Assessing Helicopter Pilots' Detect and Avoid and Collision Avoidance Performance with ACAS Xr

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Outline

- Background
- Study Objectives
- Study Design
- Results (by Condition)
- Discussion
- Conclusion

Background

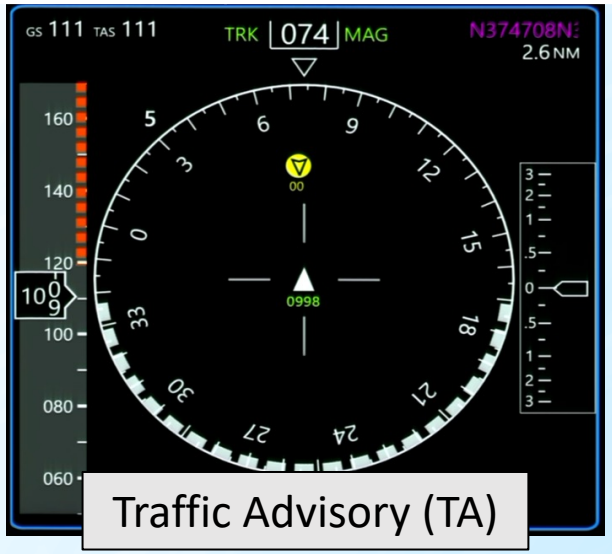
- Maintaining well clear and avoiding airborne collision hazards are critical requirements for both onboard and remote aircraft operators
- Extensive research has been performed on Detect and Avoid (DAA) and Collision Avoidance (CA) systems for fixed-wing aircraft
- Current-day helicopters and emerging Vertical Takeoff and Landing (VTOL) platforms would also benefit from DAA & CA systems

Background

- The Federal Aviation Administration's (FAA) **Airborne Collision Avoidance System X for Rotorcraft** (ACAS Xr) is being developed for these platforms
  - ACAS Xr builds on earlier ACAS X variants and corresponding research
    - ACAS Xu for large unmanned aircraft systems (UAS)
    - ACAS sXu for small UAS
- ACAS Xr supports architectures with onboard or remote pilots
  - Issues alerting and guidance aimed at preventing losses of DAA well clear and/or Near Midair Collisions (NMACs)
  - Alert schema differs by configuration

Background

- *Collision Avoidance System* (CAS) Configuration
  - Designed for platforms with an onboard pilot
  - Alerting structure highly similar to the existing Traffic Alert and Collision Avoidance System (TCAS II)
    - **Traffic Advisory** (TA) used to prepare pilot for imminent collision avoidance threat
    - **Resolution Advisory** (RA) issued with directive guidance, commanding a single or multi-axis maneuver
      - Vertical RA - commands target vertical speed
      - Horizontal RA - commands target heading
      - Blended RA - commands target heading + vertical speed



Traffic Advisory (TA)

Resolution Advisory (RA)

Background

- *Detect and Avoid* (DAA) Configuration
  - Designed primarily for remotely-piloted platforms
    - Not explicitly prohibited for use by onboard pilots*
  - Alerting designed around Minimum Operational Performance Standards (MOPS) for DAA Systems**
    - **Remain Well Clear** (RWC) alerting and guidance can be acted upon by pilot to avoid loss of DAA well clear
      - Replaces the TA as issued in CAS configuration
    - **Resolution Advisory** (RA) also issued
      - Same RA set as provided in CAS configuration

Remain Well Clear (RWC)

Resolution Advisory (RA)

**Requires additional human factors work to assess viability*

***RTCA SC-228's DO-365B*

Study Objectives

- Assess pilot and ACAS Xr system performance in a high-fidelity simulation across multiple phases of flight
  - **Onboard** pilot in full-motion simulator with VTOL vehicle model

- Pilot and system performance defined as:
  - Response times and compliance rates to alerts in the CAS and DAA configurations
  - Rates of losses of DAA well clear and NMACs across configurations

