



National Aeronautics and Space Administration

UAS Pilot Evaluations of Suggestive Guidance on Detect-and-Avoid Displays

Presenter:

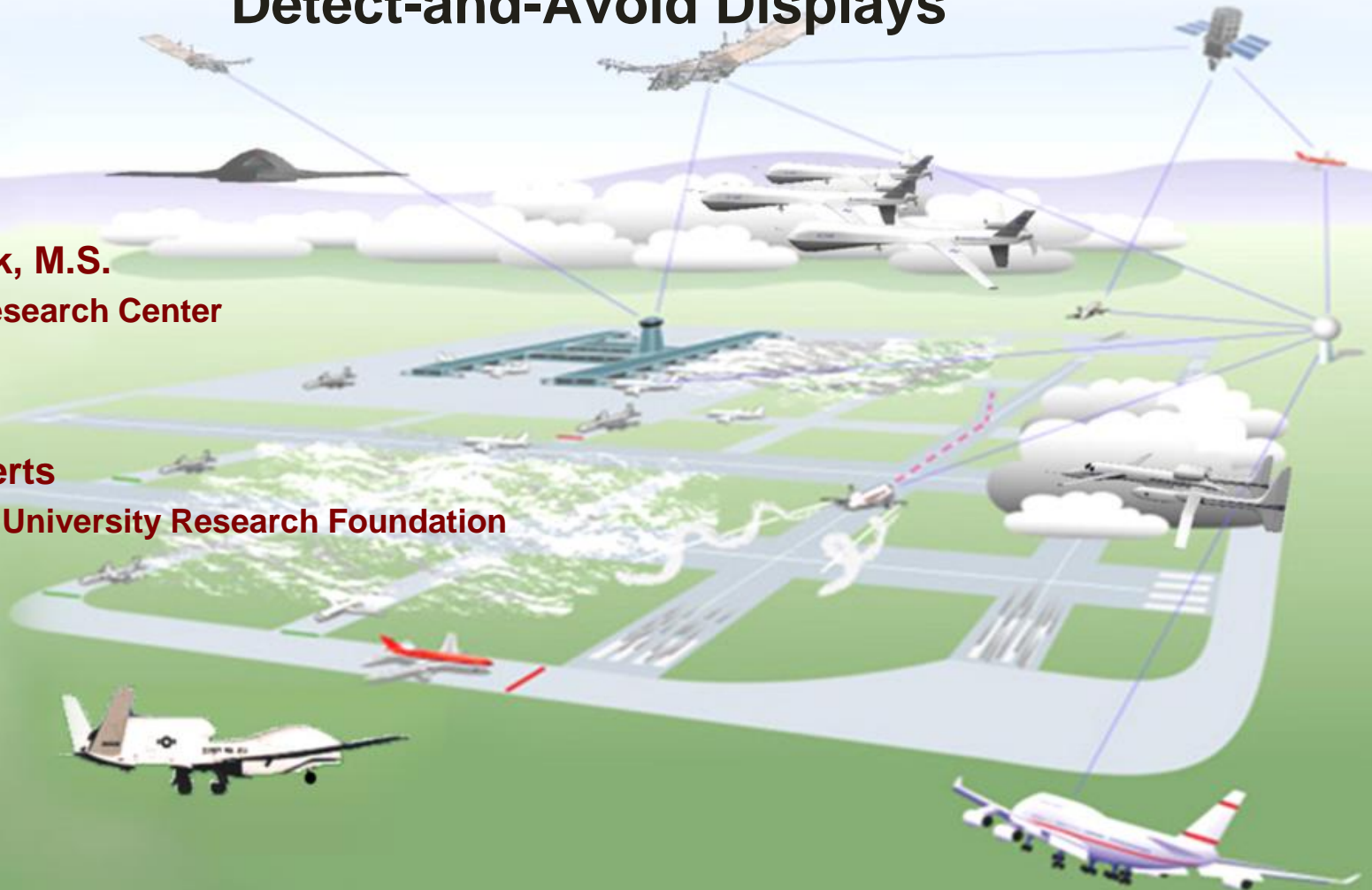
Kevin J. Monk, M.S.

