Characteristics of a Well Clear Definition and Alerting Criteria for Encounters between UAS and Manned Aircraft in Class E Airspace

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Outline

• Research and Motivation
• Analysis Overview and Definitions
• Simulation Setup
  – Traffic Scenarios
  – UAS Missions
• Fast-Time Simulation Study Results
  – Analysis 1: Characterizing Encounters at Well Clear Boundary
  – Analysis 2: Evaluating Alerting Criteria
• Conclusions
Background

14CFR Part 91, §91.113

...vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft...pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

UAS operating under IFR

Aircraft Operating under Instrument Flight Rules (IFR)

Air Traffic Control

Aircraft Operating under Visual Flight Rules without a Transponder (Non-cooperative VFR)

Aircraft Operating under Visual Flight Rules with a Transponder (Cooperative VFR)

Strategic Conflict Management

Separation Provision Service

Self-Separation

Collision Avoidance
Background: Detect and Avoid

Analysis 1: Loss of Well Clear
See and Avoid Traffic Collision Avoidance System (TCAS)

Analysis 2: Alerting the UAS Operator
Detect and Avoid Collision Avoidance Function (TCAS/ACAS/etc.)

Self-Separation
Collision Avoidance

Manned Aviation

Self-Separation
Unmanned Aviation
Analysis Overview

• Analysis 1: Characterizing encounters at well clear boundaries
  – Objective:
    • Investigate implications of using Well Clear Definitions proposed from the UAS community in terms of surveillance requirements and safety
  – Metrics:
    • Rate of Losses of Well Clear per UAS Flight Hour
    • Encounter Characteristics at the Loss of Well Clear (LoWC)
Unmitigated Encounter Rate Evaluation

Capabilities

- UAS Models
- UAS Mission Profiles
- VFR Traffic from Air Defense Radar Data

US National Airspace System Simulation

- Airspace Concept Evaluation System (ACES)

Analysis

Results

- Losses of Well Clear per UAS Flight Hour
- Altitude

Metrics

- Self Separation
- Conflict Alerting

Loss of Well Clear

International Forum for Aviation Research NASA/JAXA Virtual ATM Conference
Loss of Well Clear

DMOD

R_{xy}

t_{CPA}

HMD

ZTHR

\tau_\text{mod} = - \frac{R_{xy}^2 - \text{DMOD}^2}{\dot{R}_{xy} R_{xy}}

t_{CPA} \quad \text{Time at Closest Point of Approach}

\tau_\text{vert} = - \frac{\Delta h}{\dot{\Delta h}}

0 \leq \tau_\text{mod} \leq \tau_\text{mod}^*

R_{xy}(t_{CPA}) \leq \text{HMD}

0 \leq \tau_\text{vert} \leq \tau_\text{vert}^*

\text{OR}

|\Delta h| \leq Z\text{THR}

Note: DMOD value = HMD value
Simulation Configuration

• There are 24 different simulation runs
  – 1 simulation run is a single day in the US national airspace system (NAS)

• Each simulation had
  – UAS: 9 Different Proposed Missions
    • Total of 18,000 UAS flights in data set (~26,000 flight hours)
    • Variety of aircraft performance, mission profiles, geographic areas of operation
  – Traffic: Cooperative VFR Traffic (secondary radar returns)
    • Derived from 84th squadron air defense radar data
    • Varying volume of traffic (20-28k flights)
    • Days are spread over 4 seasons in 2012 (24 days total)
  – No Separation mitigation
    • Metrics only collected for UAS vs. VFR conflicts
    • No Detect and Avoid System was present
Analysis 1: Characterizing Encounters at Well Clear Boundaries

Results

Analysis 1: Loss of Well Clear

Collision Avoidance
Rate of Losses of Well Clear by Definition

![Bar chart showing losses of well clear per UAS flight hour for January, April, July, and October.](image)

<table>
<thead>
<tr>
<th></th>
<th>(\tau_{\text{mod}}^*) [s]</th>
<th>(\tau_{\text{vert}}^*) [s]</th>
<th>ZTHR [ft]</th>
<th>HMD [ft]</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1.1</td>
<td>30</td>
<td>20</td>
<td>475</td>
<td>6000</td>
</tr>
<tr>
<td>D1.2</td>
<td>35</td>
<td>0</td>
<td>700</td>
<td>4000</td>
</tr>
<tr>
<td>D1.3</td>
<td>35</td>
<td>0</td>
<td>450</td>
<td>4000</td>
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UAS Community Proposed Definitions

\[\tau_{\text{mod}}^* \mod [s], \tau_{\text{vert}}^* [s] \]
Relative Heading and Distance at LoWC

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Range Rate vs. Separation at LoWC (Horizontal)

- Horizontal Range Rate [knots]
- Horizontal Separation [nmi]

LoWC on Back End of Threat Boundary
Threat Boundary Violation (4000 ft)
LoWC at Modified Tau Threshold (35 seconds)
High Range Rate LOWC

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**Density**

**Legend:**
- Density colors indicate flight density levels.
Concluding Remarks

• Results indicate:
  – An unmitigated loss of well clear occurs approximately once every 40 flight hours.
  – Head-on encounters occur at further surveillance ranges then over-taking encounters
  – Most losses of well clear occur within 1-3 nautical miles and less than 200 knots closure rates

• Recommendations:
  – A time and distance-based well clear definition is motivated by:
    • maneuvering intruders
    • high closure rate intruders.
  – A minimum 4-5 nmi surveillance range is recommended to account for missed alerts.
Additional Remarks: Analysis 2

• Surveillance and Alerting Guidelines:
  – DAA system would want a surveillance range of 4-5 nmi
  – Using the proposed alerting criteria the surveillance range would nominally need to be 10 nmi to alert the UAS operator to take action
  – There is a trade-off between time to loss of well clear and percentage of nuisance alerts
    • The larger the alerting volume ➔ More time before loss of well clear and larger percentage of nuisance alerts.

• Recommendations:
  – Consider buffers for alerting criteria
  – Include ownship intent in alerting criteria
  – Consider multiple layers of alerting
Questions

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