Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Maintain and Regain Well Clear: Maneuver Guidance Designs for Pilots Performing the Detect-and-Avoid Task

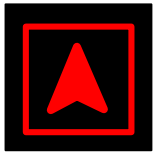
Kevin J. Monk, M.S.
NASA Ames Research Center

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)
  - Produce research findings that guide the development of RTCA Special Committee 228's Minimum Operational Performance Standards (MOPS) for UAS
    - Identify minimum DAA display information/guidance elements 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 remaining DAA well clear (DWC)
    - Detect potential threat(s) → Determine response → Execute resolution
  - UAS traffic displays with advanced conflict resolution tools have reduced DWC violations and have been rated favorably by pilots (Bell et al., 2012; Draper et al. (2014)

DAA System: Multi-Level Alerting Structure

Symbol	Name	Pilot Action	Time to Loss of DAA Well Clear	Aural Alert Verbiage
	DAA Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	25 sec	"Traffic, Maneuver Now"
	Corrective DAA Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	55 sec	"Traffic, Avoid"
	Preventive DAA Alert	• On current course, corrective action ***should not be required*** • Monitor for potential increase in threat level	N/A	"Traffic, Monitor"
	None (Target)	• No action expected	X	N/A

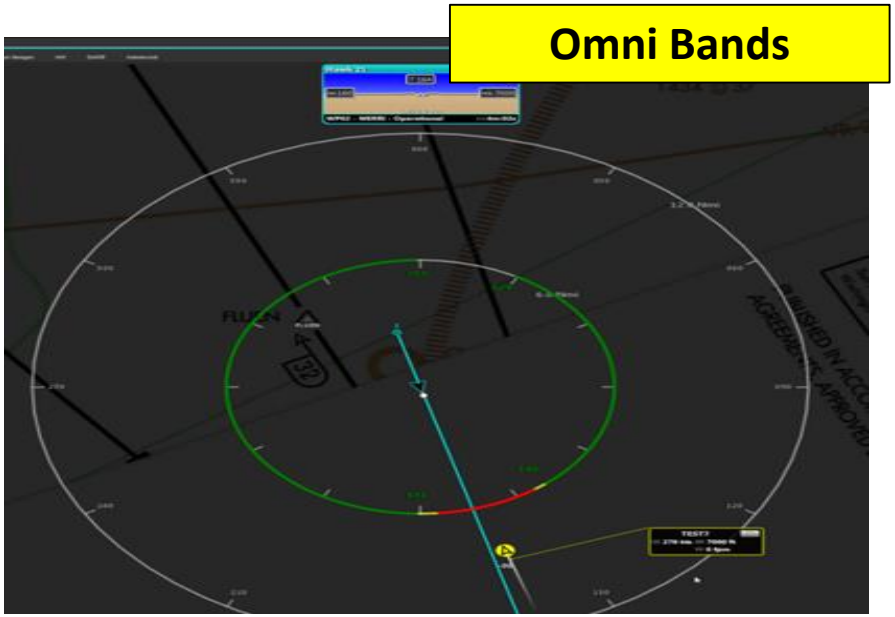
Background

- Suggestive DAA displays with maneuver guidance bands have improved pilot performance compared to informative displays
  - Quicker response times (Fern et al., 2015; Rorie & Fern, 2015)
  - Fewer DWC violations (Santiago & Mueller, 2015)
  - Depicts predicted safety level of nearby heading/altitude options:

No-Fly Bands

- Conflict regions: Yellow
  - No indication of severity
- Conflict-free regions: No bands