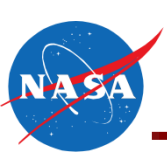
NASA Ames Research Center

Co-Authors:

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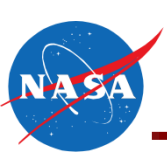
San Jose State University Research Foundation





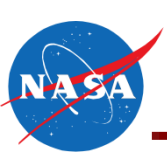
Introduction

- UAS in the NAS Project Objectives
 - Address technical and safety barriers to the expansion and integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS)
 - Currently limited to public purposes (e.g., military training) in restricted airspace
 - Produce research findings that guide the development of RTCA Special Committee 228's Minimum Operational Performance Standards (MOPS) for UAS
 - Identify minimum DAA display, alerting, & maneuver guidance that result in acceptable pilot performance and response times
- Detect and Avoid (DAA)
 - Existing regulations for manned flight operations require onboard pilots to “see and avoid” other aircraft in order to remain well clear (14CFR, Sec 91.113)
 - Unmanned operations will require a traffic display equipped with a “detect and avoid” system that provides the information necessary for self-separation
 - Effectively substituting for a manned pilots' ability to see outside of their aircraft under normal operating conditions



Background

- Past studies have explored the minimum visual information requirements necessary to perform UAS pilot-in-the-loop DAA tasks
 - Predictive displays with integrated maneuver guidance tools for conflict avoidance have improved pilot performance compared to displays with less information
 - Less near midair collisions (NMACs) (Friedman-Berg et al., 2014)
 - Reduced severity of well clear violations (Bell et al., 2012; Santiago & Mueller, 2015)
 - Quicker response times (Rorie & Fern, 2015; Rorie et al., 2016)
 - Higher pilot preference ratings (Monk et al., 2015)
 - Advanced guidance tools were tightly coupled to the vehicle control interface
 - Auto-populated maneuver resolution directly into steering window

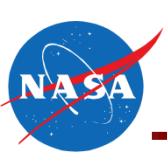


Purpose

- Examine pilot evaluations of four DAA displays with varied levels of suggestive guidance to further determine minimum information requirements for UAS ground control stations
 - Suggestive guidance tools decoupled from command-and-control interface
 - Presented range of solutions as opposed to a directive command
- *Are the pilots' perceptions of the DAA system consistent with their objective performance?* (Rorie et al., 2016)

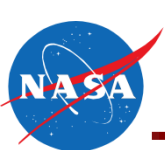
- Participants
 - 16 active duty UAS pilots
 - $\mu_{\text{age}} = 37$ years old
 - Unmanned flight experience
 - Civil: 30 hours avg.
 - Military: 1100 hours avg.
 - Manned flight experience
 - Civil: 575 hours avg.
 - Military: 1760 hours avg.
- Simulation Environment
 - Vigilant Spirit Control Station (VSCS)
 - Developed by Air Force Research Laboratory (Feitshans et al., 2008)
 - Primary field of view was Tactical Situation Display (TSD):
 - Command-and-control interface
 - DAA guidance & traffic
 - Mission route










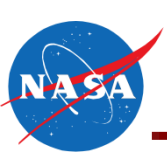
Experimental Design

- DAA Display Configuration
 - Minimum Information Only (Info Only)
 - No-Fly Bands
 - Omni Bands
 - Vector Planner
- Minimum set of traffic information was constant across all displays
 - Intruder Location & Direction
 - Relative Altitude
 - Vertical Trend Arrow
 - Call Sign (within data tag)
 - Ground Speed (within data tag)
 - Multi-Level Conflict Alerting Structure



DAA System: Multi-Level Alerting Structure

Symbol	Name	Pilot Action	Time to Loss of Well Clear	Aural Alert Verbiage
	DAA Warning Alert	<ul style="list-style-type: none">• Immediate action required• Notify ATC as soon as practicable after taking action	25 sec (TCPA approximate: 60 sec)	“Traffic, Maneuver Now”
	Corrective DAA Alert	<ul style="list-style-type: none">• On current course, corrective action required• Coordinate with ATC to determine an appropriate maneuver	75 sec (TCPA approximate: 110 sec)	“Traffic, Separate”
	Preventive DAA Alert	<ul style="list-style-type: none">• On current course, corrective action should not be required• Monitor for intruder course changes• Talk with ATC if desired	N/A	“Traffic, Monitor”
	DAA Proximate Alert	<ul style="list-style-type: none">• Monitor target for potential increase in threat level	N/A	N/A
	None (Target)	<ul style="list-style-type: none">• No action expected	X	N/A

