UAS Integration into the NAS: Detect and Avoid Display Evaluations in Support of SC-228 MOPS Development

Presented To: ICAO ASP TSG

Lisa Fern (Lisa.Fern@NASA.GOV)
The Ohio State University

Conrad Rorie (Conrad.Rorie@NASA.GOV)
San Jose State University

Jay Shively (Robert.J.Shively@NASA.GOV)
NASA Ames Research Center
Self-Separation Timeline

Time until CPA

~90 sec
~80 sec
~65 sec
~35 sec
0 sec

Latency
ATC Interaction Time (~10 sec)
Pilot Response Time (~15 sec)
Aircraft Maneuver Time (~30 sec)
Well Clear Threshold (~35 sec)
NMAC
Background

- Goal: Provide data on the effect of various Detect and Avoid (DAA) display features with respect to pilot performance of the self-separation function in order to determine the minimum information requirements for DAA displays.
  1. What is the pilot contribution to the self-separation timeline in terms of expected response time to detect, determine and execute a maneuver in response to a potential loss of well clear?
  2. What configuration of display elements meets a minimum acceptable level of performance? What, if any, level of pilot maneuver guidance is required to support this performance?
Display Types:

- Informative: Provides essential information of a hazard that the remote pilot may use to develop and execute an avoidance maneuver. *No maneuver guidance or decision aiding is provided to the pilot.*

- Suggestive: *Provides a range of potential resolution maneuvers to avoid a hazard with manual execution.* An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers.

- Directive: *Provides specific recommended resolution guidance to avoid a hazard with manual or automated execution.* An algorithm provides the pilot with specific maneuver guidance on when and how to perform the maneuver.
Background

- Approach: Conduct a series of iterative human in the loop experiments, in a representative simulation environment, with different display configuration to objectively measure pilot performance on maintaining well clear
  - Key metrics: pilot response time, losses of well clear, severity of losses of well clear
  - Three simulations have been conducted: PT4, iHITL, PT5
    - Displays are modified/improved/changed based on data/observations
    - Displays are carried through to new HITLs to create anchors or linkages to previous data for comparison
    - New displays are developed for test
    - Test/simulation environment/protocols also updated and improved between HITLs
Simulation Environment

• Emulation of representative environment:
  – UAS Ground Control Station (GCS) with DAA Display
  – DAA system components:
    • Surveillance
    • Threat detection and alerting
    • Suggestive and directive guidance
  – Air Traffic Control
  – Simulated Manned Traffic

• Integrated via NASA’s Live, Virtual, Constructive (LVC) architecture
Simulation Environment: Ground Control Station (GCS)

- The Vigilant Spirit Control Station (VSCS) developed by the Air Force Research Laboratory (AFRL)
- Main Features:
  - Robust, flexible interface
  - Realistic control and navigation displays
  - System status and health monitoring
  - STANAG 4586 Compliant
  - Multi-UAS control with VSCS has been tested in simulation and flight by AFRL
- Current UAS in the NAS version modifications/additions:
  - Single pilot – single UAS control
  - NAS-compatible database (low- and high-altitude charts with navigational aids/”fixes”)
  - Integrated traffic display
Simulation Environment: DAA System

- The Java Architecture for DAA Modeling and Extensibility (JADEM) was developed by the UAS in the NAS project at NASA Ames Research Center

- Main Functions:
  - Emulate surveillance parameters for various sensor types
    - e.g., ADS-B, active radar, TCAS, etc.
  - Receive state information from simulated traffic (MACS)
    - Determine which aircraft to show on traffic display(s) based on surveillance parameters
  - Receive trajectory information from UAS ownship (VSCS)
  - Queries all intruders for potential conflicts with ownship
  - Assigns intruders alert levels based on given thresholds
  - Host self-separation and collision avoidance algorithms which can provide conflict resolution guidance
## Simulation Environment: 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](image) | 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](image) | 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](image) | 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](image) | 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](image) | None (Target) | • No action expected | Within surveillance field of regard | X | N/A |
The Multi Aircraft Control Station (MACS) developed by the Airspace Operations Laboratory (AOL) at NASA Ames Research Center.