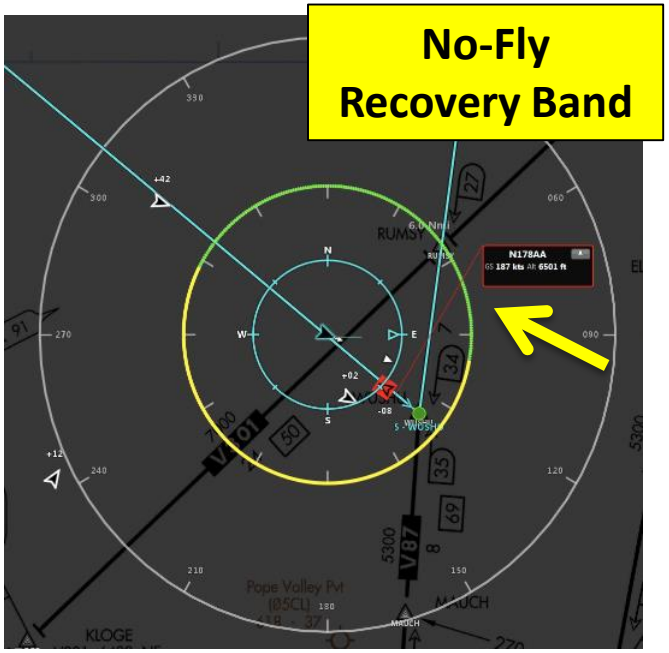
Omni Bands



- Conflict regions: Yellow or Red
  - Based on predicted threat level
- Conflict-free regions: Green

Background

- Suggestive DAA guidance was identified as a minimum display requirement in the DAA MOPS, and shall provide:
  - Threat severity of trajectory options predicted to result in loss of DWC
    - Bands distinguish caution-level (yellow) vs. warning-level (red)
  - Positive maneuver guidance to *recover* from a DWC violation once it is unavoidable
    - Regain DWC function
    - Conflict bands remain saturated
- Open Issues
  - Are conflict-free bands necessary?
  - DWC Recovery guidance concept
    - Direct assessment
      - MOPS compliant



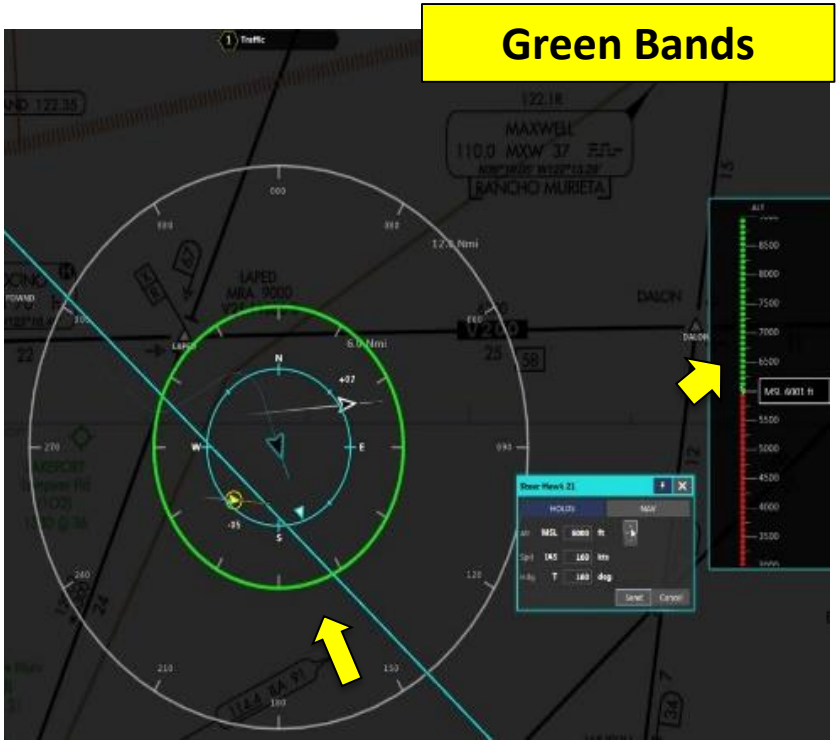
Purpose

- Examine whether the presence or absence of green conflict-free DAA bands impact pilots' ability to maintain DWC
  - Response time (RT)
  - Loss of DWC (LoDWC) rate

- Evaluate two 'well clear recovery' design concepts that aid in regaining DWC
  - 'Limited Suggestive' vs. 'Directional'
  - Does well clear recovery display type impact response times, LoDWC severity, or compliance rates?
  - Which recovery guidance design is more preferred?