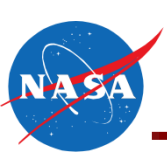


Display Configurations

1. Info Only

- Standard intruder information and multi-level alerting presented (no guidance)
 - Intruder Location & Direction
 - Relative Altitude
 - Vertical Trend Arrow
 - Call Sign (within data tag)
 - Ground Speed (within data tag)
 - Threat Level

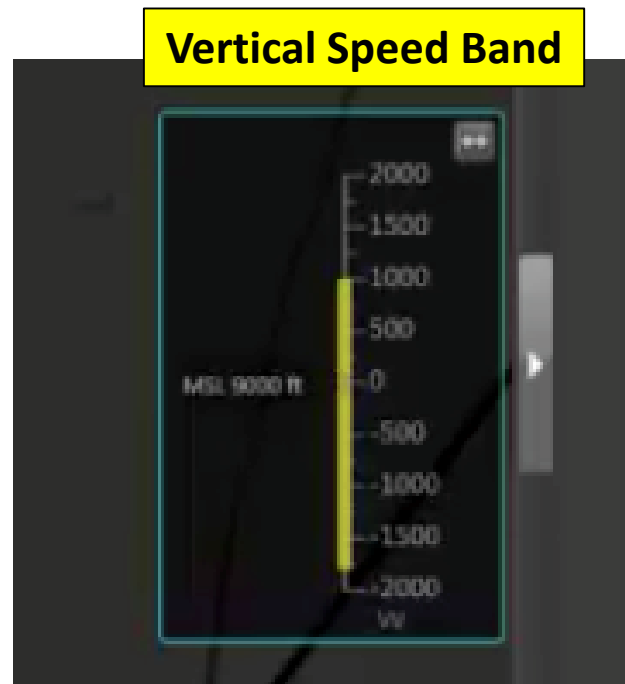
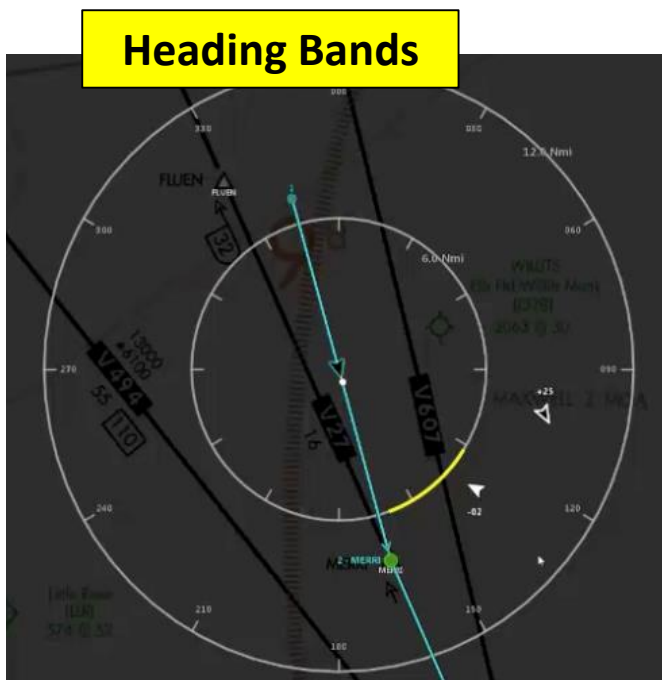


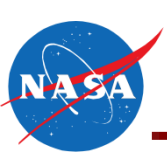


Display Configurations

2. No-Fly Bands

- Indicated headings/vertical speeds that would lead to an eventual loss of well clear
 - Maneuver outside of banding to maintain well clear

