National Aeronautics and Space Administration

Flight Test 4 JADEM Preliminary Results: NASA Ames SSI

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Outline

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- NASA Ames SSI Objectives and Scenario Preparation
- Sample Scenario Analysis
- Preliminary Findings
  - FT4 Evaluation Criteria Compliance
  - DAA Alert Timing Analysis
  - Unexpected TCAS RAs
  - Mode C Intruder Guidance Stability
  - Well Clear Recovery Performance
- Lessons Learned & Recommendations

JADEM Alerting and Guidance

Flight Test 4 – Alerting Criteria

Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Alerting Time Threshold	Aural Alert Verbiage
	TCAS RA	• **Immediate action required** • Comply with RA sense and vertical rate • Notify ATC as soon as practicable after taking action	(Driven by TCAS-II)	x	"Climb/ Descend"
	DAA Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now"
	Corrective DAA Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
	Preventive DAA Alert	• On current course, corrective action ***should not be required*** • Monitor for intruder course changes • Talk with ATC if desired	DMOD = 1.0 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
	Remaining Traffic	• No action expected	Within surveillance field of regard	X	N/A

Cooperative/Non-cooperative Alerting Structure

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	TCAS RA	"Climb/ Descend"
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now"
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	None (Target)	N/A

Alerting Hysteresis

- Section 2.2.4.2.4 Alerting: Any DAA alert **shall** persist for a minimum of four seconds, unless the intruder is declared a higher priority alert

- Evaluated = alert level evaluated by the algorithm based on state at specific time epoch
- Declared = alert level declared to pilot based on hysteresis requirement

Corrective alert prolonged

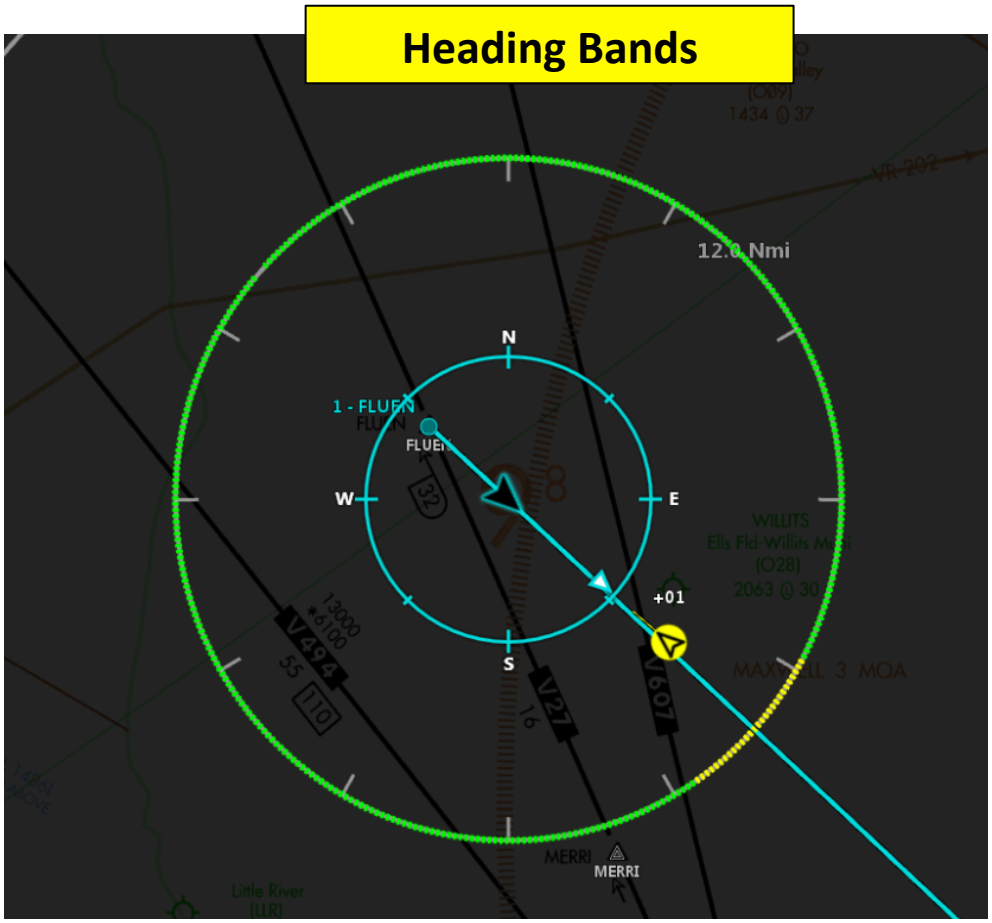
Warning alert prolonged

Preventive alert prolonged

Time	Evaluated	Declared
1	preventive	preventive
2	preventive	preventive
3	preventive	preventive
4	preventive	preventive
5	corrective	corrective
6	corrective	corrective
7	corrective	corrective
8	preventive	corrective
9	preventive	corrective
10	preventive	preventive
11	warning	warning
12	preventive	warning
13	preventive	warning
14	warning	warning
15	warning	warning
16	warning	warning
17	warning	warning
18	warning	warning
19	preventive	preventive
20	preventive	preventive
21	clear	preventive
22	clear	preventive
23	clear	preventive
24	clear	clear
25	clear	clear

Note: corrective is orange to visualize distinct colors

OmniBands



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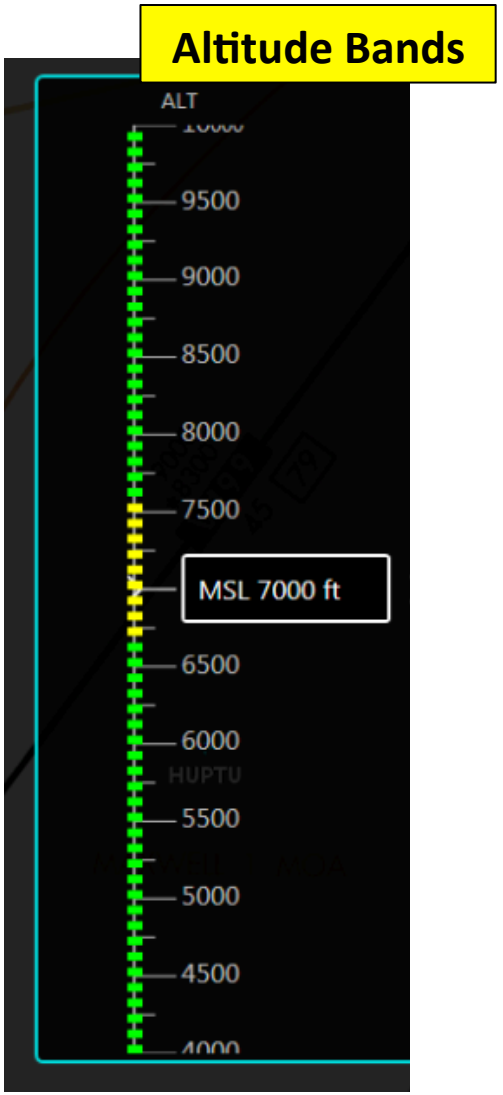
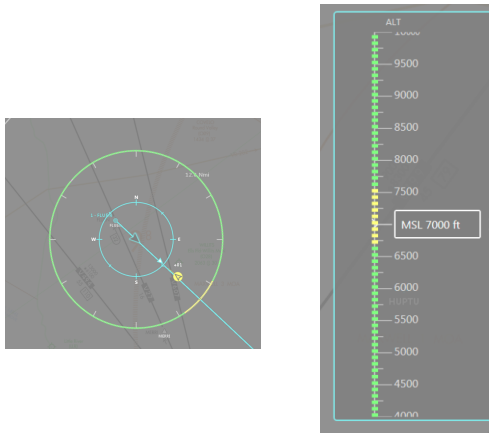


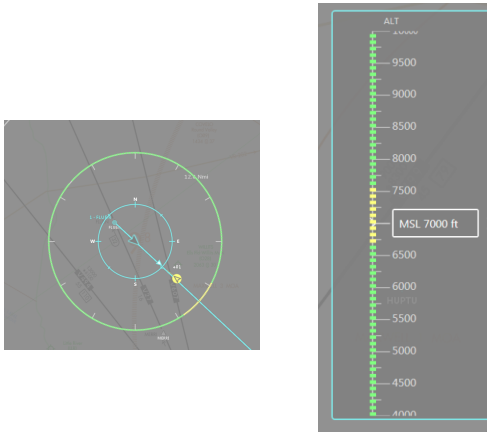
Guidance for Multiple Intruders

- Handles guidance for every intruder within field of view; generating individual heading and altitude bands based on alerting criteria for each intruder, then displaying the union of all bands into a single heading and altitude band

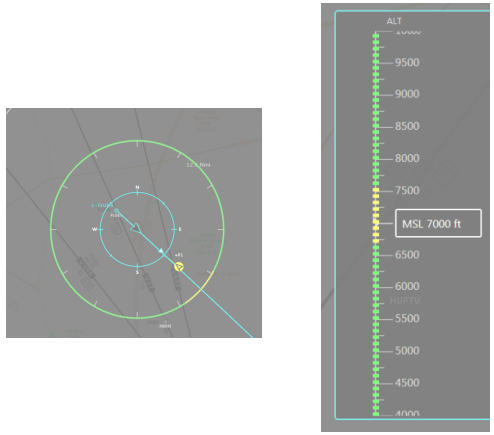
Intruder 1



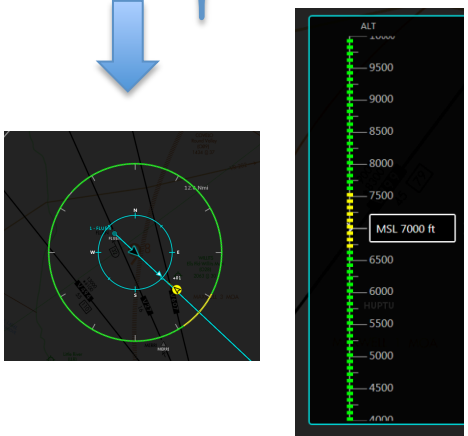
Intruder 2



Intruder N



Integrated together for all Intruders



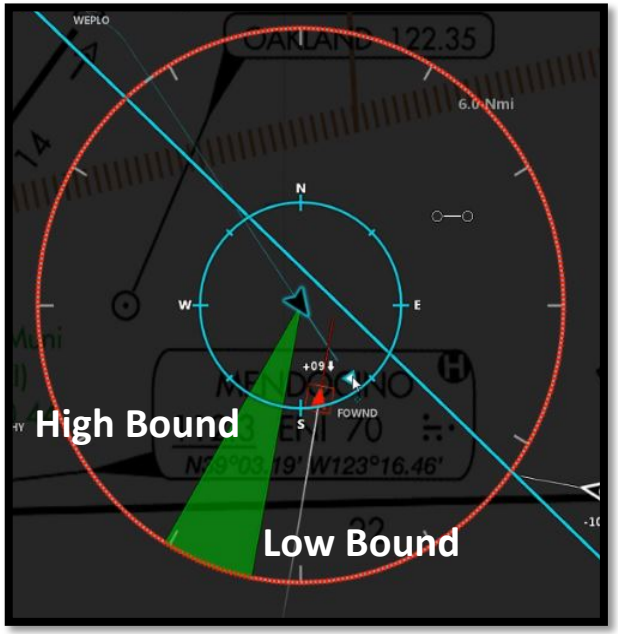
To display

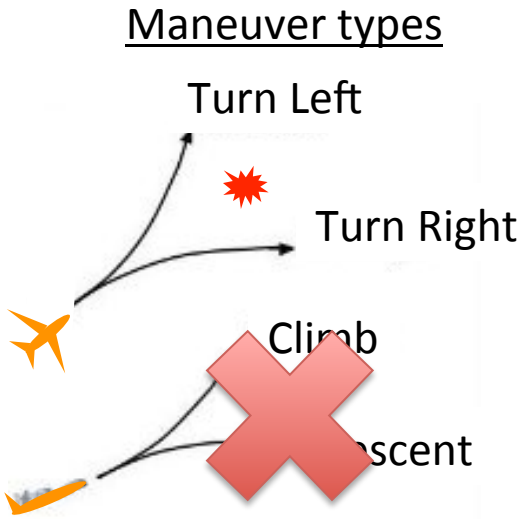
Other Features (Constraints)

- In calculating heading bands, considers a single user-specified turn rate for ownship aircraft (e.g. 3 degrees per second)
- In calculating altitude bands, considers a single user-specified climb and decent rate for ownship aircraft (e.g. 1,000 FPM)
- Limits heading bands by:
  - User-specified discretization: e.g. 1-degree intervals
  - User-specified heading range: e.g. +/- 110 degrees
- Limits altitude bands by:
  - User-specified discretization: e.g. 100 ft intervals
  - User-specified relative altitude range: e.g. +/- 3,000 ft
- Band Colors
  - Green Banding = heading/altitude is not predicted to lead to a loss of well clear
  - Yellow Banding = heading/altitude is predicted to cause a DAA Corrective Alert (i.e. potential loss of well clear in the next 25-55 seconds)
  - Red Banding = heading/altitude is predicted to lead to a DAA Warning Alert (i.e. potential loss of well clear in 25 seconds or less)

Well Clear Recovery Algorithm

- Well-Clear Recovery (WCR) provides guidance to *regain* Well Clear when no maneuvers are found to *remain* well clear (i.e., otherwise all-red OmniBands)
- WCR guidance is based on a general purpose conflict detection and resolution algorithm (GRACE, modified for FT4)
  - Evaluates multiple intruders for conflicts (threats) based on user-defined separation standards
  - Supports guidance provided by JADEM (e.g., for PT4/PT5/PT6, IHITL, OmniBands, WCR)
  - Generates a conflict avoidance maneuver of left, right (no vertical for FT4)
  - Selects the lowest cost conflict-free solution if one is found
  - Selects the lowest cost (conflicting) solution otherwise





Method: Well Clear Recovery Cost Function

- Near mid-air collision (NMAC) cost
  - Penalizes all maneuvers too close to NMAC violation for any intruder, i.e. maximizes normalized separation at new, predicted closest point of approach
  - This cost naturally dominates when close to collision, which is the case in WCR
- Maneuver change cost
  - Penalizes frequent changes of maneuver types
  - Can improve guidance stability in the presence of noise
- Maneuver type (rank) cost
  - Favors “right-of-way-like” compliant maneuvers
- Specific maneuver type costs (preferences)
  - Can selectively enforce or suppress specific maneuver types (e.g. NO CLIMBS)
- Maneuver strength cost
  - Penalizes too aggressive maneuvers (magnitude of heading or vertical speed change)
- Maneuver duration cost
  - Penalizes long deviations from flight plan

DAA/TCAS RA interoperability

- Any intruder with an active corrective RA should be removed from all DAA guidance calculations
  - Horizontal DAA guidance will be shown for non-RA aircraft
  - All DAA vertical guidance should be *suppressed* during a corrective RA to prevent showing conflicting guidance to the pilot
- During a preventive RA, TCAS guidance should be an input to the DAA vertical guidance so that it is consistent (e.g. DO NOT CLIMB)
- Well clear recovery is limited to horizontal only
  - Prevents pilots from making maneuvers near the collision avoidance boundary which may degrade TCAS II performance
  - For both 'cooperative' and 'non-cooperative' intruders
- Any time ownship's compliance with a corrective RA leads to a secondary DAA Warning alert (maneuver now), DAA guidance shall revert to well clear recovery in order to be more direct with guidance, e.g.:
  - Compliance with TCAS 'DESCEND' RA leads to a secondary DAA Warning
  - Rather than show pilot full OmniBands suggestive guidance, limited suggestive guidance is displayed (e.g. maneuver left)

NASA Ames SSI FT4 Test Objectives and Scenario Preparation

NASA Ames SSI FT4 Objectives

1. 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/S-only intruder (i.e. without ADS-B).