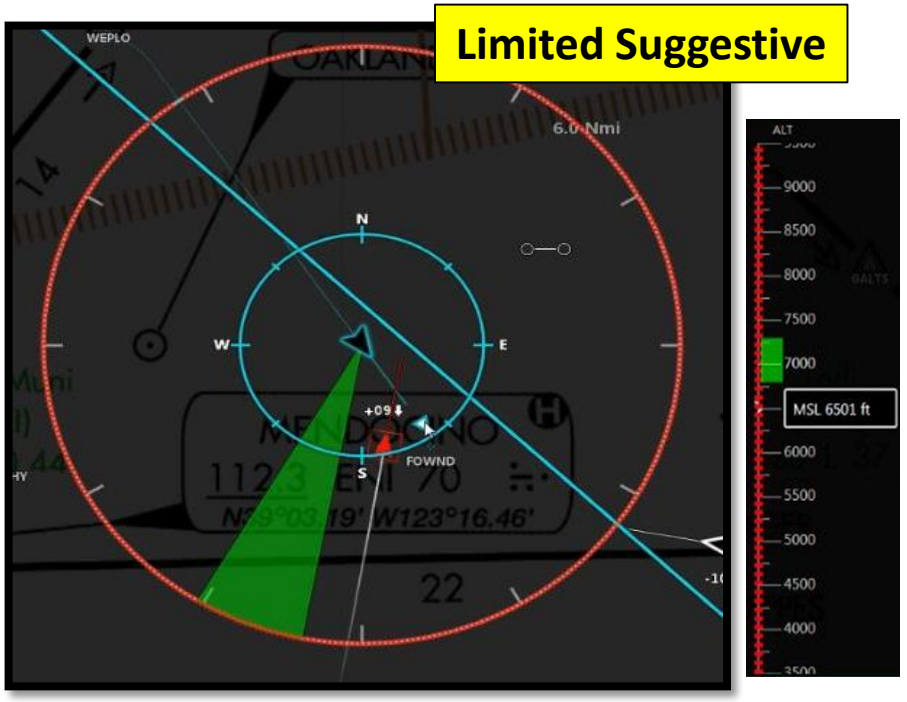
Experimental Design

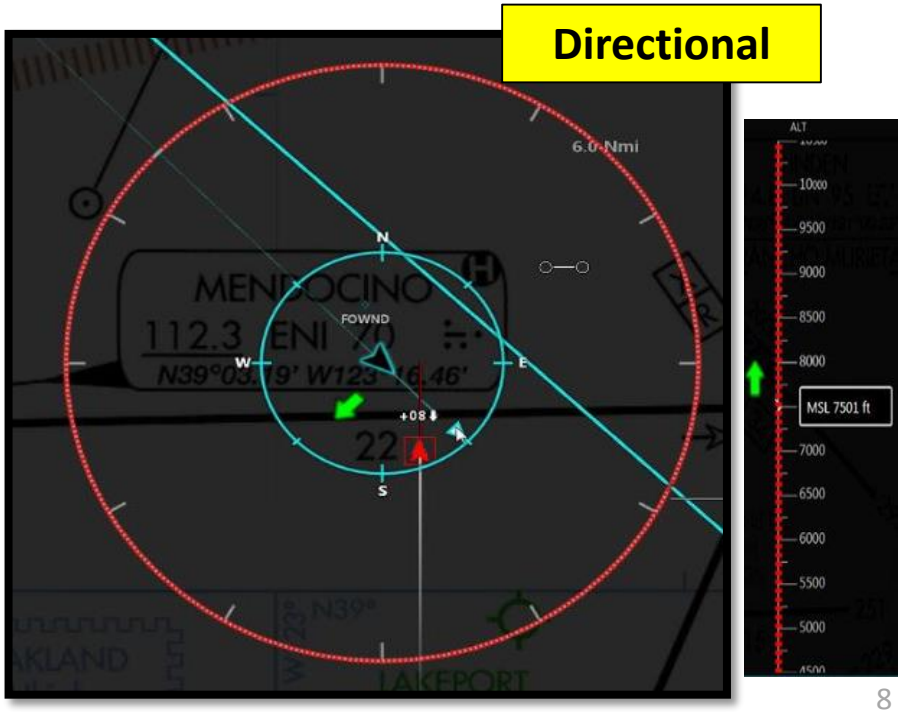
- Conflict-free DAA Bands (between-subjects)
  - Green: conflict-free trajectory options depicted by green bands
  - No Green (None): conflict-free trajectory options are left blank