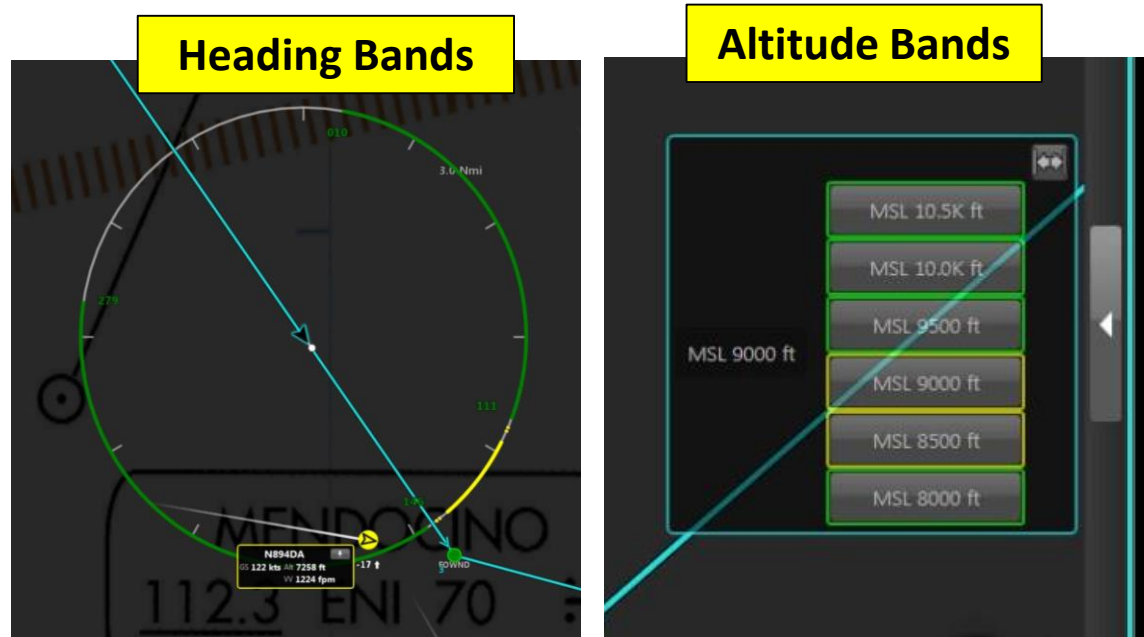


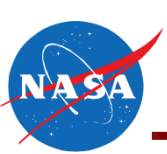


Display Configurations

3. Omni Bands

- Constantly displayed predicted threat level at nearby headings/altitudes
 - Green = regions that would maintain well clear
 - Yellow = regions that would trigger at least one Corrective alert
 - Red = regions that would trigger at least one Warning alert

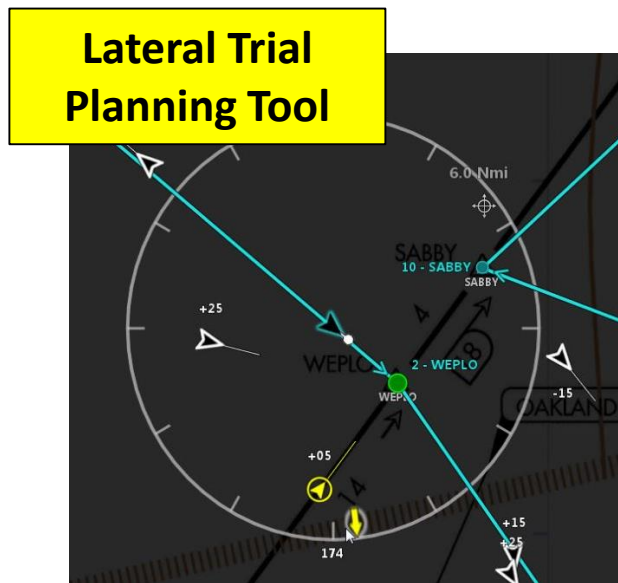


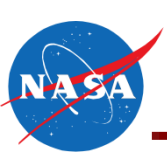


Display Configurations

4. Vector Planner

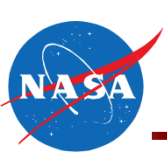
- Allowed pilots to test a single heading/altitude option for predicted threat level
 - Green = option would maintain well clear
 - Solid Yellow = option would trigger at least one Corrective alert
 - Solid Red = option would trigger at least one DAA Warning
- Tool was off by default
 - Engaged by dragging vector arrow or clicking option on altitude tape
 - 5 second time-out





Method: Procedure

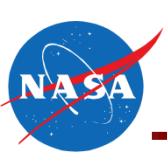
- DAA Pilot Task
 - Operate simulated MQ-9 through Class E airspace under Instrument Flight Rules
 - Maintain well clear with other aircraft
 - Four 37-minute scenarios
 - Two pre-filed flight plans
 - 9 scripted encounters with ownship
 - » 6 encounters would lead to loss of well clear without pilot action
 - Background traffic emulated busy day at Oakland Center (DOA 40/41)
 - Controlled by 'pseudopilots' via Multi-Aircraft Control Station (MACS; Prevot, 2002)
 - Sector managed by confederate ATC
 - Attend to secondary tasks
 - Chat messages requesting health/status information (e.g. fuel remaining)
 - Electronic checklists for system failure events