Provides emulation of ground- and air-side Air Traffic Control (ATC) operations:
- Air Traffic Controller work stations
- Simulated traffic generator
- Psuedo pilot work stations
- IFR and VFR simulated traffic
- Traffic scenarios in Oakland Center (ZOA 40/41) airspace based on current day traffic patterns.
Simulation Environment: Multi Aircraft Control Station (MACS)

- Oakland Center ZOA 40/41
  - Class A & E
  - Current day IFR and VFR traffic flows

- UAS mission scenario derived from FAA CONOPS scenarios
  (combination of “Loiter for Surveillance” and “Grid Pattern”)
Simulation Environment: LVC Architecture

SaaProc Input:
- Traffic
- Ownship

SaaProc Output:
- Intruders
- Saa Threat Alerts and Resolutions

SaaProc/JADEM (sensor model)

VSCS Input:
- Intruders
- SAA Threat Alerts

VSCS Output:
- Ownship

VSCS

LVC Gateway

Stratway Input:
- Intruders
- Ownship

Stratway Output:
- Stratway Bands Msg

Stratway Bands

ATC & Pseudopilot Input:
- Ownship

ATC & Pseudopilot Output:
- Traffic

Traffic:
- Flt State, Flt Plan, Traj. Intent

Ownship:
- Flt State, Flt Plan, Traj. Intent

Intruders: Flt State

ADRS (LaRC)

GCS (MACS)

ADRS

ATC & Pseudopilot System (MACS)
• Approach: Conduct a series of iterative human in the loop experiments, in a representative simulation environment, with different display configuration to objectively measure pilot performance on maintaining well clear
  – Key metrics: pilot response time, losses of well clear, severity of losses of well clear
  – Three simulations have been conducted: PT4, iHITL, PT5
    • Displays are modified/improved/changed based on data/observations
    • Displays are carried through to new HITLs to create anchors or linkages to previous data for comparison
    • New displays are developed for test
    • Test/simulation environment/protocols also updated and improved between HITLs
Self-Separation Timeline

- Time until CPA
  - Well Clear Threshold (~35 sec)

- Aircraft Maneuver Time (~30 sec)

- Pilot Response Time (~15 sec)

- ATC Interaction Time (~10 sec)

- Latency

TOTAL RESPONSE TIME:
- Detect Intruders
- Pilots Determine Resolution
- Negotiate Clearance with ATC and uplink maneuver to aircraft
Self-Separation Timeline

- **Traffic Display Alert (SS or CA)**
  - $T_0$
- **Pilot Notifies ATC**
  - $T_1$
- **ATC Approval**
  - $T_2$
- **Pilot Initiates Edit**
  - $T_3$
- **Pilot Uploads First Edit**
  - $T_{4a}$
- **Pilot Uploads Final Edit**
  - $T_{4b}$
- **Traffic Alert Removed**
  - $T_5$
- **UAS Completes Maneuver**
  - $T_6$

Phases:

- **Compliance Time**
  - Alert Duration Time
  - Total Response Time
  - Aircraft Response Time
- **Initial Response Time**
- **Clearance Approval Time**
- **Initial Edit Time (First Upload)**
- **Total Edit Time (Final Upload)**

Key Times:

- **Notification Time**
- **Total Edit Time** (Final Upload)
- **Approval vs Upload Time**
- **Notify vs Upload Time**

- **Aircraft Response Time**
- **Notification Time**
- **Clearance Approval Time**
- **Initial Edit Time (First Upload)**
- **Total Edit Time (Final Upload)**

Legend:

- **Compliance Time**
- **Initial Response Time**
- **Clearance Approval Time**
- **Initial Edit Time (First Upload)**
- **Total Edit Time (Final Upload)**

**Warning:**

- **Traffic Alert Removed**
- **UAS Completes Maneuver**

Note:

- **Total Edit Time** refers to the time from the pilot's initial action to completing the final upload.