2. 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.

3. Validate 'Well Clear Recovery' guidance in the presence of realistic sensor, tracking and navigational errors.

4. Validate DAA alerting and guidance requirements in the presence of realistic sensor, tracking and navigational errors.

5. *Collect data to support development and validation of trajectories specified in the DAA MOPS for DAA system acceptance testing.*

Sample Scenario Template: 041-Am-S2M

FT4 TEST OBJECTIVES – SSIWest.2.g (FT4 encounter: 041)

Objective 2: Validate TCAS/DAA alerting and guidance interoperability concept in the presence of realistic sensor, tracking and navigational errors: (g) level-level TCAS RA encounters (mitigated, <10kft).	**MOPS Sections 2.2.4.2.4 Alerting 2.2.4.3 Determine Processing, 2.2.4.4 Collision Avoidance Interoperability**

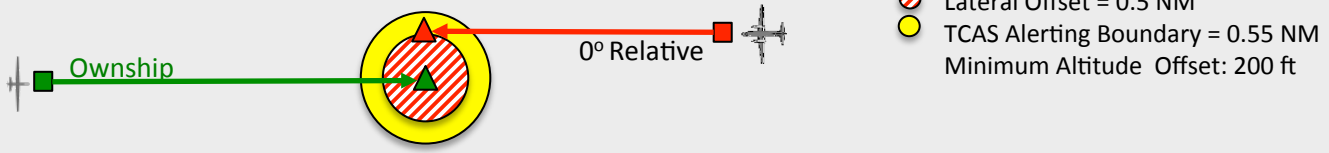
Configuration

System Under Test: Omnibands

Display: *VSCS*

Contributing Sensors:

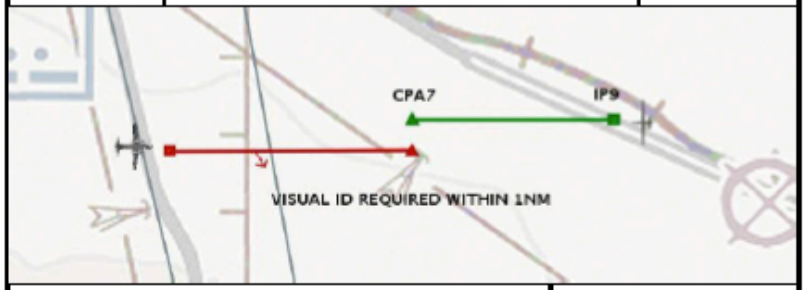
TCAS	ADS-B	Radar	Tracker
YES (S)	YES	YES	YES



Test Objectives (TO)	1. Validate DAA alert timing allows pilot sufficient time to assess options and maneuver to remain well clear. 2. Validate DAA guidance to UAS pilot is appropriate (reasonable, timely & responsive). 3. Validate DAA alerting and guidance do not interfere with UAS pilot's ability to assess and follow TCAS RA guidance.
Success Criteria (retest if criteria not met)	1. A timely (corrective initially) DAA alert is provided to the UAS pilot. 2. A corrective TCAS RA is generated for the primary intruder and the UAS pilot complies with TCAS RA guidance. 3. Data collected: LVC log file, SAAProc log files, TCAS log files for ownship and intruder, SAAP file ('raw' surveillance data).
Test Method	• MANUEVER: Pilot disregards DAA guidance and follows TCAS guidance if consistent with test constraints. • Aircraft speeds (non-accelerating): Ownship 150 KGS, Intruder 180 KGS • Encounter Length: 1 min (IP to CPA) • Stable Conditions: stable at the IP (1 minutes prior to CPA) • Test Termination Criteria: targets diverging, range > 0.75 nmi., no DAA alerts displayed. • Climb/Roll/Pitch Rates: Ownship 0/0/0, Intruder -2500 FPM/0/0 • Tolerance: ± 8 sec, ± 5 kts at IP crossing.
Evaluation Criteria (Post-test analysis to determine if test objectives are met)	1. UAS pilot receives DAA corrective alert with associated guidance. 2. Vertical DAA guidance indicates no viable vertical maneuvers in temporal proximity to TCAS RA. 3. DAA alerting and guidance for the primary intruder are removed while a TCAS RA is present for the primary intruder. 4. DAA alerting and guidance is generated once RA expires (if appropriate). 5. DAA alert(s) and guidance are removed once ownship is clear of threat.

Sample Scenario Card: 041-Am-S2M

FT4 DAA Scripted	A/C: NASA 870	S/N: 041	VERSION 4
CARD#	**041-Am-S2M**		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.

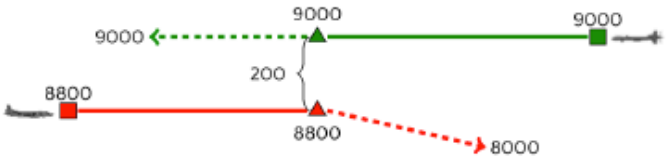
LOST LINK MISSION: 16

DECONFLICTION ALT: 9000

ADS-B IN:	OFF	IFF	TCAS	
DISPLAY:	JADEM	DAIDA.	CPDS	
MANEUVER:	OFF	Advisory	AUTO	
SENSOR SELECT:	Tracker	Radar	ADS-B	TCAS

ABORT PROCEDURE

9000	NAV TO LL WPT



COMEX TIME: IP WIND:

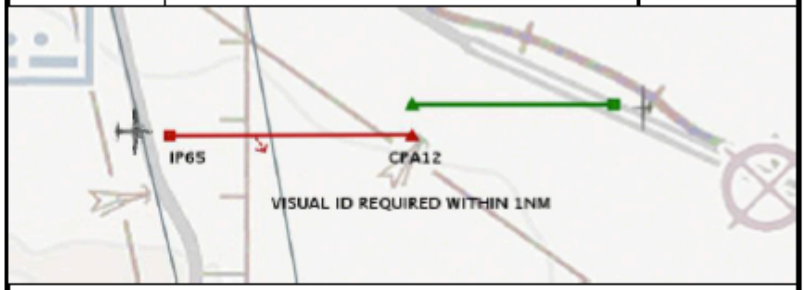
WPT	LATITUDE	LONGITUDE	ALT V/V	DIST MC	KGS	LEG TIME
IP9	N34° 57.09'	W117° 24.57'	9000	2.5	150	1+00
	N34° 57' 05.4"	W117° 24' 34.2"	0	258		
CPA7	N34° 57.09'	W117° 27.62'	9000	0.0	150	
	N34° 57' 05.4"	W117° 27' 37.2"	0	258		

NOTES: Ownship maneuver. Follow JADEM TCAS RA Guidance.

Maneuver:	YES	NO	
Guidance:	BANDS	WCR	TCAS
Direction:	Vertical		

TOLERANCE: ± 8 sec ± 5 kts

FT4 DAA Scripted	A/C: N3GC	S/N: 041	VERSION 4
CARD#	**041-Am-S2M**		INTRUDER 1



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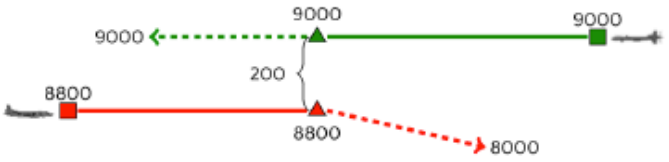
DECONFLICTION ALT: 8000

ABORT PROCEDURE

8000	RIGHT 123



COMEX TIME: IP WIND:

WPT	LATITUDE	LONGITUDE	ALT V/V	DIST MC	KGS	LEG TIME
IP65	N34° 56.69'	W117° 31.28'	8800	3.0	180	1+00
	N34° 56' 41.4"	W117° 31' 16.8"	0	078		
CPA12	N34° 56.69'	W117° 27.62'	8800	0.0	180	
	N34° 56' 41.4"	W117° 27' 37.2"	0	078		

NOTES: Expect Ownship maneuver.

TOLERANCE: ± 8 sec ± 5 kts

NASA Ames SSI FT4 Objectives

1. 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/S-only intruder (i.e. without ADS-B). (18 encounters)

2. 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. (29 encounters)

3. Validate 'Well Clear Recovery' guidance in the presence of realistic sensor, tracking and navigational errors. (9 encounters)

4. Validate DAA alerting and guidance requirements in the presence of realistic sensor, tracking and navigational errors. (16 encounters)

5. *Collect data to support development and validation of trajectories specified in the DAA MOPS for DAA system acceptance testing. (72 total encounters)*

Sample Scenario Analysis

041-Am-S2M

Test Objective Assessment: 041-Am-S2M

FT4 TEST OBJECTIVES – SSIWest.2.g (FT4 encounter: 041)

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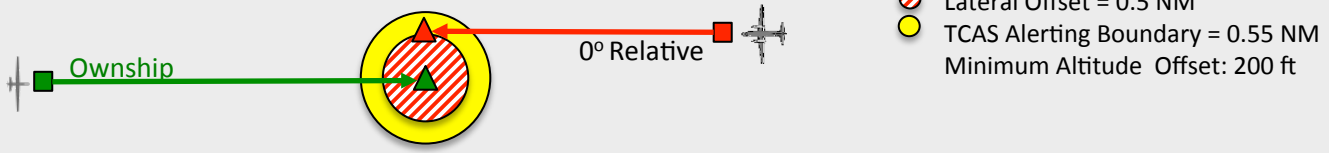

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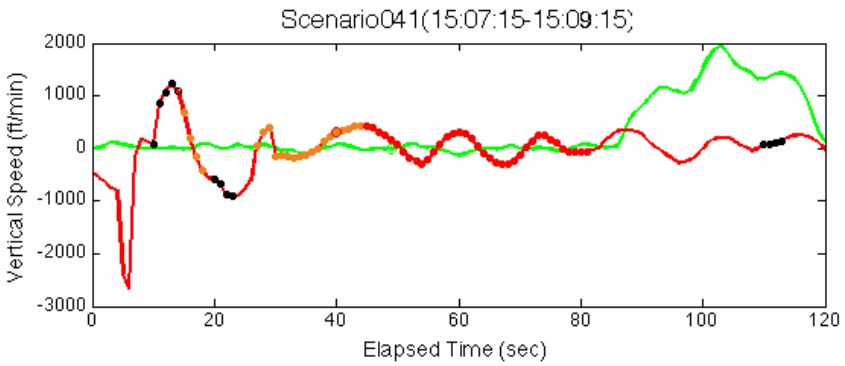
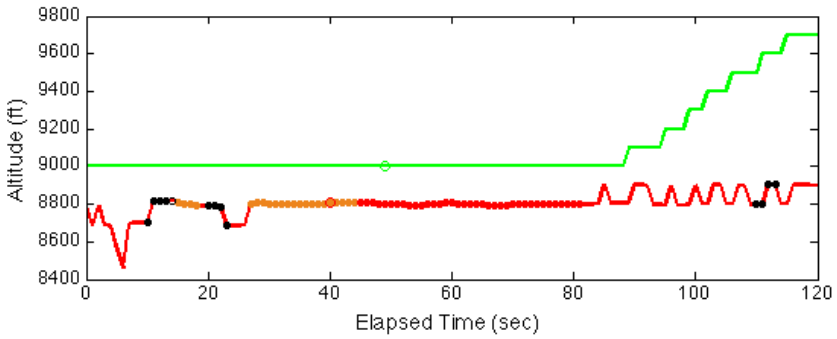
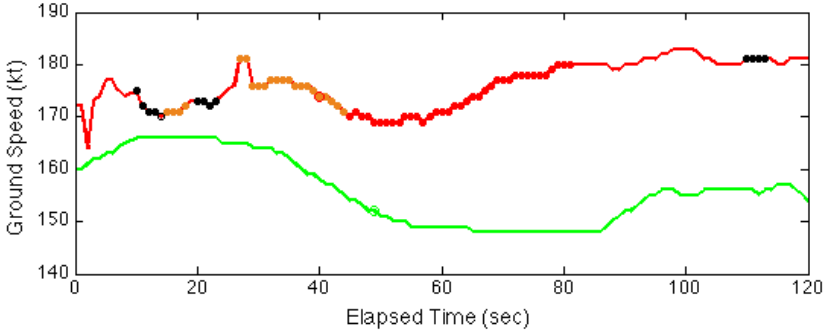
Scenario 041-Am-S2M: Event Data

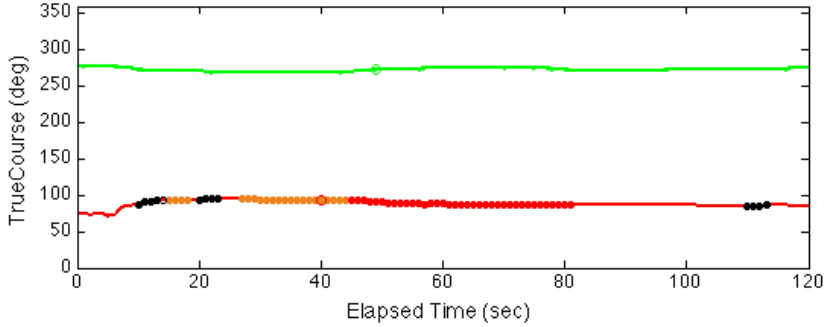
Cycle Count	Intruder	Time	Clock Time	Event
191	N3GC	1461942437.39	15:07:17	FIRST_TRACK
198	N3GC	1461942445.37	15:07:25	DAA_PREVENTATIVE
203	N3GC	1461942450.38	15:07:30	DAA_CORRECTIVE
208	N3GC	1461942455.41	15:07:35	DAA_PREVENTATIVE
215	N3GC	1461942462.35	15:07:42	DAA_CORRECTIVE
233	N3GC	1461942480.40	15:08:00	DAA_WARNING
257	n/a	1461942504.39	15:08:24	WCR_TURN_RIGHT
258	N3GC	1461942505.38	15:08:25	LOWC
270	N3GC	1461942518.39	15:08:38	TCAS_CLIMB
291	N3GC	1461942539.39	15:08:59	CPA
291	N3GC	1461942539.39	15:08:59	TCAS_LEVEL_OFF
296	N3GC	1461942544.36	15:09:04	TCAS_AA_CLEAR
297	N3GC	1461942545.39	15:09:05	DAA_PREVENTATIVE
297	N3GC	1461942545.39	15:09:05	REGAIN_WC
300	N3GC	1461942548.40	15:09:08	FINAL_ALERT
308	N3GC	1461942556.36	15:09:16	LAST_TRACK

