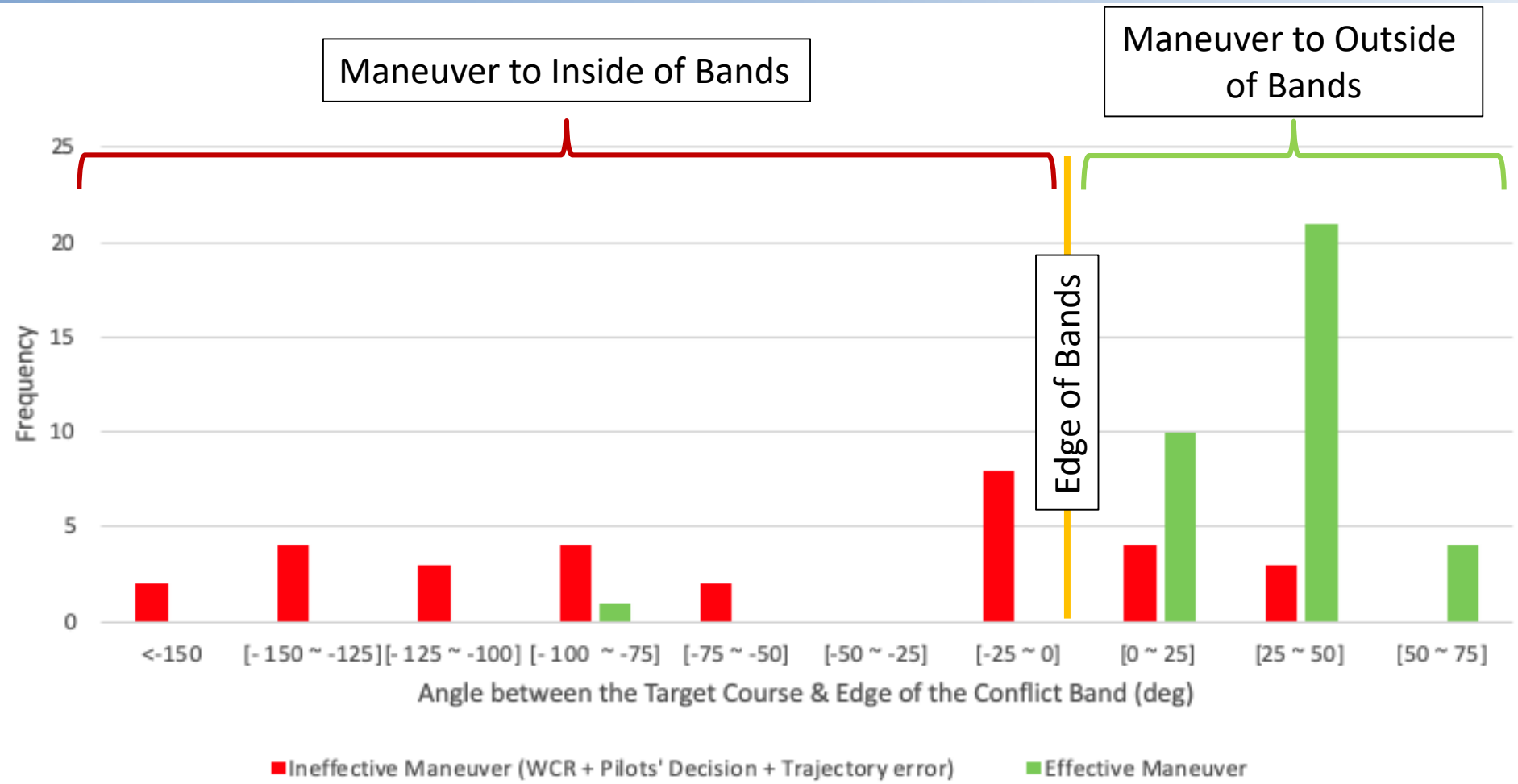
Pilot Induced Ineffective Maneuver



- Warning initially displayed due to intruder speed and surveillance range
- Selected a maneuver that required more heading change
- UAS and intruder ended up on similar headings – “tail chase”