**Units:**

- **Time**
  - Initial Response Time
  - Clearance Approval Time
  - Initial Edit Time (First Upload)
  - Total Edit Time (Final Upload)
  - Approval vs Upload Time
  - Notify vs Upload Time
Self-Separation Timeline

- **Traffic Display Alert (SS or CA)**: $T_0$
- **Pilot Notifies ATC**: $T_1$
- **ATC Approval**: $T_2$
- **Pilot Initiates Edit**: $T_3$
- **Pilot Uploads First Edit**: $T_{4a}$
- **Pilot Uploads Final Edit**: $T_{4b}$
- **Traffic Alert Removed**: $T_5$
- **UAS Completes Maneuver**: $T_6$

**Key Times:**
- Initial Response Time
- Clearance Approval Time
- Total Edit Time (Final Upload)
- Initial Edit Time (First Upload)
- Total Response Time
- Compliance Time
- Alert Duration Time
- Aircraft Response Time
- Notification Time
- Clearance Approval Time
- Total Edit Time (Final Upload)
- Initial Edit Time (First Upload)
- Approval vs Upload Time
- Notify vs Upload Time
PT4 – Experimental Design

• Goal: Evaluate candidate Detect and Avoid (DAA) displays and algorithms with respect to self-separation and collision avoidance.
  – What are the appropriate alerting thresholds for self separation?
  – What are the minimum information requirements for DAA displays?
  – Is there a performance difference between integrated and standalone displays?
  – What advanced display features improve pilot performance on maintaining well clear from other traffic?

• What advanced display features improve pilot performance on maintaining well clear from other traffic?
  – Experimental Design: Mixed Factorial Design
  – 2 (Display: Standalone, Integrated)
  – X 2 (Information: Basic, Advanced)
  – X 2 (Self-Separation Alerting Threshold)
• Display Information Level: Basic versus Advanced

1. Basic presents minimum information requirements only
   • Implementation identical as possible between Standalone and Integrated displays
   • Based on separate literature/requirements reviews by NASA and AFRL HMI teams
   • Vetted with FAA tech center (based on study they were running)
   • Similar to DO-317B (was a source document)
   • Alerting considered part of the min set

2. Advanced information elements:
   • Implementation different between Standalone and Integrated displays
   • Additional alerting information (predictive CA)
   • Time to and location of predicted CPA (intruder and ownship)
   • Pilot guidance
     – Trial/vector planner (suggestive)
     – Maneuver recommendations (directive)
   • Vertical situation display (Integrated only)
PT4 – Standalone Displays

Basic

Advanced
PT4 – Integrated Displays

Basic

Advanced
There was a significant main effect of Information on Total Response Time, $p < .05$
- Advanced was significantly faster (by 13.79 seconds on average) compared to Basic

Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
- Basic = 47.77 sec
- Advanced = 33.98 sec

There was not a significant interaction of Information by Display for Total Response Time, $p > .05$

Pilots took an average of **37.87 seconds** to complete their final edit in response to SS/CA alerts (from first alert appearance)
- Basic Standalone = 38.68 sec
- Basic Integrated = 44.86 sec
- Advanced Standalone = 35.60 sec
- Advanced Integrated = 32.35 sec
Self-Separation Timeline

**Time until CPA**

- 110 sec
- ? sec
- 35 sec

**TOTAL RESPONSE TIME:**
Detect Intruders
Pilots Determine Resolution
Negotiate Clearance with ATC and uplink maneuver to aircraft

**Well Clear Threshold**
PT4 – Response Time Results

Time until CPA

110 sec

Basic Integrated (45s)

Basic Standalone (39s)

Advanced Standalone (36s)

Advanced Integrated (32s)

Well Clear Threshold

35 sec

Aircraft Maneuver Time

30 sec

36 sec

39 sec

43 sec
PT4 – Losses of Well Clear

Proportion of Losses of Well Clear

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Advanced</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Standalone</td>
<td>0.4</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Integrated</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
PT4 – WCV Severity

[Box plots showing Actual TV Severity for Basic Std., Advanced Std., Basic Integ., and Advanced Integ.]
• Consistent advantage seen for Advanced over Basic displays in pilot response times
  – Overall, the Advanced displays had a faster Total Response Time (from initial alert appearance to the final maneuver upload) compared to Basic (14s faster, on average)
• There were no significant differences between the Standalone and Integrated condition
• No significant differences in number of, or severity of, losses of well clear, however:
  – Advanced had lower rates of LoWC than basic
  – No difference between Standalone and Integrated in rates of LoWC
  – Severity of well clear about the same across all displays
iHITL – Experimental Design

