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Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations

May 19, 2017

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Technical Report Documentation Page

Title: Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations

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Abstract:

Potential sUAS BVLOS operational scenarios/use cases and DAA approaches were collected through a number of industry wide data calls. Every 333 Exemption holder was solicited for this same information. Summary information from more than 5,000 exemption holders is documented, and the information received had varied level of detail but has given relevant experiential information to generalize use cases. A plan was developed and testing completed to assess RLOS, a potential key limiting factors for safe BVLOS ops. Details of the equipment used, flight test area, test payload, and fixtures for testing at different altitudes is presented and the resulting comparison of a simplified mathematical model, an online modeling tool, and flight data are provided. An Operational Framework that defines the environment, conditions, constraints, and limitations under which the recommended requirements will enable sUAS operations BVLOS is presented. The framework includes strategies that can build upon FAA and industry actions that should result in an increase in BVLOS flights in the near term.

Evaluating approaches to sUAS DAA was accomplished through five subtasks: literature review of pilot and ground observer see and avoid performance, survey of DAA criteria and recommended baseline performance, survey of existing/developing DAA technologies and performance, assessment of risks of selected DAA approaches, and flight testing. Pilot and ground observer see and avoid performance were evaluated through a literature review. Development of DAA criteria—the emphasis here being well clear—was accomplished through working with the Science And Research Panel (SARP) and through simulations of manned and unmanned aircraft interactions. Information regarding sUAS DAA approaches was collected through a literature review, requests for information, and direct interactions. These were analyzed through delineation of system type and definition of metrics and metric values. Risks associated with sUAS DAA systems were assessed by focusing on the Safety Risk Management (SRM) pillar of the SMS (Safety Management System) process. This effort (1) identified hazards related to the operation of sUAS in BVLOS, (2) offered a preliminary risk assessment considering existing controls, and (3) recommended additional controls and mitigations to further reduce risk to the lowest practical level. Finally, flight tests were conducted to collect preliminary data regarding well clear and DAA system hazards.

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Table of Acronyms

Acronym	Meaning
AADS	Aerospace Aircraft Display System
ABSAA	Airborne Sense And Avoid
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-R	Automatic Dependent Surveillance-Rebroadcast
AGL	Above Ground Level
AH	Artificial Horizon
APA	American Pilots' Association
API	Application Programming Interface
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASR	Airport Surveillance Radar/Airspace Surveillance Radar
ARSR	Air Route Surveillance Radar
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
AUVSI	Association for Unmanned Vehicle Systems International
BLOS	Beyond Line of Sight
BNSF	Burlington Northern and Santa Fe
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CA	Collision Avoidance
CAAI	Civil Aviation Authority of Israel
CARAC	Canadian Aviation Regulation Advisory Council
CASA	Cooperative Automatic Sense and Avoid/Civil Aviation Safety Authority
CATV	Cooperative Airspace Techniques and Visualization
CBP	Customs and Border Protection
CDRRC	Chihuahuan Desert Ranchland Research Center
CFR	Code of Federal Regulations
COA	Certificate Of Authorization or waiver
COE	Center of Excellence
CONOPS	CONcept of OPerationS
CRADA	Cooperative Research And Development Agreement
CRC	Communications Research Centre
DAA	Detect And Avoid
DASR	Digital Airport Surveillance Radar
dBi	deciBel isotropic
DLOS	Detected Line Of Sight
EAB	External Advisory Board
EASA	European Aviation Safety Agency
EIRP	Equivalent Isotropically Radiated Power
EMI	ElectroMagnetic Interference
ERL	Environmental Research Laboratory
ESSA	Environmental Science Services Administration
EVLOS	Extended Visual Line of Sight
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FCCA	Federal Office of Civil Aviation
Fed Biz Opps	Federal Business Opportunity
FERPA	Family Educational Rights and Privacy Act
FOV	Field Of View
FRAT	Flight Risk Assessment Tool
FSPL	Free Space Path Loss
GA	General Aviation
GBDAA	Ground Based Detect And Avoid

GBSAA	Ground Based Sense And Avoid
GCS	Ground Control Station
GNS	Graphical Network Simulator
GO	Ground Observer
GO IDS	Ground Observer Information Display System
GFAFB	Grand Forks Air Force Base
GPAR-RMS	Ganged Phased Array Radar-Risk Mitigation System
GPARs	Ganged Phased Array Radars
GPC	General Purpose Computer
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GFK	Grand Forks International Airport|Mark Andrews Field
GUI	Graphical User Interface
HITL	Human In The Loop
HOTL	Human Over the Loop
HSI	Horizontal Situational Indicator
HWIL	HardWare In the Loop
ICAO	International Civil Aviation Organization
IDS	Information Display System
IFR	Instrument Flight Rules
ISM	Industrial, Scientific, and Medical
ITEM	Information Technical Exchange Meeting
IWA	Phoenix-Mesa Gateway Airport
JDOSAS	John D. Odegard School of Aerospace Sciences
KSU	Kansas State University
L-R	Longley-Rice
LAT	LATitude
LD-CAP	Limited Deployment-Cooperative Airspace Project
LON	LONgitude
LOS	Line Of Sight
MAC	MidAir Collision
MESA	Metamaterial Electronically Scanning Array
MMI	Man Machine Interface
NAS	National Airspace System
NATO	North Atlantic Treaty Organization
NMAC	Near MidAir Collision
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NTIS	National Technical Information Service
NP UAS TS	Northern Plains UAS Test Site
NTSB	National Transportation Safety Board
PANCAS	Passive Acoustic Non-cooperative Collision-Alert System
PHA	Preliminary Hazard Analysis
PIC	Pilot In Charge/Command
POC	Point Of Contact
PSL	Physical Science Laboratory
RCC	Range Control Center
RCC IDS	Range Control Center Information Display System
SAA	See And Avoid
SAE	Society of Automotive Engineers
SOUP	Software Of Unknown Pedigree
SWaP	Size, Weight, And Power
RFI	Request For Information/Radio Frequency Interference
RLOS	Radio Line Of Sight
RSSI	Received Signal Strength Indicator
RTCA	Radio Technical Commission for Aeronautics

RTCA SC228	Radio Technical Commission for Aeronautics Special Committee 228
SAA	Sense And Avoid
SAR	Synthetic Aperture Radar
SARP	Science And Research Panel
SGT	Stinger Ghaffarain Technologies
SOF	Supervisor of Flight
SQL	Structured Query Language
SRC	Syracuse Research Corporation
SS	Self Separation
sUAS	small Unmanned Aircraft Systems
SWaP	Size, Weight, and Power
SWIL	SoftWare In the Loop
TAAC	Technical Analysis and Applications Center
TAWS	Terrain Awareness Warning System
TBD	To Be Determined
TCAS	Traffic Collision Avoidance System
TIS-B	Traffic Information Service-Broadcast
UAE	United Arab Emirates
UAS	Unmanned Aircraft System(s)
UND	University of North Dakota
USDA	United States Department of Agriculture
USOVP	UAS Systems Operations and Validation Program
UTM	Unmanned Aircraft System (UAS) Traffic Management/UAV Traffic Management
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VO	Visual Observer
VSO	Visualization System Observer

Table of Symbols

Symbol	Meaning
a	Effective-Earth radius
d_L	Geometric line-of-sight range
d_{L1}	Distance from antenna to highest intervening terrain
d_{L2}	Distance from UAS to highest intervening terrain
$d_{L1,2}$	Horizon distance over irregular terrain
$d_{Ls1,2}$	Horizon distance over a smooth surface
τ_{mod}	Modified tau, where tau is time to impact and the modification generally involves using some minimum separation distance
Δh	Terrain roughness factor
h_{e1}	Antenna elevation
h_{e2}	UAS altitude

Executive Summary

The UND and NMSU team was tasked by the Federal Aviation Administration (FAA) with research related to Beyond Visual Line of Sight (BVLOS) for small unmanned aircraft systems (sUAS). A small UAS weighs less than 55 pounds. BVLOS is similar to Extended Visual Line of Sight (EVLOS) and other operations where the sUAS is not in the immediate proximity of the operator. The operating scenario does not necessarily include the situation where the sUAS may be out of sight due to a natural or man-made occlusion, unless there is a technology solution for that scenario. So, in general, BVLOS is an operating environment where the sUAS is out of sight due to distance and the limitation of the human visual system. This report captures a number of elements explored by the team.

Potential sUAS use cases were gathered to assess potential BVLOS applications that may use DAA approaches. Data calls were made through a number of approaches including a Request for Information (RFI) in the Federal Business Opportunity (Fed Biz Ops) web site maintained by the Federal Government. To supplement the information from Fed Biz Ops, data calls were made to the Technical Analysis and Applications Center (TAAC) (operated by New Mexico State University) List Serve as well as published on an AUVSI website. Responses from this process as well as Fed Biz Ops were minimal, with the total receipt being approximately 40. A few use cases were reported and were mostly for mapping, land/area monitoring, and straight line inspections. Use cases reported operating altitudes between 50 and 700 feet AGL with the most typical operating altitudes were between 50 and 100 feet AGL. Use case airspeeds ranged between 6 and 33 knots, with an average speed of around 12 knots. No use cases reported actual in-flight climb or descent rates.

A number of Detect and Avoid approaches were highlighted and discussed by seven separate entities – ATC; Dynetics, Inc.; Gryphon Sensors, LLC; Honeywell; New Mexico State University; IMSAR; Echodyne; and R-Cubed. Their information is sorted into Ground-Based as well as Airborne/Mixed Detect And Avoid (DAA) systems. Further details on the various DAA systems and contacts have been provided to the FAA in a separate Point-Of-Contact Database.

To supplement these data, the 333 Exemption Holders on the FAA website were all reviewed to elicit summary sUAS information. That summary information from more than 5,000 exemption holders is contained in this report. To understand the data that were acquired from the 333 Exemptions, defined uses were created to sort each docket by business use, of which there were eleven general uses. Each of these use cases were further divided into subcategories to allow additional definition. The 333 exemptions granted over time for these eleven categories are plotted as a function of time showing the breakdown by use.

The types and different platforms requested in the 333 exemptions are also detailed. The total number of use cases collected (where a use case consists of an individual request for a specific UAS or a request to use all UAS on the FAA-approved list) is 36,826. A total of 5,553 dockets were processed. Most applications were for 4-copters (total of 6,586), followed by similar number of requests for fixed-wing (818), 6-copter (726), and 8-copter (879). There were 153 different 4-copter platforms requested. The sUAS data were also analyzed by manufacturer. Each known model was classified by type and manufacturer (there are almost 200 different manufacturers in the listing).

A "333 Use Case/DAA Data Call" was sent to more than 4,400 333 exemption holders for information regarding their operations as well as DAA approaches. Information received as a result of this data call has varied in its level of detail but has provided relevant experiential information to generalize use cases. Descriptive categories are provided for each response. Input to the RFI was received that contained

proprietary information. These data are not included in this report, but are archived along with all the raw material received in the various information requests.

An assessment of Radio Line of Sight (RLOS) coverage was completed with the goal of assessing the radio line-of-sight (RLOS) connection for small unmanned aircraft systems (sUAS) through testing. This connection element is key to ensuring safe operations, specifically if flying BVLOS. A description of the approach and testing is provided. Various modeling approaches are discussed and an RLOS range that may be achieved in applications of sUAS was developed. Propagation was modeled using the well-respected Longley-Rice Irregular Terrain Model (Longley and Rice 1968), which was developed by the U.S. Department of Commerce in 1968. The test plan addressed data collection in a test setting to validate the developed model. A number of different approaches can be used to assess the coverage. A simplified mathematical model based on a version of the Longley-Rice model and an online-based Longley-Rice model were compared to actual field measurements to assess validity of the simplified input tools.

Static and flight test operations were completed on the unpopulated and NMSU-controlled Chihuahuan Desert Ranchland Research Center (CDRRC). Testing was performed between two 3DR radios (3DR v2 telemetry SiK radio with the stock antennas), operating at 915 MHz with 100 mW transmitters (20 dBm). One unit was placed at 1 m above ground level at various locations on the ranch. This unit was attached directly to a laptop computer running MavLink control software. This allowed the laptop to record the Received Signal Strength Indicator (RSSI) of both the control unit (laptop) and the remote unit. The second radio was either connected to a fixed pole for the initial testing or to a small UAS. The resulting data did provide a clear demarcation line where the communication link degraded at distance. For UAS flights, a Pixhawk flight control unit was used and mounted as a payload below a quad-copter (remote unit) that was operated at 2400 Mhz at a nominal height of 100 ft AGL. A sampling of test points were also collected at 200, 300, and 400 ft. AGL.

Field results were plotted and compared to both an on-line calculator [one that incorporates the Longley-Rice (L-R) model, terrain databases, and user entries for the radio characteristics to produce detailed coverage maps], and a simplified Longley-Rice model developed by E. Johnson. Based on field data, an estimated field observable RLOS coverage map was drawn for a visual comparison between the models and field observations.

Based on the limited sample and analysis time permitted, the results of the field test indicate that in the scenario flown, the simplified model and the on-line calculator models provide too coarse of estimations of RLOS coverage. As the simplified model assumes a uniform terrain type (plains, hilly, mountainous, etc.), it cannot adequately account for a radio coverage area that spans multiple terrain types. This field testing has demonstrated that real-world RLOS conditions differ from the analytical models—while the mathematical models may attempt to replicate ideal conditions, site specific influences can impact actual link distances. A number of specific conclusions were drawn from this testing and are included in the report. Additional testing in different environments or geographies and with different radio systems or frequencies may add to the knowledge base. This additional testing may be warranted. With the uncertainties shown, it is logical to choose a conservative approach in selecting a safe-and-reliable RLOS operational distance.

An Operational Framework that defines the environment and conditions under which the recommended requirements will enable sUAS operations BVLOS is presented. Considerations for BVLOS operations involve a number of interrelated elements that are needed for safe flight. These elements result in potential constraints on the systems and operations. The three elements of significant interest are 1) the conditions or locations in which one flies must be conducive to safe flight operations; 2) the operator must operate in a safe fashion; and 3) the aircraft must be capable of reliable and safe BVLOS operations.

A series of assumptions and limitations are provided that can facilitate BVLOS operations. These are also supplemented by considering a number of additional considerations, relevant scenarios, the Science And Research Panel (SARP) "Well Clear" definition for sUAS, the FAA BNSF Pathfinder Effort, and other aircraft considerations. A number of international activities that provide relevant inputs are also provided. The framework may not be prescriptive nor does it include an exhaustive set of actions; the framework includes strategies that can build upon FAA and industry actions that should result in an increase in BVLOS flights in the near term. The primary strategies and recommendations to help facilitate sUAS BVLOS operations in the National Airspace System (NAS) are:

1) Require a minimal set of limitations for BVLOS operations
    a. Operating time: daytime
    b. Meteorological Conditions: Visual Meteorological Conditions (VMC)
    c. Altitude: ~500 feet AGL
    d. Overflight: no densely populated areas
    e. Airport proximity limitations: greater than or equal to 5 miles
    f. Critical operating limitations: greater than or equal to 3 miles of critical infrastructure
    g. Operational control: RLOS will determine distance; no daisy chaining of control stations
    h. Vehicle visibility: optimize color, lighting, and design for conspicuity
2) Develop a consensus-and research-based design strategy
3) Utilize common phases of flight to facilitate recommendations and potential regulatory input to the FAA
4) Develop a taxonomy and use cases that result in a manageable set of recommendations for regulatory and recommendation purposes
5) ASTM could lead the development of design and other data for BVLOS operations based upon current and proposed research
6) A DAA system, either airborne or ground-based, must be operational with the system
7) sUAS BVLOS operations in the NAS can take place without extensive and very expensive infrastructure
8) International operations and requirements should be considered in formulating the BVLOS requirements for the USA
9) Develop a more robust RLOS model for BVLOS
10) Utilize SMS to assess risk as BVLOS evolves
11) Utilizing candidate DAA and other enabling BVLOS technologies, develop, verify and validate test methodologies for these current systems and apply this to future systems
12) Anticipate that the near future will demand autonomous BVLOS without a human pilot

Evaluating approaches to sUAS DAA was accomplished through five subtasks:

1. Literature review of pilot and ground observer see and avoid performance.
2. Survey of DAA criteria and recommended baseline performance.
3. Survey of existing/developing DAA technologies and performance.
4. Assessment of risks of selected DAA approaches.
5. Flight testing.

Given the existing literature, it is concluded that for relatively small manned aircraft, an optimistic average detection distance for manned-aircraft pilots is on the order of 0.8 miles during the daytime, with this distance increasing at night through the use of accessory lighting. (It is noted that this is based upon the literature examined herein, and does not include findings from Pathfinder Focus Area II.) The actual manned-aircraft pilot intruder detection distance in a given scenario depends upon many factors, including sky condition, cockpit obstructions, and interaction geometries.

Development of DAA criteria—the emphasis here being well clear—was accomplished through working with the SARP, which developed the distance-based definition of 2000 ft horizontally and 250 ft vertically for sUAS, and through simulations of sUAS encounters with manned aircraft that were performed within this effort. These simulations indicated that:

- Some advantages are realized when the horizontal distance for well clear is expanded to 4000 ft. When this is done, avoidance of NMAC (Near MidAir Collision) is enabled given that sensors are able to provide information regarding needed maneuvers by, minimally, the well-clear threshold.
- Field Of View (FOV) has a significant impact on maintaining well clear. A 180° FOV is recommended, although a full 360° FOV may be required to handle manned-overtaking-unmanned scenarios.
- The UAS autoflight system must be considered as part of the total DAA package. Any autopilot expecting human-in-the-loop control must be capable of aircraft trajectory changes within as few control inputs as possible, as being able to respond rapidly significantly enhances the ability to maintain well clear.
- Update rates of sensors should be considered when evaluating sensing distance required to enable maintenance of well clear.
- Using a 1 Hz sensor update rate, a 2000 ft well clear distance could be maintained when the simulated sensor range was 1.75 nm. For a 4000 ft well clear distance, the required sensor detection range is 2.6 nm for a fixed wing UA (Unmanned Aircraft) and 3.5 nm for a multi-rotor UA.
- Challenges associated with maneuvering vertically to maintain well clear include ballooning past 500 ft AGL (Above Ground Level) when operating the UA manually, the threat of crashing into the ground if applying a rapid descent while in manual control, and the inability to remain vertically well clear with a simulated multi-copter while under waypoint control owing to the slowness of the maneuver.

Information regarding sUAS DAA approaches was collected through a literature review, requests for information, and direct interactions. DAA system architectures were defined according to three primary characteristics: sensor location (on/off board), degree of autonomy, and sensor type (active/passive). Given these, existing standards (e.g., environmental standards), and developing criteria (e.g., well clear), metrics and metrics values were developed for DAA systems, with the metrics divided according to whether the sensor is on or off board owing to the importance of SWaP (Size, Weight, and Power) for on board systems. These metrics were then used to develop qualitative scores for different DAA approaches. This process produces the following results:

- Only 11 DAA-intensive companies were identified. This underscores the relative youth of this field.
- The majority of DAA-intensive companies are pursuing on-board solutions.
- The only off-board solution being pursued by companies identified as DAA-intensive is radar-based. It appears as if other approaches are in earlier stages of development.
- On board solutions being explored by DAA-intensive companies include active radar, passive EO/IR, and passive acoustic. Of these, radar and EO/IR are the most popular approaches.
- Off board radar-based systems have advantages regarding sensor performance (e.g., range), with the primary barrier being acquisition cost.
- On board radar-based systems have utilization advantages (e.g., cost, installation), with the primary challenges being detection range and FOV within SWaP limitations.
- On board EO/IR-based systems provide excellent update rates and may provide utilization advantages (e.g., cost). However, FOV and SWaP appear to be challenges.
- On board passive acoustic approaches appear to enable a complete FOV, with comparable range performance at an apparently lower SWaP requirement.
- Data for some metrics (e.g., probability of detection, false alarm rate, operational environment limitations) were severely limited. Additional data are needed to solidify results.

- It is expected that some data are limited owing to a lack of flight testing. Flight testing would enable both characterization of approaches and establishment of standards that will enable future system development.

Risks were assessed by focusing on the Safety Risk Management (SRM) pillar of the SMS (Safety Management System) process. This effort (1) identified hazards related to the operation of sUAS in BVLOS, (2) offered a preliminary risk assessment considering existing controls, and (3) recommended additional controls and mitigations to further reduce risk to the lowest practical level. Within both ground and airborne based DAA systems, hazards generally coalesced into four components (1) Level of Autonomy, (2) Hardware, (3) Software, and (4) Sensor. Risks for nearly 250 hazards were identified within this architecture of system states, classified, and offered some degree or method of mitigation. Of the four primary DAA components identified, hazards related to sensor systems were the most numerous at 102, followed in decreasing order by those related to software, hardware, and level of autonomy. Following implementation of recommended mitigations and controls, residual risks:

- For autonomy were expected to reduce to 2 high risks, 13 medium risks, and 10 low risks.
- For hardware were expected to be reduced to 1 high risk, 1 medium risk, and 59 low risks.
- For software were expected to be reduced to 1 high risk, 5 medium risks, and 49 low risks.
- For sensor were expected to be reduced to 20 high risks, 34 medium risks, and 78 low risks.

Common mitigations that were identified include practical performance evaluation or equivalent, more stringent medical standards than those established under 14 CFR §107.17 for crewmembers operating sUAS BVLOS, system redundancy, and health monitoring of flight critical processes. The challenges associated with Software Of Unknown Pedigree (SOUP) surfaced repeatedly across the software component, with frequent reference to standards such as DO-178 (application of DO-178C as an existing control generally resulted in residual risks having the lowest likelihood but commonly high severity owing to the presence of single point events/failures). It is noted that the go-to-ground/land mitigation provides an overarching mitigation for alleviating unacceptable residual risk, but can be challenging to implement.

Limited flight testing was performed in conjunction with another research project. These tests enabled collection of data regarding well clear and DAA system hazards.

1 Introduction

The New Mexico State University (NMSU) and University of North Dakota (UND) Alliance for System Safety of UAS through Research Excellence (ASSURE) teams were tasked with researching Detect And Avoid (DAA) technology in Unmanned Aircraft Systems (UAS) that could enable Beyond the Visual Line of Sight (BVLOS) operation of small UAS weighing under 55 lbs (sUAS) within limited portions of the National Air Space (NAS) while achieving a level of safety equivalent to manned aircraft operating in a similar manner. The NMSU and UND ASSURE teams were tasked with considering the following research questions:

a) What are the requirements for an airborne or ground-based Detect and Avoid system compatible with sUAS (55 pounds and less) operating in limited portions of the NAS in order for the sUAS pilot to comply with 14 CFR 91.113 in a manner that does not increase the risk to other aircraft, or persons on the ground, beyond that currently present in the NAS for similar manned aircraft operations?
b) What are the requirements for a software algorithm(s), if any, to implement these requirements?
c) What are the most feasible airborne or ground-based sensors that are capable of meeting these requirements and are compatible with sUAS size, weight, and power (SWaP), and level-of certification constraints?

These questions underlie a research program, with key outputs being development of DAA requirements, standards, and, eventually, a rule set that enable BVLOS operations with sUAS. This report provides the output of the first step (first project) within this overall program. The tasks, and thus output reported herein, are divided into two primary tasks: Operational Framework and Comparison of Approaches.

2 Operational Framework

2.1 Small Unmanned Aircraft Systems Use Cases and Detect and Avoid Approaches

2.1.1 Introduction

2.1.1.1 Background

The purpose was to reach out and survey the industry's current uses of small UAS and systems to support limited BVLOS to help inform FAA rules, regulations and guidelines. These current users are the most likely source of personnel who will want to fly BVLOS in the future.

The operational framework was to be informed by an analysis of actual and proposed use cases for aviation operations (both manned and unmanned) that are conducted primarily from the surface to 500 feet above ground level (AGL). An additional set of use cases that span from the surface to 1,000 feet AGL also were to be considered. The functional and performance requirements of these use cases inform both the functional requirements for the UAS and the potential threat posed from other users of the operational environment.

2.1.1.2 Assumptions and Limitations

For this effort, the research assumed the following operating limitations:

a) Day, visual meteorological conditions (VMC) operations only.
b) UAS operations will initially be limited to Class G and Class E airspace.
c) UAS operations will be conducted from the surface to 500 feet AGL, with additional evaluation of the potential for operations up to 1,000 feet AGL.
d) UAS operations will be conducted over other than densely populated areas, unless UAS complies with potential criteria or standard that demonstrates safe flights over populated areas.

e) UAS will not be operated close to airports or heliports. 'Close' is initially defined as greater than 3 miles of an airport unless permission is granted from ATC or airport authority. A distance of greater than 5 miles will be examined if needed to support an appropriate level of safety.
f) UAS operations will be restricted to within radio line of sight (RLOS) of a single, fixed ground-based transmitter.
g) Some safety-based design and/or configuration requirements may be specified (aircraft painted in a highly-visible paint scheme to facilitate identification by other aircraft, strobe lights, etc.).
h) Small UAS (sUAS) are potentially designed to an Industry Consensus Standard and issued an FAA Airworthiness Certificate or other FAA approval.

2.1.1.3 Investigative Team

The NMSU Team was led by Henry Cathey. Members of the team included Stephen Hottman, PhD; Zachariah LaRue; Alexander VanHoudt; as well as several students who supported the processing of Section 333 data.

2.1.1.4 Report Content

The report contains the results from various data calls, all for the same information purpose. They were:

- Initial data call
    - TAAC (Technical Analysis and Applications Center), AUVSI (Association for Unmanned Vehicle Systems International)
- Fed Biz Ops RFI
- Section 333 Exemption Database Compilation
- Subsequent 333 data call

2.1.2 Initial Data Call and Outcome

A request for information (RFI) on commercial sUAS use with a focus on Detect and Avoid (DAA) procedure and technology was dispersed. The FAA posted the RFI on Fed Biz Ops, and the RFI announcement was distributed to ASSURE External Advisory Board (EAB) and then posted on the ASSURE web site on February 12, 2016. Additional information also was sent through TAAC List Serve on February 16, 2016. Fourteen responses were collected from this data call. One response discussed information for a platform greater than 55 lbs. One response discussed information on sensor technology independent of any sUAS platform. Two responses discussed operations outside of the U.S. Ten responses discussed sUAS operation for various purposes within the U.S. These 10 responses listed broad use case information, and little information on DAA technology. DAA procedural and technology description was discussed to varying degrees ranging from being present (though without any further description), to "return home" functionality with regard to specific DAA technology. Detection procedure was discussed on a see-and-avoid level tasked to the PIC and the visual observers. Additional details on the results are provided below Table 1.

Table 1. Results of initial data call. The Xs indicate that the respondent provided data for this category. The dash indicates the respondent did not provide data for this category.

Respondent	sUAS Use Case	Detect and Avoid
Modern Technology Systems, Inc.	X	-
Insitu	X (Performance Data)	-
NMSU/PSL	X	X (T&E Data)
Alexander Technical Coordinators	- (No Systems)	- (No Systems)
IMSAR	-	X
Dynetics Inc.	-	X
Gryphon Sensors	-	X
ADS	-	N/A
Danish Ministry of Environment and Food	N/A	N/A
Kurzprofil	N/A	N/A
VideoBank	- (Tool Only)	N/A
USDA	X	-

From the initial RFI, 10 UAS use cases were received. Six were received from NMSU/PSL, while one was received from Modern Technology Systems, one from the United States Department of Agriculture (USDA), and two from Insitu. Six of these cases were examples of fixed-wing aircraft, while two were helicopters and two were quadcopters (4-copters). Eight sUAS were represented, with weight ranges from 1.5 lbs to 40 lbs. One non-sUAS was represented, with a weight of 79 lbs.

Typical uses for the systems were mapping, land/area monitoring, and straight-line inspection. Typical flight patterns varied for the different uses. Mapping and monitoring cases tended to use a "serpentine" flight pattern (i.e., a progressive back-and-forth pattern, much like mowing a lawn), while straight-line inspections used a linear flight path along whatever was being inspected.

Use cases reported operating altitudes between 50 and 700 feet AGL. The most typical operating altitudes were between 50 and 100 feet AGL.

Use-case airspeeds ranged between 6 and 33 knots, with an average speed of around 12 knots.

No use case reported actual in-flight climb or descent rates. However, Insitu reported climb rate figures (varying with payload, etc.) for the sUAS included in their report.

No use case included detailed DAA information. Insitu information notes "Insitu AV do not detect." One sUAS (SenseFly eBee) used by NMSU PSL has in manufacturer's information lists "mid-air collision avoidance" as a feature, but does not go into detail. No other UAS reported has DAA information readily available. (Use cases do not include any information, and readily available manufacturer's information has no information).

Detect and Avoid technology was discussed by seven separate entities – ATC; Dynetics, Inc.; Gryphon Sensors, LLC; Honeywell; New Mexico State University; IMSAR; Echodyne; and R-Cubed. Their information is sorted into Ground-Based as well as Airborne/Mixed Detect and Avoid systems. Ground-Based DAA systems included submissions by ATC, which used a VUSIL computer program that senses surrounding air traffic and displays it to the pilot ground control station. A "Detect and Avoid" tool in the program indicates conflicts and possible avoidance maneuvers on a separate display. Flight testing has been done with simulations and manned aircraft, and the concept was validated internally.

Dynetics, Inc. reported use of a GroundAware Radar, which is technology that can track sUAS, people beyond 2 km, and vehicles to >3.5 km within 120° FOV. This display also can be integrated with optical and thermal camera data. Alert zones indicated in the display notify the user of threats based on location, heading, and classification, and automatically slew the camera in that direction. When multiple ground-based sensor units are deployed, it gives the user a 360° view.

Gryphon Sensors, LLC reported the use of single-radar detection ranges of DJI Phantom sized targets from 6-8.5 km, and small, manned targets from 15-20 km.

Honeywell reported the use of multiple sensors and sensor types, which integrated data into DAA algorithms. SAAP (the technology indicated) has the capability of integrating and using threat declaration and resolution logic algorithms. SAAP reportedly can operate with different combinations of cooperative and non-cooperative sensors and tracks threats detected for the user.

New Mexico State University reported test data on the Raytheon Sentinel Radar with hot air balloons, gliders, and UAS. Airborne/Mixed DAA Systems included: a submission from IMSAR, which discussed a miniaturized radar system with reduced weight and power requirements. This system was described as unique technology to obtain a wide FOV.

Echodyne reported on their MESA technology - a miniaturized radar that electronically steers the radar beam without phase shifters. Details on this system, however, were not yet made public.

R-Cubed reported the use of integrated radar for larger UAS (greater than 55 lbs); however, its functionality and display included cooperative/non-cooperative tracking, collision avoidance, weather, ground mapping, synthetic aperture radar, and a moving target indicator.

NMSU reported test data on EO, IR, Radar, and acoustic DAA technologies (greater than 55 lbs tested).

2.1.3 Analysis and Outcome of 333 Dockets Data

Based upon the limited response to the "initial" data call, a team was tasked with deriving relevant information from the publicly posted 333 exemptions granted by the FAA. Over 5,400 individual applications were investigated. A significant number of the exemptions granted included only general information on specific use cases, and included no DAA procedural or technological information beyond what is given within the allowances provided by a 333 exemption. A database of applicants, general uses, specific uses, sUAS platforms approved per applicant, and point of contact information per applicant was developed.

To understand the data that were acquired from the 333 Exemptions, defined uses were created to sort each docket by business use. Eleven general uses were identified, specified as follows:

- Aerial Data Collection
- Aerial Photography/Videography
- Aerial Surveying/Mapping
- Agriculture
- Emergency Services
- Flight Training/Education
- Inspection
- Marketing
- Research
- Search/Rescue
- Surveillance/Monitoring, etc.

2.1.3.1 Use Case Definitions

Where possible, these general uses were broken down further into more specific sub-categories of their respective general uses. This allowed for the collection of a greater amount of information. The definition of each general use is provided below along with the listing of their respective sub-categories. The detailed definitions of each of the sub-categories appears in Appendix A.

Aerial Data Collection: Use cases that are either described simply as "Aerial Data Collection" (or having a very similar description), or can most accurately be described as a use involving the collection of data by means of sensors or cameras on-board of the sUAS. Separate from the definitions of "Aerial Surveying/Mapping," "Agriculture," "Inspection," and "Research," the description given of the use case is not necessarily specific as to what data are collected, and what purposes the data will be used for.

- **Aerial Data Collection – Construction/Mining**
- **Aerial Data Collection – Environmental**
- **Aerial Data Collection – General**
- **Aerial Data Collection – Insurance**

Aerial Photography/Videography: Use cases that are either described simply as "Aerial Photography/Videography" (or having a very similar description), or can most accurately be described as a use involving the collection of pictures and videos for no other obvious or implied reason than to have the pictures or videos taken in the applications listed below.

- **Aerial Photography/Videography – Closed-set filming**
- **Aerial Photography/Videography – Construction**
- **Aerial Photography/Videography – General**
- **Aerial Photography/Videography – News-Gathering**
- **Aerial Photography/Videography – Outdoor Activities**
- **Aerial Photography/Videography – Real Estate**
- **Aerial Photography/Videography – Wedding**

Aerial Surveying/Mapping: Use cases that are either described simply as "Aerial Surveying/Mapping" (or having a very similar description), or can most accurately be described as a mapping or surveying operation for various purposes.

- **Aerial Surveying/Mapping – Agriculture/Mining**
- **Aerial Surveying/Mapping – Construction**
- **Aerial Surveying/Mapping – Engineering**
- **Aerial Surveying/Mapping – General**

Agriculture: Use cases that are either described simply as "Agriculture" (or having a very similar description), or can most accurately be described as a use involving the collection of data for agricultural purposes.

- **Agriculture – Crop Monitoring**
- **Agriculture – General**
- **Agriculture – Precision Agriculture**

Emergency Services: Use cases which are either described simply as "Emergency Services" (or having a very similar description), or describe a use case that can be described as aiding police officers, firefighters, medical services, etc., or in the investigation of areas that are too dangerous to put a human being in for investigative purposes.

- **Emergency Services – Crisis Response**
- **Emergency Services – General**

- **Emergency Services – Investigate Hazardous Regions**

Flight Training/Education: Use cases which are either described simply as "Flight Training," "Education" (or having a very similar description), or describe a use case involving the training employees, students, or other users in the operation of sUAS technology, and/or procedures. Use cases involved in educating individuals on sUAS principles, or in demonstrating concepts in mathematics and sciences which can demonstrated by sUAS technology.

- **Flight Training/Education – Education**
- **Flight Training/Education – General**
- **Flight Training/Education – sUAS Training**

Inspection: Use cases that are either described simply as "Inspection" (or having a very similar description), or that describe a use case involving the inspection of different kinds of structures or areas for safety, upkeep, maintaining of, etc.

- **Inspection – Communications Structures**
- **Inspection – Construction**
- **Inspection – General**
- **Inspection – Insurance**
- **Inspection – Oil/Pipeline**
- **Inspection – Power plants**
- **Inspection – Real Estate**
- **Inspection – Structure**
- **Inspection – Wind power**

Marketing: Use cases that are either described simply as "Marketing" (or having a very similar description), or describe the capture of aerial images and videos for the express purpose of using these images and videos for the marketing of a business, product, or service.

- **Marketing – Aerial Images**
- **Marketing – General**

Multiple Applications: Use cases which are either described simply as "Multiple Applications" (or having a very similar description), or have been cleared for more than one general use case.

Research: Use cases which are either described simply as "Research" (or having a very similar description), or describe a use involving imaging and data collection distinctly for scientific research purposes.

- **Research – Academics**
- **Research – Development**
- **Research – General**
- **Research – Market**
- **Research – Operations**
- **Research – Product Testing**
- **Research – Transportation**

Search/Rescue: Use cases that are either described simply as "Search / Rescue," or describe a scenario where a sUAS platform would be used to aid in various search and rescue operations.

Surveillance, Monitoring, etc.: Use cases that are either described simply as "Surveillance," "Monitoring" or having a description that can be categorized in a similar fashion.

- **Monitoring – Environmental**
- **Monitoring – General**
- **Monitoring – Legal**

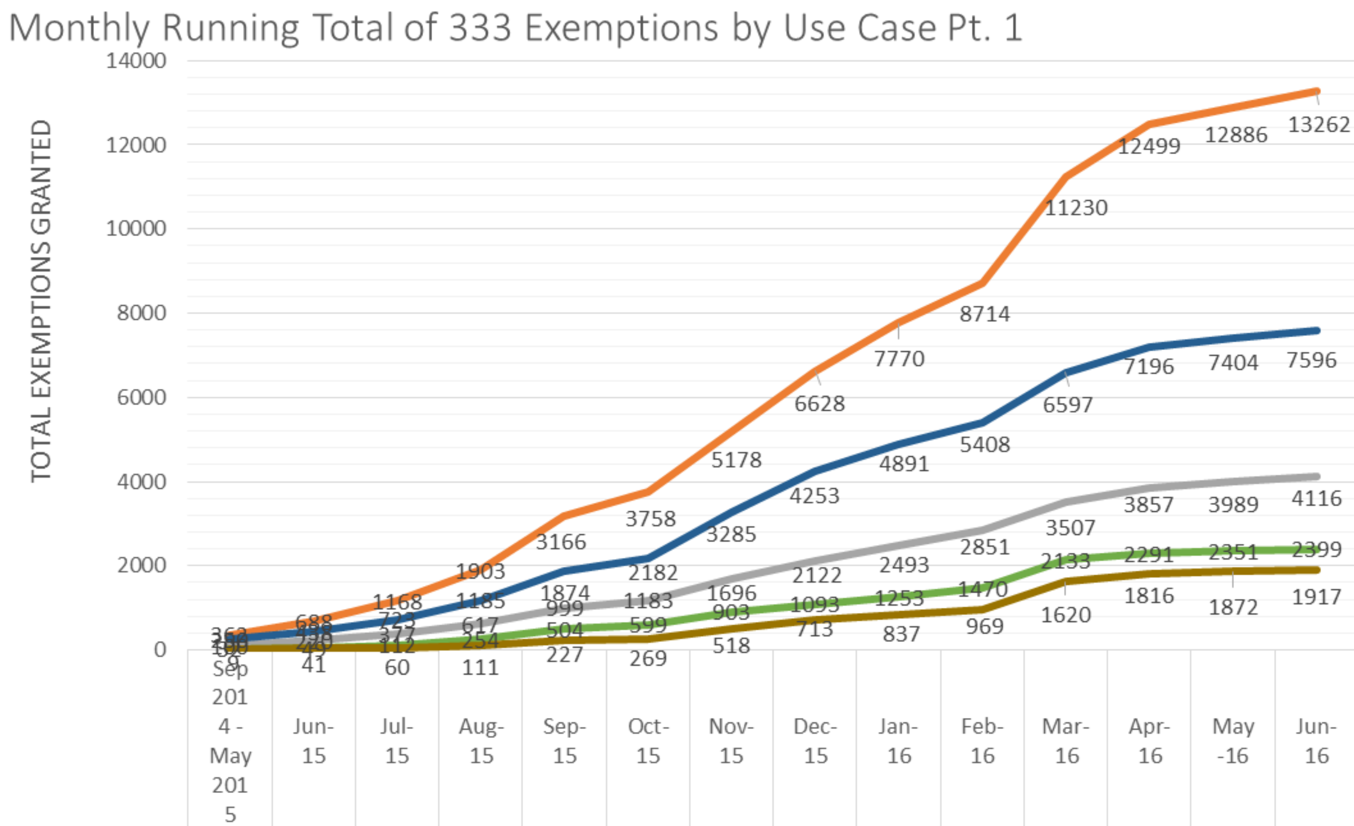
- **Monitoring – Safety**
- **Monitoring – Security**

From the data collected, Aerial Photography/Videography had the most use cases by 333-exemption holders, with 13,262 use cases granted between September 2014 and June 29, 2016. The other most common general use cases included Inspection (7596), Aerial Surveying/Mapping (4116), Flight Training/Education (2399), and Search/Rescue (1917).

2.1.3.2 Section 333 Analysis and Outcome

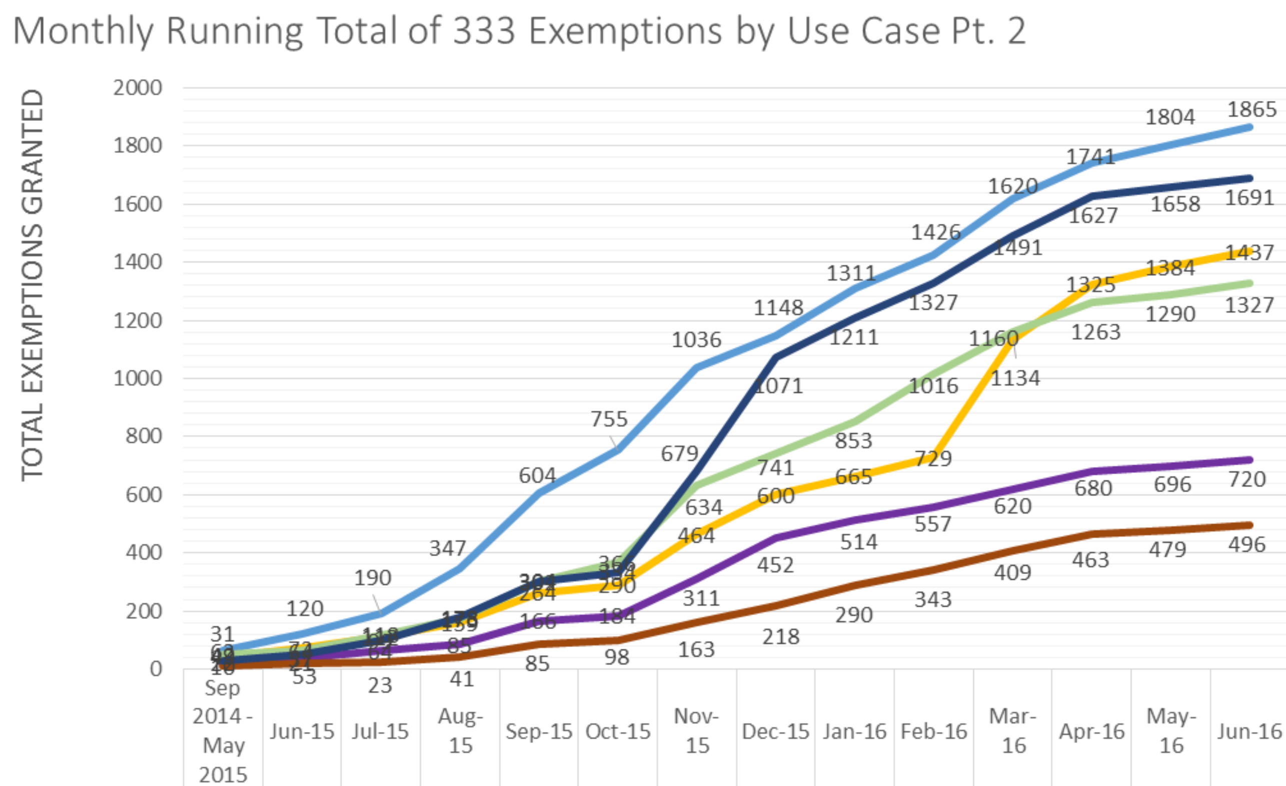
2.1.3.2.1 Date Trends

The granted 333 exemptions were analyzed by date of posting, and then broken down into their respective general uses to reflect the trends of general use requests from September 2014 to June 2016. This information is represented in the cumulative distribution functions in Figs. 1 and 2. These data were split into two separate figures so as to have appropriate Y-axis scaling for the general use requests.



	Sep 2014 - May 2015	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16
AERIAL PHOTOGRAPHY / VIDEOGRAPHY	362	688	1168	1903	3166	3758	5178	6628	7770	8714	11230	12499	12886	13262
AERIAL SURVEYING / MAPPING	100	220	377	617	999	1183	1696	2122	2493	2851	3507	3857	3989	4116
FLIGHT TRAINING / EDUCATION	32	49	112	254	504	599	903	1093	1253	1470	2133	2291	2351	2399
INSPECTION	250	438	723	1185	1874	2182	3285	4253	4891	5408	6597	7196	7404	7596
SEARCH / RESCUE	9	41	60	111	227	269	518	713	837	969	1620	1816	1872	1917

Figure 1. Exceptions granted by month--CDF.



	Sep 2014 - May 2015	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16
AERIAL DATA COLLECTION	62	120	190	347	604	755	1036	1148	1311	1426	1620	1741	1804	1865
AGRICULTURE	43	72	112	159	264	290	464	600	665	729	1134	1325	1384	1437
EMERGENCY SERVICES	22	37	64	85	166	184	311	452	514	557	620	680	696	720
MARKETING	10	21	23	41	85	98	163	218	290	343	409	463	479	496
RESEARCH	49	64	118	173	304	366	634	741	853	1016	1160	1263	1290	1327
SURVEILLANCE, MONITORING, ETC.	31	53	99	178	302	334	679	1071	1211	1327	1491	1627	1658	1691

Figure 2. Exceptions granted by month--CDF.

2.1.3.2.2 UAS Categories

The total number of use cases collected (where a use case consists of an individual request for a specific UAS or a request to use all UAS on the FAA-approved list) is 36,826. A total of 5,553 dockets were processed.

The data were analyzed to discover how many use cases requested different categories of UAS, which are depicted in Table 2.

Table 2. Types of UAS requested.

UAS Type	Number Requested
Fixed-wing	818
Helicopter	21
2-copter	17
4-Copter	6586
5-copter	4
6-copter	726
8-copter	879
12-copter	9
All on Pre-approved list	1899
Unknown/Proprietary/ etc.	273

"Unknown" UAS is a catch-all category for UAS that have little data easily available for identification– these UAS could be proprietary, or, for example, have poor manufacturer's listed specifications.

The known UAS systems that were identified in exemption requests were analyzed to discover how many models were present of each broad type (e.g., fixed-wing, helicopter, etc.) (Table 3).

Table 3. Types of UAS.

UAS Type	Platforms Classified
Fixed-wing	52
Helicopter	15
2-copter	4
4-copter	153
6-copter	63
8-copter	54
12-copter	2
Unknown models	146
Total UAS systems:	489

The "unknown" models in Table 3 roughly correspond to the "unknown" type listed in Table 2.

2.1.3.2.3 Broad Usage Requests

During the data analysis process, the data were split into three categories: "Grand Totals," "One General Use Totals," and "Multiple General Use Totals." A docket labeled as "One General Use Totals" was defined as a 333 exemption that was granted for only one of defined general use cases, a docket labeled as "Multiple General Use Totals" was defined as a 333 exemption that was granted for two or more general use cases, and the data used in the "Grand Totals" table added the information from the "One General Use Totals" and the "Multiple General Use Totals" together. The distinction between "One General Use" and "Multiple General Uses" was drawn to highlight the trend of 333 applicants requesting exemption for several unrelated general use cases, and to draw attention to the trend in the data that showed exemption holders that only applied for clearance for one general use and typically requested clearance for use from a smaller number of general use categories (namely Aerial Data Collection, Aerial Photography/Videography, Aerial Surveying/Mapping, and Inspection).

The data were analyzed for both general and more specific use cases. Each 333 Exemption required a usage in the application. These requestor-specific usages were sorted into broad categories of usage for the database, then further into narrower categories for more in-depth analysis. These data are sorted into the definitions described earlier. This tabular information is represented in Table 4 and in Figs. 3, 4, and 5 below.

Table 4. Broad usage requests.

	GRAND TOTALS	ONE GENERAL USE	MULTIPLE GENERAL USE
AERIAL DATA COLLECTION	1865	437	1428
Aerial Data Collection - Construction / Mining	62	26	36
Aerial Data Collection - Environmental	199	20	179
Aerial Data Collection - General	1518	367	1151
Aerial Data Collection - Insurance	86	24	62
AERIAL PHOTOGRAPHY/VIDEOGRAPHY	13262	3081	10181
Aerial Photography/Videography - Closed-set Filming	1630	329	1301
Aerial Photography/Videography - Construction	951	199	752
Aerial Photography/Videography - General	6128	1648	4480
Aerial Photography/Videography - News-Gathering	683	47	636
Aerial Photography/Videography - Outdoor Activities	279	41	238
Aerial Photography/Videography - Real Estate	3336	773	2563
Aerial Photography/Videography - Weddings	255	44	211
AERIAL SURVEYING/MAPPING	4116	285	3831
Aerial Surveying/Mapping - Agriculture/Mining	931	44	887
Aerial Surveying/Mapping - Construction	116	14	102
Aerial Surveying/Mapping - Environmental	88	11	77
Aerial Surveying/Mapping - General	2981	216	2765
AGRICULTURE	1437	84	1353
Agriculture - Crop Monitoring	197	15	182
Agriculture - General	752	29	723
Agriculture - Precision Agriculture	488	40	448
EMERGENCY SERVICES	720	52	668
Emergency Services - Crisis Response	254	37	217
Emergency Services - General	443	4	437
Emergency Services - Investigate Hazardous Regions	23	11	14
FLIGHT TRAINING/EDUCATION	2399	29	2370
Flight Training/Education - Education	404	2	402
Flight Training/Education - General	36	9	27
Flight Training/Education - sUAS Flight Training	1959	18	1941

Table 4 continued.

INSPECTION	7596	675	6921
Inspection - Communications Structure	282	22	260
Inspection - Construction	679	52	627
Inspection - General	3863	253	3610
Inspection - Insurance	153	23	130
Inspection - Oil/Pipeline	417	36	381
Inspection - Power Plants	575	98	477
Inspection - Real Estate	401	47	354
Inspection - Structure	951	109	842
Inspection - Wind Power	275	35	240
MARKETING	496	18	478
Marketing - Aerial Imaging	5	5	0
Marketing - General	491	13	478
RESEARCH	1327	149	1178
Research - Academics	90	11	79
Research - Development	271	12	259
Research - General	743	68	675
Research - Market	12	0	12
Research - Operations	120	41	79
Research - Product Testing	17	6	11
Research - Transportation	74	11	63
SEARCH/RESCUE	1917	19	1898
Search/Rescue - General	1917	19	1898
SURVEILLANCE, MONITORING, ETC.	1691	69	1622
Monitoring - Environmental	702	2	700
Monitoring - General	459	2	457
Monitoring - Legal	30	1	29
Monitoring - Safety	160	53	107
Monitoring - Security	340	11	329

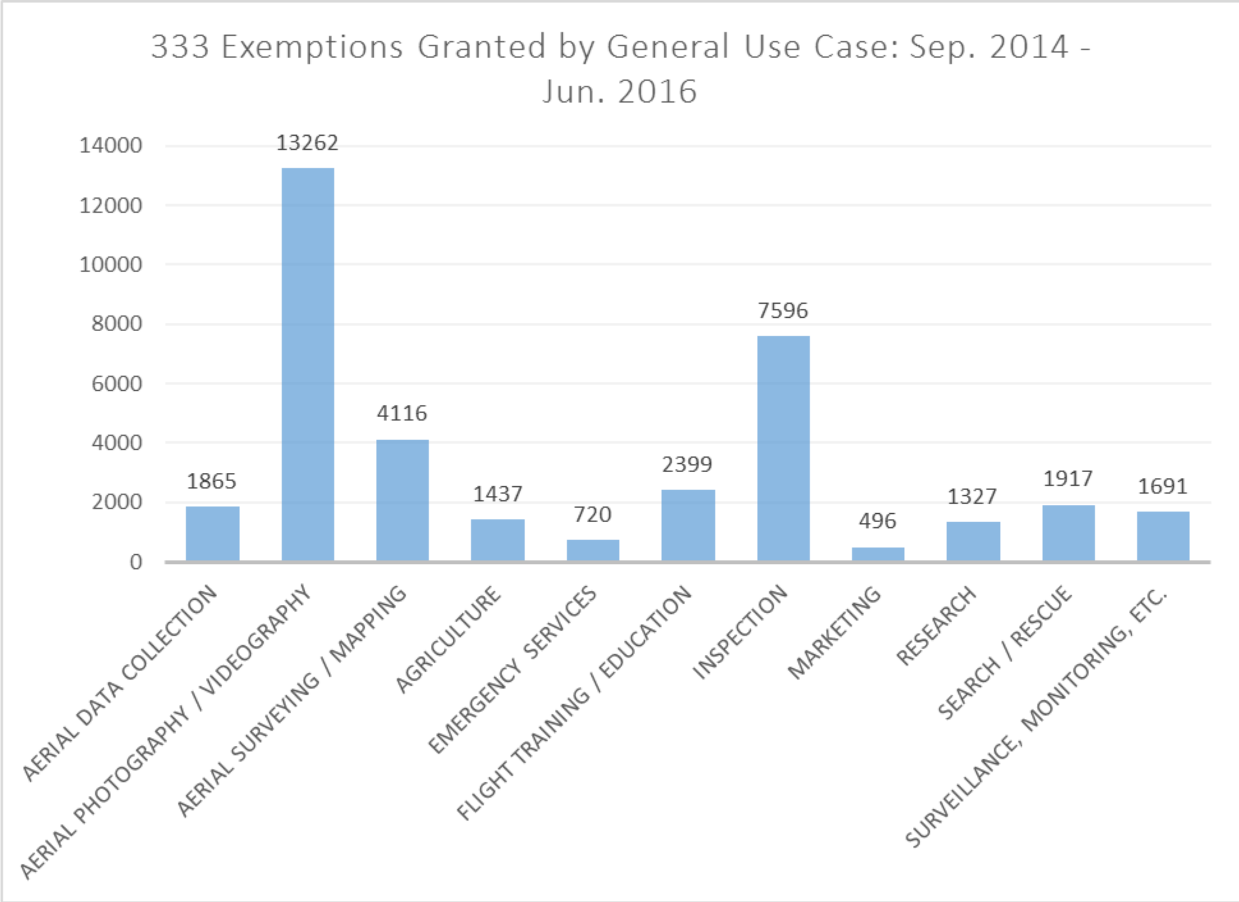


Figure 3. 333 exemptions granted by general use case: Sep. 2014 – Jun. 2016.

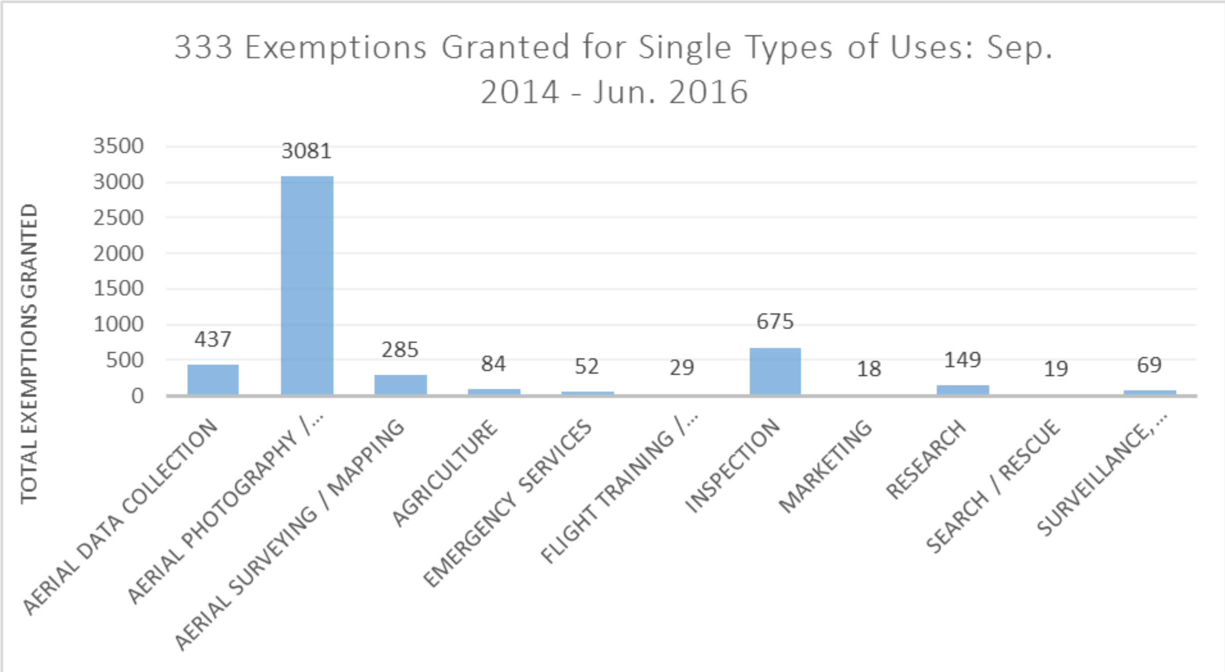


Figure 4. 333 exemptions granted for single types of uses: Sep. 2014 – Jun. 2016.

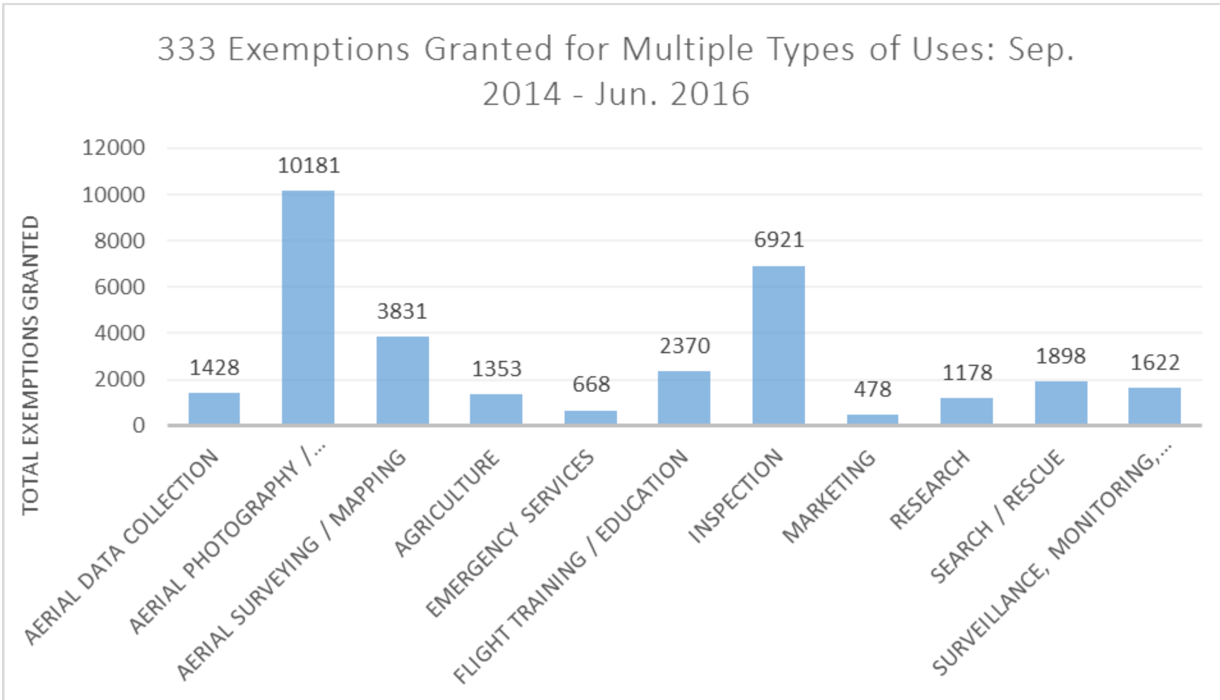


Figure 5. 333 exemptions granted for multiple types of uses: Sep. 2014 – Jun. 2016.

2.1.3.2.4 Use by UAS Type

The uses of each exemption were analyzed further by first separating the broad types of UAS (e.g., fixed-wing, helicopter, etc.), then by the usage request categories. That is, researchers checked how many requests in each use case category there were for each broad type of UAS. The following data are presented in Table 5.

The sUAS data were analyzed by manufacturer. Each known model was classified by type and manufacturer. There were a large number of manufacturers. The table that summarizes this information is included in Appendix B. It makes explicit how many of the categorized platforms are manufactured by any particular company, as well as how many categorized platforms of each type of UAS (i.e., fixed-wing, helicopter, etc.) are manufactured by a particular company.

Table 5. Use by UAS type.

	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	12-copter	FAA List	UNCL
Aerial Data Collection	60	0	2	281	0	27	46	0	70	13
Aerial Photography / Videography	42	6	1	1766	0	176	213	7	467	57
Aerial Surveying / Mapping	101	1	0	132	0	17	21	0	62	9
Agriculture	42	0	0	19	1	9	4	0	5	5
Delivery	0	0	0	0	0	0	0	0	0	0
Emergency Services	5	0	0	39	0	10	3	0	3	0
Flight Training / Education	23	0	0	32	0	3	6	1	5	3
Inspection	13	2	4	241	0	37	39	0	61	13
Marketing	0	0	0	20	0	0	1	0	7	1
Multiple Applications	499	8	9	3913	3	428	521	1	1193	159
Research	17	1	1	88	0	15	14	0	17	9
Search / Rescue	3	0	0	14	0	1	1	0	4	2
Surveillance, Monitoring, etc.	13	3	0	41	0	3	10	0	5	2

2.1.4 Section 333 Use Case/DAA Data Call

Approximately 4,500 333 exemption-holders were contacted by email with a similar message to that sent out in the FEDBIZOPS data call. The responses appear in Appendix C. The responses are re-structured but otherwise unedited responses from the exemption holders. Some of the responses included information in all the categories requested (very detailed responses) while others included information but not in all categories requested (less detailed responses). The descriptive categories provided for each response include the following:

Location
Platform
Takeoff Time
Flight Duration
Key Altitudes
Airspeeds
Climb / Descent Rates
Flight Patterns

Below is a short listing summary of the types of responses received. (Full responses are presented in Appendix C.)

2.1.4.1 Very Detailed Responses

A & R Video. POC: Andrew Sommer, asommer@arvideo.com

Monthly construction photography on primarily linear construction projects such as road widening, drainage improvements, water and sewer line installations.

Empire Unmanned. POC: Joseph Stewart, joseph.swart@adavso.com

Application: Agriculture
Application: Mining
Application: Aerial Surveying
Application: Classification and Species Identification
Application: Sawmill Inventory
Application: Fire Fighting
Application: Real Estate

Boulder Emergency Services, POC: Steve Lanaghen, stevelanaghen@boulderrescue.org

Search and Rescue

Kansas State University. POC: Travis Balthazor, travisb@ksu.edu

Varied use cases

2.1.4.2 Less Detailed Responses

Delta Southern UAS. POC: Preston White, preston@deltasouthernuas.com

UAS in agriculture to determine plant health, in law enforcement to get a usable image for planning purposes, for disaster relief and search and rescue by providing EMS with an up to date image of the affected area

Mike Knudsen Photography. POC: Mike Knudsen, mike@mikeknudsenphotography.com

Primarily for real estate work

SurvTech Solutions. POC: Jordan Kowenski, jkowenski@survtechsolutions.com

Surveying, Photogrammetry, Mapping

Rapid Aerial LLC. POC: Matt Roderick, matt@rapid-aerial.com
Rural utility line and substation inspections
Photogrammetric Surveys

DuPage County, Illinois. POC: Lucy Chang, lucy.chang@dupageco.org
Currently, the UAS is primarily used to inspect County flood control facilities and capture photographs and video footage from high elevations for use in County publications, presentations, and technical reports. Plan to expand the use of the UAS to include the monitoring of wetlands in locations that are difficult to access on foot, and monitor water quality at storm sewer outfalls.

SelectTech GeoSpatial. POC: Frank J. Beafore, fbeafore@sgamf.com
Varied with development of UAS as a driver

Forza RPV. POC: Gil, gil@forzarpv.com
sUAS powerline inspection program

Atlanta Drone Operations. POC: Pete Wambolt, pete@atldrone.com
Variety of different operations. Most of our uses are for aerial photography/videography. Also have done work with 3D mapping and have worked on a few shoots for up and coming TV shows.

JimmyC LTD. POC: Jimmy Clark, jimmyclark@usa.com
Insurance building damage assessment post catastrophic event such as earthquake, hurricane, tornado, explosion and flood.

Trans-Global Production. POC: Bob Bailey, bbailey@cableone.net
Video of an auto dealership showing aerial view of dealership buildings and inventory
Video of golf course property showing buildings, water hazards and fairways/greens
Video of a tennis tournament in progress
Aerial shots of the Christmas parade
Video at our local football stadium, of the high school graduations

Several responses that included complete data to the RFI were received. The responses were first separated into two primary categories–fixed-wing UAS and multicopter UAS. Once separated, key quantitative data points were analyzed for differences. These data points were average flight duration (in minutes), average flight altitude (in feet above ground level), and average airspeeds (in miles per hour). The data are presented in Tables 6-7.

Table 6. Multicopter characteristics.

	Flight Duration (minutes)	Flight Altitude (Feet AGL)	Speed (MPH)
Mean	20.34	154.31	17.97
Standard Deviation	11.29	77.09	11.57
Median	17.50	110	20.13

Table 7. Fixed-wing characteristics.

	Flight Duration (minutes)	Flight Altitude (Feet AGL)	Speed (MPH)
Mean	41.43	342.33	39.98
Standard Deviation	17.79	112.00	13.68
Median	50	360	46.98

While there is not enough data to accept these numbers as representative, there is a clear divide in the usages of multicopter and fixed-wing UAS. Average flight duration, flight altitude, and speed of fixed-wing UAS are all nearly double that of the respective categories for multicopter UAS.

Qualitative data about flight patterns used was also summarized. Four general patterns were categorized – elongated "s"-patterns, cross/grid patterns, linear flight, and hovering/circling a target/object. The data are provided in Tables 8-9.

Table 8. Flight patterns.

	Multicopters	Fixed-Wing
S-Pattern	4	3
Cross/Grid	7	2
Linear	4	1
Hover/Circle	8	0

The received data show a clear pattern evident in the Section 333 requests: There are far more multicopters in use than fixed-wing aircraft, and real-world flight patterns and parameters show differences in the two primary categories.

Table 9. Flight pattern descriptions.

Platform	Location	Takeoff Time	Flight Duration
Tarot 650 Quad	Florida	Usually Mid to Late Afternoon	Typically 1 - 6 flights in a day lasting 4 - 12 minutes each, with the longest lasting up to 20 minutes
Tarot 690 Hexa	Florida	Usually Mid to Late Afternoon	Typically 1 - 6 flights in a day lasting 4 - 12 minutes each, with the longest lasting up to 20 minutes
Sensefly eBee Ag	Washington State and Idaho	Dependent on client's needs	15 - 30 minutes
DJI Phantom 2	Washington State and Idaho	Dependent on client's needs	15 - 30 minutes
DJI Phantom 2	Boulder County, CO	Most flights around noon, though some start as early as 09:00, and some start as late as 17:00	1 - 29 min with an average of 14 min
DJI Phantom 3	Boulder County, CO	Most flights around noon, though some start as early as 09:00, and some start as late as 17:00	1 - 29 min with an average of 14 min
DJI S1000	Boulder County, CO	Most flights around noon, though some start as early as 09:00, and some start as late as 17:00	1 - 29 min with an average of 14 min
DJI S1000+	Central Kansas	Typically close to solar noon	22 - 28 min
3D Robotics Aero (built by Kansas State)	Central Kansas	Typically close to solar noon	40 - 55 min
3DR X8+	Salina, KS	During daylight hours	18 - 25 min
DJI S1000+	Salina, KS	During daylight hours	18 - 25 min
DJI Inspire	Salina, KS	During daylight hours	18 - 25 min
PrecisionHawk Lancaster MKIII	Salina, KS	During daylight hours	40 - 55 min
3D Robotics Aero (built by Kansas State)	Salina, KS	During daylight hours	40 - 55 min
3D Robotics Aero (built by Kansas State)	Central Kansas	Typically close to solar noon	40 - 55 min

DJI Inspire	Central Kansas	Typically close to solar noon	18 - 22 min
Sensefly eBee; DJI S900	Mississippi Delta	During Daylight Hours	Usually roughly 10 min, but can last up to 40 min depending on the wind
DJI Phantom 2+ V3	Residential neighborhoods and business complexes	Typically between 9am and 7pm	> 20 min
Non-specified Quad-Copter	Southeast US	During Daylight Hours	15 - 100 min
Non-specified Fixed Wing	Southeast US	During Daylight Hours	15 - 100 min
DJI Phantom 3 Pro	Southwest Idaho	Typically between 10am and 12pm local	10 - 20 min
DJI Inspire 1 Pro	Southwest Idaho	Typically between 10am and 12pm local	10 - 20 min
DJI Phantom 3	Dupage County, IL	Varies	4 flights at a time of up to 15 min
	Springfield, OH		
Not specified	Not specified	Not Specified	Not specified
DJI Phantom 3 Professional	In and around Atlanta, GA	Most flights take place between 10am and 4pm, though some will happen later for artistic reasons	Around 15 min with 5 - 10 flights in total
DJI Inspire	In and around Atlanta, GA	Most flights take place between 10am and 4pm, though some will happen later for artistic reasons	Around 15 min with 5 - 10 flights in total

DJI Phantom 3	Anywhere in the United States	Daytime business hours	15 - 60 min
DJI Phantom 2;	Anywhere in the United States	Daytime business hours	15 - 60 min
DJI Phantom 3 Professional	Midland / Odessa, TX area	During daylight hours	Up to 20 min

2.1.5 Fed Biz Opps Data Call

The Fed Biz Ops data call was released by the FAA.

The overall response to the Fed Biz Ops was not robust. Some of the responders also included proposed enhancements to the current technology for use by BVLOS operators in the future. The summary list of responses included the following:

Stinger Ghaffarain Technologies (SGT)

SGT provided a proposed ground-based detect and avoid (GBDAA) technology. SGT also proposed a concept of operations (not an actual use case), for use in Class G airspace

SoHaR Incorporated

Provided a proposed self-sensing error process for flight platforms.

Gryphon Sensors

Provided information on theoretical GBDAA technology, the costs and benefits of that technology, and some details on the TRL9 - a GBDAA sensor which can detect a DJI Phantom-sized obstacle from 6 - 8.5 km away, and small manned aircraft from 15-20 km away.

Harris Corporation

Provided general information on its DAA systems.

Thales Defense & Security

Described a ground-based, passive detection system – essentially a cloud of multiple ground-based sensors that are able to detect in 3D the locations of multiple aircraft, then feed that information into larger aircraft TCAS (Traffic Collision Avoidance System) systems and/or ATC systems.

AirMap

Described software designed to aid drone operators and manned aircraft in being aware of the other's presence in airspace.

Empire Unmanned

Described several general uses of sUAS.

SRC Inc.

Described a ground-based DAA system.

Accelerated Development & Support (ADS)

Proposed to do the research this program is intended to do – collect use cases, evaluate DAA technologies (both onboard and ground-based), etc.

The more detailed responses for the above are provided below.

Stinger Ghaffarain Technologies (SGT) provides a proposed ground-based detect and avoid (GBDAA) technology. They propose a use for this technology in rural areas with no sources of electromagnetic interference with the operating frequencies. There may be other obstacles present in these cases when they do not interfere with the GBDAA systems, however. One or more ground-based radar units could be paired with one or more Automatic Dependent Surveillance-Broadcast (ADS-B) ground receivers (and supporting equipment, such as antennae, power sources, etc.), The data from the sensors display a visual depiction of the airspace state, with varying levels of integration of the sensed data. They do not quantify how much time is sufficient for completing an avoidance maneuver, and assume that this will be supplied or determined externally. Examples of maneuvers include: Abort and return to base, Divert and loiter (descend/ascend to a safe altitude and loiter at that location until otherwise commanded), Divert and land (suspend current flight plan, followed by a descent at the maximum descent rate from wherever located), Land immediately, Terminate into an uncontrolled drop.

SGT also proposed a concept of operations (not an actual use case) for use in Class G airspace. In addition to detection technology and avoidance maneuvers, SGT proposes crew and procedures involving:

Supporting logic for decision-making, which can be automatic, procedural, or experience-based; Possibly one or more visual observers (VOs), to provide supplementary surveillance in the radar cone of silence; A suite of conflict resolution and avoidance procedures/maneuvers, issued under the direction of a single safety authority charged with safety-related decision making and establishment of contingency procedures to address emergencies arising from a compromise of the GBDAA system; Supporting crew members, with the appropriate procedures, suitably trained and equipped to operate the system.

SoHaR Incorporated provided a proposed self-sensing error process for flight platforms. The self-sensing process attempts to determine the discrepancy between a location that a pilot (or pre-planned flight plan) is trying to place the platform, and the actual location of the platform itself. This proposed technology can do this whether the error is caused by hardware, software, or the environment. The proposed system detects any error between the intended status of the platform by the PIC and the actual status of the platform itself, and directs the platform to its intended location. No avoidant methods are discussed. The intended process is to bring the output from the platform into agreement with the command from the PIC. This is accomplished by feeding back a representation of the output and subtracting it from the command. The difference between the two is the error signal that is used by the process to bring the output into closer agreement with the command. Deterioration, such as friction of an output element, will cause an increase in its value. Monitoring of the error signal can provide information about: overall health, type of anomaly (can distinguish between friction, backlash, or electronic causes), and prognostics.

Gryphon Sensors provided information on theoretical GBDAA technology, the costs and benefits of that technology, and some details on the TRL9—a GBDAA sensor which can detect a DJI Phantom-sized obstacle from 6-8.5 km away, and small manned aircraft from 15-20 km away. It is capable of detecting hundreds of targets simultaneously and presents the information to the PIC in a Common Ethernet interface with customizable output. No avoidant methods are discussed, however the information on the benefits and drawbacks of GBDAA technology, such as a smaller range for low-flying aircraft, an ability to track multiple platforms at a time (thus reducing cost), a reduced operating weight for the platform, and its inappropriateness for long endurance flights are provided.

Harris Corporation provided general information on its DAA systems. They synthesize real-time, FAA derived ADS-B data (en-route and terminal secondary surveillance radars, airport surface detection equipment-X band, Wide Area Multilateration, and flight plan data) to feed their Symphony line of platforms. With the given information provided for their Symphony line, their RangeVue system easily incorporates additional surveillance sources, including third-party inputs; it conducts centralized DAA processing based on available input sources and trajectory predictions, and issues alerts, warning, and maneuver guidance to the PIC.

The response from Thales Defense & Security described a ground-based, passive detection system – essentially a cloud of multiple ground-based sensors that are able to detect in 3D the locations of multiple aircraft, then feed that information into larger aircraft TCAS systems and/or ATC systems.

The response from AirMap described software designed to aid drone operators and manned aircraft in being aware of the other’s presence in airspace. The software appears to alert UAS users of near-proximity manned aircraft through the use of flight tracking via Four-dimensional flight tacking, calculated from a UAS user or FAA-filed flight plan (no active tracking).

The response from Empire Unmanned described several general uses of sUAS. Five cases utilize a fixed-wing aircraft. These cases use the SenseFly eBee Ag. The first case was to collect images of fields for farmers to improve their practices. The second case was to help mining operations calculate volumes of gravel piles, map terrain, and survey. The third case was to survey engineering installations. The fourth case is to collect spectrally-filtered images to identify aquatic plants. The fifth case was to collect images to aid a sawmill in calculating log stockpiles. These use cases all used a combination of elongated serpentine and cross-pattern flight patterns.

Two additional cases each used the DJI Phantom 2. The first case was used for post-fire damage assessment of a forest fire. The second case was for video collection of real estate for commercial promotion. The response notes in particular this case was primarily reserved for large, secluded estates due to the rule of 500' separation from non-participants. Neither of these cases used a particular flight pattern – both were flown as necessary.

The response from SRC Inc. described a ground-based DAA system. The system looks at multiple "shells" of airspace (operational volume, where the UAS can be; Declarational volume, encompassing the operational volume and the edges of where the operator should be advised of another aircraft's presence; and site surveillance volume, which encompasses the two smaller levels and is far larger than either). Using a variety of sensors, the system detects and classifies the UAS and other aircraft, alerting the UAS operator as necessary and recommending a course of action to ensure all aircraft maintain safety.

The response from Accelerated Development & Support (ADS) proposed to do the research this program is intended to do – collect use cases, evaluate DAA technologies (both onboard and ground-based), etc.

2.1.6 Summary

The NMSU ASSURE team has gathered a database of general use cases from a Fed Biz Ops RFI, as well as an investigation of 333 exemption requests. Personalized requests for more detailed information have been written, and have been sent to 333 exemption holders.

2.1.6.1 sUAS RLOS Limitation Assessment

Within the individual example use cases provided in the individual 333 exemptions that were investigated, very few instances are given where a sUAS platform's capabilities outside of the guidelines given for a 333 exemption are discussed. Ranges that are listed in the database are typically limitations given by the manufacturer. In the manufacturers' given specifications of their platforms, it is not always apparent what the limiting factor is in the platforms' range (e.g. power limitations or communications limitations). However, in the instances where the effective distance in which the controller and sensors can communicate was given, a range of to 500 m to 50 km was provided. Most of these cases can be placed into one of two categories: (1) those where the platform's controller can only effectively communicate up to 1 km; and (2) those where the platform's controller is listed as being capable of effective communication up to 5 km (usually with an explanation that this maintains FCC compliance). In certain uses, manufacturers mention that the range can be extended through the use of relays.

2.1.6.2 sUAS RLOS Boundary Recommendation

These range limitations vary widely (ranging from 59 m to 265 km dependent on the platform). It is not apparent from most of the descriptions listed in the 333 exemption applications when or how often the sUAS platforms are being used to their full range (or close to it), just as it is not immediately apparent what measures are being used to extend a platform's range to the farthest distances from the operator. As with the RLOS Limitation Assessment, most individual applications for 333 exemptions list ranges that fall into one of two categories: (1) those where the platform's controller can only effectively communicate up to 1 km; and (2) those where the platform's controller is listed as being capable of effective communication up to 5 km.

2.1.6.3 sUAS Use Case Data Collection/Analysis

164 unique, specific use cases were identified out of the applications for 333 exemptions investigated. These specific and unique use cases were grouped into 16 general use case categories. These categories included the following:

- Aerial Data Collection
- Aerial Photography/Videography
- Aerial Surveying/Mapping
- Agriculture
- Delivery
- Emergency Services
- Flight Training
- Inspection/Maintenance
- Marketing
- Multiple Applications
- Real Estate
- Research
- Search/Rescue
- Surveillance/Monitoring, etc.
- Training/Education
- Utility

2.2 Radio Line Of Sight (RLOS)

2.2.1 Test Plan

2.2.1.1 Introduction

A radio line-of-sight (RLOS) range that may be achieved in applications of small unmanned aircraft systems (sUAS) was developed. Propagation is modeled using the well-respected Longley-Rice Irregular Terrain Model (Longley and Rice 1968), which was developed by the U.S. Department of Commerce in 1968. The test plan will address data collection in a test setting to validate the developed model.

This test plan will evaluate and analyze the variances between the Longley-Rice model with terrain, Longley-Rice model without terr1ain, and field truth measurements in a real-world setting. A simplified model without terrain would be more easily incorporated into an operator's safety guideline as safe operational distances could be incorporated into aeronautical charts and tables rather than requiring field access to a complex computer model. The intent of this test plan is to determine if this concept of simplified, table-based flight safety criteria, would be a valid option in the development of safety regulations and guidance for sUAS operations.

A number of factors affect the modeled RLOS range, including the following:

- Terrain
- Weather
- Frequency in use
- Antenna gains at the ground station and the aircraft
- Transmitter power
- Receiver sensitivity

RLOS operation of small unmanned aircraft systems (sUAS) seems practical over distances of a few miles in mountainous terrain, and up to greater than 50 miles over flat terrain. The greatest ranges are achieved when using a high-gain antenna at the ground control station, but this may require actively steering the antenna to track the UAS in flight.

Popular radio frequencies for the control link include the 433 and 900 MHz as well as 2.4 GHz bands, where both licensed and unlicensed operations are possible. Achieving the benefits offered by a high-gain directional antenna, however, will usually require the operator to be licensed by the Federal Communications Commission (FCC) and to use a frequency outside the unlicensed Industrial, Scientific, and Medical (ISM) bands.

2.2.1.2 Model Assumption

The test plan will address aspects of the model in a real-world setting.

2.2.1.2.1 Line of Sight Radio Propagation

Line-of-sight radio propagation can be modeled in four regimes, of increasing range:

- Free space, where the range is so short that only the direct path from the transmitter to the receiver is important.
- Two-ray, which extends beyond the free space regime to the geometric horizon. In this large range, the received signal is modeled as a direct ray plus a ray reflected from the terrain.
- Diffraction, which models radio energy that is diffracted by the terrain for some distance over the horizon.
- Scattering, which extends beyond the diffraction range.

The RLOS range limit for sUAS applications typically will fall in the two-ray or the diffraction regime, depending on the characteristics of the radios and the terrain.

2.2.1.2.1.1 Geometric Line of Sight

The first step in bounding the RLOS range for sUAS is to determine the horizon distance. This is the range beyond which diffraction becomes important. The situation is illustrated in Fig. 6.

