The Impact of Suggestive Maneuver Guidance on Pilots Performing the Detect and Avoid Function

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PT5 Background

• Motivation
  – Build upon previous human-in-the-loop simulations results and lessons learned to identify minimum DAA display and guidance requirements for draft SC228 MOPS
    • PT4
      – A suite of integrated guidance tools led to faster pilot responses, fewer losses of well clear and less severe losses of well clear when they did occur
    • iHITL
      – Integrated guidance tools led to less severe losses of well clear and faster pilot responses than seen in PT4
    • AFRL Maneuver Study
      – Guidance (in the form of ‘banding’) led to faster pilots responses and fewer collision avoidance alerts
• Modifications from previous sims:
  – Guidance tools were no longer tightly coupled to the ground control station’s auto pilot interface
  – Removed advanced features present in iHITL (e.g., well clear ring & dead reckoning lines)
  – Modeled sensor uncertainty for the first time
    • Critical to test displays and algorithms with ‘imperfect’ data prior to flight tests
  – Implemented alerting structure as part of the draft MOPS
  – Increased workload on the pilot
    • More secondary tasks and interaction with their route
Experimental Design

• Mixed Factorial Design
  – Display Configuration (Within-Subjects Independent Variable):
    • Configuration 1: Minimum Information Set (No Guidance)
    • Configuration 2: Stratway+ No Fly Bands
    • Configuration 3: JADEM Omni Bands
    • Configuration 4: JADEM Vector Planning Tools
Experimental Design

- **Participants**
  - 16 active UAS pilots
    - Avg. 37 years old (all male)
    - Manned Flying Experience
      - Civil airspace: 575 avg. hrs
      - Military: 1760 avg. hrs
    - Unmanned Flying Experience
      - Civil airspace: 30 avg. hrs
      - Military: 1100 avg. hrs

- **Task**
  - Fly simulated MQ-9 through Class E airspace (Oakland Center – ZOA 40/41)
    - Navigate along pre-filed routes (used AFRL’s Vigilant Spirit Control Station)
    - Maintain well clear from pre-scripted conflicts
    - Coordinate with ATC
    - Attend to secondary tasks (e.g., chat messages, system alerts)
Experimental Design

- Pre-planned conflicts with ownship
  - 6 scripted encounters predicted to lose well clear
    - 3 with cooperative traffic (detected at max range of 15nm)
    - 3 with non-cooperative traffic (detected at max range of 8nm, with limited FoR)
  - 3 scripted encounters predicted to become preventive self separation alerts
Experimental Design

• Simulation confederates
  – NATCA controller managed UAS and manned traffic within ZOA 40/41
    • Simulated manned traffic based on actual sector activity
  – Pseudo-pilots managed all manned traffic to provide dynamic sector activity
  – ATC SME operated as ‘ghost’ controller to ensure conflicts were generated
## Draft MOPS Alerting Structure

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>Buffered Well Clear Criteria</th>
<th>Time to Loss of Well Clear</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
</table>
| ![Symbol] | Self Separation 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” |
| ![Symbol] | Corrective Self Separation 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 | 75 sec  
(TCPA approximate: 110 sec) | “Traffic, Separate” |
| ![Symbol] | Preventive Self Separation Alert          | • On current course, corrective action **should not be required**  
• Monitor for intruder course changes  
• Talk with ATC if desired | DMOD = 0.75 nmi  
HMD = 1.0 nmi  
ZTHR = 700 ft  
modTau = 35 sec | 75 sec  
(TCPA approximate: 110 sec) | “Traffic, Monitor” |
| ![Symbol] | Self Separation Proximate Alert           | • Monitor target for potential increase in threat level | DMOD = 0.75 nmi  
HMD = 1.5 nmi  
ZTHR = 1200 ft  
modTau = 35s | 85 sec  
(TCPA approximate: 120 sec) | N/A |
| ![Symbol] | None (Target)                             | • No action expected                                                        | Within surveillance field of regard | X                           | N/A |
Display Conditions
• Total Number of Encounters:
  – 282 encounters analyzed in following measured response data
    • 37 (13%) encounters were excluded due to pilot maneuvering prior to receiving an alert
• By Threat Level
  – 244 Corrective SS Alerts issued
  – 111 SS Warning Alerts issued
• By Intruder Equipage
  – 138 encounters with Cooperative Traffic
  – 144 encounters with Non-Cooperative Traffic
Measured Response Timeline & Associated Metrics