Independent Variables

- Phase of Flight (within-subjects)
  - *Cruise* – **110kts**; starting altitude 500-1500ft MSL
  - *Hover* – **10kts**; starting altitude 500-1500ft MSL
  - *Approach* – straight-in approach; **70kts**, starting altitude 700-1100ft, 6° glide slope

- ACAS Xr Configuration (within-subjects)
  - *CAS Mode*: TAs & RAs issued nominally in Cruise and Hover
    - Terminal area behavior: ACAS switched to “TA-Only”; all RAs suppressed
    - Low altitude behavior: fixed Descend RA inhibit below 750ft AGL
  - *DAA Mode*: RWC & RAs issued nominally in Cruise and Hover
    - Terminal area behavior: RWC alert and horizontal RAs suppressed
    - Low altitude behavior: dynamic Descend RA inhibit with lower threshold

Scenarios

- Encounters flown as ~5-minute vignettes, all in the SF bay area
  - Scripted conflicts varied by intruder angle, relative altitude, & vertical/horizontal rate
- Aircraft in auto-pilot until RWC or RA alerting appeared
  - Pilots used inceptors to follow ACAS Xr guidance
- No ATC interaction or background traffic

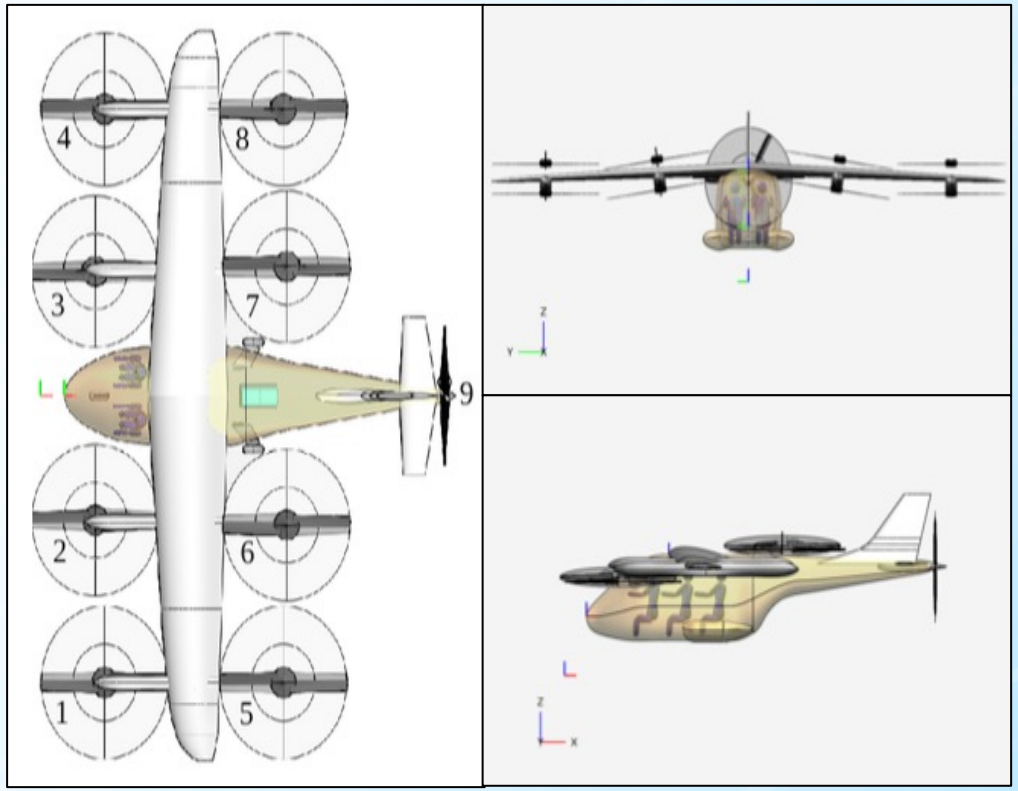
Participants

- 6 helicopter pilots participated
  - All male, average 51 years of age (*SE* = 4)
  - Each participated for 2 days total
    - Day 1 = training and data runs in CAS or DAA
    - Day 2 = training & data runs in remaining configuration