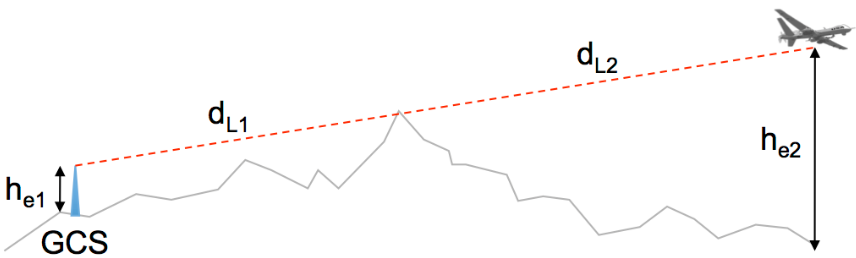


Figure 6. Horizon distance over irregular terrain.

Here, h_{e1} is the elevation of the antenna at the Ground Control Station (GCS), h_{e2} is the altitude of the UAS, and d_{L1} and d_{L2} are the distances from each to the highest point of the intervening terrain. The geometric LOS (Line of Sight) range is $d_L = d_{L1} + d_{L2}$. From the figure, it is clear that if the UAS flies beyond this range (at altitude h_{e2}) it will lose the direct radio path and enter the diffraction regime.

Mathematically, we can express the geometric line-of-sight range d_L in terms of the antenna heights, the effective Earth radius[1] a, and a terrain roughness factor Δh, as in the Longley-Rice model (Table 10).

[1] To accommodate the refractive index gradient near the Earth's surface, a value of 4/3 the Earth's actual radius is commonly used: a = 8497 km.

Table 10. Terrain roughness factor as in the Longley-Rice model.

Type of Terrain	**Δh in m**
Watery or very smooth plains	0 - 5
Smooth plains	5 - 20
Slightly rolling plains	20 - 40
Rolling plains	40 - 80
Hills	80 - 150
Mountains	150 - 300
Rugged mountains	300 - 700
Extremely rugged mountains	> 700

The horizon distances over a *smooth* surface are then

$$d_{Ls1,2} = \sqrt{0.002 \;\; a \;\; h_{e1,2}} \tag{1}$$

from which the horizon distances over irregular terrain are computed:

$$d_{L1,2} = d_{Ls1,2}\, e^{-0.07\sqrt{\Delta h / h_e}}. \tag{2}$$

Antenna heights in these formulas are in meters, and distances are in kilometers. Figure 7 shows several cases of geometric range with a GCS antenna height of 2 m.

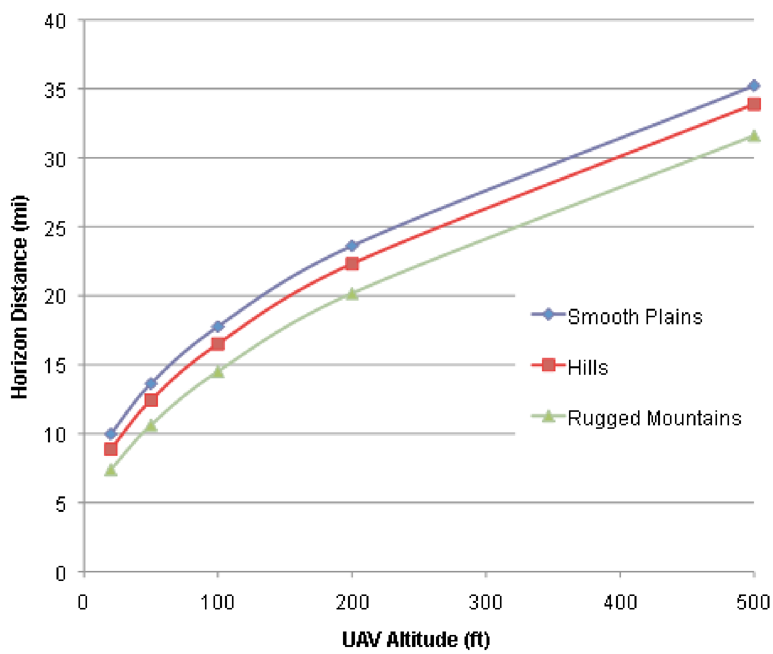


Figure 7. Geometric horizon distance for GCS antenna at 2 m.

2.2.1.2.1.2 Radio Line of Sight

Actual RLOS range may be greater (or less) than the geometric line-of-sight (horizon) distance, depending on where the radio signal becomes too weak. Pertinent radio characteristics include

- Antenna gains at the GCS and UAS
- Transmitter power
- Receiver sensitivity
- Frequency in use

A number of online calculators are available that incorporate the Longley-Rice model, terrain databases, and user entries for the radio characteristics to produce detailed coverage maps. One such online calculator is offered by the Canadian Communications Research Centre (CRC) at http://lrcov.crc.ca/main/. An example output of such a calculator is shown in Fig. 8.

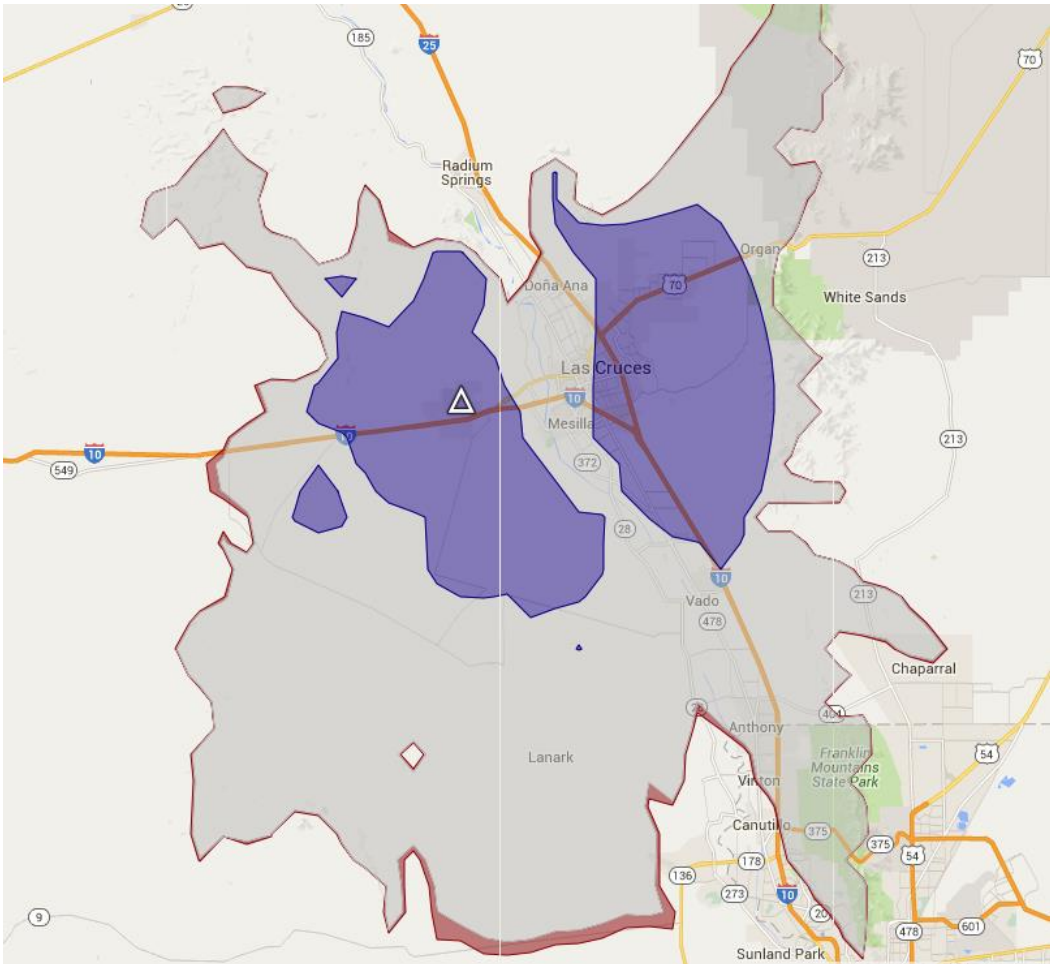


Figure 8. Example RLOS coverage map (GCS at Las Cruces Airport). The red contour surrounding the gray regions shows the RLOS range limits for one possible suite of radio equipment.

While this level of detail may be useful locally, a general formulation of RLOS range in terms of Δh, UAS altitude, and radio specifications is required for the model.

2.2.1.2.2 Application to sUAS

The Longley-Rice report (1968) includes methods for estimating signal loss over radio paths using either detailed knowledge of the terrain (as in Fig. 8) or more generically using a terrain roughness factor Δh. If the latter approach is combined with the characteristics of example radio equipment, generic estimates of RLOS ranges over various types of terrain can be produced.

2.2.1.2.2.1 Typical sUAS Radio Specifications

Common operating frequencies for sUAS are the 433 and 900 MHz bands, as well as 2.4 GHz, with 900 MHz especially common. The Industrial, Scientific, and Medical (ISM) bands at 900 MHz and 2.4 GHz offer the possibility of unlicensed operation:

- The ScanEagle sUAS (Wilke 2007) is reported to have an effective RLOS range of 50-100 km (30-60 miles) at 2000 feet altitude, when using a 900 MHz control link and a 1.8 m dish antenna (Fig. 9).
- An example 900 MHz industrial radio (Freewave Technologies 2014) offers a power output up to 1 W (30 dBm, the FCC limit), a receive sensitivity of -108 dBm, and a link range of up to 60 miles.
- 900 MHz antennas for the GCS are available with a range of antenna gains. For example, a GNS Wireless HG918G-NF dish has 18 dBi gain (16.5° vertical/horizontal beam width), while Laird OD9 series antennas offer omnidirectional gains of 5, 6, 8, and 11 dBi.

The antenna on a sUAS is expected to be approximately omnidirectional with a gain of -2 dBi.

Figure 9. Example dish antenna about 2 m above ground.

2.2.1.2.2.2 Weather Effects

Weather affects LOS radio links in two ways:

- Moisture in the atmosphere (snow, rain, or fog) and on vegetation can absorb radio frequency energy, especially around 2.4 GHz. Lower frequencies experience less loss.
- Wind does not affect the radio signal directly but can move or twist antennas. This can move the beam of a highly directional (high-gain) antenna, resulting in a fluctuating received signal level. Another effect in arid areas is a build-up of static electricity on antennas due to wind-blown dust and sand. In extreme cases, this can damage a sensitive radio receiver.

The designers of LOS radio links usually compensate for weather effects by building in a "fade margin" (i.e., raising the needed signal strength at the receiver by, for example, 15 dB).

2.2.1.2.2.3 Expected RLOS Ranges with 900 MHz Radios

Using these examples, sUAS radio specifications and a fade margin are used to compute the allowed loss of signal strength over a RLOS path. From this, the Longley-Rice model can be used to find the RLOS range limit. Radio ranges can be evaluated using both a high-gain and an omnidirectional (omni) antenna. A 6 dBi omnidirectional antenna was chosen to yield 36 dBm EIRP (Equivalent Isotropically Radiated Power), the maximum allowed by the FCC for unlicensed operation in the 900 MHz band. The link budgets are shown in Table 11.

Table 11. Link budgets for high-gain and omni-directional antennas.

	High-Gain	Omni
Transmit power	30 dBm	30 dBm
Transmit antenna gain	18 dBi	6 dBi
Receiver antenna gain	-2 dBi	-2 dBi
Receiver sensitivity	-108 dBm	-108 dBm
Fade margin	15 dB	15 dB
Allowed path loss	139 dB	127 dB

RLOS range limits for high-gain and omnidirectional GCS antennas at a height of 2 m are shown in Figs. 10 and 11, respectively, as a function of sUAS operating altitude (numerical results plotted in the following graphs are included in the Section 2.2.1.2.5). sUAS operating altitudes in all of the figures that follow are altitudes above the nominal overflight terrain (ground surface – reference h_{e2} in Fig. 6).

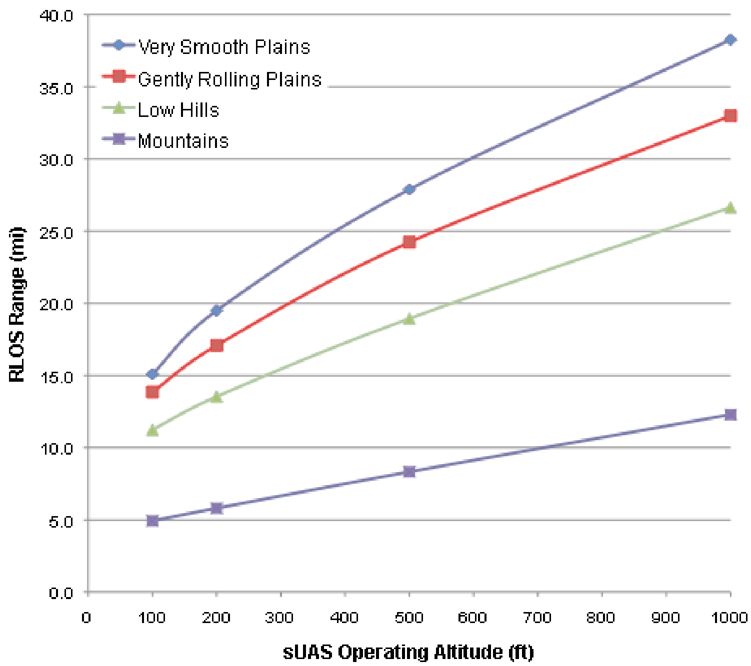


Figure 10. RLOS range for 900 MHz system, high-gain dish antenna 2 m above ground.

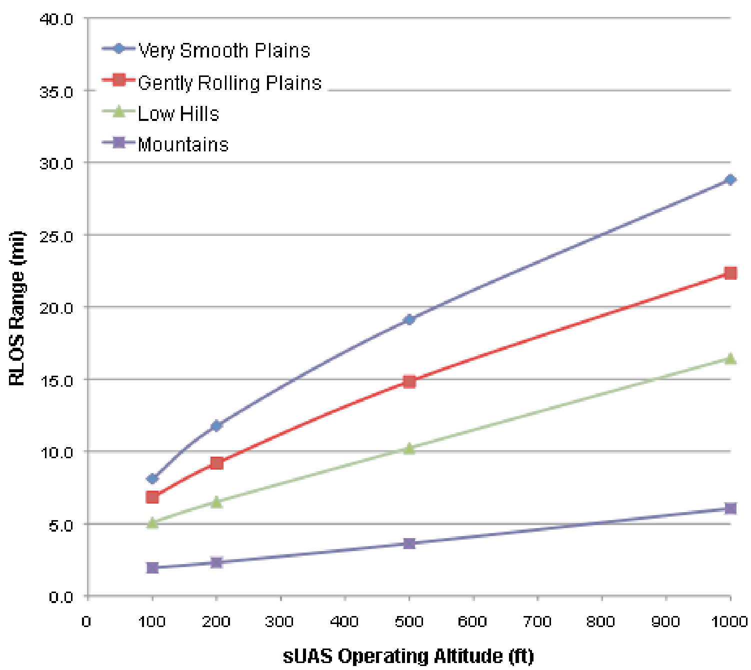


Figure 11. RLOS range for 900 MHz system, 6 dBi omni antenna 2 m above ground.

The RLOS range depends strongly on the terrain. If RLOS range is plotted versus terrain roughness at the two altitudes of interest (500 and 1000 feet above ground/nominal terrain – reference h_{e2} in Fig. 6), the results in Figs. 12 and 13 are obtained.

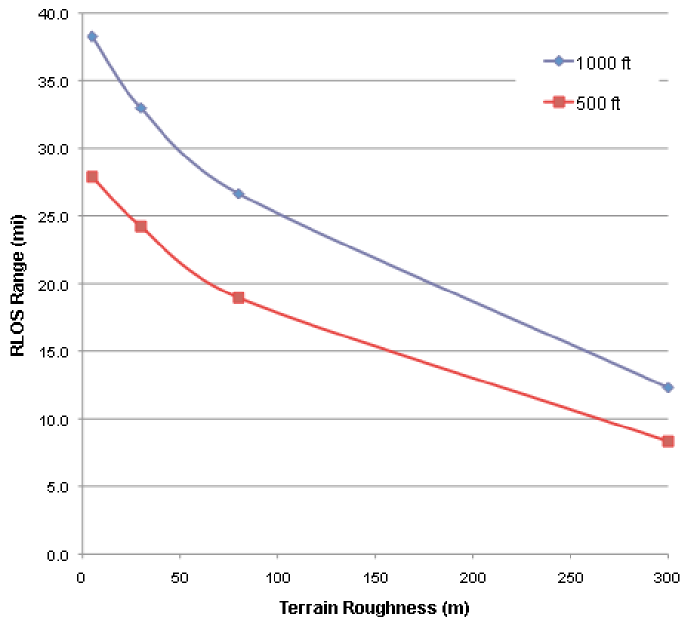


Figure 12. 900 MHz RLOS range *vs* terrain, high-gain dish antenna 2 m above ground.

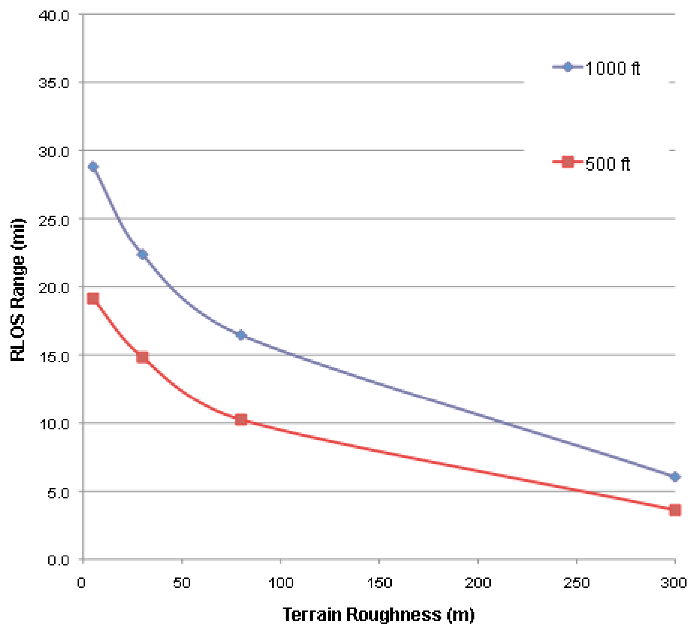


Figure 13. 900 MHz RLOS range *vs* terrain, 6 dBi omni antenna 2 m above ground.

Next, two alternatives to the baseline GCS setup are evaluated. First, an operator seeking extended range might mount a dish antenna on a 5 m tower. The resulting range is compared to the 2 m case in Fig. 14, for aircraft altitudes of 500 and 1000 feet above ground/nominal terrain (reference he2 in Fig. 6).

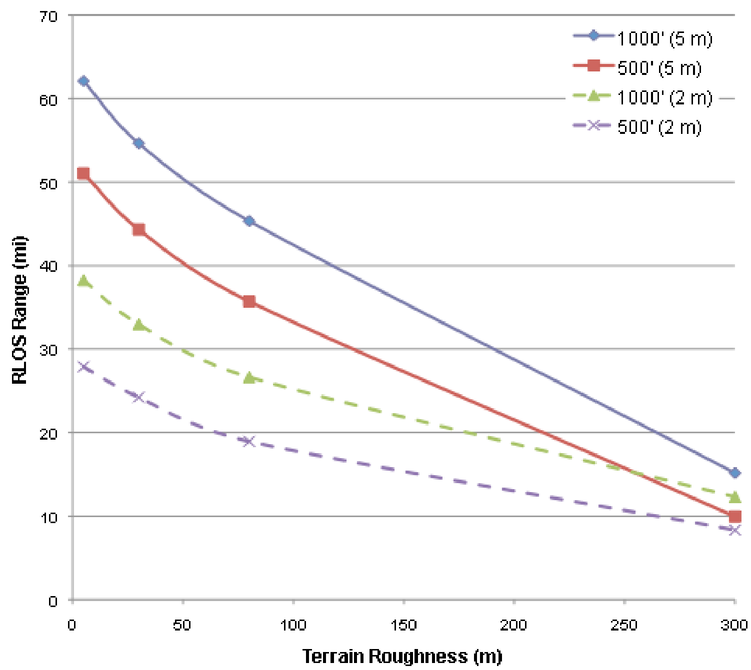


Figure 14. 900 MHz RLOS range, high-gain dish antenna at 5 m *vs* 2 m.

A second alternative is a handheld controller with a 3 dBi whip antenna at 1 m above the ground, which is compared in Fig. 15 to the 6 dBi omni at a height of 2 m.

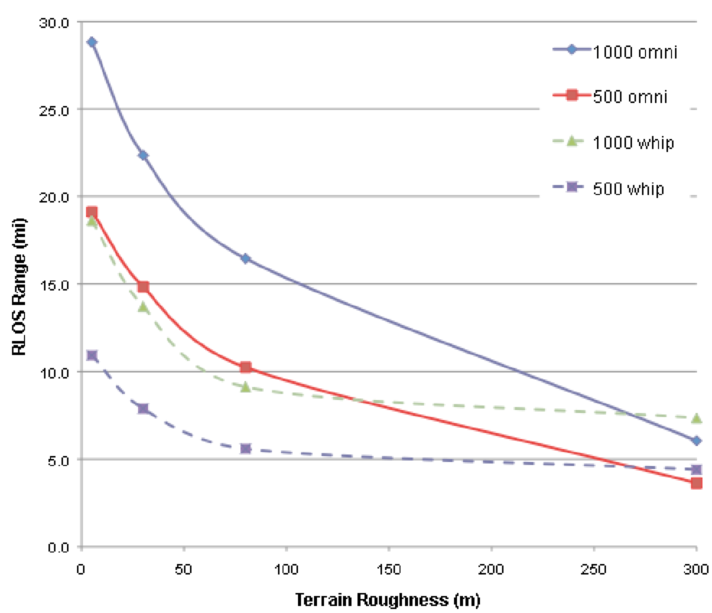


Figure 15. 900 MHz RLOS range, 6 dBi omni antenna 2 m above ground *vs* 3 dBi whip antenna 1 m above ground.

2.2.1.2.2.4 Expected RLOS Ranges with 2.4 GHz Radios

If the same radio specifications and fade margin as above are used, but with 2.4 GHz radios, the RLOS ranges shown in Figs. 16 and 17 are obtained (altitudes above ground/nominal terrain – reference he2 in Fig. 6).

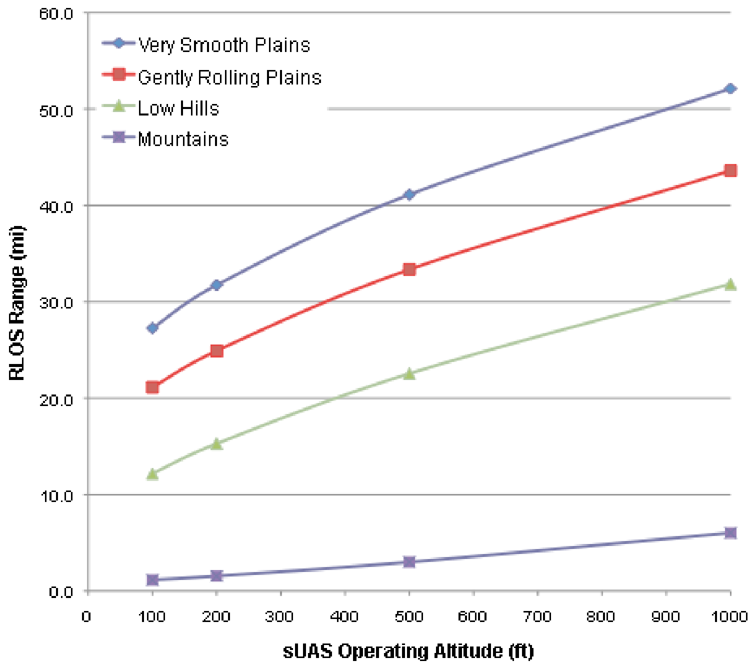


Figure 16. RLOS range for 2.4 GHz system, high-gain dish antenna, 2 m above ground.

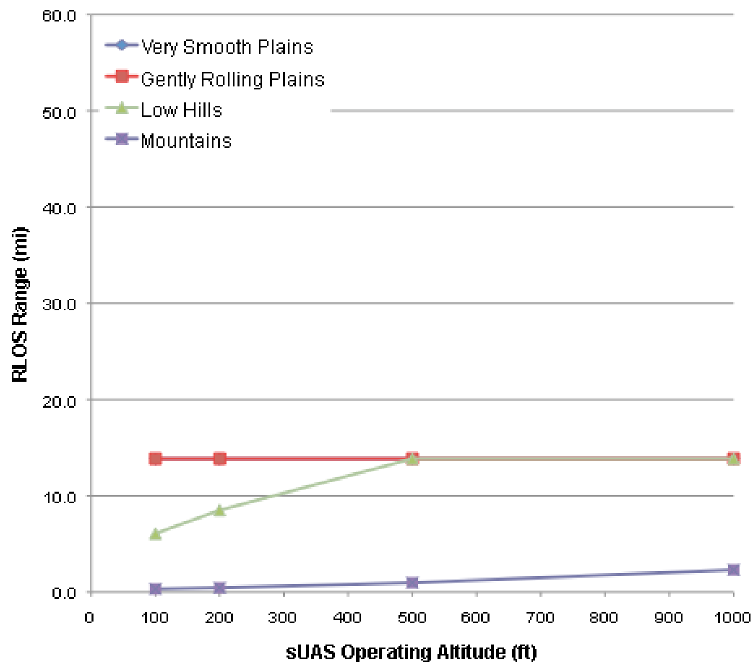


Figure 17. RLOS range for 2.4 GHz system, 6 dBi omni antenna, 2 m above ground.

In Fig. 17, the 2.4 GHz RLOS range using a 6 dBi omni antenna is limited in most cases by free-space losses, not by the terrain or UAS altitude. The free-space range limit is 22.3 km or 13.8 miles.

2.2.1.2.3 Discussion

When a directional antenna (18 dBi) is used, 2.4 GHz offers greater RLOS range except in the most rugged terrain, as shown in Fig. 18. Furthermore, directional antennas are smaller at higher frequencies, and are therefore subject to less wind loading. Thus, higher frequencies are expected to be popular in benign terrain, especially for operators using licensed bands where directional antennas may be used without a requirement to reduce transmitter power.

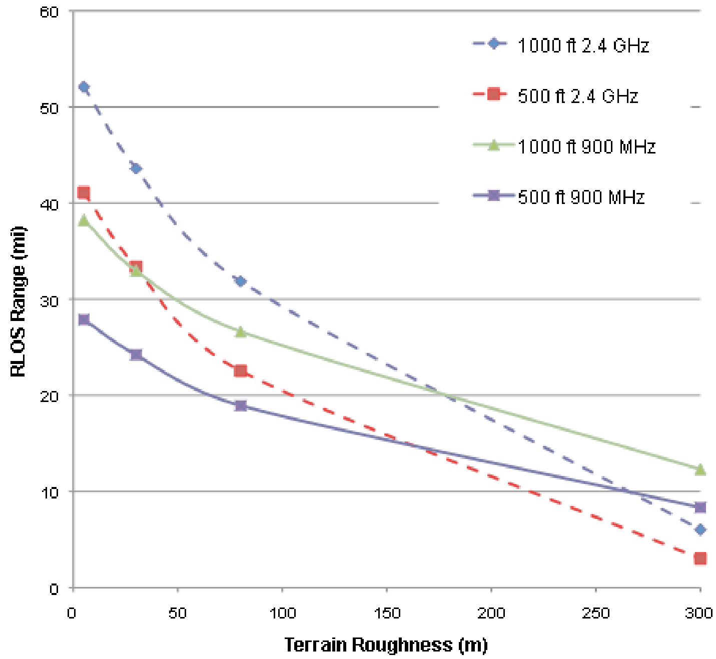


Figure 18. RLOS range for 900 MHz and 2.4 GHz systems, 18 dBi GCS antenna, 2 m above ground.

The use of directional antennas, however, may be operationally challenging, especially at high gains, due to the need to point the antenna precisely at the aircraft, and to track it as it flies. This may not be too difficult when a sUAS is used for inspection of linear infrastructure, but for applications involving flight over wide areas, operators may prefer the simplicity of an omni antenna.

2.2.1.2.4 RLOS Model Conclusions

RLOS operation of sUAS seems practical over distances of a few miles in mountainous terrain, and up to more than 50 miles over flat terrain. The greatest ranges are achieved when using a high-gain antenna at the ground control station, but this may require actively steering the antenna to track the sUAS in flight.

2.2.1.2.5 Numerical Results

The numerical results plotted in Figs. 10 through 18 for the model are in Tables 12-17. Altitudes shown are in feet above ground/nominal terrain (reference he2 in Fig. 6).

Table 12. 18 dBi dish antenna, 2 m above ground for 900 MHz systems.

Altitude (ft)	Very Smooth Plains Δh = 5 m	Gently Rolling Plains 30 m	Low Hills 80 m	Mountains 300 m
100	15.1	13.8	11.2	4.9
200	19.5	17.1	13.5	5.8
500	27.9	24.2	18.9	8.3
1000	38.3	33.0	26.6	12.3
2000	53.3	46.6	38.4	19.7

Table 13. 6 dBi omni antenna, 2 m above ground for 900 MHz systems.

Altitude (ft)	Δh = 5 m	30 m	80 m	300 m
100	8.1	6.8	5.1	1.9
200	11.8	9.2	6.5	2.3
500	19.1	14.8	10.2	3.6
1000	28.8	22.4	16.5	6.1
2000	36.6	35.0	26.6	11.4

Table 14. 18 dBi dish antenna, 5 m above ground for 900 Mhz systems.

Altitude (ft)	Δh = 5 m	30 m	80 m	300 m
100	37.4	32.4	24.8	5.3
200	41.9	36.1	28.2	6.6
500	51.0	44.3	35.7	9.9
1000	62.1	54.6	45.3	15.2
2000	78.0	69.9	60.0	24.7

Table 15. 3 dBi whip antenna, 1 m above ground for 900 Mhz systems.

Altitude (ft)	Δh = 5 m	30 m	80 m	300 m
100	4.2	3.2	2.7	2.1
200	5.9	4.6	3.5	2.7
500	10.9	7.9	5.6	4.4
1000	18.6	13.7	9.1	7.4
2000	26.1	23.3	17.1	13.7

Table 16. 18 dBi dish antenna, 2 m above ground for 2.4 GHz systems.

Altitude (ft)	Δh = 5 m	30 m	80 m	300 m
100	27.3	21.1	12.2	1.1
200	31.7	24.9	15.3	1.6
500	41.1	33.3	22.5	3.0
1000	52.1	43.6	31.9	6.0
2000	55.3	55.3	46.3	13.0

Table 17. 6 dBi omni antenna, 2 m above ground for 2.4 GHz systems. Gray shading indicates range limited by free-space attenuation, not terrain or aircraft altitude.

Altitude (ft)	Δh = 5 m	30 m	80 m	300 m
100	13.8	13.8	6.1	0.3
200	13.8	13.8	8.5	0.4
500	13.8	13.8	13.8	1.0
1000	13.8	13.8	13.8	2.3
2000	13.8	13.8	13.8	6.6

2.2.1.3 Chihuahuan Desert Rangeland Research Center

The planned test location for the RLOS model validation (and other sUAS testing) is north of Las Cruces, New Mexico, on the Chihauhuan Desert Ranchland Research Center (CDRRC) (Figs. 19-20). New Mexico State University operates the CDRRC in order to protect and ensure availability of its resources for teaching, research, and extension endeavors that benefit the citizens of New Mexico as originally declared in Congressional Act S4910, 1927.

The CDRRC conducts educational, demonstrative, and experimental development with livestock, grazing methods, and range forage, including investigation of the sustainability and management of natural resources and environmental ecosystems.

The CDRRC is part of NMSU, which is located in Las Cruces, New Mexico. It is a major source of arid lands research in the Department of Animal and Range Sciences, which is part of the College of Agricultural, Consumer, and Environmental Sciences. Established in 1927 to conduct "educational, demonstrative, and experimental development with livestock, grazing methods, and range forage," the CDRRC is administered by the NMSU Board of Regents.

The Center is located in Doña Ana County, New Mexico, at the southern end of the Jornada Plain. Now divided by Interstate 25, the Center encompasses almost 100 square miles, with one-fourth of the land west of the interstate.

Land on the Center varies widely, with elevations from 4,000 ft on the Rio Grande flood plain on the west side to 5,840 ft at the top of Summerford Mountain in the Doña Ana Mountains on the east side. The nearly level plains of the north and central parts of the Center are on the Jornada del Muerto basin, with several small playa areas where water collects after rainfall. Soils range from sandy loams to clays overlying caliche hardpan.
Several vegetation types occur on the center. Creosote bush dominates the upper slopes of the mountains and the hills along the river. At lower elevations, the creosote bush type grades into the mesquite type that grows on sandier soils, and into the tarbush type on heavier soils. The plains area, once dominated by black grama, today has been invaded by mesquite. These mesquite stands are interspersed with snakeweed and many species of grasses and forbs.

Wildlife populations on the Center are rich and varied. Among the larger mammals are mule deer, pronghorn antelope, gemsbok, bobcat, coyote, badger, and fox. Mountain lions have been sighted. There are also many rabbit and rodent species. Several bird species migrate throughout the area, but a large number also live and nest on the rangeland. Species such as roadrunners, hawks, and occasionally golden eagles are seen on the Center. Numerous lizard and snake species also inhabit these lands.

Teachers, researchers, and students from across the NMSU campus benefit from the center. The Department of Animal and Range Sciences oversees the facility with help from a steering committee of scientists from the College of Agriculture, Consumer, and Environmental Sciences and the College of Arts and Sciences. Through the Biology Department, the center is part of the Jornada Basin Long-Term Ecological Research project—a National Science Foundation Ecology Network. Current research efforts include:

- Evaluating continuous and seasonal grazing strategies at different intensities to determine effects on livestock performance as well as plant cover and composition.
- Evaluating performance of breeds of cattle in relation to quality and quantity of forage in a hot, arid environment.

- Determining the influence of range conditions on wildlife populations.
- Autecology of plant species.
- Assessing competition and other interactions between common plant species.
- Ascertaining the role of small herbivores in a desert environment.

In addition to research conducted by the Department of Animal and Range Sciences, faculty and graduate students from other NMSU departments are conducting research at the Center. Currently, much of the research is in conjunction with the Long-Term Ecological Research program, which is part of a nationwide program funded by the National Science Foundation.

The CDRRC is used for teaching, demonstration, and research projects with livestock, grazing methods, and range forage, including investigations into the sustainability and management of natural resources and environmental ecosystems.

Research at the CDRRC includes archaeology, beef cattle management and genetics, desertification, entomology, geology, grazing management hydrology, plant diversity, rangeland resource management, rangeland restoration, soils, watershed management, and wildlife.

Also unique to the CDRRC is former industry-based research facility related to national security. A significant asset for the national security work is represented by a tower that the Raytheon Corporation installed and maintained on the CDRRC. That 100 ft tower is now owned by NMSU and is available for research. The NMSU Physical Sciences Laboratory (PSL) has significant experience in conducting UAS operations at the Jornado Experimental Range that is adjacent to the CDRRC.

The CDRRC was selected as a site for the RLOS research based on a number of factors. The airspace of the CDRRC falls within the NMSU Flight Test Center (Test Site), and the current FAA Certificate of Authorization (COA) also covers this airspace. NMSU/PSL has significant UAS operating experience with a variety of UAS platforms in nearby airspace for low-altitude operations and over this area for higher UAS operations. The terrain within the CDRRC varies from the Summerford Mountain to extended desert plains with no obstacles. The population on the ground consists of a single residence at the Ranch headquarters approximately one mile from the tower, and cattle and wildlife are the only other inhabitants. So, the population density is low. This area also is remote with no paved roads, a few county roads adjacent to significant power transmission lines, and unimproved two-track roads. There is only small acreage at the northern perimeter where the public has access; otherwise, access is controlled. Both RLOS and BVLOS studies and experiments are planned at the CDRRC.

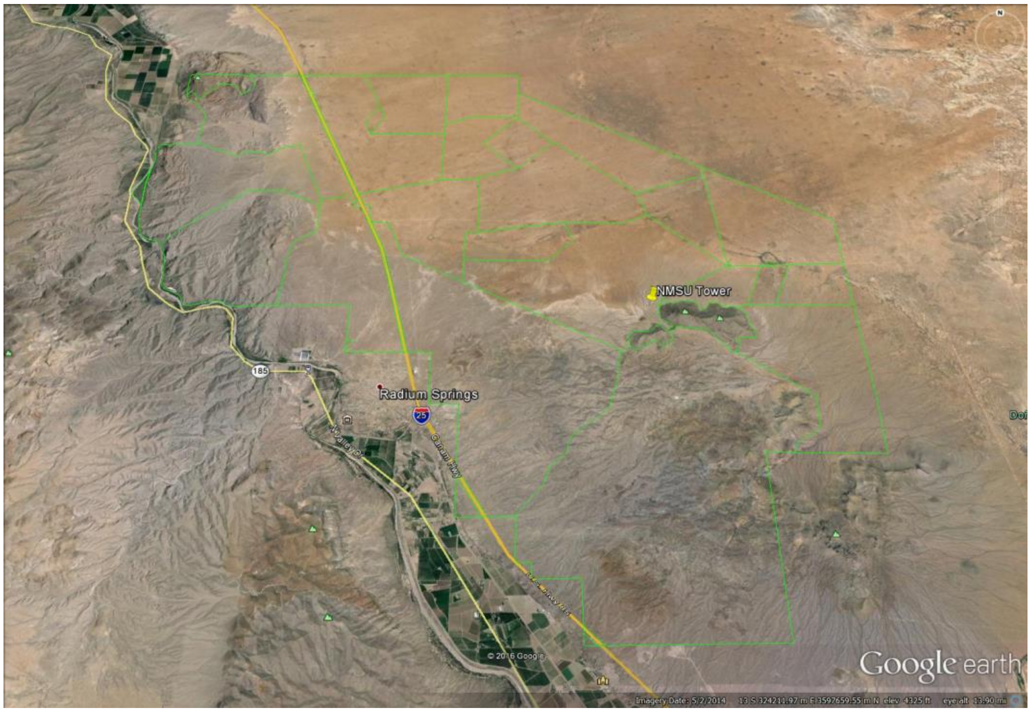


Figure 19. Satellite view of CDRRC.

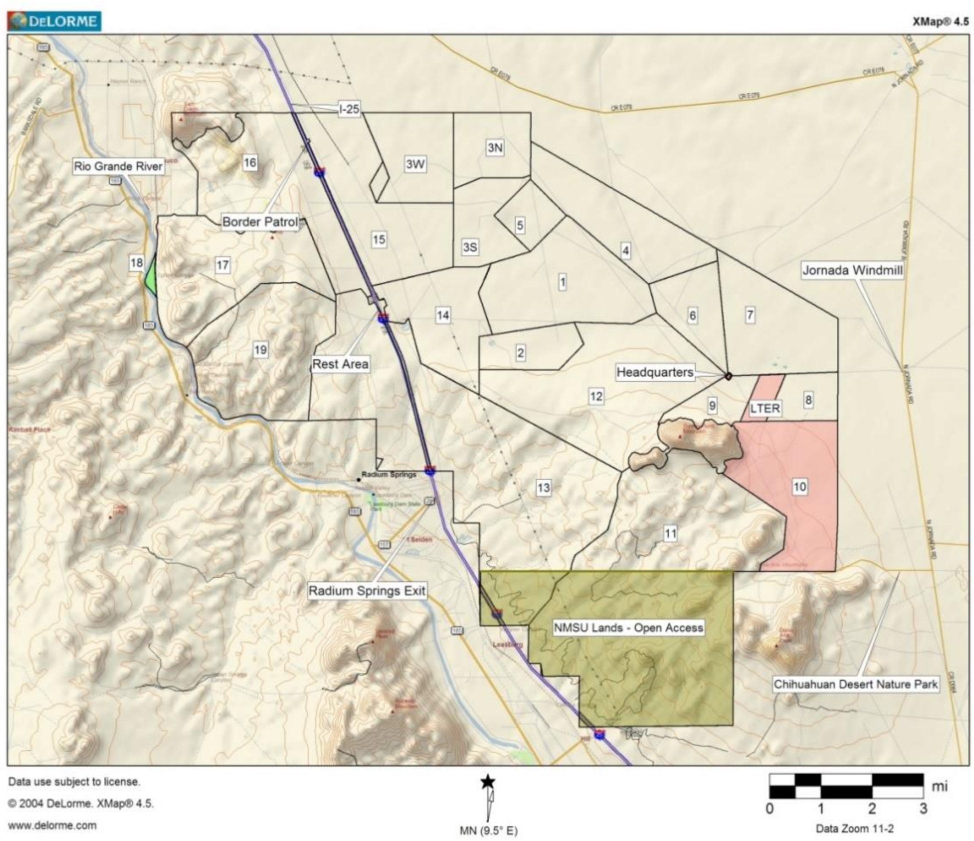


Figure 20. CDRRC Layout by pasture.

2.2.1.3.1 Tower Site Attributes

The Tower Site (previously mentioned) is located approximately one mile from the ranch headquarters. The tower is important for the RLOS data collection. The tower is in a fixed position so that any measurements will be consistent and repeatable. A tethered UAS was considered but winds aloft still would impact the precise location during data collection. A sUAS transmitter will be located at the top of the tower in various orientations as part of the test setup. From the tower location, simulating a UAS operating at 100 ft AGL, access will be available to a variety of GPS fixed locations that also are impacted by some of the geography in the area. Power also is available at the site, and as was previously discussed, there are minimal people on the ground. In addition, most local general aviation flights follow Interstate 10 to the west of the CDRRC.

2.2.1.3.2 Tower Site Location

The tower is situated on the northern slope of Summerford Mountain in the Doña Ana Mountains. Figures 21-22 show the proximity of the tower to Summerford Mountain. Figure 23 depicts a close-up of the top of the tower. Figure 24 shows the tower facing southwest. Figure 25 shows the tower facing east. Figure 26 depicts the solar array and the energy distribution building. Figures 27-29 depict the view facing generally north, northeast, and northwest from the tower.

Figure 21. Proximity of Summerford Mountain to tower.

Figure 22. 100 ft tower showing proximity to Summerford Mountain.

Figure 23. Close-up view of top of the tower.

Figure 24. 100 ft research tower—view is generally southwest.


Figure 25. 100 ft research tower—view is approximately to the east.

Figure 26. Solar array and power distribution building for the tower.

Figure 27. View looking northeast from tower area, flat desert plains.

Figure 28. View looking north from tower area, flat desert plains.

Figure 29. View looking north/northwest from tower area, flat desert plains.

2.2.1.4 RLOS Validation and Verification: Expected Test Measurements

The communications package (and/or the entire airborne platform) from a sUAS will be mounted on the top of the tower. A nonconductive support will maintain a transmitter/sUAS approximately three feet from the tower. Signal strength will be measured between the Ground Control System (GCS) and the sUAS AUT. Free space path loss (FSPL) and Fade Margin calculations at specific test points will be made as a control function. A GCS for the UAS will be operated from various directions at multiple distances to compare field measurement to the Longley Rice propagation model with and without terrain mapping. The battery pack for the communication system on the tower will be in two different states during measurements, fully charged and 50% charged. A comparison of calculated RLOS and measured coverage will be performed to validate the effectiveness of the Longley-Rice models against field measurements when applied to sUAS platforms.

2.2.1.4.1 Phase One: Static Tower Test

The Phase One test will involve the use of the Tower at the CDRRC north of Las Cruces, New Mexico. A sUAS (and/or transmitter) will be mounted at the top of the tower. The GCS for the UAS will be operated at a variety of directions and distances (including plains to the north and mountains to the southeast) from the tower. Using the Longley-Rice propagation model, a calculation will be made for the predicted performance of both a directional (1 watt, 6 dBi gain) and omni antenna (100 mW, 2 dBi gain) operating at 900 MHz. The specific parameters for the propagation model for a representative directional antenna are shown in Fig. 30, and the resulting predicted coverage is shown in Fig. 31. For an omni antenna, the representative parameters are included in Fig. 32, and the resulting predicted coverage is shown in Fig. 33. The altitude for both the antennas is fixed at 100 ft AGL, which is the height of the tower. The model will be modified with the specific antenna and transceiver used in the test prior to the actual field test. The figures shown below are the Longley-Rice propagation model with terrain mapping. Actual testing will include overlaying the Longley-Rice model without terrain mapping so that a comparison of the two models versus field measurement can be performed.

2.2.1.4.1.1 Test Apparatus

A 3-D Robotics Iris sUAS (or similar model) will be utilized (and/or the transmitter alone) as the test platform. The sUAS will be configured so it can be placed in one of four test conditions (facing north, south, east, and west) at the top of the tower. The control station will be activated at multiple test points (including plains to the north and mountains to the southeast) to determine the actual coverage versus predicted.

2.2.1.4.1.2 Data Points

The field measurement for each data point will consist of the signal strength level and a nominal sUAS control function indication assuming the entire airframe is mounted on the tower vs. just a sUAS transmitter. The control function (TBD) will demonstrate actual control and response to a specific flight function such as camera control or control surface change (aileron, flaps, etc.). The control function is a pass/fail type measurement. Since the CDRRC exists in a low humidity environment (range of 8 to 77% relative humidity), when possible, measurements will be conducted for both humidity extremes. Weather conditions (temperature, humidity, and air speed) will be recorded during each test.

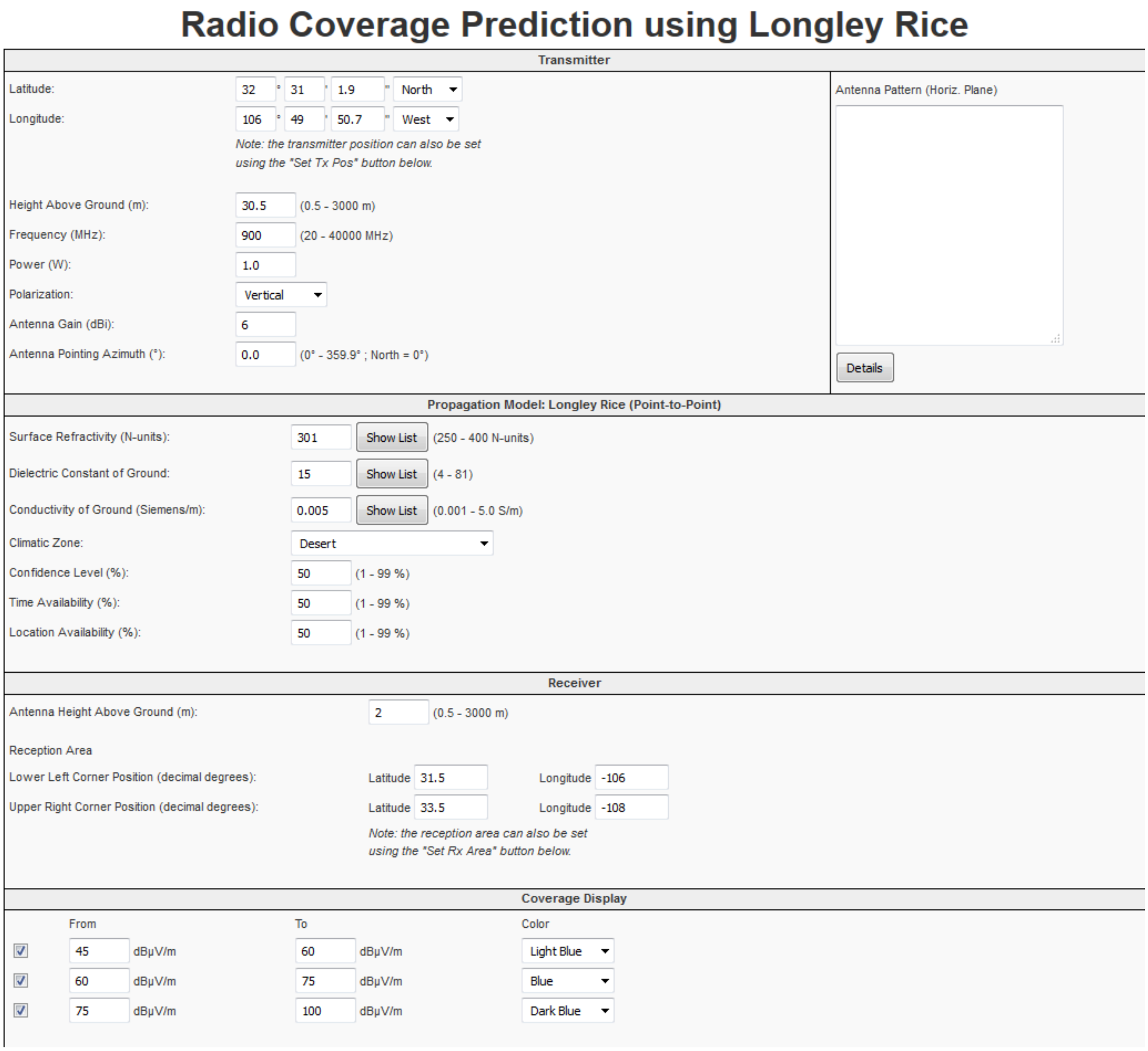


Figure 30. Longley-Rice propagation model 100 ft AGL, directional antenna (1 W, 6 dBi).

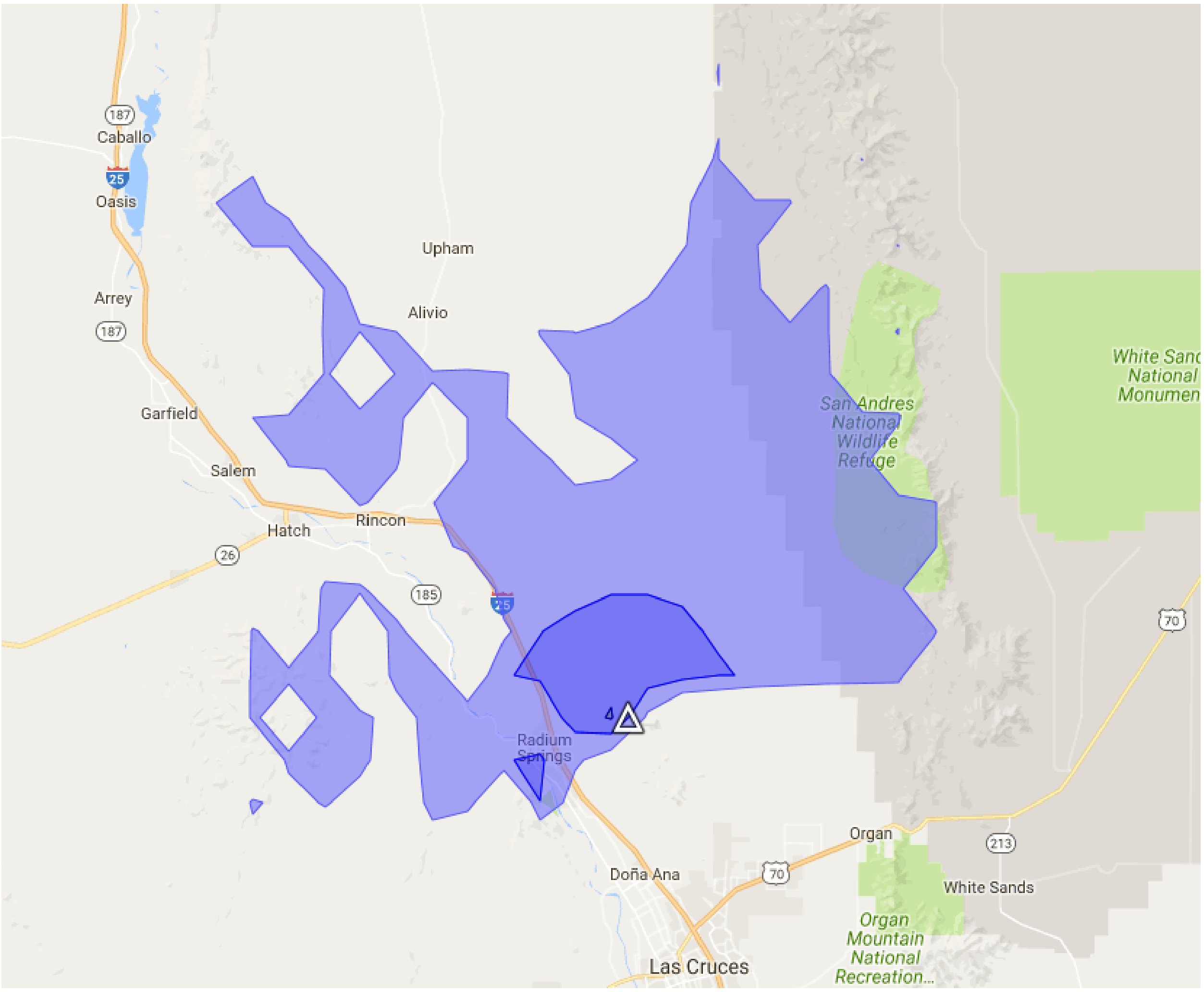


Figure 31. Predicted coverage for directional antenna (1 W, 6 dBi) at 100 ft AGL.

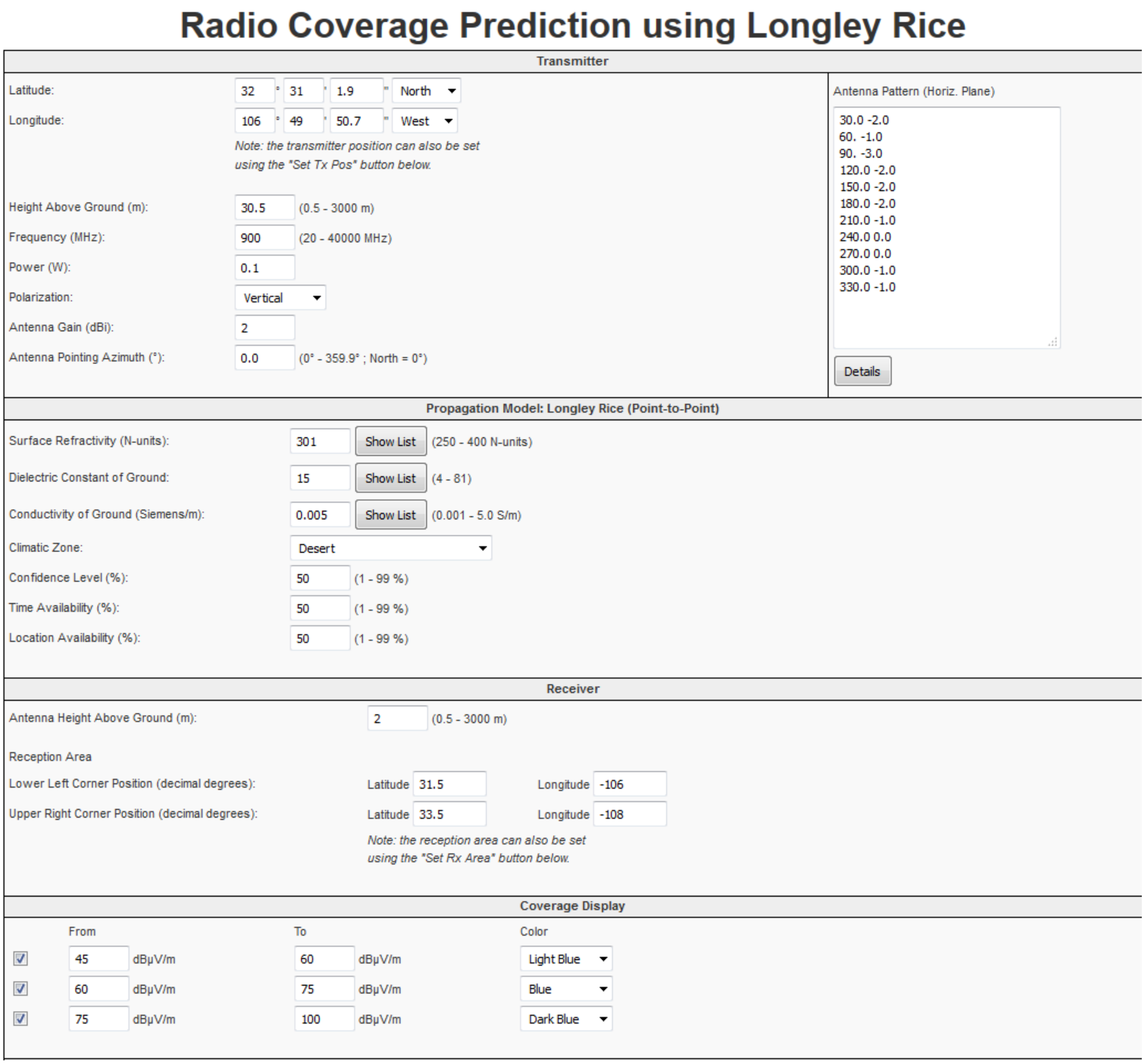


Figure 32. Longley-Rice propagation model 100 ft AGL, omni (100 mW, 2 dBi) antenna.

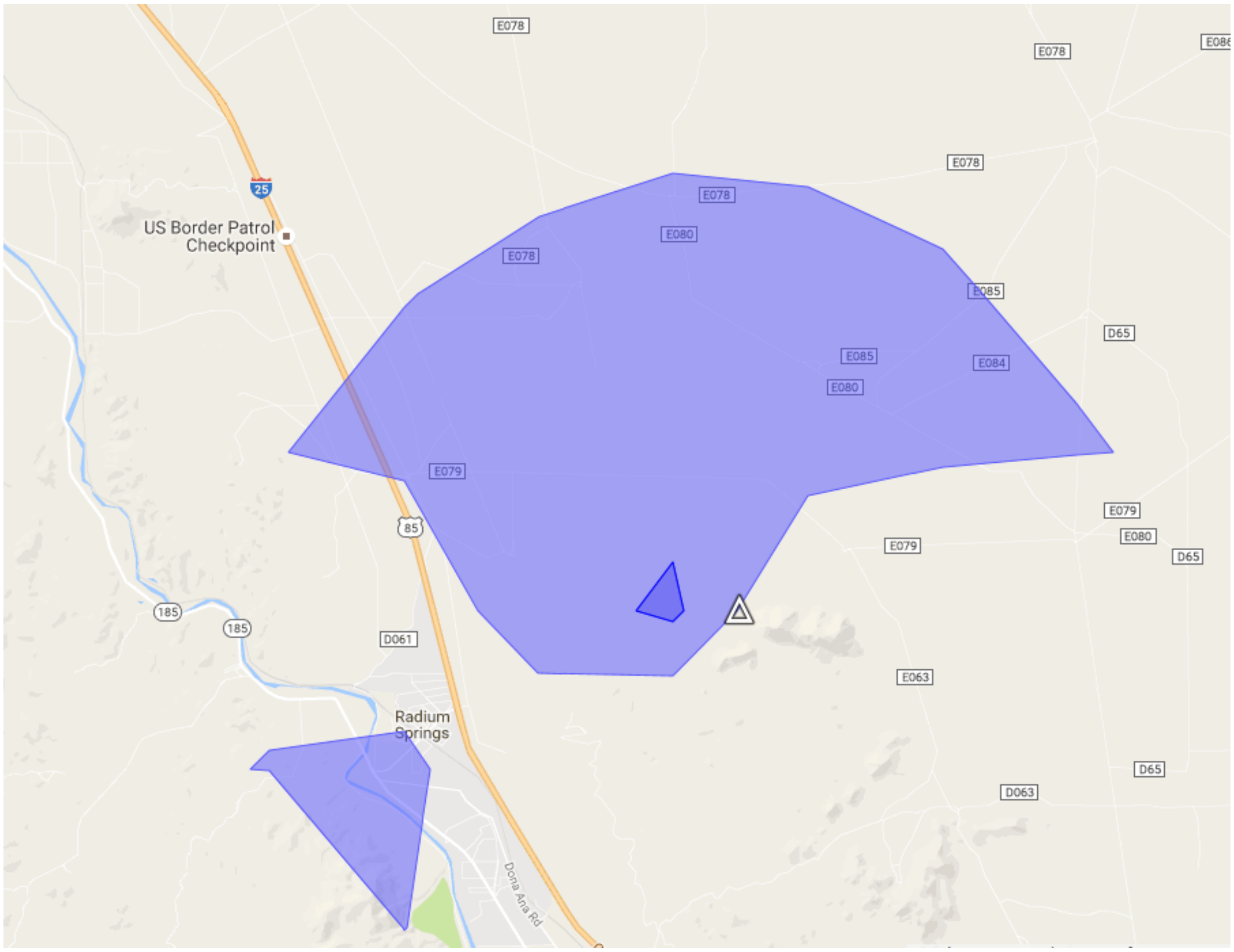


Figure 33. Predicted coverage for directional omni (100 mW, 2 dBi) antenna at 100 ft AGL.

2.2.1.4.1.3 Deliverable

A Test Report will be produced with all the results from Phase One. Environmental conditions also will be included in this report as well as lessons learned that could affect Phase Two activity.

2.2.1.4.2 Phase Two: Dynamic Flight Test

Phase One provides for the opportunity for the collection of a variety of data points that could be used to test the RLOS models. However, these tests are constrained by the overall height of the tower. In order to gather higher altitude test data, Phase Two will include actual UAS flights at three different altitudes with the data collection being taken at various directions (including plains to the north and mountains to the southeast) remote from the tower. Data obtained from the Phase One testing will be used to develop a safety margin for Phase Two testing. Phase Two testing will more closely emulate real flight conditions and various airframe orientations. Battery condition will be charged fully prior to each flight and monitored during flight. Again, utilizing the Longley-Rice propagation model (with terrain), representative calculations were made for the directional and omni antennas at 400, 500 and 1000 ft AGL. The parameters for the directional antenna for the higher altitudes are the same as those shown in Fig. 30 except for the variance in altitude. The predicted coverage for the 400 ft altitude is reflected in Fig. 34. The predicted coverage for the 500 ft altitude is shown in Fig. 35; and 1000 ft in Fig. 36. The parameters for the omni antenna for the 400 ft altitude are shown in Fig. 37, 500 ft in Fig. 38, and the predicted coverage for the

1000 ft altitude is reflected in Fig. 39. Figure 40 shows an overlay of the 100 ft (Phase One) predicted coverage versus the 400 ft (Phase Two) predicted coverage for the omni.

2.2.1.4.2.1 Test Apparatus

A 3-D Robotics Iris sUAS (or similar model) but the same as the Phase One test will be utilized as the test platform. The sUAS will be located near the tower platform in order to minimize any variation of RLOS coverage pattern and distances from Phase One testing.

2.2.1.4.2.2 Data Points

The field measurement for each data point (including plains to the north and mountains to the southeast) will consist of the signal strength level at the GCS and sUAS control function. The control function (TBD) will demonstrate actual control and response to a specific flight function such as camera control or control surface change (aileron, flaps, etc.). The control function is a pass/fail type measurement. Weather conditions (temperature, humidity, and air speed) will be recorded during each test.

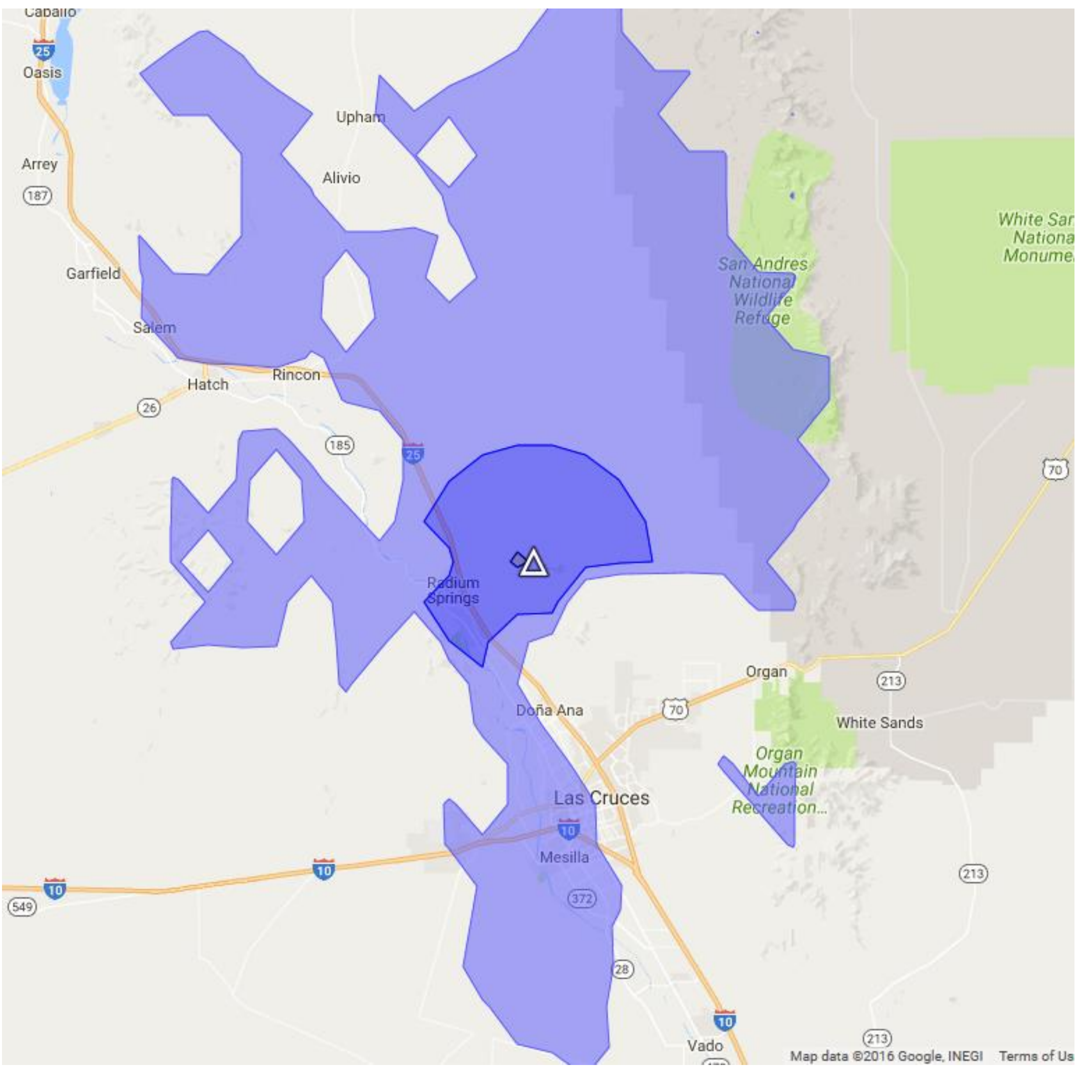


Figure 34. Predicted coverage for directional antenna (1 W, 6 dBi gain) at 400 ft AGL.

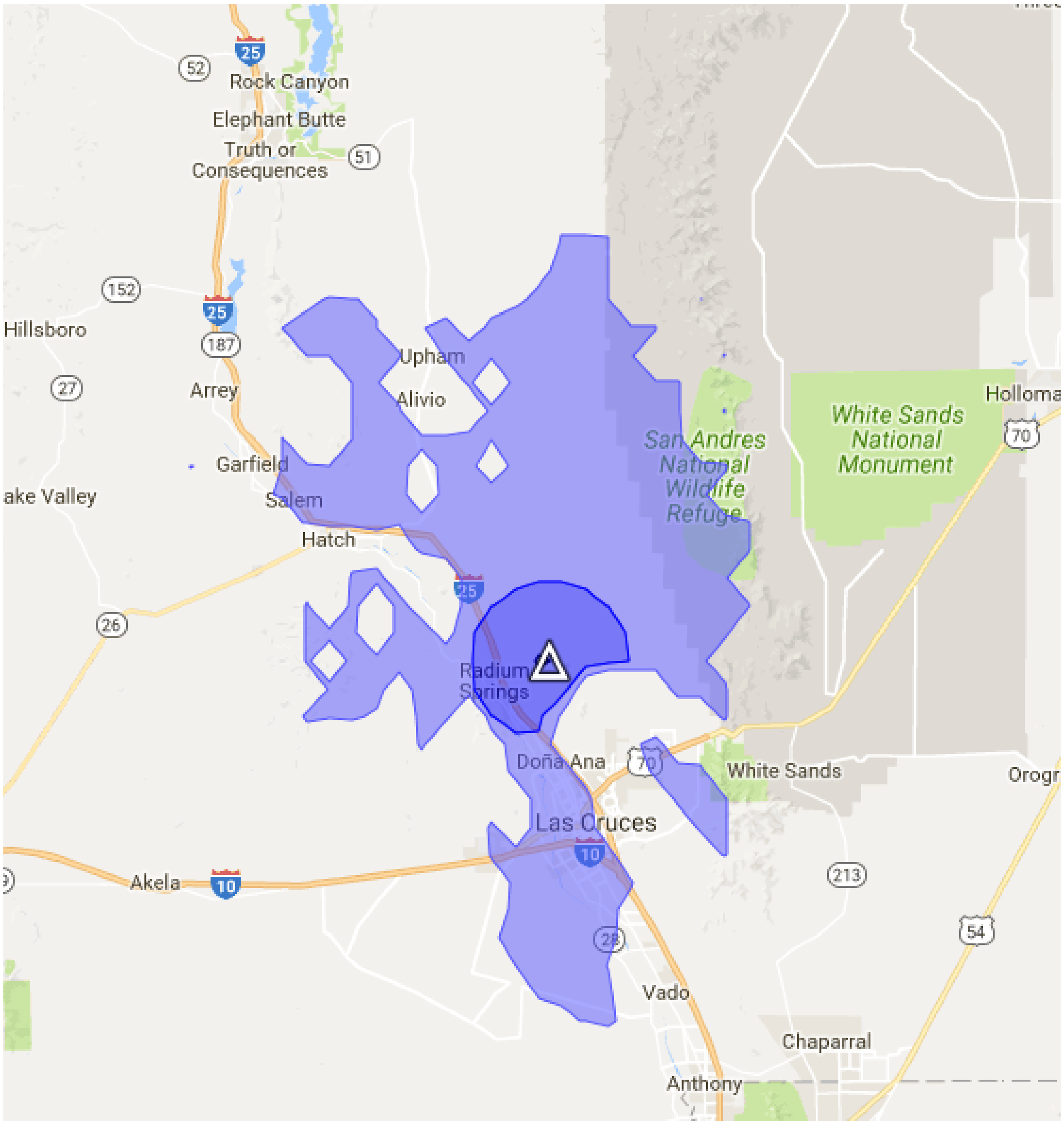


Figure 35. Predicted coverage for directional antenna (1 W, 6 dBi gain) at 500 ft AGL.

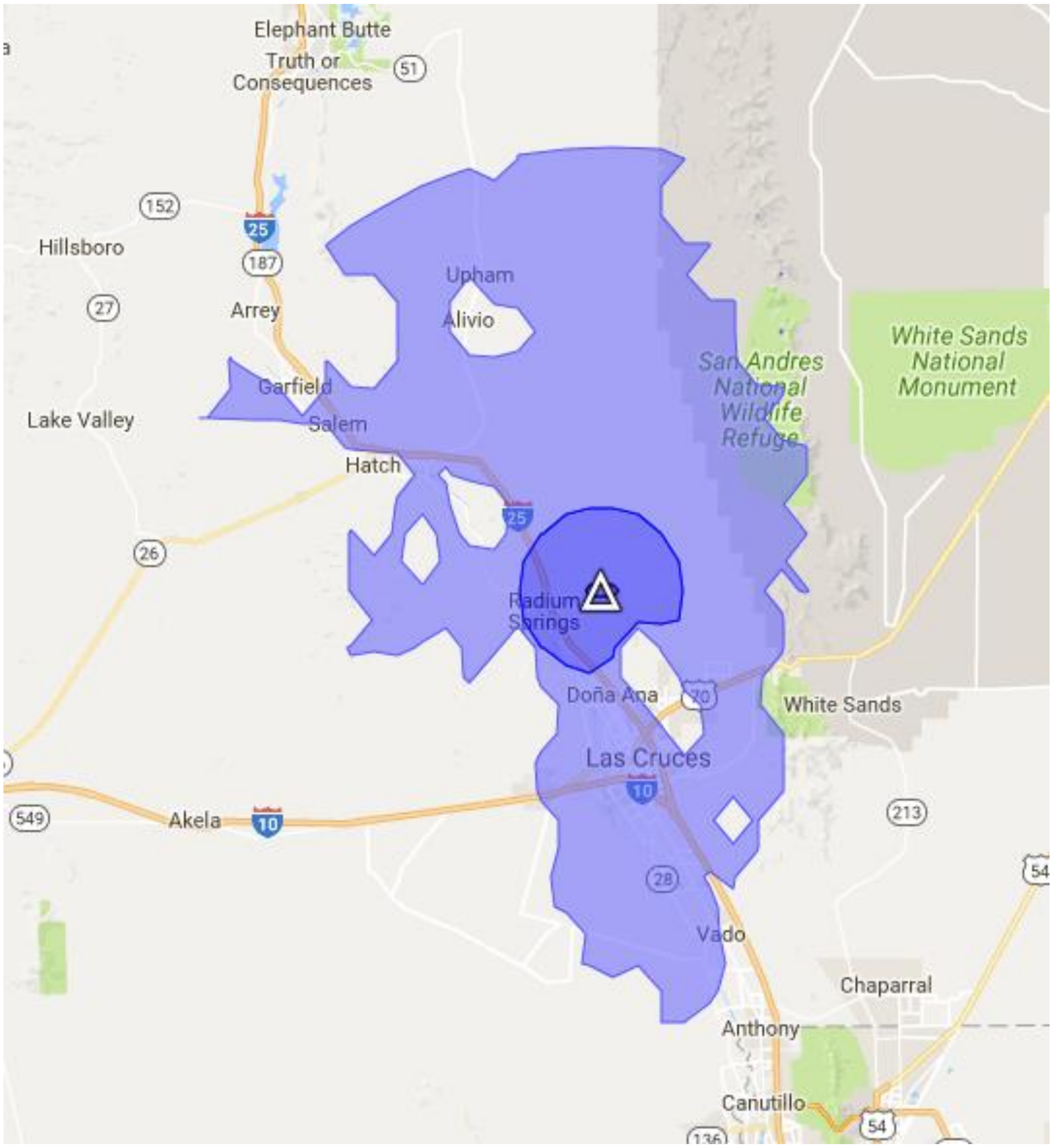


Figure 36. Predicted coverage for directional antenna (1 W, 6 dBi gain) at 1000 ft AGL.

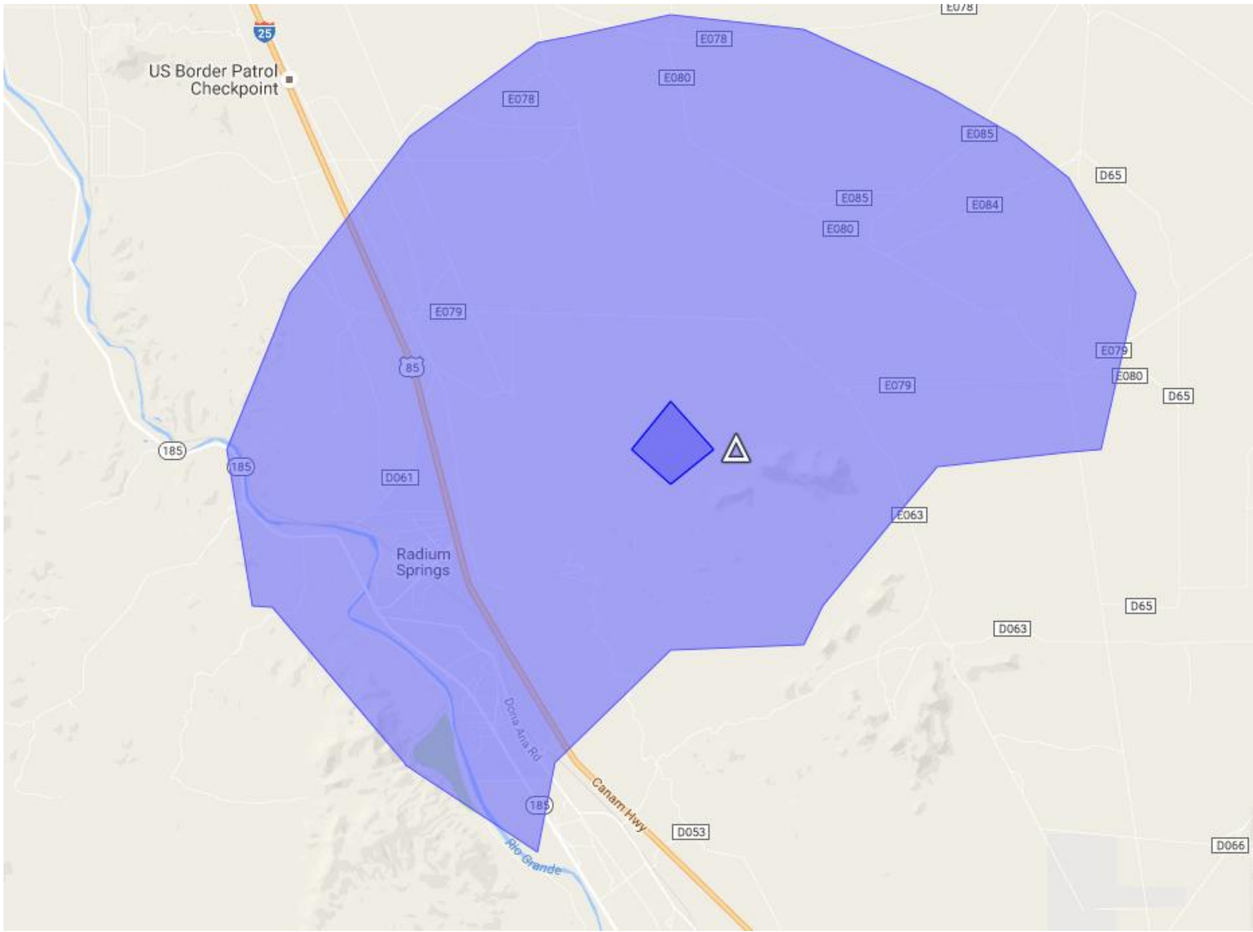


Figure 37. Predicted coverage for omni antenna (100 mW, 2 dBi gain) at 400 ft AGL.

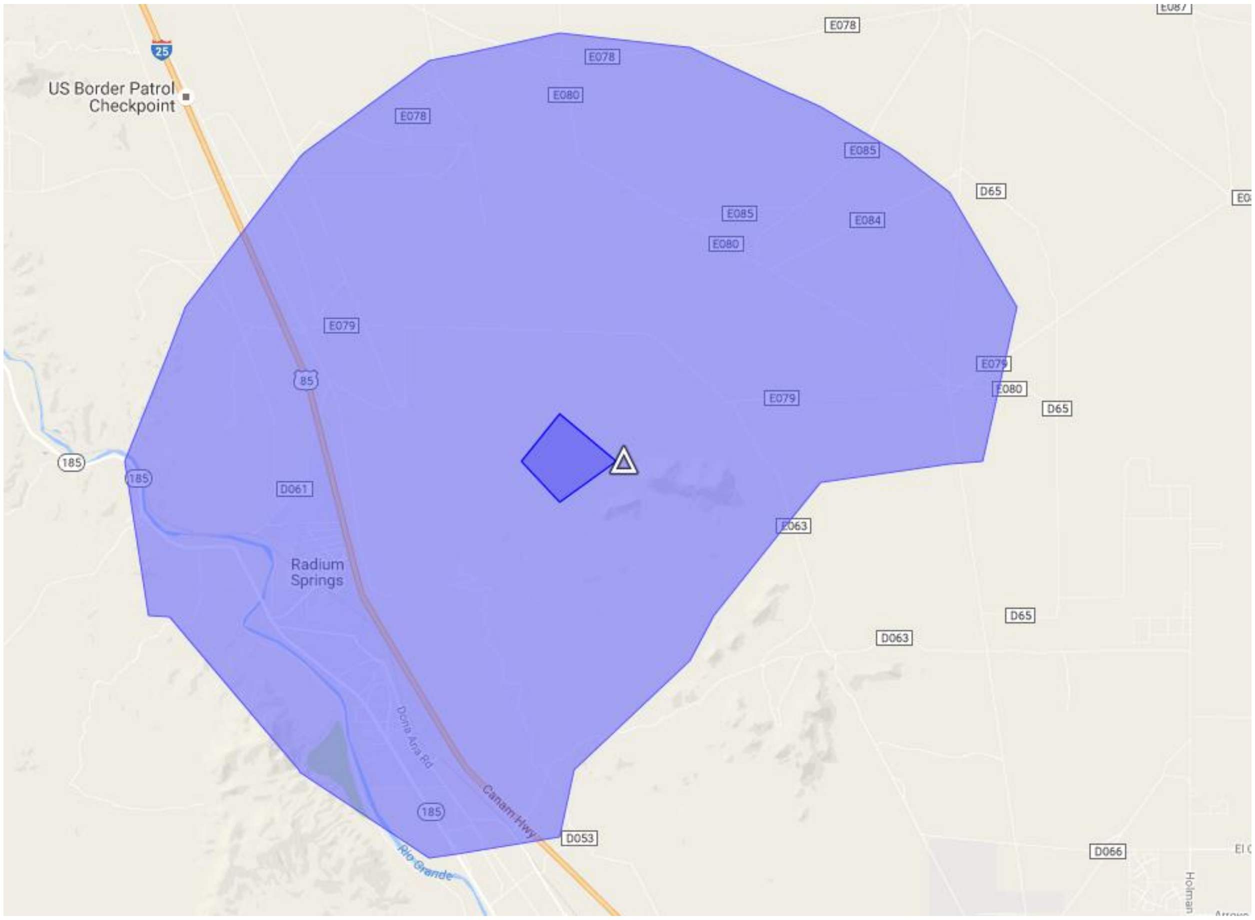


Figure 38. Predicted coverage for omni antenna (100 mW, 2 dBi gain) at 500 ft AGL.