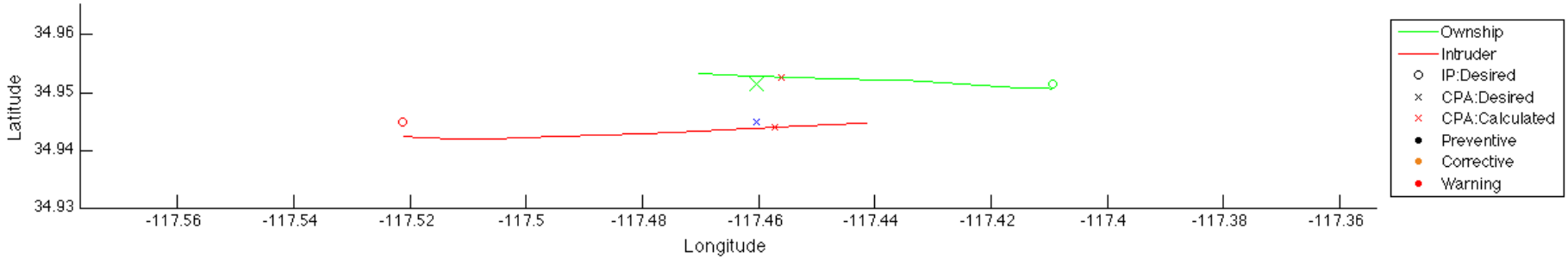
Scenario 041-Am-S2M: State Data



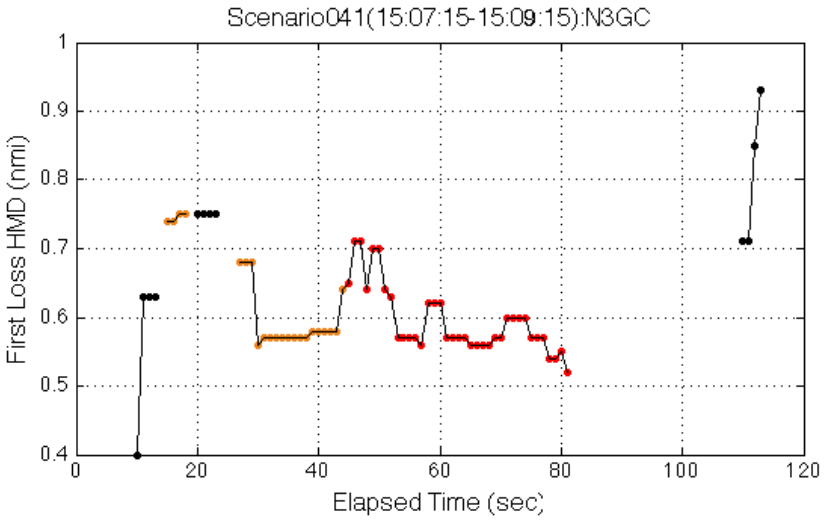


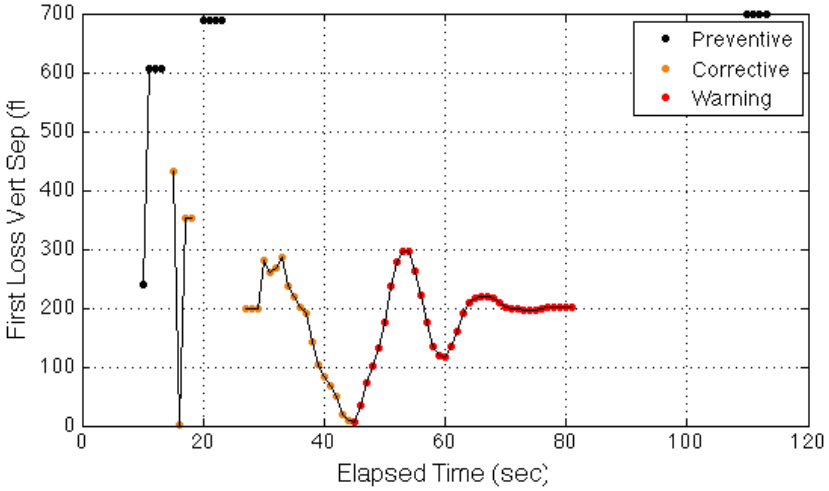


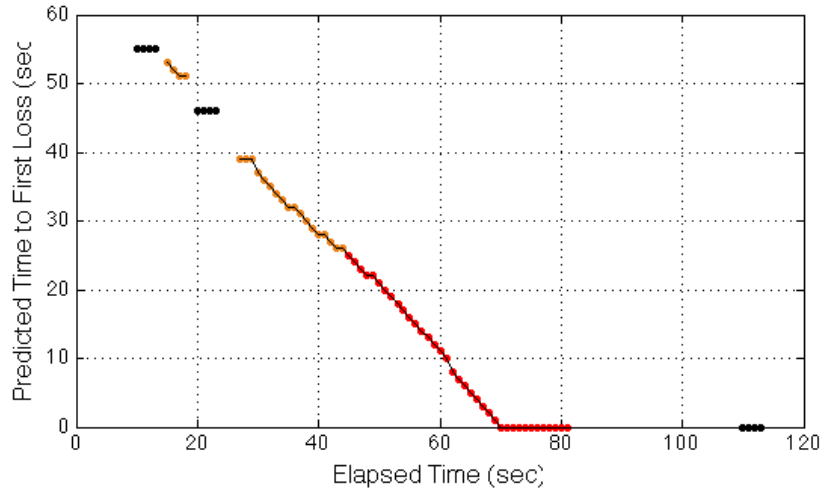


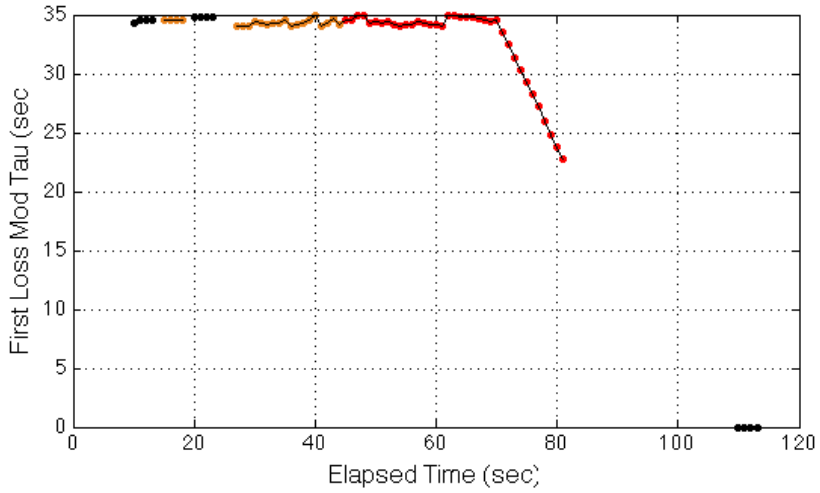


Scenario 041-Am-S2M: Threat Data

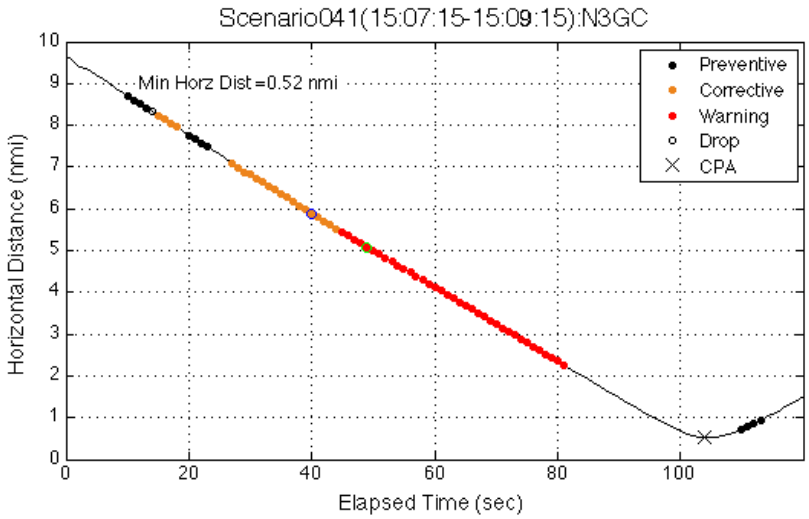


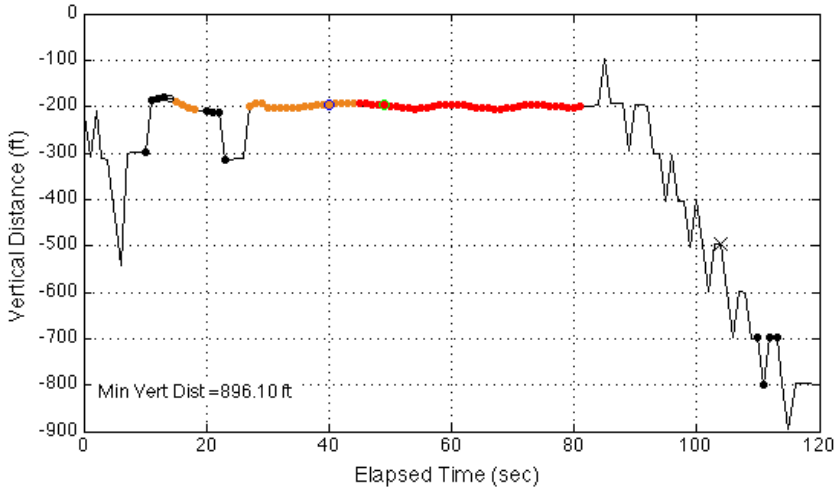


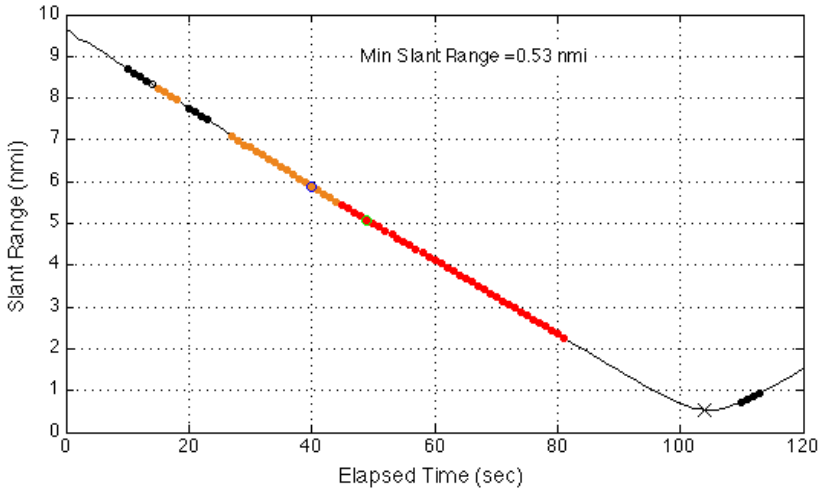


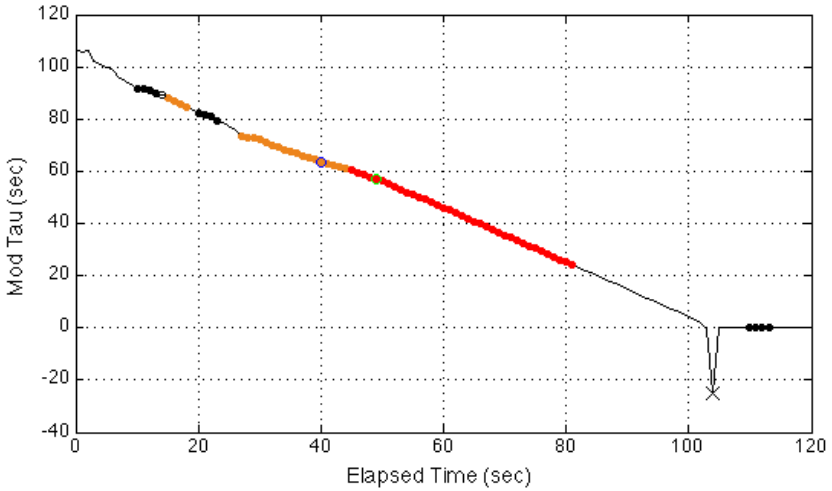


Scenario 041-Am-S2M: Encounter Data

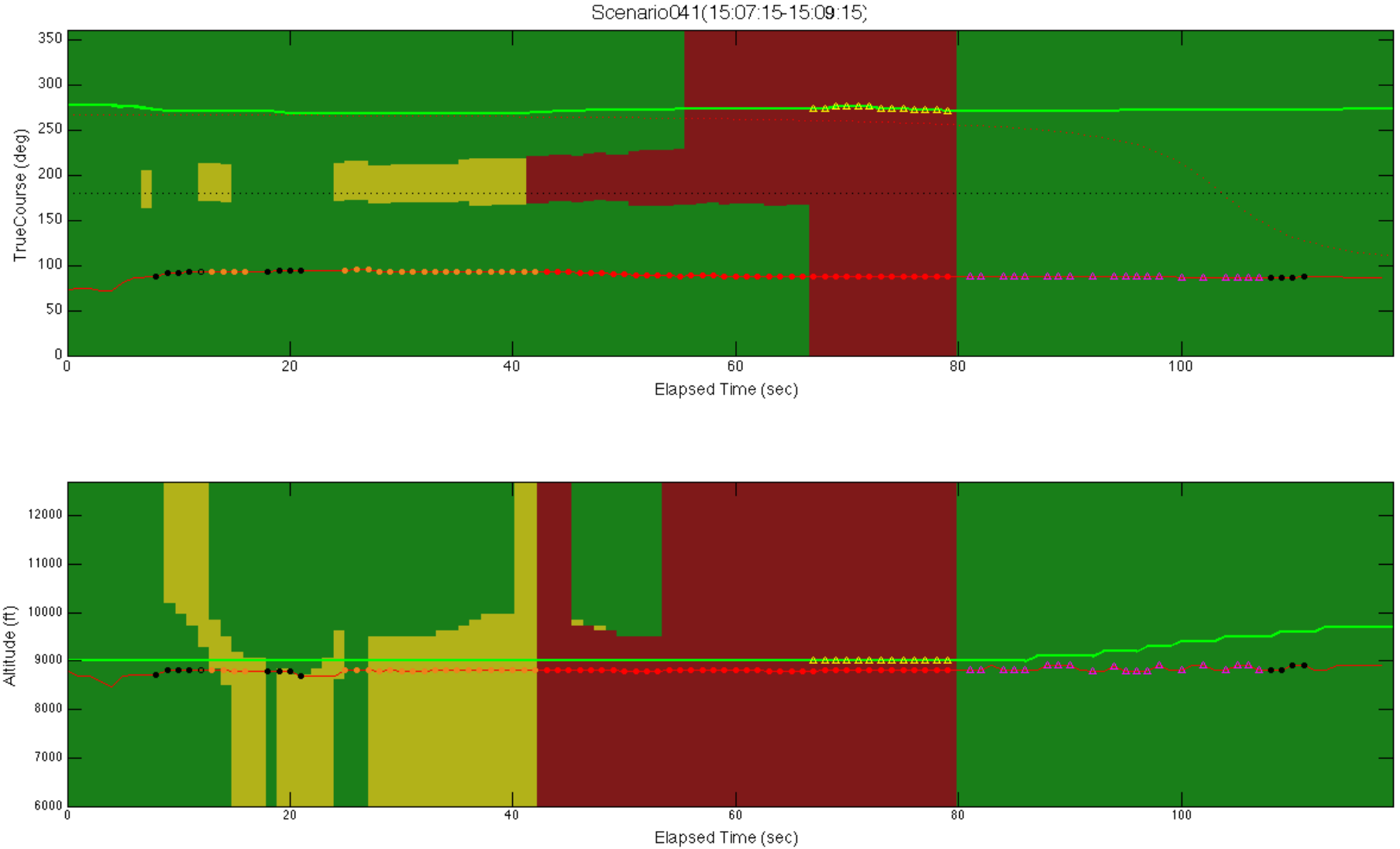




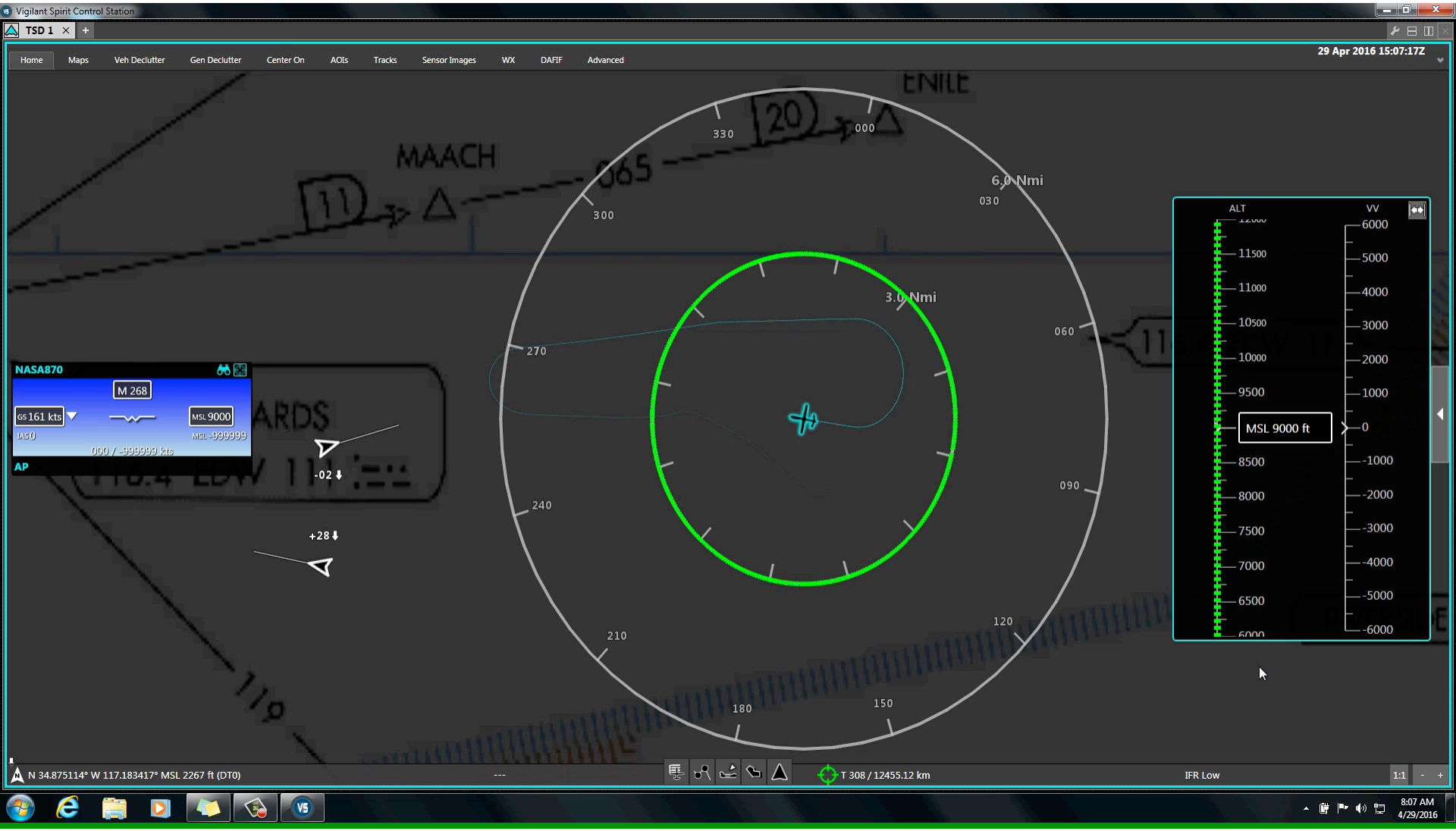




Scenario 041-Am-S2M: Guidance Data



Scenario 041-Am-S2M: VSCS Recording



Preliminary Results

FT4 Evaluation Criteria Compliance

Scenario number	Generated Corrective Alert	Remained Well Clear	DAA Alerts Removed	DAA Alerts After RA	No DAA Alert or Guidance During TCAS RA	Generated WCR Guidance	WCR maneuver and Regain Well Clear	Timely TCAS Maneuver
7	TRUE	TRUE	TRUE	n/a	n/a	n/a	n/a	n/a
9	TRUE	TRUE	TRUE	n/a	n/a	n/a	n/a	n/a
10	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a
12	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a