Buffered Heading & Encounter Effectiveness



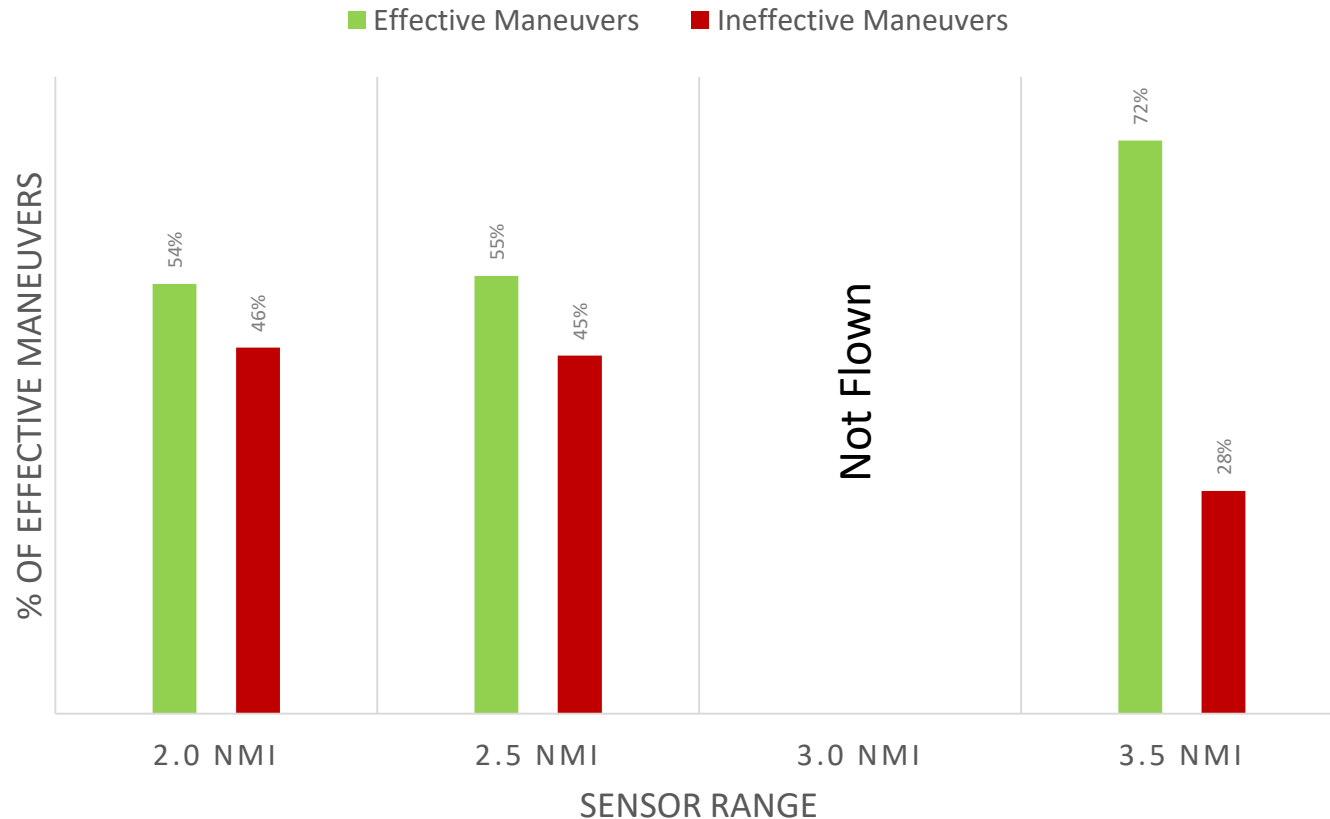
- Encounters with an additional buffer between the commanded heading and the edge of the heading band were more effective



Sensor Range and Maneuver Effectiveness

- Slightly More than half of encounters were effective with 2.0 and 2.5 nmi sensor ranges
- Significant jump in effective maneuvers at 3.5 nmi sensor range

SENSOR RANGE AND MANEUVER EFFECTIVENESS





Scripted Encounters Summary

- More than half of timely executed 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
- Benefits to adding maneuver "buffer" beyond the heading bands
 - Maneuvers are more effective when buffers are larger
- A challenging case: maneuvering intruders
 - Turning "in front" of intruder may be effective in some cases
 - An intruder maneuvering at the same time may "close the gate" to resolving the conflict
 - Accounting for intruder accelerations may improve predictions