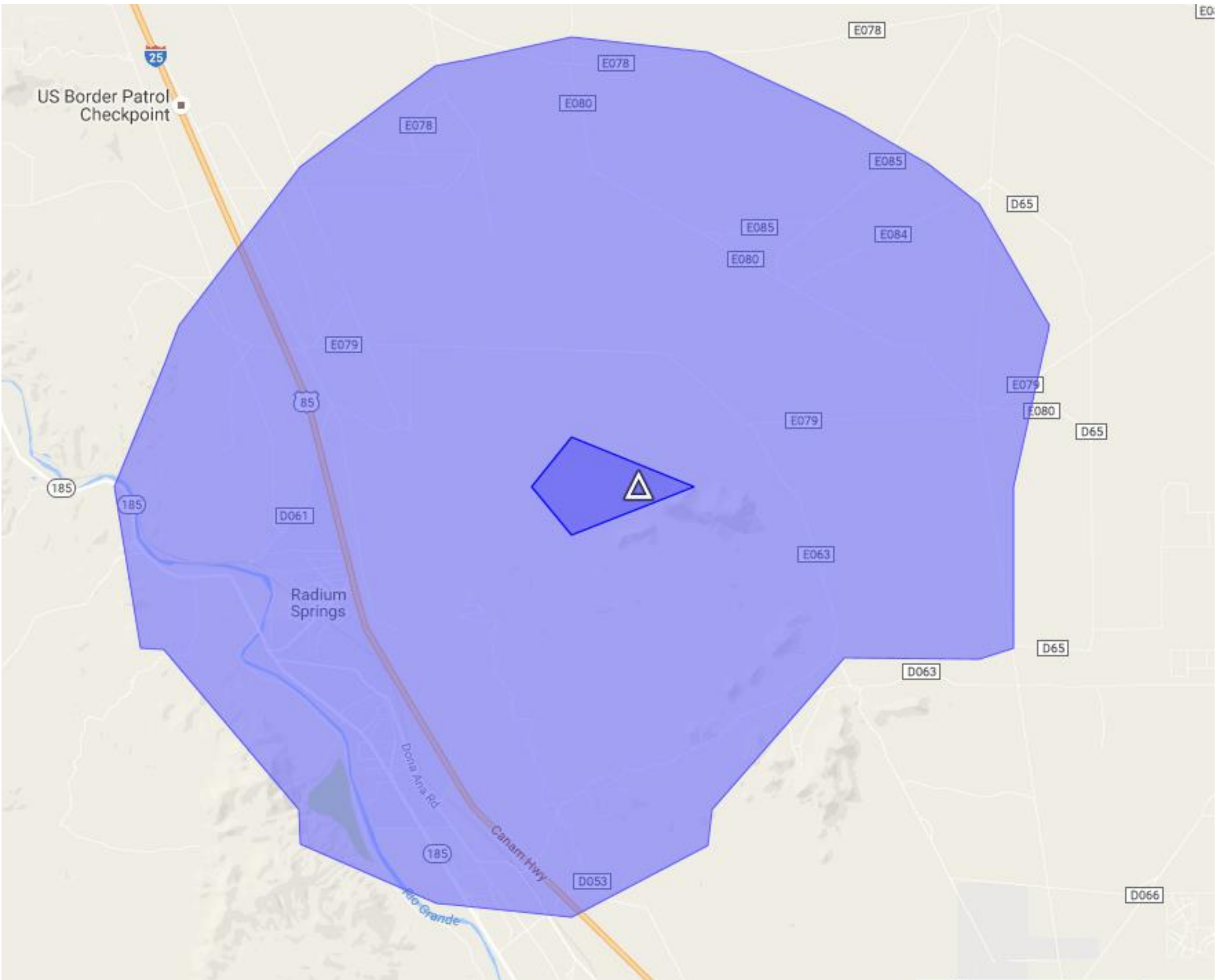


Figure 39. Predicted coverage for omni antenna (100 mW, 2 dBi gain) at 1000 ft AGL.

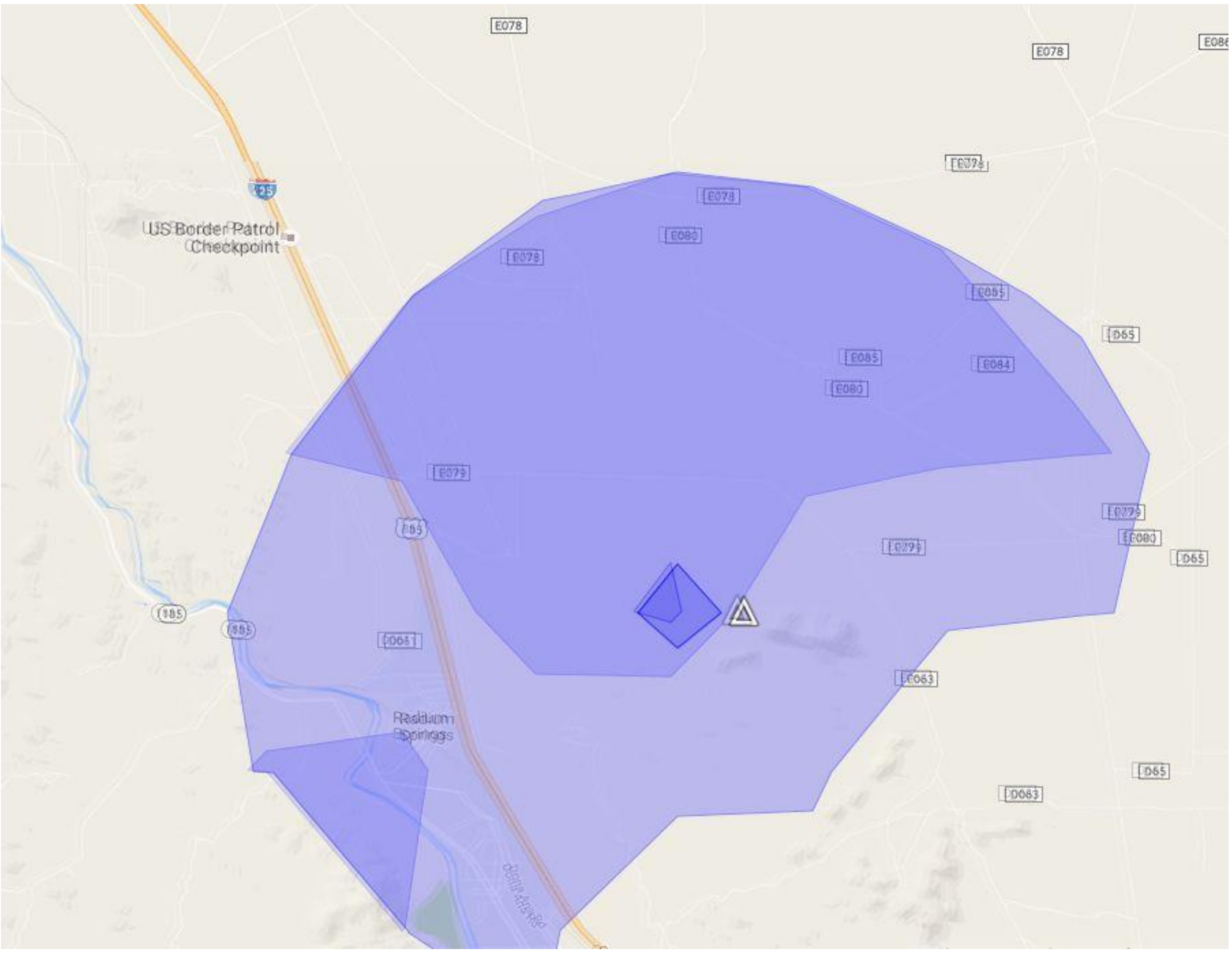


Figure 40. Omni antenna (100 mW, 2 dBi gain) at 100 versus 400 ft AGL overlay.

2.2.1.4.2.3 Deliverable

Test reporting for the Phase Two activities will result in a unique test report. The data included in this report will summarize all the information from the Phase Two activities. Any recommendations for follow-on testing will be included as lessons learned. The RLOS model also will be restated with any recommended changes to the parameters and also will be communicated as a final recommendation to the FAA.

2.2.1.5 BVLOS Technology Tests

A variety of airborne and ground-based technologies for detecting, sensing, and avoiding other aircraft will be tested starting in the near future for the safe operation of sUAS BVLOS. These technologies will be identified by a recent Request for Information distributed by NMSU as part of the FAA UAS COE BVLOS funded research. These technology tests will take place primarily on the 100 square miles of the CDRRC. As the specific technology is selected for testing, a unique test plan will be developed to guide the test and evaluation activities, or will be incorporated into this test plan.

2.2.2 Test Results

2.2.2.1 Introduction and Background

The New Mexico State University (NMSU) and University of North Dakota (UND) Alliance for System Safety of UAS through Research Excellence (ASSURE) teams were tasked with researching Detect and Avoid (DAA) technology in Unmanned Aircraft Systems (UAS) that could enable Beyond the Visual Line of Sight (BVLOS) operation of small UAS weighing under 55 lbs (sUAS) within limited portions of the National Air Space (NAS) while achieving a level of safety equivalent to manned aircraft operating in a similar manner.

One element of this research was to assess the radio line-of-sight (RLOS) connection for small unmanned aircraft systems (sUAS). This connection element is key to ensuring safe operations, specifically if flying BVLOS. A description of a proposed approach and potential testing was provided in a previously submitted test plan (Cathey 2016). In that report various modeling approaches were discussed and the potential RLOS range that may be achieved using a sUAS was developed. The signal propagation was modeled using the well-respected Longley-Rice Irregular Terrain Model (Longley and Rice 1968), which was developed by the U.S. Department of Commerce in 1968. The test plan addressed the data collection in a test setting to validate the developed model.

The test plan was designed to evaluate and analyze the variances between the Longley-Rice model with terrain, Longley-Rice model without terrain, and field truth measurements in a real-world setting. A simplified model without terrain would be more easily incorporated into an operator's safety guideline as safe operational distances could be incorporated into aeronautical charts and tables rather than requiring field access to a complex computer model. The intent of this testing was to determine if this concept of simplified, table-based flight safety criteria, would be a valid option in the development of safety regulations and guidance for sUAS operations.

As previously noted, a number of factors affect the modeled RLOS range, including the following:

- Terrain
- Weather
- Frequency in use
- Antenna gains at the ground station and the aircraft
- Transmitter power
- Receiver sensitivity

This test report's purpose is to present a set of measured field data and compare to the simplified Longley-Rice Irregular Terrain Model, and to an available online calculator. The comparison to real world data provides an assessment of the models to help make better informed decisions on allowable BVLOS flight operations. This information can be used to help inform the researchers and the FAA on how to proceed in its research efforts related to BVLOS operations and to inform FAA rules, regulations and guidelines.

This effort was carried out in collaboration with the Army Research Laboratory which provided personnel and equipment under the Cooperative Research and Development Agreement (CRADA) 16-23 between the U.S. Army Research Laboratory and New Mexico State University Physical Sciences Laboratory.

2.2.2.2 Test Purpose, Equipment, and Description

Field testing at the NMSU ranch was performed during the month of January 2017 to determine ground truth for the maximum reliable distance for a typical small UAS transceiver. The goal was to determine if the E. Johnson version of the Longley-Rice (L-R) model described in Cathey (2016) with no terrain database can be used to as the basis for a simplified methodology to provide safe flight distances to UAS operators.

Testing was performed between two 3DR radios (3DR v2 telemetry SiK radio with the stock antennas), operating at 915 MHz with 100 mW transmitters (20 dBm). The 3DR V2 radio specifications are:

- 100 mW output power
- -121 dBm receive sensitivity
- Based on HopeRF's HM-TRP module
- RP-SMA connector
- 2-way full-duplex communication through adaptive TDM
- UART interface
- Transparent serial link
- MAVLink protocol framing
- Frequency Hopping Spread Spectrum

One unit was placed at 1 m above ground level at various locations on the ranch. The unit was attached directly to a laptop computer running MavLink control software. This allowed the laptop to record the RSSI (Received Signal Strength Indicator) of both the control unit (laptop) and the remote unit. RSSI can be converted to Signal Strength in dBM using the formula:

$$\text{Signal Strength (dBm)} = \text{RSSI}/1.9 - 127. \quad (3)$$

The noise floor at 915 MHz, latitude and longitude were also recorded. From these data, distance between antennas was calculated as was the fade margin, assuming a -121 dBm receiver sensitivity.

The second unit radio with antenna was either connected to a fixed pole for the initial testing or to a small UAS. The initial static testing was performed with the remote unit mounted to a 20 ft tower/pole. In the case of the UAS, a Pixhawk flight control unit was used and mounted as a payload below a quad-copter (remote unit) which was control operated at 2400 MHz at a nominal height of 100 ft. AGL. A sampling of test points were also collected with the remote unit at 200, 300, and 400 ft AGL. These data sets are included in this report but have not yet been compared to model estimates.

Field results were plotted and then compared to both an on-line calculator (incorporates the Longley-Rice (L-R) model, terrain databases, and user entries for the radio characteristics to produce detailed coverage maps (http://lrcov.crc.ca/main/) and a simplified Longley-Rice model developed by E. Johnson. Based on field data, an estimated field observable RLOS coverage map was drawn for a visual comparison between the models and field observations.

2.2.2.3 Flight Test Area

Static and flight test operations were centered at latitude 32.51716, longitude -106.83065, on the Chihuahuan Desert Ranchland Research Center (CDRRC). The terrain consists of high desert scrub to the north and igneous mountains to the south. This area is on gated access controlled property owned by NMSU. Details and pictures of the CDRRC were noted in the test plan (Cathey 2016). The CDRRC was selected as a site for the RLOS research based on a number of factors. The airspace of the CDRRC falls within the NMSU Flight Test Site, and the current FAA Certificate of Authorization (COA) also covers this airspace. NMSU/PSL has significant UAS operating experience with a variety of UAS platforms in nearby airspace for low-altitude operations and over this area for higher UAS operations.

The terrain within the CDRRC varies from the Summerford Mountain to extended desert plains with no obstacles. The population on the ground has a single residence at the Ranch headquarters approximately one mile from the tower, and cattle and wildlife are the only other inhabitants. So, the population density is low. This area also is remote with no paved roads, a few county roads adjacent to significant power transmission lines, and unimproved two-track roads. There is only small acreage at the northern perimeter where the public has access; otherwise, access is controlled. NMSU has a controlled access area equivalent to about 100 square miles. Both RLOS and BVLOS studies and experiments are ideal at the CDRRC.

A 100 ft tower is located at the operations center, but was not used in this particular test series. It was originally envisioned that the fixed tower would be used by setting one of the transmitters on top of the tower and turned on to broadcast. There were logistical issues related to provisioning the test tower for the BVLOS tests. A plan to address tower issues should result in a more robust future test site. The number of trips required up and down the tower, time considerations, and safety considerations led the team to an alternative approach to use the small UAS as the transport for the transmitter. The tower location did still serve as the central location for all of this testing. Views of the terrain near the tower are show below in Figs. 41-44.

Figure 41. View to the south from the antenna tower.

Figure 42. Overhead view of the antenna tower.

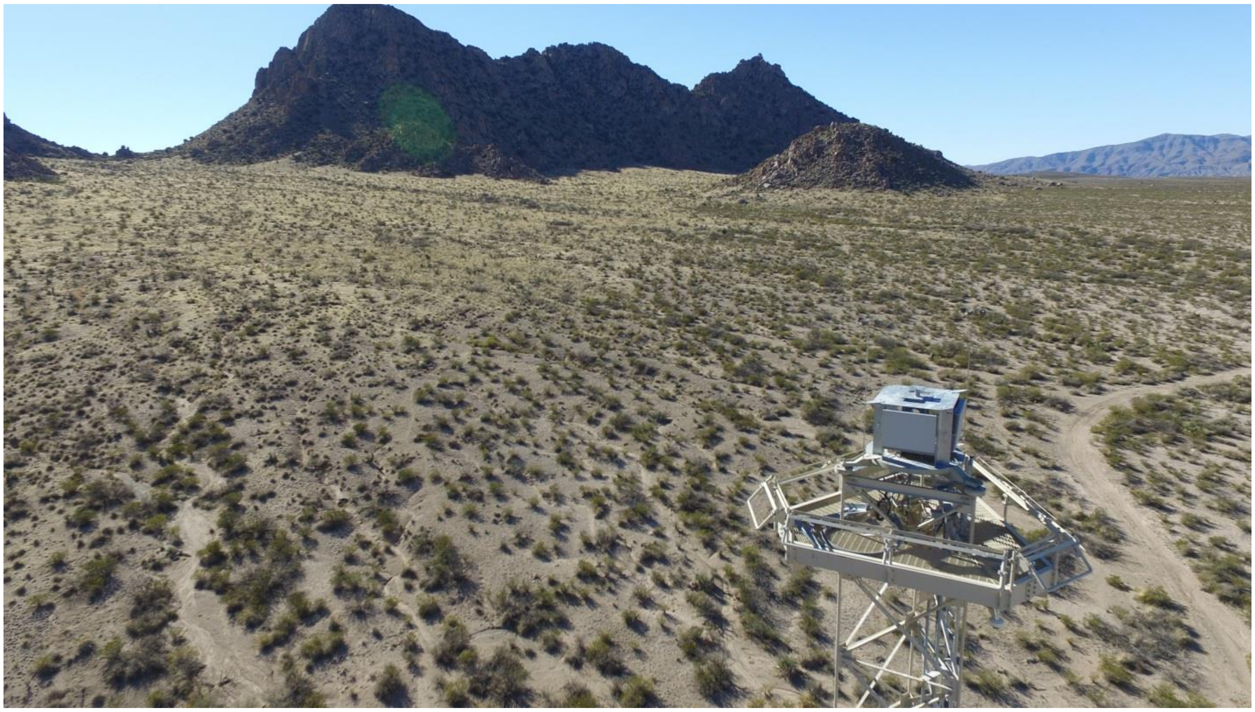


Figure 43. View from the UAS of the tower and to the southwest.

Figure 44. View from the tower to the southeast.

2.2.2.4 Test Payload and Fixtures

Tests 1 and 2, at an AGL of 20 ft, had the remote unit mounted to a pole mast. For the subsequent tests, the test platform for the remote unit was a payload slung under a quad-copter for the field test data points at 100, 200, 300, and 400 ft AGL. As noted before, the remote unit consisted of the Pixhawk flight control unit, a 3DR V2 915 MHz radio @ 100 mW, and a battery pack. Figures 45-47 show the fixed mast pole and the flight configurations.

Figure 45. Remote antenna unit at 20 ft AGL, Pole Mast Mount.

Figure 46. Quad-Copter with payload.

Figure 47. Quad-copter with payload ascending to 100 ft AGL.

2.2.2.5 Test Data for 20 ft AGL

Initial data points were collected with the remote transmitter mounted on a 20 ft pole mast. The test equipment was the same as noted above and the same as was used for the 100 ft test with the exception that the remote was mounted on a mast rather than a payload attached to a quad-copter. On-line coverage estimates where generated at this altitude only. These initial tests were done to confirm all of the equipment was working and the approach was sound. The various tests were conducted on different days and each test was designated with a different test number (TEST1 = T1, TEST2 = T2, etc.) Below is a summary of the field data in Tables 18 and 19.

Table 18. Test 1 data points (T1).

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.51955	-106.83308	11:30:00 AM	N/A	TRUE	350	64	63	-93.32	-93.84	27.68	30	-111.21
2	32.52014	-106.82489	11:38:00 AM	N/A	TRUE	634	47	49	-102.26	-101.21	18.74	29	-111.74
3	32.52218	-106.82170	11:45:00 AM	N/A	TRUE	1008	40	44	-105.95	-103.84	15.05	31	-110.68
4	32.52663	-106.81322	11:53:00 AM	N/A	TRUE	1944	37	43	-107.53	-104.37	13.47	31	-110.68
5	32.53125	-106.80515	11:58:00 AM	N/A	FALSE	2858	35	35	-108.58	-108.58	12.42	31	-110.68
6	32.53407	-106.80910	12:00:00 PM	N/A	TRUE	2760	45	49	-103.32	-101.21	17.68	30	-111.21
7	32.53988	-106.81696	12:09:00 PM	N/A	TRUE	2834	68	70	-91.21	-90.16	29.79	41	-105.42
8	32.54507	-106.82473	12:13:00 PM	N/A	FALSE	3153	35	38	-108.58	-107.00	12.42	34	-109.11
9	32.54528	-106.83556	12:19:00 PM	N/A	TRUE	3161	52	53	-99.63	-99.11	21.37	31	-110.68
10	32.54554	-106.84531	12:21:00 PM	N/A	TRUE	3442	45	45	-103.32	-103.32	17.68	32	-110.16
11	32.54598	-106.86228	12:26:00 PM	N/A	TRUE	4366	41	47	-105.42	-102.26	15.58	34	-109.11
12	32.54992	-106.86304	12:30:00 PM	N/A	TRUE	4742	34	34	-109.11	-109.11	11.89	31	-110.68
13	32.55561	-106.86421	12:40:00 PM	N/A	TRUE	5308	0	36	-127.00	-108.05	-6.00	31	-110.68
14	32.54085	-106.86111	12:52:00 PM	N/A	TRUE	3885	0	35	-127.00	-108.58	-6.00	32	-110.16

Date	1/12/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	partly cloudy			
Temp(F)	**Humid (%)**	**Solar**	**Wind (mph)**	**Pres (inHg)**
60	25		<10	29.96

Table 19. Test 2 data points (T2).

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.51399	-106.83706	7:33:00 AM	N/A	TRUE	697	46	49	-102.79	-101.21	18.21	31	-110.68
2	32.51158	-106.83715	7:39:00 AM	N/A	FALSE	870	0	36	-127.00	-108.05	-6.00	35	-108.58
3	32.51005	-106.83727	7:44:00 AM	N/A	FALSE	1005	0	43	-127.00	-104.37	-6.00	29	-111.74
4	32.50903	-106.83742	7:50:00 AM	N/A	FALSE	1105	40	42	-105.95	-104.89	15.05	31	-110.68
5	32.50931	-106.83860	8:07:00 AM	N/A	FALSE	1148	0	31	-127.00	-110.68	-6.00	30	-111.21
6	32.50848	-106.84084	8:16:00 AM	N/A	FALSE	1358	0	41	-127.00	-105.42	-6.00	32	-110.16
7	32.50363	-106.83965	8:23:00 AM	N/A	FALSE	1725	0	25	-127.00	-113.84	-6.00	26	-113.32
8	32.50162	-106.84080	8:29:00 AM	N/A	FALSE	1973	0	29	-127.00	-111.74	-6.00	30	-111.21
9	32.50463	-106.84349	8:37:00 AM	N/A	FALSE	1841	0	20	-127.00	-116.47	-6.00	30	-111.21
10	32.50421	-106.84696	8:40:00 AM	N/A	FALSE	2101	0	24	-127.00	-114.37	-6.00	26	-113.32
11	32.51667	-106.84145	10:24:00 AM	N/A	TRUE	1014	43	45	-104.37	-103.32	16.63	30	-111.21
12	32.51891	-106.84570	10:29:00 AM	N/A	TRUE	1424	40	43	-105.95	-104.37	15.05	32	-110.16
13	32.52132	-106.85032	10:34:00 AM	N/A	FALSE	1901	36	37	-108.05	-107.53	12.95	32	-110.16
14	32.51981	-106.85374	10:42:00 AM	N/A	TRUE	2185	49	49	-101.21	-101.21	19.79	30	-111.21
15	32.51955	-106.85317	10:46:00 AM	N/A	FALSE	2128	0	35	-127.00	-108.58	-6.00	35	-108.58
16	32.52032	-106.82702	11:10:00 AM	N/A	TRUE	489	72	74	-89.11	-88.05	31.89	30	-111.21
17	32.52222	-106.82163	11:15:00 AM	N/A	FALSE	1016	43	45	-104.37	-103.32	16.63	32	-110.16
18	32.52526	-106.81587	11:21:00 AM	N/A	TRUE	1653	46	46	-102.79	-102.79	18.21	30	-111.21
19	32.52711	-106.81223	11:24:00 AM	N/A	TRUE	2051	38	40	-107.00	-105.95	14.00	28	-112.26
20	32.5309	-106.80502	11:30:00 AM	N/A	TRUE	2848	36	38	-108.05	-107.00	12.95	24	-114.368
21	32.52928	-106.8021	11:35:00 AM	N/A	FALSE	2997	0	33	-127.00	-109.63	-6.00	28	-112.263
22	32.5276	-106.80106	11:43:00 AM		FALSE	3007	0	27	-127.00	-112.79	-6.00	29	-111.737

Date	1/13/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	partly cloudy			
Temp(F)	Humid (%)	Solar	Wind (mph)	Pres (inHg)
60	25		<10	29.96

The data above were compared to an on-line calculator using user entries for the radio characteristics to produce detailed coverage maps (http://lrcov.crc.ca/main/). The calculation pages are shown in Fig. 48. The resulting on-line coverage map is shown in Fig. 49.

Transmitter

Latitude:	32 ° 31 ' 1.65 " North	Antenna Pattern (Horiz. Plane)
Longitude:	106 ° 49 ' 50.5 " West	
	Note: the transmitter position can also be set using the "Set Tx Pos" button below.	
Height Above Ground (m):	6.1 (0.5 - 3000 m)	
Frequency (MHz):	900 (20 - 40000 MHz)	
Power (W):	0.1	
Polarization:	Vertical	
Antenna Gain (dBi):	2.0	
Antenna Pointing Azimuth (°):	0.0 (0° - 359.9° ; North = 0°)	Details

Propagation Model: Longley Rice (Point-to-Point)

Surface Refractivity (N-units):	301 Show List (250 - 400 N-units)
Dielectric Constant of Ground:	15 Show List (4 - 81)
Conductivity of Ground (Siemens/m):	0.001 Show List (0.001 - 5.0 S/m)
Climatic Zone:	Continental Temperate
Confidence Level (%):	80 (1 - 99 %)
Time Availability (%):	50 (1 - 99 %)
Location Availability (%):	50 (1 - 99 %)

Receiver

Antenna Height Above Ground (m):	1.5 (0.5 - 3000 m)	
Reception Area		
Lower Left Corner Position (decimal degrees):	Latitude 32.43329	Longitude -106.9580
Upper Right Corner Position (decimal degrees):	Latitude 32.61248	Longitude -106.6816
	Note: the reception area can also be set using the "Set Rx Area" button below.	

Coverage Display

	From		To		Color
☑	45	dBµV/m	60	dBµV/m	Light Blue
☑	60	dBµV/m	75	dBµV/m	Blue
☑	75	dBµV/m	100	dBµV/m	Dark Blue

Figure 48. On-Line L-R input parameters for 20 ft AGL.

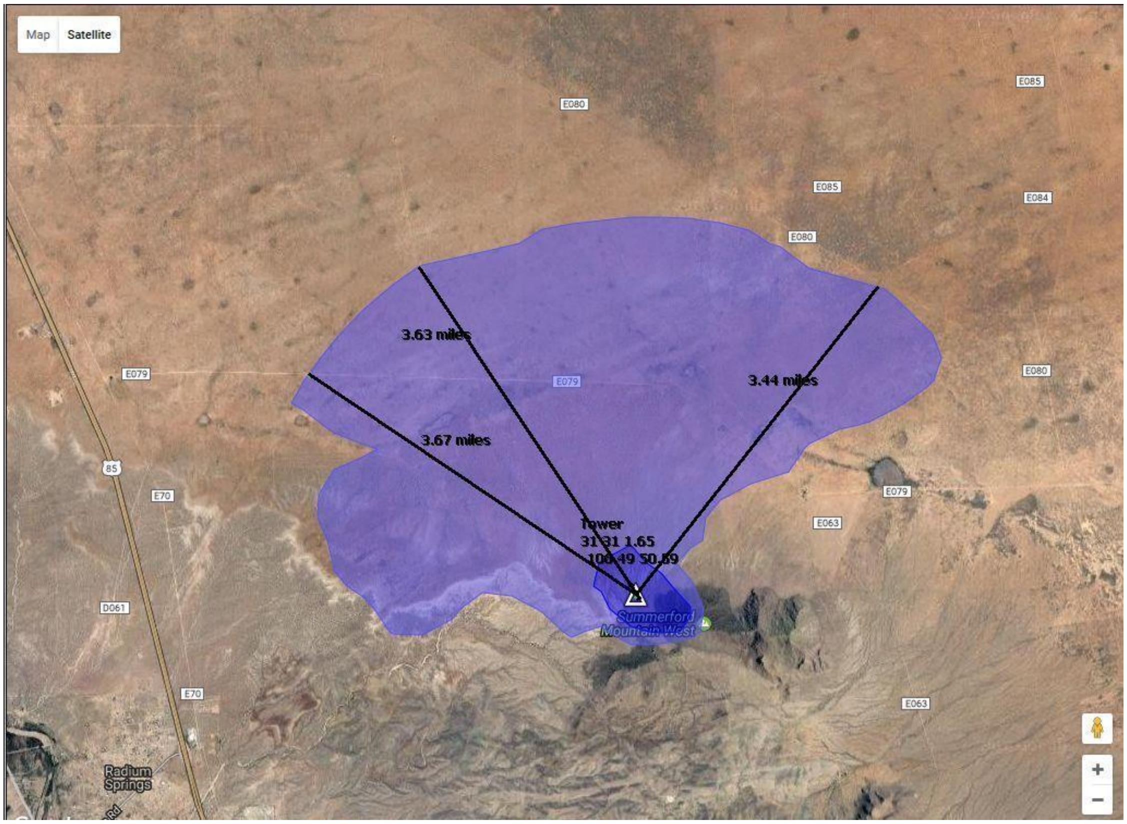


Figure 49. On-Line L-R coverage map for 20 ft AGL.

Figure 50 illustrates test 1 and 2 data points. With what will also be seen with the 100 ft AGL tests, the signal strengths below -108 dBm are too low for reliable connection even though the advertised sensitivity of the units is -121 dBm.

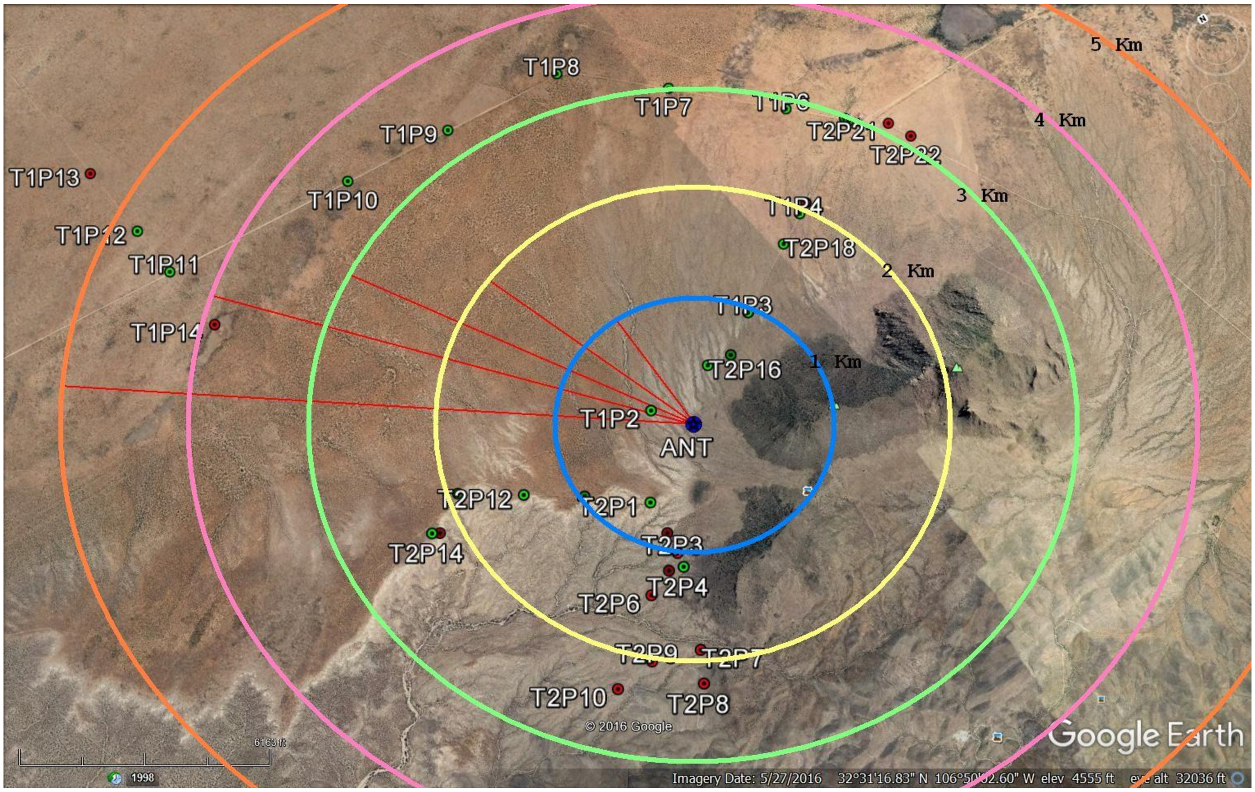


Figure 50. Test 1 and 2 data points with distances for 20 ft AGL. Green indicates test points that had communications and valid data linkage between the remote and the controller such that data could reliably be passed between the units. Red data points indicate that the linkage was unreliable or connection could not be made between the units.

2.2.2.6 Model Parameters for 100 ft AGL

Input parameters to the On-Line Longley-Rice (900 MHz, 100 mW transmitters), 100 ft AGL are provided in Fig. 51. It should be noted that:

- No Receiver Sensitivity Input parameter available in this application,
- Dielectric constant is Normal Ground (15),
- Conductivity is for poor soil conditions (0.001).

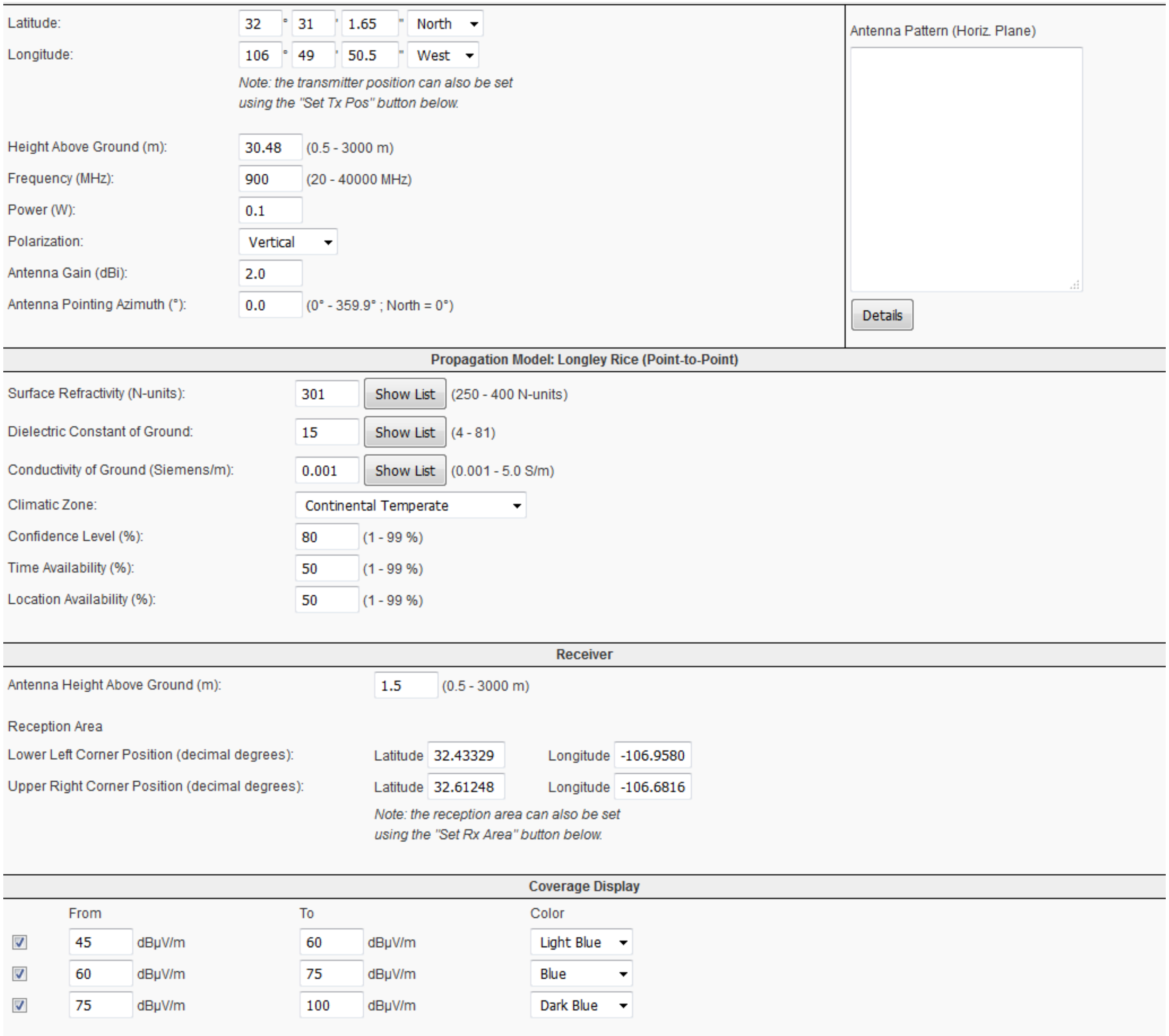


Figure 51. On-Line L-R coverage input parameters for 100 ft AGL.

The resulting coverage map based on the On-line Longley-Rice Tool showing Boundary/Road Crossing Measurement Positions at maximum range estimates for 100 ft AGL remote antenna is shown below in Fig. 52. Corresponding data points are provided in Table 20.

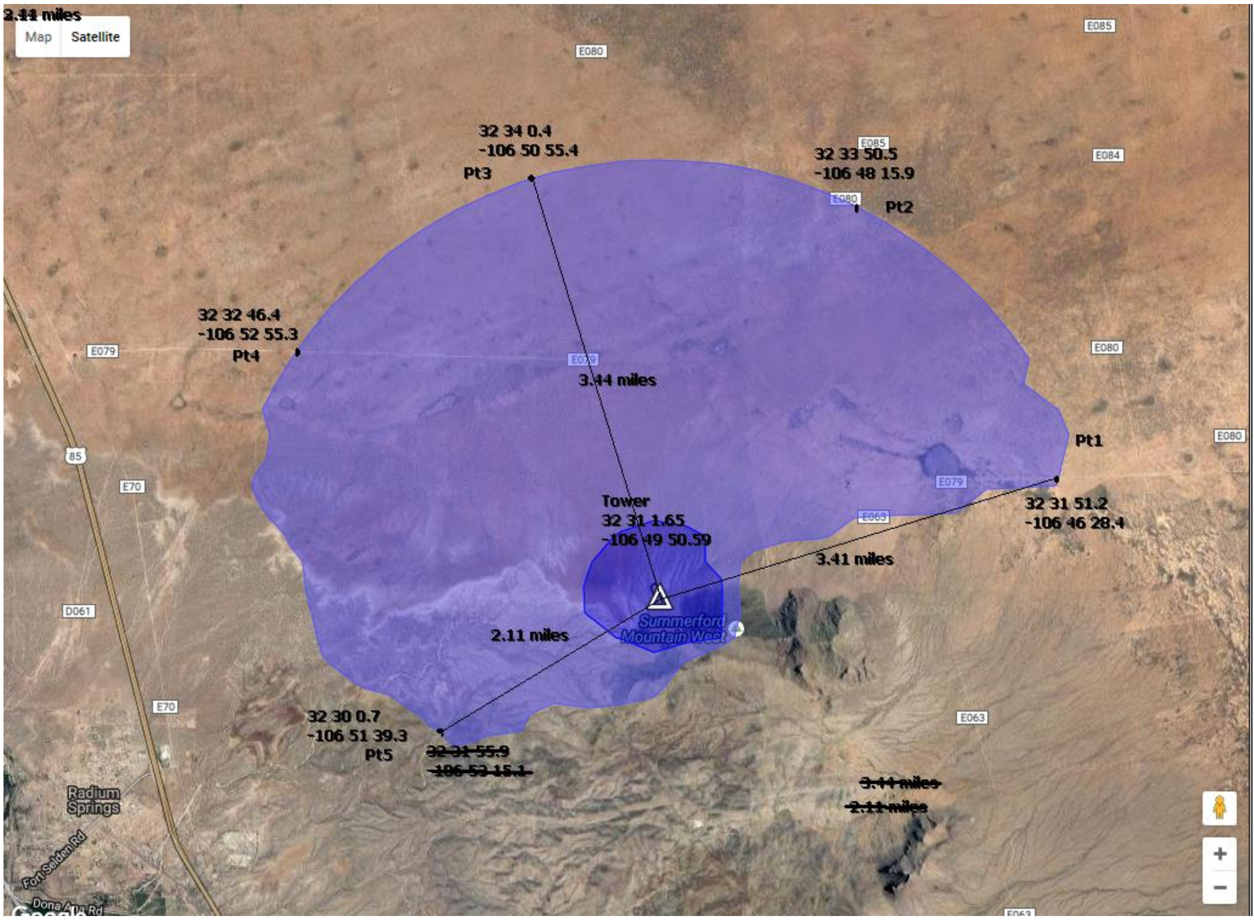


Figure 52. Estimated RLOS coverage from on-line calculator for 100 ft AGL.

Table 20. Calculated data points for RLOS coverage from on-line calculator for 100 ft AGL.

Location	Latitude	Longitude	Distance (miles)
Tower	32 31 1.65	-106 49 50.59	
Point 1	32 31 51.2	-106 46 28.4	3.41
Point 2	32 33 50.5	-106 48 15.9	
Point 3	32 34 0.4	-106 50 55.4	3.44
Point 4	32 32 46.4	-106 52 55.3	
Point 5	32 30 0.7	-106 51 39.3	2.11

The coverage from E. Johnson's Longley-Rice Model (900 MHz, 100 mW transmitters) showing maximum ranges with -121 dBm and -108 dBm receiver sensitivity using terrain roughness types of smooth plains and low hills is presented in Fig. 53 and the associated data in Table 21.

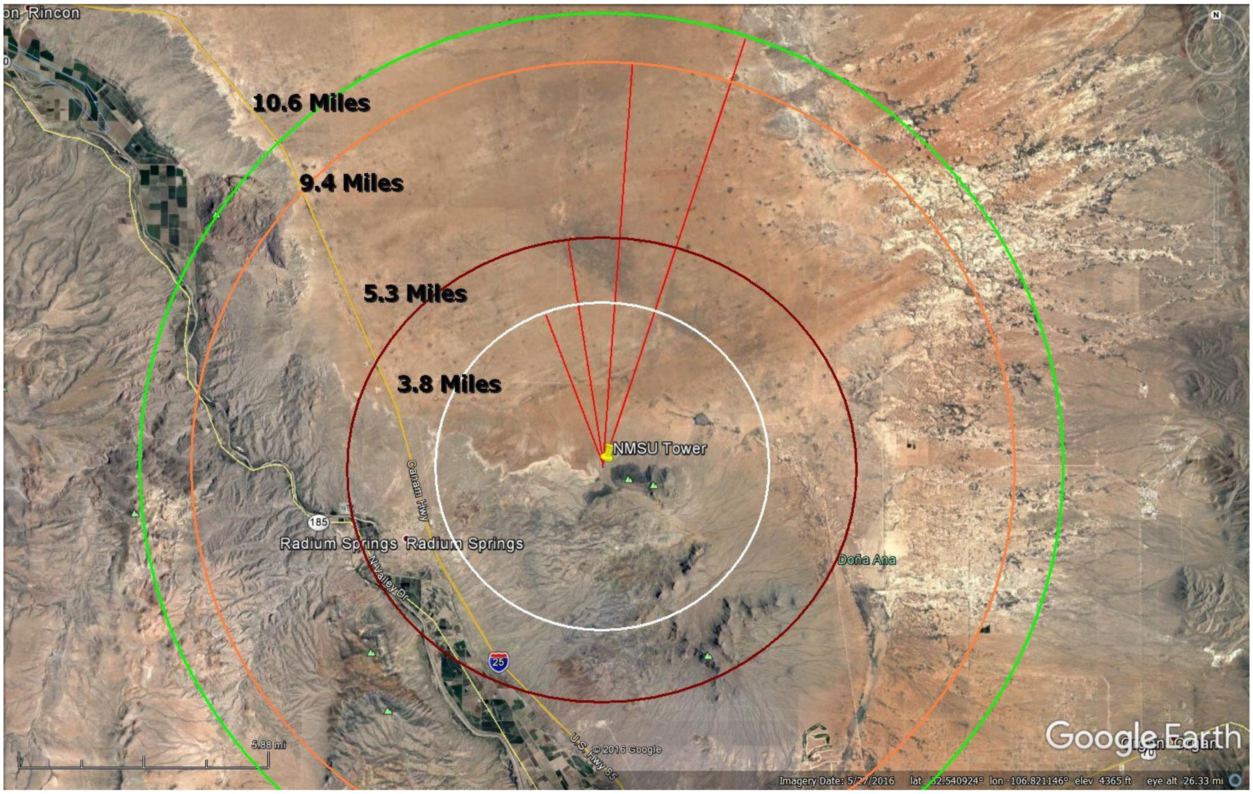


Figure 53. Coverage estimates from simplified E. Johnson L-R model for 100 ft AGL. Table 21 provides color designations.

Table 21. Calculated coverage estimates from simplified E. Johnson L-R model for 100 ft AGL. Model results were obtained using a 0 dB fade margin.

Parameter	Estimate 1	Estimate 2	Estimate 3	Estimate 4
Frequency (MHz)	900	900	900	900
Tx height (m)	1	1	1	1
Rx height (ft)	100	100	100	100
Tx Power (dBm)	20	20	30	30
Tx Ant Gain (dBi)	2	2	2	2
Rx Ant Gain (dBi)	-2	-2	-2	-2
Sensitivity (dBm)	-121	-108	-121	-108
Fade Margin (dB)	0	0	0	0
Allowed Path Loss (dB)	141	128	151	138

For the SiK Radio
Power = 100 mW (20 dBm), sensitivity = -121 dBm
Over gently rolling plains (Δh = 30 m)

2.2.2.7 Test Data for 100 ft AGL

Testing at 100 ft AGL occurred on January 20th and 26th, 2017. The remote antenna was mounted as a payload below a quad-copter and flown at 100 ft AGL at latitude 32.51716, longitude -106.83065 (antenna tower). The measurements were collected using a laptop computer connected to a 915 MHz 3DR radio, running MavLink flight control software. The test points are at the position of the laptop (Cntrl Position).

A "0" RSSI indicates that no connect was made between the remote and control units. As noted before with the tests at 20 ft AGL, these tests at 100 ft AGL, the signal strengths below -108 dBm are too low for reliable connection even though the advertised sensitivity of the units is -121 dBm. Tables 22 and 23 present the data recorded in tests.

Figure 54 is an image that depicts the test point locations and their relationship to the RLOS coverage maps for the On-Line L-R model, the E. Johnson L-R model, and an estimate of the actual coverage based on observed field data. As with the previous image presenting the data on the surface map, green data points indicates test points that had communications and valid data linkage between the remote and the controller such that data could reliably be passed between the units. The red data points indicate that the linkage was unreliable or connection could not be made between the units.

The Johnson L-R coverage displayed is the 3.8 mile estimate (6.1 km), which would be associated with -108 dBm receiver sensitivity (-121 dBm less 13 dB fade margin). By comparison the On-line Longley-Rice Tool coverage displayed is an approximate 3.4 mile estimate (5.5 km). One can see that this distance is less and coverage area is not as great as with the Johnson L-R coverage. The measured data pulls in the coverage distance even further with a coverage display of 3.1 miles (5.0 km). This is significant since the real world measurements produce a reliable coverage area less than either the Johnson L-R or the On-line Longley-Rice Tool.

It should be noted that neither the Johnson L-R nor the On-line Longley-Rice Tool model reliably predicts the RLOS area to the southwest of the tower. The coverage to the north of the antenna site is mostly LOS due to the flat or rolling surface terrain. The area southwest of the tower is mountainous. Also note that the signal strengths below -108 dBm are too low, in this case, for reliable connection even though the advertised sensitivity of the units is -121 dBm. Using a fade margin of approximately 15 dB when computing the link budget more closely aligns with field observations.

For operational purposes, the operator must consider the entire area of operation to ensure that the inputs one uses in the model match the actual geographic terrain. The range area used for these tests demonstrated how the varied geographies (rolling hills and mountains) impacted the resultant model estimates of RLOS. Models that incorporate actual terrain data will perform better in this scenario since there are dual terrain types, in this case, and the more generalized E. Johnson model only incorporates one. Further model considerations should include a factor for vegetative ground cover effects on radio signal propagation through both absorption and scattering at low incident transmission angles. The specific area in which these tests were conducted was covered in creosote bush (Larrea tridentate) which appeared to attenuate signal strengths more than expected from phase shift and multi-path effects, when a significant distance of the RF LOS vector's Fresnel zone was obstructed by this cover.

Table 22. Test 3 Data Points (T3).

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.54601	-106.86209	9:10:00 AM	N/A	TRUE	4356	51	40	-100.16	-105.95	20.84	37	-107.53
2	32.55302	-106.86359	9:15:00 AM	N/A	TRUE	5043	45	39	-103.32	-106.47	17.68	31	-110.68
3	32.55843	-106.86465	9:26:00 AM	N/A	TRUE	5587	0	26	-127.00	-113.32	-6.00	25	-113.84
4	32.52263	-106.79784	10:16:00 AM	N/A	TRUE	3136	0	40	-127.00	-105.95	-6.00	32	-110.16
5	32.53155	-106.80545	10:44:00 AM	N/A	TRUE	2854	53	48	-99.11	-101.74	21.89	37	-107.53
6	32.53068	-106.80281	10:58:00 AM	N/A	TRUE	3012	45	44	-103.32	-103.84	17.68	31	-110.68
7	32.53067	-106.79681	11:00:00 AM	N/A	TRUE	3510	45	40	-103.32	-105.95	17.68	29	-111.74
8	32.53121	-106.78152	11:07:00 AM	N/A	TRUE	4864	32	35	-110.16	-108.58	10.84	27	-112.79
9	32.53122	-106.78047	11:09:00 AM	N/A	TRUE	4958	0	34	-127.00	-109.11	-6.00	28	-112.26

Date	1/20/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	partly cloudy			
Temp(F)	**Humid (%)**	**Solar**	**Wind (mph)**	**Pres (inHg)**
45	70		15	29.78

Table 23. Test 4 Data Points (T4).

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.51320	-106.83720	8:09:00 AM	N/A	TRUE	756	0	21	-127.00	-115.95	-6.00	15	-119.11
2	32.50797	-106.84278	8:35:00 AM	N/A	FALSE	1529	0		-127.00		-6.00	40	-105.95
3	32.52961	-106.80231	9:25:00 AM	N/A	TRUE	2996	57	52	-97.00	-99.63	24.00	41	-105.42
4	32.51810	-106.79499	9:34:00 AM	N/A	FALSE	3345	0		-127.00		-6.00		
5	32.53077	-106.79427	9:54:00 AM	N/A	TRUE	3732	54	50	-98.58	-100.68	22.42	36	-108.05
6	32.53123	-106.77997	10:09:00 AM	N/A	TRUE	5003	47	45	-102.26	-103.32	18.74	33	-109.63
7	32.53134	-106.77658	10:20:00 AM	N/A	TRUE	5309	0	36	-127.00	-108.05	-6.00	30	-111.21
8	32.50458	-106.84346	11:30:00 AM	N/A	TRUE	1844	0	37	-127.00	-107.53	-6.00	33	-109.63
9	32.50347	-106.85069	11:42:00 AM	N/A	FALSE	2418	0	32	-127.00	-110.16	-6.00	33	-109.63
10	32.50309	-106.85329	11:55:00 AM	N/A	FALSE	2637	0		-127.00		-6.00		
11	32.50155	-106.84079	12:14:00 PM	N/A	FALSE	1979	0		-127.00		-6.00		

Date	1/20/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	Clear			
Temp(F)	**Humid (%)**	**Solar**	**Wind (mph)**	**Pres (inHg)**
45	43		calm	29.93

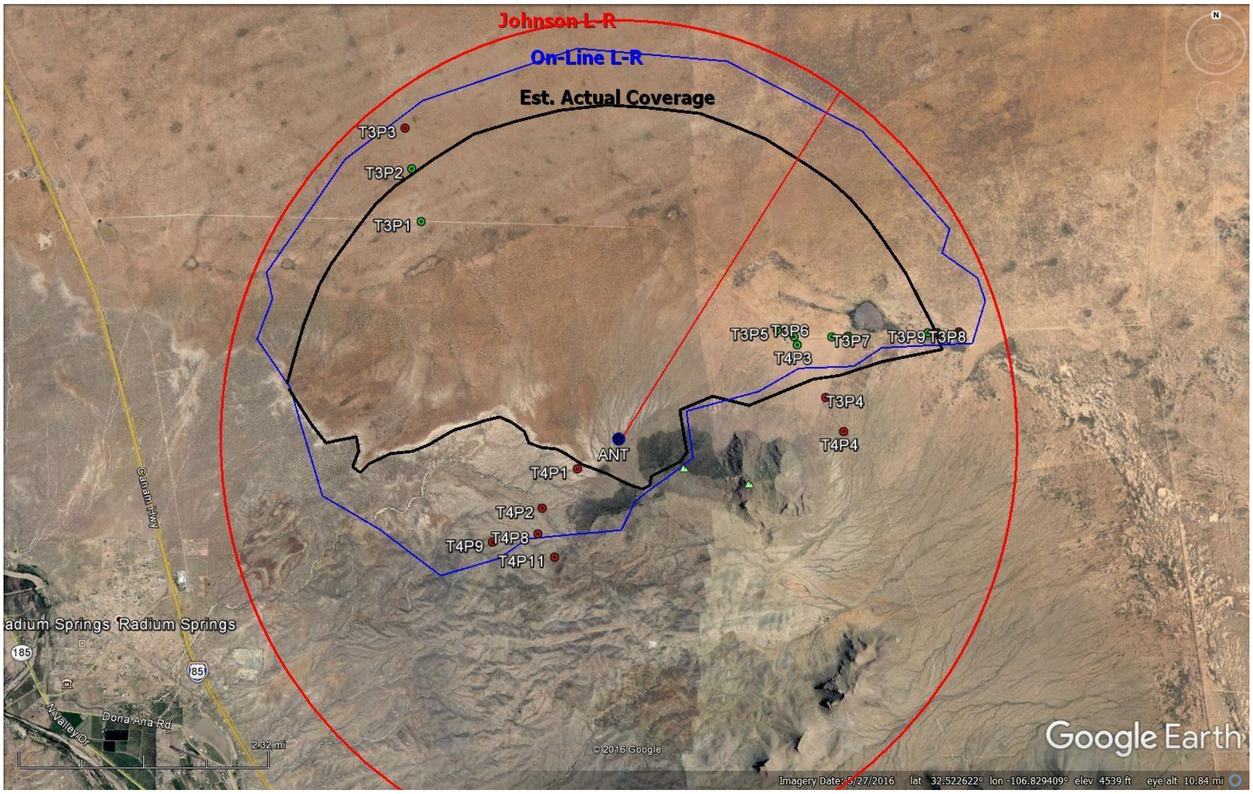


Figure 54. Test 3 and 4 data points and model coverage area for 100 ft AGL. Green indicates test points that had communications and valid data linkage between the remote and the controller such that data could reliable be passed between the units. Red data points indicate that the linkage was unreliable or connection could not be made between the units.

2.2.2.8 Test Data for 200, 300, and 400 ft AGL

To provide some additional data points, a limited amount of data were collected at 200, 300, and 400 ft AGL (Tables 24-26). This was done with the remote payload mounted on a quad-copter. No analysis has yet been performed for this data, but it is included for reference. Although not specifically noted here due to the limited amount of data points, the significance of these tests are their possible usage to determine the base level of RLOS. Radio connection at specific test points was established at the 400 ft AGL level, then the payload descended to the 300 ft and 200 ft test points. During the descent, it was possible to determine the altitude where signal was lost. This significantly improves the resolution of the base level of the RLOS diffraction zone where this occurs beyond visual line of sight. Setup and equipment were the same as used for the 100 ft AGL test.

Table 24. Test Points at 200 ft AGL.

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.51320	-106.83720	8:09:00 AM	N/A	TRUE	756	59	58	-95.95	-96.47	25.05	31	-110.68
2	32.50797	-106.84278	8:35:00 AM	N/A	FALSE	1529	0	40	-127.00	-105.95	-6.00	35	-108.58
3	32.52961	-106.80231	9:25:00 AM	N/A	TRUE	2996	58	56	-96.47	-97.53	24.53	40	-105.95
4	32.51810	-106.79499	9:34:00 AM	N/A	TRUE	3345	0		-127.00		-6.00		
5	32.53077	-106.79427	9:54:00 AM	N/A	TRUE	3732	53	45	-99.11	-103.32	21.89	40	-105.95
6	32.53123	-106.77997	10:09:00 AM	N/A	TRUE	5003	46	45	-102.79	-103.32	18.21	40	-105.95
7	32.53134	-106.77658	10:20:00 AM	N/A	TRUE	5309	0	38	-127.00	-107.00	-6.00	33	-109.63
8	32.50458	-106.84346	11:30:00 AM	N/A	TRUE	1844	52	47	-99.63	-102.26	21.37	35	-108.58
9	32.50347	-106.85069	11:42:00 AM	N/A	FALSE	2418	0	32	-127.00	-110.16	-6.00	35	-108.58
10	32.50309	-106.85331	11:55:00 AM	N/A	FALSE	2639	0		-127.00		-6.00		
11	32.50155	-106.84079	12:14:00 PM	N/A	FALSE	1979	0		-127.00		-6.00		

Date	1/20/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	Clear			
Temp(F)	**Humid (%)**	**Solar**	**Wind (mph)**	**Pres (inHg)**
45	43		calm	29.93

Table 25. Test Points at 300 ft AGL.

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.51320	-106.83720	8:09:00 AM	N/A	TRUE	756	63	52	-93.84	-99.63	27.16	37	-107.53
2	32.50797	-106.84278	8:35:00 AM	N/A	TRUE	1529	42	43	-104.89	-104.37	16.11	31	-110.68
3	32.52961	-106.80231	9:25:00 AM	N/A	TRUE	2996	59	58	-95.95	-96.47	25.05	40	-105.95
4	32.51810	-106.79499	9:34:00 AM	N/A	TRUE	3345	0		-127.00		-6.00		
5	32.53077	-106.79427	9:54:00 AM	N/A	TRUE	3732	44	42	-103.84	-104.89	17.16	35	-108.58
6	32.53123	-106.77997	10:09:00 AM	N/A	TRUE	5003	43	46	-104.37	-102.79	16.63	35	-108.58
7	32.53134	-106.77658	10:20:00 AM	N/A	TRUE	5309	42	41	-104.89	-105.42	16.11	32	-110.16
8	32.50458	-106.84346	11:30:00 AM	N/A	TRUE	1844	53	50	-99.11	-100.68	21.89	36	-108.05
9	32.50347	-106.85069	11:42:00 AM	N/A	TRUE	2418	54	50	-98.58	-100.68	22.42	42	-104.89
10	32.50309	-106.85331	11:55:00 AM	N/A	TRUE	2639	0		-127.00		-6.00		
11	32.50155	-106.84079	12:14:00 PM	N/A	FALSE	1979	0		-127.00		-6.00		

Date	1/20/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	Clear			
Temp(F)	Humid (%)	Solar	Wind (mph)	Pres (inHg)
45	43		calm	29.93

Table 26. Test Points at 400 ft AGL.

Test	Cntrl Position		Time	Op Check	DLOS	Distance	RSSI		Signal Stength (dBm)		Fade Margin	Noise Floor	
Point	LAT	LON	Local	Pass/Fail	T F	meters	Remote	Controller	Remote	Controller	Remote (dB)	RSSI	dBm
1	32.51320	-106.83720	8:09:00 AM	N/A	TRUE	756	60	60	-95.42	-95.42	25.58	32	-110.16
2	32.50797	-106.84278	8:35:00 AM	N/A	TRUE	1529	38	40	-107.00	-105.95	14.00	32	-110.16
3	32.52961	-106.80231	9:25:00 AM	N/A	TRUE	2996	57	56	-97.00	-97.53	24.00	40	-105.95
4	32.51810	-106.79499	9:34:00 AM	N/A	TRUE	3345	0	42	-127.00	-104.89	-6.00	35	-108.58
5	32.53077	-106.79427	9:54:00 AM	N/A	TRUE	3732	53	47	-99.11	-102.26	21.89	31	-110.68
6	32.53123	-106.77997	10:09:00 AM	N/A	TRUE	5003	44	44	-103.84	-103.84	17.16	35	-108.58
7	32.53134	-106.77658	10:20:00 AM	N/A	TRUE	5309	43	42	-104.37	-104.89	16.63	31	-110.68
8	32.50458	-106.84346	11:30:00 AM	N/A	TRUE	1844	54	54	-98.58	-98.58	22.42	39	-106.47
9	32.50347	-106.85069	11:42:00 AM	N/A	TRUE	2418	45	48	-103.32	-101.74	17.68	29	-111.74
10	32.50309	-106.85331	11:55:00 AM	N/A	TRUE	2639	0		-127.00		-6.00		
11	32.50155	-106.84079	12:14:00 PM	N/A	FALSE	1979	0		-127.00		-6.00		

Date	1/20/20017	
Rem Pos	32.51716	-106.83065
Recv Sens		-121

Clouds	Clear			
Temp(F)	**Humid (%)**	**Solar**	**Wind (mph)**	**Pres (inHg)**
45	43		calm	29.93

2.2.2.9 Conclusions

This field testing has demonstrated that real world RLOS conditions differ from the analytical models. While the mathematical models may attempt to replicate ideal conditions, there are site specific influences that can impact the actual link distances. The study that was conducted and the data that were collected that are documented here are by no means extensive enough to provide the exact specific limitations of the RLOS link distances, but they do provide enough information to help inform a user for potential safe operation. The following conclusions are drawn from this testing:

- The manufacturer supplied radio specifications under ideal conditions may overestimate the possible RLOS link distance in real world conditions.
- Generalized Longley-Rice models (in this case the Johnson L-R) without actual terrain elevation data require the operator to incorporate more than a single model estimated RLOS if area of operation spans multiple terrain types.
- The On-line Longley-Rice Tool overestimated coverage area based on the assumed input parameters. Fine tuning of the input parameters may improve this, but an average user may not be able to improve the inputs without testing.
- The Johnson L-R or the On-line Longley-Rice Tool may overestimate the possible RLOS link distance in real world conditions
- Inclusion of a significant link margin (15 dBm or greater) provides a closer estimate of a "safe" RLOS coverage area due to the complexity and variability of RF signal attenuation at low altitudes.
- Every sUAS may not be an optimal candidate for BVLOS operations due to variety of constraints such as battery life. In addition, as these tests have shown with the sUAS used in these tests link maintenance is critical to sustained sUAS operations. Although the FAA is allowing approximately 1300 sUAS to be used in 333 Exemption operations a determination of the utility of these systems for BVLOS operations has not been made.

Additional testing in different environments or geographies and with different radio system or frequencies may add to the knowledge base. This additional testing may be warranted. Further analysis of the collected data can also be performed using a code developed for the government called SAGE. This software is not commercially available, but NSMU has access to it and can perform additional checks and produce more detailed coverage maps. This was not done at this stage since the software is not available to all users. With the uncertainties shown, it is logical to choose a conservative approach in selecting a safe and reliable RLOS operational distance.

2.3 Operational Framework Technical Report and Assessment

2.3.1 Introduction and Background

The New Mexico State University (NMSU) and University of North Dakota (UND) Alliance for System Safety of UAS through Research Excellence (ASSURE) teams were tasked with researching Detect and Avoid (DAA) technology in Unmanned Aircraft Systems (UAS) that could enable Beyond the Visual Line of Sight (BVLOS) operation of small UAS weighing under 55 lbs (sUAS) within limited portions of the National Air Space (NAS) while achieving a level of safety equivalent to manned aircraft operating in a similar manner.

BVLOS is similar to Extended Visual Line of Sight (EVLOS) and other operations where the sUAS is not in the immediate proximity of the operator. In general, BVLOS is an operating environment where the sUAS is out of sight due to distance and the limitations of the human visual system. This section (2.3) is focused on providing an Operational Framework that defines the environment and conditions under which the recommended requirements will enable sUAS operations BVLOS. Although this framework may not be prescriptive nor does it include an exhaustive set of actions, the framework does include strategies that can build upon FAA and industry actions that should result in an increase in BVLOS flights in the near term. These strategies and the relevant research that should/must accompany them will help the USA expand BVLOS safely, effectively, and efficiently. Additionally, this framework has relevance to the future, 'will-be' state of technology—autonomous BVLOS operations without a human in the loop.

Considerations for BVLOS operations involve a number of interrelated elements that are needed for safe flight. These elements result in potential constrains on the systems and operations. The three elements of significant interest are 1) the conditions or locations in which one flies must be conducive to safe flight operations; 2) the operator must operate in a safe fashion; and 3) the aircraft themselves must be capable of reliable and safe BVLOS operations.

To put each of these elements in context a number of use cases were collected. These provided information on what types of BVLOS operations were envisioned by end users. A short summary of this and how it relates to formulating an operational framework is presented in the following section. A significant element in flight operations is the radio link. Radio Line of Sight (RLOS) testing was completed to assess estimation tools and potential limitations. It is clear that command and control should be maintained at all times, which by its nature implies a reliable and consistent radio link. In many ways, this becomes one of the driving factors in what can be done BVLOS.

A set of assumptions and limitations is presented to refine the framework. This initial set is based on best practices and gathered use case information, and presents a lowest common denominator upon which can be expanded in the future. Expansion could be via additional mitigations used (DAA for example), imposed self-separation, and/or contingency management.

Additional context is provided from looking at the Science and Research Panel (SARP) "Well Clear" definition for sUAS, the FAA BNSF (Burlington Northern and Santa Fe) Pathfinder Effort, and a number of international activities that are applicable and relevant. Some specific aircarft considerations are also included since not all approved sUAS are designed for or would be adequate or safe candidates for BVLOS operations.

2.3.2 Collected Use Case Information Considerations

Actual use cases can provide insight into potential BVLOS operations. A report titled "FAA Interim Technical Report, Small Unmanned Aircraft Systems Use Cases and Detect and Avoid Approaches" dated October 26, 2016 (revised January 18, 2017) was provided to the FAA to assess current use case information. This report captured sUAS use cases (applications of the sUAS) as well as DAA approaches for identifying aircraft in the immediate operating airspace. The capture of this information was envisioned to occur most effectively through a Request for Information (RFI) in the Federal Business Opportunity (Fed Biz Ops) web site maintained by the Federal Government. This call and response cycle produced some useful information, but it was clear that additional information was needed from actual and potential users.

To supplement the information from Fed Biz Ops, data calls were made to the Technical Analysis and Applications Center (TAAC) (operated by New Mexico State University) List Serve as well as published on an AUVSI website. The goal was to ensure that the distribution was as wide as possible to reach the entire community. It is believed that the RFI was distributed as widely as possible.

Of the use cases that were reported, most were for mapping, land/area monitoring, and straight line inspections. Use cases reported operating altitudes between 50 and 700 feet AGL, with the most typical operating altitudes were between 50 and 100 feet AGL. Use case airspeeds ranged between 6 and 33 knots, with an average speed of ~12 knots. No use cases reported actual in-flight climb or descent rates.

To supplement the data further, the 333 Exemption Holders information on the FAA website were all reviewed to elicit summary sUAS information. Summary information from more than 5,000 exemption holders was provided in the Use Case report. In addition, a unique request was sent to more than 4,400 333 exemption holders for information regarding their operations as well as potential DAA approaches. Information received as a result of that data call varied in its level of detail, but has provided relevant experiential information to generalize use cases. The descriptive categories provided for each response include the following:

Location
Platform
Takeoff Time
Flight Duration
Key Altitudes
Airspeeds
Climb / Descent Rates
Flight Patterns

The gathering of BVLOS use case information was a challenge. Since BVLOS operations for the most part were not authorized by the FAA, there were few that could be provided as actually tested cases. There were a number of areas where BVLOS operations are a natural next step for the particular operators and this information, where applicable, was provided. With all of the gathered information considered, and in an attempt to understand the data, defined uses were created to sort each docket by business use. Eleven general uses were identified, specified as follows:

- **Aerial Data Collection**
- Aerial Photography/Videography
- **Aerial Surveying/Mapping**
- **Agriculture**
- **Emergency Services**
- Flight Training/Education
- **Inspection**
- Marketing
- **Research**
- **Search/Rescue**
- **Surveillance/Monitoring, etc.**

Each of these use cases was further broken down into subcategories to allow additional definition. This is included in the Use Case report and is not repeated here. The numbers for the broad usage requests by category were detailed with the highest number of requests for Aerial Photography/Videography.

All of the general categories outlined above have potential BVLOS flight opportunities or applications. The ones shown in **bold** above are those that were identified through the responses as having either a specific, defined, or expressed pressing desire to fly BVLOS. It is not to say that these are more important than the others, it only indicates that, for example, there are operators now who could immediately expand to BVLOS missions/flights if given the go ahead. This is logical for applications like Agriculture, Mapping, Search/Rescue, etc.

Each of these use cases is different when one looks at the flight pattern. Inspection of linear infrastructure BVLOS flights would involve longer, straight, and narrow flight corridors. Agriculture-related BVLOS flights could be focused on repetitive, stepped-parallel flight passes to cover a wide area. These different applications point toward different considerations for the Operational Framework.

It should also be noted that there was a huge variety of vehicle types (close to 500 different UAS systems from the 333 approvals) and a large number of manufactures (almost 200 different manufacturers in the listings in the 333 approvals). For reference, most of the applications were for 4-copters (total of 6,586), followed by a similar number of requests for fixed-wing (818), 6-copter (726), and 8-copter (879). There were 153 different 4-copter platforms requested. Not all of these should be considered equal in terms of quality, reliability, or performance. This variation alone has implications regarding what can or cannot be considered reasonable for safe operations. One size does not fit all when looking at this variety in forms, formats, and producers.

A take away recommendation for the framework is that not all BVLOS operations are the same and may not require the same sets of rules or approaches. For example, rules applicable for linear infrastructure BVLOS operations may be burdensome on other types of flight patterns and vice versa. These potential options need to be considered in the context of the technologies and equipment being used, and the flight operational plans executed.

2.3.3 RLOS Testing Considerations

One element that is required for the development of an Operational Framework is assessment of functional radio line-of-sight for real world applications. A theoretical model assessment was completed and documented in an August 2016 report to the FAA titled, "Test Plan for the Validation of the Radio Line-of-Sight Model for Small Unmanned Aircraft Systems". The approach was to verify this through field testing and to provide real world data for comparison.

The test location for the RLOS model validation is north of Las Cruces, New Mexico, on the Chihuahuan Desert Ranchland Research Center (CDRRC). New Mexico State University operates the CDRRC in order to protect and ensure availability of its resources for teaching, research, and extension endeavors that benefit the citizens of New Mexico as originally declared in Congressional Act S4910, 1927.

The CDRRC encompasses almost 100 square miles. This area is on gated, access controlled property owned by NMSU. The airspace of the CDRRC falls within the NMSU Flight Test Site, and the current FAA Certificate of Authorization (COA) also covers this airspace. NMSU/PSL has significant UAS operating experience with a variety of UAS platforms in nearby airspace for low-altitude operations and over this area for higher UAS operations. The terrain within the CDRRC varies from the Summerford Mountain to extended desert plains with no obstacles. The terrain consists of high desert scrub to the north and igneous mountains to the south. Creosote bush dominates the upper slopes of the mountains and the hills along the river, and at lower elevations the creosote bush type grades into either the mesquite type that grows on sandier soils or the tarbush type that grows on heavier soils. Ground vegetation is important to assessing RLOS due to its absorption. The population on the ground consists of a single residence at the Ranch headquarters approximately one mile from the tower, and cattle and wildlife are the only other inhabitants. A 100 ft tower is located at the operations center.

In the test plan report, various modeling approaches were discussed and it a RLOS range that may be achieved in applications of sUAS was developed. That propagation was modeled using the well-respected Longley-Rice Irregular Terrain Model (Longley and Rice 1968), which was developed by the U.S. Department of Commerce in 1968. The test plan addressed the data collection in a test setting to validate the developed model. There are a number of different approaches that can be used to assess the coverage. Both a simplified mathematical model based on a version of the Longley-Rice model and an online based Longley-Rice model were compared to actual field measurements to assess validity of the simplified input tools.

The field testing was completed and documented in an FAA Interim Technical Report titled, "Radio Line of Sight (RLOS) Coverage Field Tests with a 900 MHz Antenna (100 mW)". This report was submitted to the FAA on February 2, 2017. A summary of the finding is presented in the following paragraphs.

The static and flight test operations were centered at latitude 32.51716, longitude -106.83065, on the CDRR. Testing was performed between two 3DR radios (3DR v2 telemetry SiK radio with the stock antennas), operating at 915 MHz with 100 mW transmitters (20 dBm). One unit was placed at 1 m above ground level at various locations on the ranch. This unit was attached directly to a laptop computer running MavLink control software. This allowed the laptop to record the Received Signal Strength Indicator (RSSI) of both the control unit (laptop) and the remote unit. The second unit radio was either connected to a fixed pole for the initial testing or to a small UAS.

The initial static testing was performed with the remote unit mounted to a 20 ft tower/pole. These tests were designed to confirm the testing processes and procedures. The resulting data did provide a clear demarcation line of where the communication link degraded at distance. In the case of the UAS flights, a Pixhawk flight control unit was used and mounted as a payload below a quad-copter (remote unit), which was control operated at 2400 Mhz at a nominal height of 100 ft AGL. Test data were also collected at 200, 300, and 400 ft AGL.

Field results were plotted and compared to both an on-line calculator [one that incorporates the Longley-Rice (L-R) model, terrain databases, and user entries for the radio characteristics to produce detailed coverage maps], and a simplified Longley-Rice model developed by NMSU's E. Johnson. Based on field data, an estimated field observable RLOS coverage map was drawn for a visual comparison between the models and field observations.

Based on the limited sample and analysis time permitted, the results of the field test indicate that in the scenario flown the simplified model and the on-line calculator model provide estimations of RLOS coverage that are too coarse. The flight area consists of rolling plains to the north of the static test point and a rugged mountain range to the south. As the simplified model assumes a uniform terrain type (plains, hilly, mountainous, etc.), it cannot adequately account for a radio coverage area that spans multiple terrain types. This field testing has demonstrated that real world RLOS conditions differ from the analytical models. While the mathematical models may attempt to replicate ideal conditions, there are site specific influences that can impact the actual link distances. The following conclusions are drawn from this testing:

- The manufacturer supplied radio specifications under ideal conditions may overestimate the possible RLOS link distance in real world conditions.
- Generalized Longley-Rice models (in this case the Johnson L-R) without actual terrain elevation data require the operator to incorporate more than a single-model-estimated RLOS if the area of operation spans multiple terrain types.
- The On-line Longley-Rice Tool overestimated the coverage area based on the assumed input parameters. Fine tuning of the input parameters may improve this, but an average user may not be able to improve the inputs without testing.
- The Johnson L-R or the On-line Longley-Rice Tool may overestimate the possible RLOS link distance in real world conditions.
- Inclusion of a significant link margin (15 dBm or greater) provides a closer estimate of a "safe" RLOS coverage area due to the complexity and variability of RF signal attenuation at low altitudes.
- Every sUAS may not be an optimal candidate for BVLOS operations due to variety of constraints such as battery life. In addition, as shown with the sUAS used in these tests, link maintenance is critical to sustained sUAS operations. Although the FAA is allowing approximately 1300 sUAS

to be used in 333 Exemption operations, a determination of the utility of these systems for BVLOS operations has not been made.

Additional testing in different environments or geographies and with different radio systems or frequencies may add to the knowledge base. This additional testing may be warranted. With the uncertainties shown, it is logical to choose a conservative approach in selecting a safe and reliable RLOS operational distance.

There are a number of resulting recommendations for the Operation Framework from the RLOS testing. It is recommended that:

- One needs to be conservative due to potential overestimate using manufacturer's specifications for the RLOS link.
- If the potential flight area has mixed terrain, then the most conservative terrain estimate should be used.
- If there is an input value where the true or estimated value is not known, then the most conservative of the choices should be used.
- Inclusion of a significant link margin (15 dBm or greater) should be used for modeling.
- Additional RLOS testing would be valuable.
- Variations in equipment need to be considered. The FAA has approved over 1300 different vehicles under the 333 exemptions. Not all of these vehicles should be considered for BVLOS operations.

2.3.4 Assumptions and Limitations

The assumptions and limitations used for the studies and that are recommended for the Operational Framework have not significantly changed from what was originally proposed. There was a common sense to the original logic proposed and through further research and collection of data, these assumptions have held up to review and assessment. The review of the use cases and the results of the RLOS testing have reinforced the assumptions and limitations shown in Table 27.

Table 27. Assumptions and limitations for BVLOS operations.

1	Operation time	Daytime only (no nighttime operations)
2	Meteorological Conditions	Visual Meteorological Conditions (VMC) operations only
3	Airspace	sUAS operations will initially be limited to Class G and Class E airspace. Additional airspace may be evaluated as necessary.
4	Altitude	sUAS operations will be conducted from the surface to 500' AGL
5	Overflight	sUAS operations will be conducted over other than densely populated areas, unless UAS complies with potential criteria or standard that demonstrates safe flights over populated areas.
6	Airport Operations Limitations	UAS will not be operated close to airports or heliports. A distance of greater than 5 miles is recommended. Exceptions would be for permission granted from ATC or airport authority for operations within those areas either directly supporting the airport or heliport or other specific approved need.
7	Critical Operations Limitations	UAS will not be operated close to critical infrastructure such as power plants, dams, etc. A distance of greater than 3 miles is recommended. Exceptions would be for permission granted from ATC, airport authority, or governing organization of the infrastructure for operations within those areas either directly supporting the critical infrastructure (ex. an Electrical utility company inspecting their own equipment) or other specific approved need.
8	Operational Control	UAS operations will be restricted to within radio line of sight (RLOS) of a single, fixed ground-based transmitter. No "daisy chaining" of controls or handoffs of flight control would be allowed.
9	Vehicle Visibility	It is recommended that some safety-based design and/or configuration requirements be used. These include aircraft painted in a highly-visible paint scheme to facilitate identification by other aircraft, strobe lights, etc.

It would be beneficial if the sUAS were all designed to an Industry Consensus Standard and issued an FAA Airworthiness Certificate or other FAA approval. As noted in section 2.3.3 above, a very large number (approximately 1,300) of sUAS have been approved by the FAA under the 333 Exemption operations alone. New vehicles and new versions of the approved vehicles are being introduced regularly. While it would be good to have some consensus standard or defined FAA approval, this is likely not possible due to the sheer number of vehicles being used.

There are some options to expand these assumptions in the future. These would include assessment of potentials such as night operations, different classes of airspace, different meteorological conditions, higher altitudes, using multiple transmitters with handoffs, etc. These will require another level of assessment.

The assumptions and limitations above provide a clear set of bounds for couching an initial Operational Framework for safe operations BVLOS.