Experimental Design

- Well Clear Recovery guidance display option (within-subjects)
  - Generated maneuver recommendation for a timely regain of DWC
    - Appeared once DAA guidance became saturated with red bands
  - Limited Suggestive: displayed a green wedge with a suggestion range of optimal headings *or* altitudes to fly in order to maximize separation
  - Directional: displayed a green arrow indicating the general direction of the recommended horizontal *or* vertical maneuver





Method

- Participants
  - 6 active-duty UAS pilots
    - μ_{age} = 36 years old
    - 1,400 hours of unmanned flight experience
    - 1,600 hours of manned flight experience
  - 4 commercial pilots
    - μ_{age} = 30 years old
    - 9,000 hours of manned flight experience

- 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

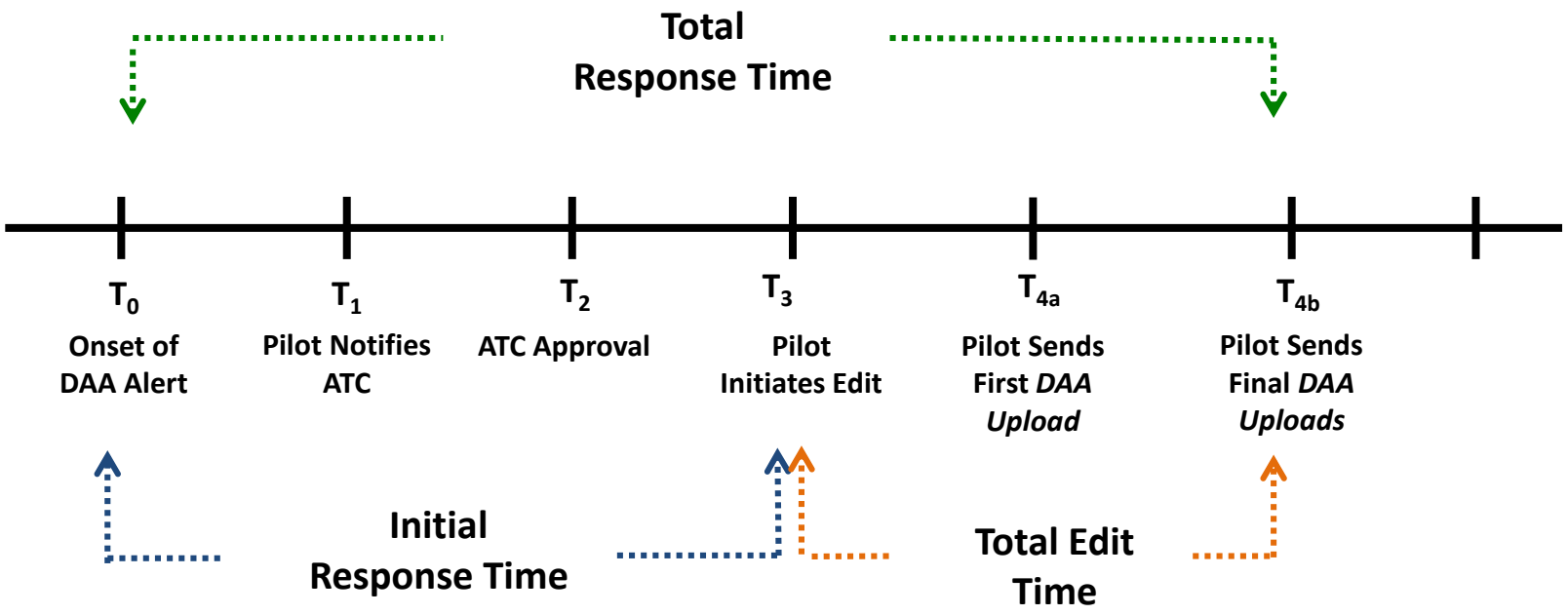
Procedure

- DAA Pilot Task
  - Operate simulated MQ-9 through Class E airspace under Instrument Flight Rules
  - Maintain DWC with surrounding aircraft
    - Regain DWC when necessary