- Experience:
  - Avg. 4,542 rotorcraft flight hours
  - 5/6 had fixed-wing experience & were IFR rated
  - Half had experience with TCAS II

Vehicle Model

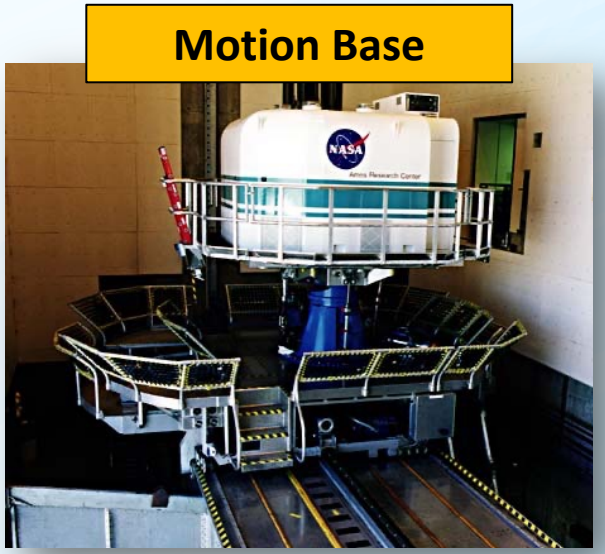
- NASA's Lift Plus Cruise (LPC) hybrid VTOL model
  - Capable of fully transitioning from thrust-borne flight to wing-borne lift
- Characteristics
  - Cruise speeds: 70-110KTAS
  - Altitude: 500-1500ft MSL
  - Max. bank: 40°
  - Max. climb rate: 1000fpm
- No sensor noise modeled

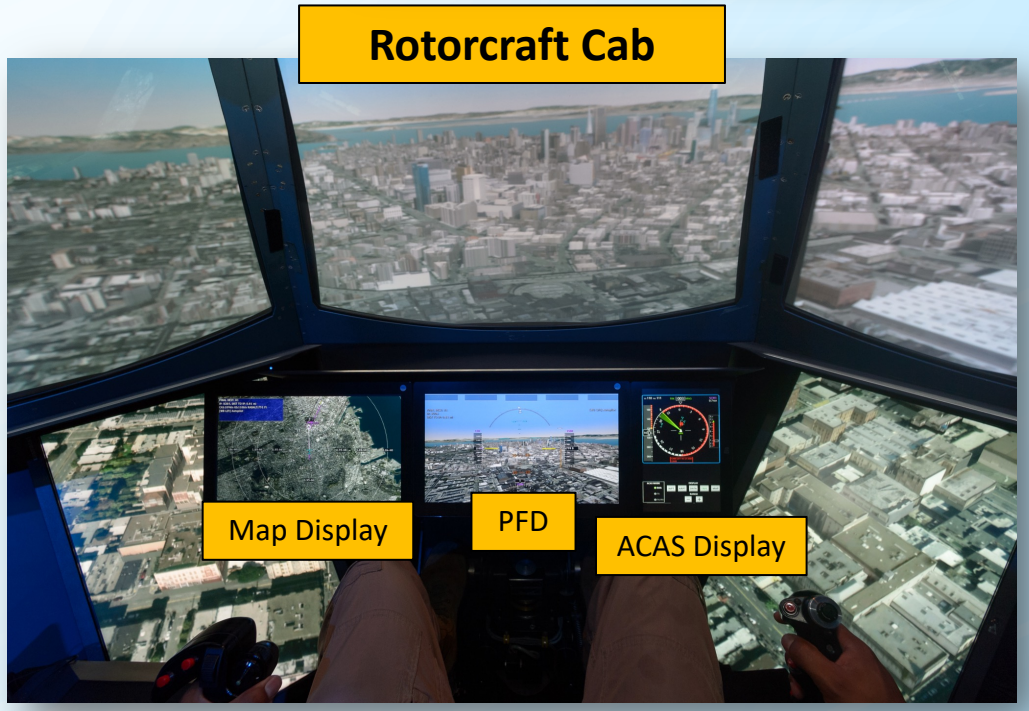


Simulator

- NASA Ames' Vertical Motion Simulator (VMS) Rotorcraft Cab (R-Cab)
  - 6D motion, turbulence, & out the window visual traffic