2.3.5 Additional Considerations

With this dynamic field and the continual introduction of new and innovative approaches, there are some additional considerations that are applicable to formulating the Operational Framework. These additional considerations are noted in the sections below. One refers to demonstration from over 10 years ago that is applicable to potential use cases. Also included are some considerations from the recent SARP "Well Clear" for sUAS recommendations, the FAA BNSF (Burlington Northern and Santa Fe) Pathfinder effort, some international activities, and a few other aircraft considerations.

2.3.5.1 Unmanned Aerial Vehicle Systems Operations and Validation Program (USOVP) Southwest Border Demonstration

A variety of use cases have been identified for sUAS. The changing regulatory climate, sUAS interest, and cost points have made sUAS attractive to a variety of different users. Although this current FAA BVLOS effort has identified a variety of sUAS use cases, one UAS demonstration that occurred in December 2004, the Southwest Border Demonstration, developed several general uses for UAS applications in the NAS, other than for DoD, that are still relevant today (Copeland et al. 2005). Although sUAS were not used for this demonstration, the general use cases (point, pattern, and wide area surveillance/observation) are relevant to the sUAS BVLOS framework. The following background, process description, and outcome describe within a general taxonomy the general use cases and a portion of the framework that came from the Southwest Border Demonstration.

The UAS Systems Operations and Validation Program (USOVP) was established, by Congressional mandate, to develop airspace and procedures to support UAS flight tests in the NAS. The USOVP was a federally funded program intended to pathfind UAS flights between New Mexico, Alaska, and Hawaii. NMSU had previously conducted UAS flights in New Mexico, but all flights had remained in the local Las Cruces airport traffic area. Local and regional UAS flights also had been conducted at various locations in Alaska as part of USOVP. The Southwest Border Demonstration served to expand the existing UAS operating envelope by incorporating flights in the regional airspace along the international border in southern New Mexico.

The Southwest Border Demonstration was conducted from 10 to 16 December 2004 south-southwest of Las Cruces, New Mexico, by the NMSU Physical Science Laboratory (NMSU/PSL). Day and night UAS missions were conducted in the airspace of the southwest border region. The demonstration concept was designed to safely perform UAS flights in the NAS as would occur if civil UAS missions were being conducted. An incremental approach was used, with each mission becoming more complex as it was conducted. The demonstration scenarios were designed to highlight the enhanced operational capabilities offered by UAS and demonstrate their application to the various civil, emergency, and law enforcement missions performed at that time in the southwest border region and elsewhere in the NAS.

In order to develop the most robust use case scenarios over 30 different Federal, State, local government, and civil organizations were gathered. These organizations provided the necessary safety and accuracy for the demonstration. Teaming with national, state, and local government agencies was essential. Organizations that supported the scenario development input included:

- Air Force Research Laboratory (AFRL)
- The Federal Aviation Administration,
- Federal Communication Commission
- DOD Area Frequency Coordinator
- NM Director of Homeland Security
- Federal Bureau of Investigation
- U.S. Customs and Border Patrol (ICE)
- NM State Aviation Division
- DOI/Bureau of Land Management
- JTF North
- NM Border Authority
- NM State Police
- Doña Ana County Sheriff's Office
- New Mexico Tech
- Las Cruces City Airport Manager
- USAF 46th Test Group
- SAIC
- General Dynamics Ordnance and Tactical Systems
- Brandes Associates, Inc

In addition to the above other organizations involved with general civil activities also participated.

2.3.5.1.1 Mission Overview

The Southwest Border Demonstration was designed to display the capability of safely operating UASs in the regional airspace along the southwest border between the United States and Mexico and to integrate the UAS flights with local civil and law enforcement agency operations. NMSU employed a crawl-walk-run approach in executing the demonstration, beginning with basic flight maneuvering and navigation and progressing through an increasingly complex mission plan. A total of five flights, two check-out and three missions, were conducted during the demonstration. The checkout flights were conducted to verify that the UAS airframe and sensor were functioning correctly. A route navigation flight was conducted to confirm control links and sensor data transmissions over the planned operating routes.

2.3.5.1.2 Scenarios

Demonstration flights encompassed a series of modular scenarios. Modular scenarios, termed Scenarios A, B, and C, were designed to address the demonstration objectives and allow the integration of lessons-learned from prior flights. Demonstration missions were planned to incorporate a combination of scenarios during the course of the flights. Each scenario represented a different type of operational monitoring activity that is applicable to a variety of different use cases, including point, line, and wide area surveillance. Tasks performed during flights included:

(1) Line observation of power lines, roads, and railroad tracks,
(2) Open area observation of farms, open range, forest, lakes, and cattle, and
(3) Tracking of vehicles, aircraft, and people.

Since the scenarios were modular in design, they could be accomplished in any sequence, or could be repeated or skipped at the discretion of the mission commander, allowing for flexibility in attaining overall demonstration objectives. Depending upon the situation, a mission flight may include all four scenarios, or a single scenario repeated several times. The mission commander selected the scenarios to be accomplished during each flight based upon results of previous flights, feedback from homeland security representatives, and progress in attaining demonstration objectives. Each of the four scenarios including the operating locations, scenarios, and demonstration events are included in the paragraphs that follow.

2.3.5.1.2.1 Scenario A: Border Patrol Checkpoint

The United States Customs and Border Protection (CPB) Agency checkpoint west of Las Cruces on Interstate 10 (I-10) was the focal point of the Scenario A. The UAS established an orbit beginning two miles west of the I-10 check point and extending three miles past that point. During the scenario, a test vehicle with four personnel traveled west on I-10 and stopped along the highway ¼-mile east of the checkpoint. Two people (simulated targets) exited the vehicle and proceeded on foot to the north and west, walking around the border patrol checkpoint and then south back to I-10. The vehicle then proceeded through the checkpoint and continued westbound for ¼-mile where it awaited the arrival of the simulated targets that were walking around the checkpoint. Related to Border Checkpoints the described situation is informally referred to as "walk arounds" and is performed by persons trying to avoid Border Patrol Agents. During the scenario, the payload sensor was observed by CBP personnel in the checkpoint. CBP Agents monitored the two simulated targets walking around the checkpoint, as well as the accompanying vehicle as it passed through the checkpoint and subsequently picked up the two people after they returned to the road.

2.3.5.1.2.2 Scenario B: Designated Point Surveillance

The UAS was commanded to a designated location in order to investigate a suspicious vehicle. The UAS established an orbit and eventually tracked the ground vehicle. Once the orbit was established, a second ground vehicle arrived at the location, exchanged passengers, and both vehicles departed in different directions. The UAS tracked and followed the first vehicle as it traveled from the designated point back to the airport.

During one night mission, the demonstration team was directed to listen, look, and report when they heard the UAS. This was done to obtain an estimate on detecting the UAS at night for law enforcement agencies.

2.3.5.1.2.3 Scenario C: Designated Line Surveillance

The UAS was commanded to a designated location along a railroad track, identified as Aden. The UAS established an orbit between Aden and a second point on the railroad track identified as Lanark. The UAS maintained the correct VFR (Visual Flight Rules) altitude while orbiting between the two points (Aden to Lanark). The payload operator scanned the railroad track and the vicinity for activity of interest. Real-time diversions from the established orbit to investigate items of interest were coordinated by the mission commander.

2.3.5.1.2.4 Scenario D: Border Surveillance

The UAS was commanded to a designated location approximately three miles north of the international border. The UAS flew a track that paralleled the border until reaching the designated turn point. Upon arrival at the turn point, the UAS made a 180° turn to the north, adjusted altitude, and flew the same track in the opposite direction. The payload operator performed wide area scans with the UAS sensor package to identify areas and activities of interest. Areas of interest were investigated by the UAS in an orbit mode.

2.3.5.1.2.5 Scenario E: Diversion Scenario

The diversion operation occurred while performing any one of the other general scenarios or use cases. The Mission Commander was provided the general location of a target from the CBP. The Mission Commander tasked the UAS crew to locate the target and provide assistance/information to the CBP Agent. When the target was located using its sensor, an attempt to track the person and/or vehicle was made while assisting Agents in directing CBP assets to make contact with the target.

2.3.5.1.3 Conclusion

The FAA COE Task A2 has determined a variety of use cases for potential BVLOS. The Southwest Border Demonstration developed scenarios and use cases based upon input from over 30 different constituent organizations. A unique outcome from these use cases was their further classification into three broad use cases: **point, line, and wide area surveillance/search**. The ability to map use cases into a general taxonomy has merit and allows dealing with the different sUAS BVLOS more efficiently and effectively. In addition, there are numerous similarities within the broad taxonomies that are shared such as takeoff, enroute, and landing which allows another grouping of common requirements for analyses and research. The ability to summarize use cases, missions, and portions of similar flight profiles allows more global vs. granular comparison and may facilitate a more general regulatory approach capturing large numbers of sUAS BVLOS uses.

2.3.5.2 SARP "Well Clear" for sUAS

The SARP was charged with developing a well clear definition for sUAS operating at low altitudes. This process followed the one previously developed for the initial recommendation for well clear for other-than-small UAS. This is discussed herein in §3.2.1. The SARP-recommended well clear definition is a "hockey puck" shape that requires 2000 ft horizontal and 250 ft vertical separation for sUAS.

In addition, Weinert (2016) provided details regarding the approach to developing the recommendations. The then current definition of well clear for sUAS needed to be extended to BVLOS. This new definition was to be based upon risk, unmitigated, and operational suitability. Risk modeling was performed that required the development of low altitude encounter models that did not exist. An outcome of the modeling was that risk was not sensitive to the assumptions, which was attributed to slow sUAS airspeeds.

2.3.5.3 FAA BNSF Pathfinder Effort

The FAA has a number of pathfinder efforts targeted at specific areas to explore commercial use of UAS beyond operations proposed in its draft UAS rule. CNN is researching visual line of sight operations for newsgathering in urban areas. PrecisionHawk is investigating agricultural operations for rural areas, flying outside line of sight. The PrecsionHawk effort is in many ways the type of mission identified as a highly desired application for BVLOS flights from the surveys completed.

The FAA tasked Burlington Northern and Santa Fe (BNSF) Railway, the second-largest freight railroad network in North America, with inspecting rail infrastructure (e. g., opportunity to diminish derailment risk) beyond visual line of sight. BNSF operates 32,500 miles of track. The pathfinder effort with BNSF Railway is focused on BVLOS operations in rural, low risk, well defined locations. These series of flights with BNSF Railway were designed to show how UAS can enhance the safety of critical infrastructure by aiding with inspections such as:

- Continuous overflight of assets
- Tunnel and bridge inspections
- Track inspections
- Track integrity flights

A goal was to improve inspections and keep employees out of harm's way and harsh conditions. BNSF worked with Insitu ScanEagle for this pathfinder.

These initial pathfinder flights took place in New Mexico and overflew some of the BNSF rail lines. This concentrated inspection of rails, rail beds, etc. was an excellent application of BVLOS flights within a well-defined operational area. BNSF Railway was exploring command-and-control challenges as part of their infrastructure inspections. This specific application of BVLOS flights operations in rural or isolated areas required an extensive infrastructure. While this is an excellent example of a well-defined and executed plan for BVLOS operations, it is resource intensive: microwave/fiber optic, physical plants, spectrum assets, legacy train control systems, and existing towers for new aviation communication (Graetz and Guterres 2016). This unique example may not be applicable to other operations. This application is noted here because it does involve BVLOS operations but may not be germane to many potential users who are small businesses and do not have this level of infrastructure.

2.3.5.4 International Activities

Within the USA the FAA originally authorized the Pathfinder efforts to help facilitate sUAS activities to include BVLOS. These were not the only BVLOS flights that were taking place, especially when considering the international scene. Within New Zealand a sUAS operator can fly BVLOS with a certification, and the same is true in Poland. In addition the Polish Civil Aviation Authority also requires training that extends beyond theoretical to obtain a certificate. These international activities have value-added information since many of these systems are commonly used around the world.

2.3.5.4.1 Canada

The Canadian Aviation Regulation Advisory Council (CARAC) Unmanned Air Vehicle Systems Program Design Working Group has developed recommended practices and guidelines for sUAS operators for BVLOS (Baillie et al. 2016). The plan is for these recommendations to be turned into regulations for sUAS depending on Transport Canada's approach. The process for developing the candidate regulations has been divided into four phases defined by UAS weight, VLOS, and BVLOS. The remainder of this section describes the current Canadian guidelines, which are not yet regulations.

A general prerequisite is that a sUAS operator seeking to operate BVLOS for the first time must have a safe record and be a compliant VLOS operator. Additional details on the Canadian recommendations are provided in Table 28.

Table 28. Canadian sUAS operator's requirements to operate BVLOS.

Requirements	Detailed Parameters
Age	18 years
Medical	Cat 4 declaration
Knowledge	Ground school course to include: air law and procedures, flight instruments, navigation, flight operations, meteorology, human factors, theory of flight; and passing grade on test.
Experience	Within 24 months received practical UAS training and manufacturer training with assessed satisfactory proficiency.
Skill	An instructor letter certifying the pilot has demonstrated normal and emergency procedures.
Credits	Private pilot's license or higher satisfies the knowledge requirement, active and retired Canadian forces pilots also satisfy the knowledge portion, active and retired Canadian forces pilots with UAS qualifications satisfy knowledge, experience, and skill requirements.
Pilot Recency	Acted as pilot within past 5 years from date of planned flight, met the requirements for the permit within the past 12 months, and active as pilot within the past six months for both day and night operations.
Flight Instructors	Meet all the above requirements and possess 50 flights or six hours of flight time including instruction techniques, solo, and night operations.

There are additional requirements for BVLOS under reduced visibility VFR, night VFR, and IFR. While the operator requirements are likely of interest to some, the reader should focus on a few points that the Canadians have included in their guidelines to date. An occlusion of the sUAS (even behind a building) is BVLOS. Also, night and reduced visibility flights are allowed, which have an impact on see and avoid and its associated technologies.

Other sections of the Canadian guideline address a variety of operator and organizational recommendations. Of particular interest is the sUAS design standard included in the guideline. Presently, no design standards exist for sUAS BVLOS in the USA. As stated elsewhere in this report, the FAA has authorized well over 1,000 separate sUAS for 333 exemptions in the NAS; however, no distinction has been made for sUAS that may be optimized for BVLOS or that meet some minimal operational capability. The proposed Canadian design standard for sUAS for VLOS and BVLOS operations includes the following systems:

- Navigation
- Autopilot
- Radio communication and lost link
- Sense and avoid
- Lost link
- Flight termination
- Systems and equipment
  - Air speed

  - Pressure altitude
  - Direction sensing
  - Ground/surface feature and cloud detection
  - Launch and recovery
  - High intensity radiated fields
  - Lighting
  - IR
- Payloads

Newer proposed sections specific to BVLOS include C2 (Command and Control), navigation, autopilot, radio communications, and control links.

The minimum system capabilities required for VLOS operations are defined by Canadian Aviation Regulations. Twelve capabilities are required, and many of those can be achieved by direct visual observation such as remaining clear of clouds. For day BVLOS operations, all of the VLOS capabilities are recommended except those for night operations, and 18 additional recommendations have been proffered. For night VFR, 6 additional recommendations are proposed, and for BVLOS IFR, the recommendations include those for night VFR as well as 5 additional capabilities. The Canadian approach has produced a set of recommendations that do specifically address sUAS design requirements. The document also addresses the entire system to even include organizational requirements. The detailed parameters included in the Canadian document were not technically evaluated or validated; however, this type of document does provide a more holistic systems approach to overall sUAS requirements for these unique BVLOS operations. A regulatory body may not be desired, but these types of details, if adopted by industry, should produce a sUAS tailored to BVLOS applications.

Transport Canada has reviewed the guide. In addition, in late 2016, Transport Canada approved the Foremost UAS Range in Alberta as the first range for BVLOS operations.

Unmanned Systems Canada published the best practice guide for sUAS operating BVLOS that has been reviewed by Transport Canada. In addition to the Canadian activities, several other countries have approved the first UAS BVLOS operations in their airspace in the last few years. The Israelis have also approved the first autonomous BVLOS flight without a pilot. These additional country examples are not an exhaustive review of all sUAS BVLOS activities but do illustrate that there are activities around the globe.

2.3.5.4.2 Switzerland

The country's Federal Office of Civil Aviation (FCCA) granted a country-wide BVLOS authorization to senseFly. The first of its kind permission includes the following restrictions: altitude of 500 feet AGL, 1000 feet over urban areas, and the required use of visual observers specifically monitoring a 2 km radius of airspace for other aircraft. With this permission, a danger area no longer will be required for BVLOS operations by senseFly.

2.3.5.4.3 Denmark

The first approved BVLOS sUAS operation was granted in 2017 to Heloscope from the Danish Transport Agency. The BVLOS use case is power line monitoring. The sUAS will operate along a pre-programmed route with a human monitoring the flight and available to take over the flight if necessary. This first Danish BVLOS activity includes participation by the University of Southern Denmark, the University of Aalborg, the Danish Transportation Construction Agency, the UAS operator Heliscope, and the imaging software company Scapito.

In addition, UAS Denmark has been created as an international test center. Part of its mission is to specifically accommodate BVLOS testing.

2.3.5.4.4 Norway

The Norwegian Civil Aviation Authority issued permanent national approval to the IRIS Group in 2017 for BVLOS of powerline inspections in all of Norway. Other entities involved with this action include eSmart Systems, which has the stated long-term goal of autonomous BVLOS airborne powerline inspections.

2.3.5.4.5 Finland

In August 2016, the first international cargo flight took place between Hanko, Finland, and Haapsulu, Estonia. The air distance between these two countries is 108 km, but traffic patterns extended the flight distance to about 150 km. This flight took place in a closed airspace corridor for the BVLOS flight. The altitude permission for the corridor that was obtained was for 2000 ft AGL and the corridor was 3 km wide. The UAS that was operated for the first UAS BVLOS flight was the AR3000. A planned handoff of the ground station control occurred mid-way due to anticipated signal strength capability.

2.3.5.4.6 Israel

Airobotics was the first organization (in the world) to be approved to fly fully automated BVLOS by the Civil Aviation Authority of Israel (CAAI) without a pilot. Artificial intelligence and software replace the UAS pilot making decisions and taking action in flight. The Airobotics UAS was certified through a two-year process beginning in 2015. The Civil Safety Aviation Authority also has issued a license to Airobotics for commercial operations at a mining site in Australia.

2.3.5.4.7 United Arab Emirates

Nokia and the United Arab Emirates (UAE) General civil Aviation Authority entered into an agreement in 2016. The Nokia UAV Traffic management (UTM) concept will be used to manage UAS in and around cities in the UAE. The UTM system will facilitate automated flight permission, no-fly zone control, and BVLOS flights.

2.3.5.4.8 China

China has issued rules applicable to civil UAS, including BVLOS operations. These rules are consistent with both current FAA and EASA (European Aviation Safety Agency) direction. Night operations are authorized for BVLOS but not VLOS. Air route priority is always for manned flight. ICAO-relevant (International Civil Aviation Organization) standards are applied for emergency situations during UAS BVLOS flights. China's rules make continuous reference and use of the cloud.

2.3.5.4.9 Australia

CASA (Civil Aviation Safety Authority) has allowed both EVLOS and BVLOS testing since 2014 for package delivery. CASA granted permission for ongoing BVLOS flights as early as 2016. To date, BVLOS flights have taken place in remote areas with no people or infrastructure in the immediate area. CASA requires an assessment of the planned airspace, including other users, the local environment, anticipated weather, aircraft performance, and communication performance. One operator—Geometric Technologies—conducted a series of BVLOS flights in 2016 with the use case being easement inspections for vegetation encroachment and power line monitoring with the DT-18 UAS.

2.3.5.5 Other Aircraft Considerations

It is worth noting again that the actual aircraft that could be used for BVLOS operations are not of the same quality or have the same level of maturity. The FAA has approved well over a thousand aircraft under 333 exemptions. Not all of these are capable of BVLOS operations due to flight time, batteries, communication links, and more. Not all of these should be considered as candidates for BVLOS operations. There has been no conclusive research done that assesses the different designs or any of the structural or operational considerations.

Research was completed under an ASSURE task titled 'Surveillance Criticality for SAA–Low Altitude Operations Safety'. This work was completed by a team of Universities led by North Carolina State University. This research was designed to develop a safety assessment process to determine the contributions of technology, pilots and controllers in aircraft separation assurance and collision avoidance. This assessment was used in an operational UAS Con Ops to evaluate the potential hazards, failure modes, effects, and criticality of selected ABDAA (Airborne Detect And Avoid) technologies. The technologies that were studied included TCAS, ADS-B, GBSAA (Ground Based Sense and Avoid), and Cellular based SAA (LATAS). The impacts were focused toward RTCA (Radio Technical Commission for Aeronautics)/ASTM (American Society for Testing and Materials) F-38, UTM (Unmanned Aircraft Systems Traffic Management), and ADS-B spectrum management strategies. This work pointed out some specific technology limitations of the electronic systems related to performance and reliability. For example, data reliability and dropouts can significantly impact required well clear distances if this is the only data source received BVLOS. These studies to date define some considerations, but do not fully define what specific vehicles are or are not capable or should be allowed to perform BVLOS. This proves to be a challenge when trying to define an Operational Framework that can be applied to all sUAS since all sUAS are not intrinsically equal or the same.

Not unlike for manned aircraft that operate at different altitudes, or have more than one engine, varied passengers, etc., a sUAS that is going to be operated BVLOS needs definition of what minimum equipment and capability list is necessary for safe operation. This list can come from a variety of sources such as RTCA, ASTM, another consensus group, the FAA, etc. Similar to the Canadian document and other international initiatives, the majority of regulators and users appreciate that a BVLOS sUAS does need different attributes than a VLOS "utilitarian" sUAS.

2.3.6 Operational Framework Overview

2.3.6.1 Strategies and Recommendations

The goal of the Operational Framework is to define the environment and conditions that will enable sUAS operations BVLOS. The use case information noted above provides a number of different potential operational environments. Most of these have been limited in geographical distance due to the initially imposed LOS requirement from the FAA. The specific use cases that explore BVLOS have not yet been pushed into the mainstream. From a top level perspective, the cases and the resulting framework must meet the listed assumptions and limitations defined in §2.3.4 above. This provides a starting point. Some or all of these assumptions and limitations can be expanded upon as desired, but this initial set provide a solid starting point.

Extracting from almost all of the use cases gathered, they involved operations primarily conducted from the surface to 500' AGL. There was little information that went up to 1,000' AGL. It was a significant challenge to gather functional and performance information on the vehicles and operations that could inform both the functional requirements for the UAS and the potential threat posed from other users of the operational environment.

The Operational Framework for potential sUAS BVLOS operations has three interrelated elements that are needed for safe flight. The conditions or locations in which one flies must be conducive to safe flight operations, the operator must operate in a safe fashion, and the aircraft themselves must be capable of reliable and safe BVLOS operations.

The recommended Operational Framework constraints follow the assumptions and limitations noted in regard to operations time, meteorological conditions, airspace, altitudes, and overflight. Operational control by one single operator within RLOS of a single, fixed ground-based transmitter limits the physical distance one can operate a sUAS, but does remove any potential hand off issues that can be a system reliability issue.

The recommended constraints, based on the assumptions and limitations for the operational conditions are as follows:

- Daytime operations
- Visual meteorological conditions
- Class G and Class E airspace
- Surface to 500' AGL

The operator must operate in a safe fashion. When looking at how a sUAS pilot flies, there are a number of elements beyond the normal flight training or legal considerations that provide additional constraints:

- Overflight over other than densely populated areas
- Operations greater than 5 miles from an airport
- Operations greater than 3 miles from critical infrastructure
- sUAS operations restricted to within RLOS of a single, fixed ground-based transmitter
- Aircraft should be made as visible as possible
- Phases of flight (see below)

There are some exceptions to the above as noted for example when doing inspections of critical infrastructure or airports when arranged for by the controlling entity.

The different phases of flight can necessitate different operator interactions. Takeoffs and landings are critical operational periods and it is recommended, for safety reasons, that they take place within LOS of the operator. Departure, enroute, and operational phase flight plans should be designed to fly at minimal reasonable flight altitudes to avoid any potential GA (General Aviation) aircraft, and far from any margins where one meets a geographical or population risk. For example, a system failure or operator error should not result in the aircraft flying over people or over an airport by accident.

Just as the phases of flight can necessitate different operator interactions, the use cases appear broad but can be condensed to make research, communication, and recommendation/regulatory development streamlined. Whether the SARP, USOVP, or another taxonomy is used, all use cases can generally be categorized into a three to five general use case types. This classification and decomposition should be done with the existing potential use cases as well as new ones that are discovered.

Big areas of potential uncertainty are the capability and reliability of a sUAS. This is a significant concern. As noted above, not all sUAS are equal when comparing the quality, construction, and reliability. There is a potential danger in allowing all aircraft that have been approved under the 333 exemptions to be used for BVLOS operations. A desire may be to be as open as possible with aircraft to be used for sUAS applications and potential use cases. Coupled with this is the foundation of flight safety that must be at the core of all BVLOS operations. To that end, it is recommended that all sUAS used for BVLOS be potentially designed to an Industry Consensus Standard and/or issued an FAA Airworthiness Certificate or other FAA approval. This may be the only way to ensure that BVLOS operations can be done with equipment and systems that are capable of safely performing BVLOS operations. Commercial electronics and other systems are typically built to set standards for safety and operation. This would be a similar approach.

The variability in the systems and components makes this area a challenge. Even with clearly defined well clear definitions, a few missed update packages on location for example can cause issues. sUAS performance related to airspeeds, endurance, maneuverability (climb rates, descent rates, turn rates, etc.) is published by some manufacturers, but there is no specific accountability or checks made to ensure that the actual aircraft meets the published standards. An Industry Consensus Standard and/or issuance of an FAA Airworthiness Certificate or other FAA approval would provide a level of accountability for performance related items.

The inclusion of a DAA system can mitigate some of these concerns. There are a number of potential approaches proposed for this. A list of both GBSAA and ABSAA (Airborne Sense And Avoid) manufacturers and systems was gathered and provided to the FAA. The solutions are varied and attack the problem from a number of different technology angles. This area has an ever evolving technology base and it is difficult to define the DAA system requirements, performance, reliability, communications range and reliability, sub-system redundancy, overall system latency, sensor performance, and notification and alerting—and all within acceptable SWaP (Size, Weight, and Power) restrictions. Cost is a consideration when looking at all of these potential approaches. The most informed way of assessment is through testing. This is proposed for follow on efforts. Flight testing will help further identify any constraints related to collision avoidance (CA), self-separation (SS) minima, and contingency management.

From a safety standpoint again, a number of potential approaches could be employed to assess risk and decision processes related to risk acceptability. Real time or mission planning/related risk management tools were not explored, but can be developed as part of the Safety Management System (SMS)/Safety Risk Management (SRM) work performed herein (§3.4). The SRM assesses a large number of potential conditions (~250), but not all are valid for all conditions.

2.3.6.2 Summary

This section contains a summary of all of the primary strategies and recommendations to help facilitate sUAS BVLOS operations in the NAS:

1) Require a minimal set of limitations for BVLOS operations
    a. Operating time: daytime
    b. Meteorological conditions: Visual Meteorological Conditions (VMC)
    c. Altitude: ~500 feet AGL
    d. Overflight: no densely populated areas
    e. Airport proximity limitations: greater than or equal to 5 miles
    f. Critical operating limitations: greater than or equal to 3 miles of critical infrastructure
    g. Operational control: RLOS will determine distance; no daisy chaining of control stations
    h. Aircraft visibility: optimize color, lighting, and design for conspicuity
2) Develop a consensus-and research-based design strategy
3) Utilize common phases of flight to facilitate recommendations and potential regulatory input to the FAA
4) Develop a taxonomy and use cases that result in a manageable set of recommendations for regulatory and recommendation purposes
5) ASTM could lead the development of design and other data for BVLOS operations based upon current and proposed research
6) A DAA system—either airborne or ground-based—must be operational with the system

7) sUAS BVLOS operations in the NAS can take place without extensive and very expensive infrastructure
8) International operations and requirements should be considered in formulating the BVLOS requirements for the USA
9) Develop a more robust RLOS model for BVLOS
10) Utilize SMS to assess risk as BVLOS evolves
11) Utilizing candidate DAA and other enabling BVLOS technologies, develop, verify and validate test methodologies for these current systems and apply this to future systems
12) Anticipate that the near future will demand autonomous BVLOS without a human pilot

3 Comparison of Approaches

3.1 Pilot Visual See and Avoid (SAA) Performance

One of the tasks is a review of Visual Observer (VO) and pilot SAA performance to provide context relative to the performance of DAA systems, which are the focus of this effort. A very brief summary of previous work in this area is provided in this section. It is noted that Williams and Gildea (2014) provide an excellent summary of work in this area.

According to Antuñano (2002), humans have three types of vision, known as photopic, mesopic, and scotopic vision. Photopic vision occurs in daytime or in highly illuminated environments, when the eyes rely on the foveal cones to see and interpret sharp images and colors of objects. Mesopic vision occurs at dawn, dusk, or full moonlight and is characterized by a decrease in visual acuity and color vision. For these conditions, the foveal cones and rods are required to maintain normal visual performance for a given situation. Scotopic vision is similar to mesopic vision, but occurs in darker conditions, such as nighttime, partial moonlight, or low illumination conditions. These conditions create difficulties for the foveal cones to maintain the appropriate visual acuity and color perception. In these conditions, if an individual looks directly at an object for longer than a few seconds, the appearance of the object will diminish—this is known as the night blind spot. With the night blind spot, which owes to the absence of rods in the fovea and is 5-10° wide, an object being viewed directly at night can go undetected or fade after the initial detection. Thus, the average VO is expected to perform better in a highly-illuminated range versus a poorly-illuminated range.

As discussed by Antuñano (2002), the normal vision field extends upward 60° and downward 75°, totaling to a 135° field. The sharpest vision extends across about 1°, and occurs within the foveal field. The normal horizontal visual field varies due to its reliance on facial structures (e.g., noses can interfere with vision), and the foveal field is the central 1°.

A number of studies have been conducted to study pilot and visual observer performance. Crognale (2009) conducted four experiments to determine the effectiveness and aptitudes of VOs, including their ability to:

1) Detect a UA approaching head-on from an undisclosed direction,
2) Determine the distance and altitude of UA,
3) Evaluate detection distances under conditions of reduced uncertainty regarding the positions of UA, and
4) Estimate the potential for collisions between UA and other aircraft.

To test 1), two Scan Eagle UA (approximately 40 lbs and wingspan of 10 ft), one painted gray and the other orange, were flown. Observers wore earplugs to eliminate the noise that could lead to positional detection through acoustics and were told to look at the ground until the UAS had been positioned at one of eight directions from the observer (N, NE, E, SE, S, SW, W, or NW and about 1.5 km from the observer). Though no correlation with the color of the UAS was detected, this experiment yielded a detection rate of 97% and a mean detection distance of 327 m, with a range of 21 m to 1,400 m. With a detection distance of 327 m, this yields the potential for a 13 second window to formulate a plan and perform a collision avoidance maneuver. It is suggested that at least 12 seconds are required for an adequate risk assessment to be performed if there is potential for a collision, in order to safely preform an avoidance maneuver. However, for the Crognale (2009) study, if a successful detection is defined only as one that provides at least 12 seconds of response time, the rate of accurate detection drops to 49%.

The second experiment tested fourteen VOs using about two or three tests each to judge their ability to determine the altitude and distance of an UA. This experiment revealed that participants were relatively poor at determining both distance and altitude of UA. The average error in distance estimates was about 40% greater than the actual distance and altitude errors were about 60% from the actual altitude. The third experiment was conducted to evaluate detection distances under conditions where there were reduced uncertainties in UA position. This produced an average detection limit of 1,276 m for a UA as it flew away from the participants and an average 898 m detection distance for UA reacquisition. The final experiment tested the ability of VOs to estimate the potential for collision between UA and aircraft. The result of this experiment was the VOs were unable to estimate the potential for collision if they were unable to see both the aircraft at the same time.

Dolgov et al. (2012) considered temporal effects (e.g., dusk, night) and their overall impact on VO performance. They observed that there was no degradation in safety between day and night conditions, and measures of visibility favored night conditions.

Dolgov (2016) is one of the most recent studies. This study considered the ability of a VO to maintain visual contact with a manned aircraft, while at the same time maintaining visual contact with two small unmanned aircraft used in the study (AeroVironment, Inc. Wasp and Raven). In this study, VO performance during daytime operations was generally lower than for dusk and nighttime operations. This resulted mainly due to the accessory lighting of the sUAS and manned aircraft. For the manned aircraft (a light-sport, two seat aircraft having a wingspan of 8.5 m), the three observers were able to visually acquire it at average distances of 1.28 km (day), 2.02 km (dusk), and 2.09 km (night). These compare to 0.72 km (day), 1.0 km (dusk), and 0.83 km (night) for the Raven and 0.76 km (day), 0.56 (dusk), and 0.76 km (night) for the Wasp. Executing an avoidance maneuver is based on a reaction time to separate the approaching aircraft after detection, whether manned or unmanned, away from each other. Visual detection depends upon the approach speed and size of the two aircraft, along with other factors such as contrast of the aircraft against the sky or terrain, etc. In the Dolgov (2016) study, the time available for a safe maneuver of the sUAS away from the manned aircraft ranged from 32 seconds during the day to approximately 52 seconds for dusk and night operations. While this study was not specifically considering the ability of the manned aircraft pilot to detect the sUAS, it was reported that the sUAS were never detected by the safety visual observer on board the manned aircraft during the day or at dusk, and the larger of the two sUAS (Raven) was only detected during three of the nineteen night events.

In comparing individual pilot SAA to individual VO visual performance, Williams and Gildea (2014) concluded that individual VOs have several advantages:

1) VOs can dedicate up to 100% of their time to detecting traffic whereas pilots typically spend only 35% of their time on this task,
2) Conflicting traffic is more likely to be in relative motion to the ground observer than to the pilot of a manned aircraft, which is more likely to draw the attention of the observer,
3) VOs are less likely to have objects (e.g., cockpit obstructions) obscuring their view of traffic, although this could be offset by the empty-field myopia effect (lack of objects in a clear sky resulting on eyes focusing only a short distance from the observer).

Given these and the results of Dolgov (2016), one can conclude that for relatively small manned aircraft, an optimistic average detection distance for MA pilots is on the order of 0.8 miles during the daytime, with this distance increasing at night through the use of accessory lighting. (It is noted that this is based upon the literature examined herein, and does not include findings from Pathfinder Focus Area II.) As discussed by Williams and Gildea (2014) and Morris (2005), the actual MA pilot intruder detection distance in a given scenario depends upon many factors, including sky condition, cockpit obstructions, and interaction geometries.

3.2 Survey of DAA Criteria and Recommended Baseline Performance

This set of tasks is directed at establishment, for sUAS, of sensing distance criteria for collision avoidance and maintenance of well clear (self-separation). The focus here is on self-separation. Because of the scope of this issue, it was approached by leveraging efforts of other groups [e.g., RTCA SC228 (Radio Technical Commission for Aeronautics Special Committee 228) and SARP (Science And Research Panel)] and by supplementing these efforts with HWIL (HardWare In the Loop) simulation efforts.

3.2.1 Literature Review

3.2.1.1 RTCA SC228

The Science and Research Panel developed the initial recommendation for well clear for other-than-small UAS. As described by Cook at al. (2015), this recommendation is a modified tau (τ_{mod}) for horizontal well clear, with 35 seconds from collision or a minimum of 4000 ft separation, and a fixed vertical distance of 700 ft. This was accepted by RTCA SC228 for other-than-small UAS, and then was modified, with FAA concurrence, such that the vertical distance is reduced to 450 ft. The RTCA SC228 has used this well clear definition for other-than-small UAS to further develop concepts relative to well clear, including prediction of loss of well clear and TCAS interoperability.

3.2.1.2 SARP

The SARP developed the initial recommendation for well clear for other-than-small UAS. Subsequent to this, SARP was charged with developing a well clear definition for sUAS operating at low altitudes. A detailed description of this development is beyond the scope of effort and is being provided by SARP members. However, Investigator Askelson participated in this process. The following description is a high-level account of this process based upon that participation.

The development of a well clear definition for sUAS operating at low altitudes generally followed the same process applied in the development of the well clear definition for other-than-small UAS. However, efforts for sUAS operating at low altitudes were significantly limited by lack of data regarding how intruders commonly fly at low altitudes. These intruders are most commonly, in areas away from airports, emergency medical aircraft, crop sprayers, and possibly aircraft that have emergencies. Some data regarding these types of flights were obtained, but were limited. A combination of actual flight data and simulated flight profiles (e.g., for UAS flights at low altitudes) were utilized to help develop the needed well clear definition. The final result was risk based, with the risks of an NMAC given well-clear violation and of a MAC given NMAC determined through Monte Carlo simulations (with no assumed maneuvering to avoid either NMAC or MAC). Based on these, a risk-based definition for well clear that is solely distance-based was produced. The driver for use of a distance-based definition, as opposed to a time-based definition (tau), is the relatively low speeds of sUAS relative to intruders. This performance differential resulted in time-based definitions providing no significant advantages to distance-based definitions. The final recommendation is separations of 2000 ft horizontally and 250 ft vertically.

The development, during the period of performance for this effort, of a proposed well clear definition for sUAS operating at low altitudes was very significant. It informed both simulations performed in this effort (§3.2.3) and flight tests performed in this effort (§3.5).

3.2.2 Definition of Encounter Timeline and Elements

Understanding sensing distance requirements can be enabled by delineating the steps within the DAA function. Once defined and with associated durations for each step, one can estimate required distances given encounter closure rates. Moreover, definition of the encounter timeline and elements enables attribution of hazards to specific functions within DAA, which is the approach that is used in the Safety Management System (SMS)/Safety Risk Management (SRM) efforts presented in §3.4.

Previous work that was considered in the development of this timeline includes Coulter (2009) and Hottman et al. (2009).

The primary steps in this timeline are Detect, Track, Evaluate, and Maneuver. In the detection step, some means (e.g., an instrument like a radar) is used to sense the presence of something that must be avoided. The highest priority intruder is manned aircraft, but this could include fixed objects like towers, houses, trees, etc.

In the second step, Track, the path of the intruder is estimated. In the case of fixed objects, this is elementary. However, for moving targets, this step can be complex, and the accuracy of the resulting track depends both upon the behavior of the intruder and upon the accuracy with which the position(s) of the intruder are determined in the Detect step.

The Evaluate step involves determining whether the identified intruder poses a threat. Herein, "threat" is taken to mean that some action is required to either avoid violating well clear, as defined for sUAS operating at low altitudes, or a collision, which, of course, takes higher precedence. Numerous considerations are contained within this step, including determining whether something is a threat, determining which threats are of greatest importance (e.g., an aircraft vs. a fixed object), etc.

The final step in the timeline is Maneuver. In this self-explanatory step, one maneuvers ownship to avoid producing an unwanted state (e.g., violation of a well-clear boundary). Numerous factors must be considered in the determination of the maneuver that is executed. These include proximity (e.g., τ_{mod}), the type of intruder, whether multiple intruders are present, right-of-way rules, etc. The possibility of fixed objects constraining the path that one might take to resolve a conflict is captured by the "Constraints" oval in Fig 55.

For the primary steps in this timeline, some detail regarding "sub-steps" or "sub-functions" is provided. These provide some detail, but of course do not cover all of the sub-functions. The intent is to illustrate some of the essential sub-functions.

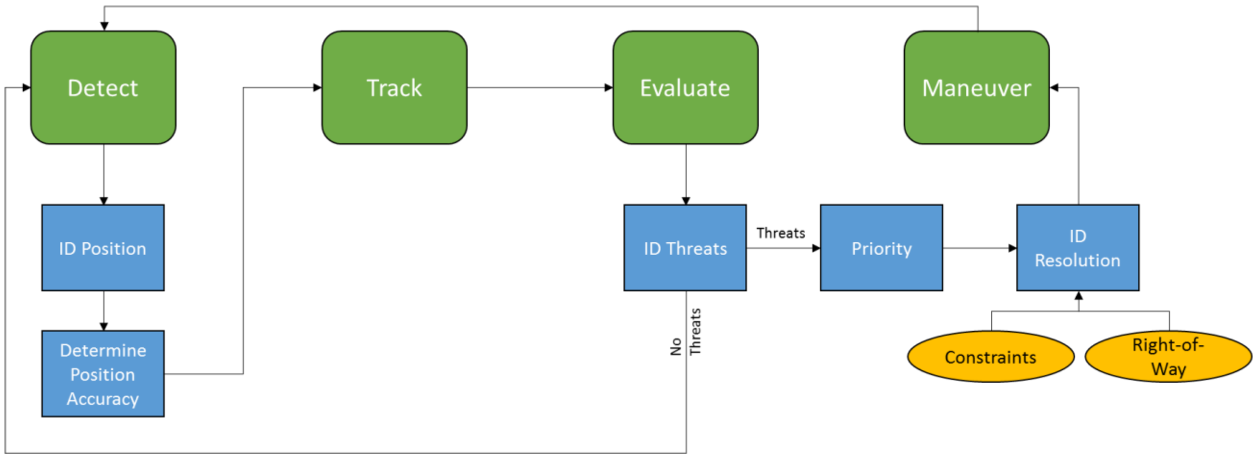


Figure 55. Illustration of the encounter timeline.

3.2.3 Estimation of Collision Avoidance and Self-Separation Thresholds

3.2.3.1 Introduction

Under the auspices of the ASSURE research partnership, the engineering team has contributed its efforts toward meeting specific goals in the A2 program by developing and using a real-time flight simulation testbed to evaluate multiple interactions between small UAS and manned aircraft. In creating simulation infrastructure and conducting a number of preliminary test encounters, this effort contributes to evaluation of requirements for DAA systems, specifically sensor system performance and high level understanding of well clear requirements for small UAS (FAA Sponsored "Sense and Avoid" Workshop 2009; Hottman et al. 2009; FAA Sponsored "Sense and Avoid" Workshop 2013; Cook et al. 2015).

The scope of the project is defined so that researchers may evaluate encounter dynamics when confronted with the performance characteristics of small UAS operating at low altitudes in uncongested airspace. The effort also provides abilities to model types of manned air traffic that will likely be encountered in day-to-day operation as well as the ability to evaluate relative advantages and limitations of different sensors, including GPS-based systems like ADS-B, radar systems, active scanning systems, and passive scanning systems.

Through this testbed, researchers may devise tests that combine interactions between the various limitations of sensors, UAS systems, human limitations, and other relevant metrics that may expose the effects of these interactions on small UAS flight safety. This testbed has already been employed to evaluate appropriate well-clear boundaries between UAS and traffic common to this environment.

3.2.3.2 Methods

3.2.3.2.1 <u>Simulation Testbed</u>

The testbed consists of a combination of off-the-shelf and custom software and hardware. Multiple systems are networked to perform a series of roles including the small UAS "ownship", an "intruder" aircraft normally operating as a general aviation airplane, a suite of sensor emulation functions, data and metrics recording functions, and an automatic avoidance algorithm organized as illustrated in Figs. 56-57.

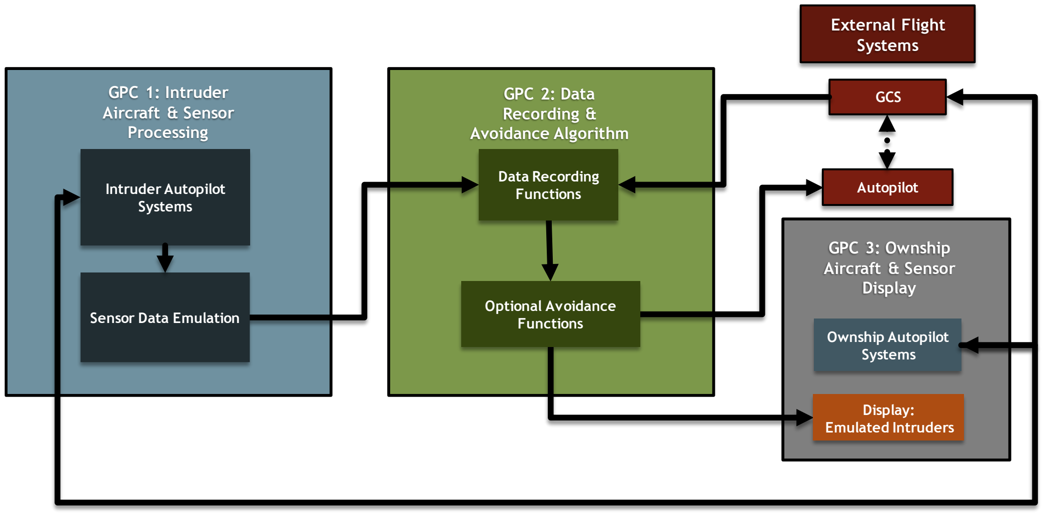


Figure 56. Testbed functions and hardware.

3.2.3.2.2 Hardware

The current configuration of the testbed's hardware is organized into three General Purpose Computers (GPCs) by their particular roles. All aircraft are simulated using Cloud Cap's Piccolo autopilot systems. Normally GPC 1 (Fig. 58) is used in a software-in-the-loop configuration (SWIL) to simulate one or more intruder aircraft and to filter intruder telemetry into a format consistent with different types of sensors. With telemetry feedback from "ownship" on GPC 3, the intruder operator may control intruder flight plans and trajectories as well as react to ownship's trajectories according to any given simulation scenario.

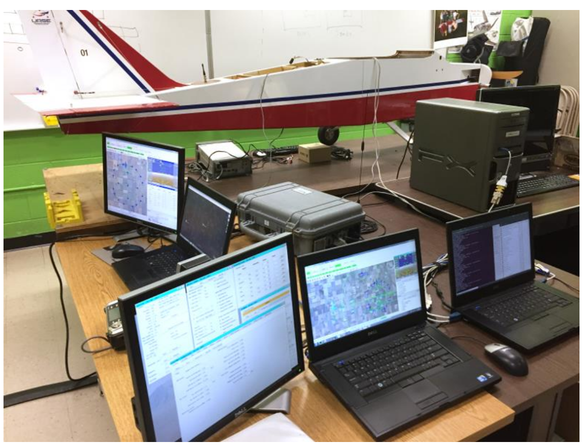


Figure 57. Full simulation testbed; GPC 1, bottom; GPC 2, right; GPC 3, upper left; external flight systems and GCS, top.

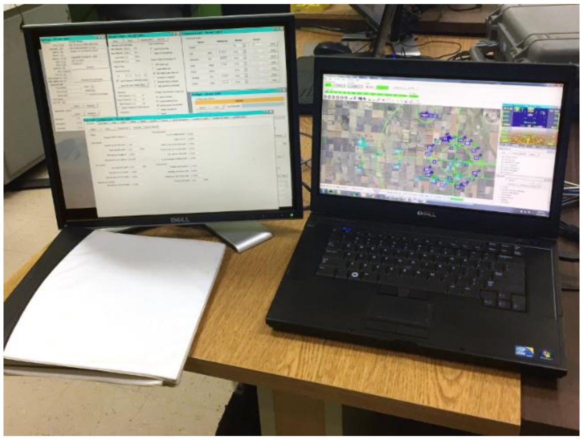


Figure 58. GPC 1 intruder aircraft systems and sensor processing (not on display).

GPC 2 (Fig. 59) is primarily used to both record relevant data from all aircraft and, if required by the scenario, run an automatic avoidance algorithm developed in-house in place of pilot action. The system records both state data for the aircraft and appropriate metrics relevant to DAA evaluation. The avoidance algorithm is run optionally and activated by the ownship pilot on GPC 3 as if the algorithm were on-board the small UAS. For the algorithm to perform appropriately, it is provided appropriate intruder data processed to emulate the limitations of sensors. For instance, data may be delayed or rendered intermittently available to emulate saturation of transceiver systems such as ADS-B or to emulate the limited update rates of radar systems. Data may also be limited by both range and field-of-view to emulate on-board active and passive sensors such as camera vision systems.

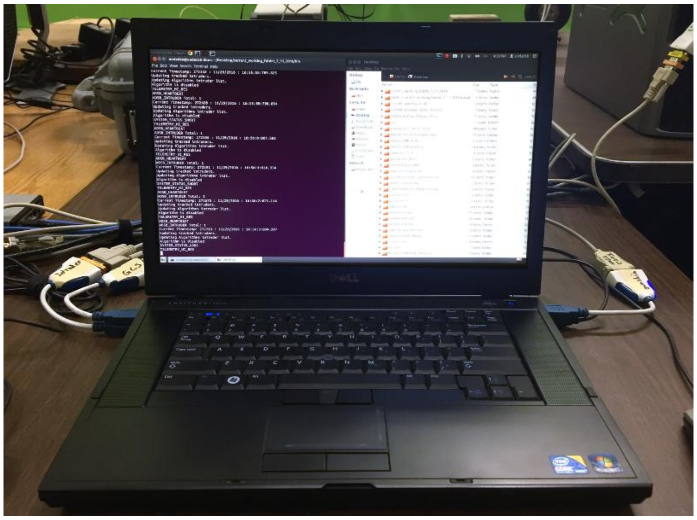


Figure 59. GPC 2 data recording and algorithm.

GPC 3 (Fig. 60) encompasses both the ownship aircraft systems as well as a sensor display system provided in one of two display engines. Ownship autopilot may be run in a variety of configurations including fixed wing and multicopter. Fixed wing configuration is normally run using autopilot hardware in a HWIL configuration. This provides three modes of control including direct pilot control using an RC console, waypoint control via the autopilot interface, and automatic control provided by the avoidance algorithm when activated by the pilot. Multicopter control is run using a SWIL configuration, with two modes of control including waypoint control via the autopilot interface and automatic control provided by the avoidance algorithm when activated by the pilot.

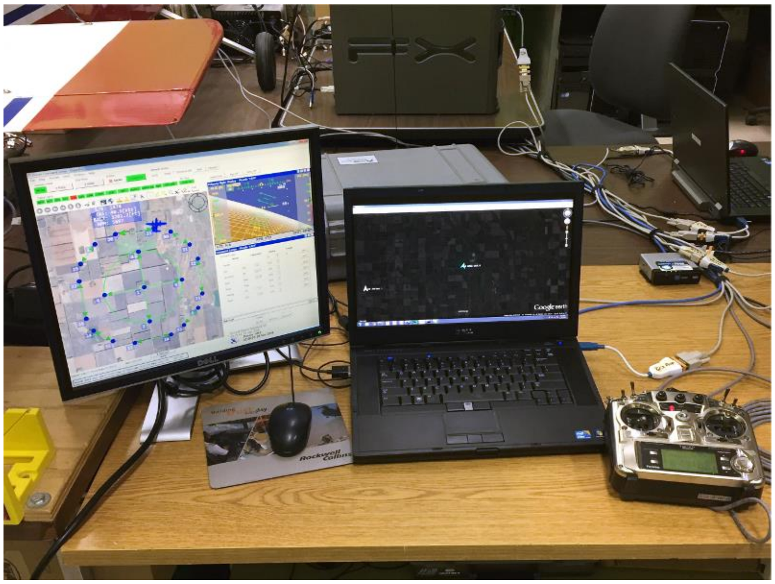


Figure 60. GPC 3 ownship systems (left) and sensor display (right).

The sensor displays system ingests both ownship and emulated sensor data from GPC 2 and displays the information using a highly customized Google Earth engine as shown in Fig. 56. The sensor display may be configured using multiple avoidance thresholds based upon sUAS and intruder performance characteristics and environmental restrictions (e.g., restrictions of flight paths owing to obstacles).

3.2.3.2.3 Software

3.2.3.2.3.1 Piccolo System

Piccolo Command Center's robust and flexible feature set enables not only navigation methods common to most UAS (including manual RC control and waypoint navigation), but also makes available command-loop overrides via software control which enables an in-house DAA avoidance algorithm to control the ownship aircraft. Likewise, multiple payload and autopilot telemetry data streams enable communications with the other systems in the testbed. For instance, telemetry from the intruder on GPC 1 may be processed as simulated sensor data for both the avoidance algorithm and the ownship's sensor display. The specifics of custom software solutions follow.

3.2.3.2.3.2 Sensor Simulation

Sensor limitations have a possibility of drastically changing pilot actions for avoidance maneuvers. With this in mind, two different sensor types were developed including Automatic Dependent Surveillance – Broadcast (ADS-B) and electro optical systems. More in depth explanations for each sensor type tested is listed below.

3.2.3.2.3.2.1 ADS-B

ADS-B is a surveillance technology where an aircraft determines its position via satellite navigation and periodically broadcasts its position and state information to other ADS-B equipped aircraft to enable it to be tracked. Broadcasting this information allows pilots of ADS-B equipped aircraft to have up-to-date position and state information of nearby aircraft with an update rate of 1 Hz. The data provided through ADS-B includes aircraft position, heading, velocity, and state information. Range is only limited by constraints on bandwidth and signal propagation, so a several mile radius is easily maintained. Due to requiring GPS satellite visibility and potential signal interference, it is possible signal dropouts may occur. To simulate this limitation, a modifiable "probability to receive" value was added to the ADS-B sensor data emulation. This means that for each 1 Hz heartbeat, there is a randomized chance at a defined probability that the ADS-B signal from a given aircraft will be received and made available to the pilot or algorithm. Tests were run using ADS-B signal availability of 100%, 60%, and 40%.

3.2.3.2.3.2.2 Electro-Optical Systems

With electro optical systems being increasingly popular as a sensor type on small UAS, a method to simulate such a sensor was developed. Most electro optical systems have limited range and field of view horizontally and vertically with an update rate based on system configuration and performance. These limitations were incorporated into an optical sensor data emulator for the system that emulates these restrictions and modifies the data stream being provided to the pilot and algorithm appropriately. While the intruder's position falls within the configured range and field of view it will show up on the provided GCS display.

3.2.3.2.4 Metrics

To facilitate the ability to easily quantify performance associated with a given simulated encounter, metric calculations were added to the simulation test bed on GPC 2. This software takes in relevant state information for ownship and intruders and calculates a given set of metrics based on this state information. The metric information from each encounter was combined to allow for easier sorting and comparison of encounters for analysis.

3.2.3.2.4.1 Selection

To facilitate easy determination of performance for an encounter and to compare against other encounters a set of metrics were chosen that best quantify performance and are relatively easy to calculate. The metrics chosen include vertical deviation, cross track deviation, time deviation, minimum separation, horizontal separation at minimum, and vertical separation at minimum. For algorithm-based encounters, initial commanded heading, indicated airspeed, and vertical velocity are calculated. These metrics best illustrate the performance of an encounter and allow for easy identification of encounters that failed to maintain a specified minimum well clear distance.

3.2.3.2.4.2 Implementation

The metric calculations were implemented on GPC 2, shown in Fig. 56. These calculations were written into custom software that interfaces between the Piccolo software or autopilot and the GCS display and algorithm. This software takes in relevant ownship and intruder state and telemetry information, performs metric calculations, and passes the state and telemetry information to the GCS display for display purposes or the optional algorithm to perform avoidance maneuvers. The metric software is setup to automatically generate time-stamped metric files based on the current date and time. Along with generating metrics, this software also logs relevant ownship and intruder state information to similarly-named state files that can be associated with a given set of metric values and encounters. The values written out to the metric file represent the minimum or maximum values, dependent on the metric, seen during the course of an encounter. To distinguish between metric encounters, the ability to automatically or manually signal the start and stop of an encounter was implemented. For the case of automatic start and stop conditions, a configurable distance-based threshold was used and for the case of manually starting and stopping the metric calculations, a configurable button was added to Piccolo Command Center on GPC 3 that allows the pilot to start and stop a metric encounter. At the start of an encounter, the metric conditions are reset and a state file for the given encounter is generated to be written to over the course of the encounter. Once the end of an encounter has been detected or indicated, the current metric values for the encounter are written out to the metric file representing the current set of encounters as a single line with the current timestamp and associated state file name.

3.2.3.2.5 Automatic Avoidance Algorithm

Along with manual and waypoint control, the test bed allows for the integration and testing of an optional automatic avoidance algorithm on GPC 2. This algorithm is fed current ownship state and simulated sensor data for intruders passed from the metric software. For the purposes of the encounters presented in this paper, an avoidance algorithm actively developed and flight tested since 2008 by the Unmanned Aircraft Systems Engineering (UASE) team at the University of North Dakota was used (Martel and Wang 2010; Martel et al. 2011; Foerster et al. 2012; Mullins et al. 2012a,b).

The automatic avoidance algorithm developed by the UASE team at the University of North Dakota is based on the Interval Programming Architecture, shown in Fig. 61, where environmental data from sensors are used by multiple behaviors to generate and populate behavior-specific decision spaces based on the performance limits of the aircraft. These decision spaces are weighted and summed together to create a final decision space used to determine the best command vector for the current ownship and intruder state information. The implemented behaviors include waypoint seeking, steadiest path, intruder avoidance, terrain avoidance, and partial right of way compliance.

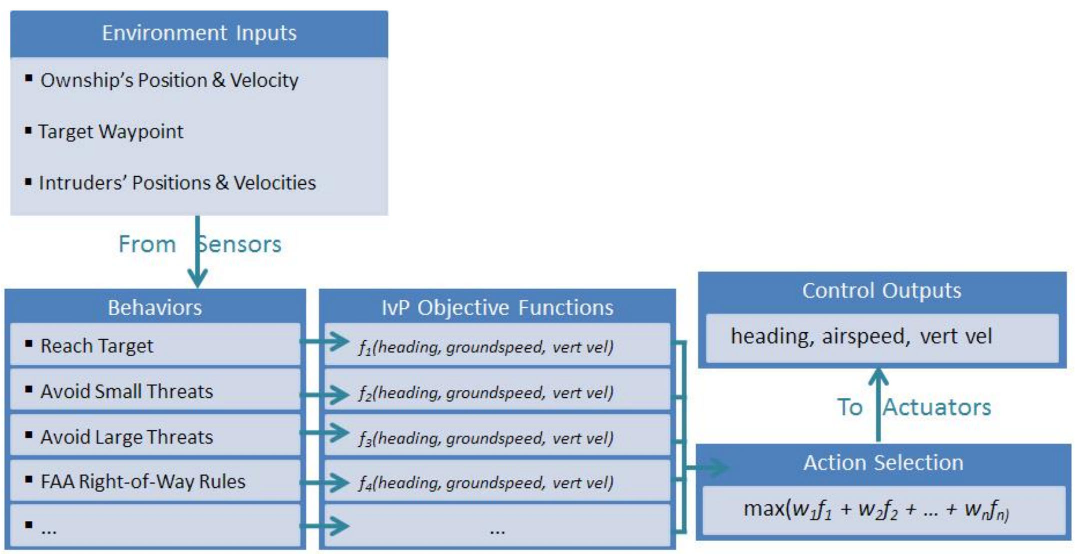


Figure 61. Interval programming structure.

3.2.3.3 User Roles

In running simulations on the testbed, user roles are normally divided into the UAS pilot and experiment operator (Figs. 62-63). The pilot role on GPC 3 may be expanded to accommodate multi-crew environments as necessary, but test conduct normally assumes a single pilot. The experiment operator will normally conduct the flight of any intruder aircraft and monitor systems functions on both the intruder station (GPC 1) and the algorithm and recording station (GPC 2). To accommodate a variety of possible ownship scenarios, the pilot may use three different controller methods in DAA operation, including: direct control that utilizes the pilot RC style console, waypoint navigation directly via the GPC, and activation of the automatic avoidance algorithm explained above.

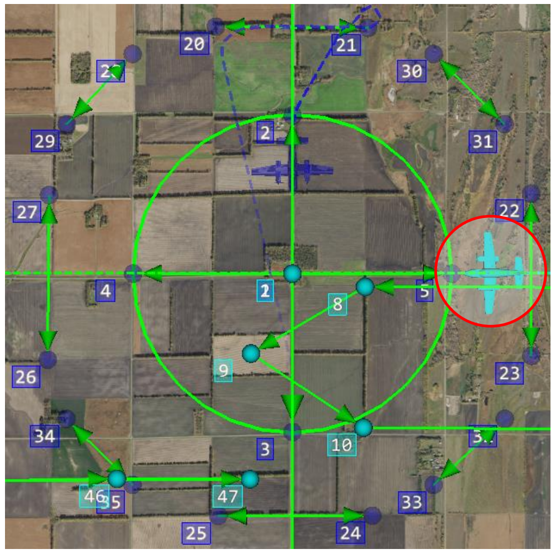


Figure 62. Systems display for intruder as flown by experiment operator. Display shows both ownship (south-bound from north) and intruder (circled, red from east) including flight plans for both.

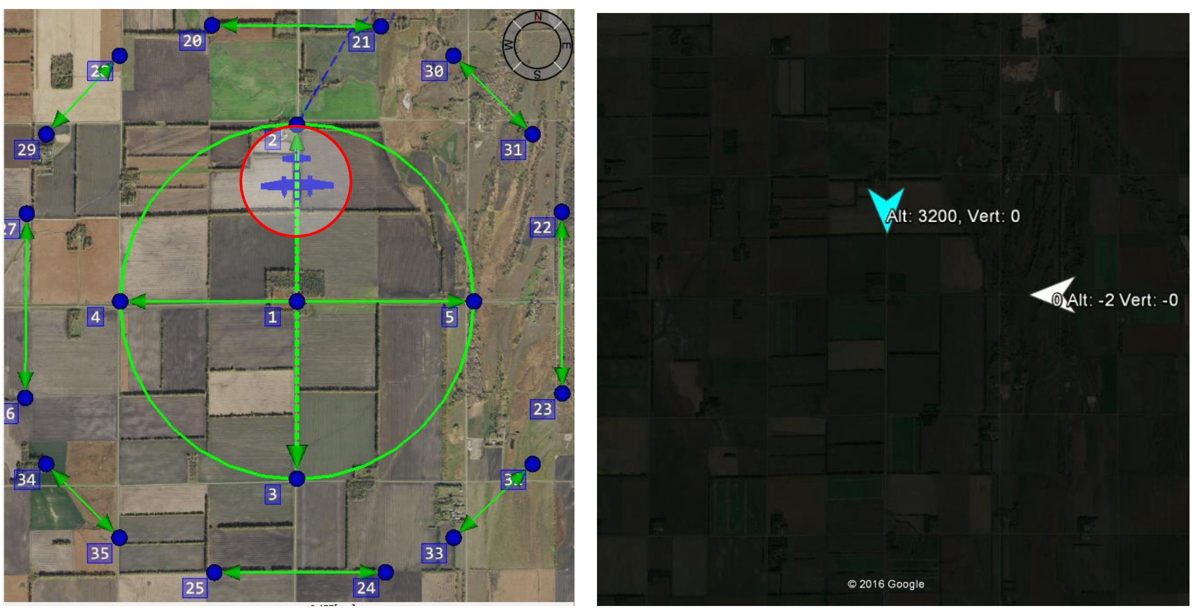


Figure 63. Systems and sensor display of pilot role. On pilot system display, only ownship is visible (circled, red from north). On sensor display, ownship is visible (cyan, right) while intruder approaches from east (white, right).

3.2.3.4 Ownship Flight

The goal of ownship simulation is to provide at least the primary emblematic performance profiles for the kinds of small UAS expected to make up the current and future sUAS fleet. For the testbed, ownship simulation includes two common UAS configurations in the small UAS fleet, one multi-rotor and one fixed-wing. The multi-rotor configuration attempts to model the performance of the popular DJI Phantom 4, a good fit for a notional multi-rotor aircraft fleet that is expected to be used extensively in aerial inspection operation. Such aircraft fit a role investigating a platform with high maneuverability but low forward speeds that limits overall agility in many manned-unmanned scenarios. The second fixed-wing UAS fits a similarly common profile with a nominal cruising speed of 30-50 knots.

3.2.3.4.1 Multi-Rotor

The multi-rotor simulator models one of the most popular systems available on market, the DJI Phantom 4. A flight model created for Piccolo Command Center provides performance characteristics and operating limits consistent with the Phantom whose performance specifications follow in Table 29.

Table 29. Phantom 4 performance characteristics.

DJI Phantom 4	Air Speed (Knots)
Max Ascent Speed	11.66
Max Descent Speed	7.78
Max Ground Speed	38.88
Cruise Speed	29.16

The multi-rotor simulation is implemented in a software-in-the-loop configuration. This setup provides both waypoint navigation and avoidance algorithm operation. For ownship experiments with the multi-rotor, waypoint navigation and avoidance maneuvering were emphasized above automatic avoidance.

Piccolo primary navigation is normally assumed to be waypoint based. While convenient and appropriate for most common UAS missions, this naturally makes avoidance maneuvering difficult. Creating a waypoint can easily delay a maneuver, increasing the risk of near-midair collisions. Therefore, the simulation team created sets of regularly located "escape" waypoints for flight tests as shown in Fig. 64 for waypoints 1 through 16. The waypoints were set up in a 360° circular pattern surrounding the mission operations area in approximately 22.5° increments. Waypoints 98, 99, and 30 comprise the lost communication waypoint, primary landing waypoint, and alternate hover waypoint, respectively. Each could be redeployed depending on the needs of the experiment. In this way the multi-rotor could be navigated along its normal sensing flight plans between waypoints 20, 21, 22, and 23 and sent to escape waypoints or landing waypoints as appropriate. Should further action be needed, autopilot command loops may be overridden with specific speed, heading, and altitude changes.

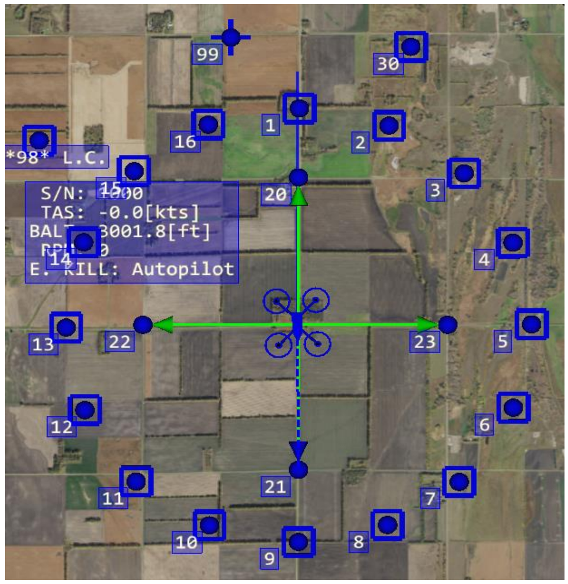


Figure 64. Multicopter operating area with safety waypoints.

3.2.3.4.2 <u>Fixed-Wing</u>

The fixed wing model uses a previously developed UAS flight model based on the BTE Super Hauler used in flight operations over a number of years. The UAS is a simple all-wood frame UAS with a Desert Aircraft 100 CC engine that is easy to fly, maintain, and modify for various experiments. The performance profile of the Super Hauler is similar in scale to many small UAS flying similar sensing missions emulated in the tests. Availability and familiarity with the systems made utilizing this model for simulation a natural fit. The model's performance characteristics are listed below in Table 30.

Table 30. BTE Super Hauler performance characteristics.

BTE Super Hauler	Ownship Airspeed (Knots)
Stall Speed	35.77
Cruise Speed	38.88
Max Ground Speed	58.32

The HWIL implementation of the ownship systems allows direct access to the autopilot hardware and also enables direct pilot control via the RC console. The systems allow single switch activation of manual control of the aircraft, enabling simulation of pilot response to intruder encounters. As with multi-rotor navigation, a similar waypoint setup with "escape" waypoints appropriate for the fixed wing aircraft were set up as shown in Fig. 65. These safety waypoints are shown as waypoints 20 through 35. Likewise, flight plans (waypoints 2-5) emulate normal sensing mission operations.

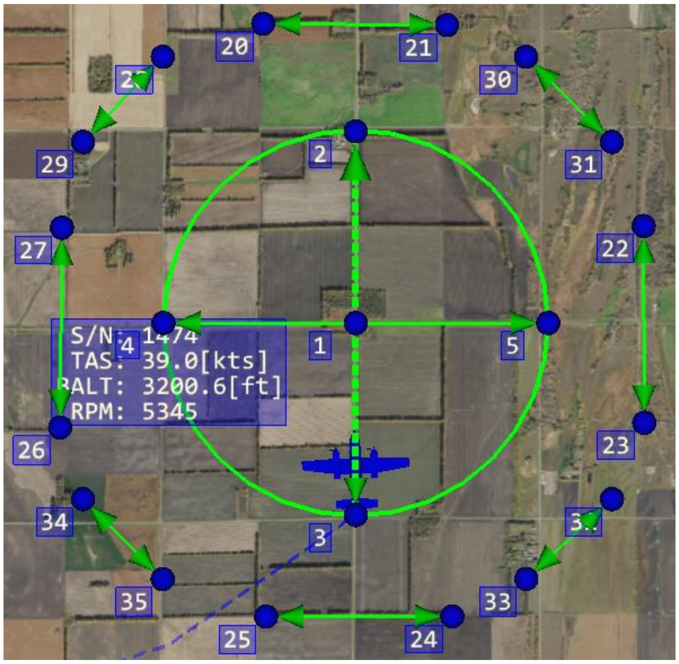


Figure 65. Fixed wing operating area with safety waypoints.

3.2.3.5 Intruder Flight Patterns

The intruder aircraft operates in a SWIL configuration using an adapted form of the Super Hauler model. The model uses an upgraded engine that can be tuned to provide fast cruise speeds between 80 and 100 knots. This simulates the speed range expected of general aviation (GA) intruders common at very low altitudes that may conflict with small UAS operations. In the opinion of researchers, the speeds of aerial applicators and medical flights will commonly not vary significantly from these profiles this close to terrain. Informal opinions gathered from several applicator pilots confirms that speeds between 80-100 knots are common profiles on crop-dusting runs. Table 31 shows the performance bounds of the adapted Super Hauler model. While not perfectly simulating a particular model of GA aircraft, these characteristics capture the category and performance likely to be encountered.

Table 31. Intruder performance characteristics.

BTE Super Hauler (Intruder Config.)	Intruder Airspeed Slower (Knots)	Intruder Airspeed Fast (Knots)
Stall Speed	35.77	35.77
Cruise Speed	83.4	100
Max Ground Speed	83.4	106

Flight plans for intruders varied between five different profiles. As in the previous figures, ownship operations are assumed to be at or around 200 feet AGL, splitting the difference between ground level where aerial sensing is less useful and an assumed 500 ft ceiling. For several intruder encounter geometries, the flight paths are intended to capture common, possibly difficult scenarios: an approach-from behind condition, head-on encounter, and 90° offset either from the left or right directions. These geometries may be varied by altitude, but are generally co-altitude to capture the difficult pilot decisions involved in whether to avoid horizontally with aircraft having limited performance or to climb toward the 500 ft ceiling or descend toward ground level.

The other two primary configurations model the climbing and descending behavior of crop-dusting aircraft. Two of the most common turn patterns of such aircraft may be a simple U-turn from one application run on the field below to another, executing a constantly shifting race-track pattern as the airplane completes application runs as shown in Fig. 66. The alternative involves a P-turn (Fig. 67) which follows the U-turn but adds a continuing descending 90° turn and then an opposite 90° turn to simulate the airplane adjusting to make a crop-dusting run adjacent to the previous run. In real life such aircraft are constantly adjusting and shifting climbs, turns, and descents to accommodate the variations in local fields where obstacles, field dimensions, and power lines dictate a crop-duster's strategy. These two turns, however, should adequately simulate the types of encounters small UAS might see in adjacent fields as crop-dusting aircraft fly at near ground level, popping up and descending back to the same field.

Figure 66. Emblematic crop-duster maneuver: climbing U-Turn to reverse course. Apex of turn (short of waypoint 9 when configured for pre-turn logic) approaches ownship path (N-S in green) at or near same altitude as ownship.

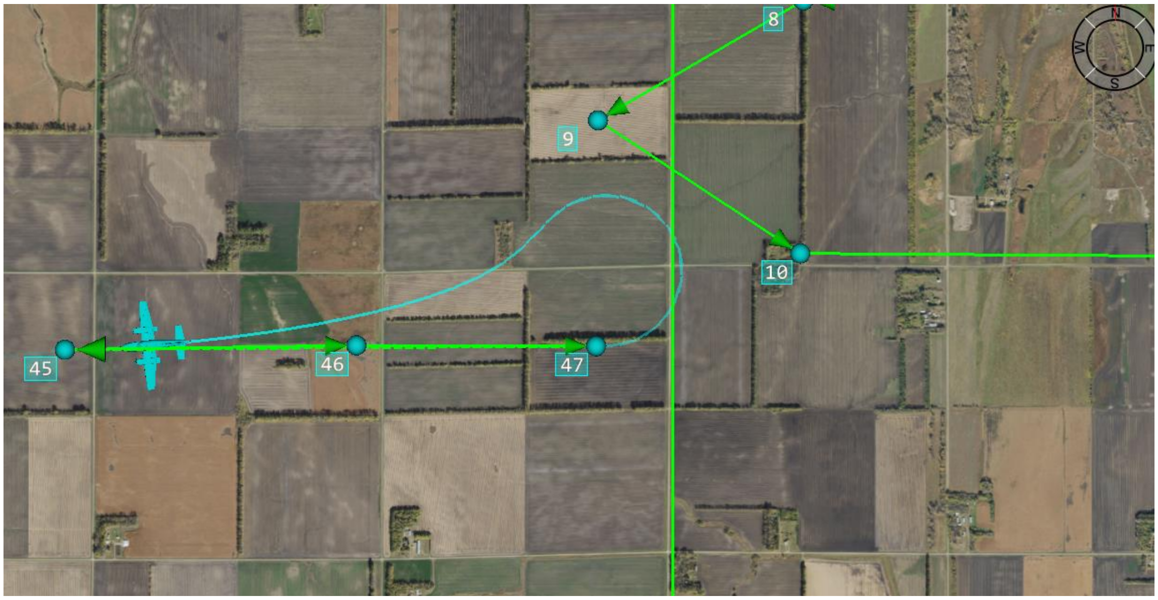


Figure 67. Emblematic crop-duster maneuver: climbing P-Turn to reverse course. Apex of turn beyond waypoint 48 crosses ownship path (N-S in green) at or near same altitude as ownship.

In this way a wide selection of scenarios varying intruder speed, sensor ranges, geometries, pilot control (whether human on-the-loop, waypoint, or manually controlled), and other limitations were employed to find a series of observations and initial findings useful for uncovering DAA needs whether involving sensor capability, algorithm capability, or pilot-machine interaction. A discussion of particular simulations, observations, and recommendations follow.

One safety note for both ownship and intruder is that both simulated ground level at an altitude of 3,000 ft. This prevents the possibility of one or both aircraft contacting ground level and tumbling in simulation, especially if a vehicle like the intruder is simulating crop-dusting patterns. Metric recording systems and the autopilot system both detect whether either aircraft has descended below an arbitrary limit. In the case of the crop-dusting patterns, ground level for the intruder is set several feet below 3,000 to accommodate control noise and limits of the autopilot controller during rapid climbs and descents.

3.2.3.6 Analysis

Total simulations to date number 117, including systems tests and follow-up tests as simulation testbed performance changes were evaluated. As testing progressed, an array of intruder encounters evolved from several parameter sweeps to investigation of particular parameters. The consequences of particular variables such as sensor range or sensor availability exposed a number of particular risks. Outlined below are several themes discussing the results of specific aircraft encounters or groups of encounters as these issues emerged.

3.2.3.6.1 Well Clear Distance Thresholds and NMAC (Near MidAir Collision)

One of the primary goals for simulating DAA systems is the evaluation of sensors and ownship maneuverability with regard to both well clear thresholds and Near MidAir Collisions (NMACs). For well clear, the group ran simulated encounters at arbitrary well clear distances of 4000 ft using a constant vertical distance of 250 ft. For NMACs the group used standard TCAS thresholds at 500 ft horizontally and 100 ft vertically, attempting to define a minimum range at which NMAC events are likely to occur given pilot attempts to maneuver clear. Both methods and the resulting observations are discussed below. It should be noted that no NMAC events occurred unless very limited sensor ranges were used. This important consideration will be explained later as sensor limitations are discussed at length.

3.2.3.6.1.1 Pilot Controlled Well Clear

There were, however, many breaches of the 4000 ft well clear radius. In many cases ownship still remained well clear as the pilot attempted to either climb or descend. While often successful, this introduced safety risks that will be discussed later. For purely horizontal maneuvers, no clear weakness emerged except that the numbers of well-clear violations at 4000 naturally increased when flying faster intruders at 100 kts. Likewise, the number of violations increased when considering the adverse head-on geometry. This can probably be attributed simply to the fact that limited time to react and avoid resulted in more well clear violations (see Fig. 68). Under optimal sensor conditions, however, this time-to-react concern is mostly moot as earlier avoidance action may be taken by simply increasing the scale of sensor display ranges.

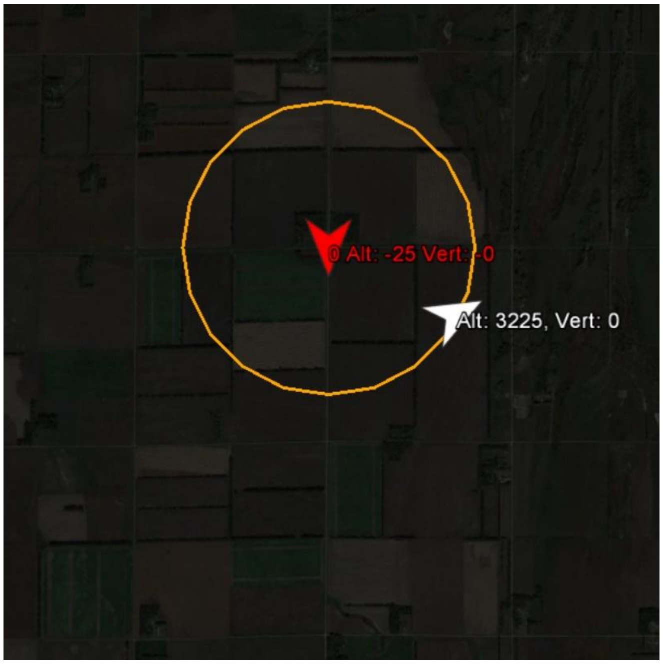


Figure 68. Well-clear violation shown on sensor display in adverse head-on geometry. Pilot (ownship, white) maneuvered late to avoid intruder (red), inducing violation.

3.2.3.6.1.2 Algorithm Controlled Well Clear

Most encounters focused predominantly on pilot control and avoidance. While not emphasized, the in-house avoidance algorithm, when tested under similar conditions, could normally avoid any given well-clear distance given an adequate triggering range. Given sufficient distance, the algorithm would attempt to "hug" close to the well-clear boundary as it efficiently avoided the intruder while attempting to remain close to its original course. In fact, across all experiments, the pilot would usually engage much more conservatively, avoiding earlier and sooner than the algorithm.

For reasonable triggering distances, it is expected that any appropriate algorithm may avoid a given well clear distance. There is not yet an assumption for what this triggering distance should be. This is not to be confused with any particular definition of well-clear, but with the algorithm's activation threshold to remain well clear. Such a distance, while not well within the scope of this research, could be designed to be purely distance-based, distance-based evaluated by time, or purely tau-based, as some current well-clear methods use.

3.2.3.6.1.3 Vertical Well Clear

Several attempts to remain well clear using a 250 ft vertical threshold were, in most cases, successful—most commonly when attempting waypoint control. Across manual control encounters, episodes of the ownship airplane ballooning past the 500 ft AGL height limit were common. This was commonly caused by difficulty holding the aircraft level as power and altitude changes were made. In the heat of an avoidance maneuver, the pilot might not have time to adequately re-trim the aircraft for changing climbs, leveling off, and speed changes. The environment of small UAS BLOS required skills similar to instrument flight, with the addition that fast avoidance maneuvers be made under the same conditions while using RC control. A well trained RC pilot may be able to adequately maintain altitudes, but the maneuver remains a high-skill one and not one to be attempted without adequate training.

Descents likewise were difficult to execute and quickly abandoned as unlikely candidates for avoidance. The likelihood of impacting ground level rendered the maneuver highly risky. Immediate landing attempts via multi-copter were nearly impossible. Automated waypoint-based landing sequences were too slow to remain vertically well clear from the intruder. Possibly an estimated or hard landing could be attempted via direct manual control of the multi-copter, but this was beyond scope of the simulation testbed development.

Overall, the most successful well-clear attempts used conservative assumptions and saw the intruder at large distances such as those 3 nm and above. Varying geometries with more favorable dynamics than head-on encounters might mitigate some of the well-clear violation frequencies and lower well-clear boundaries offer further room for maneuver, but limited sensor ranges and fields-of-view will naturally make this proposition difficult.

