A6 Surveillance Criticality

Interim Report

North Carolina State University
The Ohio State University
Embry-Riddle Aeronautical University
University of North Dakota
Oregon State University
Mississippi State University

PROJECT A6: SURVEILLANCE CRITICALITY

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1 Introduction

The ASSURE A6 Surveillance Criticality project for the FAA UAS Center of Excellence Program has completed the first major milestone of the project, the Stakeholder Workshop #1. At this point in the project the research teams are at full speed, the goals of the project are clear, and the path to success is defined. The project is currently on schedule to accomplish all research objectives and deliver the project Final Report in November 2016. This Interim Report is designed to provide a brief overview of the technical progress of the research, a review of the Stakeholder Workshop, and sample highlights from the current research activities.

The A6 research team is spread across six universities that are collaborating to answer the primary research questions associated with this project:

- For a cooperative DAA solution based on ADS-B and/or transponders, how should the current operational or technical performance requirements for ADS-B Out and/or transponders be changed (if at all) for UAS Sense and Avoid functions?
- Do current surveillance equipment technologies meet the design assurance criteria to provide UAS Sense and Avoid functions?
- What is the criteria for evaluating “equivalent level of safety” of UAS against piloted-aircraft for SAA functions?

To answer these questions, the research team has divided the research into six activities that are each tightly coupled with each other. This research design requires frequent interaction between team members, while also keeping the entire team engaged in the project for overall success. The six research activities are:

1) Surveillance System Characterization
2) Sensitivity Analysis
3) Modeling
4) Fault Trees/Failure Analysis
5) Scenario Analysis
6) Simulation

By October of 2016 the results of each of these activities will combine to provide the data and process for answering the primary research questions for the A6 Surveillance Criticality Project. The technical status of each of these activities is presented in the following section.
2 Technical Progress

This project started in December of 2015 with an extensive literature review and interview process to set the context for the research focus. The team reviewed multiple standards from RTCA and reports from SC-228 related to Detect and Avoid technology performance analysis. This literature review and discussions with industry partners provided the scope for the project to focus large UAS operations only, with a limited number of baseline scenarios from the RTCA SC-228 DAA MOPS for testing. With the scope set and technical approach defined, the team divided the research activities into six interconnected efforts to accomplish the project objectives. Those six activities are described below with technical progress summarized with each.

1) Surveillance System Characterization
The team has reviewed standards and specifications for Mode-S, TCAS, and ADS-B to identify potential failures and expected performance and failure rates. These characterizations provide opportunities for industry partners to share experience and performance measures for data accuracy and product evaluations. Mode-S, TCAS, and radar systems are currently modeled as binary systems that either function as expected or do not function. ADS-B, however, is modeled (Figure 1) with multiple potential sources for failure and the opportunity for degraded performance.

ADS-B Component Breakdown

![ADS-B Component Model](image)

Figure 1: ADS-B Component Model
2) **Sensitivity Analysis**

A Design of Experiments (DOE) methodology is being used to identify and evaluate the parameters that impact Detect and Avoid technology assessments. This methodology allows the team to develop performance metrics to evaluate the severity of the encounters in DAA scenarios. Six parameters have been identified as critical for the initial testing environment. Those six parameters are aircraft position accuracy, closing velocity accuracy, altitude reporting accuracy, aircraft identification reporting, system latency (from report received to applied action), and system specific variable for the type of DAA system. The ADS-B characterization for these six criteria are see in Figure 2.

With performance statistics from standards and industry reports, the DOE methodology for identifying parameter sensitivities the failure analysis is added depth. Monte Carlo simulations provide additional randomized data to detail the potential coupling of failures and provide a more thorough understanding of a failures severity. This allows the research team to classify failures of the complete system, while still measuring which factors are influencing the system performance.

3) **Modeling**

The research team is using the Embry Riddle simulation lab to model aircraft, surveillance technologies, and system performance to demonstrate predicted behaviors and impacts of failures in a select number of scenarios. The three baseline scenarios that are being modeled in the simulation environment and providing the context for the bow-tie analysis are from the RTCA SC-228 DAA MOPS.