- Four 40-minute scenarios
  - 16 encounters scripted to lose DWC without pilot action
    - 8 blunders that forced an immediate loss of DWC at first alert
      - Triggered onset of well clear recovery guidance

Measures

- Measured Response
  - Primary response time metric is Total Response Time
    - Comprised of Initial Response Time and Total Edit Time



Pilot Interaction Timeline

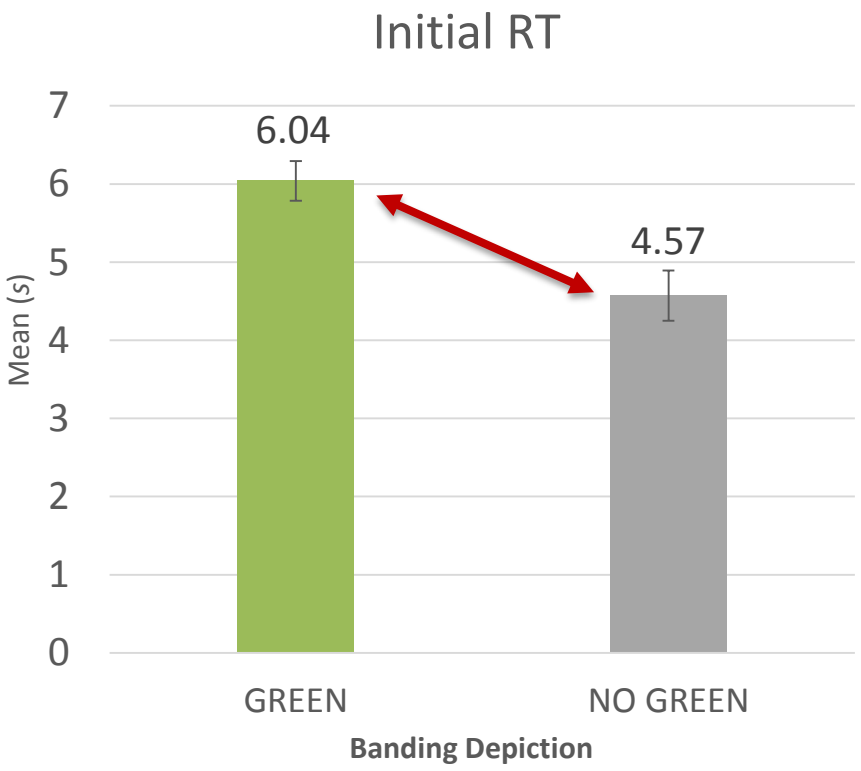
Measures

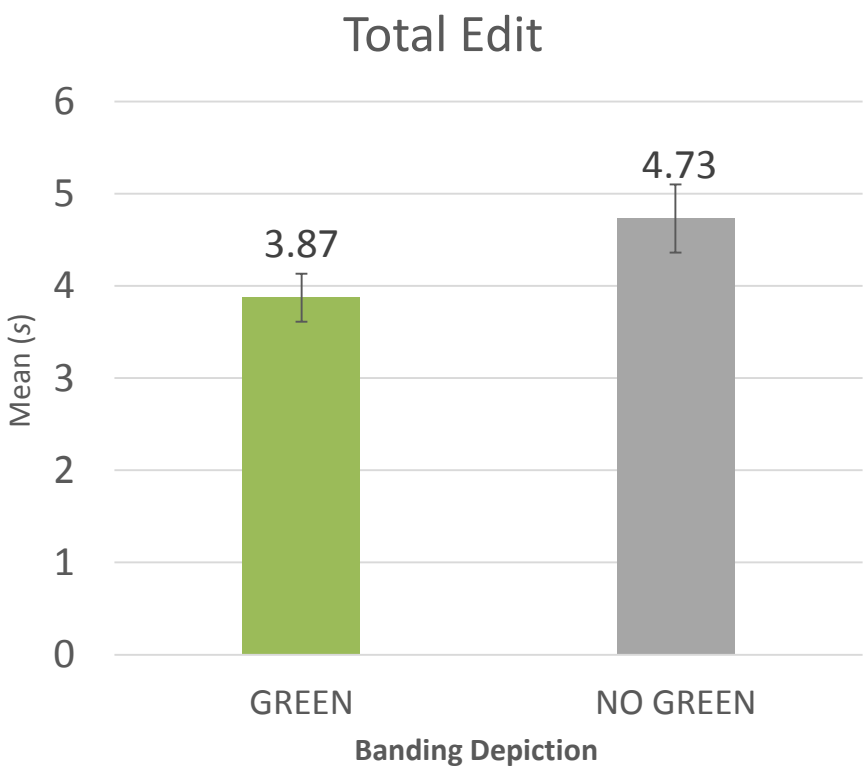
- LoDWC Severity
  - Defined by 'DAA Well Clear Penetration Integral' metric (DWCPI)
    - Combined amount of time spent within DWC threshold and geometric separation at CPA into single measure
    - Higher value = more severe
  - Reported by recovery display type
    - Only 1 DWC violation across all non-blunder encounters
- Well clear recovery compliance rate