13	TRUE	TRUE	TRUE	n/a	n/a	n/a	n/a	n/a
14	TRUE	FALSE	TRUE	n/a	n/a	n/a	n/a	n/a
15	TRUE	TRUE	TRUE	n/a	n/a	n/a	n/a	n/a
16	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a
17	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a
18	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a
19	TRUE	n/a	TRUE	n/a	TRUE	n/a	n/a	TRUE
20	TRUE	n/a	TRUE	TRUE	TRUE	n/a	n/a	n/a
21	TRUE	n/a	TRUE	n/a	TRUE	n/a	n/a	TRUE
22	TRUE	n/a	TRUE	TRUE	TRUE	n/a	n/a	n/a
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36	TRUE	n/a	TRUE	TRUE	TRUE	n/a	n/a	n/a
37	TRUE	n/a	TRUE	TRUE	TRUE	n/a	n/a	n/a
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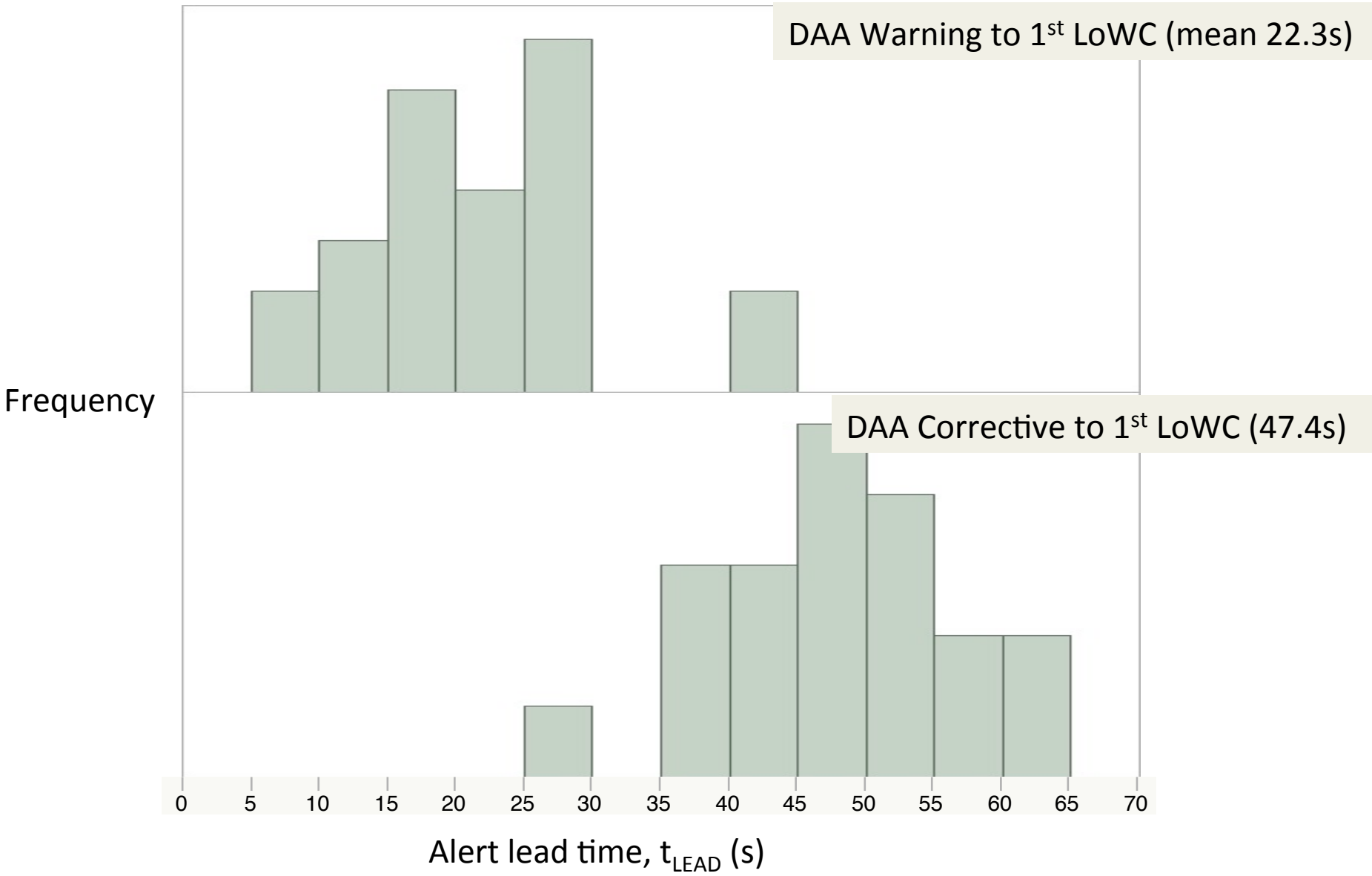
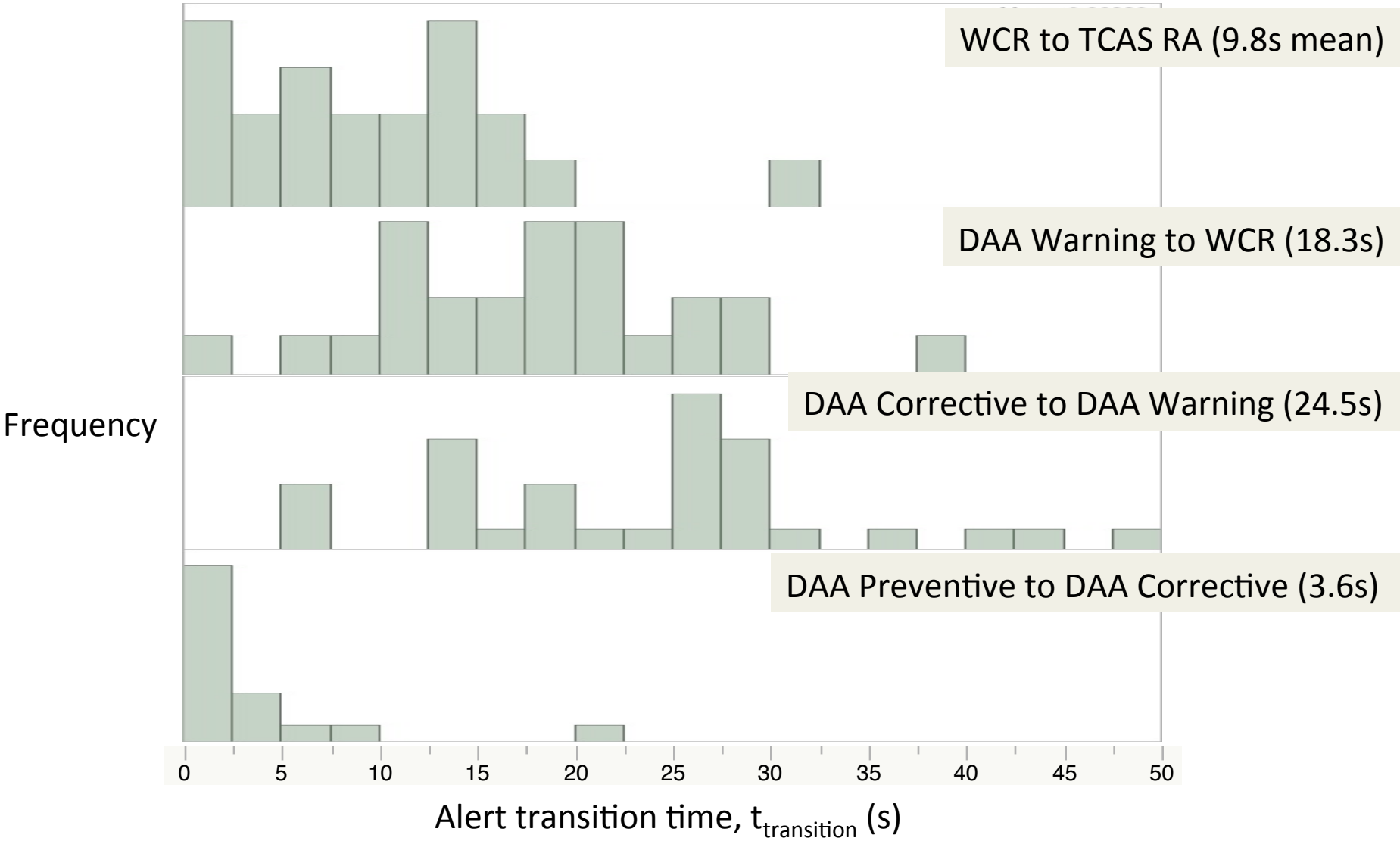
71	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a
71	TRUE	n/a	TRUE	n/a	n/a	n/a	n/a	n/a

DAA Alert Lead Time (unmitigated)



DAA Alert Transition Time (unmitigated)



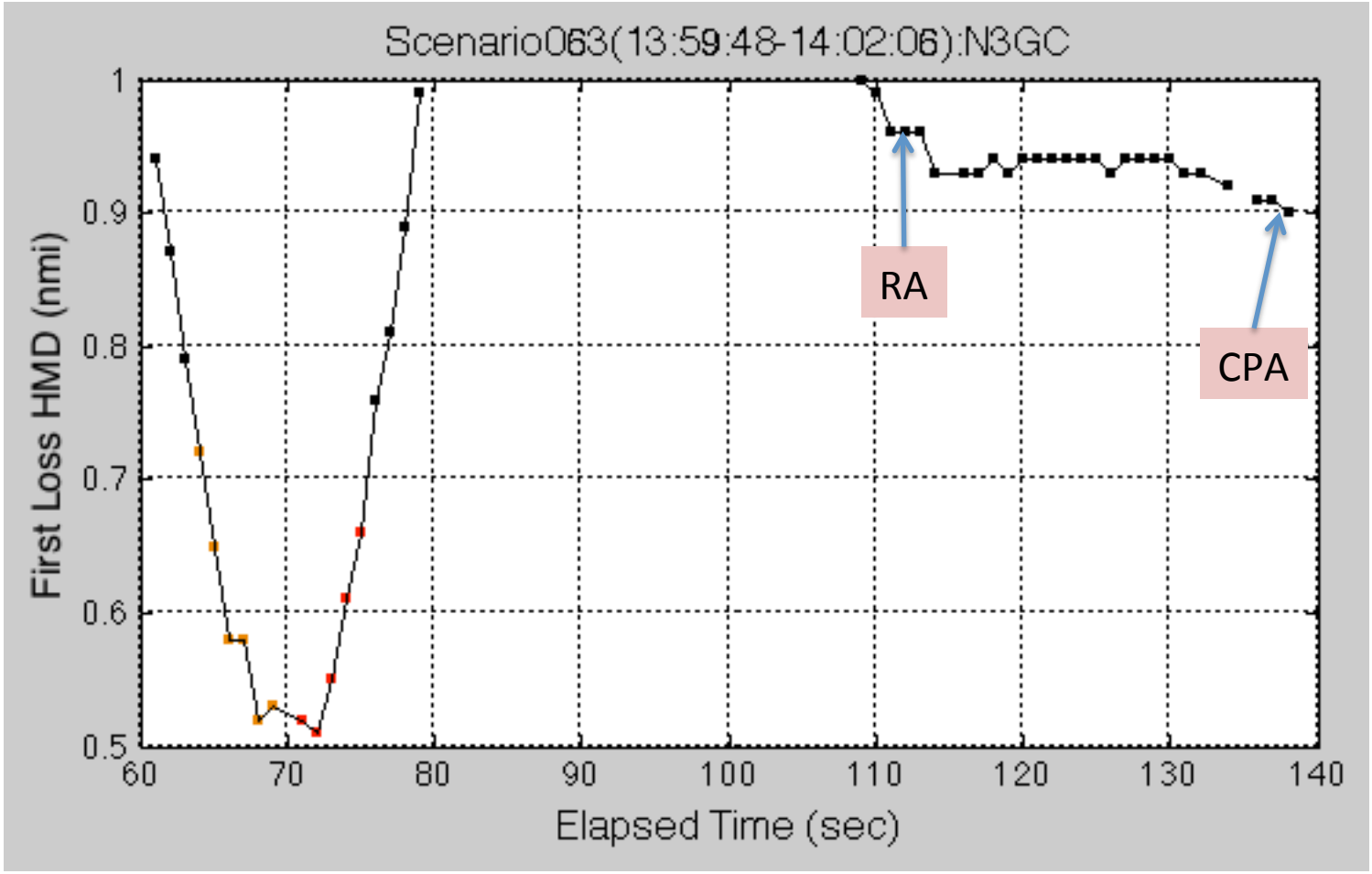
Unexpected TCAS RAs

- Definition: a corrective RA is generated while DAA guidance and alerting indicates no maneuver is necessary to remain Well Clear