- Cab controls and displays
  - 2 side-stick controllers & rudders
    - Left = accelerate/decelerate
    - Right = commands vertical rate & bank angle
  - Top-down map display (left)
  - PFD display with camera underlay (center)
  - ACAS Xr traffic display (right)



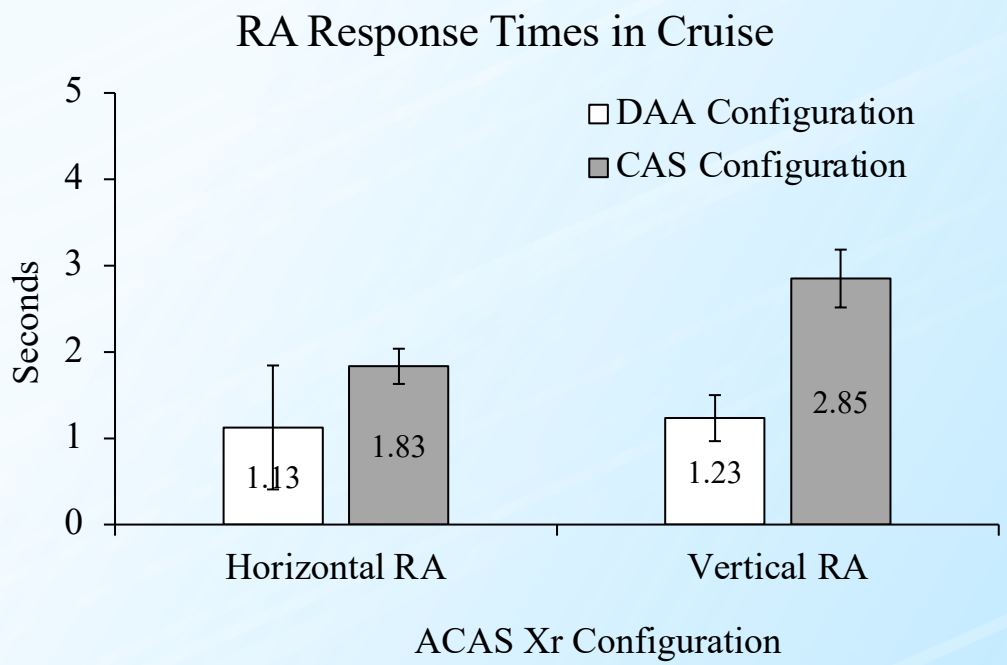


Results

Cruise Scenarios

Response Times in Cruise

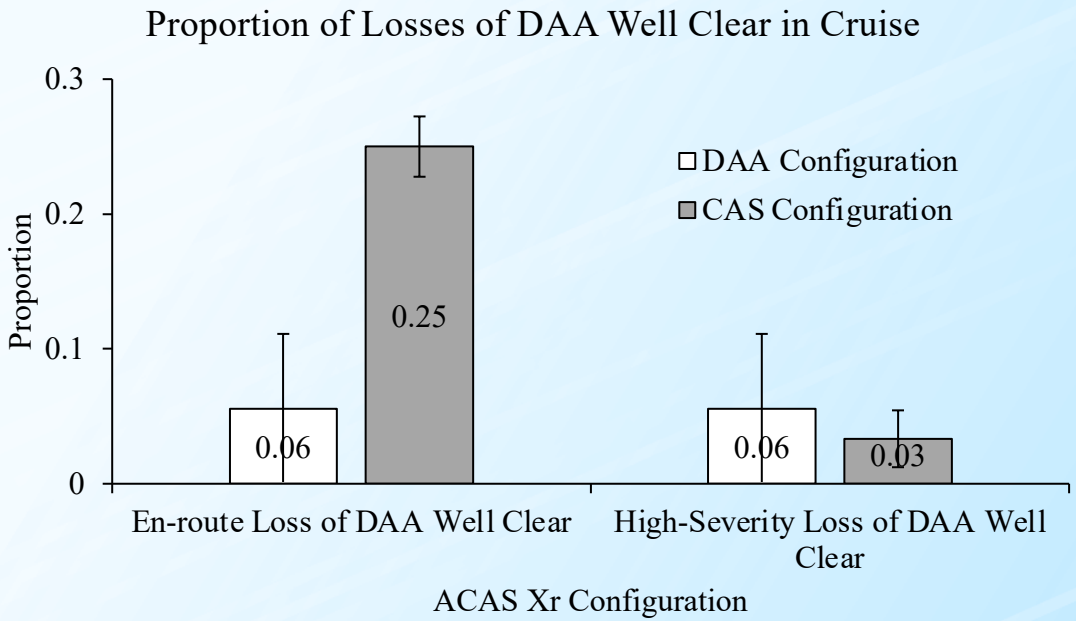
- Average DAA response time 5.24 sec (*SE* = 1.02 sec)*
  - (DAA configuration only)
- RA response times
  - Initial *Horizontal* RA: no significant difference between DAA & CAS
  - Initial *Vertical* RA: DAA significantly faster than CAS (*p* = 0.047)



** ~10 seconds faster than previous DAA research with ACAS Xu*

Losses of Separation in Cruise

- En-route losses of DAA well clear