Measures

- Pilots completed post-trial and post-simulation questionnaires with subjective ratings pertaining to the preceding display configuration
 - Responses were analyzed using a one-way repeated measures Analysis of Variance (ANOVA)
- Post Trial Questionnaire
 - Workload (NASA TLX)
 - Conflict Assessment and Avoidance
 - Ease of Use
- Post-Simulation Questionnaire
 - Information Sufficiency
 - Display Preference

$\alpha = 0.05$

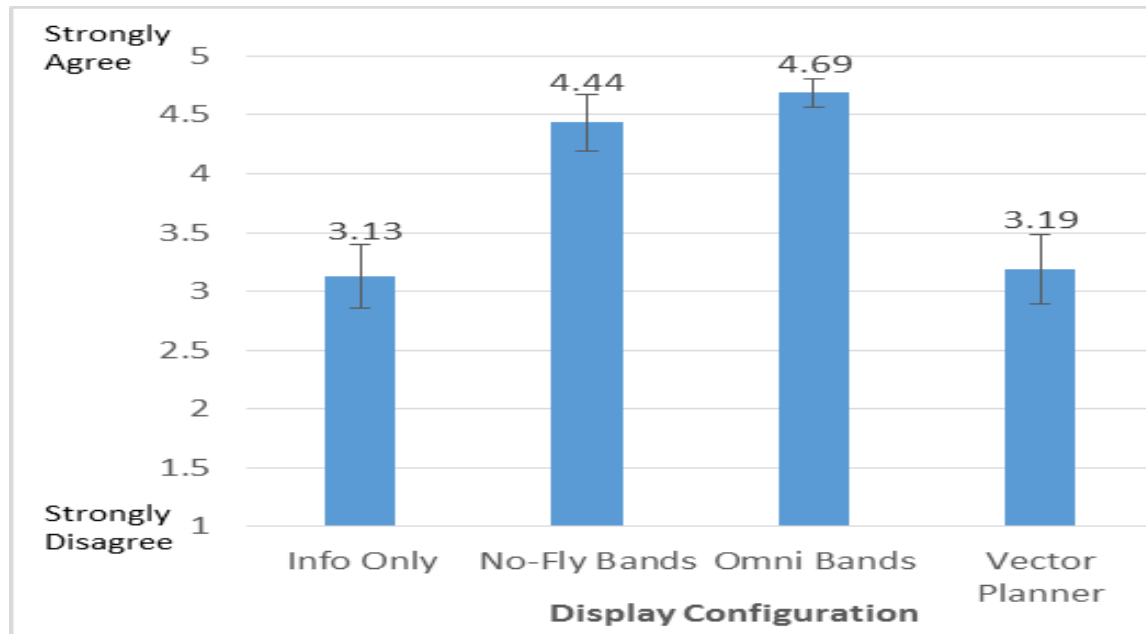


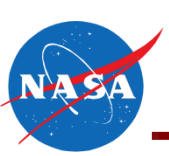
Results: Post-Trial

- Conflict Assessment

- *‘This display provided the information necessary to predict a potential loss of well clear’*