- Two observed unexpected TCAS RAs
  - Scenario 063 (maneuvering intruder to 45° intercept)
  - Scenario 047 (multi-intruder TCAS/WCR, primary intruder)
  - Both cases predicted HMD > 0.9nm at time of TCAS RA
  - Presumed TCAS bearing error led to TCAS RA while not meeting corrective or warning DAA HMD criteria (to be verified)

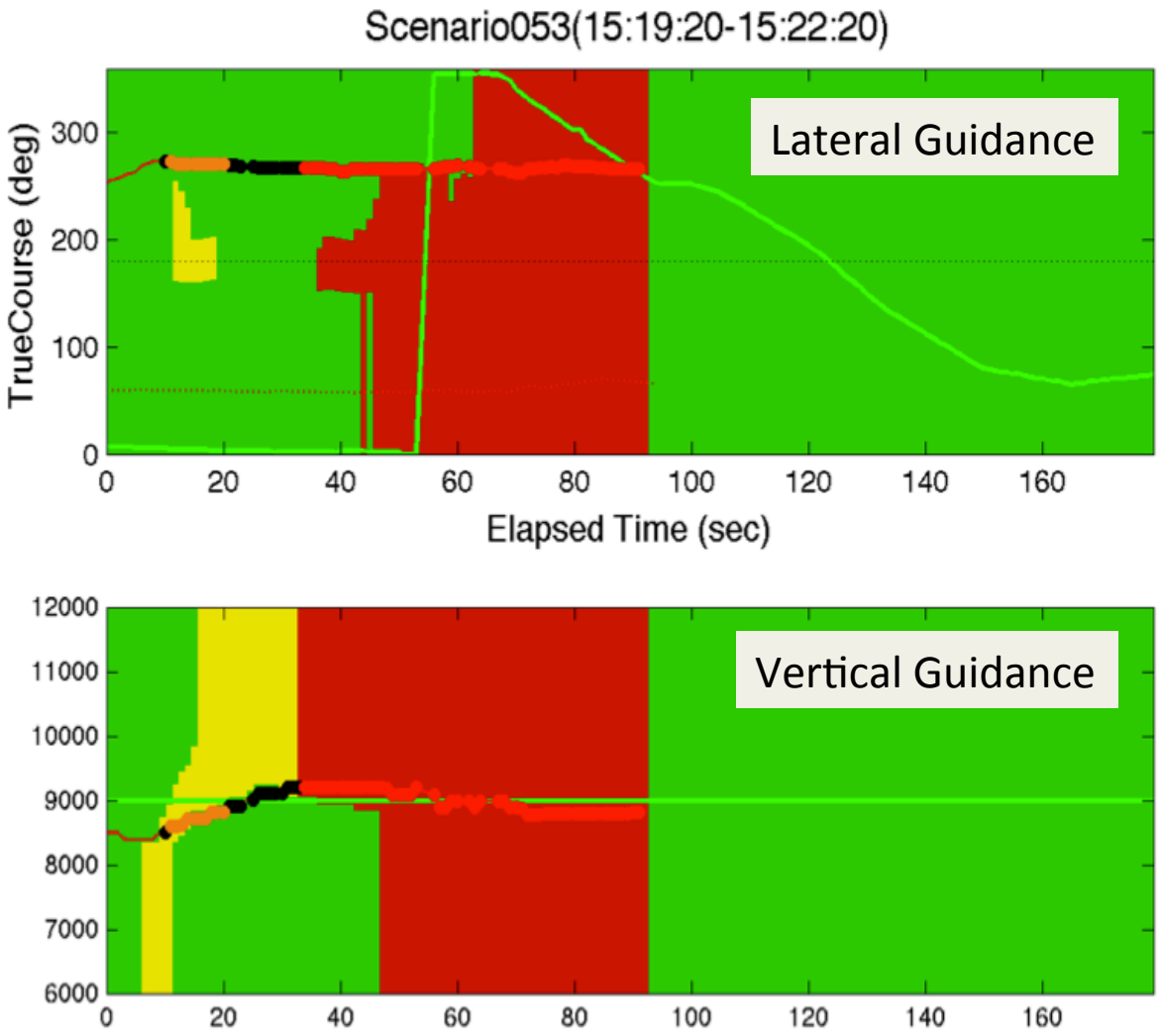
Sample Unexpected TCAS RA

Scenario 063 (TCAS RA @ 112s elapsed time)



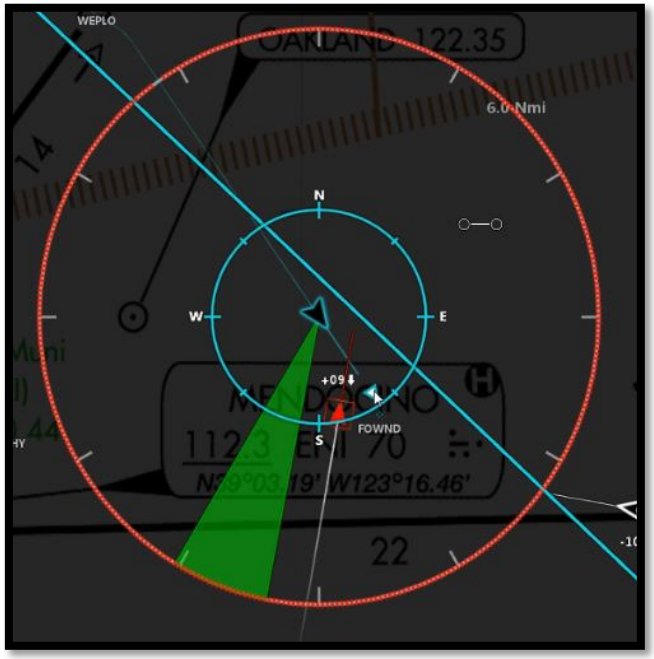
Guidance Stability for Mode C Intruders

- Some guidance instability was expected due to Mode C bearing error.
- Only 3 encounters included Mode C w/o ADS-B surveillance.
- Stable OmniBands guidance was observed in all 3 encounters.
- Bearing errors in integrated track are reduced within radar range.
- Intruder was within radar range for duration of encounter



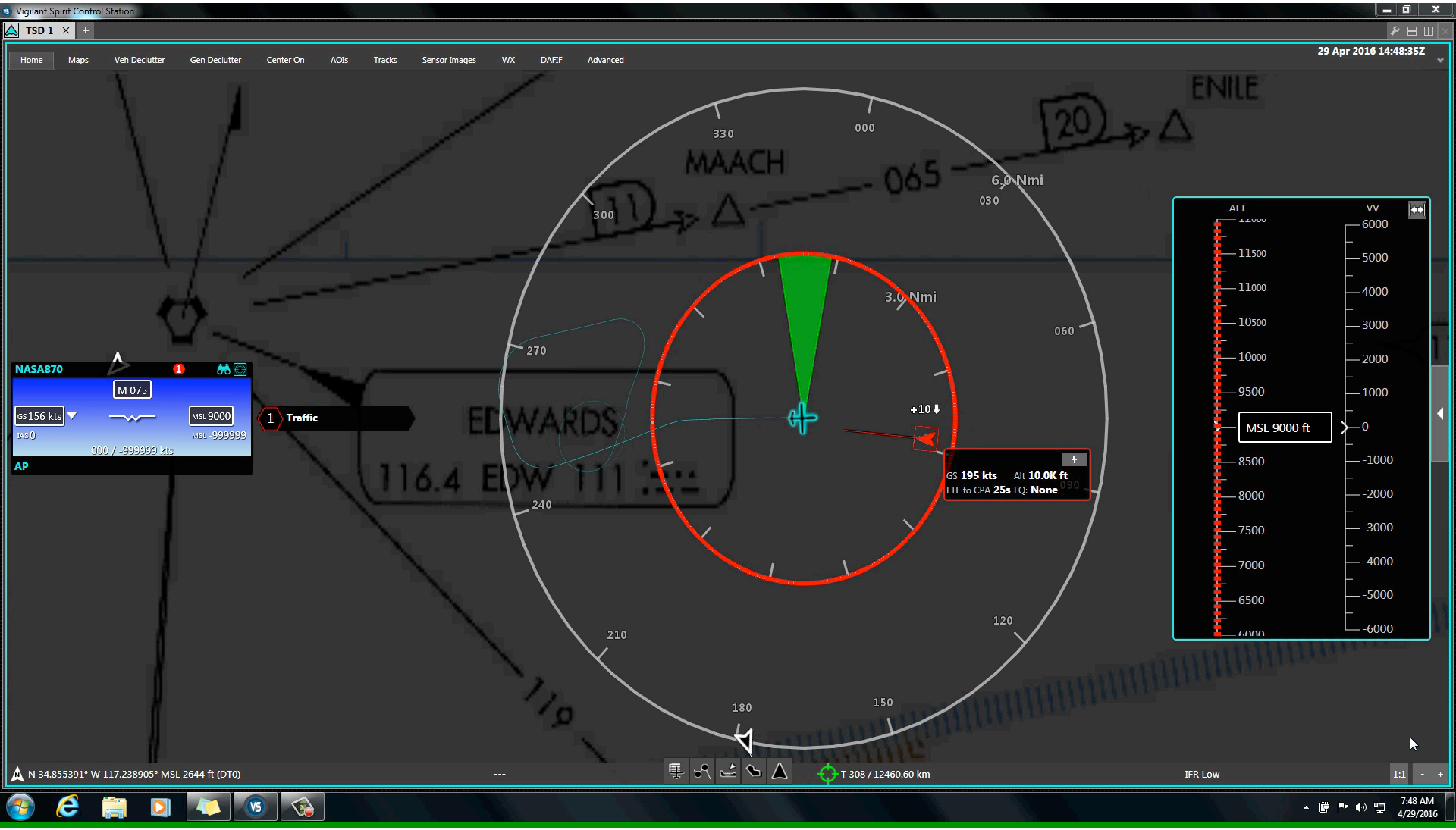
Well Clear Recovery Performance

Well Clear Recovery (WCR) guidance was observed to be of limited utility

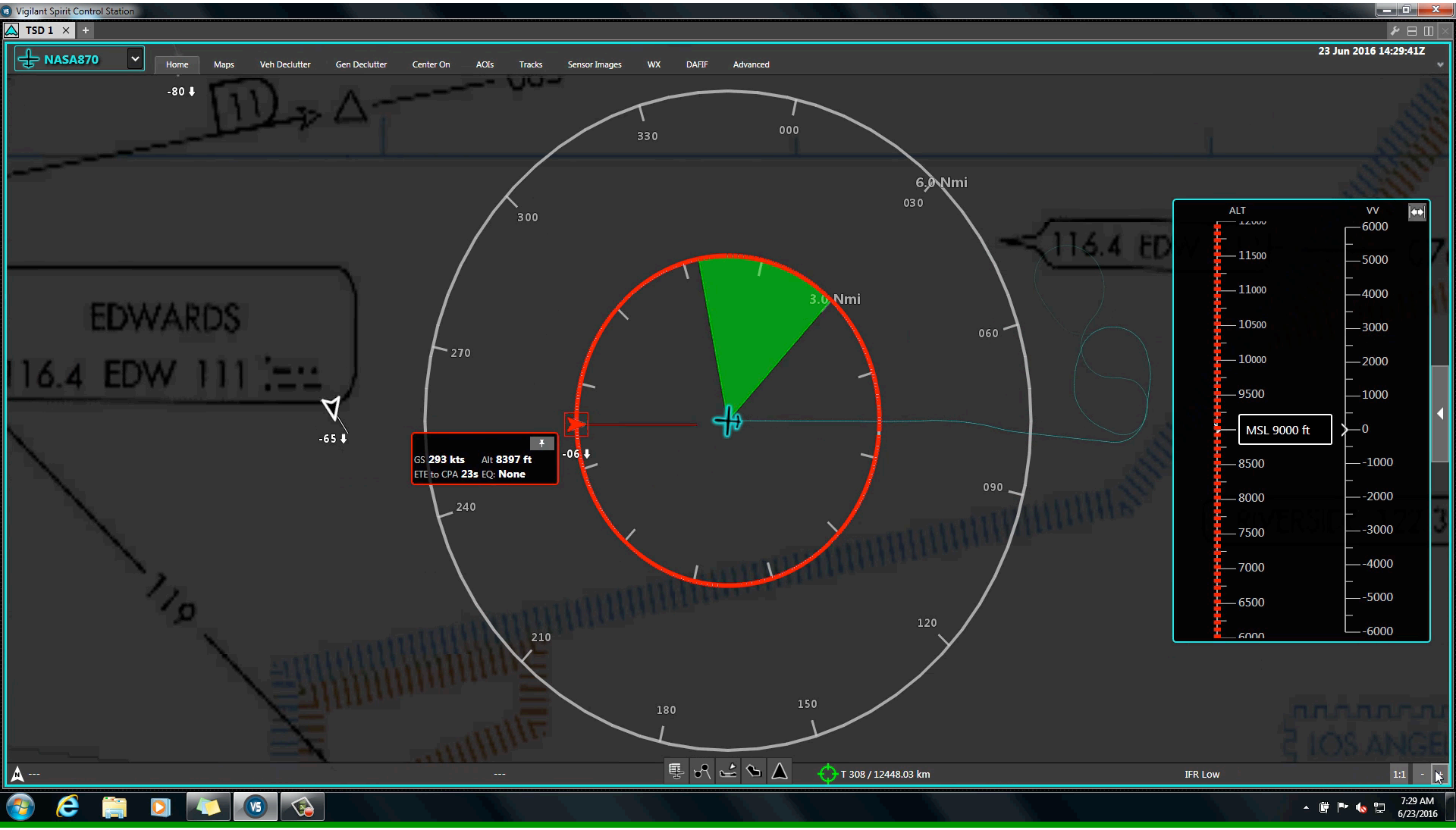


- Frequent changes to turn direction (left vs. right) of WCR guidance were observed for non ADS-B equipped intruders
- Short duration (<10s) between WCR onset and TCAS RA was observed in >50% of cases
- Large-turn WCR guidance aft of ownship was observed in some encounters.