3.2.3.6.2 Sensor Limits

Sensor limits emulated three different limitations. One was the possibility of reduced availability of a GPS or ADS-B based system, another the limitation of sensor range, and a third the limitation of field-of-view. The ADS-B based limitation provided random availability of data packets to the sensor display and avoidance algorithm. Availability of packets could be reduced as a percentage. Simulations attempted encounters at 100% (normal operation), 80%, 60%, and 40% availability. A pilot attempting manual avoidance maneuvers under any reduced availability would commonly still be able to either remain well clear or nearly well clear no matter the availability percentage. This success implies that conservative maneuvering attempts of a human pilot likely provided greater time and space to avoid.

The algorithm encountered more difficulty, however. An algorithm without using track prediction (that is every intruder packet is maintained as current) introduces increased risk of avoiding in an incorrect direction or incorrectly abandoning an avoidance maneuver when the intruder is actually still present. With straight-line track prediction, the algorithm mitigated the limited availability of the intruder correctly in most cases. The one limitation was the presence of rapidly maneuvering intruders, specifically the crop-dusting P and U turns. With an intruder constantly changing direction, especially in the case of the P-turns, experiments revealed that in most cases the algorithm struggled to remain well clear, especially at 40% availability where stretches of five or more seconds could pass without intruder data being passed to the ownship's sensor display.

The second sensor limitation involved range limits. Experiments varied limited viewing range between 3.5 nm down to 2600 ft. The ability to maintain a well clear boundary of 4000 ft depended partly on ownship category. Where the fixed-wing ownship could successfully avoid given at least a 2.6 nm range of detection, the multi-rotor ownship could not and required at least 3.5 nm detection range. Both categories were unable to maintain well clear distances of 3000 ft below 1.75 nm detection ranges. 2000 ft ranges were similar, however, requiring 1.75 nm detection.

Given well-clear violations at particular ranges, the team also experimented with NMAC, seeking to reduce detection range for both aircraft categories until NMACs began to occur. This is the only set of experiment conditions other than limited field of view that resulted in NMAC events. Under these conditions, NMAC events occurred for fixed-wing ownship at 4000 ft detection ranges. For multi-rotor, this occurred at 2700 ft detection ranges. In all cases, the objective assumed that well-clear had already been violated and that only NMAC avoidance was appropriate. And for both aircraft, large maneuvers usually involving rapidly climbing turns were required.

The third primary limitation was to limit the field of view of sensors as might be expected in passive, vision sensor classes. The primary assumption was to limit detection field of view to a total of 120° horizontally (60 right and left) and 75° vertically (37.5 up and down). Encounters under adverse conditions focused on 90° intruder encounters as well as both P and U turn encounters. In all cases, the sensor display detected the intruder too late, causing NMAC events. In two cases, ownship never detected the intruder. Expanding the field of view to 180° by 75° prevented NMACs but increased the hazard to avoidance as the pilot was unable to correctly detect when or where the intruder had passed. This sometimes required ownship to turn toward the intruder's expected position to re-expose the intruder to the limited sensor view as shown in Fig. 69. Still, in all cases ownship was able to maintain at least a well-clear distance of 3000 ft.

Figure 69. 180° field of view demonstrating regaining intruder contact (intruder in yellow) after slight left turn.

3.2.3.6.3 Control Methods

The fixed-wing ownship simulation employed three different modes of control: manual, waypoint, and algorithm. The multi-rotor ownship employed two: waypoint and algorithm. Algorithm performance has already been discussed but bears summarizing: the in-house algorithm as a stand-in for any possible avoidance algorithm will normally navigate closer to well-clear distances and perform capably given sufficient detection range and data availability. Limitations to sensors, though, may dramatically impact algorithm performance. The primary desire to evaluate human control in both waypoint and manual control exposes two trends for both fixed-wing and multi-rotor. Generally, the more precise the control method and the more confident the pilot can be in the control method, the more successful and efficient the outcome.

This primarily indicates that waypoint control is normally the more optimal strategy of the two. Pilots engaging in manual control of the fixed-wing aircraft commonly struggled under task saturation attempting to balance intruder position evaluation, aircraft trim, and instrument control of the aircraft under constant heading, speed, and altitude changes. Where a normal TCAS resolution advisory normally issues audio alerts with a command direction, the pilot looking at intruder position must evaluate strategy as the two aircraft converge. Experimenters noticed that this would commonly result in the ownship pilot making avoidance maneuvers early if possible, perhaps making more of a strategic evaluation to not just remain well-clear of the intruder, but remain well-clear of the area the intruder is in, possibly abandoning the small UAS's mission—at least temporarily.

Waypoint control resulted in less of this uncertainty and closer avoidance distances, most likely due to the precise control available to the pilot. Considered as a measure of efficiency, time-in-avoidance and distance avoidance (measurements such as cross-track deviation and vertical deviation) were consistently smaller for waypoint navigation. This prompts the observation that waypoint navigation may be preferable in DAA beyond line-of-sight navigation with some particular caveats regarding waypoint control assumptions to be discussed in recommendations.

3.2.3.6.4 Aircraft Category and Performance

Of the two aircraft evaluated, the fixed-wing and the multi-copter, it was clear that the fixed-wing was the more maneuverable of the two aircraft and could normally execute avoidance maneuvers and remain well-clear more easily and more often, commonly due to the aircraft's greater available power. The multi-rotor, again emulating the performance of an average, popular quad-copter, simply requires greater detection ranges to remain well clear, especially if maneuvering horizontally. The pilots attempted to descend, climb, and even land the aircraft in an attempt to take advantage of smaller well-clear vertical distances, but were often unable to do so for reasons to be discussed shortly. In most cases the horizontal missed distance of the multi-rotor was smaller than that of the airplane.

The only time this condition reversed is where well-clear has already been violated and the multi-copter attempted merely to avoid NMAC. This occurred during the sensor range limit tests and exposed the primary advantage of the multi-rotor: the ability to make quick vertical maneuvers to avoid, which the airplane was unable to do. This capability was less useful for remaining well-clear, but more useful for avoiding NMAC events.

3.2.3.6.5 Airspace Maneuvering Limits

Setting a 500 ft limit on maneuvering room significantly limited the ability of either aircraft to remain adequately well clear. The airplane, while able to maneuver ahead of time via waypoint navigation, proved difficult to control quickly at precise altitudes well clear above the intruder and still below the 500 ft ceiling. Descending below the intruder was likewise difficult. Multi-rotor waypoint navigation could enable more precise maneuvering above and below an intruder, but limitations and a general preference to avoid horizontally prevented these strategies from being preferable.

One significant issue with vertical avoidance is the uncertainty of altitude whether between barometric altitude and GPS altitude or between the installation errors of two barometric altimeters. The possibility that such uncertainties may wipe away any margin in vertical maneuvering further limits the suitability of vertical maneuvers. Likewise, the presence of obstacles below makes descending a difficult course of action to recommend.

One possibility available to the multi-rotor is to land. This might be possible as an emergency maneuver, but is slow when considering waypoint-based landing under normal autopilot control laws. In scenarios tested, experimenters found that attempting to land via waypoint required too much time to travel to the landing waypoint and execute a controlled, slow descend to ground level. Even this inadequacy ignores the risks inherent in attempting a landing beyond line-of-sight where the landing site may not have been surveyed ahead of time.

Given these limitations, it is not likely that vertical maneuvering becomes particularly useful for well clear avoidance as long as the UAS are constrained to 500 ft AGL. This means that horizontal maneuvering and the performance and sensor requirements of small UAS dominate safety considerations. This does not mean that vertical maneuvering is always incorrect. Pilot judgment and further tests may expose situations where combined and vertical maneuvers may allow for decreased sensor ranges.

3.2.3.6.6 <u>Visual Display Systems</u>

The visual display system used for ownship DAA avoidance shows relative positions and headings of ownship and intruder aircraft. An additional feature allows custom clearance rings to be displayed around intruders such as that shown in Fig. 70. For several tests, the team tested similar scenarios where the pilot would maneuver ownship either manually or via waypoint navigation with well clear distance rings either visible or not visible. Results from these tests indicate that avoidance maneuvers were much more conservative, resulting in larger minimum distances, than with the rings visible. This is indicative of pilot comfort in maintaining well clear by maneuvering closer to visible well-clear rings. Implementation of a visible well clear ring display may allow for more efficient maneuvers to deviate less from the intended mission path.

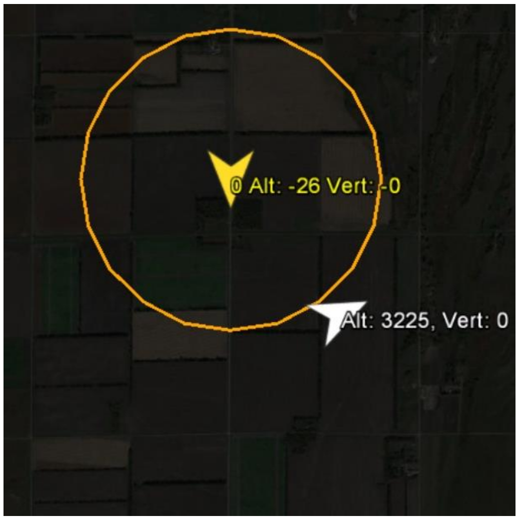


Figure 70. Appearance of well-clear ring just before violation as seen in Fig 68.

3.2.3.7 Conclusion and Recommendations

The simulation efforts, while not exhaustive, have nevertheless revealed a number of observations on which several initial recommendations can be made.

3.2.3.7.1 <u>Well Clear Recommendations</u>

Several assumptions used during the simulations should be emphasized. First, the conditions of the tests centered on adverse conditions in a purely rural environment. As the well clear observations showed, the ability for a pilot to remain well clear is hampered most when time available to avoid is limited, such as when encountering faster intruders in a head-on condition. Second, the research group used standard TCAS near midair collision definitions: 500 ft laterally and 100 ft vertically. Third, the group assumed a distance-based well clear threshold.

Given these conditions, the optimal well clear distance for small aircraft is probably close to a radius of 4,000 ft, absent of other circumstances and limitations such as sensor limitations on a DAA system or unusually fast aircraft. When reducing available detection distances in head-on scenarios, pilots encountered difficulty avoiding NMAC events even when responding rapidly and making significant climbing or descending turns. As noted before, no NMAC events occurred outside this detection range unless some other sensor limitation prevented ownship from seeing the intruder at all, as with limited field of view.

It may be that with more extensive tests and as sample size of tests increase this distance may expand or shrink. Likewise, there may be test conditions such as the assumption of faster intruders of an order of 120-150 knots that may push a required threshold out further, but under the assumptions tested for rural environments below 500 ft, the threshold is a reasonable marker.

3.2.3.7.2 High Level DAA Recommendations

Other recommendations cover experience gained through the breadth of tests, as well as several other edge cases. The engineering group recommends the following for sensors: to avoid NMAC events, sensors will require at least the same detection distance as the well-clear radius discussed above. This requires that any sensor system be able to sense, resolve, and issue appropriate data or warnings to the pilot or algorithm, if used, by 4000 ft. Using the 4000 ft threshold, the group found that to maneuver and remain well clear, sensor detection ranges greater than 2.6 nm are required. Should the required threshold expand or shrink, this distance may also change. It should be reiterated that this is again based on the conservative edge cases of pilot response in worst case encounters like head-on.

Field of view is a case where the required angle depends on relative speed. Closure geometries at 90° will not allow a DAA system equipped on a slow speed UAS to detect a much faster intruder that can remain outside the detection area through NMAC. While faster UAS may not require a larger horizontal range, the group recommends at least a 180° field of view or regard. The group also recommends that wider fields of view be considered depending on the probability of closure angles at greater than 90°. A full 360° requirement should be considered if manned-overtaking-unmanned scenarios are deemed common enough that lack of detection increases risk to an unacceptable level.

One recommendation includes the UAS's autoflight system as part of a DAA total package. If human-in-the-loop control is an assumption, any autoflight system must accommodate the pilot's need to rapidly and effectively control the aircraft to remain safe and well clear of the traffic in question. Multiple times, the experimenters noticed that the inability to exercise direct control over the UAS quickly inhibited the effectiveness of the maneuver. Where direct manual control (RC mode) can be difficult if the pilot must deal with limitations such as airplane trim and fast maneuvers in what is effectively an instrument flight environment, direct autopilot control could become difficult where the pilot needed to make two or more changes to the system, such as unlocking a configuration or clicking a standard computer dropdown menu, to change airspeed or altitude immediately. In the future, the team recommends that any autopilot expecting human-in-the-loop control must be capable of aircraft trajectory changes within as few control inputs as possible. For instance, a transport category autopilot system in altitude hold mode will normally have a rotating knob that allows quick changes in hundreds of feet. If full manual control will not be the primary means of avoidance, this kind of rapid input should be required of all autopilot systems equipped with DAA capability.

No specific recommendations are made regarding limited availability or update rates. The group has uncovered no major loss of performance when dealing with intermittent information. In nearly all scenarios, given sufficient distances described above, pilots were able to interpolate and avoid areas where intruders momentarily disappeared. Two caveats follow this recommendation, though. One caveat is that intermittent or slow-update detection should be accounted for in the required distance to detect. For instance, the update of the simulation testbed's sensor display is 1 Hz and range and threshold recommendations are based upon this capability. Slower update rates will need to be incorporated into threshold assumptions before deployment. A second caveat is that the group did not simulate adverse detection conditions when dealing with multi-sensor fusion. For instance, low-update-rate sensors fusing poorly with faster update sensors may ghost an intruder's return treating it as two aircraft.

Automatic algorithm response was not emphasized in these tests. However, the exposure of certain algorithm methods to a diversity of sensor behaviors and capabilities and its response must be accounted for when deployed. The team's in-house algorithm was upgraded to handle track prediction, for instance, to account for random sensor dropouts down to 40%. This is reasonable for most air traffic assumed to be on a consistent course whether level, climbing, or descending. Maneuvering traffic, such as that encountered when dealing with simulated crop-dusting flights, will likely require further development. No specific recommendation beyond accounting for sensor limitations is made at this time.

3.2.3.8 Future Work

There remain many avenues for further work and research beyond the scope of the current research. Further work may expand and improve the simulation testbed. For instance, accommodating real-world data feeds into simulation, for instance ASR/ARSR (Airport Surveillance Radar/Air Route Surveillance Radar) data or ADS-R (Automatic Dependent Surveillance-Rebroadcast) or TIS-B (Traffic Information Service-Broadcast) traffic could be used to evaluate the edge cases where service volume fails either normally (by equipment limit) or due to obstacles or terrain. The engineering team also identified the development of simulated sensor visualization to be highly useful in evaluating pilot response when confronting the limitations of vision sensors in tracking and avoiding an intruder. Such a 3D system would emulate the viewable information directly from the sensor, including its limitations. This means that the display could mount visualization techniques on top of the visual sensor emulation already in use. For instance, an intruder might only fade or grow into view given the range limit of a particular sensor. Fields of view could be dynamically expanded or shrunk in a similar fashion. Camera resolution could be emulated through the use of a pixilation filter. All possibilities gear toward human target recognition and could feed into human-machine interface evaluation of the adequacy of the sensor and avoidance maneuvering in a similar small UAS environment like that under current study.

Other possible work expands the work on the potential of the simulation testbed's current capabilities to determine outcomes between manned-unmanned encounters. Focused study on human response versus further tuned avoidance algorithm could yield finer results on the DAA sensor and tracking needs of automatic versus pilot avoidance. Consideration of avoidance as a strategic decision (that is, to remain well clear of not just the intruder but of the area occupied by the intruder and possibly ending or delaying the UAS mission) versus a tactical decision (to remain well clear of the intruder) could reveal possible changes in the level of expected safety in low altitude airspace as well as possible tradeoffs between economic costs (delays in mission completion) and safety gains. Further testing of the current system may also simply expand the gamut of possible manned-unmanned interactions and yield more knowledge of further edge cases in DAA capability. For instance, limited field-of-view sensors when encountering aircraft that, while not constantly maneuvering as a crop-duster does, could miss a single intruder turn, climb, or descent. The likelihood of an intruder to execute at least a single, sudden trajectory change could affect overall level of safety; however, the interaction between the likelihood of such maneuvers and small UAS is mostly unknown. Finally, there is risk in predominantly vertical encounters that has not yet been evaluated and would be potentially fertile ground in understanding capabilities of both intruder and ownship of varying performance profiles. A small UAS climbing into the path of a constant altitude intruder probably yields a different set of detection and maneuvering possibilities. Likewise one can consider the reverse, where the intruder is climbing into the UAS, possibly disrupting control links temporarily. Other possibilities exist for further testing, but the simulation testbed remains a capable method of real-time test.

3.3 Survey of Existing/Developing DAA Technologies and Performance

3.3.1 Literature Review

Reviews of DAA technologies are provided by Hottman et al. (2009) and Yu and Zhang (2015). These provide excellent summaries of both challenges associated with DAA and with the types of technologies being applied to these challenges. The approaches are generally divided between cooperative approaches (e.g., TCAS, Mode-C/S, ADS-B) and non-cooperative approaches. As outlined in these reviews, non-cooperative approaches include

- Radar
- LIDAR
- EO/IR
- Acoustic

Within these groups sub-groups exist. For instance, within the radar group one may use a Synthetic Aperture Radar (SAR) or a non-SAR radar. Moreover, approaches can be divided into passive/active and ground-based/airborne approaches. Perhaps the only approach not explicitly considered in these reviews is use of pre-existing signals (e.g., television) for DAA. This has been explored, but will require significant effort prior to practical application (Kleinman 2017).

As these reviews and the embedded references indicate, numerous approaches to DAA are being explored in a research setting. While all of these are of significant interest, the focus herein is on the most promising approaches that have been developed beyond the proof-of-concept point. These are considered below using data collected from industry by numerous means (e.g., a Fed Biz Opps call, direct interactions, etc.).

3.3.2 DAA Approaches ITEM

An important step in developing an understanding of the current state of the DAA industry was the DAA approaches ITEM (Information Technical Exchange Meeting), which was effectively conducted concurrently with the Use Case Data Call. As described in §2.1, this assisted with identification of companies/entities involved in DAA efforts and with identification of approaches being pursued.

3.3.3 Architecture Delineation

3.3.3.1 DAA Sensor on/off Board

SWaP (Size, Weight, and Power) imposes the most severe constraint on utilization of sUAS DAA systems. Thus, this is the top-tier characteristic that is used to delineate different DAA approaches for sUAS. This not only matches how most people think about such systems, it provides a natural division for both many of the hazards that may be encountered with such systems and with other characteristics of such systems (technical performance, limitations, communication requirements, cost, etc.).

3.3.3.2 Degree of Autonomy

The next level of delineation for sUAS DAA systems is the degree of autonomy. Herein, the word autonomy is used in the general sense of "acting independently", wherein the sUAS has a DAA system and utilizes that information to take action without input from a human. In fact, in such a system, a human is not able to intervene in either the DAA system or in the utilization of that information to avoid intruders.

Autonomous systems represent one far end of the spectrum with regards to this characteristic. On the other end of this spectrum is Human In The Loop (HITL). In such a DAA system, the pilot plays a critical role in avoiding intruders. However, the exact degree of human involvement varies. This can be illustrated using Fig. 71. In such a system, minimal pilot involvement occurs when the pilot is responsible only for the Execute Maneuver step. Additional pilot involvement occurs when the pilot is responsible for the last two or three steps. The greatest amount of pilot involvement occurs when the pilot is responsible for all four steps. While it may seem to be counterintuitive that the pilot may be responsible for the Detect step in a BVLOS DAA system, one can conceive of such a system. For instance, EO data could be transmitted to a display that a pilot uses to identify intruders. While such an approach is not likely, it is possible and, thus, is included herein.

Within HITL systems, function allocation can be further subdivided. For instance, within the Evaluation step, cues (e.g., visual or aural) can be provided to alert the pilot of potential conflicts. In such a case, the pilot is alleviated, at least partially, of having to identify potential conflicts. Moreover, the system may provide recommended resolutions. Again, this, at least partially, reduces the responsibility to evaluate the best course of action, although in such a system the pilot may reject the recommended resolutions.

In a Human Over the Loop (HOTL) system, human intervention is possible. Otherwise, such a system is autonomous. Such a system may or may not provide cues to illicit human intervention (visual, aural, etc.). In such a system, the human plays the role of a manager rather than of an active participant, but can take on an active participant role if needed.

3.3.3.3 Active/Passive Sensor

The final delineation level is whether a sensor is active or passive. An active sensor produces a signal that interacts with objects that enables their detection (e.g., radar). A passive sensor does not produce a signal, but rather utilizes signatures produced by objects, to detect them (e.g., passive acoustic sensor).

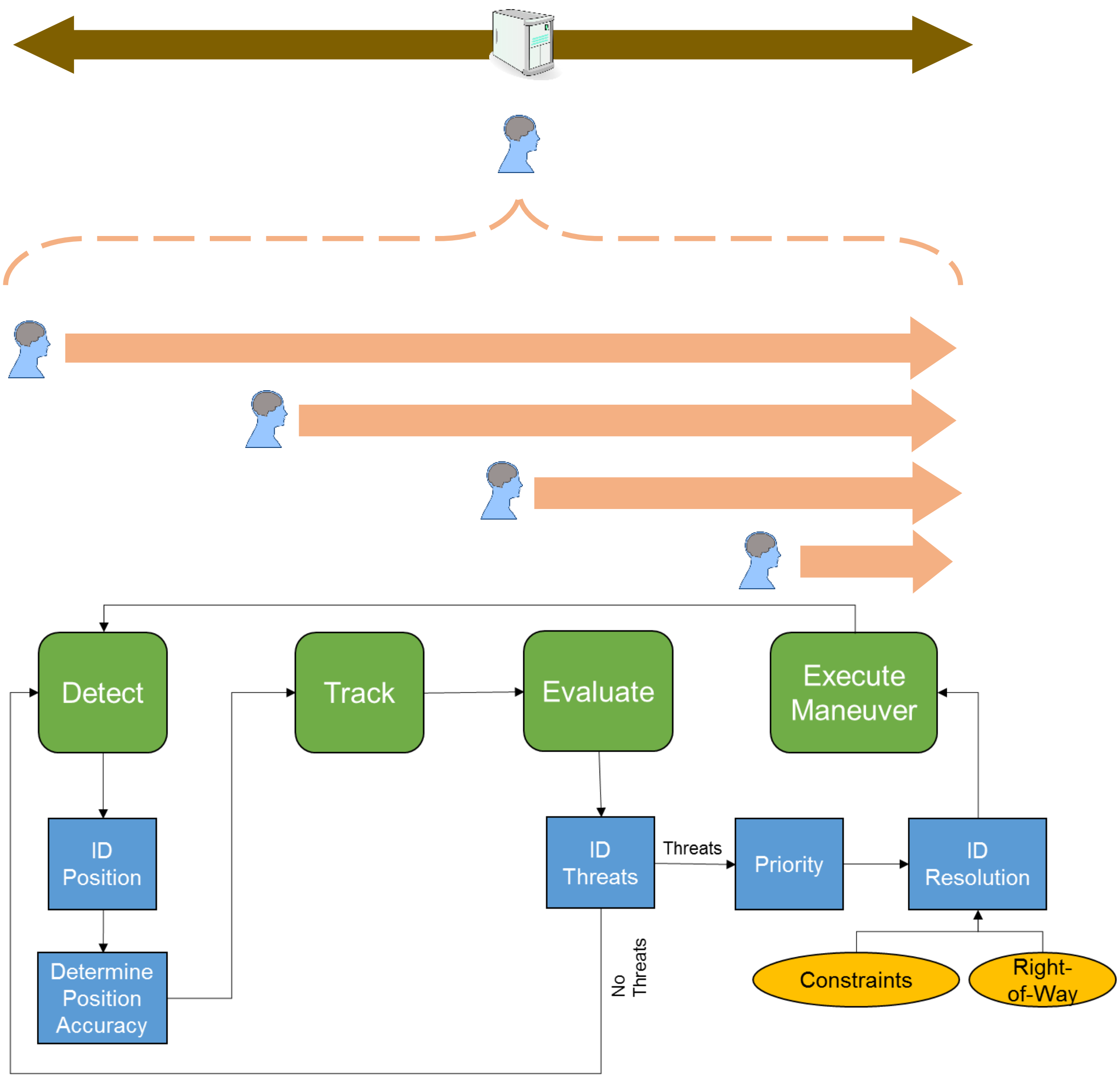


Figure 71. Illustration of architectural impacts on human involvement in the system. The flow chart represents the DAA encounter timeline. The brown arrow represents an autonomous system, the orange curly bracket represents a HOTL system, and the orange arrows represent HITL systems.

3.3.4 Assessment of Performance, Limitations, and Effectiveness

3.3.4.1 DAA Companies

To develop an understanding of the trade-offs associated with sUAS DAA systems, information regarding companies/entities in this area was gathered so that data regarding DAA systems that they are developing/provide could be acquired. This was accomplished through formal means, for example the RFI and analysis of section 333 data described in §2.1, and less formal means that include interaction with companies/entities at meetings such as AUVSI XPONENTIAL and TAAC. Through these processes, a list of 67 companies/entities was compiled (Table 32). As is apparent in Table 32, not every company/entity is actively engaged in DAA, with each company/entity provided in Table 32 for completeness. Moreover, not every entity in Table 32 is a provider of DAA technology. Again, all entities are listed for completeness.

As a means of characterization, companies that are focused on GBDAA, ABDAA (Airborne Detect And Avoid), or both, were identified. In addition, it was recognized early in this process that many companies are either interested in DAA and/or may provide technology that support DAA, but are not necessarily focused on DAA. Thus, the classification system described in the Table 32 caption was developed. Then, based on all information available, a subset of 13 companies/entities that are focused on DAA and that could provide the most useful information regarding DAA capabilities was identified (yellow highlighting in Table 32). Thus, this process identified a broad group of DAA-related companies and also what appear to be the DAA companies that are most engaged at this time (DAA-intensive companies). Further investigation indicated that IMSAR had produced the spin-off company Fortem Technologies and that the relevant DAA work was being pursued by that company. Moreover, collection of addition information indicated that TopCon is not a DAA-intensive company. Thus, subsequent results are based upon information gathered through interactions with the 11 DAA-intensive companies identified in Table 32.

It is noted that Point Of Contact (POC) information (contact name, phone number, and email address) was gathered for the companies/entities listed in Table 32. These data are not provided herein owing to privacy concerns but are available to those who have the right to access them.

Table 32. DAA companies/entities. Green indicates GBDAA companies, blue indicates ABDAA companies, purple indicates companies that are interested in/pursuing both GBDAA and ABDAA, yellow indicates DAA-intensive companies, and grey signifies companies removed from the initial DAA-intensive list. DAA Company Tiers are: 1 = Company provides or integrates a complete DAA system, 2 = DAA sensor company, 3 = Produces a sensor that could be used for DAA, 4 = Company that provides non-sensor elements, 5 = Company that has related technology but is not currently focused on DAA, 6 = Potential user, ? = Unknown.

Company/Entity	DAA Company Tier	Notes
ADS Corp.	5	
ADSYS Controls Inc.	2	Interested in EO/IR.
Aerial Applications	?	
Aeroprobe Corp.	1 or 2	Airborne sense and avoid (weight < 200 g).
Aeryon Labs Inc.	1 or 2	Airborne sense and avoid (EO/IR).
ADCOR	5	
Advanced Scientific Concepts, Inc.	5	Solid State Laser/Lidar, 75 lb system coming, 150 m range.
AeroVironment Inc.	1	
AFRL	6	
Airelectronics	3	Autopilot for UAS IR sensor and going to go to EO camera (power regulation).
Airmap	4	GBSAA input to BVLOS RFI (visualization system).
Airware	4	Looking at sensing structures.
Alexander Technical Coordinators	?	ABSAA and GBSAA input to BVLOS RFI.
American Robotics	6	
Analog Devices	5	Yes! Provides components for collision avoidance radar, connect to tech.
ANSUR Birdeye	?	
ASC LLC	?	
Blighter	2	Not at AUVSI but on UND radar list.
Botlink	4	Visualization
CGH Technologies, Inc.	?	
Defense Research Associates	1	EO/IR
DeTect Inc.	2	ABSAA input to BVLOS RFI.
Dynetics	?	GBSAA input to BVLOS RFI.
Echodyne	2	Not at AUVSI but on UND radar list.

Embry-Riddle	6	
ENSCO	?	GBSAA input to BVLOS RFI.
Fortem Technologies	2	On- and off-board radar.
FreeFlight	2	Early stages of developing DAA capabilities—primarily an ADS-B developer. Miniaturizing ADS-B for use within UAS and DAA systems.
Georgia Tech	6	
Gryphon Sensors	1	
Harris	1	Do not know which sensor to score for Harris.
Honeywell	1	ABSAA input to BVLOS RFI.
IMSAR LLC	1	SAR
Inertial Sense	5	Miniature IMU/GPS systems. Not really interested in DAA themselves, but happy to provide performance capabilities of equipment. Should be some value in estimating performance per SWaP.
INSITU	4	Supporting elements include GCS, potential visualization.
InterDigital	?	
Iris Automation	1	Working on EO-based DAA system.
JCPX Development	3	European anti-drone fighting system, but some interest in GBSAA (though very expensive system, not designed for DAA but rather for NATO military defense).
Knife Edge Software	5	
Kongsberg Geospatial	4	Situational awareness 3D software, GCS interfaces. VERY interested in research effort. ASSURE member.
L3	5	
Modern Technology Solutions Inc. (MTSI)	6	ABSAA input to BVLOS RFI.
NASA Langley Research Center	6	Interested in receiving study data.
Proxy Technologies	?	
R Cubed Engineering	1	Multimode ZEUS radar (weather, DAA, Synthetic Aperture, Doppler) that is under 10 lbs. and can be used either as ground-based DAA (NRC, NASA) or as primary radar in airborne DAA (NAVY, AirForce) with BVLOS platforms. Also provided ABSAA input to BVLOS RFI.
Rockwell Collins	4	

SARA	1	Not at AUVSI but on UND radar list.
SBT Inc.	?	
Sensurion Aerospace	5	
Squarehead	5	Have brochure. Has acoustic sensors to do obstacle avoidance.
SNC	2	System for large aircraft, but not for smalls.
SRC	2	Has DAA experience/sensors as LSTAR is part of the Army GBSAA system. Also provided GBSAA input to BVLOS RFI.
THALES	6	
TopCon	1	Currently developing DAA solution for their systems.
Trackimo	5	GPS trackers. No specific DAA system here, but could be a sensor for a DAA algorithm.
Uavionix	2	Micro ADS-B units. No non-cooperative DAA, but sensors make it easy for installing ADS-B In/Out on sUAS.
UAS in the NAS	6	
UASUSA	6	Sell UAS.
US Army	6	USA GBSAA SME's; not an RFI responder.
USDA/ARS Jornada Experimental Range	6	Use case input to BVLOS RFI.
UTC	2	Sensors that support DAA systems.
UtopiaCompression	1	EO/IR DAA.
Vectornav	5	GPS/IMU sensors. No DAA systems.
VideoBank	5	General input to BVLOS RFI.
Vigilant Aerospace Systems	1	
Ximea	5	High speed mini cameras.
Xcraft	5	Small UAS manufacturer. Working on obstacle avoidance algorithms/capabilities (early stages).

3.3.4.2 Data Collection

Data regarding the 11 companies identified in Table 32 were collected by obtaining publicly-available information (e.g., data from web sites) and by interacting with the POCs. This process was enabled through the development of DAA survey sheets, which where Microsoft Excel™ files that enabled entry of relevant data and descriptions of data items. These sheets were developed based upon the metrics used to evaluate systems, which are described below.

3.3.4.3 Company Information

High-level information regarding the DAA approach of each DAA-intensive company is provided in Table 33. As is apparent from Table 33, EO/IR and radar are the most common approaches being pursued by DAA-intensive companies. It is noted that one company, SARA, is pursuing a passive acoustic approach. It is further noted that the emphasis in this inquiry has been on systems that enable detection of all intruders. Thus, cooperative-only approaches were not evaluated in detail.

Table 33. DAA approaches of DAA-intensive companies.

Company	On/Off Board	Active/Passive	Sensor Type
AeroVironment	On Board	Passive	Unknown
Defense Research Associates	On Board	Passive	EO/IR
DeTect Inc.	On/Off Board	Active	Radar
Echodyne	On Board	Active	Radar
Fortem Technologies	On/Off Board	Active	Radar
Gryphon Sensors	Off Board	Active	Radar
Iris Automation	On Board	Passive	EO/IR
R-Cubed Engineering	On/Off Board	Active/Passive	ADS-B &Radar
SARA	On Board	Passive	Acoustic
UtopiaCompression	On Board	Passive	EO/IR
Vigilant Aerospace Systems	On Board	Passive	EO/IR

High-level information regarding each company, primarily obtained from web pages, is provided in the following sections. It is noted that companies that have an interest in both on and off board approaches are considered henceforth according to their leading approach. Thus, DeTect Inc. is considered to be an off board company and Fortem Technologies and R-Cubed Engineering are considered to be on board companies.

3.3.4.3.1 <u>Off Board</u>

3.3.4.3.1.1 Detect Inc.

DeTect Inc. is a radar company providing advanced products in intelligent radar remote sensing and sensors for aviation safety, security by surveillance, environmental protection, weather, and wind measurements utilizing 280 radar systems operating worldwide. Presently, DeTect Inc. is located in Florida, Colorado, Virginia, Canada, and England, with offices in over 80 countries. The HARRIER Security and Surveillance Radar is a product that allows for detection and tracking of small, non-cooperative, low radar-cross section, and non-linearly moving targets. This radar works well in high clutter environments and comprehends false positives from birds. HARRIER includes an SQL (Structured Query Language) data system that interfaces with third party video for a real-time simulation at specific regions. HARRIER has a subsystem known as the HARRIER GBSAA (Ground Based Sense And Avoid) Airspace Surveillance Radar (ASR) that operates at S- and/or X-band that can be installed on an automated tower system or fixed tower. The HARRIER GBSAA ASR features: an integrated TCAS and ADS-B to assist with secondary surveillance monitoring, day/night camera options, standard or custom data outputs for third party integration, two and three dimensional Geofence capability with user configurable alerts/actions, and a Video Draping Module that shows live video overlaid on a terrain map. A few applications of this radar include airspace monitoring of all cooperative and non-cooperative aircraft, low radar-cross section recognition capabilities, and full control of a UA.

3.3.4.3.1.2 Gryphon Sensors

Syracuse Research Corporation (SRC) Inc. formed Gryphon Sensors to solve DAA issues within the commercial aviation market. Gryphon Sensors provides a SkylightTM system that delivers a three-dimensional target-detection-and-tracking radar that operates regardless of the environmental conditions and time of operations. This system can be combined with additional sensors such as a slew-to-cue Electro-Optical/Infra-Red (EO/IR) camera and others based on the request of the user.

3.3.4.3.2 <u>On Board</u>

3.3.4.3.2.1 AeroVironment

AeroVironment is a leading provider of UAS systems for the U.S. military. Their systems are heavily used to provide ISR data. In addition, AeroVironment is working to serve civil sectors, including law enforcement, agriculture, and energy.

3.3.4.3.2.2 Defense Research Associates

Defense Research Associates (DRA) has developed DAA technology to assist with the highest level of safety that is necessary to operate in the NAS. This technology provides UA with an on-board EO-based system to assist with detecting, tracking, and alarming the user when a MAC is credible.

3.3.4.3.2.3 Echodyne

Echodyne is a privately-owned company with the main focus of integrating Metamaterial Electronically Scanning Array (MESA) based systems for a variety of applications that yields fast scanning and low SWaP and offers an active or passive option. Echodyne builds complete radars along with passive and active subsystems using MESA. Complete radars encompass MESA joined with a full radar transceiver, power, processing electronics, and APIs (Application Programming Interfaces).

3.3.4.3.2.4 Fortem Technologies

Fortem Technologies, Inc. is a privately held, venture-backed company that delivers an ultra-small SWaP radar for small manned aircraft as well as the data necessary for safe BLOS UA operations. The technology was developed over the last few years and is available now to meet the security expectations of the public and the safety requirements of national regulatory agencies.

3.3.4.3.2.5 Iris Automation

Iris Automation is developing a collision avoidance system for UA to enable beyond visual line of sight operations.

3.3.4.3.2.6 R-Cubed Engineering

R-Cubed Engineering has worked to develop DAA solutions for both cooperative and non-cooperative intruders. These include ADS-B based solutions and radar-based solutions. Work in this area has included not only sensor utilization, but also algorithms that identify conflicts.

3.3.4.3.2.7 Scientific Applications and Research Associates (SARA), Inc.

The applications of Scientific Applications and Research Associates, Inc. (SARA) Passive Acoustic Non-cooperative Collision-Alert System (PANCAS) include utilizing UA to detect a possible threat and track the intruder and change course if safe separation is lost—with or without operator intervention. There are various advantages to the PANCAS sensor: all-weather collision-avoidance capabilities allowing for UA to assist in the detection of intruders and maintain safe separation, the sensor hardware can be integrated into small UA, the system offers spherical instantaneous coverage (assists with detection of traffic from any angle), the acoustic sensor provides cueing of narrow field-of-view sensors, and sound sources are detected at all hours in all-weather conditions.

3.3.4.3.2.8 UtopiaCompression

UtopiaCompression has a variety of different technologies, with the most pertinent being their SAA (Sense And Avoid) capabilities of any entity whether it be a manned powered or unpowered aerial machines (e.g. airplanes, gliders, blimps, parachutes, etc.). UtopiaCompression provides a low SWaP SAA solution for DAA of non-cooperative aircraft that may or may not have on-board electronics (i.e., transponders or ADS-B). Their solutions involve passive intruder detection, monocular passive ranging, collision avoidance Ladar, imminent collision detection, and autonomous cloud avoidance.

3.3.4.3.2.9 Vigilant Aerospace Systems

Vigilant Aerospace Systems is a provider of both licensing and commercialization of NASA flight safety technologies and a developer of situational awareness, collision avoidance, and autonomous flight products for manned and unmanned aircraft. The key features of their products include, but are not limited to, traffic awareness and visualization for BVLOS, real-time DAA with traffic alerts and specific avoidance commands, 2D and 3D synthetic cockpit views, and real-time weather radar overlay.

3.3.4.4 Evaluation of Off Board Approaches

3.3.4.4.1 <u>Metrics</u>

Perhaps the greatest challenge in evaluating approaches was establishment of the metrics that would enable comparison. Metrics that would provide measures of important characteristics of systems are, of course, desired. These had to be weighed against the ability to obtain information regarding these metrics. Information regarding, for instance, system (sensor plus processing systems, displays, etc.) characteristics such as data latency, assurance, bandwidth, and security are very difficult to obtain because either the information is unknown owing to lack of testing or because information is not being publicly-provided at this time. Because of this, the metrics that were developed focused on sensor characteristics, as information regarding sensors is much more available. Metrics were categorized into three primary groups: sensor performance, operational environment, and utilization.

A confounding factor was establishment of metric values for specific metrics. The lack of standards for characteristics such as detection range, for instance, resulted in dependence upon evolving recommendations, such as the SARP-proposed definition for sUAS well clear, and results developed within (e.g., detection distances required for maintaining well-clear discussed in §3.2.3.6.2). The metrics, metric values, and corresponding scores that are used to evaluate off board systems are provided in Tables 34-36. As is apparent in these tables, a five-point Likert scale (5 is best performance) is used for scoring systems. Justifications for the metric values and corresponding scores are provided in Appendix D.

Table 34. Off board DAA sensor performance metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table.

Sensor Performance	1	2	3	4	5
Horizontal Range (ft/km/mi/nmi)	≥ 10560/3.22/2.0/1.74	26785/8.16/5.07/4.41 ≤ hr < cat 3	43010/13.11/8.15/7.08 ≤ hr < cat 4	59235/18.05/11.22/9.75 ≤ hr < cat 5	≥ 75460/23/14.3/12.4
Vertical Range (ft/km/nmi)	≥ 235/0.072/0.039	285/0.087/0.047 ≤ vr < cat 3	335/0.1/0.055 ≤ vr < cat 4	850/0.26/0.14 ≤ vr < cat 5	≥ 1450/0.44/0.24
Horizontal Resolution/Accuracy (ft)	≥ 1000	500 < hr < 1000	250 < hr ≤ 500	100 < hr ≤ 250	≤ 100
Vertical Resolution/Accuracy (ft)	≥ 200	100 < vr < 200	50 < vr ≤ 100	20 < vr ≤ 50	≤ 20
Scan Time/Update Rate (s)	≥ 8	2 < st < 8	1.5 < st ≤ 2	1 < st ≤ 1.5	≤ 1
Sensor Latency (s)	≥ 5	2.0 < sl < 5.0	1.0 < sl ≤ 2.0	0.1 < sl ≤ 1.0	≤ 0.1
Sensitivity (m^2)	≥ 20 (CRJ)	5 < sens < 20 (King Air)	1 < sens ≤ 5 (Cessna 172)	0.05 < sens ≤ 1 (human)	≤ 0.05 (small UAS/birds)
Aircraft Classification/Type	None	Big v small	Big v small and Fixed v rotary wing	MA intruder aircraft type	All intruder (MA, UA, and bird) intruder type
Probability of Detection (per sample)	< 70%	70-85%	85-95%	95-99%	> 99%
False Alarm Rate (per sample)	> 10%	5-10%	2.5-5%	1-2.5%	< 1%

Table 35. Off board DAA operational environment metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table.

Operational Environment	1	2	3	4	5
Temperature Range (°C)	0 to +20	-20 to +40	-40 to +50	-55 to +50	-55 to +85
Humidity Range (%)	20-80	10-90	0-90	0-95	0-100
Lighting Conditions	Night Only	Day Only	Away from minor (lightbulb) artificial light sources	Away from major (spotlights) artificial light sources	All
Range of Winds (mph)	< 70	70-93.3	93.3-116.6	116.6-140	> 140

Table 36. Off board DAA utilization metrics and metric values. Numbers within the top row are metric scores associated with the performance levels provided in the table.

Utilization	1	2	3	4	5
Acquisition cost ($)	> $500,000	$100,000-$500,000	$10,000-$100,000	$1000-$10,000	< $1000
Crew requirements	Requires additional FT crew	Existing crew workload increase	Accommodated by existing crew	Existing crew workload reduction	Reduces existing FT crew
Resources Needed for Installation	> 24 hours or establishment of new permanent infrastructure	16-24 hours or establishment of relocatable infrastructure	8-16 hours	1-8 hours	< 1 hour (plug and play)
Ease of Use	> 16 hours training, currency limits	8-16 hrs training, currency limits	4-8 hours training, annually	1-4 hours one time training	0-1 hours one-time training, intuitive
Reliability/Mean Time to Failure (hrs)	< 10	10-100	100-1000	1000-5000	> 5000

3.3.4.4.2 Comparison

Results for off-board approaches are presented in Table 37. Before analyzing the results, it is important to consider the challenges associated with such an analysis.

It is apparent that this field is relatively young, with few DAA-intensive companies. Considering that most DAA-intensive companies have an on board focus, this means that the amount of data available for evaluation of off board approaches is severely limited. This is compounded by the fact that not every company is able or ready to provide all of the data that are desired. This resulted data being available from the two candidate companies for only two metrics, with data from one company providing information for 11 other metrics and no data being available for six metrics. Moreover, only one off board approach—radar—is represented. While other approaches may be possible, companies appear to be focused on radar-based off board approaches.

As indicated in Table 37, radar-based off-board approaches appear to perform fairly well with regards to range and resolution. Performance is lower when it comes to scan time and sensor latency. One company indicated that it can provide excellent information regarding aircraft types.

Operational environment data were limited. For the metrics for which scores are available, systems appear to provide medium performance.

Acquisition cost and ease of use metrics may be barriers to utilization of radar-based off board systems. On the other hand, crew-requirements are moderate and mean time to failure, based on one input, appears excellent.

Table 37. Off board system scores.

Radar (2 Companies)					
Metric	Average	High	Low	Comments	# of Values Reported
Sensor Performance					
Horizontal Range	5	5	5		2
Vertical Range	5	5	5		1
Horizontal Resolution/ Accuracy	5	5	5		1
Vertical Resolution/ Accuracy					0
Scan Time/Update Rate	2	2	2		1
Sensor Latency	3	3	3		1
Sensitivity					0
Aircraft Classification/Type	5	5	5		1
Probability of Detection					0
False Alarm Rate					0
Operational Environment					
Temperature Range	2	2	2		1
Humidity Range					0
Lighting Conditions					0
Range of Winds	3	3	3		1
Utilization					
Acquisition Cost	1.5	2	1		2
Crew Requirements	3	3	3		1
Resources Needed for Installation					1
Ease of Use	1	1	1		1
Reliability/Mean Time to Failure	5	5	5		1
All Metrics	3.68	5	1		15

3.3.4.5 Evaluation of On Board Approaches

3.3.4.5.1 Metrics

Metrics for on board approaches are provided in Tables 38-42. Metrics were organized into four primary groups: sensor performance, SWaP, operational environment (either based on established standards or ranges), and utilization.

One of the metrics for which establishment of values was most challenging is (horizontal) range. For this, a score of 3 was assigned to the distance that simulations (§3.2.3) indicated enabled avoidance of an NMAC. A score of 4 was assigned to the distance that enabled maintenance of well clear (2000 ft horizontally per the SARP-proposed definition) as indicated through simulations (§3.2.3). The best score (5) enables action by the time the intruder reaches the "warning" boundary, which is approximately 30 s beyond the well-clear boundary (tau-framework).

Justifications for the metric values and corresponding scores are provided in Appendix E.

Table 38. On board DAA sensor performance metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table.

Sensor Performance	1	2	3	4	5
Horizontal Range (ft/km/nmi)	≥ 1850/0.56/0.3	3000/0.9/0.5 ≤ hr < cat 3	4000/1.22/0.66 ≤ hr < cat 4	10650/3.25/1.75 ≤ hr < cat 5	≥ 14600/4.45/2.4
Vertical Range (ft/km/nmi)	≥ 235/0.072/0.039	285/0.087/0.047 ≤ vr < cat 3	335/0.1/0.055 ≤ vr < cat 4	850/0.26/0.14 ≤ vr < cat 5	≥ 1450/0.44/0.24
Horizontal Resolution/Accuracy (ft)	≥ 1000	500 < hr < 1000	250 < hr ≤ 500	100 < hr ≤ 250	≤ 100
Vertical Resolution/Accuracy (ft)	≥ 200	100 < vr < 200	50 < vr ≤ 100	20 < vr ≤ 50	≤ 20
Scan Time/Update Rate (s)	≥ 8	2 < st < 8	1.5 < st ≤ 2	1 < st ≤ 1.5	≤ 1
Field of View (°)	< 30° & < 30°	(31-99)°x(31-64)°	(100-199)° x (65-134)°	(200-359)°x(135-179)°	360°x180°
Sensor Latency (s)	≥ 5	2.0 < sl < 5.0	1.0 < sl ≤ 2.0	0.1 < sl ≤ 1.0	≤ 0.1
Sensitivity (m^2)	≥ 20 (CRJ)	5 < sens < 20 (King Air)	1 < sens ≤ 5 (Cessna 172)	0.05 < sens ≤ 1 (human)	≤ 0.05 (small UAS/birds)
Aircraft Classification/Type	None	Big v small	Big v small and Fixed v rotary wing	MA Intruder aircraft type	All intruder (MA,UA, and bird) intruder type
Probability of Detection (per sample)	< 70%	70-85%	85-95%	95-99%	> 99%
False Alarm Rate (per sample)	> 10%	5-10%	2.5-5%	1-2.5%	< 1%

Table 39. On board DAA SWaP metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table.

SWaP (Size, Weight, and Power)	1	2	3	4	5
Size (cm^3)	> 101,614	4500-101,614	2700-4500	168.75-2700.00	< 168.75
Weight (kg)	> 3.3 (7.25 lbs)	> 1.13 to ≤ 3.3 (7.25 lbs)	> 0.15 to ≤ 1.13 (2.5 lbs)	> 0.050 to ≤ 0.15 (0.33 lbs)	≤ 0.050 (0.11 lbs)
Power to Operate (W)	> 12 - 28 V @ 25 W or requires auxiliary or self-contained power supply.	12 - 28 V @ 8 - 25 W	5 to 12 V @ 1 - 8 W	0.5 - 5 v @ 0.5 - 1 W	0 - 0.5 V @ < 0.5 W

Table 40. On board DAA operational environment based on established standards metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table. Categories correspond to those in RTCA (1984).

Operational Environment Based on Established Standards	1	2	3	4	5
Low Operating Temp/Category (°C)	0	-5	-15 (A1-A3)	-20 (B1)	-45 (B2)
High Operating Temp/Category (°C)	+25	+35	+45	+55 (B1)	+70 (B2)
High Short Time Operating Temp/Category (°C)	+25	+35	+45	+55	+70 (B2)
Low Temperature Ground Survival/Category (°C)	0	-10	-25	-40	-55 (B2)
High Temperature Ground Survival/Category (°C)	+25 (B2)	+40 (B2)	+55 (B2)	+70 (B2)	+85 (B2)
Temperature Variation/Category (°C min^{-1})	1	2 (C)	5 (B)	7.5	10 (A)
Humidity/Category	Category A with +40 °C in step 1	Category A with +45 °C in step 1	Category A (standard humidity environment)	Category C (severe humidity environment I)	Category B (severe humidity environment I)
Waterproofness Category	Category X	Category W but only falling mist	Category W	Category R	Category S
Sand and Dust Category	Category X		Category D only passing first cycle		Category D

Table 41. On board DAA operational environment metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table.

Operational Environment	1	2	3	4	5
Temperature Range (°C)	0 to +20	-20 to +40	-40 to +50	-55 to +50	-55 to +85
Humidity Range (%)	20-80	10-90	0-90	0-95	0-100
Lighting Conditions	Night Only	Day Only	Away from minor (lightbulb) artificial light sources	Away from major (spotlights) artificial light sources	All

Table 42. On board DAA utilization metrics and metric values. Numbers within the top row are scores associated with the performance levels provided in the table.

Utilization	1	2	3	4	5
Acquisition cost ($)	> $500,000	$100,000-$500,000	$10,000-$100,000	$1000-$10,000	< $1000
Crew requirements	Requires additional FT crew	Existing crew workload increase	Accomdated by existing crew	Existing crew workload reduction	Reduces existing FT crew
Resources Needed for Installation	OEM factory installed only	8-16 hours, OEM site	1-8 hours OEM, user site	1-8 hours user, some customization	< 1 hour user (plug and play)
Ease of Use	> 16 hours training, currency limits	8-16 hrs training, currency limits	4-8 hours training, anually	1-4 hours one time training	0-1 hours one-time training, intuitive
Reliability/Mean Time to Failure (hrs)	< 10	10-100	100-1000	1000-5000	> 5000

3.3.4.5.2 Comparison

Results for on board systems are present in Tables 43-45. As with off board systems, analysis is complicated by the fact that the field is relatively young, with a limited number of companies actively developing DAA solutions, and the fact that not every company is able or ready to provide all of the data that are desired.

Results for radar-based systems are presented in Table 43. As is apparent, information for nearly all of the metrics is available, although for some only one input is available. Arguably, the greatest challenge for such systems is having enough range to detect aircraft far enough away to enable avoiding them while keeping the SWaP manageable. As indicated in Table 43, it appears as if this technology is starting to reach this level of performance, with detection ranges that enable NMAC avoidance and that are getting closer to enabling maintenance of well clear (according to the SARP proposed definition). The SWaP required to accomplish this appears moderate, from a size and weight perspective, although the power requirements are still significant. It is noted that FOV is also a concern with these types of systems, with performance being moderate for the systems that were considered. As indicated in §3.2.3.6.2, simulations indicate that limited field of view has an impact on maintenance of well clear.

For EO/IR systems, information for systems provided by two companies was obtained. Since one of these companies is developing three different systems, the data in Table 44 includes input for four different systems. As is apparent, the amount of information that is available for analysis is limited. Based on one input value, it appears as if the range performance for this approach is not as good as that for off board radar-based systems and on board radar-based systems. Relative to on board radar based systems, the SWaP requirements appear to be greater. While no data regarding utilization was available, it is expected that such systems may have a lower price point, possibly lowering barriers to their use.

The final approach for which data was obtained is (passive) acoustic. As is apparent from Table 45, the amount of data available for this approach is minimal. However, given the information that was available, it appears as if this approach has the potential to at least avoid NMAC. Moreover, this approach appears to enable a complete FOV, thus eliminating the issue discussed in §3.2.3.6.2. In addition, the SWaP requirements are moderate, which is enabling.

Table 43. On board system scores for radar based systems.

Radar (2 Companies)					
Metric	**Average**	**High**	**Low**	**Comments**	**# of Values Reported**
Sensor Performance					
Horizontal Range	3	3	3		2
Vertical Range	5	5	5		1
Horizontal Resolution/ Accuracy	2	2	2		1
Vertical Resolution/ Accuracy	2	2	2		1
Scan Time/Update Rate	5	5	5		2
Field of View	2.5	3	2		2
Sensor Latency	4.5	5	4		2
Sensitivity	4	5	3		2
Aircraft Classification/Type	3.5	5	2		2
Probability of Detection	3	3	3		1
False Alarm Rate	5	5	5		1
Size, Weight, and Power (SWaP)					
Size	4	4	4		2
Weight	3	3	1		3
Power to Operate	1	1	1		2
Operational Environment					
Temperature Range	3	3	3		1
Humidity Range					
Lighting Conditions	5	5	5		1
Range of Winds					
Utilization					
Acquisition Cost	3.5	4	3		2
Crew Requirements	5	5	5		1
Resources Needed for Installation	4	4	4		1
Ease of Use	4.5	5	4		2
Reliability/Mean Time to Failure	5	5	5		2
All Metrics	3.7	5	1		34

Table 44. On board system scores for EO/IR based systems.

EO/IR (2 Companies/4 Systems)					
Metric	Average	High	Low	Comments	# of Values Reported
Sensor Performance					
Horizontal Range	2	2	2		1
Vertical Range					
Horizontal Resolution/ Accuracy					
Vertical Resolution/ Accuracy					
Scan Time/Update Rate	5	5	5		1
Field of View					
Sensor Latency					
Sensitivity					
Aircraft Classification/Type					
Probability of Detection	3	3	3		1
False Alarm Rate	2	2	2		1
Size, Weight, and Power (SWaP)					
Size	2	2	2		1
Weight	1	1	1		2
Power to Operate	1	1	1		2
Operational Environment					
Temperature Range					
Humidity Range					
Lighting Conditions					
Range of Winds					
Utilization					
Acquisition Cost					
Crew Requirements					
Resources Needed for Installation					
Ease of Use					
Reliability/Mean Time to Failure					
All Metrics	2.3	5	1		9

Table 45. On board system scores for acoustic based systems.

Acoustic (1 Company)					
Metric	Average	High	Low	Comments	# of Values Reported
Sensor Performance					
Horizontal Range	3	3	3		1
Vertical Range	5	5	5		1
Horizontal Resolution/ Accuracy					
Vertical Resolution/ Accuracy					
Scan Time/Update Rate					
Field of View	5	5	5		1
Sensor Latency					
Sensitivity					
Aircraft Classification/Type					
Probability of Detection					
False Alarm Rate					
Size, Weight, and Power (SWaP)					
Size	4	4	4		1
Weight	3	3	3		1
Power to Operate	3	3	3		1
Operational Environment					
Temperature Range					
Humidity Range					
Lighting Conditions					
Range of Winds					
Utilization					
Acquisition Cost					
Crew Requirements					
Resources Needed for Installation					
Ease of Use					
Reliability/Mean Time to Failure					
All Metrics	3.8	5	3		6

3.3.4.6 Summary

As is expected given the relative youth of this area, a limited amount of information was available for analysis. A limited number of companies focus on DAA for sUAS and those that do are at different points in system development, which means that some either do not have information used in this analysis or are not ready to share their data. Given this, conclusions drawn from these data should be considered with healthy skepticism.

Given the data available, the following can be concluded:

- The majority of DAA-intensive companies are pursuing on-board solutions.
- The only off-board solution being pursued by companies identified as DAA-intensive is radar-based. It appears as if other approaches are in earlier stages of development.

- On board solutions being explored by DAA-intensive companies include active radar, passive EO/IR, and passive acoustic. Of these, radar and EO/IR are the most popular approaches.
- Off board radar-based systems have advantages regarding sensor performance (e.g., range), with the primary barrier being acquisition cost.
- On board radar-based systems have utilization advantages (e.g., cost, installation), with the primary challenges being detection range and FOV within SWaP limitations.
- On board EO/IR-based systems provide excellent update rates and may provide utilization advantages (e.g., cost). However, FOV and SWaP appear to be challenges.
- On board passive acoustic approaches appear to enable a complete FOV, with comparable range performance at an apparently lower SWaP requirement.
- Data for some metrics (e.g., probability of detection, false alarm rate, operational environment limitations) were severely limited. Additional data are needed to solidify results.
- It is expected that some data are limited owing to a lack of flight testing. Flight testing would enable both characterization of approaches and establishment of standards that will enable future system development.

3.4 Assessment of Risks of Selected DAA Approaches

3.4.1 Introduction

3.4.1.1 The Safety Management System (SMS)

The FAA encourages every aviation service provider to develop and implement a Safety Management System (SMS). While the term aviation service provider includes air carriers, airlines, maintenance repair organizations, air taxi operators, single pilot operators, pilot schools and so on, the intent is to also include all entities involved in UAS activities as well. The FAA SMS framework utilized by the research team is organized around four pillars of safety management: (1) Safety Policy, (2) Safety Risk Management, (3) Safety Assurance, and (4) Safety Promotion. Each of these are essential for a safety-oriented management system.

3.4.1.1.1 Safety Policy

The first pillar in the SMS framework is Safety Policy. This pillar defines the policies, procedures, and organizational structures that act as the foundation of the three functional pillars that follow (FAA 2015). Elements included in this pillar are (1) safety policy, (2) management commitment and safety accountabilities, (3) key safety personnel, (4) emergency preparedness and response, and (5) SMS documentation and records (FAA 2015). This research team examined existing controls, such as policies, procedures, regulatory controls, and guidelines, with the goal of informing adaptations or additions for this novel use case.

3.4.1.1.2 Safety Risk Management

The second pillar, Safety Risk Management (SRM), identifies hazards and works to reduce risk to an acceptable level. It is the formal process within the SMS that identifies the hazards, assesses the risk, analyzes that risk, and then controls for it (FAA 2015). The SRM pillar is composed of two elements: (1) hazard identification and analysis, and (2) risk assessment and control (FAA 2015). These elements enabled a better understanding of critical aspects and existing controls related to sUAS BVLOS operations. This systemic perspective was used to identify potential gaps in existing controls and to offer recommendation for additional defenses and controls.

3.4.1.1.3 Safety Assurance

Safety Assurance, the third SMS pillar, ensures that the risk mitigations put in place by SRM continue to be effective in a dynamic operational environment. This pillar provides confidence that an organization meets or exceeds safety requirements by applying system safety concepts and quality management processes (FAA 2015). The safety assurance pillar is composed of three elements: (1) safety performance monitoring and measurement, (2) management of change, and (3) continuous improvement (FAA 2015). While the scope of this effort is completion of the SRM process, flight tests under related and future efforts can offer validation for the safety assurance process and results of the preliminary risk assessment.

3.4.1.1.4 <u>Safety Promotion</u>

The final pillar, Safety Promotion, provides guidance for promoting safety as a core value and developing practices that support a sound safety culture (FAA 2015). This pillar is composed of the elements (1) competencies and training and (2) communications and awareness (FAA 2015). Presentation and publication of results from this effort will be used to raise public awareness of the risk management process, as well as offer industry stakeholders insight into the hazards, risks, controls, and opportunities unique to sUAS BVLOS operations.

3.4.1.2 SRM Focus

Giving initial focus to the Safety Risk Management (SRM) pillar of the SMS process, this effort (1) identifies hazards related to the operation of sUAS in BVLOS, (2) offers a preliminary risk assessment considering existing controls, and (3) recommends additional controls and mitigations to further reduce risk. While this effort is framed within a relatively small set of conditions, this process aims to advance understanding of the critical aspects and existing controls in BVLOS operations for sUAS. Application of these results advance efforts to realize BVLOS operations across a much broader portion of the NAS.

3.4.2 Methodology

This preliminary risk assessment for sUAS DAA in limited BVLOS Operations was accomplished utilizing the FAA SMS framework detailed in FAA (2015). Members of the research team convened in a weekly workshop setting for an average of three hours across the period of performance.

3.4.2.1 Assumptions and Limitations

This risk assessment began with the following set of sponsor provided assumptions and limitations:

- Day, Visual Meteorological Conditions (VMC) operations only.
- A potential for night VMC operations enabled by new standards and rules.
- UAS operations will initially be limited to Class G and Class E airspace. Additional airspace may be evaluated as necessary.
- UAS operations will be conducted from the surface to 500 ft AGL, with additional evaluation of the potential for operations up to 1,000 ft AGL.
- UAS operations will be conducted over other than densely populated areas, unless UAS complies with potential criteria or standard that demonstrates safe flights over populated areas.
- UAS will not be operated close to airports or heliports. ‘Close’ is initially defined as within 3 miles of an airport unless permission is granted from ATC or an airport authority. A distance of greater than 5 miles will be examined if needed to support an appropriate level of safety.
- UAS operations will be restricted to within RLOS of a single, fixed ground-based transmitter.
- Some safety-based design and/or configuration requirements may be specified (aircraft painted in a highly-visible paint scheme to facilitate identification by other aircraft, strobe lights, etc.)
- Small UAS are potentially designed to an Industry Consensus Standard and issued an FAA Airworthiness Certificate or other FAA approval.

In addition to these, the research team focused their efforts further by assuming the following:

- sUAS PIC is subject to the eligibility requirements of 14 CFR §107.61
  "Subject to the provisions of §107.57 and §107.59, in order to be eligible for a remote pilot certificate with a small UAS rating under this subpart, a person must:
    - (a) Be at least 16 years of age;
    - (b) Be able to read, speak, write, and understand the English language. If the applicant is unable to meet one of these requirements due to medical reasons, the FAA may place such operating limitations on that applicant's certificate as are necessary for the safe operation of the small unmanned aircraft;
    - (c) Not know or have reason to know that he or she has a physical or mental condition that would interfere with the safe operation of a small unmanned aircraft system; and
    - (d) Demonstrate aeronautical knowledge by satisfying one of the following conditions:
        - (1) Pass an initial aeronautical knowledge test covering the areas of knowledge specified in §107.73(a); or
        - (2) If a person holds a pilot certificate (other than a student pilot certificate) issued under part 61 of this chapter and meets the flight review requirements specified in §61.56, complete an initial training course covering the areas of knowledge specified in §107.74(a) in a manner acceptable to the Administrator."
- sUAS PIC is subject to the aeronautical knowledge recency of 14 CFR §107.65
  "A person may not operate a small unmanned aircraft system unless that person has completed one of the following, within the previous 24 calendar months:
    - (a) Passed an initial aeronautical knowledge test covering the areas of knowledge specified in §107.73(a);
    - (b) Passed a recurrent aeronautical knowledge test covering the areas of knowledge specified in §107.73(b); or
    - (c) If a person holds a pilot certificate (other than a student pilot certificate) issued under part 61 of this chapter and meets the flight review requirements specified in §61.56, passed either an initial or recurrent training course covering the areas of knowledge specified in §107.74(a) or (b) in a manner acceptable to the Administrator."
- sUAS PIC is in compliance with the medical conditions of 14 CFR §107.17
  "No person may manipulate the flight controls of a small unmanned aircraft system or act as a remote pilot in command, visual observer, or direct participant in the operation of the small unmanned aircraft if he or she knows or has reason to know that he or she has a physical or mental condition that would interfere with the safe operation of the small unmanned aircraft system."
- RFI/EMI (Radio Frequency Interference/ElectroMagnetic Interference) evaluation is completed to ensure de-confliction.
- Fully autonomous systems were not considered.
- Intruders may be either cooperative or non-cooperative traffic.
- Willful violations of 14 CFR and rouge actors in the case of the sUAS PIC and intruders were considered out of scope.

Relative to the hypothetical DAA systems considered, it was assumed that the system must be operational for BVLOS flight and is able to acquire information regarding own ship position. The DAA system was not construed to be responsible for providing information regarding attitude or direction of flight for ownship. Furthermore, it was assumed that DAA systems will utilize data fusion approaches that are consistent with best practices (e.g., best source selection or Kalman filtering). Given these approaches, target location uncertainty would not be expected to exceed that of the best instrument.

3.4.2.2 Hazard Identification and Analysis

The SRM process identifies hazards for a specific operation and works to reduce risk to an acceptable level. In this preliminary risk assessment for sUAS BVLOS operations, hazards were defined as "a condition that could foreseeably cause or contribute to an aircraft accident as defined in Title 49 of the Code of Federal Regulations (49 CFR) part 830, §830.2" (FAA 2015). Operationally, consideration was given to any real or potential condition that can cause injury, illness, or death to people; damage to, or loss of, a system (hardware of software), equipment, or property; or damage to the environment. In the hazard identification and analysis phase of this effort, conditions that fell under this definition and within the assumptions and limitations above were generated and then organized according to an architecture of system states illustrated in Fig. 72.

Development of the DAA system architecture in Fig. 72 was an iterative process. Description of potential DAA systems for sUAS was generally divided between GBDAA and ABDAA. In this effort, hypothetical DAA systems were categorized as GBDAA only if all of the detect, track, evaluate, and maneuver functions occurred off board the aircraft. Likewise, a system fell within a working description of ABDAA only if all of these DAA functions (i.e. detect, track, evaluate, and maneuver) were accomplished onboard. If any of the four primary functions were shared between on and off board systems, the architecture was considered a hybrid design. Within each DAA configuration, hazards coalesced into four components (1) Level of Autonomy, (2) Hardware, (3) Software, and (4) Sensor. While these components reduce to a hierarchical structure in a general sense, hazards groups that related to Software and the Man Machine Interface (MMI) (and others) do not follow the strict hierarchical structure suggested by Fig. 72.

Each of the four components were further separated into sub-categories to represent more minute differences between future DAA designs. For example, hazards related to level of autonomy were divided among human execution errors [i.e., Human in the Loop (HITL)] or human management errors [i.e., Human over the Loop (HOTL)]. The hardware component included supporting software both on and off board the aircraft, as well as equipment that supports the MMI for both HITL and HOTL configurations, and also the equipment on which the algorithm resides. The software component addressed hazards related to the algorithm as well as the software supporting the MMI, and the sensor component was divided between active and passive systems. To emphasize architecture level differences between the ground-based and airborne models of DAA, systems states that were not given consideration (e.g., onboard supporting systems for GBDAA) are depicted by an unlabeled box positioned to mirror the corresponding element in the opposite system.

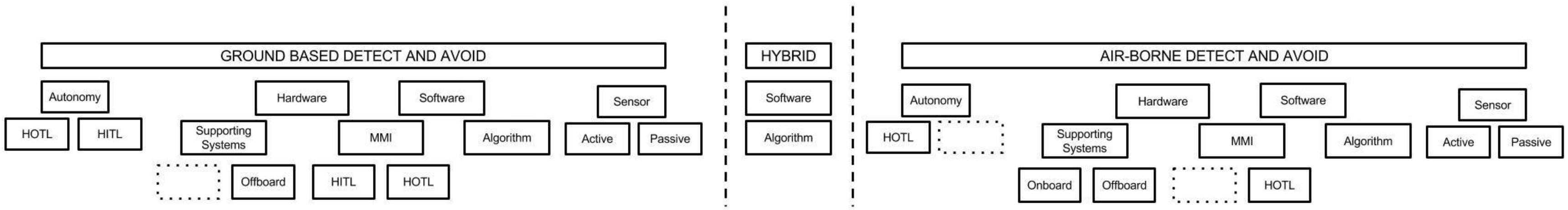


Figure 72. Illustration of sUAS DAA system architectures/states. MMI stands for Man Machine Interface.

3.4.2.3 Risk Assessment and Control

In the next phase, the research team considered and documented existing controls for each of the nearly 250 hazards identified in the previous phase. Efforts to estimate severity and likelihood for each hazard resulted in a measure of initial risk. As initial risk was reached, additional mitigations and controls were proposed to reduce risk to the lowest practical level. In this phase of the SRM, great consideration was given to avoid recommending undue, unrealistic, or impractical mitigation requirements for sUAS BVLOS operations.

Severity is defined as the consequence or impact of a hazard's effect or outcome in terms of degree of loss or harm. Severity is determined prior to, and is considered independent of, likelihood. To assess this aspect of risk, a novel severity scale was developed. Detailed in Table 46, this scale framed the severity of risks associated with sUAS BVLOS operations to a variety of effects on established separation criteria [e.g., MAC (MidAir Collision) and NMAC] and the evolving definition of well clear for sUAS. Setting a MAC to represent a catastrophic effect and maintaining well clear as representing the minimal effect, the scale presents a narrow variation relative to scales in the extant literature that may range from single or multiple fatalities at catastrophic to injury or discomfort at the minimal-effect end. In development and application of this scale, it was assumed that flight of the sUAS would be conducted such that maneuvering would occur to maintain well clear at all times (i.e., the UA is operated well clear, plus some distance, from the boundaries of the well surveilled volume). Prior to use in the risk assessment and control process, this scale was examined and approved by the sponsor.

Table 46. Well clear severity scale.

Catastrophic 1	Hazardous 2	Major 3	Minor 4	Minimal 5
Midair Collision (MAC)	Violation of well clear criteria resulting in a NMAC. (less than 500 ft horizontal and 100 ft vertical)	Violation of well clear criteria requiring immediate corrective or evasive action.	Violation of well clear criteria that does not require corrective action by either sUAS or manned aircraft.	Well clear criteria met; however the manned aircraft or sUAS takes precautionary action, impacts flight path of either the sUAS or manned aircraft.

When estimating likelihood, the scale detailed in Table 47 was used to express rates of occurrence relative to a specific sUAS mission. Adapted to be assessed relative to a single or specific sUAS mission, the likelihood scale below was also examined and approved by the sponsor prior to use in the risk assessment and control process.

Table 47. Hazard likelihood scale.

Frequent A	Probable B	Remote C	Extremely Remote D	Extremely Improbable E
Expected to occur more than once per week during a specific sUAS mission.	Expected to occur about once every month during a specific sUAS mission.	Expected to occur about once every year during a specific sUAS mission.	Expected to occur about once every 10 years during a specific sUAS mission.	Expected to occur less than once every 100 years during a specific sUAS mission.

The risk assessment matrix shown in Fig. 73 was used to categorize initial and residual risks into one of three possible risk levels (i.e. high, medium, or low). Hazards categorized within the high risk area are considered unacceptable. These hazards must be mitigated to medium or low-risk, and the predicted residual risk should be monitored and tracked in relation to the safety performance targets until the predicted residual risk can be verified. As indicated in Fig. 73, hazards with catastrophic effects that are caused by single point events or failures, common cause events or failures, or undetectable latent events in combination with single point or common cause events are considered high risk, even if the possibility of occurrence is extremely improbable. An example of a single point failure is found in a system with redundant hardware, in which both pieces of hardware rely on the same battery for power. In this case, if the battery fails, the entire system will fail. A common cause failure is a single fault resulting in the corresponding failure of multiple components. An example of a common cause failure is found in a system with redundant computers running on the same software, which is susceptible to the same software bugs.

Hazards categorized within the medium risk area are considered acceptable risks and represent the minimum acceptable safety objective. While initial medium risk is acceptable, it is recommended and desirable that safety requirements be developed to reduce severity and/or likelihood. These hazards should also be monitored and tracked in relation to the safety performance targets until the predicted residual risk can be verified. Again, a catastrophic severity and corresponding extremely improbable likelihood qualify as a medium risk, provided that the effect is not the result of a single point or common cause failure. If the cause is a single point or common cause failure, the hazard is categorized as high risk.

Hazards categorized within the low risk area are considered acceptable risk without restriction or limitation. It is not mandatory to develop safety requirements for low-risk hazards; however, a monitoring plan with at least one safety performance target should be developed.

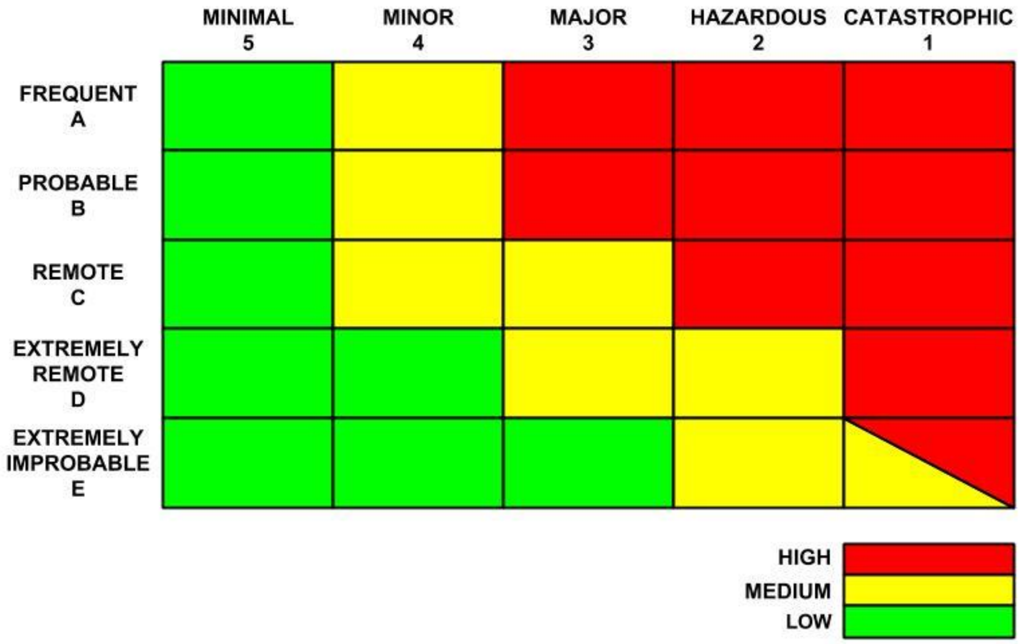


Figure 73. Risk assessment matrix.

3.4.3 Results

Completion of the risk assessment and control completed the SRM for sUAS BVLOS operations. In total, the risks for nearly 250 hazards were identified, classified, and offered some degree or method of mitigation. An annotated listing of the initial and residual risks for each of the four major DAA system components (i.e. Autonomy, Hardware, Software, and Sensors) are offered below. Initial risk of most hazards were mitigated with a single set of controls or mitigations. In the case of several risks, however, multiple or elective mitigations—separated by "AND" and "OR" respectively in "additional controls"—were proposed. The inclusion of these multiple or elective mitigations occasionally result in unique residual risks, as in the case of the hazard "Signal used for detection ceases" in the passive sensor component of GBDAA. Hazards like this one result in the discrepancy between the number of hazards analyzed (i.e., 238) and the higher number of initial and residual risks reported in each component below. For the reader's convenience, each hazard has been transposed into a table format in Appendix F.

3.4.3.1 Level of Autonomy

Hazards related to level of autonomy were divided among human execution errors [i.e., Human in the Loop (HITL)] or human management errors [i.e., Human over the Loop (HOTL)]. Again, note that fully autonomous systems were not considered within this effort and remain an object for future study. A total of 29 hazards were identified within this component of GBDAA and ABDAA systems. The majority of these hazards were represented within the HITL or human execution error classification; an area analyzed for GBDAA systems but not for ABDAA. Initial risks (25) in the level of autonomy area all fell under high-risk classifications, indicating an area where existing controls may not adequately mitigate the hazards of BVLOS operations for sUAS. Residual risks in this area were expected to be reduced to 2 high-risk, 13 medium-risk, and 10 low-risk with the implementation of recommended mitigations and controls.

In this component, the errors of execution committed by the PIC were identified as a single point of failure, barring situations when a second crewmember could be utilized to supplement decision-making. A second single point of failure was also recognized in the line of communication between the individual providing DAA guidance [e.g., VSO (Visualization System Observer)] and the PIC.

3.4.3.2 Hardware

Hazards related to hardware included supporting software both on and off board the aircraft, equipment that supports the MMI for both HITL and HOTL configurations, and equipment on which the algorithm resides. A total of 42 hazards were identified and analyzed within this component of DAA systems for sUAS use. The largest contingent of these hazards rested within supporting systems for both HITL and HOTL configurations. Across the entire Hardware component, 55 initial risks were categorized as high-risk and 6 were categorized as low-risk. Following implementation of recommended mitigations and controls, residual risks in this area were expected to be reduced to 1 high-risk, 1 medium-risk, and 59 low-risk.

The only single point of failure identified for this component was the possibility of data corruption between the DAA and flight control system resulting in an incorrect maneuver. Minor data corruptions are known to exist in networking applications. Though unlikely, this network connection in the supporting systems represents a single point of failure when—as in an ABDAA configuration—execution of the resolution maneuver may not necessarily be accomplished by the PIC.

3.4.3.3 Software

The software component of DAA for sUAS BVLOS primarily addressed those hazards related to the algorithm as well as the software supporting the MMI for both GBDAA and ABDAA system designs. Amassing a total of 64 hazards, the software component is second only to the sensors component in number of identified hazards. Hazards in this component appear to be distributed with relative equity across algorithm and MMI for GBDAA and ABDAA configurations. Initial risks across the entire component were classified as 32 high risks, 19 medium risks, and 4 low risks. Residual risks, after considering the effect of recommended mitigations and controls, fell to 1 high, 5 medium, and 49 low-risk classifications, respectively.

In this component, an algorithm that is improperly tested, configured, installed, etc., and is put into operation was considered a single point of failure. An established level within, or equivalent to, the DO-178 software development standards (RTCA 2011) was recommended as a mitigation to greatly reduce the likelihood of this risk. A midair collision was still considered credible, however, depending on the time needed to recover the DAA system following a malfunction.

3.4.3.4 Sensors

Hazards related to active and passive sensor systems incorporated across both ground-based and airborne DAA system designs were the most numerous at 102. In this component, hazards again appear to be distributed with relative equity across the four combinations of active and passive sensors for GBDAA and ABDAA. Across these combinations of sensor hazards, 81 high, 24 medium, and 4 low initial risks were classified. Following implementation of recommended mitigations and controls, residual risks in this area were expected to be reduced to 20 high risk, 34 medium risk, and 78 low risk.

Without assuming a DAA system will have redundant sensors, mechanical and software failure within the DAA's sensor emerged as single points of failure in every combination of active, passive, ground-based, and airborne DAA systems. Along similar lines, sustained loss of signal due to interference, and detection holes in the well surveilled volume—perhaps caused by propagation issues or weather—also represent single points of failure worthy of continued consideration.

3.4.3.5 Mitigation-Driven Results

SRM results are provided according to mitigation types in Appendix G. These provide the mitigation, the associated hazard, the DAA function (detect, track, evaluate, or maneuver), initial risk, residual risk, and associated notes. This format is expected to be enabling since DAA system producers will be most interested in what mitigations may be required. The types of mitigations, along with the number of mitigations (GBSAA/ABSAA), are:

- System Redundancy (50/36)
- System Functionality (27/19)
- Pre-Flight (25/21)
- Training and Performance Evaluation (13/4)
- Health Monitoring (19/16)
- Procedural (26/21)
- Medical (2/0)
- Software Standards (2/3)

It is noted that the number of mitigations for a type of system (e.g., GBSAA) do not add up perfectly to other numbers presented herein because multiple mitigations may be applied to a particular hazard. Because of this, individual mitigations may not be responsible for the total difference between residual and initial risks that are provided in Appendix G. Finally, it is noted that the number of mitigations associated with software standards are low because an equivalent of DO-178C (RTCA 2011) was commonly assumed as an existing control for software-based systems.

3.4.4 Discussion and Conclusion

Focusing on the Safety Risk Management (SRM) pillar of the SMS process, this effort (1) identified hazards related to the operation of sUAS in BVLOS, (2) offered a preliminary risk assessment considering existing controls, and (3) recommended additional controls and mitigations to further reduce risk to the lowest practical level. The risk assessment began with a set of sponsor provided assumptions and limitations. Generally speaking, operations in day, VMC conditions, within Class G and E airspace over other than densely populated areas were considered within scope. These operations were to be limited from the surface to 500 ft AGL (although flight up to 1000 ft could be considered), further than 3 miles from an airport or heliport, and within RLOS of a fixed ground-based transmitter. Following its release, several eligibility requirements and conditions of 14 CFR §107 were added to this list of assumptions for consideration as existing controls in the risk assessment.

3.4.4.1 Safety Risk Management

Within the ground-based and airborne DAA configurations, hazards generally coalesced into four components (1) Level of Autonomy, (2) Hardware, (3) Software, and (4) Sensor (see Fig. 72). Risks for nearly 250 hazards were identified within this architecture of system states, classified, and offered some degree or method of mitigation. Of the four primary DAA components identified, hazards related to sensor systems were the most numerous at 102, followed in decreasing order by those related to software, hardware, and level of autonomy.

