Low Size, Weight, and Power (SWaP) Sensor Analyses Plan
Agenda

• Overview
• Analysis objectives
• Analysis assumptions
• Dataset assumptions
• Analysis methodology
• Schedule
Overview

• RTCA SC-228 WG1 is creating a new class of air-to-air radar (ATAR) in DO-366 Phase 2 MOPS development for low size, weight, and power (SWaP) UAS

• RTCA SC-228 WG1 may also create a class of low SWaP EO/IR sensor equipment

• Analyses will be performed to understand trade space for Field of Regard (FoR) and Radar Declaration Range (RDR) requirements for low SWaP sensors
Overview

- Phase 1 analyses will be repeated for the low SWaP radar and EO/IR sensor parameters
  - **DO-366 Appendix C** investigates cases where field of regard (FOR) limits the timely detection of targets according to alerting requirements for DAA.
  - **DO-366 Appendix D** verifies that the radar declaration range (RDR) provides enough time margin, from detection to loss of well clear (LoWC), to meet DAA alerting requirements.

- Since the surveillance volume requirements have not been established, multiple values of RDR and FoR will be used as independent variables
Analysis Objectives

• Explore implications of low SWaP sensor FoR and RDR on ability to detect intruders and maintain DAA well clear definitions

• Requirements addressed for low SWaP in DO-366
  – 2.2.6 Radar Field of Regard
    • Azimuth (026) /Elevation Coverage (027)
  – 2.2.7 Radar Tracks
    • Intruder track acquisition time (022)
    • RDR for Small (039), Medium (040), and Large (041) intruders
Analysis Objectives

• Perform fast time, unmitigated simulation of a large number of encounters using candidate Low SWaP Radar and EO/IR sensor parameters

• Analyze data to
  – estimate the probability of an intruder entering the sensor field of regard within the sensor declaration range (Appendix C)
  – validate the radar declaration volume against DAA alerting requirements (Appendix D)
# Radar Requirements

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Phase 1</th>
<th>Phase 2, Non-cooperative, Low SWaP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOR</td>
<td>Field of Regard, Azimuth</td>
<td>+/- 110°</td>
<td>+/- 110°, +/- 135° preferred</td>
</tr>
<tr>
<td>FOR</td>
<td>Field of Regard, Elevation</td>
<td>+/- 15°</td>
<td>+/- 15°</td>
</tr>
<tr>
<td>RDR</td>
<td>Radar Declaration Range, at Azimuth = 0°</td>
<td>5.4, 6, 6.7 NMi</td>
<td>2, 2.5, 3, 3.5 NMi (TBD)</td>
</tr>
<tr>
<td>RDR</td>
<td>Radar Declaration Range, Correction Factor</td>
<td>(See next slide)</td>
<td>? – From AAG</td>
</tr>
<tr>
<td>RCPR</td>
<td>Radar Closest Performance Range</td>
<td>4000 ft</td>
<td>? – From Honeywell</td>
</tr>
<tr>
<td></td>
<td>“Track Acquisition Time” from DO-366 requirement 2.2.7.22. †</td>
<td>15 s</td>
<td>? – From Honeywell</td>
</tr>
</tbody>
</table>

†: For intruders that enter the FOR within 95% of the RDR, in 90% of these encounters, tracks must meet accuracy requirements (2.2.8) within 15s after entering FOR/RDR (DO-366 requirement 2.2.7.22). This was the requirement that was validated in appendix C.
Radar Requirements:
RDR Correction Factor

<table>
<thead>
<tr>
<th>Intruder Bearing Angle</th>
<th>RDR Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>angle</td>
</tr>
<tr>
<td>30 ≤</td>
<td>angle</td>
</tr>
<tr>
<td>60 ≤</td>
<td>angle</td>
</tr>
<tr>
<td></td>
<td>angle</td>
</tr>
</tbody>
</table>

(from phase 1, DO-366 2.2.7.14)
# DAA Well Clear Alerting Requirements

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Phase 1</th>
<th>Phase 2, Non-cooperative, Low SWaP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$HMD^*$</td>
<td>Horizontal Miss Distance Threshold</td>
<td>4000 ft</td>
<td>2200 ft*</td>
</tr>
<tr>
<td>$h^*$</td>
<td>Vertical Separation Threshold, Corrective &amp; Warning</td>
<td>450 ft</td>
<td>450 ft*</td>
</tr>
<tr>
<td>$h^*$</td>
<td>Vertical Separation Threshold, Preventive</td>
<td>700 ft</td>
<td>700 ft</td>
</tr>
<tr>
<td>$\tau_{mod}^*$</td>
<td>Modified Tau Threshold</td>
<td>35 s</td>
<td>0 s*</td>
</tr>
<tr>
<td>$MIR$</td>
<td>Maneuver Initiation Range</td>
<td></td>
<td>1.9 NMi*</td>
</tr>
<tr>
<td>$THR_{Late}$</td>
<td>Late Threshold, Preventive &amp; Corrective</td>
<td>20 s</td>
<td>20 s</td>
</tr>
<tr>
<td>$THR_{Late}$</td>
<td>Late Threshold, Warning</td>
<td>15 s</td>
<td>15 s</td>
</tr>
<tr>
<td></td>
<td>Minimum Average Alert Time, Preventive &amp; Corrective</td>
<td>55 s</td>
<td>55 s</td>
</tr>
<tr>
<td></td>
<td>Minimum Average Alert Time, Warning</td>
<td>25 s</td>
<td>25 s</td>
</tr>
</tbody>
</table>

Note: Non-Hazard alerting requirements have not been established.