- A.5.4: UA Climbing IFR through Class G Airspace and Encounters VFR Traffic
- A.5.7 Class E VFR Intruder Separated Vertically by 500’
- A.5.10: Intruder Maneuvers after DAA Maneuver Has Begun and Causes Change in DAA Maneuver

### ADS-B Sensitivity Ranges

<table>
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<tr>
<th>Factors</th>
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<tr>
<td>Position (A)</td>
<td>(+) 500 ft</td>
</tr>
<tr>
<td></td>
<td>(-) 50 ft</td>
</tr>
<tr>
<td>Closing Velocity (B)</td>
<td>(+) 200 mph</td>
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<tr>
<td></td>
<td>(-) 50 mph</td>
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<tr>
<td>Altitude (C)</td>
<td>(+) 100 ft</td>
</tr>
<tr>
<td></td>
<td>(-) 25 ft</td>
</tr>
<tr>
<td>Identity/Performance of the aircraft (D)</td>
<td>(+) 0.3g</td>
</tr>
<tr>
<td></td>
<td>(-) 0.1g</td>
</tr>
<tr>
<td>Latency (E)</td>
<td>(+) 10 sec</td>
</tr>
<tr>
<td></td>
<td>(-) 1 sec</td>
</tr>
<tr>
<td>System Specific Limits [Message Failure Rate] (F)</td>
<td>(+) 50%</td>
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<tr>
<td></td>
<td>(-) 5%</td>
</tr>
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</table>

Figure 2: ADS-B Parameter Range Description
These three scenarios define the interactions and operating environment for evaluating surveillance technology performance in ownship and fleet operations. Traffic surveillance technology configurations in the initial research activities consisted of two options: TCAS with ADS-B and ADS-B only equipage. After the Stakeholder Workshop, those configurations are redefined into the following three options for failure analysis and simulation modeling:

- 1- Active Surveillance + ADS-B + radar
- 2- TCAS + ADS-B + radar
- 3- ADS-B + radar

4) **Fault Trees/Failure Analysis**

The research team has developed an initial set of spreadsheets for performing the complete failure mode, effects, and criticality analysis (FMECA). These spreadsheets are evolving with inputs from industry partners and further research into system performance capabilities. Actual performance versus expected performance discrepancies may influence the validity of the analysis, but the structure for the analysis and methodology is accurate. Built on the original characterizations, these fault trees and failure expectations are the primary product of the A6 project. The sensitivity analysis, scenario analysis, and simulation performance rely on the accuracy and calculations in the FMECA. These spreadsheets (Figure 3) will be reviewed frequently with FAA and industry partners as the project continues.

![Figure 3: Sample FMECA Spreadsheet](image-url)
5) **Scenario Analysis**

The team is modifying each of the baseline scenarios to include a variety of interactions and events that may occur in each scenario to evaluate the FMECA performance. Working within the scope of the baseline scenarios, different failures and degraded performance behaviors are modeled to test the analysis architecture. These modifications include the three specific scenarios most discussed at Workshop #1, in addition to other scenarios possible within the models. This research is actively reviewing Resolution Advisories and anticipated pilot responses for scenario descriptions and modeling in the simulation environment.

6) **Simulation**

The simulation environment is providing a parallel validation method for verifying the accuracy of the surveillance technology characterizations and performance capabilities and scenario descriptions for evaluating the FMECAs. Ultimately the research team will use the simulations to visualize the results of the FMECAs in defined scenarios. The simulation environment does provide the opportunity for manned pilots to make decisions that conform to the scripted scenario or diverge from an expected behavior. While this ability may provide additional data for scenario modifications in the analysis process, this capability is not a benefit for the scope of the A6 project. This could be valuable for future research in evaluating pilot performance against FAA/standard expected behaviors in response to a failure or command.