$\alpha = .05$

Results: Conflict-free DAA Bands

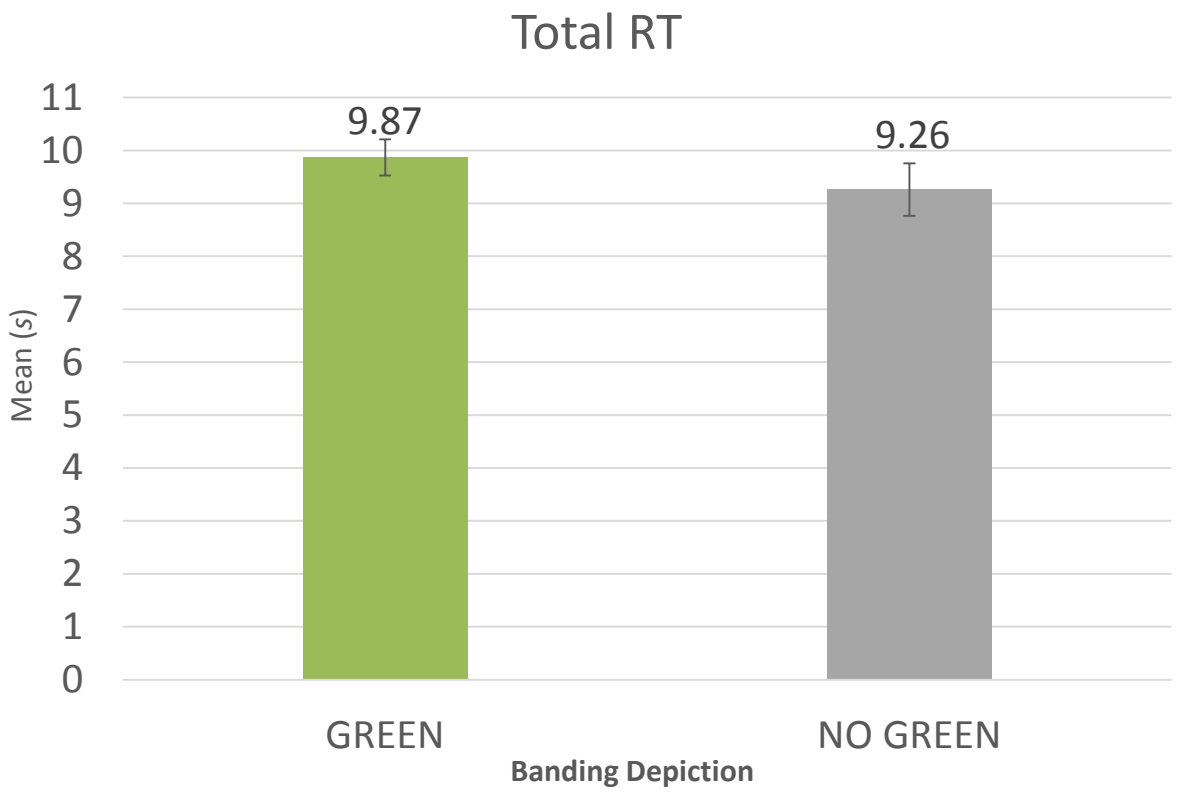
- Initial RT
  - Initial RTs were, on average, **1.47s** quicker with No Green Bands display ($p < .001$)
- Total Edit
  - Pilots with green DAA bands completed their edits **0.86*s*** quicker ($p = .054$)