- **T₀**: Traffic Display Alert (SS or CA)
- **T₁**: Pilot Notifies ATC
- **T₂**: ATC Approval
- **T₃**: Pilot Initiates Edit
- **T₄a**: Pilot Uploads First Edit
- **T₄b**: Pilot Uploads Final Edit

**Metrics**:
- Initial Response Time
- Total Response Time
- Initial Edit Time (First Upload)
- Total Edit Time (Final Upload)
- Total Response Time
• There was no significant effect of Configuration on Notify Time for all SS alerts, $p > .05$

• On average, pilots took **16.15s** to notify ATC in response to a Corrective SS or SS Warning alert
  
  – 50% within 12s, 90% within 33s
• Configuration had a significant effect on Initial RTs, $p < .01$:
  – Initial RTs for Stratway+ were **7.03s** shorter, on average, than those in Vector Planner, $p < 0.5$
  – Initial RTs for Omni Bands were **5.07s** shorter, on average, than those in Vector Planner, $p = .05$
  – No other configurations differed significantly

• On average, pilots took **12.35s** to initiate an edit in response to a Corrective SS or SS Warning alert
  – 50% within 12s, 90% within 36s
• No effect of configuration on initial edit times ($p > .05$)
• On average, pilots took 8s to make an initial edit following a Corrective SS or SS Warning alert
  – 50% within 6s, 90% within 16s
• Configuration had a significant effect on Total Edit times, $p < .05$:
  – Total Edit times for Vector Planner were 6.6s shorter, on average, than those in Info Only, a significant difference, $p < 0.1$
  – No other configurations differed significantly
• On average, pilots took 10.7s to upload their final maneuver after the initiation of an edit
  – 50% within 7s, 90% within 22s
Configuration had a significant effect on Total RTs:

- Total RTs for Stratway+ were **8.2s** shorter, on average, than those in Info Only, a significant difference ($p=0.02$)
- No other configurations differed significantly

On average, pilots took **22.8s** to upload a final maneuver following the onset of a Corrective SS or SS Warning alert

- 50% within 19s, 90% within 42s
• Maneuver Type
  – 88% of maneuvers were in horizontal dimension
  – 8% of maneuvers were in vertical dimension
  – 4% of maneuvers were made in both dimensions
• Info Only resulted in horizontal maneuvers that were, on average, 10deg larger than seen with the three guidance displays
  – Also see less variability between the three guidance displays
• Not enough data points to look at average vertical maneuver size
Pilots required an average of **1.34** uploads per encounter in Info Only condition, compared to (roughly) **1.10** uploads per encounter with the remaining displays.

- **25%** of encounters in the Info Only display required more than 1 upload to maintain separation.
Results Summary

• Notification Time & Initial Edit Time
  – No differences
• Initial Response Time
  – Vector Planning tools resulted in the slowest times, while remaining 3 displays were roughly equal
• Total Edit Time
  – Vector Planning tools resulted in fastest times, with banding displays slightly slower and Information Only the slowest
• Total Response Time
  – Fastest for Stratway+, but very close with Omni Bands
    • Vector Planning tools substantially slower, but Information Only far slower
• Maneuver Type
  – Overwhelming preference for lateral maneuvers, little variation between displays
• Maneuver Size
  – Larger lateral maneuvers for Information Only display, little difference between rest
• Encounters with Multiple Uploads
  – Least common with 2 banding displays
    • Vector planner roughly twice as likely, information only 4x as likely
Conclusion

• Suggestive maneuver guidance resulted in faster responses and more efficient maneuvers
  – The 2 banding displays (Stratway+ & Omni Bands) helped maintain consistently low interaction times – initial RT, initial & total edit
    • Vector Planner increased edit times but raised initial RT times
  – The 2 banding displays also minimized maneuver size and the number of multiple-upload maneuvers
    • Vector planner helped minimize maneuver sizes but led to twice the number of multiple-upload maneuvers than the banding displays