- Goals:
  1) Determine the individual contributions of the various PT4 advanced display features to pilots’ response times and ability to maintain well clear
  2) Introduce non-cooperative intruders to examine effect of different sensor ranges on pilots ability to maintain well clear

- One-Way Repeated Measures Factorial: Display Information Level (4 Level; Within Subjects)
  - D1: Advanced Display with Information Only (Informative)
  - D2: Advanced Display with Information + Vector Planner (Suggestive)
  - D3: Advanced Display with Information + Auto Resolutions (Directive)
  - D4: Advanced Display with Information + Vector Planner + Auto Resolutions (Suggestive + Directive)
    - Roughly same as ‘Advanced’ suite in PT4

- Embedded Variable
  - Intruder Equipage (manipulated within each scenario)
    - Transponder-equipped (detected via UAS’s ADS-B)
    - No Transponder (detected via UAS’s on-board RADAR)
iHITL – Display Conditions
Predictive SS Alerts

- Predictive SS = encounters that are predicted to lose well clear at any point during the encounter
- There was a near significant effect of Display on Total Response Time for Predictive SS alerts, $p = .056$
- Pilots took an average of **16.22 seconds** to complete their final edit in response to Predictive SS alerts (from first alert appearance)

IHITL and PT4 Display Comparison (All Encounters)
PT4 – Response Time Results

- Basic Integrated (45s) 30 sec
- Basic Standalone (39s) 36 sec
- Advanced Standalone (36s) 39 sec
- Advanced Integrated (32s) 43 sec

Time until CPA: 110 sec, ? sec, 35 sec

Well Clear Threshold: 30 sec
iHITL – Response Time Results

- Time until CPA
- Aircraft Maneuver Time
- Well Clear Threshold

- D1 (21s)
- D2 (20s)
- D3 (16s)
- D4 (16s)

- 110 sec
- ? sec
- 35 sec

- 54 sec
- 55 sec
- 59 sec
- 59 sec
iHITL – Losses of Well Clear

Proportion of Losses of Well Clear

![Bar chart showing the proportion of losses for D1, D2, D3, and D4.](chart.jpg)
iHITL – LoWC Severity

When actually losing well clear
iHITL – Results Summary

• Total Response Time:
  – No significant differences between displays
  – Trend shows **Directive Only** and **Suggestive + Directive** as faster than Information Only and Suggestive Only

• Well Clear Metrics:
  – No significant differences between displays
  – **Information** and **Suggestive Only** (D1 and D2) display conditions had 2.5X as many LoWCs than the **Suggestive + Directive** combined (D4)
  – Severity data shows evidence of trends toward performance benefits with **Suggestive + Directive** compared to other three displays
PT5 – Overview

• Goal: Continue evaluation of candidate Detect and Avoid (DAA) displays and algorithms with respect to self-separation and collision avoidance to inform SC-228 DAA Minimum Operational Performance Standards

• Method:
  – Build upon results of previous hitl simulations results and lessons learned to identify minimum DAA display and guidance requirements for draft SC228 MOPS
    • PT4: Advanced better than Basic (but issues; well clear & display training, pop-ups)
    • iHITL: No significant differences between Advanced information features from PT4, but trends favoring combined Suggestive + Directive (D4) guidance
    • Maneuver Study (AFRL): Banding display showed faster response time compared to informative and directive displays; banding and advanced informative had least losses of well clear (neither results statistically significant)
PT5 – 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
  – *Sensor Performance* (Between-Subjects Independent Variable)
    • Level 1: Perfect Surveillance Data
    • Level 2: Imperfect Surveillance Data

• Embedded Variable
  – *Intruder Equipage* (manipulated within each scenario)
    • Transponder-equipped (detected via UAS’s ADS-B)
    • No Transponder (detected via UAS’s on-board RADAR)
PT5 – Display Conditions
PT5 – Total Response Time Results