  - Significantly more in CAS configuration (p = 0.036)
- High-severity losses of DAA well clear
  - No significant difference between conditions
- No NMACs recorded



	Horizontal Separation	Vertical Separation	Time to Closest Point of Approach (CPA)
En-route loss of DAA well clear	4000’	450’	35 seconds
High-severity loss of DAA well clear	4000’	450’	N/A
NMAC	500’	100’	N/A

RA Non-Compliance* in Cruise

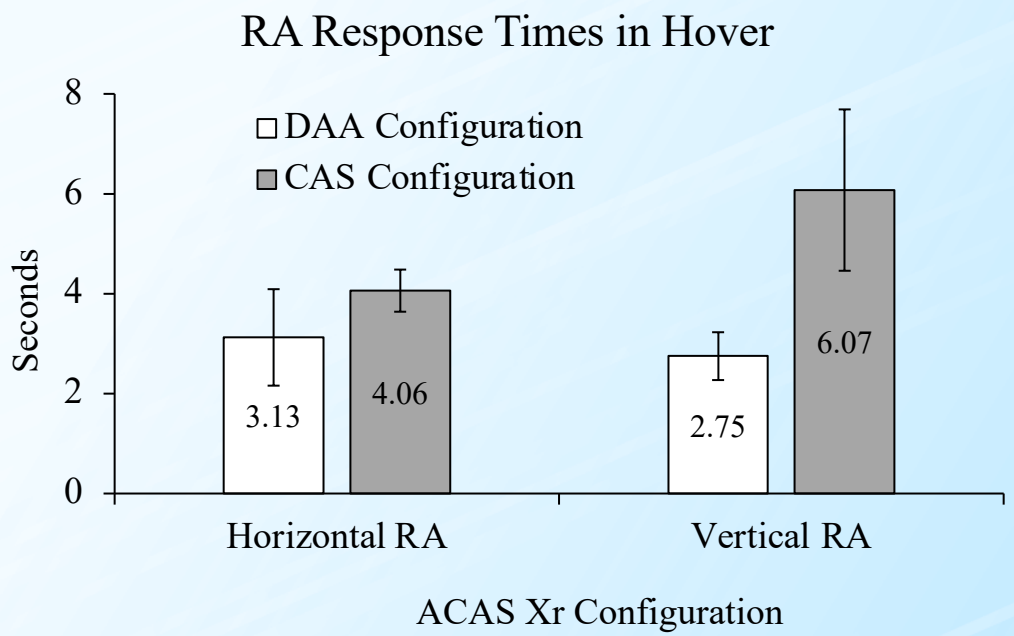
- No significant difference between conditions
  - DAA configuration non-compliance rate = 0.11 (*SE* = 0.07)
    - **2** total cases; 1 was apparent pilot error
  - CAS configuration non-compliance rate = 0.18 (SE = 0.07)
    - **11** total cases; primarily a result of pilots disagreeing with a Level Off RA (preferring a climb/descent)