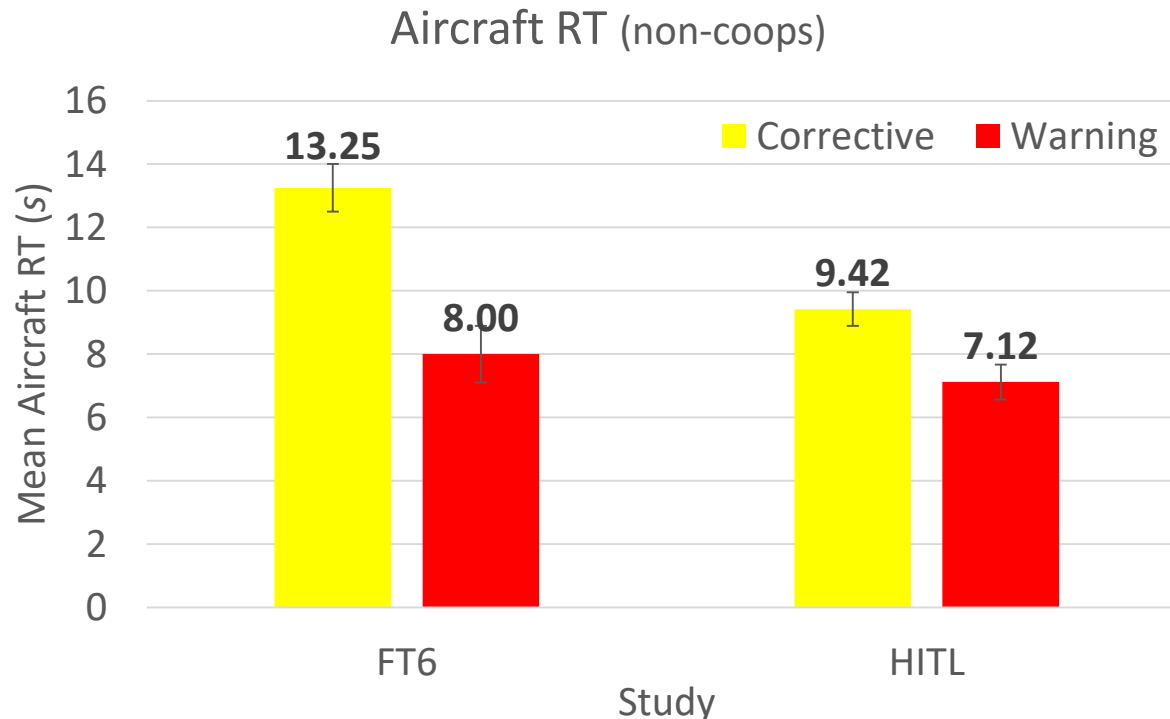


FULL MISSION RESULTS



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
- Reaction time (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)