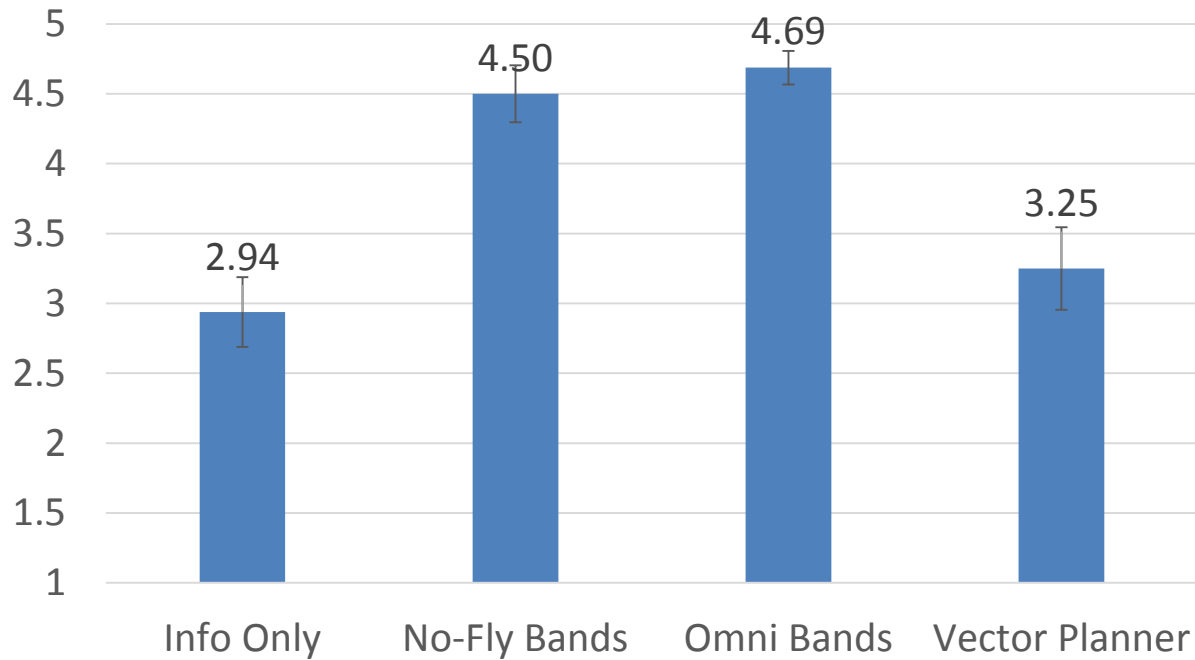
- Omni Bands received higher assessment ratings compared to the Info Only and Vector Planner displays, $p < .001$
- No-Fly Bands received higher assessment ratings compared to the Info Only display, $p < .05$

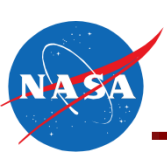




Results: Post-Trial

- Conflict Avoidance
 - *'This display provided the information necessary to perform avoidance maneuvers for well clear maintenance'*
 - Conflict avoidance ratings were greater for the No-Fly and Omni Bands displays compared to the Info Only and Vector Planner displays, $p < .001$