![Figure 4: Screenshot from Simulated Interaction](image-url)
At the end of June 2016 the entire research team hosted Stakeholder Workshop #1 at Embry Riddle Aeronautical University in Daytona Beach, Florida. That workshop was a successful technical interchange and mid-project status update between the A6 team, several key industry partners that participated, and the FAA team. The complete set of Minutes from the workshop are included as an attachment to this report. Highlights and Action Items from the workshop include:

- **Stakeholder Workshop #1 Highlights**
  - Research team needs to spend more time on fault trees and failure analysis! More details, more numbers, more combinations (failures and scenario variations)
  - Assume Part 23 certified aircraft performance for all aircraft in scenarios.
  - “We are doing what SC-228 is ignoring.”
  - Use simulations to visualize behaviors and results of failures, not data collection.
  - Aircraft equipage configurations for analysis scenarios:
    - 1- Active Surveillance + ADS-B + radar
    - 2- TCAS + ADS-B + radar
    - 3- ADS-B + radar
  - Reminder that transponders and ADS-B are secondary support for ATC and pilots to provide separation standards today of 3-10 miles. Our research is looking at operating in a UAS DAA function to determine if these surveillance technologies meet separation requirements of 0.6 miles?
  - Research analysis is more about the fleet, not so much on ownship.
  - We can expose existing DAA (component) failure mitigation strategies as a product of the research.

- **Stakeholder Workshop #1 Action Items**
  - Review more analysis from SC-228 on Severity of Loss of Well-Clear (SLOW-C).
  - Use industry more for fault tree structures and failure numbers.
  - Use industry more for looking for a data set to compare reported performance and actual performance.
  - Include a GPS-denied environment scenario in analysis.
  - Include scenario with disagreement between barometric altimeter and GPS-altimeter in analysis.
  - Look at scenarios where the pilot would make a different resolution than the algorithm (TCAS) recommends in analysis.
  - Workshop #2 set for September 19-20 at NC State, Raleigh, NC.
3  Next Steps

For the next phase of technical research (July through September 2016) the team will focus on action items from the first workshop and analysis tasks as originally planned.

- Collaborate with industry partners for data accuracy and depth
- Refine analysis structure for more details in failures and fault trees
- Expand analysis scenarios
- Host Workshop #2 at NC State University September 20 (19th is university team meeting)

For potential future research, the team has identified the following areas that the research approach and architecture at the conclusion of A6 will support.

- More large UAS scenarios for analysis to validate conclusions and air traffic system performance expectations.
- Add EO/IR sensors and/or other technologies for surveillance performance analysis.
- Repeat complete process for small UAS including new equipage configurations, new scenarios, new performance qualities, and new technologies such as LATAS from industry partner Precision Hawk.
4 Budget Status

The A6 project budget is BELOW the original spend plan. An updated projection has the team at full strength for the remainder of the project to accomplish all objectives by the end of November 2016. Total spending as of June 30, 2016 is approximately $260,200.

The A6 work plan is ON schedule based on the revised schedule from April 2016.
A6 Surveillance Criticality

Workshop #1
Minutes
June 2016

North Carolina State University
The Ohio State University
Embry-Riddle Aeronautical University
University of North Dakota
Oregon State University
Mississippi State University
1 Workshop #1 Minutes/Notes

1.1 EXECUTIVE SUMMARY
The workshop was a very productive 2-day event. Having the complete research team with the FAA in a room together for the first time was invaluable and probably should have been scheduled earlier in the project. Although the industry participation was limited, for those that were there, they were insightful and left with a clearer picture about how to get involved. Based on the broad and constructive discussions, the research team will be intensifying the development of the fault trees and failure analyzes for 3 configurations of the large UAS Detect and Avoid system. These configurations will be modeled in the simulation environment for a visual demonstration of the behaviors produced in the hazards analysis and bow-tie analysis. The team will complete the complete set of failure analyzes (with frequent updates to Paul Campbell) this summer in preparation for the Second A6 Workshop September 19-20 at NC State.

1.2 ATTENDEES

<table>
<thead>
<tr>
<th>University</th>
<th>FAA</th>
<th>Industry</th>
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<tbody>
<tr>
<td>NCSU- Kyle Snyder, Evan Arnold</td>
<td>Bill Oehlschlager</td>
<td>Keith Hoffler- Adaptive Aerospace Group</td>
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<tr>
<td>UND- Will Semke, Asma Tabassum</td>
<td>Paul Campbell</td>
<td>Joe d’Hedouville- CGH Technologies</td>
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<tr>
<td>ERAU- Mohammad Moallemi, Jayson Clifford, Richard Stansbury</td>
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<td>Tom Vogl- Rockwell Collins</td>
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<td>Ohio St- Matt McCrink</td>
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<td>Oregon St- Michael Wing</td>
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<td>Mississippi St- JW Bruce</td>
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</tbody>
</table>