Sample WCR Instability: Short Duration



Sample WCR Instability: Direction Swap



Lessons Learned and Recommendations

- A wide array of encounters were successfully executed to evaluate the performance of prototype DAA alerting and guidance logic in a realistic environment… big thanks to entire FT4 team. Test criteria were largely met.

- Alert timing was largely acceptable, providing ample time for pilot to evaluate guidance and maneuver aircraft in most encounters -> acceptable alerting thresholds

Lessons Learned and Recommendations (cont.)

- WCR guidance was of limited utility for intruders lacking ADS-B.
  - WCR guidance should select a direction and maintain guidance except in cases of overwhelming evidence to the contrary
  - WCR guidance should include reasonable turn limits (e.g., no >90° turns)
  - Lead time from WCR to TCAS RA observed <10s in more than half of cases
  - WCR performance improved with ADS-B surveillance
  - May need to revisit TCAS interoperability concept regarding differences between ADS-B equipped and non-equipped intruders for WCR

- Stability of guidance for Mode C intruders appears adequate, but further investigation is warranted due to the limited sample size, particularly for high-speed, Mode C intruders.

- Unexpected TCAS RAs are possible due to differences in predicted HMD for DAA and TCAS… mitigations to prevent unexpected RAs may be required.

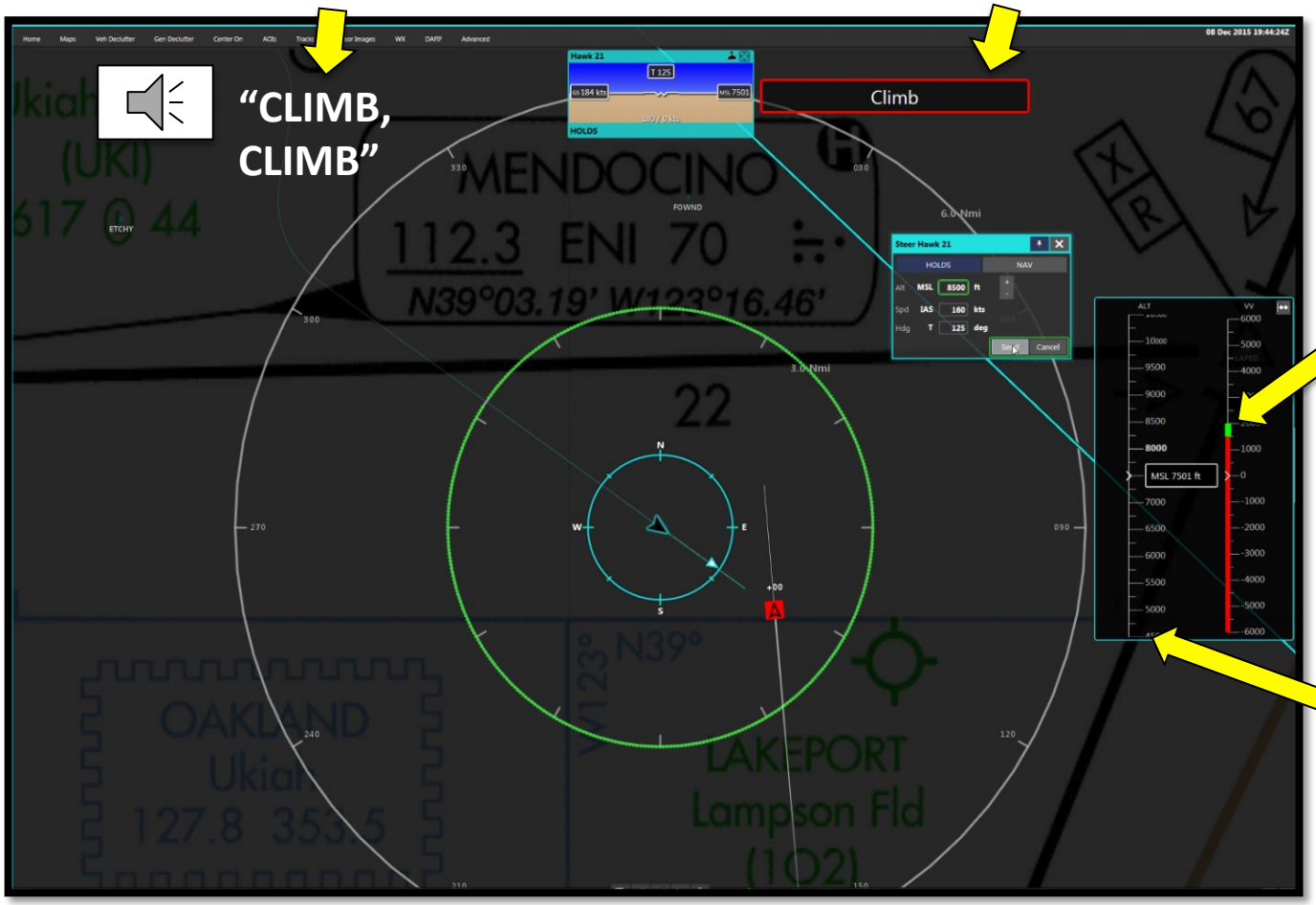
Next Steps

- Analyze trajectory prediction performance for each intruder sensor combination (i.e. Horizontal & Vertical CPA errors vs. time-to-CPA)
- Validate Mode C (non ADS-B) intruder guidance stability
- Develop and assess enhanced WCR guidance logic
  - Enhanced directional guidance stability
  - Turn angle limitation
  - Different logic for intruders with/without ADS-B
- Analyze scenarios from last 2 flights (17 scenarios)
- Investigate 'TCAS RA dropouts' to determine if new WCR guidance requirement(s) are necessary
- Further investigate 'unexpected TCAS RAs'… are increased thresholds or buffers warranted?

Backup Slides

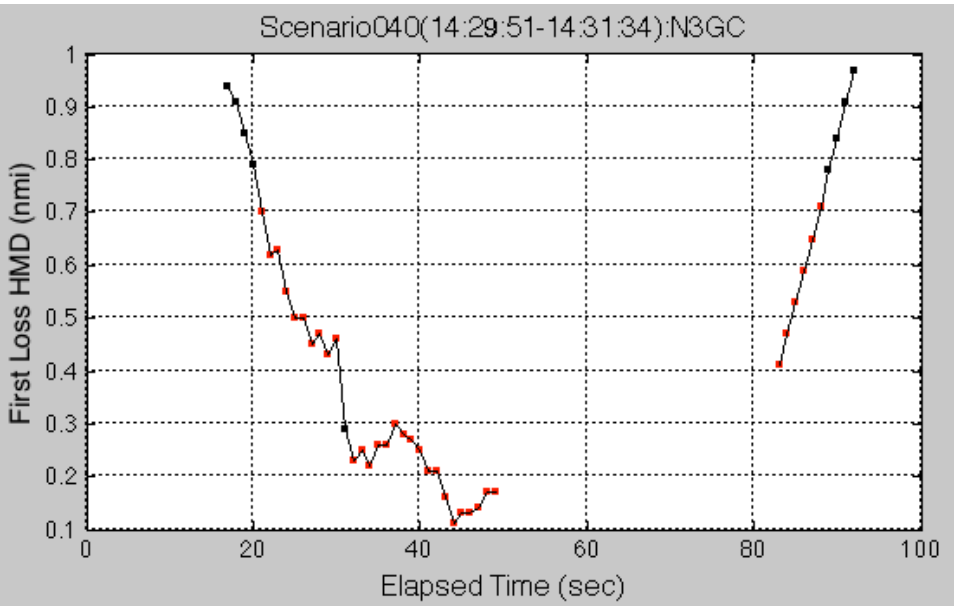
TCAS-II Display Integration

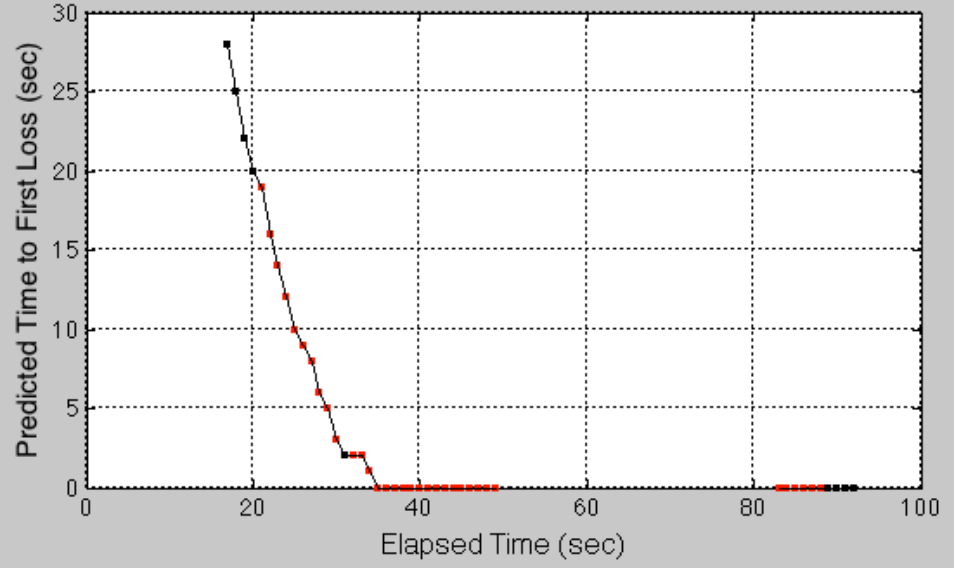
- Auditory Alert
  - RA sense presented aurally (source: TCAS II v7.1)
- Text Based
  - RA sense shown in text box next to Baseball Card

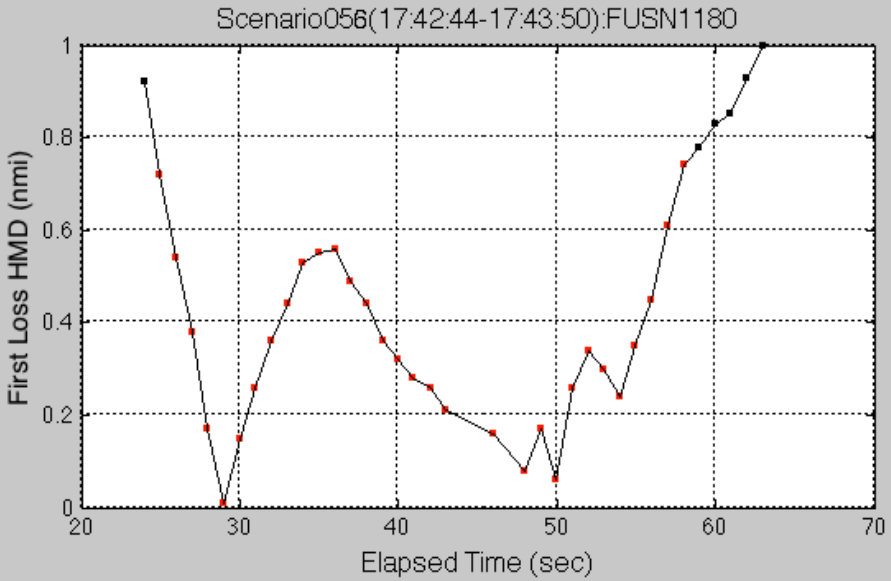


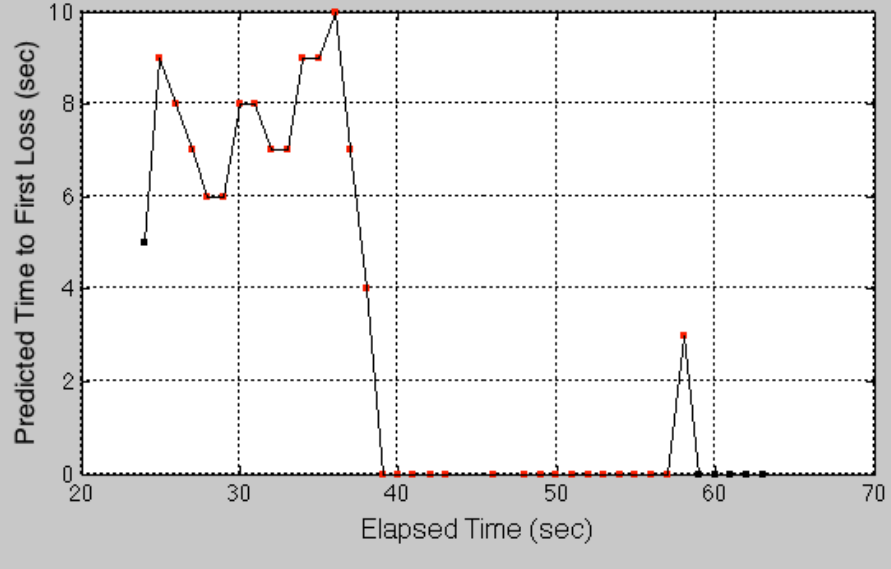
- TCAS Vertical Rate Guidance
  - Presented within VVI
  - Green = desired vertical speed
  - Red = vertical speed to avoid
- Inhibit DAA Altitude Guidance

No Corrective Alert Prior to Warning Alert









Mitigated LoWC: Non-Procedural

FT4 TEST OBJECTIVES – SSIWest.1.e (FT4 encounters: 013-015)

Objective 1: Validate DAA requirements in stressing cases that drive MOPS requirements: (e) low speed intruder (mitigated, <10kft MSL)	**ACES Simulation Results – Common non-cooperative encounters**

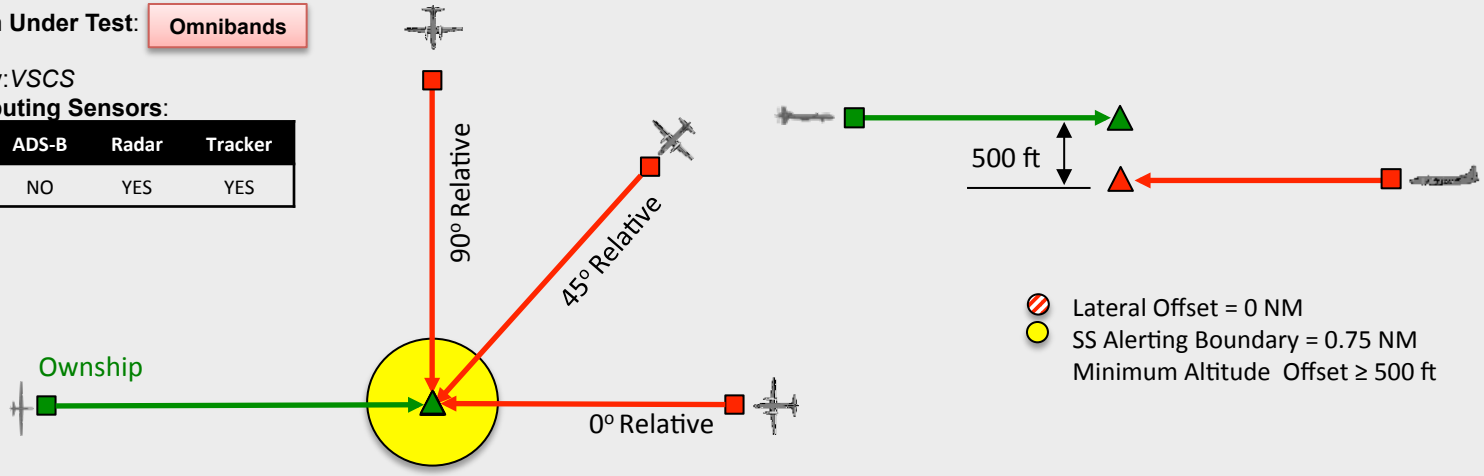
Configuration

System Under Test: Omnibands

Display: *VSCS*

Contributing Sensors:

TCAS	ADS-B	Radar	Tracker
NO	NO	YES	YES



Test Objectives (TO)

1. Validate DAA alert timing allows pilot sufficient time to assess options and maneuver to remain well clear.
2. Validate DAA guidance to UAS pilot is appropriate (reasonable, timely & responsive).
3. Validate selected DAA maneuver results in remaining well clear, and removal of the alert once clear of threat.