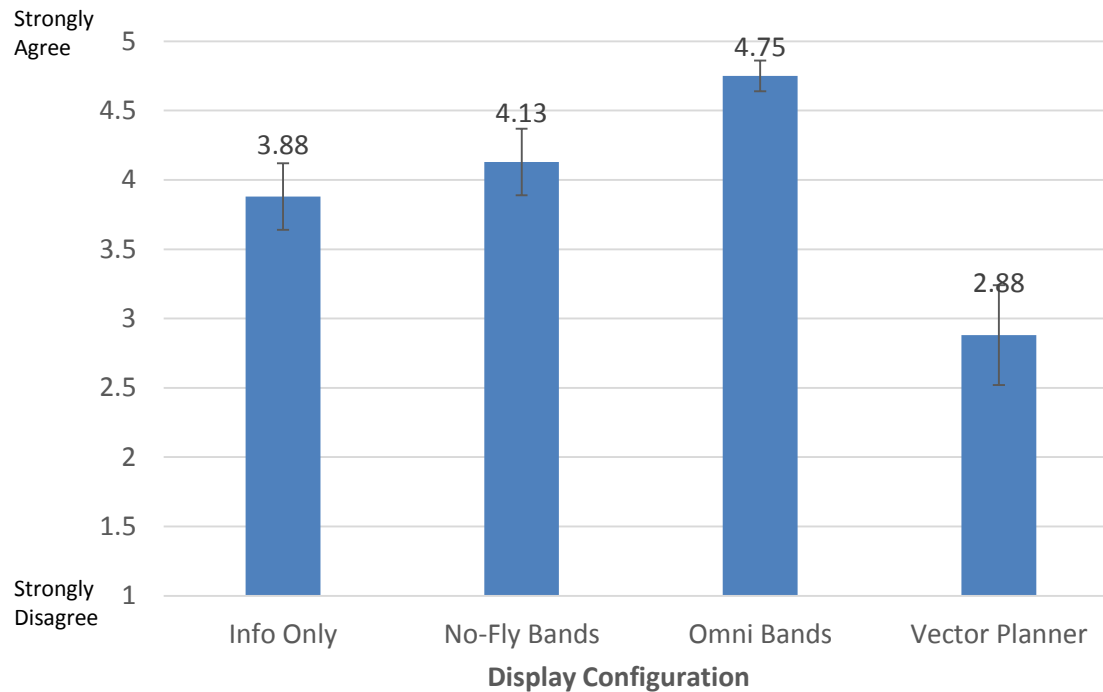
Results: Post-Trial

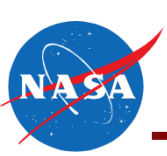
- Ease of Use

- *'This display was easy to use'*

- Pilots rated the Omni Bands display as easier to use than the Info Only, No-Fly Bands, and Vector Planner displays, $p = .001$

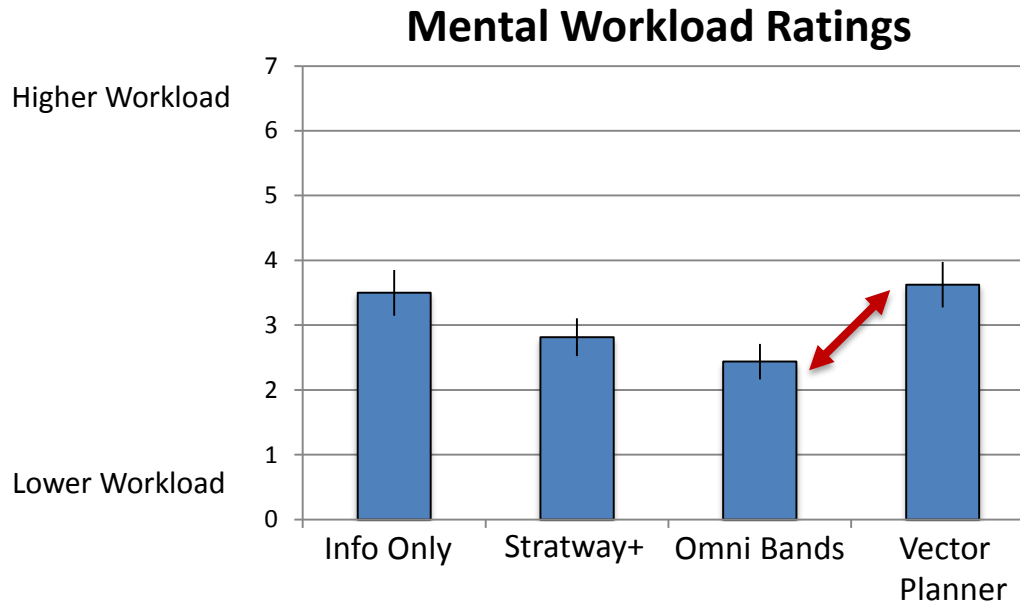
- Info Only display was rated easier to use than Vector Planner, $p < .05$

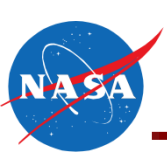




Post-Trial: Workload

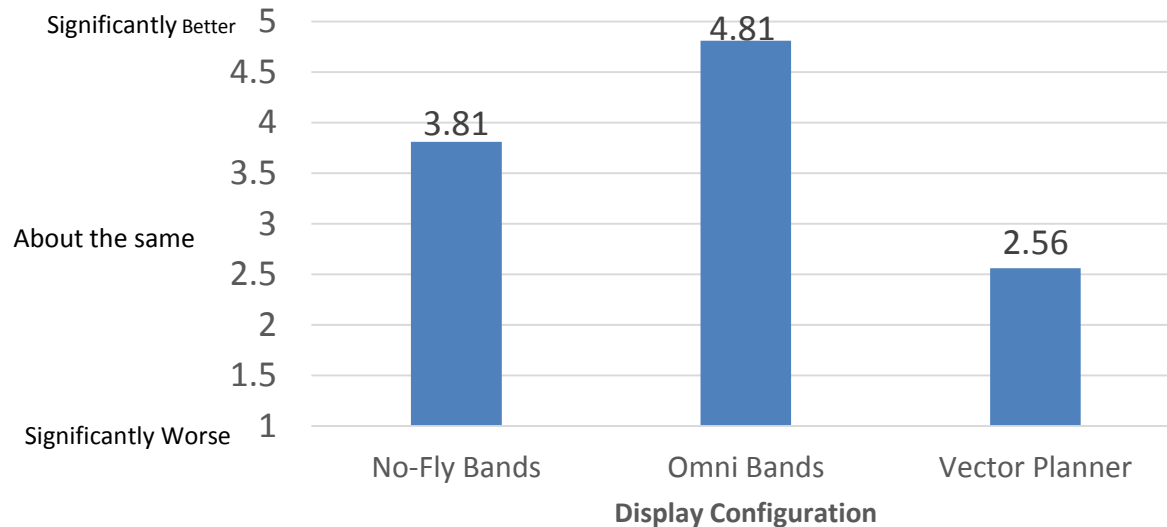
- Omni Bands resulted in significantly lower workload ratings than the Vector Planner for 5 of the 6 scales:
 - Mental, Temporal, Effort, Frustration, & Performance Degradation
 - Only Physical Demands failed to result in a significant difference