Following implementation of recommended mitigations and controls, residual risks for sensor hazards were expected to be reduced to 20 high risks, 34 medium risks, and 78 low risks. Not anticipated at the outset, relatively few differences surfaced between active ground-based and airborne DAA or between passive sensor systems in the ground-based and airborne configurations. Residual risks in level of autonomy were expected to reduce to 2 high risks, 13 medium risks, and 10 low risks. Inclusion of a practical performance evaluation (e.g., a check ride) or equivalent, and more stringent medical standards than those established under 14 CFR §107.17 for crewmembers operating sUAS BVLOS, emerged as common themes within additional controls and mitigations for this component.

Residual risks for software were reduced to 1 high risk, 5 medium risks, and 49 low risks; hardware residual risks were expected to be reduced to 1 high risk, 1 medium risk, and 59 low risks. In both of these components, system redundancy and health monitoring of flight critical processes emerged as common mitigations. Discussions around the health monitoring mitigation in particular begged consideration of pilot expectations and other human factors that would influence the preferred method (e.g. alerts, warnings, cautions) for communicating information, abnormalities, and failures to the PIC. The challenges associated with Software Of Unknown Pedigree (SOUP) surfaced repeatedly across the software component with frequent reference to standards such as DO-178 (e.g., RTCA 2011) as a recommended mitigation.

3.4.4.2 Potential Mitigations

Throughout the discussion and assessment of the above risks, a relationship seems to emerge between operating environment (e.g., airspace density), sensor uncertainty, and procedural separation (e.g., well clear). That is, the sensor uncertainty an operation is able to tolerate—and the extent of procedural separation minimums—for a given operation is dependent on the operating environment of the sUAS. Tolerance for positional uncertainty in approving BVLOS operations within airspace with low traffic density will be higher than in high density airspace. Likewise, the temporal uncertainty of the DAA sensor (i.e., refresh or update rate) will also contribute to this model for BVLOS approval across the myriad of airspaces in the NAS. An established threshold for sensor uncertainty may permit BVLOS approval in many areas. Access to airspace with higher traffic density may not be precluded, but will certainly carry much higher criteria for DAA sensors. Such a model might also inform minimum acceptable mitigations such as a requirement to communicate uncertainly to the PIC (e.g., visual or aural) and/or the degree of additional procedural mitigations (e.g., separation minima over and above well clear) necessary. The model or metric represented by these relationships could offer a broader range of acceptable BVLOS solutions in the NAS for a proposed operation.

In the way of an example, The Northern Plains Unmanned Aircraft Systems Test Site (NP UAS TS) has received approval for a BVLOS COA (Certificate Of Authorization or waiver) for operations of a large UAS out of the Grand Forks Air Force Base (GFAFB) under a waiver granted by the FAA. A CONcept of OPerationS (CONOPS) was developed to support the COA case, which outlines the methods and procedures that will be used to safety and efficiently operate UAS in a BVLOS environment. These operations will further research and develop BVLOS concepts, procedures, and supporting infrastructure for UAS, and will occur as Public Aircraft Operations as defined by 49 U.S.C. §40102, 49 U.S.C. §40125, and FAA Advisory Circular 00-1.1A. The CONOPS has been produced as the result of the combined time and effort from many entities and personnel, including support from the FAA. The NP UAS TS has full confidence in the ability for this concept of operations to be executed safety and effectively in the United States' NAS. To mitigate the risk of a mid-air collision, this CONOPS utilizes a visualization system connected to the Digital Airport Surveillance Radar (DASR) at the Grand Forks Air Force Base. A dedicated radar observer uses the visualization system and information from the DASR to assist in the detection of all traffic, cooperative and non-cooperative, and provide that information to the PIC. This CONOPS is expected to be modified and capitalize on technology advances as they become available. However, at the base of the CONOPS, no algorithms are required for the system to warn of potential conflicts. This function resides primarily between the radar observer and the PIC as this system has a high level of human-in-the-loop capabilities. A ground visual observer will be used at the launch and recovery area. Once positive radar identification has been made, the radar observer will have the responsibility for see-and-avoid. The radar observer and the PIC will employ well-clear volumes and first alert edges, which are defined volumes and boundaries of airspace around the UAS, to warn of potential conflicts. The well-clear volume and first alert edges are predefined to incorporate sensor uncertainty and are conservatively defined, which is effective in this setting given the relatively low airspace density. The UAS will continue to utilize this technology to reach flight altitudes between 10,000 and 18,000 ft, where it will then perform its mission. When this technology is used in conjunction with appropriate procedures, this will mitigate the hazards associated with potentially encountering conflicting traffic in and around the UAS.

As noted above, hazards categorized within the high-risk area are considered unacceptable. These hazards must be mitigated to medium or low-risk. Although 24 hazards could not be reduced below this level in the course of the risk assessment, mitigation may be found in the ever present option to have the sUAS simply go to ground in certain situations. This mitigation was not employed casually for a number of reasons: (1) damage to the aircraft, (2) safety of persons and property on the ground, (3) practicality should operations be expanded to consider populated areas or operations over people, and (4) public perception of sUAS operations if over-applied. Residual risks categorized as high-risk must be addressed, but application of this last resort is more complex than it appears on the surface. Action items, however, do not stop at the high-risk threshold. When predicted residual risk is categorized as either high or medium-risk, the associated hazards should be monitored and tracked in relation to set safety performance targets until the predicted residual risk can be verified. It is even recommended that safety requirements are developed for residual risks in the low category and the associated hazards are monitored with at least one safety performance target in mind. In addition to these verification efforts, future work might also focus on consideration and evaluation of the hazards associated with fully autonomous algorithms and development of a template for a Flight Risk Assessment Tool (FRAT). Development of a FRAT could address threat and error management on the basis of a single flight—a micro scale by comparison—and be specific to a certain operator and operations.

It is important to emphasize that this is the first step with regards to the SRM pillar for sUAS DAA. Important next steps include socialization with stakeholders to further refine the list of hazards, existing mitigations, inherent risks, relevant additional mitigations, and residual risks. Through this process it is expected that important revisions will be applied. As this process is based on subject matter expertise, uncertainty is present in all of these areas, with data especially needed to better understand inherent risk levels and the degree of risk mitigation (both likelihood and severity) associated with recommended mitigations and controls. Thus, an additional next step is flight testing that enables validation and revision of this analysis. Consequently, that provided herein represents a first, albeit very important, step.

Application of these results to date can advance efforts to realize BVLOS operations across a much broader portion of the NAS. However, as described above, a mature and effective SMS is a continual effort. Expanding these efforts into the safety policy, assurance, and promotion pillars will more fully realize the value of this preliminary assessment. As demonstrated by the incremental progress of efforts like Certificates of Authorization or Waiver, Section 333 Exemptions, and most recently 14 CFR §107, “deliberately accepted risks” are a hallmark of extraordinary accomplishments for sUAS in the NAS.

3.5 Flight Testing

3.5.1 Collaboration with the Cooperative Airspace Techniques and Visualization (CATV) Project

The Cooperative Airspace Techniques and Visualization (CATV) project was being executed during the same time as this project. CATV, funded by Research North Dakota with Harris as the industry partner, had the following as objectives:

- Evaluate the potential for providing information regarding aircraft obtained through primary radar returns through TIS-B messages.
- Explore use of small ADS-B receivers as gap fillers (Harris ADS-B Xtends).
- Test Harris RangeVue with local sensors as a GBSAA system.
- Perform flight tests to evaluate the system.
- Develop a Preliminary Hazard Analysis (PHA).

The execution of flight tests from October 2016-February 2017 enabled collection of information that was helpful to this effort. Most notably, tests using the SARP-proposed well clear definition (§3.2.1.2) were executed. These data are currently being analyzed as part of CATV, but preliminary results have been presented to SARP. It is noted that in a couple of tests maintenance of well clear in the encounters was challenging. The cause of these issues are currently being discerned.[2]

In addition, data were collected using the University of North Dakota's 2D Detect Inc. Harrier radar. This data collection was supported by this effort, and provides a non-cooperative data set that will enable continued evaluation of these flight tests.

3.5.2 Flight Test Support

The University of North Dakota has worked on DAA challenges for many years. Because of this, work on a current related project (e.g., CATV), and work on this project, numerous tools that support flight testing are available. Some of these resources are described henceforth.

3.5.2.1 Display Systems

3.5.2.1.1 Ganged Phased Array Radar-Risk Mitigation System

In the mid-2000's UND was contracted (contract number FA4861-06-C-C006) by the United States Air Force to explore ways of integrating Unmanned Aircraft Systems (UASs) into the NAS. The core of the risk mitigation system was three Ganged Phased Array Radars (GPARs) and other sensors connected to a set of Information Display Systems (IDSs). This system is referred to as the GPAR-RMS (Ganged Phased Array Radar-Risk Mitigation System). Publications regarding the GPAR-RMS include Marsh et al. (2009a,b; 2010a,b; 2011) and Reza et al. (2010).

The GPAR-RMS was meant to be an extension of ground-based observer(s). The system integrates aircraft position (latitude, longitude, and altitude) data from sources such as ADS-B, ground based radar, and telemetry data from Global Positioning System (GPS) equipped aircraft. Sensor data are fused and forwarded to the Range Control Center (RCC). Data from a weather station located at the (mobile) UAS operations center and Doppler weather radar (from a website) are forwarded to the RCC. As the data are fused they are multicast (for scalability) to the IDSs, including a high-resolution wide-screen Range Control Center Information Display System (RCC IDS) and one, or more, high-resolution wide-screen Ground Observer Information Display Systems (GO IDSs). The RCC IDS, which is modeled after existing Air T Well clear was actually maintained in these tests as aircraft were always separated by at least 500 ft vertically, with software-based altitude spoofing used to create scenarios that appeared to be co-altitude to the algorithms that were being tested.raffic Control display systems and existing Traffic Information Service-Broadcast display systems, displays the georeferenced GPS positions of all aircraft operating in the area, the georeferenced positions of ground-based hazards/targets, weather information, system health data, and an operational risk parameter. The GO IDS, which is modeled after existing Flight Information Service-Broadcast moving map display systems, portrays the positions of all aircraft operating in the area in relation to a specific UAS of interest, weather information, system health data, and the operational risk parameter. Both the RCC-IDS and GO-IDS were georeferenced to a Cartesian coordinate system. Figures 74 and 75 show the two main IDSs for the GPARS-RMS system.

[2] Well clear was actually maintained in these tests as aircraft were always separated by at least 500 ft vertically, with software-based altitude spoofing used to create scenarios that appeared to be co-altitude to the algorithms that were being tested.

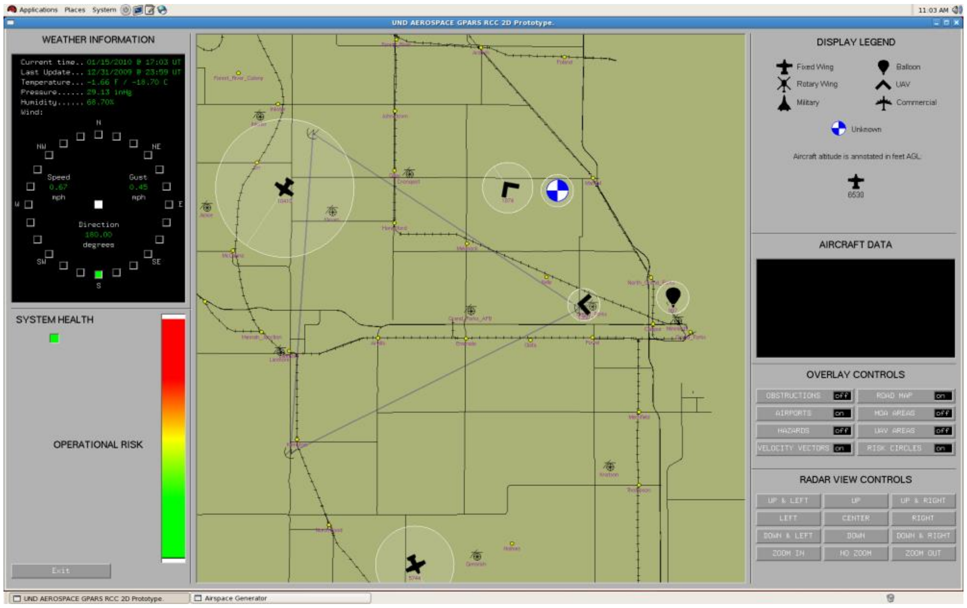


Figure 74. GPAR-RMS RCC IDS.

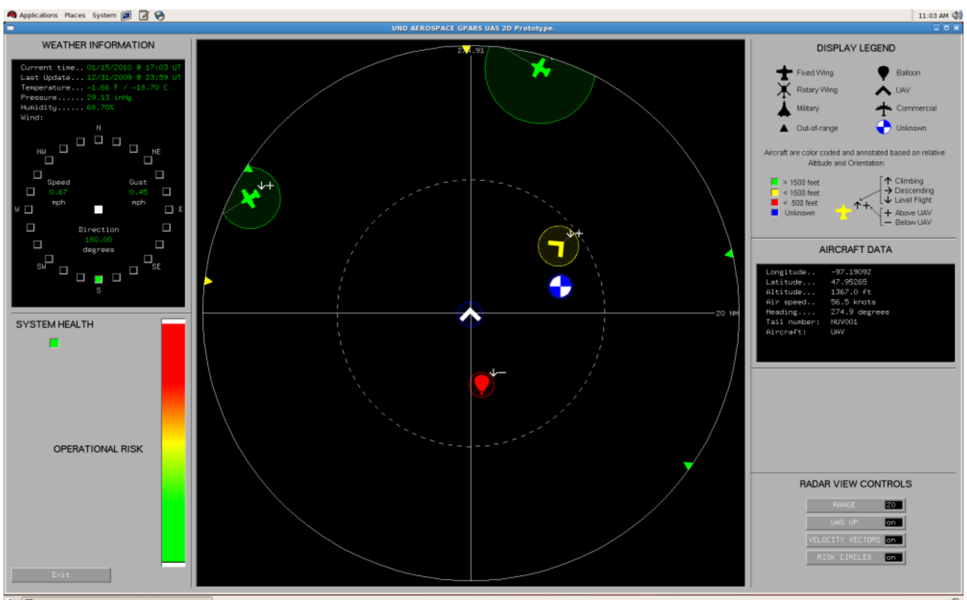


Figure 75. GPAR-RMS GO IDS.

3.5.2.1.2 Aerospace Aircraft Display System (AADS)

3.5.2.1.2.1 John D. Odegard School of Aerospace Sciences Flight Operations Requirements

The John D. Odegard School of Aerospace Sciences (JDOSAS) at the University of North Dakota (UND) is a world-renowned center for aerospace learning, nationally acclaimed for achievements in collegiate aviation education, atmospheric research, space studies, and computer science applications. JDOSAS operates flight training centers at the Chandler-Gilbert Community College in Phoenix, Arizona, the University of Minnesota, Crookston at Crookston, Minnesota, and the University of North Dakota in Grand

Forks, North Dakota. The JDOSAS flight operations at the Grand Forks International Airport|Mark Andrews Field (GFK) is the largest, with approximately 120,000 flight hours per year.

About the same time the GPAR-RMS system was developed, UND's Flight Operations became interested in a similar system to help them schedule and track student pilots. While the IDSs developed for the GPAR-RMS system worked well for the contract, they were not well suited for use by UND's Flight Operations—in particular the Supervisor of Flight (SOF)—for the following reasons:

- As GFK is located in northeastern North Dakota, on the North Dakota Minnesota border, the JDOSAS has established practice areas in northeastern North Dakota and northwestern Minnesota. Practice areas are assigned to each training flight with the exception of Instrument Flight Rules (IFR), cross country, and traffic pattern flights. The purpose is to help spread the fleet out over a wider area, increasing safety and reducing risk to the flight crews. The SOF monitors and assigns the practice areas based upon a maximum number in each. Once an area is full, it is no longer available until one of the aircraft assigned to that area returns. Some practice areas are used more than others, specifically ones that have other airports within them or that are closer to GFK (to reduce transit flight times). Therefore, in addition to being able to locate aircraft, it is important for the SOF to have these practice areas displayed on the IDS.
- As hazardous weather conditions may impact the fleet, or flight operations, weather situational awareness is important. In order to assist with overall weather situational awareness, it was determined that the IDS should incorporate current NOAA (National Oceanic and Atmospheric Administration) Doppler radar data. The radar overlay is most often used when incoming thunderstorms or blizzard conditions are forecast or spotted, and allows the SOF to provide guidance to dispatched aircraft regarding the incoming hazardous weather conditions.
- To be consistent with information readily available and used by pilots, it was decided that the background should be an aviation sectional chart because these charts provide detailed information important to aviators, such as terrain elevations, ground features, airspace classes, ground-based navigation aids, radio frequencies, longitude and latitude, and navigation waypoints useful to pilots. However, as aviation sectional charts use a Lambert conformal conic projection system, the new IDS would require a coordinate transformation from the Cartesian coordinate system to the Lambert conformal conic projection system (shown in Fig. 76).

Figure 76. World map in Lambert conformal conic projection (source: Wikipedia).

- It was also deemed important to include a search feature in which the SOF would be able to type an aircraft tail number (or call sign) into a search field and the IDS would locate and highlight the desired aircraft on the display. Basic information about the selected aircraft was also to be displayed, including altitude, heading, and ground speed.

- Finally, it was desired that the IDS be a single display (that could be mirrored at a variety of locations) that had everything (aircraft, Doppler Weather radar overlay, practice area boundaries, etc.) georeferenced to the local aviation sectional chart.

3.5.2.1.2.2 AADS Version I

UND's need led to the development of a new IDS, one specifically suited to UND's needs. However, the design of an IDS is not as obvious as one might think as there is no single model to follow. As a Yuditsky et al. (2004) indicate, several different types of IDSs are in use throughout FAA facilities. The variety of IDSs may be expected given the variety of tasks each FAA facility is expected to perform; however, what is not expected is that supposedly identical IDSs have different interfaces depending on who the contractor was. Yet, it can be argued that this is to be expected given the work of Nielsen (1999), who concluded that "No design standard can ever specify a complete user interface" and the work of Ahlstrom (2016) who points out that the same (interface) standard may be implemented in a variety of ways. Given the lack of a uniform IDS model and the unique requirements of UND's AADSs, it seemed prudent to design an IDS from first principles using a spiral model (such as Boehm's) where the designers can work directly with those developing the rest of the system and with those who will use the resulting AADS.

Using the Yuditsky et al. (2004) as a guideline, for example, it is seen that an IDS should be:

- Well organized and that organization of the information and controls greatly affects the operator's ability to effectively use the system.
- Navigable and consistent.
- Clearly indicative of when pertinent information was last updated.
- Providing information that is complete and relevant. Use of color and color combinations should be consistent. Buttons should be represented in shades of gray and use a consistent font size and font type.

Hardware selection is also an important issue as the use of a keyboard for required data entry should only be provided to operators who have the authority to enter data. The use of a mouse or trackball versus a touch screen display has advantages and disadvantages. Both facilitate interaction with the IDS. However, use of a mouse/trackball requires the operator to coordinate the position of the physical device with the icon on the screen and when used with multiple displays the operator can momentarily lose track of the icon during screen-to-screen transitions. Use of a touch screen can be problematic if the screen has a low touch resolution, a touch screen requires some form of adjustable mounting as the operator's arm will fatigue, and a touch screen requires frequent cleaning to remove fingerprints that obscure information. Yuditsky et al. (2004) indicate that touch screen users often preferred to use a trackball over their finger/stylus or a mouse. Finally, screen size and resolution must be sufficient to clearly display the relevant information.

Xing (2006) cites the non-standard use of color schemes by different manufacturers of ATC displays and proposes guidelines for use of color in IDSs such as:

- To capture attention. However, the effectiveness of color in this manner is highly dependent on the luminance and chromaticity differences of the colors used and on the consistent use of specific colors to represent specific situations across all components in the IDS.
- To identify certain types of information to improve the operator's effectiveness in retrieving relevant information in complex/cluttered displays.
- To segment complex display scenes to organize/cluster related information. However, in some cases segmentation is better achieved through a reorganization of the display.

It should be noted that many of these concerns/requirements are echoed in the US Department of Defense's Design Criteria Standard (DoD 1999).

Taking into account the previous work performed in this area (the GPARS-RMS RCC), the AADS was developed with the ability to:

- Import near real-time data (1 second intervals) from the ADS-B transceiver.
- Import and display regional Aviation Sectional Charts, allow the user to toggle this overlay on or off, and allow the user to set the transparency of this overlay.
- Import and display (georeferenced to the sectional chart) the region's NOAA Doppler radar data, allow the user to toggle this overlay on or off, and allow the user to set the transparency of this overlay.
- Import from a file and display (georeferenced to the sectional chart) boundaries of regions such as aircraft practice areas and allow the user to toggle this overlay on or off.
- Display cooperative aircraft types using NATO/APA (North Atlantic Treaty Organization/American Pilot's Association) icons (icons are rotated to indicate the current aircraft heading).
- Allow the user to zoom, pan and/or scroll the display (the display is always North-up).
- Provide the time and date of the last ADS-B, Doppler radar, and weather sensor (barometric pressure) updates.
- Allow the user to select an aircraft via the mouse to obtain information (position, heading, etc.) regarding that aircraft.
- Allow the user to search for aircraft via the tail number.
- Display non-cooperative (or unknown) aircraft types using an icon that readily distinguishes them from other aircraft.

The AADS has proven to be accurate enough with aircraft positioning relative to the aviation sectional map, which is enabled by the fact that ADS-B information is accurate to within several meters. The SOF can zoom in and watch aircraft takeoff and land on the indicated runways at any airport in range. Accuracy at this level is easily within 15 feet and is well within the tolerances needed for UND Flight Operations. A ground-based ADS-B antenna is utilized that provides an exceptional range for a standalone system. As of this writing, aircraft within 50 nm are visible within the system all the way to the ground. Airborne aircraft at moderate training altitudes have been located out to 150 nm and beyond.

The AADS has dramatically improved operational safety and situational awareness across the board for UND's Flight Operations. It is proven to be effective, efficient, and a game changing tool with regards to management and coordination of the dispatched fleet during normal operations as well as during times of inclement weather or in-flight distress. AADS has helped UND Flight Operations move one step further up the aerospace ladder of excellence.

3.5.2.1.2.3 AADS Version II

While version I of the AADS did meet the demands of the SOF and feedback from them was very positive, concerns did arise and they were addressed in version II. Version I was unable to receive Traffic Information Services-Broadcast (TIS-B) data due to the configuration of the Garmin GDL-90 ADS-B receiver. TIS-B allows non-ADS-B transponder equipped aircraft that are tracked with radar (e.g. MODE-C/S) to have their location and track information re-broadcast to ADS-B equipped aircraft through the use of a ground station. This data stream was deemed to be very important for future research applications of the AADS. Thus, it was incorporated in version II. Another consideration was human factor concerns obtained through feedback from the SOF that suggested that some changes to the menu options and their locations as well as changes to the colors used in the display area would be helpful.

The most significant changes that were incorporated into version II of AADS are:

- Import and display of near real-time ADS-B and TIS-B data from the ADS-B transceiver.

- The Doppler radar data are now georeferenced to the local aviation sectional chart using an inverse conversion to reduce conversion artifacts (e.g., blockiness).
- Improved filtering of Doppler radar noise.
- Aircraft icon colors are now blue and turn red after an aircraft stops transmitting (has landed, etc.) for a period of time (currently set at five minutes). After another period of time (currently set at five minutes) these "red" icons are removed from the display. This helps reduce display clutter, yet gives the SOF a very evident indicator of any aircraft that is no longer transmitting.
- The tail-number search option was modified such that a stippled line is drawn from the display base of operations (GFK in Fig. 77) out to the aircraft (if found).
- Sensors (Doppler radar, ADS-B, and atmospheric pressure) have more clearly defined timestamps that show the latest updates. Currently, the timestamps are shown in green and turn red if a sensor has not responded within a set time period (specific to each sensor). The default color may be changed to blue to match the aircraft icon color scheme, but the SOF does not consider this a priority. So, this is still only a consideration.
- The menus have a record option, so the SOF can more easily customize the display. This option is useful when versions of the AADS are put in public places as one can customize the display and run the AADS with most of the GUI (Graphical User Interface) options disabled, thus protecting the identity of the aircraft/student pilots (FERPA - Family Educational Rights and Privacy Act).
- Support for multiple airports was added via command line arguments and simple data files that hold the configuration details (Lambert conformal conic projection conversions, Doppler radar coordinates, etc.) specific to each airport (Phoenix–Mesa Gateway Airport in Fig. 78).
- Greater conformance to DO-178B/C (Software Considerations in Airborne Systems and Equipment Certification).
- The current atmospheric pressure is automatically uploaded to the display allowing the display of corrected (converted from ADS-B standard pressure altitude) mean sea level (MSL) altitude information for selected aircraft.

Again, Fig. 77 shows the AADS when tracking aircraft operating out of GFK and Fig. 78 shows the AADS when tracking aircraft operating out of IWA (Phoenix-Mesa Gateway Airport). Note that in both cases the physical location of the displays is immaterial—the system will allow connections from any permissible computer.

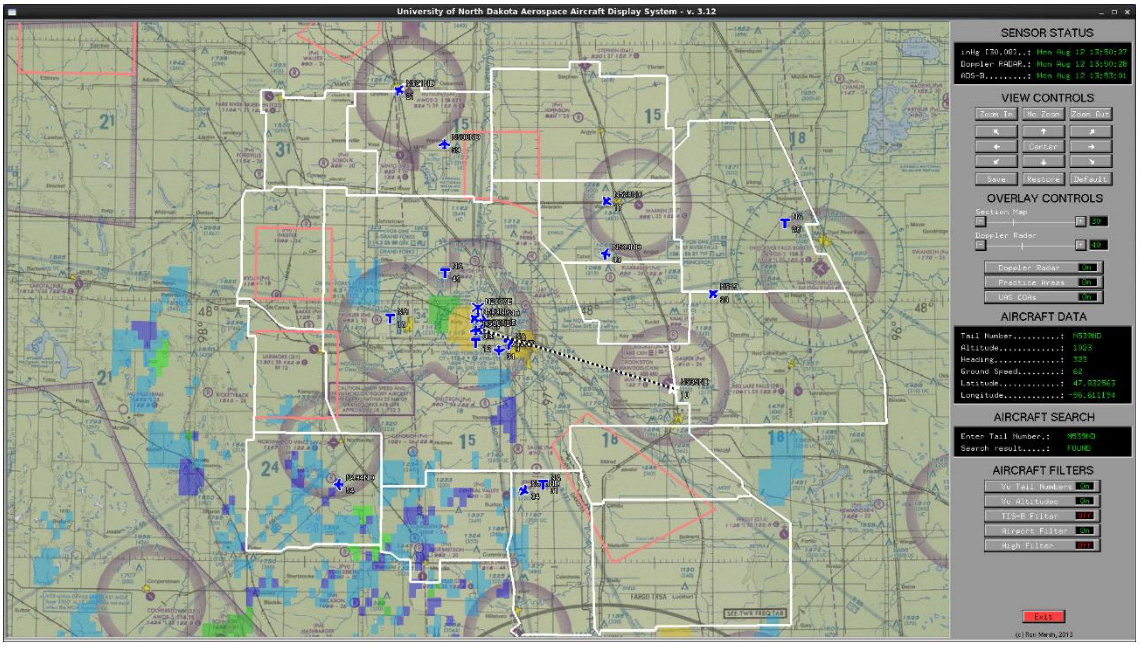


Figure 77. AADS display for GFK.

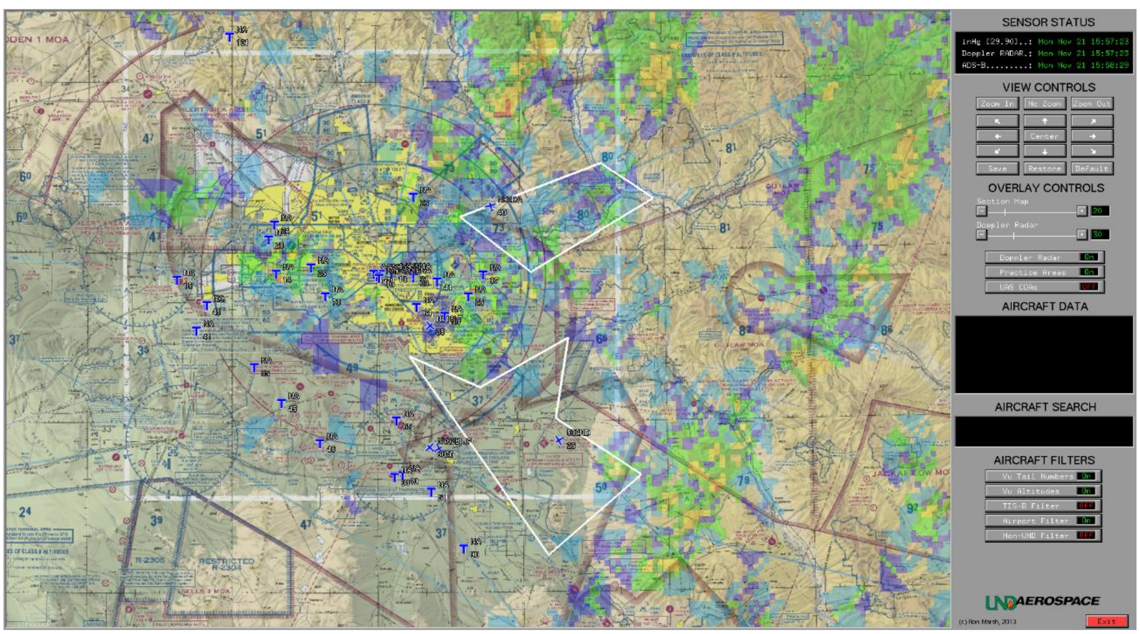


Figure 78. AADS display for Phoenix–Mesa Gateway Airport (IWA).

3.5.2.1.2.4 AADS Architecture

While several different companies have recently begun to offer similar solutions for fleet tracking and surveillance, the AADS has offered UND the same, if not better, tracking and monitoring solutions from an in-house system at a mere fraction of the cost of packaged solutions. UND's software engineers are able to adapt and modify AADS to meet any new requests or operational requirements as they arise.

With the current architecture/configuration, the AADS server interfaces, via a serial port, with a Garmin GDL-90 ADS-B Transceiver mounted on the roof of the five story flight services building at GFK. The Garmin GDL-90 is connected to an omni-directional ADS-B antenna manufactured by dB Systems Inc. and is configured to operate with this single antenna instead of the two aircraft fin antenna commonly used with this system (this ADS-B unit is designed for installation on aircraft which is why fin antennas are commonly used for such a device). The GDL-90 is also connected to the supplied GPS. The antenna is approximately 78 inches in length and was mounted such that it extended its height by approximately seven feet. Thus, the top of the antenna is approximately 106 feet above ground level. This antenna was installed with a lightning protection system and provides 9 dB/iso of gain operating at frequencies between 960 MHz and 1215 MHz. These characteristics enabled ADS-B data to be collected at ranges far exceeding those provided by the commonly used fin antennas. As ADS-B data are received they are forwarded to any AADS IDS unit connection (via a socket) to the AADS server. Figure 79 depicts the current AADS system architecture.

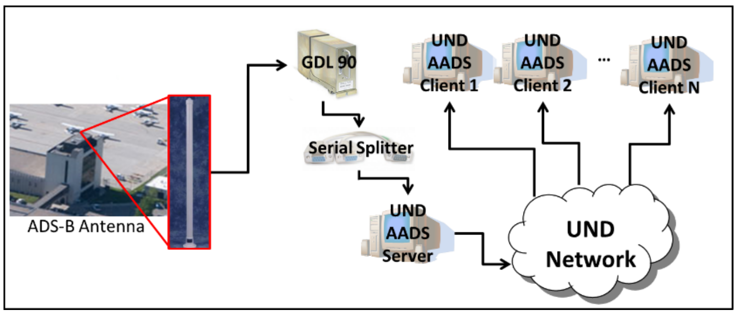


Figure 79. AADS architecture.

3.5.2.1.3 Limited Deployment-Cooperative Airspace Project (LD-CAP) Flight Test Support

The AADS was modified for use with a recent research project called the Limited Deployment – Cooperative Airspace Project (LD-CAP), during which test flights were conducted in northeastern North Dakota in September 2012 and July 2013, and in Virginia in August 2013. This project is a collaborative research effort between several entities including the University of North Dakota, NASA-Langley, MITRE, and Draper Laboratories to test Cooperative Automatic Sense and Avoid (CASA) algorithms through simulation and flight testing, with the purpose being to provide data to aid with the integration of UASs into the NAS.

Prior to the test flights, effort was directed at customizing the AADS to satisfy specific needs of the LD-CAP effort. These included the ability to insert geographical points and boundaries into the AADS to aid with aircraft encounter setup. Toggle buttons were also added to allow the user to easily turn on and off these features in the display. Other customized features for LD-CAP include the addition of adjustable distance circles around the two aircraft (configurable), the ability to show aircraft historical tracks, and the option to have an aircraft centric display that offers track-up or north-up orientation. These features supported operations during the 2013 LD-CAP North Dakota flight tests. AADS running in LD-CAP mode is shown in Fig. 80.

During the 2013 North Dakota flight tests, three algorithms were tested using 134 encounters (note the labeled points in the lower left of Fig. 80). Each algorithm successfully maneuvered the surrogate UAS (aircraft with green circle in center right of Fig. 80) away from conflicts.

In actuality, the flight test director utilized both versions of the AADS to help direct the encounters. One AADS was set to the standard LD-CAP configuration (Fig. 80) while the other display was configured as an aircraft-centric display (Fig. 81) and was centered on the NASA surrogate UAS. Each display was configured to show distance circles, LD-CAP encounter points, and LD-CAP special areas. These displays allowed the flight test director to observe the encounters, see how close the aircraft came to each other (horizontally) via the distance circles, monitor altitudes through the ADS-B data stream, and determine if changes to the encounter setup or algorithms were needed before the next flight. The AADS running in the LD-CAP GO (Ground Observer) mode with aircraft (surrogate UAS) heading "up" is shown in Fig. 81.

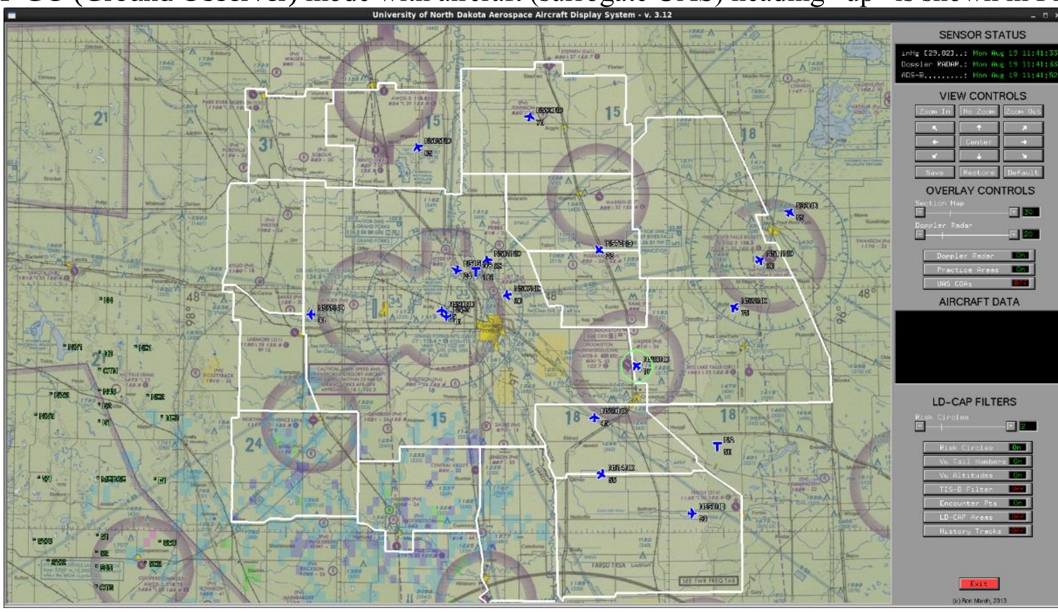


Figure 80. AADS display in LD-CAP mode.

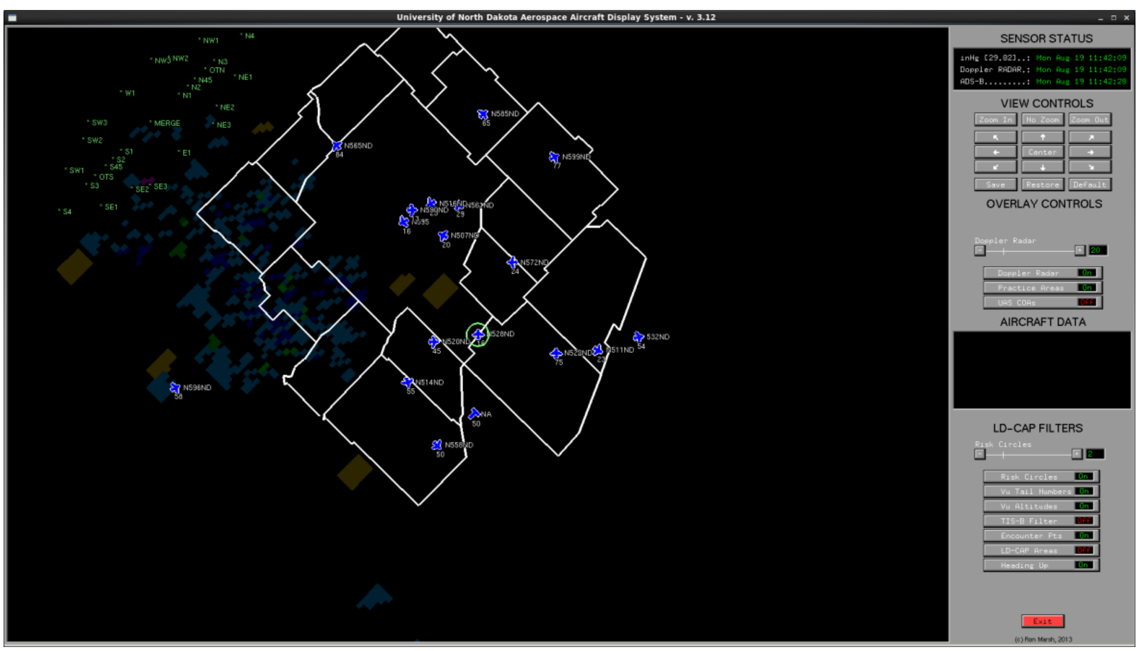


Figure 81. AADS display in LD-CAP GO mode.

The LD-CAP flight tests were approximately 60 nm from the ADS-B antenna and data were collected down to approximately 1000 feet AGL at that range. Aircraft were also tracked out to 100 nm (depending on the aircraft's altitude). The wide bandwidth of the antenna also allows for processing of Mode S/C targets on the 1090 MHz band with an addition of a 1090 receiver (anticipated future purchase). This setup provided robust and reliable ADS-B data that were very important to the success of LD-CAP flight tests. To gain even more from this effort, the potential generation of TIS-B messages using primary radar returns is being explored. This would rebroadcast the primary radar return only targets (non-cooperative targets) as a TIS-B message that can then be displayed—making the entire airspace semi-cooperative.

3.5.2.1.4 Cooperative Airspace Technology and Visualization (CATV) Flight Test Support

The AADS was again modified for use with a current research project called the Cooperative Airspace Technology and Visualization (CATV) project, where once again test flights are being conducted in northeastern North Dakota to evaluate DAA algorithms, with the purpose being to provide data to aid with the integration of UASs into the NAS. CATV is very similar in intent to the LD-CAP project; however, as the specific needs of the project are different the AADS was once again modified to better suit the needs of the project.

In this case, the AADS was further modified (from that shown in Fig. 81) in that a road map was added to aid in locating where the flight operations were occurring. Additionally, two detect and avoid (DAA) algorithms were included. One is based on a "hockey puck" (the SARP-recommended 2000 ft horizontal and 500 ft vertical separation) and a second based on the RTCA SC228 tau (time to collision) method. Upon startup the user can specify which DAA method is to be used. In either case, offending aircraft are painted red, yellow, or white (from the normal blue) to signify their level of intrusion. Details regarding the seriousness of the intrusion are also provided on the display (lower right) and logged to a data file. The distance circles were also changed to 5 nm and 10 nm. The CATV version of the display is shown in Fig. 82.

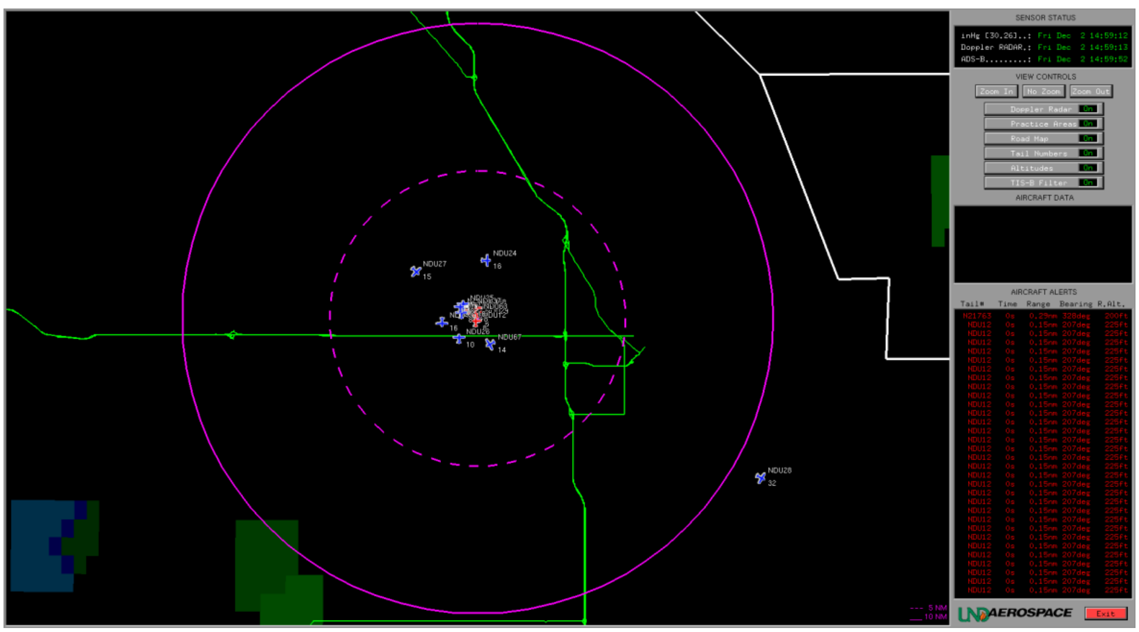


Figure 82. AADS display in CATV mode.

3.5.2.1.5 Future Developments

UND Aerospace is currently working to expand its ADS-B coverage of northeastern North Dakota by installing two additional ADS-B units (units that can receive both 1090 and UAT signals) and by replacing the current GDL-90 with a similar dual-band unit. The resultant data streams will be fused into a single stream and served out to the AADS (or derivative) displays by a computer/server located in a "machine room". This will improve coverage, especially for aircraft operating at low altitudes, capacity by allowing more AADS IDS to be connected, and reliability by having the server located in a properly managed machine room.

3.5.2.2 Warning Provision Investigation

One of the areas investigated is the methods currently in use to alert pilots to the various hazards that they may encounter. Three methods were investigated: audible, tactile, and visual.

3.5.2.2.1 Audible

Commercial aircraft use audible warnings for a variety of alerts. However, general alerting sounds are chosen by the manufacturer of the cockpit systems. Stall warnings, autopilot disconnect alerts, fire alarms, etc. are not standardized, with the exception of the words spoken by the Ground Proximity Warning System/Terrain Awareness Warning System (GPWS/TAWS) and Traffic Collision Avoidance System (TCAS) systems. Even sounds within aircraft from the same manufacturer may be different. For example, the fire warning in a Boeing 737 sounds like a physical fire bell, while that on a Boeing 777 is an electronic "beep beep beep" sound. In addition, research has found that, on average, a pilot could remember and differentiate ten different caution/warning signals, leading the FAA to limit the amount of different warning signals to eight (Part 25 certification), with speech counted as one of those eight. However, there is no limit on the number of spoken audible warnings. Table 48 shows the general audible alerts for one type of aircraft. Table 49 shows the GPWS audible alerts, while Table 50 shows the TCAS audible alerts.

Table 48. General audible alerts.

3 low pitch tones	Auto pilot disconnect
Repeating mid pitch tones	Incorrect takeoff configuration
3 high pitch tones	Exited selected altitude
Constant tone	Desired altitude reached
“APU”	APU overspeed or overtemp
“Door”	Open/unsafe passenger door
“Jetpipe overheat”	Overheat indicator in jetpipe/pylon
“Smoke”	Smoke detection in cabin
“Wing overheat”	Overheat in fuselage wing anti-ice ducts
“Anti-ice duct”	Air leak in fuselage or wing anti-ice ducts
“Bleed air duct”	Leak in different part of air duct system
“Brakes”	Brake overheat
“Config Brakes”	Parking brake set while airborne
“Gear disagree”	Gear indicator does not match handle position
“Gear bay overheat”	Overheat in main gear bay
“Node door”	Nose gear door open and > 250 knots
“Engine oil”	Oil pressure < 25 psi
“Config autopilot”	Autopilot not configured for takeoff
“Config flaps”	Flaps not configured for takeoff
“Config spoilers”	Spoilers not configured for takeoff
“Config trim”	Trim not configured for takeoff
“Config brakes”	Brakes not configured for takeoff
“Fire left engine”	Fire in left engine
“Fire right engine”	Fire in right engine

Table 49. Ground Proximity Warning System (GPWS) audible alerts.

Siren and “pull up”	Excessive rate of descent
“Pull Up - Sink Rate”	Descending to fast
“Too low - gear”	Low altitude and gear up
“Too low - terrain”	High speed @ low altitude
“Too Low – Flaps”	No flaps @ low altitude
“Pull-Up - Terrain”	Terrain closure alert
“Don’t sink”	Altitude loss after takeoff
“Windshear”	Windshear alert
“Glide slope”	Below glide slope
“Bank angle”	Bank angle > 35°

Table 50. Traffic Collision Avoidance System (TCAS) audible alerts.

“Clear of conflict”	Conflict resolved
“Traffic, Traffic”	Conflicting traffic approaching

"Climb, Climb"	Climb immediately
"Descend, Descend"	Descend immediately
"Increase Climb"	Climb immediately at a faster rate
"Increase Descent"	Descend immediately at a faster rate
"Climb, Climb – Now"	Climb immediately
"Descend, Descend – Now"	Descend immediately
"Don't Climb"	Issued instead of "Descend Descend" when the aircraft is at a low height.

Finally, Begault and Pittman (1996) have proposed that stereo audible alerts be used to cue the pilot to look in a specific direction. The results look promising, but the pilots would have to wear stereo headsets.

3.5.2.2.2 Tactile

Larkin (1983) indicated that a tactile device produced the lowest reaction times to alerts/warnings and modern commercial aircraft use tactile warnings for a variety of alerts. Perhaps the most common and best known is the Stick Shaker, which is a mechanical device that rapidly and noisily vibrates the control yoke (the "stick") of an aircraft to warn the pilot of an imminent stall. Another tactile warning device is the Stick Pusher/Nudger (Bateman 2011), which is also a mechanical device installed in fixed-wing aircraft to prevent the aircraft from entering an aerodynamic stall. The Stick Pusher pushes back on the yoke making it more difficult to raise the nose beyond the stall limit. Rotary wing aircraft may have at least two additional tactile devices, the Collective Shaker and the Pedal Shaker. The Collective Shaker (Rosenberg 2017) provides two noticeably different levels of warning. A low-speed shake warns that a pre-determined operational level is being approached. A high-speed shake provides a more urgent alert as the limit is reached or exceeded. The shake continues only as long as the exceedance exists. When the shaking stops the pilot knows immediately that he is once again operating within the helicopter's normal limits. Safe Flight's Pedal Shaker (Greene and Greene 1999) warns the pilot when approaching the pedal limit. The Pedal Shaker enhances the pilot's situational awareness during out-of-ground-effect hover situations, high crosswind operations, or high-density altitude situations, where power required may exceed power available. The shaker activates at a predetermined limit, giving the pilot time to maintain control. Finally, Boeing has proposed a vibrating cockpit seat as an alternative to visual/aural indicators (Kaminski-Morrow 2011).

3.5.2.2.3 Visual

According to Bahrami (2010), systems should present the alerts according to the urgency and the prioritization philosophy (warning, caution, and advisory categories). Normally, this means time-critical warnings are first, other warnings are second, cautions are third, and advisories are last. Depending on the phase of flight, there may be a need to re-categorize certain alerts from a lower urgency level to a higher urgency level. Furthermore, prioritization within alert categories may be necessary. For example, when near threatening terrain, time-critical aural warnings must be prioritized before other warnings within the warning-alert category. The advisory also recommends that if using aural alerts with multiple meanings, a corresponding visual, tactile, or haptic alert should be provided to resolve any potential uncertainty relating to the aural alert and clearly identify the specific alert condition.

Of particular interest here is that visual alert indications must conform to the following color convention:

1. Red for warning-alert indications. And, the color displayed for the visual master warning alert must be the same color used for the associated warning alerts.
2. Amber or yellow for caution-alert indications. And, the color displayed for the master caution alert must be the same color used for the associated caution alerts.

3. A separate and distinct color should be used to distinguish between caution and advisory alerts. If a distinctive color is not used to distinguish between caution and advisory alerts, other distinctive coding techniques must be used to meet the general requirements.
4. Any color except red or green can be used for advisory alert indications. Green is usually used to indicate "normal" conditions; therefore, it is not an appropriate color for an advisory alert. An advisory alert is used to indicate a "non-normal" condition.
5. The colors red, amber, and yellow must be used consistently. This includes alert color consistency among propulsion, flight, navigation, and other displays and indications used on the flight deck.

Yiu (2017) found that the correct use of color schemes can aid in alerting the crew if something needs to be bought to their attention. Using too many different colors, however, may clutter the screen and cause confusion. The main colors used for system monitoring are green (normal), amber (caution) and red (alert or emergency). The colors that are typically used on the Horizontal Situational Indicator (HSI) are shown in Table 51.

Table 51. Colors typically used in the HSI.

Green	Active or selected mode and/or dynamic conditions
White	Present status situation and scales
Magenta	Command information, pointers, symbols and fly to tracks. Magenta is also used on the weather radar to indicate areas of strong return (ie: possible turbulence/wind shear)
Cyan	Non active and background information
Red	Warnings
Yellow/Amber	Cautions, flags and faults
Black	Blank areas or system off

Another item to consider when designing a visual display is the concept of a "quiet/dark" design (Novacek 2003). This design philosophy states that information is not displayed until something goes wrong. The screen or annunciator stays black until a system condition warrants notifying the pilot.

One must also be aware of the differences between Western designs and Eastern designs. For example, the Artificial Horizon (AH) is a key instrument for manual flight control and for monitoring automatic flight control. An unfamiliar AH display can cause or contribute to confusion, uncertainty, and/or delay when trying to recover from an unusual attitude. Using a Western design (being an "inside looking out" display), the artificial horizon line tilts in alignment with the outside horizon and the airplane symbol remains fixed horizontally. Using an Eastern design (an "outside looking in" display), the artificial horizon line remains horizontal and the airplane symbol tilts to show the airplane's bank angle. Military pilots often claim the Eastern design is a better display when maneuvering in fast combat.

Finally, The U.S. National Transportation Safety Board (NTSB) has repeatedly recommended installation of audible and visual alerting for at least some situations (such as the need to reduce the angle of attack).

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Appendix A: Use Case Definitions

Use Case Definitions

Where possible, these general uses were broken down further into more specific sub-categories of their respective general uses. This allowed for the collection of a greater amount of information. The definition of each general use and their respective sub-categories is considered as follows:

Aerial Data Collection: Use cases that are either described simply as "Aerial Data Collection" (or having a very similar description), or can most accurately be described as a use involving the collection of data by means of sensors or cameras on-board of the sUAS. Separate from the definitions of "Aerial Surveying / Mapping," "Agriculture," "Inspection," and "Research," the description given of the use case is not necessarily specific as to what data is collected, and what purposes the data will be used for.

> **Aerial Data Collection – Construction/Mining:** A use case that was approved by the FAA in the 333 exemption request for the collection of non-specified data from construction and/or mining-related sites.
>
> **Aerial Data Collection – Environmental:** A use case that was approved by the FAA in the 333 exemption request for the collection of data from the environment for non-specified reasons.
>
> **Aerial Data Collection – General:** A use case that was approved by the FAA in the 333 exemption request for the collection of non-specified data from non-specified areas, or is simply listed as "Aerial Data Collection," "Aerial Acquisitions," etc.
>
> **Aerial Data Collection – Insurance:** A use case that was approved by the FAA in the 333 exemption request for the collection of non-specified data for insurance purposes that does not indicate that it is being used for inspection.

Aerial Photography/Videography: Use cases that are either described simply as "Aerial Photography/Videography" (or having a very similar description), or can most accurately be described as a use involving the collection of pictures and videos for no other obvious or implied reason than to have the pictures or videos taken in the applications listed below.

> **Aerial Photography/Videography – Closed-set filming:** A use case that was approved by the FAA in the 333 exemption request for the collection of aerial images and videos taken for films, web videos, music videos, etc. from a closed-set.
>
> **Aerial Photography/Videography – Construction:** A use case that was approved by the FAA in the 333 exemption request for the collection of aerial images and videos of construction sites, where the use case does not indicate that it is collecting data for analysis, surveying, mapping, inspection, research, or surveillance.
>
> **Aerial Photography/Videography – General:** A use case that was approved by the FAA in the 333 exemption request for the collection of aerial videos and images for when the use case cleared is simply listed as "Aerial Photography/Videography," "Aerial Photography," "Aerial Videography," etc.
>
> **Aerial Photography/Videography – News-Gathering:** A use case that was approved by the FAA in the 333 exemption request for the collection of aerial images and videos to be used in the news-reporting media, whether it be newspaper, magazine, web content, mobile news, etc.
>
> **Aerial Photography/Videography – Outdoor Activities:** A use case that was approved by the FAA in the 333 exemption request for the collection of aerial images and videos that show uses in outdoor activities such as golf, hiking, climbing, rafting, team sports, etc.
>
> **Aerial Photography/Videography – Real Estate:** A use case that was approved by the FAA in the 333 exemption request for the collection of aerial images and videos that show structures and properties for the promotion and sale of real estate.

Aerial Photography/Videography – Wedding: A use case that was approved by the FAA in the 333 exemption request and is listed as "Wedding Photography," or describes the collection of aerial images and videos from weddings.

Aerial Surveying/Mapping: Use cases that are either described simply as "Aerial Surveying/Mapping" (or having a very similar description), or can most accurately be described as a mapping or surveying operation for various purposes.

Aerial Surveying/Mapping – Agriculture/Mining: A use case that was approved by the FAA in the 333 exemption request for the collection of aerial surveying and mapping for agricultural and/or mining purposes that does not fit the description or specificity of the general, or precision agricultural use case parameters.

Aerial Surveying/Mapping – Construction: A use case that was approved by the FAA in the 333 exemption request for the collection of aerial surveying and mapping of construction sites or structures.

Aerial Surveying/Mapping – Engineering: A use case that was approved by the FAA in the 333 exemption request for the collection of aerial surveying and mapping of generally listed sites for engineering purposes.

Aerial Surveying/Mapping – General: A use case that was approved by the FAA in the 333 exemption request for the collection of general aerial surveying and mapping purposes, or when the use case is simply listed as "Aerial Surveying and Mapping," "Aerial Surveying," "Aerial Mapping," etc.

Agriculture: Use cases that are either described simply as "Agriculture" (or having a very similar description), or can most accurately be described as a use involving the collection of data for agricultural purposes.

Agriculture – Crop Monitoring: A use case that is listed as "Crop monitoring," or was approved by the FAA in the 333 exemption request to fly over crop fields, collecting data on various measures of crop status.

Agriculture – General: A use case that is listed simply as "Agriculture," or was approved by the FAA in the 333 exemption request for sub-types of agricultural data collection that does not meet the definition of "Agriculture – Crop Monitoring" or of "Agriculture – Precision Agriculture."

Agriculture – Precision Agriculture: A use case that is listed as "Precision Agriculture," or was approved by the FAA in the 333 exemption request to scout agricultural regions for the use of precision agriculture, or describes uses that fall under the definition of precision agriculture. These include soil collection, aerial imaging through various sensors, GPS-guidance of agricultural technologies, etc.

Emergency Services: Use cases which are either described simply as "Emergency Services" (or having a very similar description), or describe a use case that can be described as aiding police officers, firefighters, medical services, etc. or in the investigation of areas that are too dangerous to put a human being in for investigative purposes.

Emergency Services – Crisis Response: A use case that is listed as "Crisis Response" or was approved by the FAA in the 333 exemption request that was approved by the FAA in the 333 exemption request for aiding law enforcement in various purposes, are able to relay messages in a crisis scenario, in considering emergency preparedness, etc.

Emergency Services – General: A use case that is listed as "Emergency Services" or with similar wording, is described with ambiguous enough wording that it was not clear whether the use was for either crisis response, the investigation of hazardous regions specifically, or described the use of sUAS for a form of emergency services covered by neither the definitions of crisis response nor investigate hazardous regions.

Emergency Services – Investigate Hazardous Regions: A use case that is listed as "Investigation of Hazardous Regions" or was approved by the FAA in the 333 exemption request to investigate an area that is too dangerous for a human to investigate directly. These include regions that are on fire, involve radiation, where footing is weak, etc.

Flight Training/Education: Use cases which are either described simply as "Flight Training," "Education" (or having a very similar description), or describe a use case involving the training employees, students, or other users in the operation of sUAS technology, and/or procedures. Use cases involved in educating individuals on sUAS principles, or in demonstrating concepts in mathematics and sciences which can demonstrated by sUAS technology.

Flight Training/Education – Education: A use case that is listed as "Education," or describes the teaching of mathematical, science, etc. concepts through the use of sUAS technology.

Flight Training/Education – General: A use case that was described with ambiguous enough wording that it was not clear whether the use was for either flight training or education specifically.

Flight Training/Education – sUAS Training: A use case that is listed as "Training," or describes the training of users in operating sUAS.

Inspection: Use cases that are either described simply as "Inspection" (or having a very similar description), or that describe a use case involving the inspection of different kinds of structures or areas for safety, upkeep, maintaining of, etc.

Inspection – Communications Structures: A use case that describes the inspection of communication structures including, but not limited to, cell towers, satellite dishes, etc.

Inspection – Construction: A use case that describes the inspection of construction sites and structures under construction through the use of sUAS.

Inspection – General: A use case that includes multiple sub-types of inspection through the use of sUAS, or is simply listed as "Inspection."

Inspection – Insurance: A use case that includes descriptions of inspection for insurance purposes through the use of sUAS.

Inspection – Oil/Pipeline: A use case that includes descriptions of inspection for the oil industry, including drilling structures, and oil transportation pipelines through the use of sUAS.

Inspection – Power plants: A use case that includes descriptions of inspection of power plant structures (such as powerlines), resources, and operations through the use of sUAS.

Inspection – Real Estate: A use case that includes descriptions of inspection of real estate structures and properties (including roofs) through the use of sUAS.

Inspection – Structure: A use case that includes descriptions of inspection of structures including non-real-estate-buildings (for architectural and integrity inspections) and infrastructure including roads, bridges, etc. through the use of sUAS.

Inspection – Wind power: A use case that includes descriptions of the inspection specifically of wind power turbines through the use of sUAS.

Marketing: Use cases that are either described simply as "Marketing" (or having a very similar description), or describe the capture of aerial images and videos for the express purpose of using these images and videos for the marketing of a business, product, or service.

Marketing – Aerial Images: A use case that specifically mentions marketing through the use of aerial image / video capture through the use of sUAS.

Marketing – General: A use case that is listed simply as "Marketing" or describes sUAS applications other than aerial image/video capture for marketing purposes (such as demonstrations).

Multiple Applications: Use cases which are either described simply as "Multiple Applications" (or having a very similar description), or have been cleared for more than one general use case.

Research: Use cases which are either described simply as "Research" (or having a very similar description), or describe a use involving imaging and data collection distinctly for scientific research purposes.

Research – Academics: A use case that describes academic research. Examples include archaeological, ecological, architectural, and engineering data collection for academic research.

Research – Development: A use case that describes a clearance for the use of research in the development of sUAS technology, or for the development of sUAS use protocol.

Research – General: A use case that describes a clearance for sUAS usage in general research, or is listed simply as "Research."

Research – Market: A use case that describes a clearance for sUAS usage involved in Market research.

Research – Operations: A use case that describes the research of operational applications of a drone. Examples include the study of flight techniques for different applications – such as search/rescue, emergency services, agricultural scouting, etc.

Research – Product Testing: A use case that describes the testing of sUAS platforms and components.

Research – Transportation: A use case that includes descriptions of the inspection of traffic patterns through the use of sUAS.

Search/Rescue: Use cases that are either described simply as "Search / Rescue," or describe a scenario where a sUAS platform would be used to aid in various search and rescue operations.

Surveillance, Monitoring, etc.: Use cases that are either described simply as "Surveillance," "Monitoring" or having a description that can be categorized in a similar fashion.

Monitoring – Environmental: Use cases that involve wildlife and environmental monitoring over different timeframes.

Monitoring – General: Use cases that are either simply stated as "Monitoring," or something similar.

Monitoring – Legal: Use cases that include applications for legal purposes, including the gathering of evidence.

Monitoring – Safety: Use cases that include applications for safety purposes.

Monitoring – Security: Use cases that include applications for security purposes.

From the data collected, Aerial Photography/Videography had the most use cases by 333-exemption holders, with 13,262 use cases granted between September 2014 and June 29, 2016. The other most common general use cases included Inspection (7596), Aerial Surveying/Mapping (4116), Flight Training/Education (2399), and Search/Rescue (1917).

Appendix B: Table of Manufacturer Metrics

Table B1. Manufacturer metrics.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
3D Robotics Inc.	11	2	0	0	5	0	1	3	0	0	0
Adaptive Flight, Inc.	1	0	1	0	0	0	0	0	0	0	0
Advanced Robotics Corporation	2	0	0	0	1	0	1	0	0	0	0
AEE Technologies	2	0	0	0	2	0	0	0	0	0	0
Aerial MOB Drone Services & Aerial Cinematography	7	0	0	0	1	0	1	1	0	0	4
Aerial Technology International	4	0	1	0	1	0	1	1	0	0	0
Aerialtronics	2	0	0	0	2	0	0	0	0	0	0
AeriCam	1	0	0	0	0	0	1	0	0	0	0
Aeritech	1	1	0	0	0	0	0	0	0	0	0
Aerobo	1	0	0	0	0	0	0	0	0	0	1
Aerologix GIS	1	1	0	0	0	0	0	0	0	0	0
Aeromao Inc.	2	2	0	0	0	0	0	0	0	0	0
Aeronavics Ltd.	3	0	0	0	1	0	0	2	0	0	0
Aerosky	2	0	0	0	0	0	2	0	0	0	0
AeroTestra Inc.	1	0	0	0	1	0	0	0	0	0	0
AeroVironment	5	3	0	0	2	0	0	0	0	0	0
Aeryon Labs, Inc.	3	0	0	0	3	0	0	0	0	0	0
AgEagle Aerial Systems Inc.	2	2	0	0	0	0	0	0	0	0	0
Agribotix LLC	2	1	0	0	1	0	0	0	0	0	0
Aibotix	1	0	0	0	1	0	0	0	0	0	0
Airborne Mechatronics OÜ	1	0	0	0	0	0	0	0	0	0	1
AirCover Integrated Solutions	1	0	0	0	1	0	0	0	0	0	0
Airphrame Inc.	1	0	0	0	0	0	0	0	0	0	1
AirRobot GmBH & Co. KG	3	0	0	0	2	0	1	0	0	0	0
AirStar International	1	0	0	0	1	0	0	0	0	0	0
ALIGN Corp Ltd.	4	0	3	0	0	0	1	0	0	0	0
Alpha Drone SIA	2	0	0	0	1	0	0	1	0	0	0
Altavain, Inc.	3	2	0	0	0	0	0	1	0	0	0
Altus UAS Ltd.	1	0	0	0	0	0	0	1	0	0	0
Alware	1	0	0	0	0	0	0	1	0	0	0
American Drones LLC	4	0	0	0	2	0	2	0	0	0	0

Table B1 continued.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
Applied Aeronautics	1	1	0	0	0	0	0	0	0	0	0
Arch Aerial	1	0	0	0	0	0	0	1	0	0	0
Aries	1	0	0	0	1	0	0	0	0	0	0
Ascending Technologies GmBH	3	0	0	0	2	0	0	1	0	0	0
Ascent AeroSystems	1	0	0	1	0	0	0	0	0	0	0
Auburn University	2	0	0	0	0	0	0	0	0	0	2
Aurora Flight Sciences	1	0	0	0	0	0	0	0	0	0	1
Autocopter Corp.	1	0	1	0	0	0	0	0	0	0	0
Avigators	1	1	0	0	0	0	0	0	0	0	0
Avyon	2	2	0	0	0	0	0	0	0	0	0
Bergen	1	0	0	0	0	0	0	1	0	0	0
BirdsEyeView Aerobotics	1	0	0	0	0	0	1	0	0	0	0
Bormatec	1	1	0	0	0	0	0	0	0	0	0
Bruce Tharpe Engineering	1	1	0	0	0	0	0	0	0	0	0
CarbonCore Ltd.	3	0	0	0	1	0	1	1	0	0	0
C-Astral d.o.o.	2	2	0	0	0	0	0	0	0	0	0
Century Helicopter Products	1	0	0	0	0	0	1	0	0	0	0
Cheerson	2	0	0	0	2	0	0	0	0	0	0
Cloud 9 Drones	1	0	0	0	0	0	0	0	0	0	1
CropCopter	1	0	0	0	1	0	0	0	0	0	0
CyberQuad	1	0	0	0	1	0	0	0	0	0	0
Cyphy Works Inc.	1	0	0	0	0	0	1	0	0	0	0
DJI	23	0	0	0	15	0	4	4	0	0	0
DraganFly Innovations Inc.	4	0	0	0	3	0	1	0	0	0	0
DreamQii, Inc.	1	0	0	0	1	0	0	0	0	0	0
Drone America	1	0	0	0	0	0	0	1	0	0	0
Drone Aviation Corp.	1	0	0	0	0	0	0	1	0	0	0
Drone2GIS	1	0	0	0	0	0	0	0	0	0	1
DroneFleet Aerospace Management	1	0	0	0	0	0	0	0	0	0	1
DRONESTHATWORK, LLC	3	0	1	0	0	0	0	0	0	0	2
DroneX BV	1	0	0	0	1	0	0	0	0	0	0
ECA Group	1	0	0	1	0	0	0	0	0	0	0

Table B1 continued.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
EHANG	2	0	0	0	2	0	0	0	0	0	0
Embry-Riddle Aeronautical University	1	0	0	0	1	0	0	0	0	0	0
Emmen Aerospace	1	1	0	0	0	0	0	0	0	0	0
EMT Penzburg	1	0	1	0	0	0	0	0	0	0	0
Event 38 Unmanned Systems	1	1	0	0	0	0	0	0	0	0	0
FiNWing Hobby	1	1	0	0	0	0	0	0	0	0	0
Flite Evolution	1	1	0	0	0	0	0	0	0	0	0
FlyAbility	1	0	0	0	0	0	0	0	0	0	1
flying-cam	1	0	1	0	0	0	0	0	0	0	0
FlyingCinema	1	0	0	0	1	0	0	0	0	0	0
FlyPro	1	0	0	0	1	0	0	0	0	0	0
Foxtech	2	0	0	0	1	0	0	1	0	0	0
FPV Manuals LLC	5	0	0	0	5	0	0	0	0	0	0
Freefly	4	0	0	0	1	0	2	1	0	0	0
GeoBlu Services	1	0	0	0	0	0	0	1	0	0	0
goFarm	1	0	0	0	0	0	0	1	0	0	0
Grand Wing System	1	0	0	0	0	0	0	0	0	0	1
Gryphon Dynamics	2	0	0	0	0	0	1	1	0	0	0
Guangzhou Walkera Technology Co Ltd.	7	0	0	0	5	0	2	0	0	0	0
Harris Aerial	2	0	0	0	0	0	0	1	0	0	1
Height Tech GmbH & CO. KH	3	0	0	0	0	0	1	2	0	0	0
HeliVideo	1	0	0	0	0	0	0	0	0	0	1
Hexacrafter Ltd.	2	0	0	0	0	0	1	1	0	0	0
HiSystems GmBH	2	0	0	0	0	0	1	1	0	0	0
Hobbico	1	1	0	0	0	0	0	0	0	0	0
Hobby King	9	4	0	0	2	0	1	0	0	0	2
Honeycomb Corp.	1	1	0	0	0	0	0	0	0	0	0
Horizon Hobby Inc.	9	1	1	0	7	0	0	0	0	0	0
Hoverfly	3	0	0	0	1	0	0	2	0	0	0
Hubsan	4	1	0	0	3	0	0	0	0	0	0
ICR Service Inc.	2	0	0	0	0	0	0	0	0	0	2
ImmersionRC Limited	1	0	0	0	1	0	0	0	0	0	0

Table B1 continued.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
ING Robotic Aviation	1	0	1	0	0	0	0	0	0	0	0
Innovative Machines LLC	1	1	0	0	0	0	0	0	0	0	0
Intuitive Aerial, Inc.	1	0	0	0	0	0	0	0	0	1	0
Jason A. Gadrim	3	0	0	0	1	0	2	0	0	0	0
Javad	1	0	0	0	1	0	0	0	0	0	0
Kespry Inc.	2	0	0	0	1	0	0	0	0	0	1
Krossblade Aerospace Systems LLC	1	0	0	0	0	0	0	0	0	0	1
Latitude Engineering	1	0	0	0	0	0	0	0	0	0	1
Lehmann Aviation	1	1	0	0	0	0	0	0	0	0	0
Leptron Unmanned Aircraft Systems Inc.	2	0	1	0	1	0	0	0	0	0	0
Lily Robotics, Inc.	1	0	0	0	1	0	0	0	0	0	0
Littlebirds View	1	0	0	0	0	0	0	0	0	0	1
Lockheed Martin Corporation	5	4	0	0	1	0	0	0	0	0	0
Marcus UAV Corp.	1	1	0	0	0	0	0	0	0	0	0
Martin UAV	2	2	0	0	0	0	0	0	0	0	0
MAVinci GmbH	1	1	0	0	0	0	0	0	0	0	0
Microdrones GmbH	3	0	0	0	3	0	0	0	0	0	0
MicroUAV	1	0	0	0	0	0	0	0	0	0	1
Minicopter	1	0	1	0	0	0	0	0	0	0	0
Monarch Inc.	2	0	0	0	2	0	0	0	0	0	0
Mozi Robotics	1	0	0	0	0	0	0	0	0	0	1
Multirotor GmbH	5	0	0	0	3	0	2	0	0	0	0
Multiworks UAV	1	0	0	0	0	0	0	0	0	1	0
MyFlyDream	1	1	0	0	0	0	0	0	0	0	0
Ohio State University	1	1	0	0	0	0	0	0	0	0	0
Oklahoma State University	1	0	1	0	0	0	0	0	0	0	0
Only Flying Machines	1	0	0	0	1	0	0	0	0	0	0
Parrot SA.	2	0	0	0	2	0	0	0	0	0	0
Perspective Robotics AG	1	0	0	0	1	0	0	0	0	0	0
Phoenix Aerial Systems	3	1	1	0	0	0	0	1	0	0	0

Table B1 continued.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
Pictorvision	3	0	0	0	0	0	0	0	0	0	3
Pinnacl X	1	0	0	0	1	0	0	0	0	0	0
PMG Multirotors	1	0	0	0	1	0	0	0	0	0	0
PowerUp Toys	1	1	0	0	0	0	0	0	0	0	0
Precision Drone	1	0	0	0	0	0	1	0	0	0	0
PrecisionHawk	3	3	0	0	0	0	0	0	0	0	0
Price Aviation Group	1	0	0	0	1	0	0	0	0	0	0
Prioria Robotics	2	1	0	0	1	0	0	0	0	0	0
PSI Tactical Robotics	2	0	0	0	2	0	0	0	0	0	0
Pulse Aerospace Inc.	2	0	0	2	0	0	0	0	0	0	0
QuestUAV Ltd.	2	2	0	0	0	0	0	0	0	0	0
RangeVideo	1	0	0	0	0	0	0	0	0	0	1
RCTimer Power Model Co. Ltd.	2	0	0	0	0	0	1	1	0	0	0
ReadyMade RC LLC	7	6	0	0	0	0	0	0	0	0	1
RIEGL Laser Measurement Systems Group GmbH	1	0	0	0	0	0	0	1	0	0	0
Rocketship Systems Inc.	1	1	0	0	0	0	0	0	0	0	0
Salamati Productions Inc.	1	0	0	0	0	0	0	1	0	0	0
Seahawk AP	1	0	0	0	0	0	0	0	0	0	1
SelectTech GeoSpatial	1	0	0	0	1	0	0	0	0	0	0
SenseFly	6	5	0	0	1	0	0	0	0	0	0
Sensurion Aerospace	1	1	0	0	0	0	0	0	0	0	0
Shenzhen Idea-Fly Technology Co. Ltd.	1	0	0	0	1	0	0	0	0	0	0
SIG Manufacturing	1	1	0	0	0	0	0	0	0	0	0
Sky Flight Robotics	1	0	0	0	0	0	0	0	0	0	1
Skycatch Inc.	1	0	0	0	1	0	0	0	0	0	0
Sky-Hero	2	0	0	0	0	0	2	0	0	0	0
Skylark	1	0	0	0	1	0	0	0	0	0	0
SkyView Aerial Solutions	2	0	0	0	1	0	0	1	0	0	0
Skyward.io	1	1	0	0	0	0	0	0	0	0	0
Smartplanes	1	1	0	0	0	0	0	0	0	0	0
Stark Aerospace	2	1	0	0	0	1	0	0	0	0	0

Table B1 continued.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
Steadidrone	5	0	0	0	3	0	0	2	0	0	0
SwellPro	2	1	0	0	1	0	0	0	0	0	0
Swift Radioplanes LLC	1	1	0	0	0	0	0	0	0	0	0
Syma Toys Co. Ltd.	3	0	0	0	2	0	0	0	0	0	1
Tarot RC	11	0	0	0	2	0	5	3	0	0	1
Tayzu Robotics	3	0	0	0	1	0	0	2	0	0	0
Topcon	3	3	0	0	0	0	0	0	0	0	0
Trigger Composites	1	1	0	0	0	0	0	0	0	0	0
Trimble Navigation, Ltd.	3	2	0	0	0	0	1	0	0	0	0
Troy Built Models	5	3	0	0	1	0	1	0	0	0	0
TURBO ACE	3	0	0	0	1	0	2	0	0	0	0
UAS Academy	4	0	0	0	0	0	0	0	0	0	4
UAS USA	1	1	0	0	0	0	0	0	0	0	0
UAV America	1	0	0	0	0	0	0	0	0	0	1
UAV Factory	2	2	0	0	0	0	0	0	0	0	0
UAV Solutions, Inc.	2	1	0	0	0	0	1	0	0	0	0
UDI RC	1	0	0	0	1	0	0	0	0	0	0
Unmanned Sensing Systems LLC	1	1	0	0	0	0	0	0	0	0	0
Unmanned Systems, Incorporated	1	1	0	0	0	0	0	0	0	0	0
Viking UAS	8	1	0	0	3	1	2	0	0	0	1
Volt Aerial Robotics LLC	1	0	0	0	1	0	0	0	0	0	0
Vulcan UAV	4	0	0	0	1	0	1	1	0	0	1
Waterproof Drones	2	0	0	0	1	0	1	0	0	0	0
X_UAV	1	1	0	0	0	0	0	0	0	0	0
X12 Production Services	1	0	0	0	0	0	0	0	0	0	1
XactSense	1	0	0	0	0	0	0	1	0	0	0
Xcam Aerials	1	0	0	0	0	0	0	1	0	0	0
Xcellent Drones	2	0	0	0	0	0	0	0	0	0	2
Xfold	4	0	0	0	0	0	0	3	0	1	0
X-UAV	1	1	0	0	0	0	0	0	0	0	0
Yamaha	1	1	0	0	0	0	0	0	0	0	0
YiZahan	1	0	0	0	1	0	0	0	0	0	0

Table B1 continued.

List of Manufacturers	# of Categorized Platforms	Fixed-wing	Helicopter	2-copter	4-copter	5-copter	6-copter	8-copter	10-copter	12-copter	Unknown
YUNEEC	7	0	0	0	5	0	2	0	0	0	0
Zerouav	1	0	0	0	0	0	0	1	0	0	0
Zeta Science Limited	2	2	0	0	0	0	0	0	0	0	0
Unknown	32	4	3	0	3	0	5	2	0	0	15

Appendix C: Section 333 Use Case/DAA Call Responses

Section 333 Use Case/DAA Data Call

Approximately 4,500 333 exemption-holders were contacted by email with a similar message to that sent out in the FEDBIZOPS data call. The following are re-structured but otherwise unedited responses from the exemption holders. Some of the responses included information in all the categories requested (very detailed responses) while others included information but not in all categories requested (less detailed responses).

Very Detailed Responses

A & R Video. POC: Andrew Sommer, asommer@arvideo.com

- Use Case: "We use sUAV 5-10 lbs for monthly construction photography on primarily linear construction projects such as road widening, drainage improvements, water and sewer line installations. All flights are over designated construction zones with appropriate "Maintenance of Traffic"

  MOT warnings rather than traditional manned aircraft giving clients 2-4 aerial photos per mile taken at 1000 feet AGL, we produce 60-120 photos per mile taken at 100 feet AGL with much more detail. This allows interested parties to review construction progress in great detail down to individual culverts and utility installs. Presently, all missions are flown manually with GPS assist with no recorded data or telemetry other than captured imagery which I'm not authorized to release. Future plans call for full automation with telemetry to monitor by Pilot."
- Location: Florida
- Platform: Tarot 650 Quad; Tarot 690 Hexa
- Takeoff Time: Depends on weather and sun angle; usually mid-late afternoon
- Flight Duration: Typically 1-6 flights (depends on distance needed) @ 4-12 minutes each. Potentially up to 20 minutes.
- Airspeeds: Range from hover to 30 mph
- Climb / Descent Rates: Unknown, but mission starts once the desired height is obtained, which is typically in under 10 seconds.
- Flight Pattern: linear out then back
- Desired Modifications to Existing FAA Limits: "We have tested our system in unimproved open areas out to 1 mile+, approximately 5500 feet, and can still maintain Line of Sight. It is tiny but visible unaided LOS. Industry norms are LOS meaning no further than 1500 linear feet from pilot. This forces us to take off fly back 1500' start run go past pilot another 1500' and return. Then move 3000 feet down range and repeat. We would like to operate out to BLOS using First Person View and missions guided by on board GPS/Controller with pilot monitoring via FPV and telemetry fully utilizing the range capabilities of the aircraft to go down range out to 1 or more miles using a minimum number of flights. Instead of two flights per mile. Thus cutting the most risky portions, take off and landings, in half maybe more give the three mile round trip range of the aircraft. More efficient overall and given the technology capabilities safer with less takeoffs and landings from the public right-of-way.

Empire Unmanned. POC: Joseph Stewart, joseph.swart@adavso.com
6/1/2016
Joseph Swart
Empire Unmanned
1159 N Atlas Road
Hayden, ID 83835
sUAS BVLOS Team
New Mexico State University

sUAS BVLOS Team,

My name is Joseph Swart, and I'm an instructor pilot for Empire Unmanned based in Hayden, ID. Thanks for reaching out to us. I apologize for the delayed participation since we were involved with other projects regarding our business. As of right now, our flight operations for sUAS are limited to 400 feet AGL outside of 5 nautical miles from towered airports. Moreover, we are limited to fly no closer than 500 feet from any nonparticipating persons, structures, and vehicles. Lastly, our pilots are required to maintain visual line of sight of our sUAS and must have a separate visual observer present to keep an eye on the sUAS. Due to our expanding operations and market potential, we feel that current regulations are restrictive to our business. We prefer to have more flexibility. BVLOS flexibility will greatly enhance our sUAS operations and create much needed efficiency. Currently, we use two types of UA systems to cover our sUAS operations. Below is a list of flight profiles for each application as requested.