Results: Conflict-free DAA Bands

- Total RT
  - Banding depiction did not significantly affect Total RTs (*MD* = 0.61*s*)



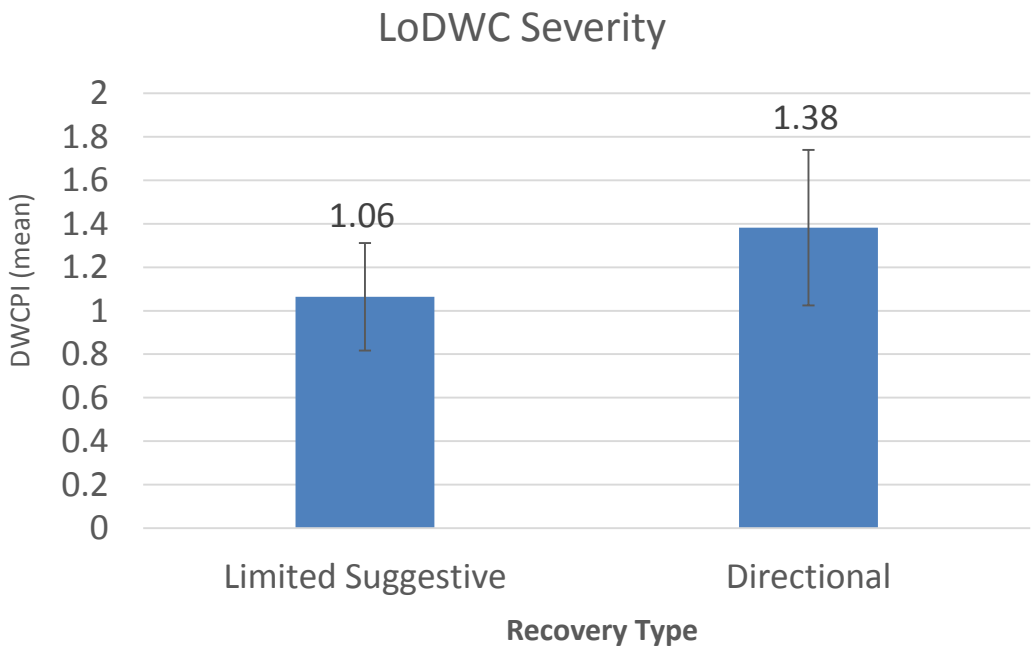
Results: Recovery Guidance Type

- Measured Response
  - Initial RT
    - No significant difference found by display type (*MD* = 0.37*s*)
  - Total Edit
    - No significant difference found by display type (*MD* = 0.51*s*)
  - Total RT
    - No significant difference found by display type (*MD* = 0.14*s*)

- Compliance Rate
  - Pilots complied with recovery guidance **98%** of the time
    - Equal compliance rate between displays

Results: Recovery Guidance Type

- LoDWC Severity
  - DWC violations were slightly less severe with the Limited Suggestive display
    - Difference was nonsignificant (high variability)



Conflict-free Bands for Remaining DWC

- Suggestive DAA Banding Guidance remains effective at supporting the primary DAA task, regardless of whether conflict-free bands are present
  - Maintained DWC at a nearly equal rate with each display
    - Performance comparable to previous analyses

- Implementation of green conflict-free bands is considered optional in DAA MOPS

Recovery Guidance for Regaining DWC

- No significant impact of recovery type on pilot performance, preference or compliance
  - Response times were nearly identical
    - Recovery guidance calls for immediate action
    - Minimal decision-making required
  - Limited Suggestive preferred by 60% of pilots
    - Presented a more specific solution range
    - Slightly less time spent within DWC threshold compared to Directional
    - Referenced as a viable recovery design in DAA MOPS

- Multiple viable guidance options for DWC maintenance/recovery

THANK YOU!

kevin.j.monk@nasa.gov