1.3 MINUTES FORMAT
1- Points of emphasis from discussions and assignments are in bold.
2- A6 team action Items are in Italics and highlight yellow.
3- FAA action items are highlighted green
4- Open questions are highlighted in gray

1.4 TECHNICAL STATUS REVIEW
1) Introduction
a. Kyle provided a brief overview of the project objectives and task breakdown to make sure everybody was on the same page.

b. PC: Need to make sure we are keeping up with SC-228 MOPS developments. Also need to include radar and EO sensors for DAA system configuration!

2) Characterization and Failure Analysis
a. Reviewed potential areas for failures in ADS-B and TCAS.
   1. Need to consider degraded performance too.

b. Review proposed performance factors- Position, Closing Velocity, Altitude, Aircraft Identification, Latency, and System Specific Limits
   1. Discussion on TCAS II alerts
   2. KH- We need to pull alert ranges from 228 ConOps to assess alert performance, and compare too early and late alert announcement impacts
   3. Discussion on TCAS sensitivities based on different altitudes. Most systems don’t work (or aren’t used) below 1500’, so 1200’ is VERY low.
   4. TCAS Performance is ALL or NOTHING as a failure analysis (it works or it doesn’t).
      1. PC: TCAS is measured against NMACs and Collisions
      5. Detection DOES NOT EQUAL mitigation. Look at risk ratios!

c. Discussion on Severity of Loss of Well-Clear (SLOW-C)
   1. Need to pull some reference presentations from 228. - DONE
   2. FAA will provide the reference paper on “squircles”. - DONE

d. Discussion on DAA Sensor Configurations
   1. Class 1/A = 3 Sensors
      1. Active Surveillance Sensor (Mode S)
      2. ADS-B
      3. Radar
   2. Class 2/B = Class 1 + TCAS (with algorithms for alerts and Resolution Advisories)
   3. This provides the baseline for 2 of the 3 tests for the Bow-tie analysis and all simulation scenarios
      1. Class 1
      2. Class 2
      3. ADS-B + radar only
4. **These configurations apply to ownship and other-ship**

4- Failures can take 2 forms
   1. False/misleading = bad mitigation
   2. No knowledge (not reported) = is there any mitigation?

e. **Open question**: What level of assurance is the aircraft altimeter TSOed to?

f. PC: **More focus on the fault trees!**

g. PC and KH: “We are doing what 228 is ignoring.”

h. Discussion on potential failures
   1- Need to look at a GPS-denied environment scenario. What the impact on DAA?
      1. Does active surveillance work?
      2. Can a radar DAA component meet the safety needs
      3. If we decide that GPS is essential and must work, then we have failed!
   2- Look at what really happens in the real world, not just operations by the standard/specs. Just because the product meets the standard/spec on Day 1, does not mean it is performing that way 2 years later.
      1. Start looking for a data set to compare reported performance and actual performance. For TCAS and ADS-B (and source components).

2. **Talk to Industry. – IN PROGRESS**

3. **Frame question for industry and FAA (Tech Center). -MSU**

3- Controllers interrogate pilots with erroneous altitudes based on transponder reports all the time. **Are these recorded?**

4- PC: remember the focus of the project- transponders and ADS-B are secondary support for ATC and pilots to provide separation standards today of 3-10 miles. Operating in a UAS DAA function, do they meet separation requirements of 0.6 miles?
   1. **Look at Design Assurance for GPS, Navigation systems (INS), Transponding. - NCSU**

5- PC: **Worry about the fleet, not so much on ownship.**

6- Project Goals
   1. We can replace pilot trouble shooting with algorithms. We will have the combined data of TCAS/ADS-B/radar to make recommendations.
   2. This research will inform 228 MOPS development for:
a. Mode S Calibration requirements (increased frequency)
b. ADS-B calibration requirements. (increased frequency, add component redundancy- baro altimeter, multiple layers).
c. Maintenance of fleet requirements updates
d. Ways for algorithms to vote on RAs
e. Fault isolation