*From NASA, MIT/LL, CAL Analytics DWC Joint Briefing 03/05/2019
## Ownship Simulation Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase 1</th>
<th>Phase 2, Non-cooperative, Low SWaP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn Rate</td>
<td>3°/s</td>
<td>7°/s</td>
</tr>
<tr>
<td>Velocity</td>
<td>40 – 200 KTAS</td>
<td>40 – 100 KTAS</td>
</tr>
<tr>
<td>Min Altitude, AGL</td>
<td>1000 ft (AGL)</td>
<td>500 ft (AGL)</td>
</tr>
<tr>
<td>Max Altitude, MSL</td>
<td>10,000 ft (MSL)</td>
<td>10,000 ft (MSL)</td>
</tr>
</tbody>
</table>

- Extended operations in airspace classes D, E (non-terminal), or G (non-terminal).
- Transit operations in classes B and C.
Dataset Assumptions

- Recommend low SWaP encounter set used by MIT/LL for NASA Mitigated Well Clear Analysis dated March 5, 2019
  - See next slide for details

- Modeling & Sim tool for sweeping linear encounter parameters
  - Altitude separation, closest point of approach (CPA), heading
Encounter characteristics

- Minimum Separation at Encounter Start: 800 ft (vertically) or 1.5 NM (horizontally)
- Max HMD: 3 NM
- Max VMD: 1500 ft
- Closest Approach: 150 sec
- Encounter duration: 180 sec
  - Extended up to 300 sec if necessary to satisfy initial minimum separation

- Airspace classes: E/G

Aircraft characteristics

- Ownship speed: 40-100 kts
- Intruder speed: 0-170 kts
- Ownship/intruder altitude: 500 AGL-10000 ft MSL
Appendix C Analysis

- Objective: estimate the probability of an intruder entering the sensor field of regard within the radar declaration range (RDR)
  - Determine probability of those impacted by track acquisition time requirement of 15s

- Analyze multiple RDRs for FoRs to cover possible final values of RDR

- Perform micro-level analysis of encounters which enter FoR within RDR to better understand challenging encounter scenarios

*Figure C-2*  Capturing the FOR Entry Time Margin

Taken from DO-366, Appendix C
Analysis Workflow: Appendix C

1M Low C-SWaP Encounters → Determine Closest Point of Approach (CPA) → Determine if CPA resulted in LoWC or NMAC → LoWC or NMAC criteria met?

- Yes: Sufficient time before LoWC / NMAC?
  - Yes: Compile & Analyze Results
  - No: Last encounter?
    - Yes: Compile & Analyze Results
    - No: Determine & store time when Range<=RDR & within FoR → Back Propagate Encounters

- No: Determine & store time impact due to establishing track → Last encounter?
  - Yes: Compile & Analyze Results
  - No: Determine Closest Point of Approach (CPA)
Appendix D Analysis

- Objective: Verify that radar declaration range (RDR), subject to the Field of Regard (FOR), provides enough Time Margin, from detection to loss of well clear (LoWC), for DAA alerting
  - Compare RDR Time Margin per encounter to Minimum Average Alert Times and Late Alert Thresholds
  - Compute Required RDR per encounter and compare statistics to candidate RDRs
- Time Margins resulting from various RDR candidates will be examined
- Statistics will be generated for different geometries and encounter categories

Figure D-1  RDR Time before LoWC against Corrective Alerting Requirements
Taken from DO-366, Appendix D
• RDR Time Margin and Minimum Required RDR will be analyzed per encounter to generate statistics

* RDR Time Margin statistics will be compared to the time parameters from phase 1: **Minimum Average Alert Times** and **Late Alert Thresholds**.

† Minimum Required RDR statistics will be compared to current RDR candidates.
## Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyses of the Alerting Timeline with Low C-SWaP Sensors’ Field of Regard</td>
<td>4/15/2019</td>
<td>10/28/2019</td>
</tr>
<tr>
<td>Coordination with SC-228</td>
<td>4/15/2019</td>
<td>6/15/2019</td>
</tr>
<tr>
<td>Development</td>
<td>4/30/2019</td>
<td>09/09/2019</td>
</tr>
<tr>
<td>Report Preparation</td>
<td>9/10/19</td>
<td>9/30/2019</td>
</tr>
</tbody>
</table>
Backup
Analysis Workflow: Appendix C

- For each encounter, determine if LoWC or NMAC occurred
- If sufficient time within the encounter does not exist, back propagate encounters
  - E.g. encounter starts within RDR/FoR
- Determine intruder times when:
  - First enter FoR
  - First enter RDR
  - First time when intruder is in FoR AND RDR
- Determine time impact due to track acquisition requirement
- Compile and analyze results to assess if intruder entered FoR within RDR
- Analysis
  - Micro analysis figures of challenging encounter geometries
  - Encounter distribution plots for time margin for entering FoR
  - Computed probabilities of intruder entering FoR within RDR for RDRs detailed above
The correlation of Time Margin and RDR to ownship / intruder speeds, and relative heading, will be investigated

Time Margin will be computed for various RDR

The percentage of targets detected vs. Time Margin will be computed

Statistics will be computed from…
- all encounters
- non-accelerating encounters
- accelerating encounters
- turning encounters
- vertically converging encounters
- Intruder overtake encounters