Application: Agriculture

- Description: We fly the sUAS over farmers' fields to take pictures. We combine all the pictures for each field in order to provide imagery analysis of those fields for farmers' consumption. Those analytical products can help farmers improve their farming practices.
- Location: We flew in various locations within Washington state and Idaho over farm fields. We're expanding operations in the western U.S. and, hopefully, nationwide.
- Type Aircraft: Sensefly eBee Ag
- Takeoff time: Varies based on client's needs and schedule. We usually have multiple flights per day, so takeoff times can occur anytime during daylight hours.
- Flight Duration: 15 to 30 minutes
- Key Altitudes: 200 to 400 ft AGL. Altitudes limited due to various COAs that were approved for us. Higher altitudes will offer better flexibility and capability for our operations.
- Airspeeds: max cruise 48 knots, min cruise 21 knots, approach speed 24 knots
- Climb/Descent Rates: climb 1575 ft/min, descent 1575 ft/min
- Flight Pattern: elongated "S" pattern, cross pattern (overlapping perpendicular "S" patterns)

Application: Mining

- Description: We fly the sUAS over open mine fields to take pictures. We combine all the pictures for each field in order to provide gravel mound volume calculation, terrain mapping, and area surveying.
- Location: We flew in various locations within Washington state and Idaho over open mine fields. We're expanding operations in the western US and, hopefully, nationwide.
- Type Aircraft: Sensefly eBee Ag
- Takeoff time: Varies based on client's needs and schedule. We usually have multiple flights per day, so takeoff times can occur anytime during daylight hours.
- Flight Duration: 15 to 30 minutes
- Key Altitudes: 200 to 400 ft AGL. Altitudes limited due to various COAs that were approved for us. Higher altitudes will offer better flexibility and capability for our operations.
- Airspeeds: max cruise 48 knots, min cruise 21 knots, approach speed 24 knots
- Climb/Descent Rates: climb 1575 ft/min, descent 1575 ft/min
- Flight Pattern: elongated "S" pattern or cross pattern (overlapping perpendicular "S" patterns)

Application: Aerial Surveying

- Description: We fly the sUAS over installations of engineering firms. We provide a 3D representation of their installation to give clients a to-scale view of their sites in order to aid in construction or site planning.

- Location: We flew in various locations within Washington state and Idaho over their installations. We're expanding operations in the western U.S. and, hopefully, nationwide.
- Type Aircraft: Sensefly eBee Ag
- Takeoff time: Varies based on client's needs and schedule. We usually have multiple flights per day, so takeoff times can occur anytime during daylight hours.
- Flight Duration: 15 to 30 minutes
- Key Altitudes: 200 to 400 ft AGL. Altitudes limited due to various COAs that were approved for us. Higher altitudes will offer better flexibility and capability for our operations.
- Airspeeds: max cruise 48 knots, min cruise 21 knots, approach speed 24 knots
- Climb/Descent Rates: climb 1575 ft/min, descent 1575 ft/min
- Flight Pattern: elongated "S" pattern or cross pattern (overlapping perpendicular "S" patterns)

Application: Classification and Species Identification

- Description: We flew for the Kootenai/Shoshone County Water Conservation District to see if the spectral filtered imagery from our sUAS would provide information regarding the classification of species of plants.
- Location: Coeur d'Alene River in Idaho
- Type Aircraft: Sensefly eBee Ag
- Takeoff time: We had multiple flights that day, so takeoff times occurred between 0900 and 1500 PST.
- Flight Duration: 15 to 30 minutes
- Key Altitudes: 400 ft AGL. Altitudes limited due to various COAs that were approved for us. Higher altitudes will offer better flexibility and capability for our operations.
- Airspeeds: max cruise 48 knots, min cruise 21 knots, approach speed 24 knots
- Climb/Descent Rates: climb 1575 ft/min, descent 1575 ft/min
- Flight Pattern: elongated "S" pattern

Application: Sawmill Inventory

- Description: We flew for a Sawmill to provide volume calculation for their log stockpiles.
- Location: Northern Idaho
- Type Aircraft: Sensefly eBee Ag
- o Takeoff time: We had multiple flights that day, so takeoff times occurred between 0900 and 1600 PST.
- Flight Duration: 15 to 30 minutes
- Key Altitudes: 200 ft AGL.
- Airspeeds: max cruise 48 knots, min cruise 21 knots, approach speed 24 knots
- Climb/Descent Rates: climb 1575 ft/min, descent 1575 ft/min
- Flight Pattern: cross pattern (overlapping perpendicular "S" patterns)

Application: Fire Fighting

- Description: We flew for the Idaho Department of Land to help with post fire damage assessment of a forest fire. We were escorted by a fire fighter and used hand radios to clear for other firefighting aircraft. We recorded full motion video and provided real-time video feed on the ground for firefighters to view.
- Location: Bayview, ID
- Type Aircraft: DJI Phantom 2

- Takeoff time: We had multiple flights that day, so takeoff times occurred between 0900 and 1600 PST.
- Flight Duration: 10 to 20 minutes
- Key Altitudes: 0 to 200 ft AGL. Altitudes limited due to various COAs that were approved for us.
- Airspeeds: max cruise 29 knots
- Climb/Descent Rates: climb 1181 ft/min, descent 394 ft/min
- Flight Pattern: nothing specific. Pilot defined.

Application: Real Estate

- Description: We flew for several ranches and estates with large acres of surrounding land. Due to our COA limiting us to stay beyond 500 ft from nonparticipating persons, buildings, or vehicles, we focused on large estates that were secluded. We flew the sUAS to capture full motion video of residential estates to provide aerial view for the purposes of real estate promotion.
- Location: Various locations in Spokane County, WA and northern Idaho.
- Type Aircraft: DJI Phantom 2
- Takeoff time: We had multiple flights for each day, so takeoff times occurred during daylight hours.
- Flight Duration: 10 to 20 minutes
- Key Altitudes: 0 to 200 ft AGL
- Airspeeds: max cruise 29 knots
- Climb/Descent Rates: climb 1181 ft/min, descent 394 ft/min
- Flight Pattern: nothing specific. Pilot defined.

That covers the bulk of our operations within our company. However, we are always looking for new applications that can be covered by our sUAS capabilities, and we are always looking to expand our business regionally as well. Since we can keep situational awareness on our sUAS using GPS information displayed on our mobile devices and using our radio and eyes to clear for manned traffic, we believe that having BVLOS flexibility will greatly improve our operations without a sacrifice of safety. Moreover, given the weights and sizes of our sUAS and the parameters of our operations, we believe the risk and damage of a sUAS accident to bystanders and structures is extremely low (basically nonexistent).

Therefore, we believe our FAA-required 500 ft buffer from nonparticipating persons, structures, and vehicles is overly cautious and unnecessary, especially considering hobby and recreational users don't have this restriction even when flying the exact same sUAS. Nevertheless, we still comply with FAA regulations despite the restriction and limitation to our operations.

Thank you for your invitation to include our company to this study, and I hope that our data will provide the needed information to help the cause. I will be your point of contact, so if you have any questions or require more information, please don't hesitate to contact me via email or phone listed on the signature block.

Boulder Emergency Services, POC: Steve Lanaghen, stevelanaghen@boulderrescue.org

"Per your request for flight information in furtherance of building a case for BVLOS flight authorization with the FAA, below is the information for the Boulder Emergency Squad (BES), a search and rescue organization operating in Boulder, Colorado.

BES strongly supports your efforts. In actual search and rescue missions over wilderness terrain, we have found that it our capabilities are most valuable in searching areas which are remote or difficult to access on foot. Operating within VLOS conditions, our range is not significantly longer than what can be done with a ground search team, although it can be done faster and safer. However, if we were allowed to operate in XVLOS or BVLOS conditions, our search capabilities would be far more effective in searching areas which are far more difficult and time consuming for ground crews to reach. We are interested in obtaining a waiver from Part 107 and/or our Section 333 exemption for XVLOS or BVLOS operations and would appreciate any precedent or supporting data you might be able to share."

- Use Case: "The Boulder Emergency Squad has begun using UAS for search and rescue operations, and intends to begin using them for fire and law support functions as well. Most of the flights in the attached data set are training flights.

  Attached is a spreadsheet containing flight information for the flights we have made over the past year or so. Mission Notes, Pilot, Payload Operator and Visual Observer fields have been redacted for privacy reasons and other fields not pertinent to your research (i.e., battery ID, UAS ID, etc.) have also been removed. Weather conditions have been included in many cases and any damage or malfunctions encountered during the flight have been included as they seem very pertinent to your research even though there were not requested."
- Location: All operations have been conducted in Boulder County, Colorado.
- Platform: DJI Phantom 2, DJI Phantom 3, DJI Inspire and DJI S1000
- Takeoff Time: Takeoff time and landing time are all included in the attached flight data.
- Flight Duration: Flight durations are typically in the 10-16 minute range. Flight duration is included in the attached flight data.
- Key Altitudes: Both maximum AGL altitude and MSL altitude of the home point are included in the attached flight data.
- Airspeeds: We do not track airspeed, but speeds vary from 0-15 knots. Higher airspeeds are typical of transit between target locations or autonomous flight patterns at higher altitudes with clear skies, with lower airspeeds at lower altitudes, over rough terrain and near obstacles.
- Climb / Descent Rates: We do not track ascent and descent rates, but I would estimate rates to be typically 1-5 fps on descent and 1-10 fps on ascent.
- Flight Patterns: We do not track flight patterns, but we typically operate in one of three modes:
  - a box grid pattern in which we take overlapping orthographic photos for subsequent analysis for a search operation.
  - a point of interest loiter in which we would circle or hover in a specific location to gain situational awareness using a live feed, or to document a scene for documentation purposes
  - free flight for training and evaluation of pilots and/or hardware/software.

Kansas State University. POC: Travis Balthazor, travisb@ksu.edu

Mr. Hottman,

Please find the attached document containing the KSU UAS you requested. Should you have any questions regarding the data please let me know. Thanks!

Travis Balthazor
UAS Chief Pilot
Kansas State University-Polytechnic Campus

The Kansas State data is presented in Appendix A.

Less Detailed Reponses

Delta Southern UAS. POC: Preston White, preston@deltasouthernuas.com

-Use Case: "We currently use our UAS in agriculture to determine plant health, in law enforcement to get a usable image for planning purposes, for disaster relief and search and rescue by providing EMS with an up to date image of the affected area"

- Location: The Mississippi Delta
- Platform: Sensefly eBee and DJI S900
- Flight Duration: Usually roughly 10 minutes, but flight duration can last up to 40 minutes depending on wind
- Airspeeds: 20-40 kts.
- Climb / Descent Rates: Relatively fast for the DJI S900 and the eBee can clear 200 ft of altitude in about the same distance across the ground
- Flight Patterns: Typically a grid

Mike Knudsen Photography. POC: Mike Knudsen, mike@mikeknudsenphotography.com

- Use Case: "Primarily for real estate work. An important element of this use case is it is always low altitude, line of sight, daylight hour flying, typically not near crowds or restricted airspace, and well within the limits imposed by even the strictest interpretation of the proposed guidelines. Some of the test questions I've seen for the part 104 certification are manned aircraft pilot level in nature, and, in my opinion, inappropriate for this use case."
- Location: Residential and commercial neighborhoods, business complexes, etc.
- Platform: DJI Phantom 2+ V3
- Takeoff time: Daylight hours, typically between 9am and 7pm
- Flight Duration: Less than 20 minutes
- Key Altitudes: Generally less than 200 feet
- Airspeeds: Hover
- Climb / Descent Rates: Moderate – typically well below the aircraft capability
- Flight Patterns: mostly vertical ascent to appropriate photo height, with some circling to get varied vantage points

SurvTech Solutions. POC: Jordan Kowenski, jkowenski@survtechsolutions.com

- Use Case: Surveying, Photogrammetry, Mapping
- Location: Southeast US
- Platform: Quad-copter and fixed wing
- Flight Duration: 15 – 100 minutes
- Airspeeds: 5 – 20 mph
- Key Altitudes: Shallow, 100 – 400 ft. AGL
- Climb / Descent Rates: Shallow, 200 – 300 FPM
- Flight Patterns: Linear

Rapid Aerial LLC. POC: Matt Roderick, matt@rapid-aerial.com

"I own and operate a general UAV service business, for many of my operations I'm not interested in adding BVLOS capability but for those operations where it could be useful, I've included the requested information."

Use Application Rural utility line and substation inspections

- Location: Southwest Idaho
- Platform: DJI Phantom 3 Pro and DJI Inspire 1 Pro
- Takeoff Time: typically around 10AM local
- Flight Duration: 10-20 minutes
- Key Altitudes: 40-200' AGL
- Airspeeds: less than 20MPH
- Climb/Descent Rates: 900FPM climb, 600'FPM descent
- Flight Patterns: A long circuit, "down and back" of several consecutive utility structures. BVLOS would allow me to cover more structures at a time, increasing my efficiency

Use Application Photogrammetric Surveys

- Location: Southwest Idaho
- Type of Aircraft: DJI Phantom 3 Pro and DJI Inspire 1 Pro
- Takeoff Time: typically around 11AM-noon local
- Flight Duration: 10-20 minutes
- Key Altitudes: 150-400' AGL
- Airspeeds: less than 30 MPH
- Climb/Descent Rates: 900 FPM climb, 600 FPM descent
- Flight Patterns: Serpentine or grid pattern of flight lines over an area of interest. BVLOS capabilities would allow me to cover larger areas in single "set ups" saving time and money.

DuPage County, Illinois. POC: Lucy Chang, lucy.chang@dupageco.org

"I am responding to your request for information, which was originally sent to my colleague John Blickem. I am a water resources engineer for DuPage County, Illinois. There are three of us on staff here who have passed the private pilot license exam and are authorized to fly the County's drone. We are looking to expand the use of our drone and possibly upgrade to a more sophisticated UAS.

I would like to participate in your study, and I would also appreciate any information or research results you can share. Here us our information:

- Name of Organization: DuPage County Stormwater Management
- Use Case: Currently, the UAS is primarily used to inspect County flood control facilities and capture photographs and video footage from high elevations for use in County publications, presentations, and technical reports. We will soon expand the use of the UAS to include the monitoring of wetlands in locations that are difficult to access on foot, and monitor water quality at storm sewer outfalls.
- Location: DuPage County, Illinois (approximately 30 miles west of Chicago)
- Type of Aircraft: DJI Phantom 3
- Takeoff Time: Varies
- Flight Duration: 4 x 15 minutes (battery life is approximately 15 minutes, and we have four batteries)
- Key Altitudes: 100-200 feet
- Flight Patterns: No established flight pattern. We often follow the flow path of waterways

SelectTech GeoSpatial. POC: Frank J. Beafore, fbeafore@sgamf.com

Sirs,

We do have active 333's and COA's.

What you want will require some work on our part. Currently, I do not have anyone I can afford to assign this to. However, you can visit our web site http://www.sgamf.com/suas/ and get most of the answers you need from reading the material and attachments. If you need further information, e-mail me.

Frank B."

Forza RPV. POC: Gil, gil@forzarpv.com

Dr. Hottman,

I was contacted through my gmail account for possible participation in your study. I may be interested but have a few questions.

My background is nearly a dozen years in the electric utility industry conducting helicopter flights operations where a primary activity was powerline inspection. I was responsible for flight operations and developed the company's HD/IR gyro-stabilized camera program.

While I no longer work for that company (I now live in Silicon Valley), I am actively involved in commercial drone flight operations on a daily basis. An area of interest and current discussion is developing an sUAS powerline inspection program based on my previous experience in the utility trade - my assessment is that such a program is complex to implement because of the required flight profiles and the structure geometries.

Would you be interested in scheduling a telephone conversation to discuss some concepts?

Sincerely,

Gil

Atlanta Drone Operations. POC: Pete Wambolt, pete@atldrone.com

- Use Application: A Variety of different operations are conducted here at Atlanta Drone Consultants. Most of our uses are for aerial photography/ videography. We also have done work with 3D mapping and have worked on a few shoots for up and coming TV shows.
- Location: The majority of our flights happen in and around Atlanta, GA
- Platform: We mainly operate DJI Inspire 1 but also operate the Phantom 3 professional
- Takeoff Time: Most of our flight will happen between 10 am and 4 pm although sometimes we run later to get a more artistic view
- Flight Duration: Our flights will normally be around 15 min each with 5-10 flights in total
- Key Altitudes: Our type of work demands that we fly at different altitudes everyday remaining between 50-400 ft AGL
- Airspeeds: Our airspeed never exceeded 35 mph
- Climb / Descent Rates: Climb and descent rates do not exceed 9 mph
- Flight Patterns: Flight patterns change on a daily basis depending on what the job details. More often than not we have a few basic patterns. Including point of interest (where we do a circle around something with the camera pointed at it the entire time), also we do a lot of reveal shots where we start very low and close and fade out to high and far. Most of the time we have two operators so that one is controlling the camera while the other is flying the UA.

JimmyC LTD. POC: Jimmy Clark, jimmyclark@usa.com

- Use Case: Our application/use of the UAV is for insurance building damage assessment post catastrophic event such as earthquake, hurricane, tornado, explosion and flood.

- Location: We can deploy anywhere in the US and typically fly within 80' of building and other structures. With some flights at altitude of 100' for overall photo of structure.
- Platform: Primary UAV are the quadcopter, i.e. DJI Phantom 2, DJI Phantom 3
- Takeoff Time: Daytime business hours
- Flight Duration: 15 – 60 minutes
- Key Altitudes: 20 to 200 ft AGL, but typical 60 ft AGL
- Airspeeds: 1-3 mph
- Flight Patterns: Circular over damaged structures

Trans-Global Production. POC: Bob Bailey, bbailey@cableone.net

- Use Case: Video of an auto dealership showing aerial view of dealership buildings and inventory. An occasional shot went almost beyond line of sight but was still able to be monitored with the iPad.
- Use Case: Video of golf course property showing buildings, water hazards and fairways along with greens. Occasionally, a shot was just beyond Line of sight. But the shot could still be monitored on the iPad.
- Use Case: Video of a tennis tournament in progress. Shots were from outside the perimeters of the fans in the stands and the court itself. No flights were made over the top of the stands or over the court. A maximum height above ground was around 60 feet at an angle of approximately 45 degrees. Line of sight was always maintained.
- Use Case: Most important was the job we did not take, which was ordered by the City of Odessa to shoot aerials of the Christmas parade. Because the shoot time was after dark and because the close vicinity of the onlookers may have been too dangerous, we did not take the job. The use of the Phantom 3 for these aerials would have provided for some very nice video. I feel that with extra care, keeping the Phantom away from the crowds of onlookers would have been possible, perhaps with a second observer, but the real problem was and still is the fact that the drones are not to be flown after sunset. In this case, the streets were well lit and line of sight would not have been a problem.
- Use Case: We produce a video each year at our local football stadium, of the high school graduations. But, again, in order to use the drone we would have to be able to fly after sunset. It would be easy to fly at the stadium and still keep the drone away from the audience in the stands as well as the students who are graduating. Line of sight should be no problem. I personally feel that the ability to shoot in well-lit areas after dark should be allowed.
- Location: In the Midland and Odessa, TX area with possible travel out of market
- Platform: DJI Phantom 3 Professional
- Takeoff Time: NA
- Flight Duration: Up to 20 min
- Key Altitudes: 35 to 50 feet AGL
- Airspeeds: 5 – 25 mph
- Climb / Descent Rates: Ease in and out
- Flight Patterns: As necessary

Appendix D: Justifications for Off Board DAA Metric Values and Scores

The following provide justifications for metric values and corresponding scores that are used to evaluate off board DAA approaches. It is noted that explanations are not provided for all metric values as justifications for some are readily apparent.

Sensor Performance Capabilities

Horizontal Range

Table D1. Explanation of off board horizontal range metric values and scores.

Score:	1	2	3	4	5
Value (ft/km/mi/nmi):	10560/3.22/2.0/1.74	26785/8.16/5.07/4.41	43010/13.11/8.15/7.08	59235/18.05/11.22/9.75	75460/23/14.3/12.4
Explanation:	According to Pathfinder results presented at TAAC 2016, VLOS is ~1 mile and EVLOS is ~ 2 miles. Here, BVLOS is expected to, at the minimum, extend the VLOS distance by 1 mile. Also, from the ABSAA metrics, one needs to see 0.66 nmi (0.76 mi) out to avoid an NMAC. Thus, if one is flying at the edge of VLOS and out to 1.25 miles (0.25 miles beyond VLOS), then a system that can scan out to 2 mi would enable avoidance of an NMAC, but would not enable maintenance of well clear.	Linearly distributed between 1 and 5.	Linearly distributed between 1 and 5.	Linearly distributed between 1 and 5.	Because radar is a leading technology in this area, its performance is used to establish an upper bound for what might be possible. The limiting factor is EM propagation, which is assumed here to occur under standard propagational conditions, which result in the radar beam rising relative to the Earth with increasing range from a radar. A maximum UAS altitude of 450 ft is assumed given that a 50 ft buffer is used to separate from traffic flying at 500 ft and above. Given this and the 335 ft buffer required to avoid an NMAC (from the ABSAA metrics), the radar would have to see down to 115 ft off the ground to avoid an NMAC with a pop-up. Now, in reality this is an exaggeration, as the 335 ft value assumes the worst case (one descending and the other climbing at the maxium rate). Regardless, this works as it is larger than the 250 ft well-clear distance and provides an 85 ft buffer (~5 s buffer to the well clear boundary if the intruder is climing at 1000 ft/min) beyond well clear that may enable maintenance of well clear if one can see 335 ft below the UA. It is noted that verification of maintenance of well clear using these numbers and for this scenario would have to be verified through simulation. Given this, a 0.0° elevation radar beam from a radar at a height of 3 m off the ground at MSL reaches the above-radar-ground-level height of 115 ft at a range of ~23 km (23.325 km). These

	Finally, a scan range of 2 miles would enable one to scan a section, which is 1 mi by 1 mi, and avoid an NMAC owing to pop-ins from the lateral boundary.				settings are fairly representative, as if one put the radar on the top of Mt. Everest with the other settings the same the range is 23.35 km. Also, if the radar were 10 m (0.0 m) off the ground with all of the other settings the same the range is 20.625 km (24.4 km). It is noted that 0.0° is commonly the lowest elevation angle that is used owing to ground clutter impacts, although systems with excellent ground clutter suppression could utilize negative elevation angles. To enable flights out to this distance the radar would have to be able to scan a little beyond 23 km to avoid pop-ins from the outer boundary.

Vertical Range

The same numbers that are used for ABDAA are used here. In applying these to GBDAA systems, the idea is that the ground based system would provide sensing this far above and below the UA within the intended operation volume, which is assumed to be the service volume of the system.

Table D2. Explanation of off board vertical range metric values and scores.

Score:	1	2	3	4	5
Value (ft/km/nmi):	235/0.072/0.039	285/0.087/0.047	335/0.1/0.055	850/0.26/0.14	1450/0.44/0.24
Explanation:	Based on the expectation that it would take 3 seconds to determine what to do (3 detections at an update rate of 1 Hz), 1 second to enact, and 3 seconds to avoid a collision. Uses climbing/descending rates of 1000 ft/min for the MA and UA for creating the hazard (maximizes the vertical distance). A vertical avoidance maneuver is assumed here.	1/2 the distance from category 1 to 3.	Distance to avoid an NMAC (100 ft vertically) uses logic similar to category 1: 3 seconds to determine what to do, 1 second to enact, and 3 seconds to achieve required climb/descent rate or horizontal maneuver. A vertical avoidance maneuver is assumed.	Estimated vertical distance to maintain well clear. This follows logic similar to that used in categories 1 and 3. However, it is assumed that the update rate is worst case (5 s) and that it takes 3 detections to determine what to do. With this, the expectation that it takes 3 seconds to decide on and enact a maneuver, one has 18 seconds of possible closure until the maneuver is enacted. With maximum ascent/descent rates of 1000 ft/min for both the MA and UA, this corresponds to 600 ft, which must be added to the 250 ft for well clear. It is not known, however, if this ~26 second tau (18 + 7.5) truly provides enough time to maintain well clear as the simulations were not as conclusive here.	Applies the same logic as in category 4, but is the distance needed to enact a maneuver by the time one reaches the distance in category 4. Thus, this is the equivalent to the horizontal case wherein the maneuver is enacted by the "warning" boundary.

Horizontal Resolution/Accuracy
Same as with ABDAA.

Table D3. Explanation of off board horizontal resolution/accuracy metric values and scores.

Score:	1	2	3	4	5
Value (ft):	≥ 1000	500 < hr < 1000	250 < hr ≤ 500	100 < hr ≤ 250	≤ 100
Explanation:	1000 is NMAC h x 2	1000 is NMAC h x 2	500 is NMAC h	250 is (NMAC h)/2	100 is (NMAC h)/5

Vertical Resolution/Accuracy
Same as with ABDAA.

Table D4. Explanation of off board vertical resolution/accuracy metric values and scores.

Score:	1	2	3	4	5
Value (ft):	≥ 200	100 < vr < 200	50 < vr ≤ 100	20 < vr ≤ 50	≤ 20
Explanation:	200 ft is NMAC v x 2	200 ft is NMAC v x 2	100 ft is NMAC v	50 ft is (NMAC v)/2	20 ft is (NMAC v)/5

Scan Time/Update Rate
Same as with ABDAA.

Table D5. Explanation of off board scan time/update rate metric values and scores.

Score:	1	2	3	4	5
Value (s):	≥ 8	2 ≤ st < 8	1.5 < st ≤ 2	1 < st ≤ 1.5	≤ 1
Explanation:	At an 8 second update rate, if one detected an aircraft 55 seconds from the tau-based well clear boundary and needed 7 points to establish a track, one would do so at about the time the well-clear boundary would be violated.				

Sensor Latency
Same as with ABDAA.

Table D6. Explanation of off board sensor latency metric values and scores.

Score:	1	2	3	4	5
Value (s):	≥ 5	2.0 < sl < 5.0	1.0 < sl ≤ 2.0	0.1 < sl ≤ 1.0	≤ 0.1
Explanation:	This would correspond to the common scan rate of radars and could occur if the data are provided only after a scan is completed.		ADS-B data latency must be less than 2 s (p. 7 of https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%2020-165.pdf).		

Sensitivity
Same as with ABDAA.

Table D7. Explanation of off board sensitivity metric values and scores.

Score:	1	2	3	4	5
Value in terms of RCS (m^2):	≥ 20 (CRJ)	5 < sens < 20 (King Air)	1 < sens ≤ 5 (Cessna 172)	0.05 < sens ≤ 1 (human)	≤ 0.05 (small UAS/birds)
Explanation:	Source is slide 10 of http://ece.wpi.edu/radarcourse/Radar%202010%20PDFs/Radar%202009%20A_7%20Radar%20Cross%20Section%201.pdf. They list the RCS for a medium jet airliner to be 40 m^2.		Source is p. 31 of Radar Detectability of Light Aircraft (1976).	Source is ARL document (Computer Models of the Human Body Signature for Sensing Through the Wall Radar Applications 1997).	

Aircraft Classification/Type

Same as with ABDAA.

Table D8. Explanation of off board aircraft classification/type metric values and scores.

Score:	1	2	3	4	5
Value:	None	Big v small	Big v small and fixed v rotary wing	MA intruder aircraft type	All intruder (MA, UA, and bird) intruder type
Explanation:				ADS-B is the example here…one could figure out what kind of aircraft it is from its identifier.	If it can indicate MA intruder type but cannot distinguish between birds and small UA, it may still be scored as a 5.

Probability of Detection

Same as with ABDAA.

Table D9. Explanation of off board probability of detection metric values and scores.

Score:	1	2	3	4	5
Value:	< 70%	70-85%	85-95%	95-99%	> 99%
Explanation:	The round reliability for FAA radars is ~75%.				

False Alarm Rate
Same as with ABDAA.

Table D10. Explanation of off board false alarm rate metric values and scores.

Score:	1	2	3	4	5
Value:	> 10%	5-10%	2.5-5%	1-2.5%	< 1%
Explanation:					

Operational Environment

These values were developed by considering existing standards, including DO-160B (RTCA 1984) and MIL-STD-1472F (DoD 1999), and conditions sUAS are expected to experience given climatological information. These are the same as the Operational Environment Based on Ranges values for ABSAA systems, with the addition of the wind loading category.

Range of Winds

Table D11. Explanation of off board range of winds metric values and scores.

Score:	1	2	3	4	5
Value (mph):	< 70	70-93.3	93.3-116.6	116.6-140	> 140
Explanation:	The definitive standard for wind loading for towers appears to be spelt out in TIA-222-G. Information regarding the wind load ranges indicate that the winds are distributed from 70-140 mph (e.g., http://www.eham.net/ehamforum/smf/index.php?topic=61530.0;wap2). Thus, these extremes are used, with an even distribution between the end points.				

Utilization

Acquisition Cost
The cost ($) of establishing supporting infrastructure is included here.

Table D12. Explanation of off board acquisition cost metric values and scores.

Score:	1	2	3	4	5
Value:	> $500,000	$100,000-$500,000	$10,000-$100,000	$1000-$10,000	< $1000
Explanation:					

Resources Needed for Installation

Table D13. Explanation of off board resources needed for installation metric values and scores.

Score:	1	2	3	4	5
Value:	> 24 hours or establishment of new permanent infrastructure	16-24 hours or establishment of relocatable infrastructure	8-16 hours	1-8 hours	< 1 hour (plug and play)
Explanation:	More than 3 days or requires establishment of new, permanent infrastructure.	2-3 days to set up or requiring infrastructure that is relocatable but not portable. An example is a relocatable radar installation that can be moved, but doing so requires significant effort (beyond simply hooking onto a truck and pulling it).	1-2 days to add the DAA system. This may include portable infrastructure (e.g., a trailer).	Less than a day to add the DAA system. This may include portable infrastructure (e.g., a trailer).	Plug and play. This may include portable infrastructure (e.g., a trailer).

Reliability/Mean Time to Failure

The following was used as a reference: https://src.alionscience.com/pdf/TypicalEquipmentMTBFValues.pdf. These are the same as with ABDAA.

Table D14. Explanation of off board reliability/mean time to failure metric values and scores.

Score:	1	2	3	4	5
Value (hrs):	< 10	10-100	100-1000	1000-5000	> 5000
Explanation:					

Appendix E: Justifications for On Board DAA Metric Values and Scores

The following provide justifications for metric values and corresponding scores that are used to evaluate on board DAA approaches. It is noted that explanations are not provided for all metric values as justifications for some are readily apparent.

Sensor Performance Capabilities

Horizontal Range

Table E1. Explanation of on board horizontal range metric values and scores.

Score:	1	2	3	4	5
Value (ft/km/nmi):	1850/0.56/0.3	3000/0.9/0.5	4000/1.22/0.66	10650/3.25/1.75	14600/4.45/2.4
Explanation:	Based on the expectation that it would take 3 seconds to determine what to do, 1 second to enact maneuver, and 3 seconds to maneuver away from a collision. Uses UAS speeds of 50 m/s (MA) and 30 m/s (UA). At a minimal 300 ft/min ascent or descent rate, 3 seconds would enable one to move 15 ft vertically, which would avoid the collision (barely).	~1/2 the distance from category 1 to category 3.	Simulations indicate that avoiding an NMAC (500 ft horizontally) requires detection at ~4000 ft.	Distance that simulations indicate is needed to maintain well clear with a horizontal well clear boundary of 2000 ft. In terms of tau and an intruder speed of 100 kts (50 m/s) and UA speed of 20 kts (10 m/s) (values used by SARP), this corresponds to a beyond-the-well-clear-boundary tau of 43 s. This tau is on the order of 33 s when one assumes that the UA speed can be up to 60 kts, which is the value used in the simulations for the fixed wing (30 kts was used for the rotary wing). This does not perfectly align with SC-228 in that in SC-228 one has knowledge of intruder track by 33 s. Here, the first detection of the intruder is ~33 s out. With a 1 Hz sampling rate, this means that the track is established after 3 seconds and with recognition occurring a couple of seconds after that, one obtains a warning tau in this case of ~28 s.	Assuming a head on approach with a closing speed of 80 m/s (50 m/s for MA and 30 m/s for UA), one needs ~4000 feet to establish a track over 3 detections that are separated 5 s apart (worst case scenario). This is 4000 ft beyond the "warning" boundary associated with category 4. Thus, this enables action by the time one reaches the warning boundary. This corresponds to a beyond the well clear boundary tau of ~48 s.

Vertical Range

This is only relevant for certain types of instruments. For instance, this is not relevant for a radar, as the ability to detect an intruder vertically is driven by range and field of view. For a radar, then, one would not score this category. This category is being retained, however, because conceivably an instrument could have different horizontal and vertical capabilities (e.g., ADS-B), and thus scoring this way (and not including FOV) is appropriate.

Table E2. Explanation of on board vertical range metric values and scores.

Score:	1	2	3	4	5
Value (ft/km/nmi):	235/0.072/0.039	285/0.087/0.047	335/0.1/0.055	850/0.26/0.14	1450/0.44/0.24
Explanation:	Based on the expectation that it would take 3 seconds to determine what to do (3 detections at an update rate of 1 Hz), 1 second to enact, and 3 seconds to avoid a collision. Uses climbing/descending rates of 1000 ft/min for the MA and UA for creating the hazard (maximizes the vertical distance). A vertical avoidance maneuver is assumed here.	1/2 the distance from category 1 to 3.	Distance to avoid an NMAC (100 ft vertically) uses logic similar to category 1: 3 seconds to determine what to do, 1 second to enact, and 3 seconds to achieve required climb/descent rate or horizontal maneuver. A vertical avoidance maneuver is assumed.	Estimated vertical distance to maintain well clear. This follows logic similar to that used in categories 1 and 3. However, it is assumed that the update rate is worst case (5 s) and that it takes 3 detections to determine what to do. With this, the expectation that it takes 3 seconds to decide on and enact a maneuver, one has 18 seconds of possible closure until the maneuver is enacted. With maximum ascent/descent rates of 1000 ft/min for both the MA and UA, this corresponds to 600 ft, which must be added to the 250 ft for well clear. It is not known, however, if this ~26 second tau (18 + 7.5) truly provides enough time to maintain well clear as the simulations were not as conclusive here.	Applies the same logic as in category 4, but is the distance needed to enact a maneuver by the time one reaches the distance in category 4. Thus, this is the equivalent to the horizontal case wherein the maneuver is enacted by the "warning" boundary.

Horizontal Resolution/Accuracy

At this time, horizontal and vertical resolutions are not tied to range capabilities from a scoring standpoint. Thus, the uncertainty in the sensor is not considered in the distances used in the range capability sections. Presumably, in operations, one would have to extend the detection ranges by the uncertainties in order to ensure that, for instance, the well clear or NMAC boundaries are not violated.

Table E3. Explanation of on board horizontal resolution/accuracy metric values and scores.

Score:	1	2	3	4	5
Value (ft):	≥ 1000	500 < hr < 1000	250 < hr ≤ 500	100 < hr ≤ 250	≤ 100
Explanation:	1000 is NMAC h x 2	1000 is NMAC h x 2	500 is NMAC h	250 is (NMAC h)/2	100 is (NMAC h)/5

Vertical Resolution/Accuracy

At this time, horizontal and vertical resolutions are not tied to range capabilities from a scoring standpoint. Thus, the uncertainty in the sensor is not considered in the distances used in the range capability sections. Presumably, in operations, one would have to extend the detection ranges by the uncertainties in order to ensure that, for instance, the well clear or NMAC boundaries are not violated.

Table E4. Explanation of on board vertical resolution/accuracy metric values and scores.

Score:	1	2	3	4	5
Value (ft):	≥ 200	100 < vr < 200	50 < vr ≤ 100	20 < vr ≤ 50	≤ 20
Explanation:	200 ft is NMAC v x 2	200 ft is NMAC v x 2	100 ft is NMAC v	50 ft is (NMAC v)/2	20 ft is (NMAC v)/5

Scan Time/Update Rate

Table E5. Explanation of on board scan time/update rate metric values and scores.

Score:	1	2	3	4	5
Value (s):	≥ 8	2 ≤ st < 8	1.5 < st ≤ 2	1 < st ≤ 1.5	≤ 1
Explanation:	At an 8 second update rate, if one detected an aircraft 55 seconds from the tau-based well clear boundary and needed 7 points to establish a track, one would do so at about the time the well-clear boundary would be violated.				

Field of View

The nomenclature is horizontal x vertical.

Table E6. Explanation of on board field of view metric values and scores.

Score:	1	2	3	4	5
Value (°):	< 30° & < 30°	(31-99)° x (31-64)°	(100-199)° x (65-134)°	(200-359)° x (135-179)°	360° x 180°
Explanation:			Roughly the field of view out of a GA cockpit is (100-130)x(65-85).	Human eye range is roughly 200x135.	Full field of view.

Sensor Latency

Table E7. Explanation of on board sensor latency metric values and scores.

Score:	1	2	3	4	5
Value (s):	≥ 5	2.0 < sl < 5.0	1.0 < sl ≤ 2.0	0.1 < sl ≤ 1.0	≤ 0.1
Explanation:	This would correspond to the common scan rate of radars and could occur if the data are provided only after a scan is completed.		ADS-B data latency must be less than 2 s (p. 7 of https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%2020-165.pdf).		

Sensitivity

Table E8. Explanation of on board sensitivity metric values and scores.

Score:	1	2	3	4	5
Value in terms of RCS (m^2):	≥ 20 (CRJ)	5 < sens < 20 (King Air)	1 < sens ≤ 5 (Cessna 172)	0.05 < sens ≤ 1 (human)	≤ 0.05 (small UAS/birds)
Explanation:	Source is slide 10 of http://ece.wpi.edu/ radarcourse/Radar%202010%20PDFs/		Source is p. 31 of Radar	Source is ARL document (Computer	

	Radar%202009%20A_7%20Radar%20 Cross%20Section %201.pdf. They list the RCS for a medium jet airliner to be 40 m^2.		Detectability of Light Aircraft (1976).	Models of the Human Body Signature for Sensing Through the Wall Radar Applications 1997).	

Aircraft Classification/Type

Table E9. Explanation of on board aircraft classification/type metric values and scores.

Score:	1	2	3	4	5
Value:	None	Big v small	Big v small and fixed v rotary wing	MA intruder aircraft type	All intruder (MA, UA, and bird) intruder type
Explanation:				ADS-B is the example here…one could figure out what kind of aircraft it is from its identifier.	If it can indicate MA intruder type but cannot distinguish between birds and small UA, it may still be scored as a 5.

Probability of Detection

Table E10. Explanation of on board probability of detection metric values and scores.

Score:	1	2	3	4	5
Value:	< 70%	70-85%	85-95%	95-99%	> 99%
Explanation:	The round reliability for FAA radars is ~75%.				

False Alarm Rate

Table E11. Explanation of on board false alarm rate metric values and scores.

Score:	1	2	3	4	5
Value:	> 10%	5-10%	2.5-5%	1-2.5%	< 1%
Explanation:					

SWaP (Size, Weight, and Power)

<u>Size</u>

The sizes were based upon currently-used sUAS as described below. The overall dimensions were collapsed into volumes, however, because of the unknowns regarding form factor and mounting options. For instance, one could mount a system on a wing or even on top of a rotor-based system. While these are non-traditional mounting locations, they are possible. Because of these unknowns, a simpler volumetric metric is utilized.

Table E12. Explanation of on board size metric values and scores.

Score:	1	2	3	4	5
Value (cm^3):	> 101,614	4500-101,614	2700-4500	168.75-2700.00	< 168.75
Explanation:		A DJI S1000 "like" was chosen as this UA had the greatest lift specifications within this group. Size calculated was based on the size of a payload not overlapping or interfering into the propeller downwash such that lift would be affected. Measured as the rotor arms extent minus propeller radius. Since most copters do not have "payload bays" no dimensions are given for depth and a volumetric value is used.	A Senior Telemaster Plus "like" was chosen as this fixed wing aircraft's payload was between the S1000 and the Phantom. Size of payload calculated is representative of this type of platform with no modifications to the aircraft.	A DJI Phantom "like" was chosen as this represents a common quad copter that has been popular with the hobbyist. Size calculated was based on the size of a payload not overlapping or interfering into the propeller downwash such that lift would be affected. Measured as the rotor arms extent minus propeller radius. Since most copters do not have "payload bays" no dimensions are given for depth and a volumetric value is used.	These numbers are a scaled down from 4. It is assumed that UA this small are not designed to carry payloads but rather have sensors already build in.

Weight

Table E13. Explanation of on board weight metric values and scores.

Score:	1	2	3	4	5
Value (kg):	> 3.3 (7.25 lbs)	> 1.13 to ≤ 3.3 (7.25 lbs)	> 0.15 to ≤ 1.13 (2.5 lbs)	> 0.050 to ≤ 0.15 (0.33 lbs)	≤ 0.050 (0.11 lbs)
Explanation:	If DAA payload is greater than 3.3 kg (7.25 lbs.) a score of one will be assessed.	A DJI S1000 "like" was chosen as this UA had the greatest lift specifications within this group. Payload weight selected is one half the maximum payload weight calculated by manufactures specifications. This allows for carrying of sensors.	A Senior Telemaster Plus "like" was chosen as this fixed wing aircraft's payload was between the S1000 and the Phantom. Payload weight selected is one half the maximum payload specified by the manufacturer.	A DJI Phantom "like" was chosen as this represents a common quad copter that has been popular with the hobbyist. Payload weight selected is one half the camera weight similar to what is flown on this system. No payload weight is given by the manufacturer.	These numbers are a scaled down from 4. It is assumed that UA this small are not designed to carry payloads but rather have sensors already build in.

Power

Table E14. Explanation of on board power metric values and scores.

Score:	1	2	3	4	5
Value (W):	> 12 - 28 V @ 25 W or requires auxiliary or self-contained power supply.	12 - 28 V @ 8 - 25 W	5 to 12 V @ 1 - 8 W	0.5 - 5 v @ 0.5 - 1 W	0 - 0.5 V @ < 0.5 W
Explanation:		A DJI S1000 "like" was chosen as this UA had the greatest lift specifications within this group. Power listed equates to a typical small synthetic aperture radar.	A Senior Telemaster Plus "like" was chosen as this fixed wing aircraft's payload was between the S1000 and the Phantom. Power listed equates to the requirement of	A DJI Phantom "like" was chosen as this represents a common quad copter that has been popular with the hobbyist. Power requirement of 5 V @ ≤ 500 mW	These numbers are a scaled down from 4. It is assumed that UA this small are not designed to carry payloads but rather have sensors already build in.

			a small LIDAR system.	if powered by onboard autopilot.	

Operational Standards Based on Established Standards

These are generally based on tests in DO-160 B (RTCA 1984). For temperature tests, aircraft category B2—equipment installed within nonpressurized and noncontrolled temperature locations on an aircraft that is operated at altitudes up to 25,000 ft—seems to provide the best general fit. However, since the high temperatures for this category seem to be excessive, it is not used for all metrics for all operational environments based on existing standards.

Low Operating Temperature

Classifiers in parentheses (e.g., B1) indicate category as specified in RTCA (1984).

Table E15. Explanation of on board low operating temperature metric values and scores.

Score:	1	2	3	4	5
Value (°C):	0	-5	-15 (A1-A3)	-20 (B1)	-45 (B2)
Explanation:					

Temperature Variation

These are generally based on tests in DO-160B (RTCA 1984). For temperature variation, category A—equipment external to the aircraft—seems to be the most appropriate category. Classifiers in parentheses (e.g., B1) indicate category as specified in RTCA (1984).

Table E16. Explanation of on board temperature variation metric values and scores.

Score:	1	2	3	4	5
Value (°C):	0	-5	-15 (A1-A3)	-20 (B1)	-45 (B2)
Explanation:					

Operational Environment

These values were developed by considering existing standards, including DO-160B (RTCA 1984) and MIL-STD-1472F (DoD 1999), and conditions sUAS are expected to experience given climatological information.

Utilization

Resources Needed for Installation

Table E17. Explanation of on board resources needed for installation metric values and scores.

Score:	1	2	3	4	5
Value:	OEM factory installed only	8-16 hours, OEM site	1-8 hours OEM, user site	1-8 hours user, some customization	< 1 hour user (plug and play)
Explanation:	Cannot add in the DAA system after the fact. The aircraft OEM must build it in during original assembly.	You can add in a DAA system after the fact, but must take your aircraft to the aircraft (or the DAA vendor's) facility to do so, and it's 1-2 days.	Less than a day to add the DAA system. Can be done at user site, with OEM help.	Less than a day to add the DAA system, and can be done completely by user.	Plug and play.

Reliability/Mean Time to Failure

The following was used as a reference: https://src.alionscience.com/pdf/TypicalEquipmentMTBFValues.pdf

Table E18. Explanation of on board reliability/mean time to failure metric values and scores.

Score:	1	2	3	4	5
Value (hrs):	< 10	10-100	100-1000	1000-5000	> 5000
Explanation:					

Appendix F: SRM Hazard Analysis Data

GBDAA HOTL Human Management Error

	Ground Based Detect and Avoid HOTL, Human Management Error
Hazard	User takes no action to resolve hardware issues
Description	An indication of a hardware issue is presented by the system, but the human does not respond (human doesn't understand/recognize/or choose to take action)
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Significant system failure that could result in not having situational awareness of a conflict resulting in a MAC.
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates indicate a DTEM hardware failure would occur once a year, and the user may take no action once out of 10 times conservatively. SC-228 standards may push this to an E
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Odds of MAC if you are at the boundary of well clear is approximately 0.005.
INITIAL RISK (Worst Credible)	1E
Additional Controls	System design should include audio and visual alarms. AND Training Emphasis on most common critical failures AND Automatic Mitigations
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid HOTL, Human Management Error
Hazard	User takes no action to resolve DTEM software issues
Description	An indication of a software issue is presented by the system, but the human does not respond (human doesn't understand/recognize/or choose to take action)
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Significant system failure that could result in not having situational awareness of a conflict resulting in a MAC.
Pre-Mitigation Likelihood	E
Likelihood Rationale	SME estimates indicate a DTEM software failure would occur once a month, and the user may take no action once out of 10 times conservatively. It is credible that COTs Windows and Unix Oss that have not been developed for safety critical will be utilized in HD used for the management function. Thus software issues associated with the management function and OSs will impact the overall management systems. Assumed that onboard systems adhere to a DO178 or ASTM F38 F3201-16 Standards
INITIAL RISK	1E
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Odds of MAC if you are at the boundary of well clear is approximately X.
INITIAL RISK (Worst Credible)	1E
Additional Controls	System design should include audio and visual alarms. AND Training Emphasis on most common critical failures AND Automatic Mitigations
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Ground Based Detect and Avoid HOTL, Human Management Error	
Hazard	User executes inappropriate procedure given an abnormality or failure
Description	Decisional error
Existing Controls	ADM training and checklist usage (covered by Assumptions)
Pre-Mitigation Severity	1
Severity Rationale	e.g. given a DTEM failure, user executes a decisional error credibly resulting in a MAC
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates indicate a DTEM hardware (most likely) failure would occur once a year, and the user may make a decisional error once out of 10 times conservatively.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Compounded probability of MAC starting with well clear
INITIAL RISK (Worst Credible)	1E
Additional Controls	System design should include audio and visual alarms. AND Training Emphasis on ADM AND Command of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate
Post-Mitigation Severity	2
Post-Mitigation Likelihood	Additional time required for user to process the automated challenge maintains an NMAC as credible
Residual Risk	2E
Post-Mitigation Likelihood (Worst Credible)	2E
Residual Risk (Worst Credible)	2E

Ground Based Detect and Avoid HOTL, Human Management Error	
Hazard	User lacks experience to troubleshoot abnormalities
Description	Literature indicates that user with less than 100 hour (or equivalent for UAS) operate at an elevated risk for incidents and accidents resulting in the User improperly taking no action or executing the incorrect procedure
Existing Controls	Training and initial qualification
Pre-Mitigation Severity	1
Severity Rationale	MAC is credible given no action or an incorrect action by the user
Pre-Mitigation Likelihood	D
Likelihood Rationale	Compounded probability of 1) abnormality or failure with 2) User condition (i.e. lack of experience). Mark paranoid: Precedence set with HD failure rate above
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Compounded probability of MAC starting with well clear
INITIAL RISK (Worst Credible)	1E
Additional Controls	Appropriate crew supervision following initial qualification AND Audible warnings and alarms OR command execution from above
Post-Mitigation Severity	2
Post-Mitigation Likelihood	E
Residual Risk	2E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

GBDAA HITL Human Execution Error

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Task saturation
Description	Human is over saturated with tasks and has degraded performance. This can result in errors of omission and fixation leading to Controlled Flight into Terrain/Aircraft/Obstacles.
Existing Controls	- Utilize geofencing capabilities within Ground Control Station software. - GCS design proper to ensure no task saturation. - Flight occurs in low density airspace. - Utilizing a second crewmember at the Ground Control Station to help operate the system.
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	Separation Criteria - Uncontrolled loss of separation, to an unknown degree, which means there could be a complete loss of separation resulting in an MAC.
Pre-Mitigation Likelihood	D (Extremely Remote)
Likelihood Rationale	Low density traffic below 1000' AGL; Low likelihood of task saturation duration that is large enough such that you are unable to resolve the conflict.
INITIAL RISK	1D High
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Automation system that alerts/takes over control to avoid MAC.
Post-Mitigation Severity	1 Catastrophic
Post-Mitigation Likelihood	E
Residual Risk	1E
Responsible party for implementing additional controls	DAA system vendor

Ground Based Detect and Avoid HITL, Human Execution Error		
Hazard	User(s) is poorly trained on the man-machine interface	
Description	Wrong action taken by crewmember	
Existing Controls	- Crewmember received training and testing.	
Pre-Mitigation Severity	1 (Catastrophic)	
Severity Rationale	If the user does not understand the MMI, a MAC becomes a credible outcome	
Pre-Mitigation Likelihood	B (Probable)	
Likelihood Rationale	Conservative estimate	
INITIAL RISK	1B	
Pre-Mitigation Likelihood (Worst Credible)	D	
Likelihood Rationale (Worst Credible)	0.005 from the edge of well clear	
INITIAL RISK (Worst Credible)	1D	
Additional Controls	Utilizing a second qualified crewmember at the Ground Control Station to help operate the system.	OR Practical performance evaluation added to training
Post-Mitigation Severity	1	1
Post-Mitigation Likelihood	D	D
Residual Risk	1D	1D
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	1E

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	misinterpretation of target data
Description	Crewmember didn't understand target data relative to ownship
Existing Controls	- Visualization system uses design standards - Crewmember received training and testing.
Pre-Mitigation Severity	2 (Hazardous)
Severity Rationale	If the paths of intruding aircraft are misinterpreted by the PIC, a corrective action would be instituted. However, an NMAC may become credible during this maneuver.
Pre-Mitigation Likelihood	B (Probable)
Likelihood Rationale	Conservative estimate
INITIAL RISK	2B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	The likelihood that an intruder is close enough, such that this hazard could result in an NMAC is estimated at 0.1 or less. Starting at the edge of well clear, the likelihood of an NMAC is 0.1.
INITIAL RISK (Worst Credible)	2D
Additional Controls	Practical performance evaluation added to training AND visual cues (e.g. trail information of intruders) AND Aural and Visual alerts
Post-Mitigation Severity	2
Post-Mitigation Likelihood	D
Residual Risk	2D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	User is colorblind when the Man-Machine interface uses color
Description	Crewmember does not distinguish target information or alerts (e.g information may wash into the background)
Existing Controls	Self-certified health per part 107
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	if a target cannot be distinguished from the background, a MAC is credible.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	Approx 10% of the population experience colorblindness, this must be compounded with the likelihood of target information being affected by this limitation in the MMI
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	The likelihood that the color limitation would be unreported or unrecognized is low
INITIAL RISK (Worst Credible)	1E
Additional Controls	Practical performance evaluation added to training. AND required reporting of colorblindness
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Unclear communication between RPIC and individual providing DAA guidance
Description	A communication protocol absent the confirmation of command from the RPIC, results in the DAA guidance individual needing to issue a new command based upon UA maneuvering.
Existing Controls	Standard phraseology and read back
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	resolving crew miscommunications make an NMAC credible
Pre-Mitigation Likelihood	B (Probable)
Likelihood Rationale	Communication issues are common during 2 way radio communications
INITIAL RISK	1B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	0.005
INITIAL RISK (Worst Credible)	1D
Additional Controls	Develop and validate UAS DAA centric phraseology AND Practical performance evaluation AND Place DAA monitor in front of the PIC
Post-Mitigation Severity	1
Post-Mitigation Likelihood	D
Residual Risk	1D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	1E

Ground Based Detect and Avoid HITL, Human Execution Error	
Hazard	over congestion leads to target vector ambiguity
Description	Is a cause of improper maneuver hazard already addressed
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	User is deaf when the Man-Machine interface uses aural alerts
Description	Crewmember is unable to hear aural alerts.
Existing Controls	- Visualization system uses design standards - Crewmember received training and testing.
Pre-Mitigation Severity	2 (Hazardous)
Severity Rationale	If aural alerts are used to provide warnings about collisions then the inability to receive such alerts could result in a MAC.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	Approximately 2-3 percent of the population has significant hearing loss.
INITIAL RISK	2C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 Likelihood of MAC if flying at the edge of well clear and the user would have to be task saturated to not visually recognize the conflict (assumes a visual interface is provided).
INITIAL RISK (Worst Credible)	2E
Additional Controls	Practical performance evaluation added to training. AND required reporting of hearing limitations
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	User has low proficiency in recognizing conflict
Description	For whatever reason, the user has difficulty recognizing conflicts.
Existing Controls	Crewmember received training and testing.
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	If a user has difficulty recognizing conflicts, a MAC could result.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	It is not known exactly how many people would suffer from this, but it is expected that this would be quite rare.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 likelihood of MAC if flying at the edge of well clear.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Practical performance evaluation.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

Ground Based Detect and Avoid HITL, Human Execution Error	
Hazard	User misinterprets scale of the visualization system
Description	The user misinterprets the scale of the visualization system, resulting in intruder aircraft being closer or further away than believed.
Existing Controls	Crewmember received training and testing.
Pre-Mitigation Severity	2 (Hazardous)
Severity Rationale	If the user believes aircraft are further away than they really are, then an aircraft could get quite close before the user reacts, making an NMAC credible.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	This seems to be quite unlikely given the user has received training and testing.
INITIAL RISK	2C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	If flying at the edge of well clear, the likelihood of an NMAC is 0.1.
INITIAL RISK (Worst Credible)	2D
Additional Controls	Use of "bubbles" to illustrate well-clear boundaries relative to either intruders or ownship OR Provision of warnings (either visual or aural) regarding potential violation of well clear.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid HITL, Human Execution Error	
Hazard	User does not recognize a conflict
Description	For whatever reason, the user does not recognize a conflict.
Existing Controls	Crewmember received training and testing.
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	If the user does not recognize a conflict, a MAC is credible.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	This seems to be quite unlikely given the user has received training and testing.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 likelihood of a MAC if flying at the edge of well clear.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Use of alerts that are visual, aural, or both.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	C
Residual Risk	2C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

Ground Based Detect and Avoid HITL, Human Execution Error	
Hazard	User has low proficiency in identifying conflict resolutions
Description	For whatever reason, the user has difficulty identifying effective conflict resolutions.
Existing Controls	Crewmember received training and testing.
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	If a user has difficulty identifying effective conflict resolutions, a MAC is credible.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	It is not known exactly how many people would suffer from this, but it is expected that this would be quite rare.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 likelihood of MAC if flying at the edge of well clear.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Practical performance evaluation.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Pilot is given or chooses an improper maneuver for avoiding conflict
Description	An improper maneuver is applied.
Existing Controls	-Crewmember received training and testing -Software is functioning properly (e.g., if software provides maneuver information).
Pre-Mitigation Severity	2 (Hazardous)
Severity Rationale	The fact that a maneuver is improper will become apparent, at which point the pilot would apply another maneuver. Given the time this would take, an NMAC is credible.
Pre-Mitigation Likelihood	B (Probable)
Likelihood Rationale	A conservative estimate is that this could happen once a month.
INITIAL RISK	2B
Pre-Mitigation Likelihood (Worst Credible)	C
Likelihood Rationale (Worst Credible)	0.1 likelihood of NMAC if flying at the boundary of well clear.
INITIAL RISK (Worst Credible)	2C
Additional Controls	Use of alerts that are visual, aural, or both to indicate if a poor maneuver is being applied.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	B
Residual Risk	3B
Post-Mitigation Likelihood (Worst Credible)	C
Residual Risk (Worst Credible)	3C

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Maneuver information provided to pilot (if pilot is not VO) is bad
Description	Same as "Pilot is given or chooses an improper maneuver for avoiding conflict"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid HITL, Human Execution Error	
Hazard	Pilot executes intended maneuver incorrectly
Description	The pilot does not execute the intended maneuver.
Existing Controls	-Pilot is properly qualified.
Pre-Mitigation Severity	2 (Hazardous)
Severity Rationale	If the pilot is properly qualified, then the improper execution of the maneuver would consist of a relatively small deviation relative to the intended maneuver. The worst credible outcome is an NMAC.
Pre-Mitigation Likelihood	B (Probable)
Likelihood Rationale	This is hard to estimate since what constitutes an incorrect maneuver is not defined. However, it is expected that a "significant" deviation from the intended maneuver could occur, conservatively, once/month.
INITIAL RISK	2B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	If flying at the edge of well-clear, the likelihood of an NMAC, given no maneuvering, is 0.1. Since maneuvering is occurring, the likelihood of an NMAC is estimated to be 0.1 of this.
INITIAL RISK (Worst Credible)	2D
Additional Controls	Use of alerts that are visual, aural, or both to indicate if a poor maneuver is being applied.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	B
Residual Risk	3B
Post-Mitigation Likelihood (Worst Credible)	C
Residual Risk (Worst Credible)	3C

Ground Based Detect and Avoid HITL, Human Execution Error	
Hazard	Pilot fails to execute maneuver
Description	The pilot does not execute a maneuver when one is needed.
Existing Controls	-Pilot is properly qualified.
Pre-Mitigation Severity	1 (Catastrophic)
Severity Rationale	If a maneuver is needed but not executed, a MAC is credible.
Pre-Mitigation Likelihood	C (Remote)
Likelihood Rationale	If the pilot is properly qualified, then the likelihood of the pilot not executing a maneuver when needed is remote.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If flying at the edge of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Have a backup VO or PIC present OR Provision of alerts (visual, aural, or both).
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	D
Residual Risk (Worst Credible)	3D

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Pilot maneuvers aircraft outside of its performance envelope
Description	Out of scope
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Pilot becomes complacent failing to maneuver from an actual intruder believing it is a false target
Description	Pilot becomes complacent failing to maneuver from an actual intruder believing it is a Ghost target
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	If PIC believes a target is not real, a MAC becomes credible
Pre-Mitigation Likelihood	B
Likelihood Rationale	Experience indicates that ghost targets can be quite common (e.g., they have arisen with ADS-B data).
INITIAL RISK	1B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	probability is compounded by 0.005
INITIAL RISK (Worst Credible)	1D
Additional Controls	Assume all targets are real and mitigate appropriately
Post-Mitigation Severity	5
Post-Mitigation Likelihood	D
Residual Risk	5D
Post-Mitigation Likelihood (Worst Credible)	D
Residual Risk (Worst Credible)	5E

	Ground Based Detect and Avoid HITL, Human Execution Error
Hazard	Pilot becomes fixated during maneuvers from a ghost target of ownship resulting in diminished Situational Awareness
Description	Pilot maneuvers from a ghost target of ownship creating a collision hazard
Existing Controls	None
Pre-Mitigation Severity	3
Severity Rationale	in a low density environment, it is unlikely that a PIC would maneuver into another target
Pre-Mitigation Likelihood	B
Likelihood Rationale	Likelihood may be greater than B if both ADS-B and mode S are used. Industry has not yet incorporated technology which would create this issue every day.
INITIAL RISK	3B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	The operational environment reduces the likelihood of an intruder being present.
INITIAL RISK (Worst Credible)	3D
Additional Controls	PIC is trained to recognize ghost targets and to validate with procedure turns
Post-Mitigation Severity	4
Post-Mitigation Likelihood	D
Residual Risk	4D
Post-Mitigation Likelihood (Worst Credible)	D
Residual Risk (Worst Credible)	4D

GBDAA Hardware for Supporting Systems

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	Latency exceeds threshold rendering target data unusable
Description	The supporting systems become task saturated slowing performance
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Latent data result in a MAC being credible
Pre-Mitigation Likelihood	D
Likelihood Rationale	Systems are expected to be designed to handle the expected workload
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probablity of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	User indication of target latency (e.g. timestamp or color status) AND procedural action (i.e. RTB and more conservative separation minimums)
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	4E

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	Power outage
Description	Supporting systems lose power requiring a reboot (once power is restored). Complete loss of situational awareness
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Complete loss of situational Awareness results in a MAC being a credible outcome
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	UPS, back-up power (e.g. generator)
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

Ground Based Detect and Avoid Hardware, Supporting Systems		
Hazard	Mechanical failure due to fatigue, environmental impacts, or improper use	
Description	supporting systems hardware fails due to fatigue leading to complete loss of situational awareness	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational Awareness results in a MAC being a credible outcome	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates mean time to failure is greater than once per year	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probablity of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND Supporting system redundancy	Replacement parts (can include PC) AND procedure action (e.g. RTB, go to ground, loiter)
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E (UAO C1)	E (UAO C1)
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

	Ground Based Detect and Avoid Hardware, Supporting Systems	
Hazard	Fusion box failures	
Description	Fusion box fails leading to complete loss of situational awareness	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational Awareness results in a MAC being a credible outcome	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates mean time to failure is greater than once per year	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probablity of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND fusion box system redundancy	Health monitoring and replacement parts (can include PC) AND procedure turn if needed
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E (UAO C1)	E (UAO C1)
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

	Ground Based Detect and Avoid Hardware, Supporting Systems	
Hazard	Data communication failure within DAA supporting systems	
Description	Primarily a networking issue. Communications fail and DAA system is not functional.	
Existing Controls	None	
Pre-Mitigation Severity	1	
Severity Rationale	complete lack of data makes a MAC credible	
Pre-Mitigation Likelihood	C	
Likelihood Rationale	Understanding the entire network as a single point of failure, SME estimates place this hazard as once every decade.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.0005 est, 0.1 outside well clear, 0.1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Ping across LAN components (i.e. health monitoring) to identify issues AND Procedural action (e.g. RTB, descend and loiter, go to ground)	Redundant network
Post-Mitigation Severity	3	5
Post-Mitigation Likelihood	C	E
Residual Risk	3C	5E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	3E	5E

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	unknown amount of data Comms from sensor is corrupted for less than, or equal to, 3 seconds, and is nonrecurring
Description	corrupt data regarding intruders is passed and presented on the display (e.g. position)
Existing Controls	internal checks prevent KNOWN corrupt data from moving forward to display
Pre-Mitigation Severity	3
Severity Rationale	3 seconds plus a recovery time is well within the well clear cushion
Pre-Mitigation Likelihood	B
Likelihood Rationale	absent TCP or check sum procedures, minor corruptions are known to exist in networking applications
INITIAL RISK	3B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	In low airspace density environments the likelihood of being close enough to an intruder, such that a sig well clear violation could occur is estimated to be less than 0.01.
INITIAL RISK (Worst Credible)	3D
Additional Controls	Redundant communication logical checks (e.g. filtering impossible aircraft motion)
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	C
Residual Risk (Worst Credible)	5C

	Ground Based Detect and Avoid Hardware, Supporting Systems	
Hazard	unknown amount of data Comms from sensor is corrupted for longer than 3 seconds	
Description	Corrupt data pass systems' internal checks and are presented on the display	
Existing Controls	internal checks prevent KNOWN corrupt data from moving forward to display	
Pre-Mitigation Severity	1	
Severity Rationale	unannounced corrupt data for extended periods results in a MAC being credible	
Pre-Mitigation Likelihood	D	
Likelihood Rationale	SME estimates place this hazard as plausible more than once every century (i.e. rare)	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.0005 est, 0.1 outside well clear, 0.1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Redundant communication AND logical checks (e.g. filtering impossible aircraft motion)	Logical checks (e.g. filtering impossible aircraft motion)
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E	E
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	Data Comms to evaluation system fails
Description	See "Data communication failure within DAA supporting systems"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	Unknown amount of data Comms to evaluation system is corrupted
Description	See “unknown amount of data Comms from sensor is corrupted for less than, or equal to, 3 seconds, and is nonrecurring” and “unknown amount of data Comms from sensor is corrupted for longer than 3 seconds”
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	High autonomy, commanded maneuver data are corrupted for less than 3 seconds
Description	DAA determines resolution and provides as input to CS, CS sends command for maneuver, supporting systems failure results in data corruption lasts for less than 3 seconds and an incorrect maneuver
Existing Controls	internal checks prevent KNOWN corrupt data from moving forward to CS
Pre-Mitigation Severity	1
Severity Rationale	If an incorrect maneuver is received, a MAC is credible
Pre-Mitigation Likelihood	B
Likelihood Rationale	absent TCP or check sum procedures, minor corruptions are known to exist in networking applications
INITIAL RISK	1B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	Corrupted maneuvers are considered equally severe as not maneuvering
INITIAL RISK (Worst Credible)	1D
Additional Controls	Redundant communication AND Rigorous data integrity checks
Post-Mitigation Severity	2
Post-Mitigation Likelihood	E
Residual Risk	2E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

	Ground Based Detect and Avoid Hardware, Supporting Systems
Hazard	High autonomy, commanded maneuver doesn't reach CS
Description	Commanded maneuver never reaches CS
Existing Controls	Internal checks prevent KNOWN corrupt data from moving forward to CS
Pre-Mitigation Severity	1
Severity Rationale	If no maneuver is received, a MAC is credible
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates place this hazard as plausible more than once every century (i.e. rare)
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 est, 0.1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	Redundant communication
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

GBDAA Hardware HITL MMI

	Ground Based Detect and Avoid Hardware, HITL MMI
Hazard	Power outage
Description	MMI loses power requiring a reboot (once power is restored). Complete loss of situational awareness
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Complete loss of situational Awareness results in a MAC being a credible outcome
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	UPS, back-up power (e.g. generator)
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

	Ground Based Detect and Avoid Hardware, HITL MMI	
Hazard	Mechanical failure due to fatigue, environmental impacts, or improper use	
Description	MMI hardware fails due to fatigue leading to complete loss of situational awareness	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational Awareness results in a MAC being a credible outcome	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates mean time to failure is greater than once per year	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND MMI system redundancy	Replacement parts (can include PC) AND procedure turn if needed
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E (UAO C1)	E (UAO C1)
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

	Ground Based Detect and Avoid Hardware, HITL MMI
Hazard	Latency exceeds threshold rendering target data unusable
Description	The MMI PC becomes task saturated slowing performance
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Latent data result in a MAC being credible
Pre-Mitigation Likelihood	D
Likelihood Rationale	Systems are expected to be designed to handle the number of anticipated targets.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	User indication of target latency (e.g. timestamp or color status) AND procedural action (i.e. RTB and more conservative separation minimums)
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	4E

GBDAA Hardware HOTL MMI

	Ground Based Detect and Avoid Hardware, HOTL Man-Machine Interface
Hazard	Power outage
Description	MMI loses power requiring a reboot (once power is restored). Complete loss of situational awareness
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Complete loss of situational Awareness results in a MAC being a credible outcome
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	UPS, back-up power (e.g. generator)
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

Ground Based Detect and Avoid Hardware, HOTL Man-Machine Interface		
Hazard	Mechanical failure due to fatigue	
Description	MMI hardware fails due to fatigue leading to complete loss of situational awareness	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational Awareness results in a MAC being a credible outcome	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates mean time to failure is greater than once per year	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND MMI system redundancy	OR replacement parts (can include PC) AND procedure turn if needed
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E (UAO C1)	E (UAO C1)
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

	Ground Based Detect and Avoid Hardware, HOTL Man-Machine Interface
Hazard	Mechanical failure due to environmental impacts
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Hardware, HOTL Man-Machine Interface
Hazard	Mechanical failure due to improper use
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

GBDAA Hardware Algorithm

Please see ABDAA Hardware Algorithm.

GBDAA Software HITL MMI

	Ground Based Detect and Avoid Software, MMI
Hazard	Horizontal/Vertical representation of multiple targets has additional uncertainty beyond sensor measurement error
Description	Additional measurement error on position (e.g. Additional latency in data collection, incorrect survey of the well surveilled volume, uncertainty in coordinate projections, and CPU processing limitations, etc.)
Existing Controls	*Standard map transformation techniques. Software is operating as designed.
Pre-Mitigation Severity	1
Severity Rationale	Without a display of sensor uncertainty, an error in spacial judgement could still result in a MAC.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Based on experience, something like this can surface once a year during operations.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 going well clear to MAC with minimum of two targets will only drop 2 orders of magnitude in likelihood.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Separation standards (for nominal conditions) plus a buffer are employed as a condition of current CONOPs (e.g. 3-5 NM with ASR-11) AND Alert from health monitoring system regarding latency OR User is trained on sensor capabilities AND Alert from health monitoring system regarding latency OR Uncertainty error is directly communicated to User
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	4E

	Ground Based Detect and Avoid Software, MMI
Hazard	Erroneous aircraft altitude displayed for multiple aircraft
Description	The MMI simply displays the incorrect information. Purely a software issue.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	Incorrect altitude makes a MAC credible
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide redundant information (e.g., from GCS) -OR- Apply a procedural mitigation such as checking aircraft altitudes via radio communications -AND- Apply a mitigation like return-to-base or land
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Ground Based Detect and Avoid Software, MMI	
Hazard	erroneous aircraft category displayed
Description	The incorrect aircraft category is displayed owing to MMI software failure.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	3
Severity Rationale	If an aircraft category is used to infer aircraft flight characteristics, one could incorrectly estimate flight trajectories that result in well clear being maintained.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	C
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	3C
Additional Controls	Check categories of known targets (e.g., ownship). OR Procedurally preclude PIC from assuming intruders' performance based on category AND additional separation standards
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	C
Residual Risk (Worst Credible)	5C

	Ground Based Detect and Avoid Software, MMI
Hazard	False target
Description	A target that is not present is displayed-this is commonly a target that tails another target, but does not have to be. This could result from faulty sensor information or software issues. It is assumed that all targets are being avoided.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	4
Severity Rationale	The user would avoid all targets. Appearance of a ghost target could result in rapid maneuvering to avoid it that could result in an impact on well-clear relative to an actual intruder.
Pre-Mitigation Likelihood	A
Likelihood Rationale	Experience indicates that ghost targets can be quite common (e.g., they have arisen with ADS-B data).
INITIAL RISK	4A
Pre-Mitigation Likelihood (Worst Credible)	B
Likelihood Rationale (Worst Credible)	scarcity of targets in operating environment
INITIAL RISK (Worst Credible)	4B
Additional Controls	Training for PIC to recognize ghost targets.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	A
Residual Risk	4A
Post-Mitigation Likelihood (Worst Credible)	B
Residual Risk (Worst Credible)	4B

	Ground Based Detect and Avoid Software, MMI
Hazard	Incorrect horizontal target positions displayed
Description	The MMI simply displays the incorrect information. Purely a software issue.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	Incorrect intruder locations makes a MAC credible
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005. Even with several targets the probability is compounded by 0.015.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide redundant information [e.g., direct feed from sensor(s) on a separate display] Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) -AND- Apply a mitigation like return-to-base or land
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Software, MMI
Hazard	Latency exceeds threshold rendering target data unusable
Description	The target data are latent such that uncertainty in position is very large. This could result from a sensor issue, latency within supporting hardware and software, etc.
Existing Controls	
Pre-Mitigation Severity	1
Severity Rationale	Large intruder location uncertainty makes a MAC credible
Pre-Mitigation Likelihood	C
Likelihood Rationale	Significant latency resulting from sensor issues are expected to occur roughly 1/year.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide health monitoring such that the user is alerted that latency has become too large. This mitigation would be provided within the MMI.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Software, MMI
Hazard	Sustained loss of multiple targets
Description	Intruders are not displayed within the MMI owing to MMI software failure
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	Targets not being displayed makes a MAC credible
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005. Even with several targets the probability is compounded by 0.015.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide redundant information [e.g., direct feed from sensor(s) on a separate display] Provide health monitoring that alerts to loss of targets on display (e.g. inclusion of reference to a fixed relative target) -AND- Apply a mitigation like return-to-base or land
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Software, MMI
Hazard	Multiple targets never displayed, Sustained loss of all targets, No targets displayed
Description	See "Sustained loss of multiple targets"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, MMI
Hazard	Horizontal representation of ownship incorrect
Description	The representation of ownship position is incorrect, which is always true owing to uncertainty in sensors used to derive ownship position (generally GPS), but can be more severe owing to software issues (e.g., within the MMI), issues associated with the data being fed to the MMI, and latency with the data being fed to the MMI).
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C. Use of ADS-B data or direct links to GCS to obtain ownship position (results in errors, with no latency, being those given by GPS on UA).
Pre-Mitigation Severity	1
Severity Rationale	Having incorrect ownship position results in a MAC being credible.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level. In flight tests, issues with ownship position have not been observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005
INITIAL RISK (Worst Credible)	1E
Additional Controls	Health monitoring system to alert accuracy of ownship position. Not sure what this will look like OR Cross-reference to an independent display
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

GBDAA Software HOTL MMI

Please see ABDAA Software HOTL MMI

GBDAA Software Algorithm

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm will always provide imperfect historical and current position (i.e. track) for single target
Description	Target position and tracks will have inherent measurement error. System is operating normally, but the user assumes absolute position
Existing Controls	Software is operating as designed.
Pre-Mitigation Severity	1
Severity Rationale	Without a display of sensor uncertainty, an error in spatial judgement could still result in an MAC
Pre-Mitigation Likelihood	A
Likelihood Rationale	Measurement error from sensors are always present
INITIAL RISK	1A
Pre-Mitigation Likelihood (Worst Credible)	C
Likelihood Rationale (Worst Credible)	The likelihood of a user error large enough to violate the NMAC volume is low
INITIAL RISK (Worst Credible)	1C
Additional Controls	End user is provided a representation of this measurement error and considers for operation (with separation standards).
Post-Mitigation Severity	4
Post-Mitigation Likelihood	A
Residual Risk	4A
Post-Mitigation Likelihood (Worst Credible)	A
Residual Risk (Worst Credible)	4A

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Multiple aircraft causes ambiguity resulting in errant track(s)
Description	Algorithm becomes confused when two or more tracked targets cross, resulting in errant tracks.
Existing Controls	Track data are presented to the user. Cooperative aircraft ID information is provided to the correlator/fusion algorithm. Well clear was maintained prior to incident.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls and the assumed buffer for pop-ups. The user will still be able to maintain well clear.
Pre-Mitigation Likelihood	C
Likelihood Rationale	multiple crossing targets are relatively uncommon but feasible
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	The compound likelihood is extremely unlikely
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Software, Algorithm	
Hazard	Algorithm fails to provide a track
Description	Software is working correctly. Plot is not displayed on the visualization system, only track data are provided to the user.
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	User is unaware of target because plot data have not been passed along
Pre-Mitigation Likelihood	A
Likelihood Rationale	With an individual probability of detection of 0.90 the likelihood of missing two consecutive targets in the well surveilled volume is 0.01
INITIAL RISK	1A
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1D
Additional Controls	Send plot data to display
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm fails to provide tracks for multiple targets
Description	Software is working correctly. Sensor data is intermittent causing track to not be produced and plot data is not shown on visualization system.
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	User is unaware of target because plot data have not been passed along
Pre-Mitigation Likelihood	B
Likelihood Rationale	A tenth as likely as a single track not being provided
INITIAL RISK	1B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	1/10 of 0.000005 est from a single track not being provided.
INITIAL RISK (Worst Credible)	1D
Additional Controls	Send plot data to display
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides errant track for multiple targets
Description	Algorithm becomes confused from sensor input being lower quality, resulting in errant tracks of multiple targets.
Existing Controls	Track data are presented to the user. Cooperative aircraft ID information is provided to the correlator/fusion algorithm. Well clear was maintained prior to incident.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls and the assumed buffer for pop-ups. The user will still be able to maintain well clear.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Since track data are still shown, the pilot will try to self-separate from these tracks. The distance between the UAS and errant track should still be far enough away that a NMAC is not valid, but well-clear violation may be reasonable.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	The compound likelihood is extremely unlikely
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Software, Algorithm	
Hazard	Algorithm fails to ID conflict with intruder(s) (HITL) at twice the distance of well-clear
Description	Sensor data provided to tracking system may be inaccurate preventing the algorithm from properly assessing the situation.
Existing Controls	Human user is in the loop. Training has special emphasis on track uncertainty.
Pre-Mitigation Severity	3
Severity Rationale	Human user being intimately involved in the use of the system could identify system issues preventing more severe outcomes.
Pre-Mitigation Likelihood	C
Likelihood Rationale	This will happen for only at extremely low angles of incidence.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	As the aircraft come closer together, there will be less uncertainty on violating well-clear.
INITIAL RISK (Worst Credible)	3D
Additional Controls	System needs to display uncertainties to human user.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	4E

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm fails to ID conflict with intruder(s) (HOTL) at twice the distance of well-clear
Description	Sensor data provided to tracking system may be inaccurate preventing the algorithm from properly assessing the situation.
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	System doesn't understand that there is a conflict and will proceed on a normal path
Pre-Mitigation Likelihood	
Likelihood Rationale	This will happen for only at extremely low angles of incidence.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	As the aircraft come closer together, there will be less uncertainty on violating well-clear.
INITIAL RISK (Worst Credible)	1D
Additional Controls	Algorithm needs to understand and utilize sensor uncertainties in target positions.
Post-Mitigation Severity	
Post-Mitigation Likelihood	D
Residual Risk	4D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	4E

Ground Based Detect and Avoid Software, Algorithm	
Hazard	Algorithm fails to ID conflict with multiple intruders
Description	See "Algorithm fails to ID conflict with intruder(s) (HOTL) at twice the distance of well-clear"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides improper resolution of conflict for single/multiple intruder(s) at twice the distance of well-clear
Description	Uncertainty in track provided to the algorithm may temporarily produces convergence rather than divergence in a conflict resolution. Depends on magnitude of uncertainty in track position/heading.
Existing Controls	None
Pre-Mitigation Severity	4
Severity Rationale	Using radar as a model, heading errors would be at worst 2-3 degrees. If the intruder turned heading error would be on the order of 15 deg on a radar system with a 5 sec update rate. Assume 5 seconds for operator to react and obtain a new heading. Given that, you are still 500 ft from well-clear boundary. Signification violation seems unlikely.
Pre-Mitigation Likelihood	C
Likelihood Rationale	1 out of 100 resolution with a few conflict resolutions being provided every day.
INITIAL RISK	4C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	1 out of 10 of these scenarios would reduce likelihood down one level.
INITIAL RISK (Worst Credible)	4D
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides proper resolution resulting in CFIT/obstacle
Description	See Column A (CFIT)
Existing Controls	Flight Planning, Site visits, operator can input constraints in system for flight area based on site surveys and planning.
Pre-Mitigation Severity	1 (FC)
Severity Rationale	If the algorithm doesn't have knowledge of terrain or obstacles, there is a possibility the conflict resolution will create a collision with the terrain or obstacle
Pre-Mitigation Likelihood	D
Likelihood Rationale	If operator performs a proper flight planning and site visit, the likelihood of flying in to these objects/terrain would be very unlikely.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	Same as G18
INITIAL RISK (Worst Credible)	1D
Additional Controls	Algorithm utilizes a DTED and Geospatial data regarding obstacles to define no-fly locations in conjunction with site survey to determine any changes from what is currently in database.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Software, Algorithm
Hazard	The resolution confuses the manned aircraft
Description	UAS was not following right-of-way rules and maneuvers by UAS may cause manned aircraft pilot to become confused.
Existing Controls	Follow right-of-way rules (both algorithm and UAS pilot)
Pre-Mitigation Severity	4
Severity Rationale	Well clear may be violated due to the confusion caused by UAS maneuvering. Manned aircraft could then maneuver in a way that was unpredictable to UAS causing a bust in well-clear.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Manned aircraft may still be able to see UAS (visually or technologically) but may be confused at what the intention of the flight path would be.
INITIAL RISK	4D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Manned pilot would likely try to stay farther away from UAS.
INITIAL RISK (Worst Credible)	4E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides proper resolution that results in conflict with another aircraft (HITL)
Description	See column A - Human users identifies maneuver
Existing Controls	Human in the loop; right-of-way rules
Pre-Mitigation Severity	4
Severity Rationale	Human will be able to recognize a multi-conflict scenario and appropriately maneuver to maintain well-clear
Pre-Mitigation Likelihood	D
Likelihood Rationale	The chance that these scenarios occur in the low density airspace are remote.
INITIAL RISK	4D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Chances of not being able to handle this situation is extremely improbable
INITIAL RISK (Worst Credible)	4E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides proper resolution that results in conflict with another aircraft (HOTL)
Description	See column A - Algorithm chooses resolution and maneuvers
Existing Controls	Right-of-way rules
Pre-Mitigation Severity	3
Severity Rationale	Algorithms that don't take into account multiple conflicts in a resolution may cause an artifact that the algorithm is chasing resolutions in a more highly congested airspace
Pre-Mitigation Likelihood	D
Likelihood Rationale	The chance that these scenarios occur in the low density airspace are remote.
INITIAL RISK	3D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Chances of not being able to handle this situation is extremely improbable
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides a resolution that is outside the performance envelope of the sUAS
Description	Algorithm not designed to take into account limitations of airframe.
Existing Controls	Aircraft will not execute beyond limits
Pre-Mitigation Severity	3
Severity Rationale	Airframe will not execute maneuver outside its limits, but will result in the potential loss of well clear requiring further maneuvering.
Pre-Mitigation Likelihood	D
Likelihood Rationale	User generally takes into account the capabilities of its airframe during operations.
INITIAL RISK	3D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Given expectation that maneuvers occur twice the distance to well-clear, it is unlikely well-clear will be violated.
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides a resolution alien to right of way rules
Description	Errant track resulting in a conflict resolution inconsistent with ROW rules
Existing Controls	Right-of-way rules
Pre-Mitigation Severity	4
Severity Rationale	Using radar as a model, heading errors would be at worst 2-3 degrees. If the intruder turned heading error would be on the order of 15 deg on a radar system with a 5 sec update rate. Assume 5 seconds for operator to react and obtain a new heading. Given that, you are still 500 ft from well-clear boundary. Signification violation seems unlikely.
Pre-Mitigation Likelihood	C
Likelihood Rationale	1 out of 100 resolution with a few conflict resolutions being provided every day.
INITIAL RISK	4C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	1 out of 10 of these scenarios would reduce likelihood down one level.
INITIAL RISK (Worst Credible)	4D
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