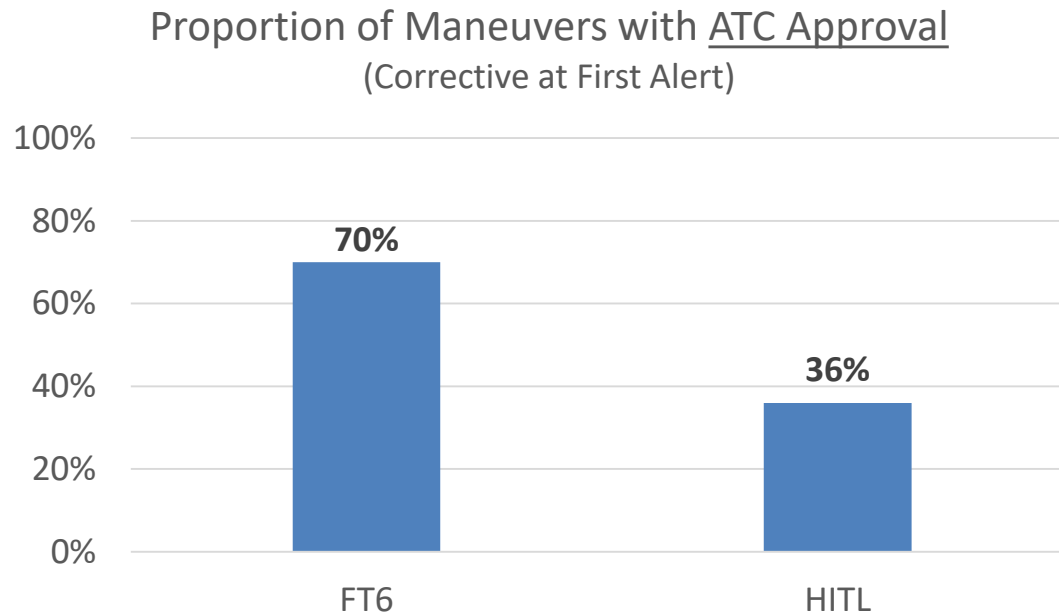


Aircraft response time – time elapsed from alert to first maneuver upload



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

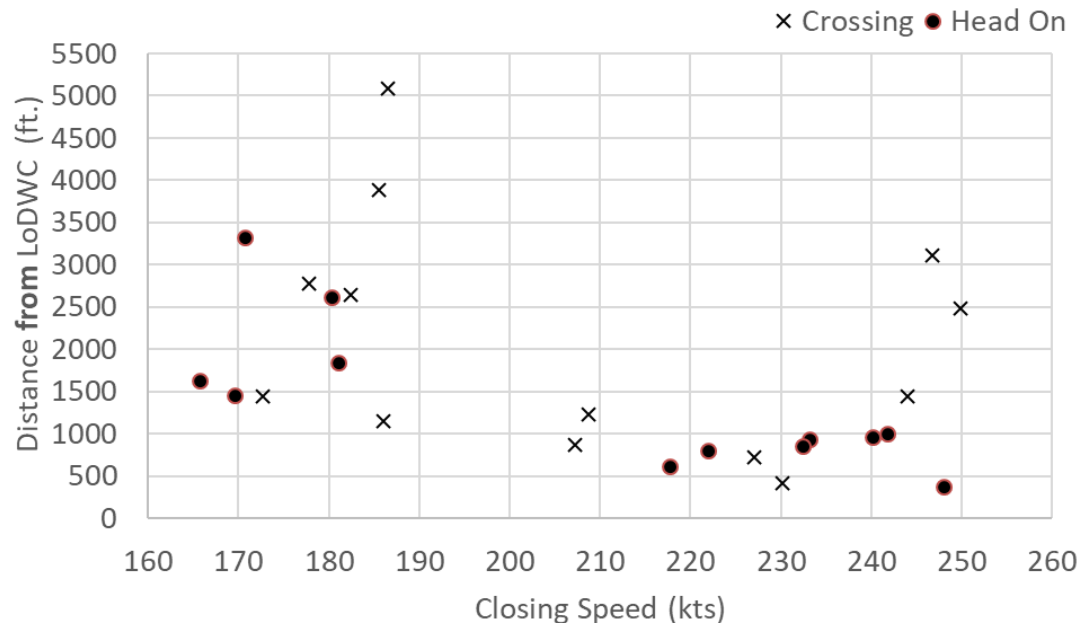




Separation Performance

- Zero Losses of DWC with either equipage
 - ‘Fast’ intruders accounted for the lowest closest points of approach
 - Closest call: 2577ft. Horz. (Fast Head On, 27sec-to-LoDWC @ 1st alert)
 - Unintentional button click delayed pilot’s response
 - Cooperative intruders predictably had higher closest points of approach due to unrestricted detection range
 - Mean Cooperative CPA: 8628 ft.
 - Mean Non-cooperative CPA: 4729 ft.