**Non-compliance = pilot intentionally disregarded RA or maneuvered contrary to what was commanded*

Hover Scenarios

Response Times in Hover

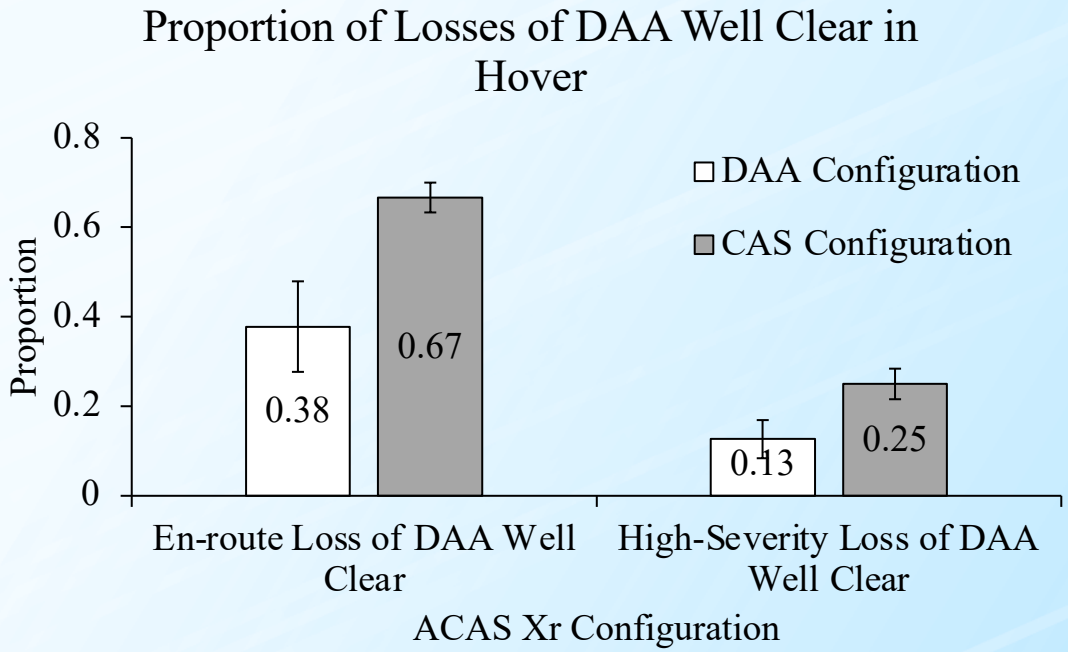
- Average DAA response time 7.18 sec* (*SE* = 1.04 sec)
  - (DAA configuration only)
- RA response times
  - No significant differences



** ~8 seconds faster than previous DAA research with ACAS Xu*

Losses of Separation in Hover

- En-route losses of DAA well clear
  - Significantly more in CAS configuration (p = 0.018)
  - *Rates 3-6 times higher than in Cruise*
- High-severity losses of DAA well clear
  - Significantly more in CAS configuration (p = 0.049)
  - *Rates 2-8 times higher than in Cruise*
- No NMACs recorded