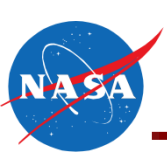




Results: Post-Sim

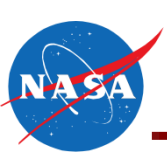
- Display Preference
 - *‘Rank the displays in order of their effects on your ability to maintain well clear’*
 - Banding displays were most favored overall
 - 88% of pilots voted **Omni Bands** as the most beneficial
 - No-Fly Bands ranked second by 63% of pilots
 - Vector Planner received the lowest average ranking (ranked last by 50% of pilots)
 - Only one pilot rated Info Only display as top-2 preferred
 - *‘How did the three suggestive guidance displays affect your ability to maintain well clear compared to Info Only?’*





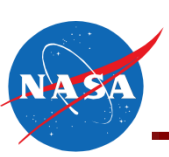
Discussion

- Subjective ratings revealed that suggestive maneuver guidance in the form of banding is highly favored by UAS pilots
 - Information on all displays were rated as sufficient to DAA task performance overall
 - Banding displays rated most conducive to conflict detection and resolution
 - Provided guidance that was constantly visible to pilots
 - Omni Bands ranked most preferred and easiest to use
 - Indicated severity of potential threat(s)
 - Provided specific altitude values to achieve
 - Reduced cognitive workload compared to Vector Planner and Info Only
 - Vector Planner required manual activation that lasted just five seconds
 - » “Added an undesirable lag in decision-making”
 - » Only display rated difficult to use
 - Consistent with objective performance (Rorie et al., 2016)
 - Quicker response times and less well clear violations with the banding displays



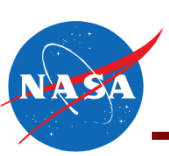
Conclusion

- Suggestive maneuver guidance in the form of banding is advantageous to pilot acceptability, response time, and performance
- DAA display considerations
 - Suggestive guidance that is not readily available may fare worse for task performance compared to no guidance at all if not implemented well
 - Trial planning tools previously rated more favorably when coupled with navigation interface in past research (Monk et al., 2015)
 - Further research needed to determine minimum information requirements
 - All displays rated as sufficient despite differences in subjective/objective performance
 - Interoperability with existing collision avoidance systems
 - Variations in aircraft performance, airspace environment, navigation interface, etc.



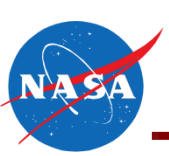
The End

Questions?



Display Conditions (VIDEO BACKUP)

The screenshot displays the Vigilant Spirit Control Station interface. The main window shows a dark-themed map with a flight path for Hawk 21, marked with waypoints 1 through 11. A circular radar display is centered on the path, showing a range of 12.0 Nmi. A 'Steer Hawk 21' control panel is overlaid on the map, displaying flight parameters: WP: WP02 - WEPLO - Ope, Alt: MSL 9000 ft, Spd: IAS 160 kts, and Hold On status. A 'Hawk 21' status window in the top center shows 'Full' fuel and 'Operational' status. The right sidebar contains a 'Navigation' panel with 'Automation' set to 'Manual / Off', 'Quick Commands', 'Steering' controls, and a 'Flight Plan' section. The bottom status bar shows coordinates: N 39.354640° W 123.279017° MSL 2625 R (D11).



Results: Post-Trial (Backup?)

- Task Performance

- *‘Rate your ability to handle all pilot responsibilities’*

- Pilots indicated greater ability to handle DAA tasks in the No-Fly and Omni Bands displays compared to Info Only and Vector Planner, $p = .001$