Success Criteria (retest if criteria not met)

1. A timely (corrective initially) DAA alert is provided to the UAS pilot.
2. UAS pilot maneuvers in response to DAA alert.
3. Data collected: LVC log file, SAAProc log files, TCAS log files for ownship and intruder, SAAP file ('raw' surveillance data).

Test Method

- MANUEVER: Pilot to manually select and execute 'minimum' maneuver at edge of band.
- Aircraft speeds (non-accelerating): Ownship 120 KGS, Intruder 100 KGS
- Encounter Length: 2 min (IP to CPA)
- Stable Conditions: stable at the IP (2 minutes prior to CPA)
- Test Termination Criteria: targets diverging, range > 0.75 nmi., no DAA alerts displayed.
- Climb/Roll/Pitch Rates: 0/0/0
- Tolerance: ± 8 sec, ± 5 kts at IP crossing.

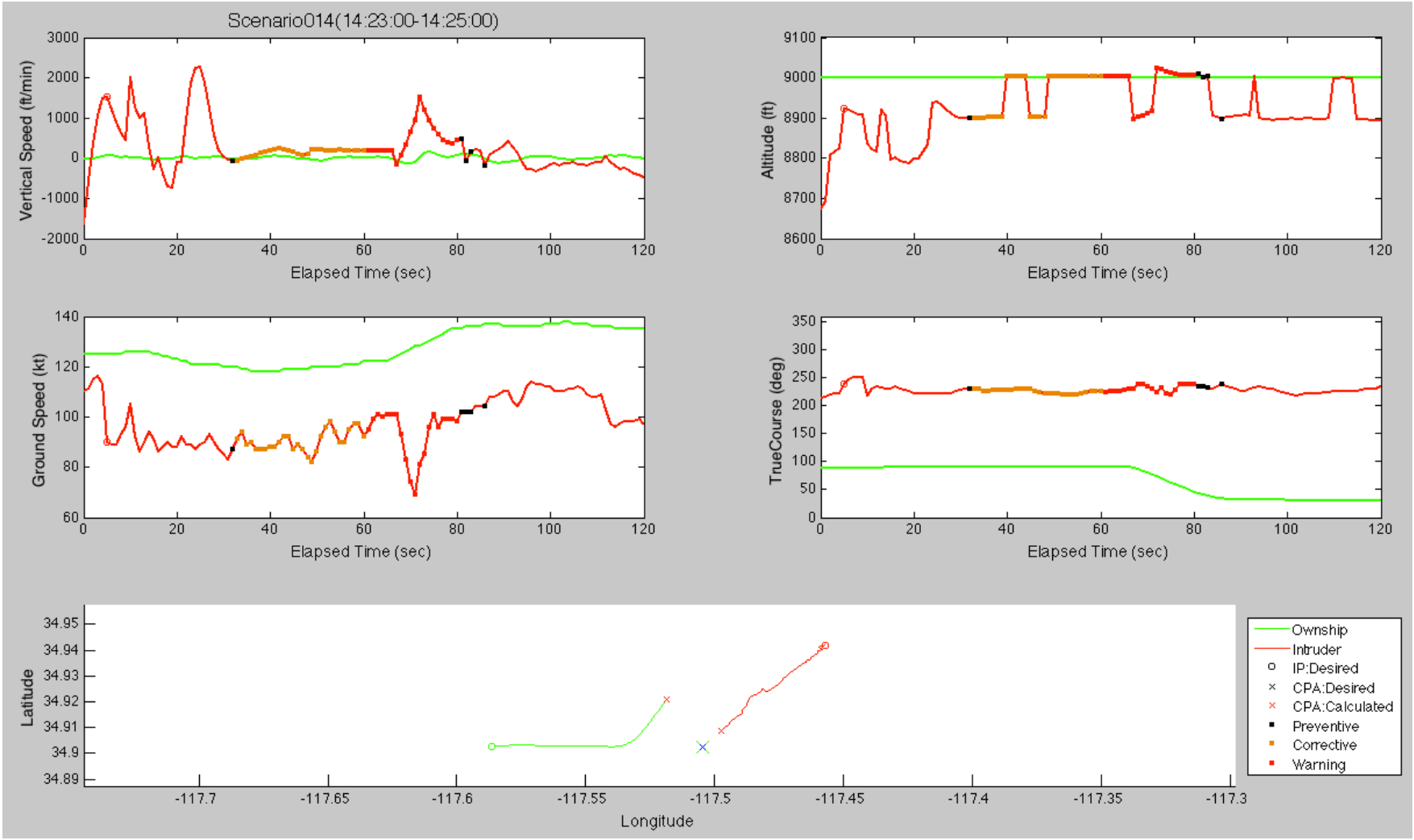
Evaluation Criteria (Post-test analysis to determine if test objectives are met)

1. UAS pilot receives DAA corrective alert with associated guidance
2. UAS pilot maneuvers in response to DAA alert and remains well clear of intruder.
3. DAA alert(s) and guidance are removed once ownship is clear of threat.

Additional Information

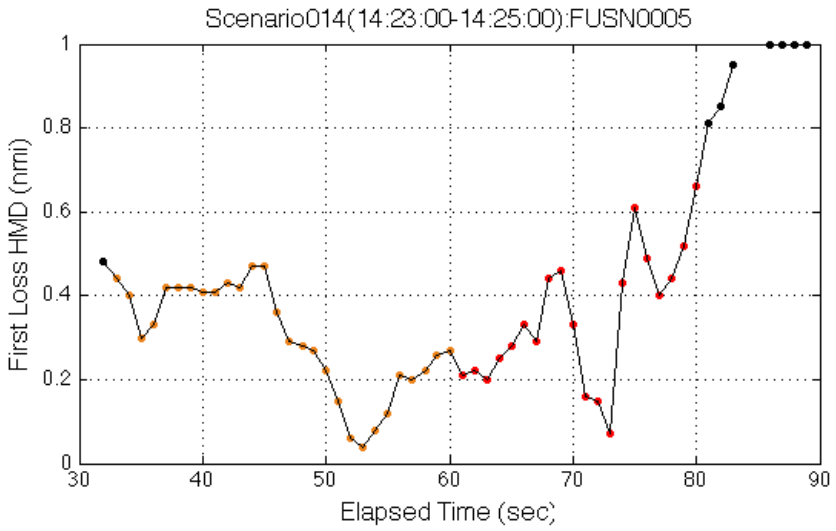
Mitigated LoWC: Non-Procedural

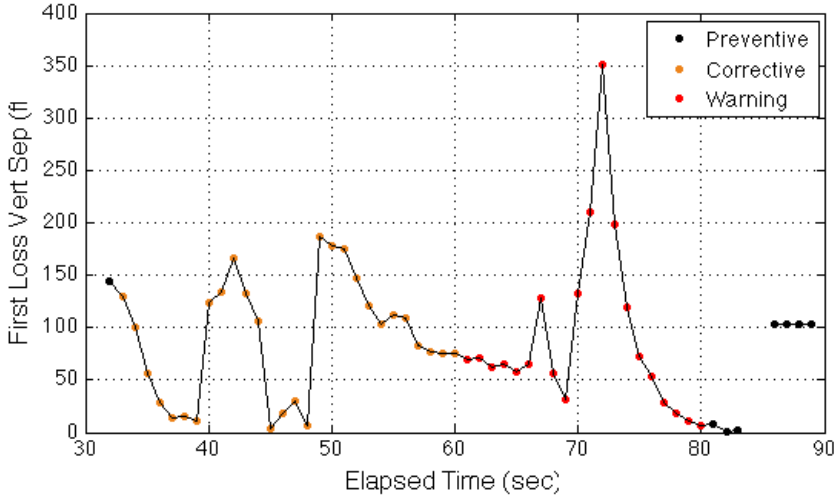
Scenario 014 (mitigated, low-speed, 45°, LoWC @ 78s elapsed time)

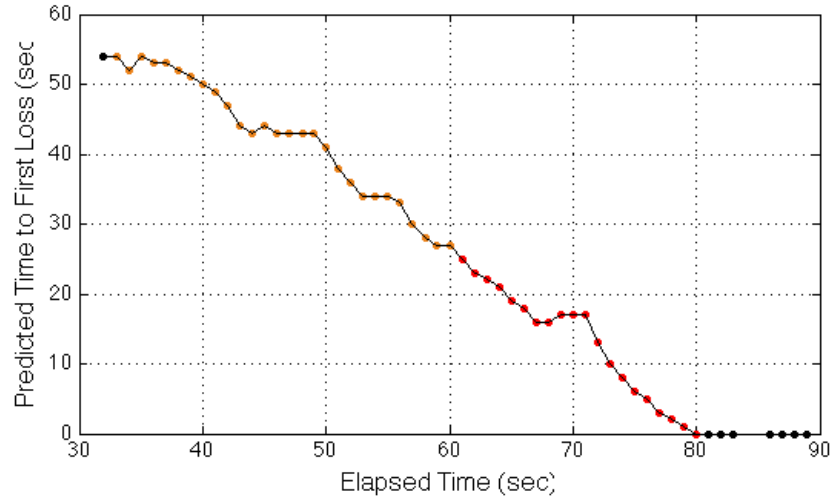


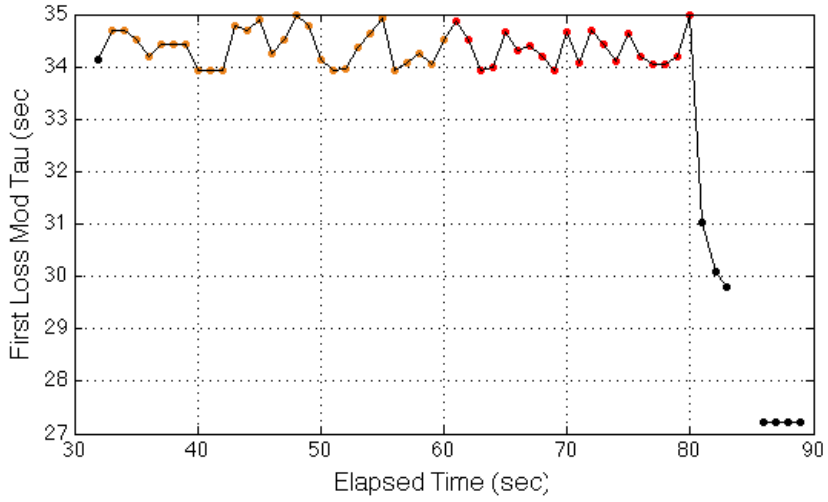
Mitigated LoWC: Non-Procedural

Scenario 014 (mitigated, low-speed, 45°, LoWC @ 78s elapsed time)