	Horizontal Separation	Vertical Separation	Time to Closest Point of Approach (CPA)
En-route loss of DAA well clear	4000’	450’	35 seconds
High-severity loss of DAA well clear	4000’	450’	N/A
NMAC	500’	100’	N/A

RA Non-Compliance* in Hover

- Significantly higher rate in DAA configuration (p = 0.001)
  - DAA configuration non-compliance rate = **0.46** (*SE* = 0.08)
    - **15** total cases; all due to pilots stopping their descent while Descend RA was still active
  - CAS configuration non-compliance rate = 0.13 (SE = 0.04)
    - **8** total cases; half were a result of pilots disagreeing with a Level Off RA (preferring a climb/descent)

**Non-compliance = pilot intentionally disregarded RA or maneuvered contrary to what was commanded*

Approach Scenarios

Response Times on Approach

- Average TA response time 22.88 sec (*SE* = 7.07 sec)
  - (CAS configuration only; no RAs issued)

- Average Vertical RA response time 2.64 sec (*SE* = 0.25)
  - (DAA configuration only; only Vertical RAs issued)

Losses of Separation on Approach

- Terminal-area losses of DAA well clear
  - No significant effect of configuration
    - DAA configuration rate = 0.22 (*SE* = 0.05)
    - CAS configuration rate = 0.30 (*SE* = 0.12)

- 4 NMACs recorded
  - 2 in DAA & 2 in CAS configuration
    - All due to the same encounter type (ownship overtaking intruder)
    - In DAA configuration, ACAS Xr commanded Level Off RA, providing insufficient separation
    - In CAS configuration, pilots hesitated when determining if/when to maneuver against TA

	Horizontal Separation	Vertical Separation
Terminal-area loss of DAA well clear	1500’	450’
NMAC	500’	100’

RA Non-Compliance* on Approach

- DAA configuration non-compliance rate = 0.18 (*SE* = 0.11)
  - **10** total cases; 9 were due to pilots disagreeing with a Level Off RA (preferring a climb/descent)
  - (No RAs issued in CAS configuration on approach)

**Non-compliance = pilot intentionally disregarded RA or maneuvered contrary to what was commanded*

Discussion

Discussion

- Effect of ACAS Xr configuration
  - Minimal impact on response times
    - DAA response times especially fast - ~10 seconds faster than previous DAA work
    - RA response times within expected response window (5 seconds)
  - As expected, DAA configuration reduced rates of losses of well clear
    - CAS performed as well as DAA in preventing *high-severity* losses of well clear in Cruise
      - But had twice as many high-severity losses in Hover scenarios
  - Non-compliance rate far higher for DAA configuration compared to CAS in Hover scenarios
    - Result of Descend RAs bringing pilots closer to ground in DAA than CAS

Discussion

- Effect of phase of flight
  - Losses of DAA well clear in the DAA configuration were far more common in Hover than in Cruise
    - Result of ACAS Xr not accounting for the time needed for the vehicle to accelerate
    - RAs twice as common in Hover than in Cruise in the DAA configuration
  - In approach scenarios, configuration had no impact on rates of losses of DAA well clear and NMACs
    - In CAS configuration, pilots struggled to handle conflicts without RAs
    - In DAA configuration, Level Off RAs seemed to not produce adequate vertical separation

Conclusion

Conclusion

- Cruise Scenarios
  - Strong overall performance
  - Occasional non-compliance against Level Off RAs
    - Pilots desired additional separation
- Hover Scenarios
  - Alerting should take time needed to accelerate into account when aircraft in in low-speed flight regime
  - Frequent non-compliance in DAA configuration against Descend RAs
    - Pilots uncomfortable with proximity to terrain
- Approach Scenarios
  - Both configurations had similar rates of losses of DAA well clear and NMACs
  - Level Off RAs failed to generate adequate separation
    - Also inconsistent with pilot expectation (go-around more appropriate)

Questions?