- Pilots responded, on average, **10s** faster to SS Warning Alerts than they did to Corrective SS Alerts
  - Pilots exhibited less variability between displays when responding to SS Warning Alerts than to Corrective SS Alerts
    - Range for SS Warning Alerts: 11s - 15s
    - Range for Corrective SS Alerts: 19s – 30s
  - Variability due to coordination with ATC – adds ~ 10 secs to total response time
• Pilots responded, on average, 4.5s faster to non-cooperative traffic than they did to cooperative traffic, which was a significant difference ($p=.008$)
  – There was also less variability in pilots’ responses to Non-Cooperative encounters
• Sensor model was not found to have any effect on pilot’s Total RTs
Info Only (19.8%) was roughly four times as likely as Stratway+ (6.5%) and Omni Bands (4.2%) to result in LoWC, a significant difference (p<.05)
  – Info Only was roughly two times as likely as Vector Planner (10.3%) to lead to LoWC, which approached significance (p=.086)

- No significant differences seen between the three guidance displays in terms of LoWC
PT5 – LoWC Severity

- All Displays:
  - Actual Separation / Separation Threshold
  - Less than 1 = spatial separation was NOT maintained

![Severity Index Distribution Chart]

Number of Encounters

Severity Index

No Separation

Increased Separation
Total Response Times Across Simulations

### Part Task 5

- **Info**: 27.05
- **Stratway**: 18.78
- **Omni Bands**: 20.90
- **Vector**: 24.47
- **D1**: 20.54
- **D2**: 19.71
- **D3**: 16.34
- **D4**: 15.74

### iHITL

- **Int_Basic**: 44.86
- **Int_Advanc**: 32.35
- **SA_Basic**: 38.68
- **SA_Advanc**: 35.60

### Part Task 4

- **Configuration**

---

Seconds
PT5 – Results Summary

• Suggestive guidance in the form of banding resulted in *safer* and *more timely* maneuvers away from conflicts
  – Fewer overall number of LoWC for both banding displays
  – Less severe LoWC for both banding displays
  – Shorter Total RTs for both banding displays
  – Pilots self-report as preferring the banding displays

• Results support decision for suggestive guidance as a minimum information requirement for DAA displays

• Results indicate that pilots can respond to a DAA Warning alert (no ATC coordination required) in ~ 15 seconds

• Results indicate that pilots can respond to a DAA Corrective alert (ATC coordination is required) in ~ 25 seconds

• ATC coordination adds approximately 10 seconds to DAA timeline
Suggestive Guidance Display – Example
PT4 – Total Response Times

- **Basic Integrated (45s)**: 30 sec
- **Basic Standalone (39s)**: 36 sec
- **Advanced Standalone (36s)**: 39 sec
- **Advanced Integrated (32s)**: 43 sec

**Time to CPA**
- 110 sec
- ? sec
- 35 sec

**Aircraft Maneuver Time**
- 30 sec
- 36 sec
- 39 sec
- 43 sec

**Well Clear Threshold**
iHITL – Total Response Times

- Time to CPA
  - 110 sec
  - ? sec
  - 35 sec

- Well Clear Threshold
- Aircraft Maneuver Time
  - D1 (21s): 54 sec
  - D2 (20s): 55 sec
  - D3 (16s): 59 sec
  - D4 (16s): 59 sec
PT5 – Total Response Times

Time to CPA

110 sec

Info Only (27s)

Stratway+ (19s)

Omni Bands (21s)

Vector Planner (24s)

Time to CPA

Aircraft Maneuver Time

Well Clear Threshold

48 sec

48 sec

56 sec

54 sec

51 sec
Self-Separation Timeline

- **Time until CPA Well Clear Threshold (~35 sec)**
- **Aircraft Maneuver Time (~30 sec)**
- **NMAC (~80 sec)**
- **Pilot Response Time (~15 sec)**
- **ATC Interaction Time (~10 sec)**

**TOTAL RESPONSE TIME:**
- Detect Intruders
- Pilots Determine Resolution
- Negotiate Clearance with ATC and uplink maneuver to aircraft

Approximate detection range = 8 nm
Approximate detection range = 6 nm

Approximate detection range = 8 nm
Approximate detection range = 6 nm
Questions?
Backup Slides
Sensor Parameters

- Sensor Ranges
  - Simulated **cooperative** sensor: ADS-R/TCAS-like ranges
    - Lateral Range: 15 nm
    - Vertical Range: +/- 5000 ft
  - Simulated **non-cooperative** sensor: based on state-of-the-art airborne RADAR
    - Lateral Range: 8 nm
    - Azimuth: +/- 110 degrees
    - Elevation: +/- 20 degrees
## Parameters for Noisy Cooperative Sensor