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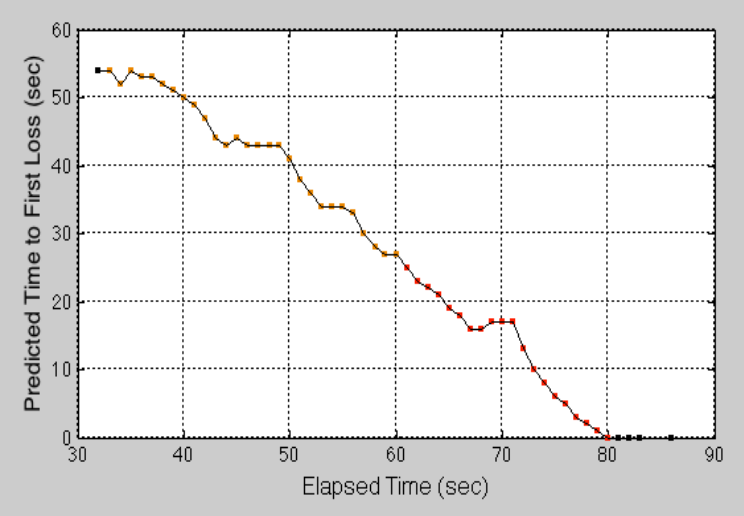
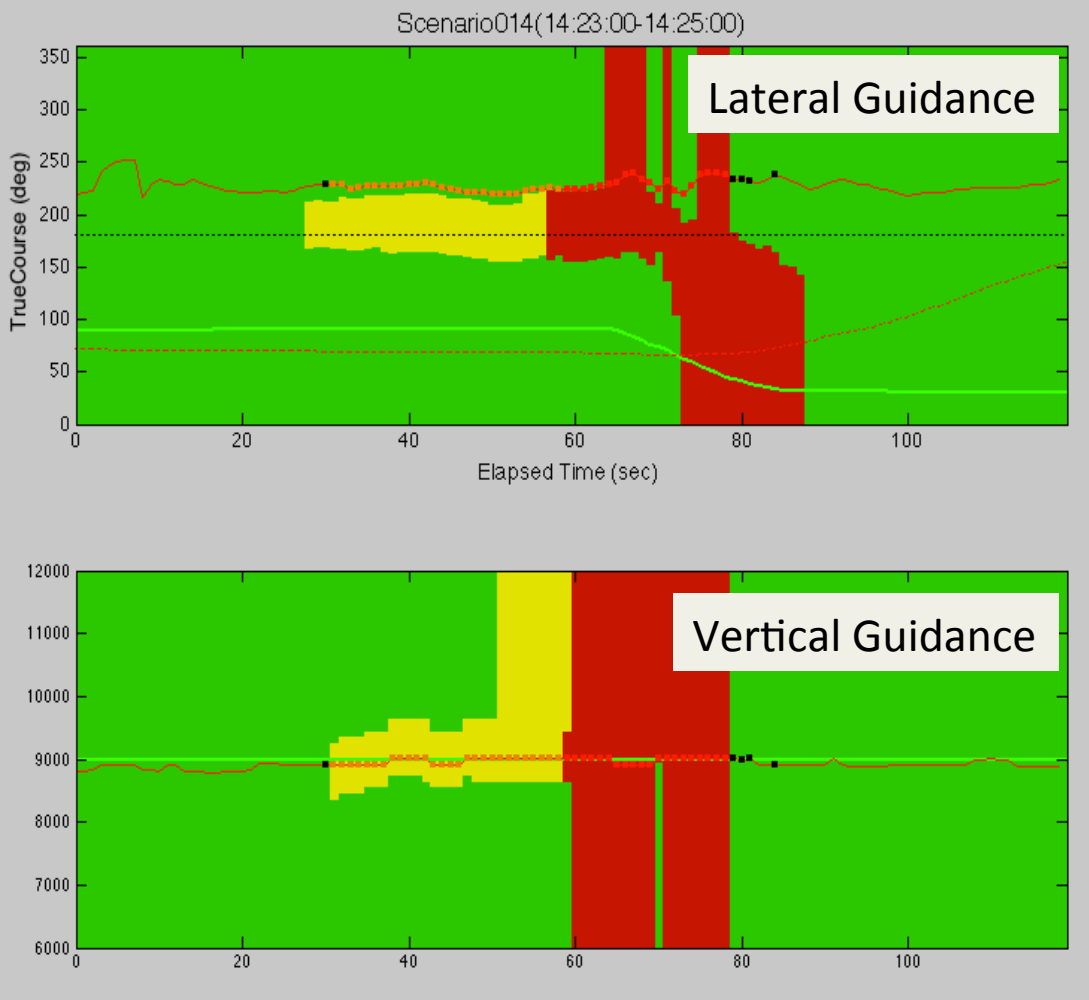
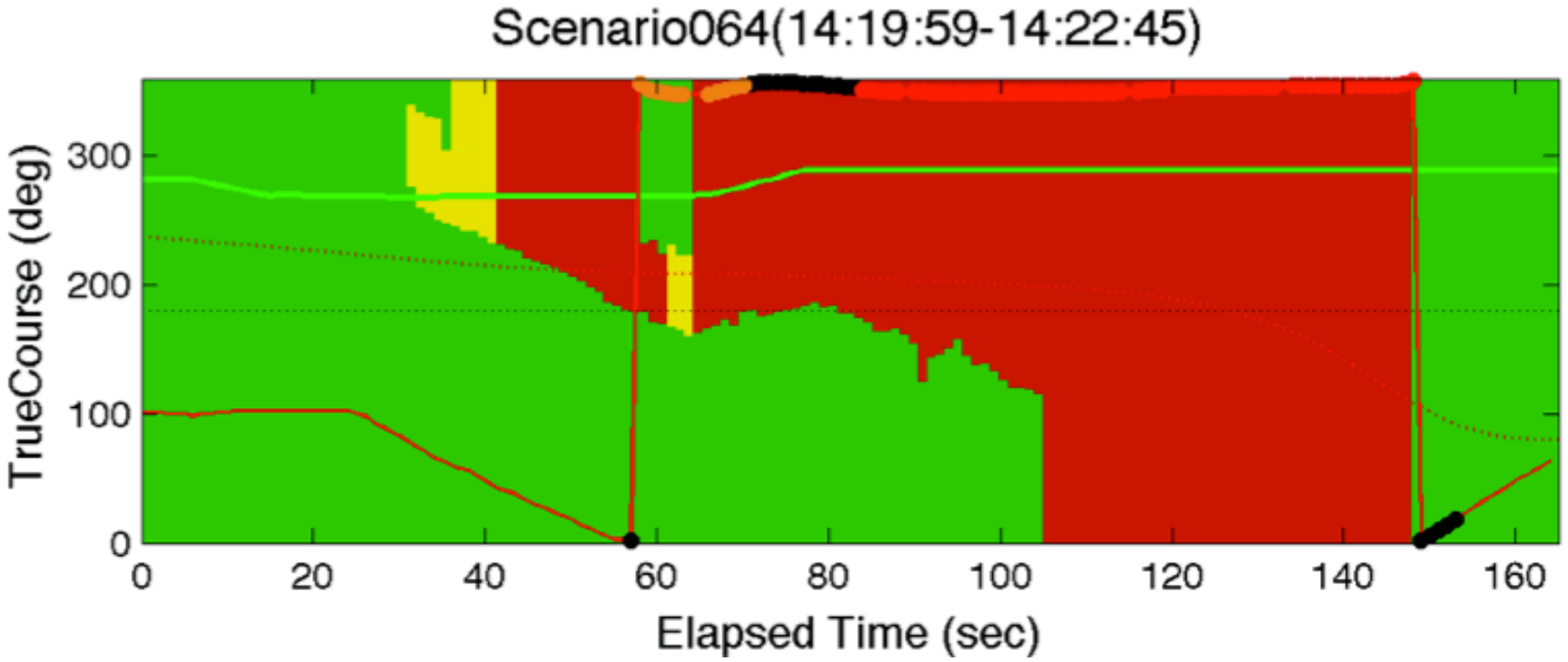




- Moderate ground speed and heading variance following ownship maneuver.
- LoWC for 2s @ >0.5nm HMD and with WCR guidance

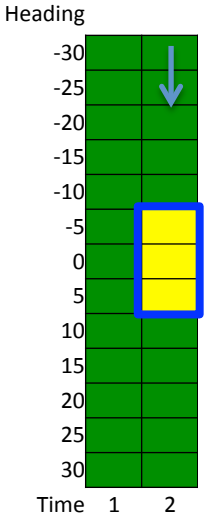
Mitigated LoWC: FT4 Procedural



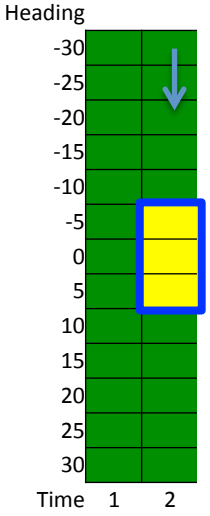
Guidance Buffering

- In the presence of noisy sensors, the sizes and alert level within the bands may "jitter"
  - E.g. Yellows bands jumping from 30 degrees to 50 degrees back to 30 degrees in a matter of seconds
- Implemented buffering algorithm to keep the more conservative DAA guidance persistent over some user-specified time
- In example to the right, time window is 4
- Pro: "stable" guidance
- Con: over conservative in maneuver guidance, e.g. showing +/- 15 degree turn as necessary but +/- 5 degrees would be sufficient

Instantaneous guidance



Buffered guidance displayed to pilot



Head of queue is displayed to pilot

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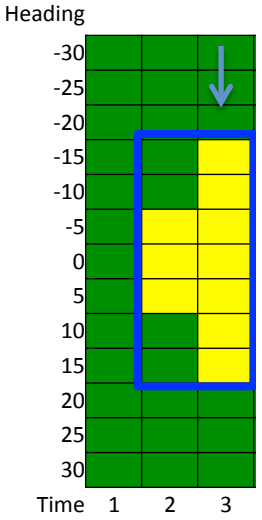
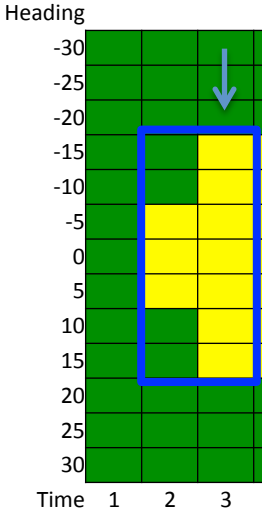


Buffered guidance displayed to pilot



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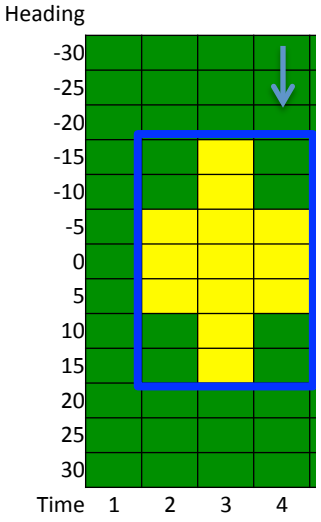
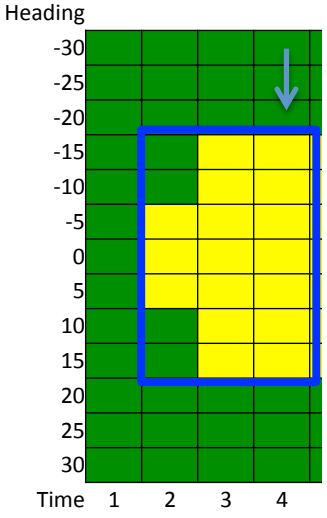


Buffered guidance displayed to pilot



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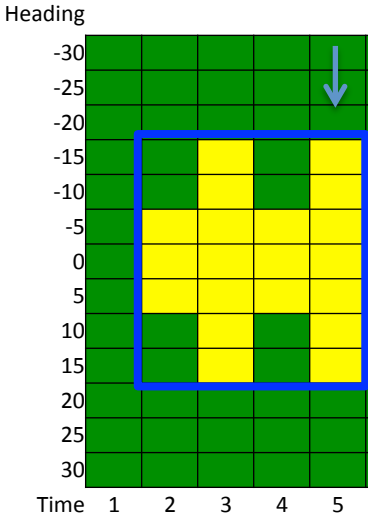
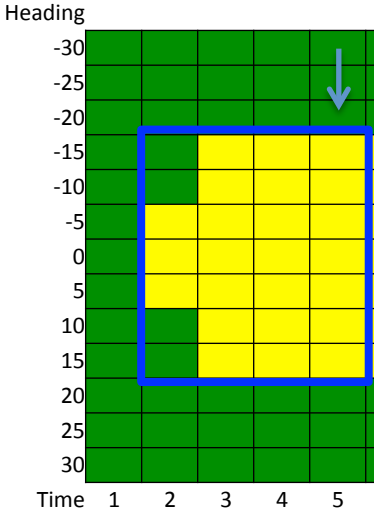
- Con: over conservative in maneuver guidance, e.g. showing +/- 15 degree turn as necessary but +/- 5 degrees would be sufficient

Instantaneous guidance



Buffered guidance displayed to pilot



Head of queue is displayed to pilot

Guidance Buffering

- In the presence of noisy sensors, the sizes and alert level within the bands may "jitter"
  - E.g. Yellows bands jumping from 30 degrees to 50 degrees back to 30 degrees in a matter of seconds
- Implemented buffering algorithm to keep the more conservative DAA guidance persistent over some user-specified time
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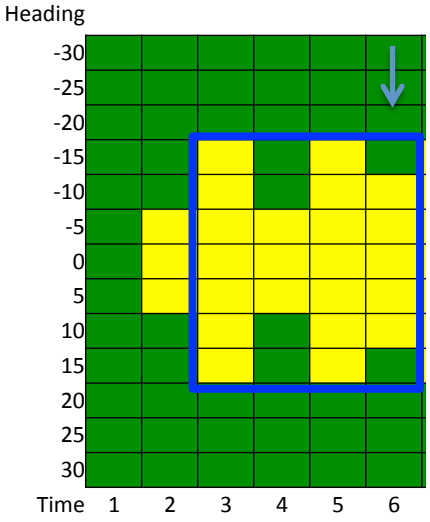

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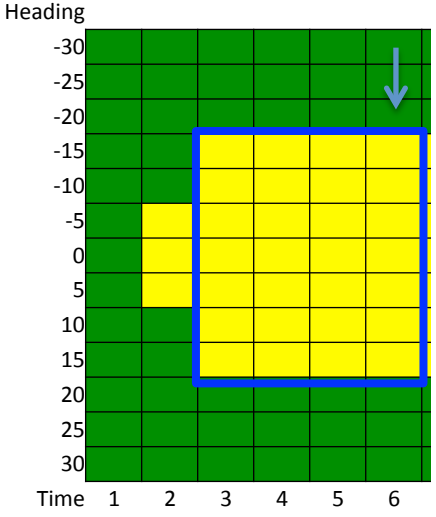

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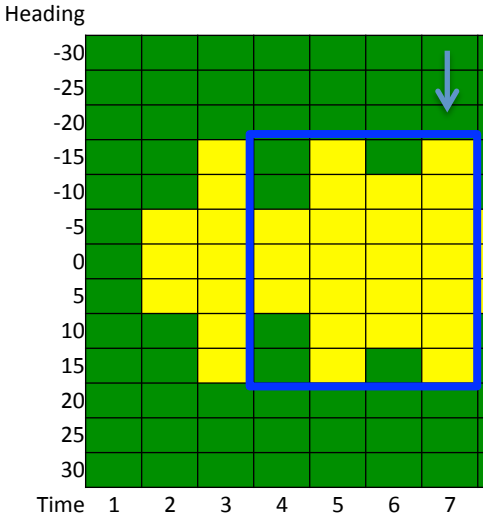
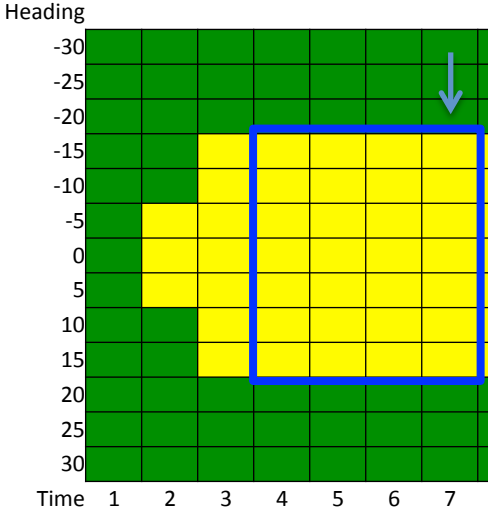


Buffered guidance displayed to pilot



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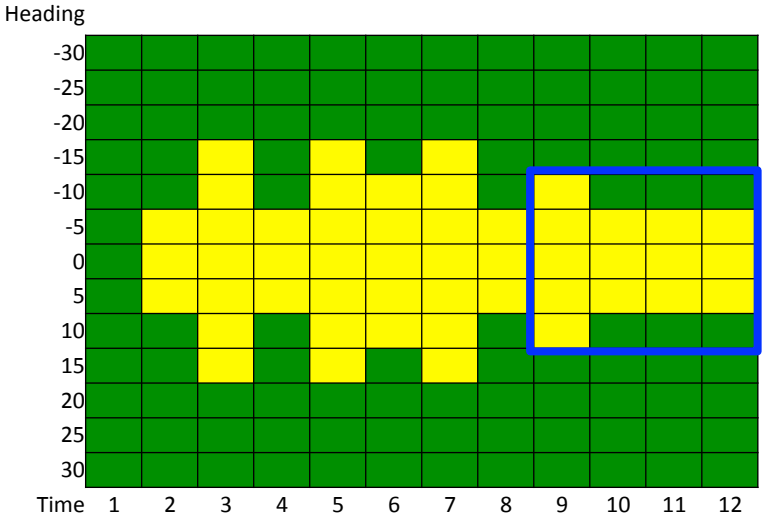

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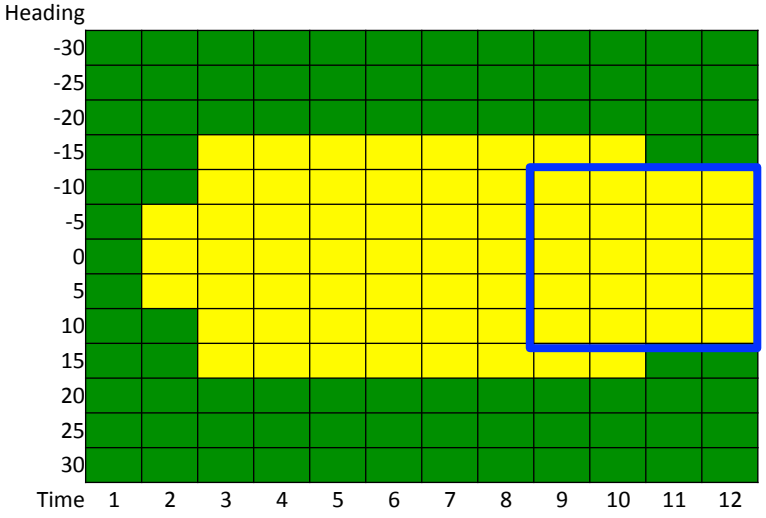

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