3. We can expose existing DAA (component) failure mitigation strategies
   a. How often does a pilot check his altitude report onboard against the airport listed altitude pre-takeoff?
   b. How do pilots react to failure? With/without ATC?

   i. DAA alert discussion
      1- UAS DAA system provides alerts at all altitudes, all the way to the ground
      2- TCAS only gives vertical Resolution Advisories, which are disabled below a certain altitude (1500’ typically)
      3- DAA MOPS call for both TCAS and DAA alerts
         1. DAA alerts give “right” and “left” turn commands
         2. DAA alerts include ground proximity knowledge
         3. MOPS details how these systems are combined
         4. DAA is NOT terrain aware

       4- Do not worry about ground proximity sensor failure in our scenarios!

3) Scenario design discussions
   a. Just focus on scenarios with threats in front of ownship for now.
      1- Actively measure what’s in front with radar and compare altitude report with transponder message
      2- Evaluate vote resolution: if ADS-B and Mode S don’t agree? AVOID BOTH.
      3- Consider the scenario where the Predator “sees” a Cessna on Mode S and radar. If those reports do not match, which one is followed (Considered truth)? Probably the radar.
      4- Include the scenario with a barometric altimeter failure
      5- There probably are not statistics to define performance when ADS-B/Mode S have failed because the pilot has been the mitigator that ultimately still provided separation.
b. **Look at scenarios where the pilot would make a different resolution than the algorithm (TCAS) recommends.** -IN PROGRESS  It may be a better decision, it may not be.

c. **PC:** The scenarios selected are reasonable, but we need to excursions and variations to showcase the lessons from the failures.

d. **PC:** Assume we are operating Part 23 aircraft with fully certified, TSOed equipment, including a Mode S transponder.

e. In our scenario descriptions, we need more details about the failures. That will enable more versions of the basic scenario and determine how many we want to actually model.

4) Simulation Discussion

a. The goal for this project is not to run a large number of batch sims to validate pilot performance. **Use the simulation to demonstrate behaviors seen in the fault tree and failure analysis!**

b. Need the DAA system display/algorithms to integrate into ERAU sim

   1- **BO: will talk to FAA Tech Center**
   2- **BO: will provide DAA display standards**
   3- **BO: will provide tracker algorithms**

5) **KH:** focus for this project is DAA and components that feed DAA only! Autopilots and other components are out of scope for this A6 project.

6) **PC:** Can use the failure analysis chart to show that catastrophic failures cannot result from a system with single redundancy levels. To flight certified, aircraft have higher redundancies or no-single redundant components that allow for catastrophic failure.

**1.5 ADDITIONAL ACTION ITEMS**

1) Join SC-228 ASAP! - NCSU-complete, ERAU and OhSt were already members. - DONE

2) FAA to provide radar performance models (or at least the reference to specific 228 location).

3) Integrate Mississippi State references into updated Lit Review - NCSU

4) Provide Workshop #2 description to Bill - DONE

5) Develop scheme/concept for getting actual (bad) performance data sets - MSU

**1.6 NEXT STEPS**

1) Use the Tech Center as a resource for gathering or sharing data. Frame the need, Paul/Bill will help access. JoeD will also help.

2) Plan to attend next RTCA SC-228 meeting. Probably first week of October.
3) Workshop #2 - September 19-20 at NC State, Raleigh, NC
4) More frequent data sharing with Paul!
5) Use the industry partners now to fill in data sets with actual performance data, product failure analyzes, and knowledge/experience regarding behaviors in scenarios.

1.7 FUTURE RESEARCH CONCEPTS
1) Evaluate the DAA performance with an electro-optical sensor option for TCAS/ADS-B alternative
2) Evaluate the DAA performance in additional scenarios- Class A airspace, higher traffic areas, more complex operations, other encounter scenarios from RTCA SC-228 DAA MOPS.
3) Evaluate small UAS DAA solutions and scenarios.
4) Include more actual DAA technology and pilot behavior performance data for evaluation accuracy (not just ranges and recommendations from published specs).
5) Include more NextGen 4DT (Four-Dimension Trajectory) operations concepts
6) Look at non-DAA system failures and evaluate their impact on DAA operations, for instance autopilots or ATC commands.