Geographic Horizontal Separation at Closest Point





Field of Regard (FOR) Considerations

- Intruder fell out of FOR during 26 of 27 avoidance events
 - 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, symbols 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 Clear of Conflict	Avg. Turn Size (Fast Intruders)
FT6	11/27 (41%)	128deg
HITL	9/36 (25%)	90 deg

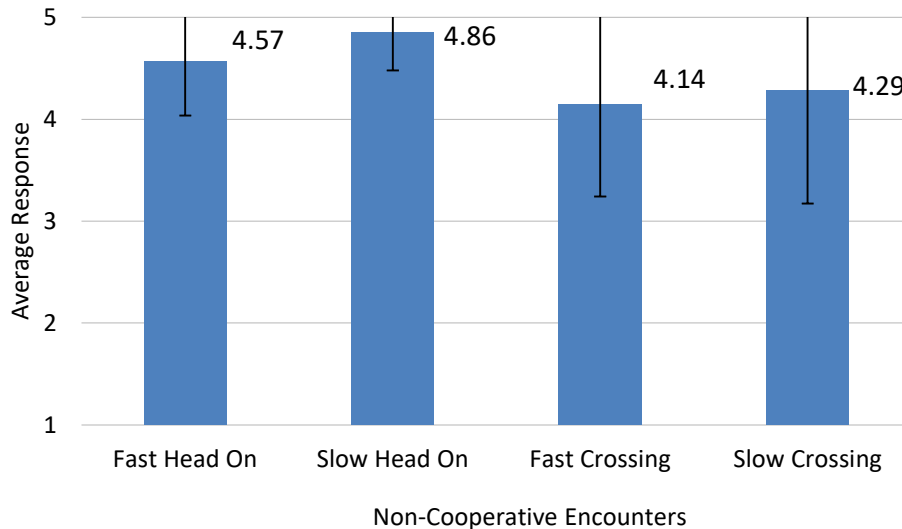


Post-Encounter

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

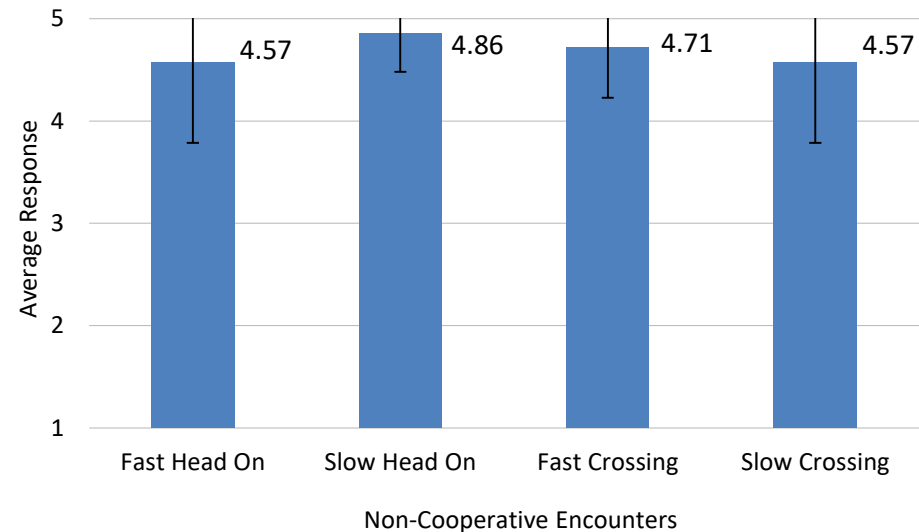
I was able to achieve sufficient separation from the intruder aircraft(s) using the alerting and guidance in this encounter:

1 = Strongly Disagree, 5 = Strongly Agree



The DAA guidance bands were useful for solving this encounter:

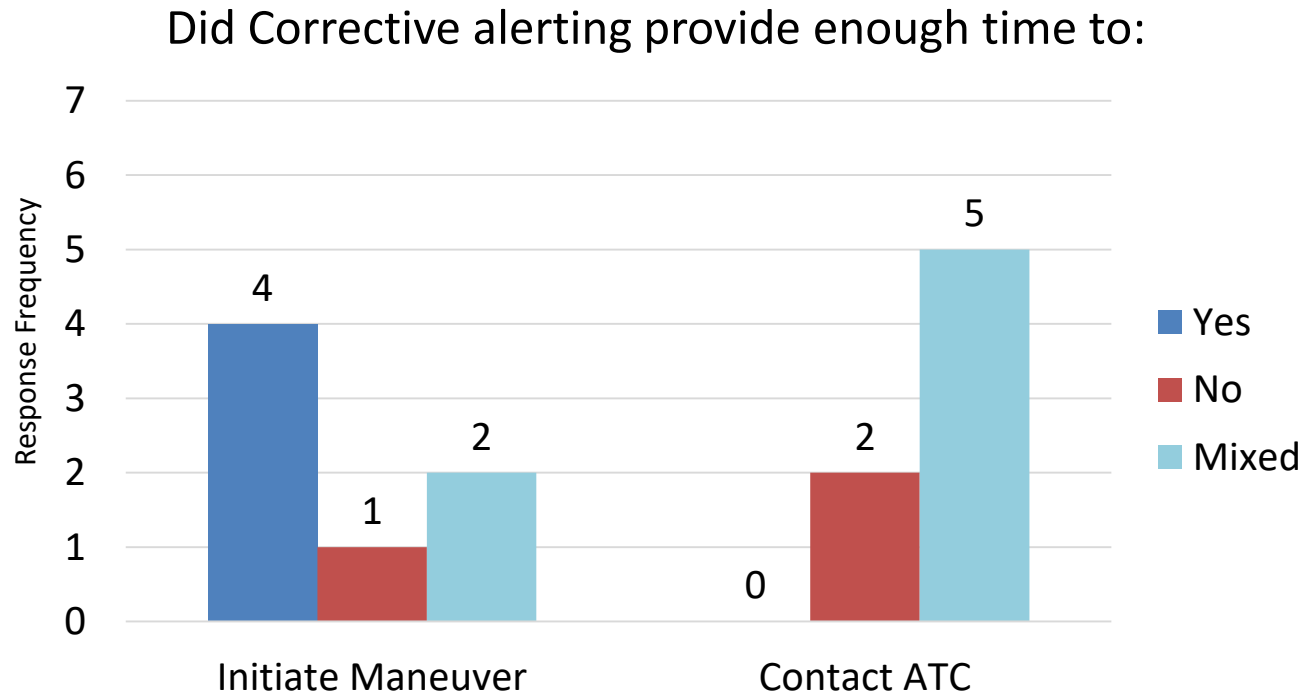
1 = Strongly Disagree, 5 = Strongly Agree





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”





Summary

- 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 often unable to respond to Corrective alerts
 - All but two encounters reached warning-level status
 - Larger path deviations & more time spent off course
 - Lost visual of intruder aircraft during all but one encounter
 - 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
 - More conservative on minimally-acceptable RDR during debrief
 - Pilots desired at least 3NM despite high subjective performance at 2.5NM
 - Factors: closure rate, necessity of ATC coordination, vigilance decrement



Special Thanks To....

- AFRC

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- Rocky Garcia
- Hernon Posada
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- Zach Roberts
- Andrew Cone
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- Stephen Hamilton
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- Bryan Hazlett
- Tia Williams
- Emily Fox
- Charles Zera

- Honeywell

- Jamal Haque
- Marc Pos
- John Ihlen
- Eric Euteneuer

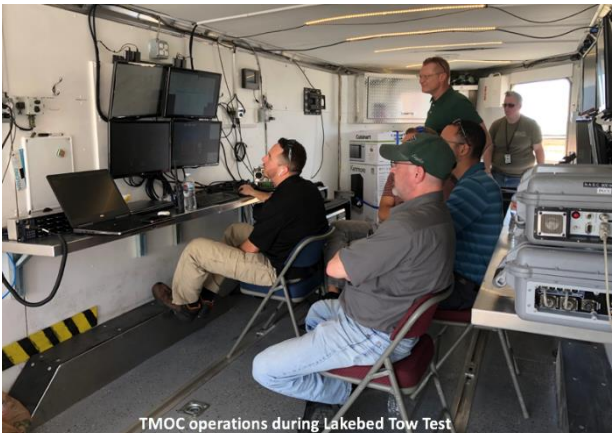


End



[NASA X Video](https://youtu.be/3b113o_dT5o)

https://youtu.be/3b113o_dT5o





QUESTIONS?



BACKUP