**Noisy Cooperative Sensor (“Transponder”)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Of Regard</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>15</td>
<td>nmi</td>
</tr>
<tr>
<td>Azimuth</td>
<td>360</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation</td>
<td>+/-90</td>
<td>deg</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range Error Mean</td>
<td>0</td>
<td>nmi</td>
</tr>
<tr>
<td>Range Error Std. Dev</td>
<td>0</td>
<td>nmi</td>
</tr>
<tr>
<td>Range Moving Avg. Window Size</td>
<td>1</td>
<td>measures</td>
</tr>
<tr>
<td>Azimuth Error Mean</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Azimuth Error Std. Dev</td>
<td>2</td>
<td>deg</td>
</tr>
<tr>
<td>Azimuth Moving Avg. Window Size</td>
<td>3</td>
<td>measures</td>
</tr>
<tr>
<td>Altitude Quantization</td>
<td>100</td>
<td>feet</td>
</tr>
<tr>
<td>Altitude Moving Avg. Window</td>
<td>6</td>
<td>measure</td>
</tr>
</tbody>
</table>

Yellow denotes the noise model variables that will used for PT5.
### Parameters for Noisy Non-Cooperative Sensor

#### Noisy Non-Cooperative Sensor ("Airborne Radar")

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Of Regard</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>6</td>
<td>nmi</td>
</tr>
<tr>
<td>Azimuth</td>
<td>+/-110</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation</td>
<td>+/-20</td>
<td>deg</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range Error Mean</td>
<td>0.008</td>
<td>nmi</td>
</tr>
<tr>
<td>Range Error Std. Dev.</td>
<td>0.001</td>
<td>nmi</td>
</tr>
<tr>
<td>Range Moving Avg. Window Size</td>
<td>1</td>
<td>measures</td>
</tr>
<tr>
<td>Azimuth Error Mean</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Azimuth Error Std. Dev.</td>
<td>2</td>
<td>deg</td>
</tr>
<tr>
<td>Azimuth Moving Avg. Window Size</td>
<td>3</td>
<td>measures</td>
</tr>
<tr>
<td>Elevation Error Mean</td>
<td>1</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation Error Std. Dev.</td>
<td>1</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation Moving Avg. Window Size</td>
<td>6</td>
<td>measure</td>
</tr>
</tbody>
</table>

*Yellow denotes the noise model variables that will be used for PT5.*
### Parameters for “Perfect” Cooperative Sensor ("ADS-B")

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Of Regard</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>15</td>
<td>nmi</td>
</tr>
<tr>
<td>Azimuth</td>
<td>360</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation</td>
<td>+/-90</td>
<td>deg</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitude Error</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Latitude Error Std. Dev.</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Latitude Moving Avg. Window Size</td>
<td>1</td>
<td>measures</td>
</tr>
<tr>
<td>Longitude Error</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Longitude Error Std. Dev.</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Longitude Moving Avg. Window Size</td>
<td>1</td>
<td>measures</td>
</tr>
<tr>
<td>Altitude Error</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Altitude Error Std. Dev.</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Altitude Moving Avg. Window Size</td>
<td>1</td>
<td>measure</td>
</tr>
</tbody>
</table>
### Parameters for “Perfect” Non-Cooperative Sensor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Of Regard</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>6</td>
<td>nmi</td>
</tr>
<tr>
<td>Azimuth</td>
<td>+/-110</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation</td>
<td>+/-20</td>
<td>deg</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range Error Mean</td>
<td>0</td>
<td>nmi</td>
</tr>
<tr>
<td>Range Error Std. Dev.</td>
<td>0</td>
<td>nmi</td>
</tr>
<tr>
<td>Range Moving Avg. Window Size</td>
<td>1</td>
<td>measures</td>
</tr>
<tr>
<td>Azimuth Error Mean</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Azimuth Error Std. Dev.</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Azimuth Moving Avg. Window Size</td>
<td>1</td>
<td>measures</td>
</tr>
<tr>
<td>Elevation Error Mean</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation Error Std. Dev.</td>
<td>0</td>
<td>deg</td>
</tr>
<tr>
<td>Elevation Moving Avg. Window Size</td>
<td>1</td>
<td>measure</td>
</tr>
</tbody>
</table>