GBDAA Active Sensor

	Ground Based Detect and Avoid Sensor, Active
Hazard	Brief Power Outage (≤ 5 s)
Description	Power to sensor is lost for ≤ 5 s resulting in complete loss of situational awareness during power loss
Existing Controls	Sensor auto-restarts with resumed power
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume)
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Back-up power (e.g. generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Sensor, Active
Hazard	Extended Power outage
Description	Sensor loses power for > 5 s and is the sole sensor providing information to the GBDAA system. Complete loss of situational awareness.
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO CI)
Likelihood Rationale	Extended power losses are much less common during operations than short-duration power losses.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Back-up power (e.g., generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

		Ground Based Detect and Avoid Sensor, Active
Hazard	Mechanical failure due to fatigue	
Description	Sensor hardware fails due to fatigue leading to complete loss of situational awareness.	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	Experience indicates that the mean time to failure is greater than 1 month.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan	Sensor system redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

Ground Based Detect and Avoid Sensor, Active

Hazard	Mechanical failure due to environmental impacts	
Description	Cold weather, heat, moisture, wind, dust problems, etc., result in a mechanical failure.	
Existing Controls	IEC/IP equipment ratings (standard 60529) or conformance to a standard like RTCA DO-160B or MIL-STD-810G.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates that failures are only common when equipment is used outside OEM limitations.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Health monitoring for environmental threats	Sensor diversification AND additional procedural limitations on environmental conditions.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	E (UAO C1)	C
Residual Risk	1E	4C
Post-Mitigation Likelihood (Worst Credible)		E
Residual Risk (Worst Credible)		4E

Ground Based Detect and Avoid Sensor, Active	
Hazard	Mechanical failure due to improper use
Description	Out of Scope--precluded by assumptions.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

		Ground Based Detect and Avoid Sensor, Active
Hazard	Software failure	
Description	Software fails, resulting in loss of situational awareness.	
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	DO-178C equivalent software assurance level.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	DO178 B standard	Sensor diversification/ redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

	Ground Based Detect and Avoid Sensor, Active
Hazard	Brief loss of target(s) due to interference (≤ 5 s)
Description	Temporary noise level increases and prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume).
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Sensor, Active
Hazard	Sustained loss of target(s) due to Interference (> 5 s)
Description	Sustained increase in noise level prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible prior to RTB, for example, is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	1
Post-Mitigation Likelihood	D
Residual Risk	1D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	1E

	Ground Based Detect and Avoid Sensor, Active	
Hazard	Propagation issues producing detection holes	
Description	Targets are missed as a result of propagation detection holes.	
Existing Controls	Mapping out the service volume and flying with a buffer for pop-ups, pop-downs, and pop-ins.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Uncertainty in service volume buffers results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Based upon approximate knowledge of propagation variation, a buffer is used. The likelihood of that buffer being exceeded is very low.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible is estimated to be ≤ 0.01.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Better definition of needed buffer based on propagation modeling using observed soundings OR	Real-time propagation modeling during operations.
Post-Mitigation Severity	1	2
Post-Mitigation Likelihood	E	E
Residual Risk	1E	2E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	2E

	Ground Based Detect and Avoid Sensor, Active			
Hazard	Weather (rain, clouds, etc.) causing detection holes			
Description	Targets are missed as a result of propagation detection holes.			
Existing Controls	VFR is a possible mitigation in that the DAA system replaces the "Visual" of VFR. However, current manned aviation can be VFR in precipitation and the DAA system replacing that see-and-avoid function may not work in such conditions owing, for instance, to attenuation of the signal in rain. Therefore, the control is preflight planning for an unmanned aircraft flight to ensure it will be in conditions in which the DAA system is functional.			
Pre-Mitigation Severity	1			
Severity Rationale	If you do not know where they are, a MAC is credible.			
Pre-Mitigation Likelihood	C (UAO C1)			
Likelihood Rationale	If we are not expressly considering weather impacts, in real time, on the DAA sensor, then degraded DAA sensor performance could easily happen at this rate.			
INITIAL RISK	1C			
Pre-Mitigation Likelihood (Worst Credible)	E			
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.			
INITIAL RISK (Worst Credible)	1E			
Additional Controls	Preflight planning takes into consideration weather impacts to the DAA sensors	real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	use of additional sensors that do not have the same weather limitations	All listed options
Residual Risk	1D	3D	3D	3E
Post-Mitigation Likelihood (Worst Credible)	E	E	E	
Residual Risk (Worst Credible)	1E	3E	3E	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Terrain-induced detection holes
Description	Terrain producing areas where DAA sensor is unable to detect.
Existing Controls	Sensor calibration on initial deployment. Surveillance volume analysis during initial setup of sensor at a specific location. Preflight planning,
Pre-Mitigation Severity	2
Severity Rationale	Flying UAS with some buffer above lowest elevation angle of sensor and C2 radio line of sight. This buffer allows for the intruder that would be considered to be a pop-up to be potentially within NMAC considerations, but not MAC.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Identified to be a rare event as it would only result with complete mis-use/mis-understanding of systems being used.
INITIAL RISK	2D
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Sensor producing false targets
Description	Display shows targets that are not actually there resulting in excessive maneuvering.
Existing Controls	Proper calibration of sensor prior to flight.
Pre-Mitigation Severity	5
Severity Rationale	Since no intruder is present, ownship maneuvers excessively with no well-clear violation.
Pre-Mitigation Likelihood	A
Likelihood Rationale	False targets are common, especially at low altitudes.
INITIAL RISK	5A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	None
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	5A
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

		Ground Based Detect and Avoid Sensor, Active
Hazard	Improper identification of real targets among many false targets	
Description	The user becomes complacent and believe that real targets are false targets.	
Existing Controls	User training.	
Pre-Mitigation Severity	2	
Severity Rationale	The user suspects that a real target is a false target and deviates slightly to avoid, but not enough to maintain well-clear, resulting in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	False targets are common, but it is less common that a real target will be believed to be a false target.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Avoid all targets	Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided.
Post-Mitigation Severity	5	4
Post-Mitigation Likelihood	A	D
Residual Risk	5A	4D
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

	Ground Based Detect and Avoid Sensor, Active
Hazard	"Target" is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)
Description	Signal is below noise level of sensor.
Existing Controls	Calibrate sensor according to manufacturer guidelines. Operate within limitations of sensor.
Pre-Mitigation Severity	2
Severity Rationale	There is an unknown, unidentified target in the well surveilled volume. The most common area for interaction will be near the edges of this volume.
Pre-Mitigation Likelihood	A
Likelihood Rationale	This scenario (i.e. individual detection failures) would not be common, but could occur once a week.
INITIAL RISK	2A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Tracking intruders AND avoiding operations near the edge of your well surveilled volume.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	D
Residual Risk	2D
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Partial target data are provided
Description	Degraded sensor performance such that partial data (at least horizontal or altitude) are transmitted, providing some target information to the flight crew.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers. Network monitoring.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls, the chance for NMAC violation is removed.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Experience indicates that prolonged issues with sensor data are commonly identified prior to flight and corrected and that prolonged issues during flight that are not recognized are rare.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Degraded sensor performance such that no positional target data are provided
Description	Degraded sensor performance such that all target positional data are missing.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers Network monitoring
Pre-Mitigation Severity	2
Severity Rationale	Loss of target positional data will put the UAS at risk of an NMAC with the user applying previous target information to avoid aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Prolonged loss of information is oftentimes recognized early.
INITIAL RISK	2C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Sensor cannot provide accurate enough position information
Description	Sensor positional uncertainty cannot be refined enough to differentiate multiple targets within a given volume that is outside of well clear distances for each target.
Existing Controls	No standards currently exist for UAS DAA system sensors to operate at a defined performance level.
Pre-Mitigation Severity	3
Severity Rationale	Target position with large positional uncertainty is generally sufficient for remaining well clear.
Pre-Mitigation Likelihood	A
Likelihood Rationale	The sensor uncertainty is known to some degree and is added to well clear distances. This reduces the chances for violation of the 'true' well clear by adding additional buffers.
INITIAL RISK	3A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor, Active	
Hazard	Sensor experiences partial failure resulting in blind spots or missed detections
Description	Same as improper identification of real targets among many false targets.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor, Active	
Hazard	Inadequate effective range
Description	Out of scope as one should not use a sensor that does not adequately sample your airspace.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active	
Hazard	Refraction causing inaccurate target information	
Description	Environmental conditions are such that refraction is not conforming to standard wave propagation theory.	
Existing Controls	None	
Pre-Mitigation Severity	2	
Severity Rationale	The change in location is not sufficient in the horizontal such that it shall become an NMAC. However, the change in vertical position could result in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	Highly dependent on environmental conditions. If weather impacts on the DAA sensor Is not expressly considered, then degraded DAA sensor performance could easily happen at this rate.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Real-time EM propagation modeling to correct errors in intruder positions	Multiple sensors to cross-check/fuse.
Post-Mitigation Severity	4	4
Post-Mitigation Likelihood	B	B
Residual Risk	4B	4B
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

	Ground Based Detect and Avoid Sensor, Active
Hazard	Non-eye-safe lidar
Description	Out of scope
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Light sources (e.g. Sun, etc.) oversaturates the sensor
Description	Unresolved as more information regarding hazard is needed
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor, Active
Hazard	Reflections off water
Description	Unresolved as more information regarding hazard is needed
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

GBDAA Passive Sensor

	Ground Based Detect and Avoid Sensor Passive
Hazard	Brief Power Outage (≤ 5 s)
Description	Power to sensor is lost for ≤ 5 s resulting in complete loss of situational awareness during power loss
Existing Controls	Sensor auto-restarts with resumed power
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume)
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Back-up power (e.g. generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Ground Based Detect and Avoid Sensor Passive	
Hazard	Extended Power outage
Description	Sensor loses power for > 5 s and is the sole sensor providing informtion to the GBDAA system. Complete loss of situational awareness.
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO CI)
Likelihood Rationale	Extended power losses are much less common during operations than short-duration power losses.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Back-up power (e.g., generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor Passive		
Hazard	Mechanical failure due to fatigue	
Description	Sensor hardware fails due to fatigue leading to complete loss of situational awareness.	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	Experience indicates that the mean time to failure is greater than 1 month.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan	sensor system redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

	Ground Based Detect and Avoid Sensor Passive	
Hazard	Mechanical failure due to environmental impacts	
Description	Cold weather, heat, moisture, wind, dust problems, etc., result in a mechanical failure.	
Existing Controls	IEC/IP equipment ratings (standard 60529) or conformance to a standard like RTCA DO-160B or MIL-STD-810G.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates that failures are only common when equipment is used outside OEM lmitations.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Health monitoring for environmental threats	Sensor diversification AND additional procedural limitations on environmental conditions.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	E (UAO C1)	C
Residual Risk	1E	4C
Post-Mitigation Likelihood (Worst Credible)		E
Residual Risk (Worst Credible)		4E

Ground Based Detect and Avoid Sensor Passive		
Hazard	Software failure	
Description	Software fails, resulting in loss of situational awareness.	
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	DO-178C equivalent software assurance level.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	DO178 B standard	Sensor diversification/ redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

Ground Based Detect and Avoid Sensor Passive	
Hazard	Brief loss of target(s) due to interference (≤ 5 s)
Description	Temporary noise level increases and prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume).
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Sensor Passive
Hazard	Sustained loss of target(s) due to Interference (> 5 s)
Description	Sustained increase in noise level prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible prior to RTB, for example, is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	1
Post-Mitigation Likelihood	D
Residual Risk	1D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	1E

		Ground Based Detect and Avoid Sensor Passive
Hazard	Propagation issues producing detection holes	
Description	Targets are missed as a result of propagation detection holes.	
Existing Controls	Mapping out the service volume and flying with a buffer for pop-ups, pop-downs, and pop-ins.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Uncertainty in service volume buffers results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Based upon approximate knowledge of propagation variation, a buffer is used. The liklihood of that buffer being exceeded is very low.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible is estimated to be ≤ 0.01.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Better definition of needed buffer based on propagation modeling using observed soundings	Real-time propagation modeling during operations.
Post-Mitigation Severity	1	2
Post-Mitigation Likelihood	E	E
Residual Risk	1E	2E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	2E

Ground Based Detect and Avoid Sensor Passive				
Hazard	Weather (rain, clouds, etc.) causing detection holes			
Description	Targets are missed as a result of propagation detection holes.			
Existing Controls	VFR is a possible mitigation in that the DAA system replaces the "Visual" of VFR. However, current manned aviation can be VFR in precipitation and the DAA system replacing that see-and-avoid function may not work in such conditions owing, for instance, to attenuation of the signal in rain. Therefore, the control is preflight planning for an unmanned aircraft flight to ensure it will be in conditions in which the DAA system is functional.			
Pre-Mitigation Severity	1			
Severity Rationale	If you do not know where they are, a MAC is credible.			
Pre-Mitigation Likelihood	C (UAO C1)			
Likelihood Rationale	If we are not expressly considering weather impacts, in real time, on the DAA sensor, then degraded DAA sensor performance could easily happen at this rate.			
INITIAL RISK	1C			
Pre-Mitigation Likelihood (Worst Credible)	E			
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.			
INITIAL RISK (Worst Credible)	1E			
Additional Controls	Preflight planning takes into consideration weather impacts to the DAA sensor	real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	use of additional sensors that do not have the same weather limitations	All of the Above
Residual Risk	1D	3D	3D	3E
Post-Mitigation Likelihood (Worst Credible)	E	E	E	
Residual Risk (Worst Credible)	1E	3E	3E	

	Ground Based Detect and Avoid Sensor Passive
Hazard	Terrain-induced detection holes
Description	Terrain producing areas where DAA sensor is unable to detect.
Existing Controls	Sensor calibration on initial deployment. Surveillance volume analysis during initial setup of sensor at a specific location. Preflight planning,
Pre-Mitigation Severity	2
Severity Rationale	Flying UAS with some buffer above lowest elevation angle of sensor and C2 radio line of sight. This buffer allows for the intrueder that would be considered to be a pop-up to be potentially within NMAC considerations, but not MAC.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Identified to be a rare event as it would only result with complete mis-use/mis-understanding of systems being used.
INITIAL RISK	2D
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor Passive	
Hazard	Sensor producing false targets
Description	Display shows targets that are not actually there resulting in excessive maneuvering.
Existing Controls	Proper calibration of sensor prior to flight.
Pre-Mitigation Severity	5
Severity Rationale	Since no intruder is present, own ship maneuvers excessively with no well-clear violation.
Pre-Mitigation Likelihood	A
Likelihood Rationale	False targets are common, especially at low altitudes.
INITIAL RISK	5A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	None
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	5A
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor Passive		
Hazard	Improper identification of real targets among many false targets	
Description	The user becomes complacent and believe that real targets are false targets.	
Existing Controls	User training.	
Pre-Mitigation Severity	2	
Severity Rationale	The user suspects that a real target is a false target and deviates slightly to avoid, but not enough to maintain well-clear, resulting in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	False targets are common, but it is less common that a real target will be believed to be a false target.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Avoid all targets	Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided.
Post-Mitigation Severity	5	4
Post-Mitigation Likelihood	A	D
Residual Risk	5A	4D
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

	Ground Based Detect and Avoid Sensor Passive
Hazard	"Target" is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)
Description	Signal is below noise level of sensor.
Existing Controls	Calibrate sensor according to manufacturer guidelines. Operate within limitations of sensor.
Pre-Mitigation Severity	2
Severity Rationale	There is an unknown, unidentified target in the well surveilled volume. The most common area for interaction will be near the edges of this volume.
Pre-Mitigation Likelihood	A
Likelihood Rationale	This scenario (i.e. individual detection failures) would not be common, but could occur once a week.
INITIAL RISK	2A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Tracking intruders AND avoiding operations near the edge of your well surveilled volume.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	D
Residual Risk	2D
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor Passive
Hazard	Partial target data are provided
Description	Degraded sensor performance such that partial data (at least horizontal or altitude) are transmitted, providing some target information to the flight crew.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers. Network monitoring.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls, the chance for NMAC violation is removed.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Experience indicates that prolonged issues with sensor data are commonly identified prior to flight and corrected and that prolonged issues during flight that are not recognized are rare.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor Passive	
Hazard	Degraded sensor performance such that no positional target data are provided
Description	Degraded sensor performance such that all target positional data are missing.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers Network monitoring
Pre-Mitigation Severity	2
Severity Rationale	Loss of target positional data will put the UAS at risk of an NMAC with the user applying previous target informaton to avoid aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Prolonged loss of information is oftentimes recognized early.
INITIAL RISK	2C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor Passive
Hazard	Sensor cannot provide accurate enough position information
Description	Sensor positional uncertainty cannot be refined enough to differentiate multiple targets within a given volume that is outside of well clear distances for each target.
Existing Controls	No standards currently exist for UAS DAA system sensors to operate at a defined performance level.
Pre-Mitigation Severity	3
Severity Rationale	Target position with large positional uncertainty is generally sufficient for remaining well clear.
Pre-Mitigation Likelihood	A
Likelihood Rationale	The sensor uncertainty is known to some degree and is added to well clear distances. This reduces the chances for violation of the 'true' well clear by adding additional buffers.
INITIAL RISK	3A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor Passive		
Hazard	Refraction causing inaccurate target information	
Description	Environmental conditions are such that refraction is not conforming to standard wave propagation theory.	
Existing Controls	None	
Pre-Mitigation Severity	2	
Severity Rationale	The change in location is not sufficient in the horizontal such that it shall become an NMAC. However, the change in vertical position could result in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	Highly dependent on environmental condistions. If weather impacts on the DAA sensor Is not expressly considered, then degraded DAA sensor performance could easily happen at this rate.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Real-time EM propagation modeling to correct errors in intruder positions	Multiple sensors to cross-check/fuse.
Post-Mitigation Severity	4	4
Post-Mitigation Likelihood	B	B
Residual Risk	4B	4B
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

Ground Based Detect and Avoid Sensor Passive		
Hazard	Signal used for detection ceases	
Description	The signal being used ceases either for more than 3 s or in an intermittent fashion.	
Existing Controls	It is expected that planned outages of the signal would be monitored and that operations would not occur during such outages.	
Pre-Mitigation Severity	1	
Severity Rationale	If the signal is lost, all situational awareness is lost if this is the only type of sensor being used.	
Pre-Mitigation Likelihood	C	
Likelihood Rationale	It is expected that non-planned, significant outages of signals could occur 1 yr^{-1}, although this may be a conservative estimate.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Health monitoring of signal AND procedural mitigation (e.g., land)	sensor redundancy
Post-Mitigation Severity	3	4
Post-Mitigation Likelihood	C	C
Residual Risk	3C	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	3E	4E

Ground Based Detect and Avoid Sensor Passive	
Hazard	Signal used for detection degrades
Description	The signal used for detection of intruders degrades such that performance (e.g., coverage) is affected.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers. Network monitoring.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls, the chance for NMAC violation is removed.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Experience indicates that prolonged issues with sensor data are commonly identified prior to flight and corrected and that prolonged issues during flight that are not recognized are rare.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor Passive	
Hazard	Dirty lens	
Description	The lens used in the sensor becomes dirty with contaminants (e.g., dust).	
Existing Controls	Pre- and post-flight cleaning.	
Pre-Mitigation Severity	1	
Severity Rationale	If the lens is dirty, then an intruder may not be identified and a MAC is credible.	
Pre-Mitigation Likelihood	C	
Likelihood Rationale	This is a very difficult likelihood to estimate. Once yr^{-1} seems to be reasonable, but additional data are needed.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Procedural mitigation (e.g., land)	A means for cleaning the lens in flight.
Post-Mitigation Severity	3	5
Post-Mitigation Likelihood	C	C
Residual Risk	3C	5C
Post-Mitigation Likelihood (Worst Credible)	E	
Residual Risk (Worst Credible)	3E	

Ground Based Detect and Avoid Sensor Passive	
Hazard	Image Saturation
Description	Unresolved as more information regarding hazard is needed.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Ground Based Detect and Avoid Sensor Passive	
Hazard	Lack of contrast
Description	Same as “Brief loss of target(s) due to interference (≤ 5 s)
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Ground Based Detect and Avoid Sensor Passive
Hazard	Erroneous signal or position data
Description	Ownship signal has errors, which could include incorrect positional information. This could result from either a hardware malfunction (e.g., GPS) or a software issue.
Existing Controls	Pre-flight status check (e.g., is ownship position sensible).
Pre-Mitigation Severity	1
Severity Rationale	If one does not know ownship position, a MAC is credible.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Because software could contribute to this and software is assumed to be designed to a level equivalent to DO 178C, C is appropriate.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Checks for physical realizability to identify issues with ownship position AND enactment of a procedural mitigation (e.g., land).
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Ground Based Detect and Avoid Sensor Passive
Hazard	Loss of signal and position data
Description	The signal providing ownship information is lost for a significant period of time (e.g., > 3 s) or intermittently.
Existing Controls	Health monitoring or some other form of situational awareness regarding loss of ownship data.
Pre-Mitigation Severity	1
Severity Rationale	If one does not know ownship position, a MAC is credible.
Pre-Mitigation Likelihood	C
Likelihood Rationale	This could be either a hardware or a software failure (e.g., avionics or systems used to communicate data). It is expected that software and networking are the most likely to fail. The software is assumed to be developed to the equivalent of DO 178C.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Procedural mitigation such as return to base or land.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

ABDAA HOTL Human Management Error

Airborne Based Detect and Avoid HOTL, Human Management Error	
Hazard	User takes no action to resolve hardware issues
Description	An indication of a hardware issue is presented by the system, but the human does not respond (human doesn't understand/recognize/or choose to take action)
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Significant system failure that could result in not having situational awareness of a conflict resulting in a MAC.
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates indicate a DTEM hardware failure would occur once a year, and the user may take no action once out of 10 times conservatively. SC-228 standards may push this to an E
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Odds of MAC if you are at the boundary of well clear is approximately 0.005.
INITIAL RISK (Worst Credible)	1E
Additional Controls	System design should include audio and visual alarms. AND Training Emphasis on most common critical failures AND Automatic Mitigations
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Airborne Based Detect and Avoid HOTL, Human Management Error	
Hazard	User takes no action to resolve DTEM software issues
Description	An indication of a software issue is presented by the system, but the human does not respond (human doesn't understand/recognize/or choose to take action)
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Significant system failure that could result in not having situational awareness of a conflict resulting in a MAC.
Pre-Mitigation Likelihood	E
Likelihood Rationale	SME estimates indicate a DTEM software failure would occur once a month, and the user may take no action once out of 10 times conservatively. It is credible that COTs Windows and Unix Oss that have not been developed for safety critical will be utilized in HD used for the management function. Thus software issues associated with the management function and OSs will impact the overall management systems. Assumed that onboard systems adhere to a DO178 or ASTM F38 F3201-16 Standards
INITIAL RISK	1E
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Odds of MAC if you are at the boundary of well clear is approximately X.
INITIAL RISK (Worst Credible)	1E
Additional Controls	System design should include audio and visual alarms. AND Training Emphasis on most common critical failures AND Automatic Mitigations
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Airborne Based Detect and Avoid HOTL, Human Management Error	
Hazard	User executes inappropriate procedure given an abnormality or failure
Description	Decisional error
Existing Controls	ADM training and checklist usage (covered by Assumptions)
Pre-Mitigation Severity	1
Severity Rationale	e.g. given a DTEM failure, user executes a decisional error credibly resulting in a MAC
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates indicate a DTEM hardware (most likely) failure would occur once a year, and the user may make a decisional error once out of 10 times conservatively.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Compounded probability of MAC starting with well clear
INITIAL RISK (Worst Credible)	1E
Additional Controls	System design should include audio and visual alarms. AND Training Emphasis on ADM AND Command of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate
Post-Mitigation Severity	2
Post-Mitigation Likelihood	Additional time required for user to process the automated challenge maintains an NMAC as credible
Residual Risk	2E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

	Airborne Based Detect and Avoid HOTL, Human Management Error
Hazard	User lacks experience to troubleshoot abnormalities
Description	Literature indicates that user with less than 100 hour (or equivalent for UAS) operate at an elevated risk for incidents and accidents resulting in the User improperly taking no action or executing the incorrect procedure
Existing Controls	Training and initial qualification
Pre-Mitigation Severity	1
Severity Rationale	MAC is credible given no action or an incorrect action by the user
Pre-Mitigation Likelihood	D
Likelihood Rationale	Compounded probability of 1) abnormality or failure with 2) User condition (i.e. lack of experience). Mark paranoid: Precedence set with HD failure rate above
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Compounded probability of MAC starting with well clear
INITIAL RISK (Worst Credible)	1E
Additional Controls	Appropriate crew supervision following initial qualification AND Audible warnings and alarms OR command execution from above
Post-Mitigation Severity	2
Post-Mitigation Likelihood	E
Residual Risk	2E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

ABDAA Hardware Supporting Systems On Board

	Airborne Based Detect and Avoid Hardware, Supporting Systems On
Hazard	Power failure
Description	Supporting systems lose power requiring a reboot (once power is restored). Complete loss of situational awareness
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Complete loss of situational awareness results in a MAC being a credible outcome
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	Redundancy in power supply to supporting DAA system hardware onboard.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

Airborne Based Detect and Avoid Hardware, Supporting Systems On		
Hazard	Mechanical failure due to fatigue	
Description	Supporting systems hardware fails due to fatigue leading to complete loss of situational awareness	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational Awareness results in a MAC being a credible outcome	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates mean time to failure is greater than once per year	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND Supporting system redundancy	Procedure action (e.g. RTB, go to ground, loiter)
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E (UAO C1)	E (UAO C1)
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

Airborne Based Detect and Avoid Hardware, Supporting Systems On	
Hazard	Mechanical failure due to environmental impacts
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems On
Hazard	Mechanical failure due to improper use
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Hardware, Supporting Systems On	
Hazard	Unknown amount of C2 data are corrupted
Description	Out of scope as this is a C2 issue.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Hardware, Supporting Systems On	
Hazard	C2 comms failure
Description	Out of scope as this is a C2 issue.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems On
Hazard	Data corrupted -for less than 3 seconds- between onboard DAA system and CS (CS is presumably onboard)
Description	DAA determines resolution and provides as input to CS, CS sends command for maneuver, supporting systems failure results in data corruption lasts for less than 3 seconds and an incorrect maneuver
Existing Controls	internal checks prevent KNOWN corrupt data from moving forward to CS
Pre-Mitigation Severity	1
Severity Rationale	If an incorrect maneuver is received, a MAC is credible
Pre-Mitigation Likelihood	B
Likelihood Rationale	Absent TCP or check sum procedures, minor corruptions are known to exist in networking applications
INITIAL RISK	1B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	Corrupted maneuvers are considered equally severe as not maneuvering.
INITIAL RISK (Worst Credible)	1D
Additional Controls	Redundant communication AND Rigorous data integrity checks
Post-Mitigation Severity	1
Post-Mitigation Likelihood	E
Residual Risk	1E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	1E

	Airborne Based Detect and Avoid Hardware, Supporting Systems On
Hazard	Commanded maneuver doesn't reach CS
Description	Commanded maneuver never reaches CS
Existing Controls	internal checks prevent KNOWN corrupt data from moving forward to CS
Pre-Mitigation Severity	1
Severity Rationale	If no maneuver is received, a MAC is credible
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates place this hazard as plausible more than once every century (i.e. rare)
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.005 est, 0.1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	Redundant communication
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

ABDAA Hardware Supporting Systems Off Board

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	Power failure
Description	Supporting systems lose power requiring a reboot (once power is restored). Complete loss of situational awareness
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Complete loss of situational awareness results in a MAC being a credible outcome
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1E
Additional Controls	UPS, back-up power (e.g. generator)
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	5E

Airborne Based Detect and Avoid Hardware, Supporting Systems Off		
Hazard	Mechanical failure due to fatigue	
Description	Supporting systems hardware fails due to fatigue leading to complete loss of situational awareness	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational Awareness results in a MAC being a credible outcome	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates mean time to failure is greater than once per year	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND Supporting system redundancy	Replacement parts (can include PC) AND procedure action (e.g. RTB, go to ground, loiter)
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E (UAO C1)	E (UAO C1)
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	5E	3E

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	Mechanical failure due to environmental impacts
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	Mechanical failure due to improper use
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	Unknown amount of C2 data are corrupted
Description	Out of scope as this is a C2 issue.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	C2 comms failure
Description	Out of scope as this is a C2 issue.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	Data corrupted -for less than 3 seconds- between C2 system and MMI
Description	Corrupt information gets to the MMI, but has a life of less than 3 seconds. Not affecting the CS or PIC.
Existing Controls	internal checks prevent KNOWN corrupt data from moving forward to C2
Pre-Mitigation Severity	5
Severity Rationale	The User is unlikely to react to the corrupt information in less than 3 seconds.
Pre-Mitigation Likelihood	B
Likelihood Rationale	Absent TCP or check sum procedures, minor corruptions are known to exist in networking applications
INITIAL RISK	5B
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Hardware, Supporting Systems Off
Hazard	Total network failure between C2 and MMI (no data)
Description	All DAA systems are running no data are reaching the MMI
Existing Controls	None
Pre-Mitigation Severity	5
Severity Rationale	If DAA is operational, well clear should be maintained.
Pre-Mitigation Likelihood	D
Likelihood Rationale	SME estimates place this hazard as plausible more than once every century (i.e. rare)
INITIAL RISK	5D
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	While no mitigation may be necessary, ensuring human management functionality, the flight should be discontinued to repair the system
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

ABDAA Hardware HOTL MMI

	Airborne Based Detect and Avoid Hardware, System Management Man-Machine Interface
Hazard	Power outage
Description	MMI loses power requiring a reboot (once power is restored). Loss of management awareness/functionality.
Existing Controls	None
Pre-Mitigation Severity	5
Severity Rationale	Loss of management MMI results in the inability to perform management functions. However, the DAA system is still functioning, and thus there is no impact upon maintaining well clear.
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights.
INITIAL RISK	5C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	5C
Additional Controls	UPS, back-up power (e.g. generator) OR Procedural action (e.g., land) until management MMI is restored.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Hardware, System Management Man-Machine Interface	
Hazard	Mechanical failure due to fatigue
Description	MMI fails owing to mechanical failure caused by fatigue.
Existing Controls	None
Pre-Mitigation Severity	5
Severity Rationale	Loss of management MMI results in the inability to perform management functions. However, the DAA system is still functioning, and thus there is no impact upon maintaining well clear.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Experience indicates that mean time to failure is greater than 1 year.
INITIAL RISK	5D
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	5D
Additional Controls	Procedural action until management MMI is restored.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	D
Residual Risk	5D
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Hardware, System Management Man-Machine Interface	
Hazard	Mechanical failure due to environmental impacts
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Hardware, System Management Man-Machine Interface	
Hazard	Mechanical failure due to improper use
Description	See "Mechanical failure due to fatigue"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

ABDAA Hardware Algorithm

	Airborne Based Detect and Avoid Hardware, Algorithm	
Hazard	Hardware failure with system on which the algorithm (conflict identification and resolution identification) resides.	
Description	Algorithm box fails, leading to complete loss of ability to identify and resolve conflicts.	
Existing Controls	None	
Pre-Mitigation Severity	1	
Severity Rationale	Loss of algorithm hardware results in DAA system being non-functional.	
Pre-Mitigation Likelihood	D	
Likelihood Rationale	Experience indicates that mean time to failure is greater than 1 year.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan AND fusion box system redundancy	OR Health monitoring (MMI) and procedural mitigation (e.g., RTB or land)
Post-Mitigation Severity	5	3
Post-Mitigation Likelihood	E	E
Residual Risk	5E	3E
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

ABDAA Software HOTL MMI

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Misleading health/status/mode information
Description	Information regarding the health/status/mode of the DAA system is misleading.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	If the DAA system is not functioning but it is believed to be functioning, then a MAC is credible.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C standard.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If flying at the edge of well clear, the likelihood of a MAC is 0.005.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Use of alerts within the MMI such that the human is made aware when the aircraft does not maneuver relative to an intruder.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	C
Residual Risk	2C
Post-Mitigation Likelihood (Worst Credible)	D
Residual Risk (Worst Credible)	2D

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Lack of an intruder Display System (IDS) to aid in situational awareness for mitigation enactment
Description	No IDS is provided in the management MMI. This is a compound hazard as the IDS provides information to the human that enables the human to recognize if something is not working properly.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	If something is not working properly AND no IDS is present to help indicate that AND the health monitoring system does not properly provide the needed information, then a MAC is credible.
Pre-Mitigation Likelihood	E
Likelihood Rationale	Something must not work properly with the DAA system (C likelihood) and health monitoring system does not provide needed information (C likelihood), resulting in this well within E likelihood.
INITIAL RISK	1E
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If flying at the edge of well clear, the likelihood of a MAC is 0.005.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Use of alerts within the MMI such that the human is made aware when the aircraft does not maneuver relative to an intruder.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	E
Residual Risk	2E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	2E

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	Horizontal representation of multiple targets is incorrect (in optional IDS)
Description	The IDS simply displays the incorrect information. Purely a software issue.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	Incorrect intruder locations in the optional IDS could lead the human to maneuver the aircraft into an actual aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005. Even with several targets the probability is compounded by 0.015.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide redundant information [e.g., direct feed from sensor(s) on a separate display] OR Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) AND Apply a mitigation like return-to-base or land
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Horizontal representation of single target is incorrect (in optional IDS)
Description	If software has an issue, then it will affect multiple targets (see "Horizontal representation of multiple targets is incorrect")
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	Erroneous aircraft altitude displayed for single aircraft (in optional IDS)
Description	If software has an issue, then it will affect multiple targets (see "Erroneous aircraft altitude displayed for multiple aircraft")
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Erroneous aircraft altitude displayed for multiple aircraft (in optional IDS)
Description	The MMI simply displays the incorrect information. Purely a software issue.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	Incorrect intruder altitudes in the optional IDS could lead the human to maneuver the aircraft into an actual aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide redundant information (e.g., from GCS) -OR- Apply a procedural mitigation such as checking aircraft altitudes via radio communications -AND- Apply a mitigation like return-to-base or land
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Erroneous aircraft ID/category displayed (in optional IDS)
Description	The incorrect aircraft category or ID is displayed owing to MMI software failure.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	3
Severity Rationale	If an aircraft category is used to infer aircraft flight characteristics, the human could take over for the algorithm to ensure separation and in doing so could degrade the degree of separation.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	C
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	3C
Additional Controls	Check categories of known targets (e.g., ownship). OR Procedurally preclude PIC from assuming intruders' performance based on category
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	5C

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	False target (in optional IDS)
Description	A target that is not present is displayed-this is commonly a target that tails another target, but does not have to be. This could result from faulty sensor information or software issues. It is assumed that all targets are being avoided.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	4
Severity Rationale	The algorithm would avoid all targets if the source is a sensor. If the source is software (e.g., in the MMI), then the human could act to avoid it, which could impact well clear status relative to another aircraft.
Pre-Mitigation Likelihood	A
Likelihood Rationale	Experience indicates that ghost targets can be quite common (e.g., they have arisen with ADS-B data).
INITIAL RISK	4A
Pre-Mitigation Likelihood (Worst Credible)	B
Likelihood Rationale (Worst Credible)	Scarcity of targets in operating environment
INITIAL RISK (Worst Credible)	4B
Additional Controls	Training for PIC to recognize ghost targets.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	A
Residual Risk	4A
Post-Mitigation Likelihood (Worst Credible)	B
Residual Risk (Worst Credible)	4B

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Latency exceeds threshold rendering target data unusable (in optional IDS)
Description	The target data are latent such that uncertainty in position is very large. This results from latency within the MMI hardware.
Existing Controls	None
Pre-Mitigation Severity	5
Severity Rationale	The DAA system is still functioning--the IDS is not useful owing to latency issues.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Significant latency resulting from sensor issues are expected to occur roughly 1/year.
INITIAL RISK	5C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	5C
Additional Controls	Because the IDS can provide useful information, it is recommended that operations are halted until the issue is resolved.
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	Sustained loss of one target in the midst of other targets (in optional IDS)
Description	See "Sustained loss of multiple targets"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Sustained loss of multiple targets (in optional IDS)
Description	Intruders are not displayed within the IDS owing to MMI software failure.
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C
Pre-Mitigation Severity	1
Severity Rationale	If the system appears to be maneuvering unnecessarily, the human may take control and in doing so, since intruders are not represented, may fly into an aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005. Even with several targets the probability is compounded by 0.015.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Provide redundant information [e.g., direct feed from sensor(s) on a separate display] -OR- Provide health monitoring that alerts to loss of targets on display (e.g. inclusion of reference to a fixed relative target)
Post-Mitigation Severity	5
Post-Mitigation Likelihood	C
Residual Risk	5C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	Multiple targets never displayed (in optional IDS)
Description	See "Sustained loss of multiple targets"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	Sustained loss of all targets (in optional IDS)
Description	See "Sustained loss of multiple targets"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	No targets displayed (in optional IDS)
Description	See "Sustained loss of multiple targets"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, System Management Man-Machine Interface
Hazard	Horizontal representation of ownship incorrect (in optional IDS)
Description	The representation of ownship position is incorrect, which is always true owing to uncertainty in sensors used to derive ownship position (generally GPS), but can be more severe owing to software issues (e.g., within the MMI), issues associated with the data being fed to the MMI, and latency with the data being fed to the MMI).
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C. Use of ADS-B data or direct links to GCS to obtain ownship position (results in errors, with no latency, being those given by GPS on UA).
Pre-Mitigation Severity	1
Severity Rationale	Having incorrect ownship within the MMI could result in the human taking control when the DAA system, in the user's view, allows ownship to get too close to another aircraft. In the resulting maneuvering, a MAC is credible because of the error in ownship position.
Pre-Mitigation Likelihood	C
Likelihood Rationale	DO-178C equivalent software assurance level. In flight tests, issues with ownship position have not been observed.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Probability is compounded by 0.005
INITIAL RISK (Worst Credible)	1E
Additional Controls	Health monitoring system to alert accuracy of ownship position. Not sure what this will look like OR Cross-reference to an independent display.
Post-Mitigation Severity	3
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Airborne Based Detect and Avoid Software, System Management Man-Machine Interface	
Hazard	Erroneous service status displayed
Description	Uncertain as to the meaning of this hazard…left for future consideration.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

ABDAA Software Algorithm

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Software lacks robustness/maturity
Description	A software algorithm that is improperly tested, configured, installed, etc. that is put into operation in a highly safety critical environment.
Existing Controls	Software development standards
Pre-Mitigation Severity	1
Severity Rationale	A number of causes can occur that will cause the severity to include a MAC.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Generally software is tested in laboratory setting to work out more critical issues with the system prior to being deployed. Assuming that software developers are following best practices, these causes to the hazard are reduced in likelihood.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	Depending on the amount of time to recover the system after a malfunction, a MAC is still low.
INITIAL RISK (Worst Credible)	1D
Additional Controls	Build and test software to an agreed level within DO-178
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	D
Residual Risk (Worst Credible)	4D

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm will always provide imperfect historical and current position (i.e. track) for single target
Description	Target position and tracks will have inherent measurement error. System is operating normally, but the user assumes absolute position
Existing Controls	Software is operating as designed.
Pre-Mitigation Severity	1
Severity Rationale	Without knowledge of sensor uncertainty, an error in spacial understanding could still result in an MAC
Pre-Mitigation Likelihood	A
Likelihood Rationale	Measurement error from sensors are always present
INITIAL RISK	1A
Pre-Mitigation Likelihood (Worst Credible)	C
Likelihood Rationale (Worst Credible)	The likelihood of an algorithm error large enough to violate the NMAC volume is low
INITIAL RISK (Worst Credible)	1C
Additional Controls	Algorithm utilizes measurement error and considers for operation. (with separation standards)
Post-Mitigation Severity	4
Post-Mitigation Likelihood	A
Residual Risk	4A
Post-Mitigation Likelihood (Worst Credible)	A
Residual Risk (Worst Credible)	4A

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Multiple aircraft causes ambiguity resulting in errant track(s)
Description	Algorithm becomes confused when two or more tracked targets cross, resulting in errant tracks.
Existing Controls	Track data are presented to the algorithm. Cooperative aircraft ID information is provided to the correlator/fusion algorithm. Well clear was maintained prior to incident.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls and the assumed buffer for pop-ups. The algorithm will still be able to maintain well clear as it will remain far enough away from both targets even if they are fused as one.
Pre-Mitigation Likelihood	C
Likelihood Rationale	multiple crossing targets are relatively uncommon but feasible
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	The compound likelihood is extremely unlikely
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides errant track for multiple targets
Description	Algorithm becomes confused from sensor input being lower quality, resulting in errant tracks of multiple targets.
Existing Controls	Track data are presented to the algorithm. Cooperative aircraft ID information is provided to the correlator/fusion algorithm. Well clear was maintained prior to incident.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls and the assumed buffer for pop-ups. The algorithm will still be able to maintain well clear as it will remain far enough away from both targets even if they are fused as one.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Since track data are still available, the algorithm will try to self-separate from these tracks. The distance between the UAS and errant track should still be far enough away that a NMAC is not valid, but well-clear violation may be reasonable.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	The compound likelihood is extremely unlikely
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm fails to provide a track
Description	Software is working correctly and uses track data to decide on potential maneuvers.
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	If algorithm doesn't utilize a target because no track data is available, the could lead to a MAC
Pre-Mitigation Likelihood	A
Likelihood Rationale	With an individual probability of detection of 0.90 the likelihood of missing two consecutive targets in the well surveilled volume is 0.01
INITIAL RISK	1A
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	0.000005 est, starting with 0.01, .1 outside well clear, .1 probability of NMAC, .05 MAC given NMAC
INITIAL RISK (Worst Credible)	1D
Additional Controls	Utilize plot data in algorithm along with track data.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm fails to provide tracks for multiple targets
Description	Software is working correctly. Sensor data is intermittent causing track to not be available to algorithm and plot data is not utilized.
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	Algorithm is unaware of target because plot data have not been passed along
Pre-Mitigation Likelihood	B
Likelihood Rationale	A tenth as likely as a single track not being provided
INITIAL RISK	1B
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	1/10 of 0.000005 est from a single track not being provided.
INITIAL RISK (Worst Credible)	1D
Additional Controls	Utilize plot data in algorithm along with track data.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm fails to ID conflict with intruder(s) (HOTL) at twice the distance of well-clear
Description	Sensor data provided to tracking system may be inaccurate preventing the algorithm from properly assessing the situation.
Existing Controls	None
Pre-Mitigation Severity	1
Severity Rationale	System doesn't understand that there is a conflict and will proceed on a normal path
Pre-Mitigation Likelihood	C
Likelihood Rationale	This will happen for only at extremely low angles of incidence.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	As the aircraft come closer together, there will be less uncertainty on violating well-clear.
INITIAL RISK (Worst Credible)	1D
Additional Controls	Algorithm understands and utilize sensor uncertainties in calculated target positions.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	D
Residual Risk	4D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	4E

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides improper resolution of conflict for single intruder at twice the distance of well-clear
Description	Uncertainty in track provided to the algorithm may temporarily produces convergence rather than divergence in a conflict resolution. Depends on magnitude of uncertainty in track position/heading.
Existing Controls	None
Pre-Mitigation Severity	4
Severity Rationale	Using radar as a model, heading errors would be at worst 2-3 degrees. If the intruder turned heading error would be on the order of 15 deg on a radar system with a 5 sec update rate. Assume 5 seconds for operator to react and obtain a new heading. Given that, you are still 500 ft from well-clear boundary. Signification violation seems unlikely.
Pre-Mitigation Likelihood	C
Likelihood Rationale	1 out of 100 resolution with a few conflict resolutions being provided every day.
INITIAL RISK	4C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	1 out of 10 of these scenarios would reduce likelihood down one level.
INITIAL RISK (Worst Credible)	4D
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides proper intruder resolution but results in CFIT/obstacle
Description	Algorithm provides proper intruder resolution but results in CFIT/obstacle
Existing Controls	Flight Planning, Site visits, operator can input constraints in system for flight area based on site surveys and planning.
Pre-Mitigation Severity	1 (FC)
Severity Rationale	If the algorithm doesn't have knowledge of terrain or obstacles, there is a possibility the conflict resolution will create a collision with the terrain or obstacle
Pre-Mitigation Likelihood	D
Likelihood Rationale	If operator performs a proper flight planning and site visit, the likelihood of flying in to these objects/terrain would be very unlikely.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	Same as G20
INITIAL RISK (Worst Credible)	1D
Additional Controls	Algorithm utilizes a DTED and Geospatial data regarding obstacles to define no-fly locations in conjunction with site survey to determine any changes from what is currently in database.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	The resolution confuses the manned aircraft
Description	UAS was not following right-of-way rules and maneuvers by UAS may cause manned aircraft pilot to become confused.
Existing Controls	Follow right-of-way rules (both algorithm and UAS pilot)
Pre-Mitigation Severity	4
Severity Rationale	Well clear may be violated due to the confusion caused by UAS maneuvering. Manned aircraft could then maneuver in a way that was unpredictable to UAS causing a bust in well-clear.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Manned aircraft may still be able to see UAS (visually or technologically) but may be confused at what the intention of the flight path would be.
INITIAL RISK	4D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Manned pilot would likely try to stay farther away from UAS.
INITIAL RISK (Worst Credible)	4E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides proper resolution that results in conflict with another aircraft (HOTL)
Description	See column A - Algorithm chooses resolution and maneuvers
Existing Controls	Right-of-way rules
Pre-Mitigation Severity	3
Severity Rationale	Algorithms that don't take into account multiple conflicts in a resolution may cause an artifact that the algorithm is chasing resolutions in a more highly congested airspace
Pre-Mitigation Likelihood	D
Likelihood Rationale	The chance that these scenarios occur in the low density airspace are remote.
INITIAL RISK	3D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Chances of not being able to handle this situation is extremely improbable
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides a resolution that is outside the performance envelope of the sUAS
Description	Algorithm not designed to take into account limitations of airframe.
Existing Controls	Aircraft will not execute beyond limits
Pre-Mitigation Severity	3
Severity Rationale	Airframe will not execute maneuver outside its limits, but will result in the potential loss of well clear requiring further maneuvering.
Pre-Mitigation Likelihood	D
Likelihood Rationale	User generally takes into account the capabilities of its airframe during operations.
INITIAL RISK	3D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	Given expectation that maneuvers occur twice the distance to well-clear, it is unlikely well-clear will be violated.
INITIAL RISK (Worst Credible)	3E
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Software, Algorithm
Hazard	Algorithm provides a resolution alien to right of way rules
Description	Errant track resulting in a conflict resolution inconsistent with ROW rules
Existing Controls	Right-of-way rules
Pre-Mitigation Severity	4
Severity Rationale	Using radar as a model, heading errors would be at worst 2-3 degrees. If the intruder turned heading error would be on the order of 15 deg on a radar system with a 5 sec update rate. Assume 5 seconds for operator to react and obtain a new heading. Given that, you are still 500 ft from well-clear boundary. Signification violation seems unlikely.
Pre-Mitigation Likelihood	C
Likelihood Rationale	1 out of 100 resolution with a few conflict resolutions being provided every day.
INITIAL RISK	4C
Pre-Mitigation Likelihood (Worst Credible)	D
Likelihood Rationale (Worst Credible)	1 out of 10 of these scenarios would reduce likelihood down one level.
INITIAL RISK (Worst Credible)	4D
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

ABDAA Active Sensor

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Brief Power Outage (≤ 5 s)
Description	Power to sensor is lost for ≤ 5 s resulting in complete loss of situational awareness during power loss
Existing Controls	Sensor auto-restarts with resumed power
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume)
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Back-up power (e.g. generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Airborne Based Detect and Avoid Sensor, Active	
Hazard	Extended Power outage
Description	Sensor loses power for > 5 s and is the sole sensor providing information to the ABSAA system. Complete loss of situational awareness.
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO CI)
Likelihood Rationale	Extended power losses are much less common during operations than short-duration power losses.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Back-up power (e.g., generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active	
Hazard	Mechanical failure due to fatigue	
Description	Sensor hardware fails due to fatigue leading to complete loss of situational awareness.	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	Experience indicates that the mean time to failure is greater than 1 month.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan	Sensor system redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

	Airborne Based Detect and Avoid Sensor, Active	
Hazard	Mechanical failure due to environmental impacts	
Description	Cold weather, heat, moisture, wind, dust problems, etc., result in a mechanical failure.	
Existing Controls	IEC/IP equipment ratings (standard 60529) or conformance to a standard like RTCA DO-160B or MIL-STD-810G.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates that failures are only common when equipment is used outside OEM limitations.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Health monitoring for environmental threats	Sensor diversification AND additional procedural limitations on environmental conditions.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	E (UAO C1)	C
Residual Risk	1E	4C
Post-Mitigation Likelihood (Worst Credible)		E
Residual Risk (Worst Credible)		4E

Airborne Based Detect and Avoid Sensor, Active	
Hazard	Mechanical failure due to improper use
Description	Out of scope – precluded by assumptions
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Sensor, Active		
Hazard	Software failure	
Description	Software fails, resulting in loss of situational awareness.	
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	DO-178C equivalent software assurance level.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	DO178 B standard	Sensor diversification/ redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

Airborne Based Detect and Avoid Sensor, Active	
Hazard	Brief loss of target(s) due to interference (≤ 5 s)
Description	Temporary noise level increases and prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume).
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Sustained loss of target(s) due to Interference (> 5 s)
Description	Sustained increase in noise level prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible prior to RTB, for example, is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	1
Post-Mitigation Likelihood	D
Residual Risk	1D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	1E

	Airborne Based Detect and Avoid Sensor, Active	
Hazard	Propagation issues producing detection holes	
Description	Targets are missed as a result of propagation detection holes.	
Existing Controls	Mapping out the service volume and flying with a buffer for pop-ups, pop-downs, and pop-ins.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Uncertainty in service volume buffers results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Based upon approximate knowledge of propagation variation, a buffer is used. The likelihood of that buffer being exceeded is very low.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible is estimated to be ≤ 0.01.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Better definition of needed buffer based on propagation modeling using observed soundings OR	real-time propagation modeling during operations.
Post-Mitigation Severity	1	2
Post-Mitigation Likelihood	E	E
Residual Risk	1E	2E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	2E

	Airborne Based Detect and Avoid Sensor, Active			
Hazard	Weather (rain, clouds, etc.) causing detection holes			
Description	Targets are missed as a result of propagation detection holes.			
Existing Controls	VFR is a possible mitigation in that the DAA system replaces the "Visual" of VFR. However, current manned aviation can be VFR in precipitation and the DAA system replacing that see-and-avoid function may not work in such conditions owing, for instance, to attenuation of the signal in rain. Therefore, the control is preflight planning for an unmanned aircraft flight to ensure it will be in conditions in which the DAA system is functional.			
Pre-Mitigation Severity	1			
Severity Rationale	If you do not know where they are, a MAC is credible.			
Pre-Mitigation Likelihood	C (UAO C1)			
Likelihood Rationale	If we are not expressly considering weather impacts, in real time, on the DAA sensor, then degraded DAA sensor performance could easily happen at this rate.			
INITIAL RISK	1C			
Pre-Mitigation Likelihood (Worst Credible)	E			
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.			
INITIAL RISK (Worst Credible)	1E			
Additional Controls	Preflight planning takes into consideration weather impacts to the DAA sensors	real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	use of additional sensors that do not have the same weather limitations	All listed options
Post-Mitigation Severity	1	3	3	3
Residual Risk	1D	3D	3D	3E
Post-Mitigation Likelihood (Worst Credible)	E	E	E	
Residual Risk (Worst Credible)	1E	3E	3E	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Terrain-induced detection holes
Description	Terrain producing areas where DAA sensor is unable to detect.
Existing Controls	Sensor calibration on initial deployment. Surveillance volume analysis during initial setup of sensor at a specific location. Preflight planning,
Pre-Mitigation Severity	2
Severity Rationale	Flying UAS with some buffer above lowest elevation angle of sensor and C2 radio line of sight. This buffer allows for the intruder that would be considered to be a pop-up to be potentially within NMAC considerations, but not MAC.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Identified to be a rare event as it would only result with complete mis-use/mis-understanding of systems being used.
INITIAL RISK	2D
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Sensor producing false targets
Description	Display shows targets that are not actually there resulting in excessive maneuvering.
Existing Controls	Proper calibration of sensor prior to flight.
Pre-Mitigation Severity	5
Severity Rationale	Since no intruder is present, ownship maneuvers excessively with no well-clear violation.
Pre-Mitigation Likelihood	A
Likelihood Rationale	False targets are common, especially at low altitudes.
INITIAL RISK	5A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	None
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	5A
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active	
Hazard	Improper identification of real targets among many false targets	
Description	The user becomes complacent and believe that real targets are false targets.	
Existing Controls	User training.	
Pre-Mitigation Severity	2	
Severity Rationale	The user suspects that a real target is a false target and deviates slightly to avoid, but not enough to maintain well-clear, resulting in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	False targets are common, but it is less common that a real target will be believed to be a false target.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Avoid all targets	Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided.
Post-Mitigation Severity	5	4
Post-Mitigation Likelihood	A	D
Residual Risk	5A	4D
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

	Airborne Based Detect and Avoid Sensor, Active
Hazard	"Target" is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)
Description	Signal is below noise level of sensor.
Existing Controls	Calibrate sensor according to manufacturer guidelines. Operate within limitations of sensor.
Pre-Mitigation Severity	2
Severity Rationale	There is an unknown, unidentified target in the well surveilled volume. The most common area for interaction will be near the edges of this volume.
Pre-Mitigation Likelihood	A
Likelihood Rationale	This scenario (i.e. individual detection failures) would not be common, but could occur once a week.
INITIAL RISK	2A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Tracking intruders AND avoiding operations near the edge of your well surveilled volume.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	D
Residual Risk	2D
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Partial target data are provided
Description	Degraded sensor performance such that partial data (at least horizontal or altitude) are transmitted, providing some target information to the flight crew.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers. Network monitoring.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls, the chance for NMAC violation is removed.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Experience indicates that prolonged issues with sensor data are commonly identified prior to flight and corrected and that prolonged issues during flight that are not recognized are rare.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Degraded sensor performance such that no positional target data are provided
Description	Degraded sensor performance such that all target positional data are missing.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers Network monitoring
Pre-Mitigation Severity	2
Severity Rationale	Loss of target positional data will put the UAS at risk of an NMAC with the user applying previous target information to avoid aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Prolonged loss of information is oftentimes recognized early.
INITIAL RISK	2C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Sensor cannot provide accurate enough position information
Description	Sensor positional uncertainty cannot be refined enough to differentiate multiple targets within a given volume that is outside of well clear distances for each target.
Existing Controls	No standards currently exist for UAS DAA system sensors to operate at a defined performance level.
Pre-Mitigation Severity	3
Severity Rationale	Target position with large positional uncertainty is generally sufficient for remaining well clear.
Pre-Mitigation Likelihood	A
Likelihood Rationale	The sensor uncertainty is known to some degree and is added to well clear distances. This reduces the chances for violation of the 'true' well clear by adding additional buffers.
INITIAL RISK	3A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Sensor experiences partial failure resulting in blind spots or missed detections
Description	Same as "Improper identification of real targets among many false targets"
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Inadequate effective range
Description	Out of scope as one should not use a sensor that does not adequately sample your airspace
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active	
Hazard	Refraction causing inaccurate target information	
Description	Environmental conditions are such that refraction is not conforming to standard wave propagation theory.	
Existing Controls	None	
Pre-Mitigation Severity	2	
Severity Rationale	The change in location is not sufficient in the horizontal such that it shall become an NMAC. However, the change in vertical position could result in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	Highly dependent on environmental conditions. If weather impacts on the DAA sensor Is not expressly considered, then degraded DAA sensor performance could easily happen at this rate.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Real-time EM propagation modeling to correct errors in intruder positions	Multiple sensors to cross-check/fuse.
Post-Mitigation Severity	4	4
Post-Mitigation Likelihood	B	B
Residual Risk	4B	4B
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Non-eye-safe lidar
Description	Out of scope
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Light sources (e.g. Sun, etc.) oversaturates the sensor
Description	Unresolved as more information regarding hazard is needed
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Active
Hazard	Reflections of water
Description	Unresolved as more information regarding hazard is needed
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

ABDAA Passive Sensor

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Brief Power Outage (≤ 5 s)
Description	Power to sensor is lost for ≤ 5 s resulting in complete loss of situational awareness during power loss
Existing Controls	Sensor auto-restarts with resumed power
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume)
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Based on current operational pace and what has been experienced with flights. Short loss of power is not generally observed.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Back-up power (e.g. generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Extended Power outage
Description	Sensor loses power for > 5 s and is the sole sensor providing information to the ABSAA system. Complete loss of situational awareness.
Existing Controls	None
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO CI)
Likelihood Rationale	Extended power losses are much less common during operations than short-duration power losses.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Back-up power (e.g., generator)
Post-Mitigation Severity	3
Post-Mitigation Likelihood	E
Residual Risk	3E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Mechanical failure due to fatigue	
Description	Sensor hardware fails due to fatigue leading to complete loss of situational awareness.	
Existing Controls	None	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	Experience indicates that the mean time to failure is greater than 1 month.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Recurring maintenance plan	Sensor system redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

	Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Mechanical failure due to environmental impacts	
Description	Cold weather, heat, moisture, wind, dust problems, etc., result in a mechanical failure.	
Existing Controls	IEC/IP equipment ratings (standard 60529) or conformance to a standard like RTCA DO-160B or MIL-STD-810G.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Experience indicates that failures are only common when equipment is used outside OEM limitations.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Health monitoring for environmental threats	Sensor diversification AND additional procedural limitations on environmental conditions.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	E (UAO C1)	C
Residual Risk	1E	4C
Post-Mitigation Likelihood (Worst Credible)		E
Residual Risk (Worst Credible)		4E

	Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Software failure	
Description	Software fails, resulting in loss of situational awareness.	
Existing Controls	Software validation (underlying assumption) has been performed to an equivalent of DO 178C.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	C (UAO C1)	
Likelihood Rationale	DO-178C equivalent software assurance level.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	DO178 B standard	Sensor diversification/ redundancy.
Post-Mitigation Severity	1 (SC & UAS)	4
Post-Mitigation Likelihood	D (UAO C1)	C
Residual Risk	1D	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	4E

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Brief loss of target(s) due to interference (≤ 5 s)
Description	Temporary noise level increases and prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	3 [SC & UAS] & 4 UAO
Severity Rationale	Loss of situational awareness leads to well clear violation; possible manned aircraft maneuvering; slight safety margin reduction (possibly half-way into well-clear volume).
Pre-Mitigation Likelihood	C (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a significant well-clear violation could occur is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	3E
Additional Controls	Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	D
Residual Risk	3D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Sustained loss of target(s) due to Interference (> 5 s)
Description	Sustained increase in noise level prevents target(s) from being detected.
Existing Controls	Initial calibration and configuration, FCC regulations, and the operational environment is removed from most sources of noise.
Pre-Mitigation Severity	1 (SC & UAS)
Severity Rationale	Loss of situational awareness results in a MAC being a credible outcome.
Pre-Mitigation Likelihood	D (UAO C1)
Likelihood Rationale	Assumptions preclude majority of credible sources for interference and natural mitigations further reduce likelihood.
INITIAL RISK	1D
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible prior to RTB, for example, is estimated to be ≤ 0.01.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.
Post-Mitigation Severity	1
Post-Mitigation Likelihood	D
Residual Risk	1D
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	1E

	Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Propagation issues producing detection holes	
Description	Targets are missed as a result of propagation detection holes.	
Existing Controls	Mapping out the service volume and flying with a buffer for pop-ups, pop-downs, and pop-ins.	
Pre-Mitigation Severity	1 (SC & UAS)	
Severity Rationale	Uncertainty in service volume buffers results in a MAC being a credible outcome.	
Pre-Mitigation Likelihood	D (UAO C1)	
Likelihood Rationale	Based upon approximate knowledge of propagation variation, a buffer is used. The likelihood of that buffer being exceeded is very low.	
INITIAL RISK	1D	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	In low airspace density environments, the likelihood of being close enough to an intruder such that a MAC is possible is estimated to be ≤ 0.01.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Better definition of needed buffer based on propagation modeling using observed soundings OR	real-time propagation modeling during operations.
Post-Mitigation Severity	1	2
Post-Mitigation Likelihood	E	E
Residual Risk	1E	2E
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	1E	2E

Airborne Based Detect and Avoid Sensor, Passive				
Hazard	Weather (rain, clouds, etc.) causing detection holes			
Description	Targets are missed as a result of propagation detection holes.			
Existing Controls	VFR is a possible mitigation in that the DAA system replaces the "Visual" of VFR. However, current manned aviation can be VFR in precipitation and the DAA system replacing that see-and-avoid function may not work in such conditions owing, for instance, to attenuation of the signal in rain. Therefore, the control is preflight planning for an unmanned aircraft flight to ensure it will be in conditions in which the DAA system is functional.			
Pre-Mitigation Severity	1			
Severity Rationale	If you do not know where they are, a MAC is credible.			
Pre-Mitigation Likelihood	C (UAO C1)			
Likelihood Rationale	If we are not expressly considering weather impacts, in real time, on the DAA sensor, then degraded DAA sensor performance could easily happen at this rate.			
INITIAL RISK	1C			
Pre-Mitigation Likelihood (Worst Credible)	E			
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.			
INITIAL RISK (Worst Credible)	1E			
Additional Controls	Preflight planning takes into consideration weather impacts to the DAA sensors	real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	use of additional sensors that do not have the same weather limitations	All listed options
Post-Mitigation Severity	1	3	3	3
Residual Risk	1D	3D	3D	3E
Post-Mitigation Likelihood (Worst Credible)	E	E	E	
Residual Risk (Worst Credible)	1E	3E	3E	

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Terrain-induced detection holes
Description	Terrain producing areas where DAA sensor is unable to detect.
Existing Controls	Sensor calibration on initial deployment. Surveillance volume analysis during initial setup of sensor at a specific location. Preflight planning,
Pre-Mitigation Severity	2
Severity Rationale	Flying UAS with some buffer above lowest elevation angle of sensor and C2 radio line of sight. This buffer allows for the intruder that would be considered to be a pop-up to be potentially within NMAC considerations, but not MAC.
Pre-Mitigation Likelihood	D
Likelihood Rationale	Identified to be a rare event as it would only result with complete mis-use/mis-understanding of systems being used.
INITIAL RISK	2D
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	E
Residual Risk	4E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Sensor producing false targets
Description	Display shows targets that are not actually there resulting in excessive maneuvering.
Existing Controls	Proper calibration of sensor prior to flight.
Pre-Mitigation Severity	5
Severity Rationale	Since no intruder is present, ownship maneuvers excessively with no well-clear violation.
Pre-Mitigation Likelihood	A
Likelihood Rationale	False targets are common, especially at low altitudes.
INITIAL RISK	5A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	None
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	5A
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

		Airborne Based Detect and Avoid Sensor, Passive
Hazard	Improper identification of real targets among many false targets	
Description	The user becomes complacent and believe that real targets are false targets.	
Existing Controls	User training.	
Pre-Mitigation Severity	2	
Severity Rationale	The user suspects that a real target is a false target and deviates slightly to avoid, but not enough to maintain well-clear, resulting in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	False targets are common, but it is less common that a real target will be believed to be a false target.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Avoid all targets	Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided.
Post-Mitigation Severity	5	4
Post-Mitigation Likelihood	A	D
Residual Risk	5A	4D
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	"Target" is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)
Description	Signal is below noise level of sensor.
Existing Controls	Calibrate sensor according to manufacturer guidelines. Operate within limitations of sensor.
Pre-Mitigation Severity	2
Severity Rationale	There is an unknown, unidentified target in the well surveilled volume. The most common area for interaction will be near the edges of this volume.
Pre-Mitigation Likelihood	A
Likelihood Rationale	This scenario (i.e. individual detection failures) would not be common, but could occur once a week.
INITIAL RISK	2A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Tracking intruders AND avoiding operations near the edge of your well surveilled volume.
Post-Mitigation Severity	2
Post-Mitigation Likelihood	D
Residual Risk	2D
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Partial target data are provided
Description	Degraded sensor performance such that partial data (at least horizontal or altitude) are transmitted, providing some target information to the flight crew.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers. Network monitoring.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls, the chance for NMAC violation is removed.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Experience indicates that prolonged issues with sensor data are commonly identified prior to flight and corrected and that prolonged issues during flight that are not recognized are rare.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Degraded sensor performance such that no positional target data are provided
Description	Degraded sensor performance such that all target positional data are missing.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers Network monitoring
Pre-Mitigation Severity	2
Severity Rationale	Loss of target positional data will put the UAS at risk of an NMAC with the user applying previous target information to avoid aircraft.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Prolonged loss of information is oftentimes recognized early.
INITIAL RISK	2C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Sensor cannot provide accurate enough position information
Description	Sensor positional uncertainty cannot be refined enough to differentiate multiple targets within a given volume that is outside of well clear distances for each target.
Existing Controls	No standards currently exist for UAS DAA system sensors to operate at a defined performance level.
Pre-Mitigation Severity	3
Severity Rationale	Target position with large positional uncertainty is generally sufficient for remaining well clear.
Pre-Mitigation Likelihood	A
Likelihood Rationale	The sensor uncertainty is known to some degree and is added to well clear distances. This reduces the chances for violation of the 'true' well clear by adding additional buffers.
INITIAL RISK	3A
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.
Post-Mitigation Severity	5
Post-Mitigation Likelihood	E
Residual Risk	5E
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

		Airborne Based Detect and Avoid Sensor, Passive
Hazard	Refraction causing inaccurate target information	
Description	Environmental conditions are such that refraction is not conforming to standard wave propagation theory.	
Existing Controls	None	
Pre-Mitigation Severity	2	
Severity Rationale	The change in location is not sufficient in the horizontal such that it shall become an NMAC. However, the change in vertical position could result in an NMAC.	
Pre-Mitigation Likelihood	B	
Likelihood Rationale	Highly dependent on environmental conditions. If weather impacts on the DAA sensor Is not expressly considered, then degraded DAA sensor performance could easily happen at this rate.	
INITIAL RISK	2B	
Pre-Mitigation Likelihood (Worst Credible)		
Likelihood Rationale (Worst Credible)		
INITIAL RISK (Worst Credible)		
Additional Controls	Real-time EM propagation modeling to correct errors in intruder positions	Multiple sensors to cross-check/fuse.
Post-Mitigation Severity	4	4
Post-Mitigation Likelihood	B	B
Residual Risk	4B	4B
Post-Mitigation Likelihood (Worst Credible)		
Residual Risk (Worst Credible)		

Airborne Based Detect and Avoid Sensor, Passive		
Hazard	Signal used for detection ceases	
Description	The signal being used ceases either for more than 3 s or in an intermittent fashion.	
Existing Controls	It is expected that planned outages of the signal would be monitored and that operations would not occur during such outages.	
Pre-Mitigation Severity	1	
Severity Rationale	If the signal is lost, all situational awareness is lost if this is the only type of sensor being used.	
Pre-Mitigation Likelihood	C	
Likelihood Rationale	It is expected that non-planned, significant outages of signals could occur 1 yr^{-1}, although this may be a conservative estimate.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Health monitoring of signal AND procedural mitigation (e.g., land)	sensor redundancy
Post-Mitigation Severity	3	4
Post-Mitigation Likelihood	C	C
Residual Risk	3C	4C
Post-Mitigation Likelihood (Worst Credible)	E	E
Residual Risk (Worst Credible)	3E	4E

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Signal used for detection degrades
Description	The signal used for detection of intruders degrades such that performance (e.g., coverage) is affected.
Existing Controls	Data heartbeat monitor. Procedural mitigations if prolonged issues are identified; Crew is trained to take corrective action (e.g. return to safe state, land, etc.). Checksums on data transfers. Network monitoring.
Pre-Mitigation Severity	3
Severity Rationale	With existing controls, the chance for NMAC violation is removed.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Experience indicates that prolonged issues with sensor data are commonly identified prior to flight and corrected and that prolonged issues during flight that are not recognized are rare.
INITIAL RISK	3C
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	More detailed health monitoring of sensor data.
Post-Mitigation Severity	4
Post-Mitigation Likelihood	C
Residual Risk	4C
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Passive	
Hazard	Dirty lens	
Description	The lens used in the sensor becomes dirty with contaminants (e.g., dust).	
Existing Controls	Pre- and post-flight cleaning.	
Pre-Mitigation Severity	1	
Severity Rationale	If the lens is dirty, then an intruder may not be identified and a MAC is credible.	
Pre-Mitigation Likelihood	C	
Likelihood Rationale	This is a very difficult likelihood to estimate. Once yr^{-1} seems to be reasonable, but additional data are needed.	
INITIAL RISK	1C	
Pre-Mitigation Likelihood (Worst Credible)	E	
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.	
INITIAL RISK (Worst Credible)	1E	
Additional Controls	Procedural mitigation (e.g., land)	A means for cleaning the lens in flight.
Post-Mitigation Severity	3	5
Post-Mitigation Likelihood	C	C
Residual Risk	3C	5C
Post-Mitigation Likelihood (Worst Credible)	E	
Residual Risk (Worst Credible)	3E	

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Image saturation
Description	Unresolved as more information regarding hazard is needed.
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Lack of contrast
Description	Same as "Brief loss of target(s) due to interference (≤ 5 s)
Existing Controls	
Pre-Mitigation Severity	
Severity Rationale	
Pre-Mitigation Likelihood	
Likelihood Rationale	
INITIAL RISK	
Pre-Mitigation Likelihood (Worst Credible)	
Likelihood Rationale (Worst Credible)	
INITIAL RISK (Worst Credible)	
Additional Controls	
Post-Mitigation Severity	
Post-Mitigation Likelihood	
Residual Risk	
Post-Mitigation Likelihood (Worst Credible)	
Residual Risk (Worst Credible)	

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Erroneous signal or position data
Description	Ownship signal has errors, which could include incorrect positional information. This could result from either a hardware malfunction (e.g., GPS) or a software issue.
Existing Controls	Pre-flight status check (e.g., is ownship position sensible).
Pre-Mitigation Severity	1
Severity Rationale	If one does not know ownship position, a MAC is credible.
Pre-Mitigation Likelihood	C
Likelihood Rationale	Because software could contribute to this and software is assumed to be designed to a level equivalent to DO 178C, C is appropriate.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Checks for physical realizability to identify issues with ownship position AND enactment of a procedural mitigation (e.g., land).
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

	Airborne Based Detect and Avoid Sensor, Passive
Hazard	Loss of signal and position data
Description	The signal providing ownship information is lost for a significant period of time (e.g., > 3 s) or intermittently.
Existing Controls	Health monitoring or some other form of situational awareness regarding loss of ownship data.
Pre-Mitigation Severity	1
Severity Rationale	If one does not know ownship position, a MAC is credible.
Pre-Mitigation Likelihood	C
Likelihood Rationale	This could be either a hardware or a software failure (e.g., avionics or systems used to communicate data). It is expected that software and networking are the most likely to fail. The software is assumed to be developed to the equivalent of DO 178C.
INITIAL RISK	1C
Pre-Mitigation Likelihood (Worst Credible)	E
Likelihood Rationale (Worst Credible)	If on the boundary of well clear, the likelihood of a MAC is 0.005 times the likelihood of the hazard.
INITIAL RISK (Worst Credible)	1E
Additional Controls	Procedural mitigation such as return to base or land.
Post-Mitigation Severity	3
Post-Mitigation Likelihood	C
Residual Risk	3C
Post-Mitigation Likelihood (Worst Credible)	E
Residual Risk (Worst Credible)	3E

Appendix G: SRM Hazard Analysis Data Organized According to Mitigations

System Redundancy Mitigations

System Type and Element:	**GBDAA, HITL, Human Execution Error**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Automation system that alerts/takes over control to avoid MAC	Task Saturation	T	1D	1E	
Utilize a second qualified crewmember to help operate the system	User is poorly trained on the MMI	T	1D	1E	
Practical performance evaluation added to training AND visual cues (e.g. trail information of intruders) **AND Aural and Visual alerts**	Misinterpretation of target data	T	2D	2E	
Develop and validate UAS DAA centric phraseology AND Practical performance evaluation **AND Place DAA monitor in front of the PIC**	Unclear communication between RPIC and individual providing DAA guidance	T	1D	1E	
Use of "bubbles" to illustrate well-clear boundaries relative to either intruders or ownship OR Provision of warnings (either visual or aural) regarding potential violation of well clear	User misinterprets scale of the visualization system	E	2D	4C	
Use of alerts that are visual, aural, or both	User does not recognize a conflict	E	1E	2E	
Use of alerts that are visual, aural, or both to indicate if a poor maneuver is being applied	Pilot is given or chooses an improper maneuver for avoiding conflict	E	2C	3C	
Use of alerts that are visual, aural, or both to indicate if a poor maneuver is being applied	Pilot executes intended maneuver incorrectly	M	2D	3C	
Have a backup VO or PIC present OR Provision of alerts (visual, aural, or both)	Pilot fails to execute maneuver	M	1E	3D	

System Type and Element:	**GBDAA, HOTL, Human Management Error**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
System design should include audio and visual alarms AND Training Emphasis on most common critical failures AND **Automatic Mitigations**	User takes no action to resolve hardware issues	DTEM	1E	3E	
System design should include audio and visual alarms AND Training Emphasis on most common critical failures AND **Automatic Mitigations**	User takes no action to resolve DTEM software issues	DTEM	1E	3E	
S**ystem design should include audio and visual alarms** AND Training Emphasis on ADM AND **Command of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate**	User executes inappropriate procedure given an abnormality or failure	DTEM	1E	2E	
Appropriate crew supervision following initial qualification AND **Audible warnings and alarms** OR C**ommand of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate**	User lacks experience to troubleshoot abnormalities	DTEM	1E	2E	

System Type and Element:	GBDAA, Sensor, Active				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Back-up power (e.g. generator)	Brief Power Outage (≤ 5 s)	D	3E	3E	
Back-up power (e.g. generator)	Extended Power outage	D	1E	3E	
Sensor system redundancy	Mechanical failure due to fatigue	D	1E	4E	
Sensor diversification AND additional procedural limitations on environmental conditions	Mechanical failure due to environmental impacts	D	1E	4E	
Sensor diversification/ redundancy	Software failure	D	1E	4E	
Use of additional sensors that do not have the same weather limitations	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	
Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided	Improper identification of real targets among many false targets	D	2B	4D	
Multiple sensors to cross-check/fuse	Refraction causing inaccurate target information	D	2B	4B	

System Type and Element:	GBDAA, Sensor, Passive				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Back-up power (e.g. generator)	Brief Power Outage (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Back-up power (e.g. generator)	Extended Power outage	D	1E	3E	Same as GBDAA, Sensor, Active
Sensor system redundancy	Mechanical failure due to fatigue	D	1E	4E	Same as GBDAA, Sensor, Active
Sensor diversification AND additional procedural limitations on environmental conditions	Mechanical failure due to environmental impacts	D	1E	4E	Same as GBDAA, Sensor, Active
Sensor diversification/ redundancy	Software failure	D	1E	4E	Same as GBDAA, Sensor, Active
Use of additional sensors that do not have the same weather limitations	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	Same as GBDAA, Sensor, Active
Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided	Improper identification of real targets among many false targets	D	2B	4D	Same as GBDAA, Sensor, Active
Multiple sensors to cross-check/fuse.	Refraction causing inaccurate target information	D	2B	4B	Same as GBDAA, Sensor, Active
Sensor Redundancy	Signal used for detection ceases	D	1E	4E	

System Type and Element:	GBDAA, Hardware, Supporting Systems				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
UPS, back-up power (e.g. generator)	Power outage	DTEM	1E	5E	
Recurring maintenance plan AND **Supporting system redundancy**	Mechanical failure due to fatigue	DTEM	1E	5E	
Replacement parts (can include PC) AND procedure action (e.g. RTB, go to ground, loiter)	Mechanical failure due to fatigue	DTEM	1E	3E	
Recurring maintenance plan AND f**usion box system redundancy**	Fusion box failures	T	1E	5E	
Health monitoring and **replacement parts (can include PC)** AND procedure turn if needed	Fusion box failures	T	1E	3E	
Redundant network	Data communication failure within DAA supporting systems	T	1E	5E	
Redundant communication	Unknown amount of data Comms from sensor is corrupted for less than, or equal to, 3 seconds, and is nonrecurring	T	3D	5C	
Redundant communication AND logical checks (e.g. filtering impossible aircraft motion)	Unknown amount of data Comms from sensor is corrupted for longer than 3 seconds	T	1E	5E	
Redundant communication AND Rigorous data integrity checks	High autonomy, commanded maneuver data are corrupted for less than 3 seconds	M	1D	2E	
Redundant communication	High autonomy, commanded maneuver doesn’t reach CS	M	1E	5E	

System Type and Element:	**GBDAA, Hardware, HOTL MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
UPS, back-up power (e.g. generator)	Power outage	TE	1E	5E	
Recurring maintenance plan AND MMI system redundancy	Mechanical failure due to fatigue		1E	5E	
Replacement parts (can include PC) AND procedure turn if needed	Mechanical failure due to fatigue	TE	1E	3E	

System Type and Element:	**GBDAA, Hardware, HITL MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
UPS, back-up power (e.g. generator)	Power outage	TE	1E	5E	
Recurring maintenance plan AND MMI system redundancy	Mechanical failure due to fatigue		1E	5E	
Replacement parts (can include PC) AND procedure turn if needed	Mechanical failure due to fatigue	TE	1E	3E	

System Type and Element:	**GBDAA, Software, MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Provide redundant information (e.g., from GCS) OR **Apply a procedural mitigation such as checking aircraft altitudes via radio communications** AND Apply a mitigation like return-to-base or land	Erroneous aircraft altitude displayed for multiple aircraft	T	1E	3E	
Provide redundant information [e.g., direct feed from sensor(s) on a separate display] OR Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) AND Apply a mitigation like return-to-base or land	Incorrect horizontal target positions displayed	T	1E	3E	
Provide redundant information [e.g., direct feed from sensor(s) on a separate display] OR Provide health monitoring that alerts to loss of targets on display (e.g. inclusion of reference to a fixed relative target) AND Apply a mitigation like return-to-base or land	Sustained loss of multiple targets	T	1E	3E	
Health monitoring system to alert accuracy of ownship position (not sure what this will look like) OR **Crossreference to an independent display**	Horizontal representation of ownship incorrect	E	1E	3E	

System Type and Element:	ABDAA, HOTL, Human Management Error				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
System design should include audio and visual alarms AND Training Emphasis on most common critical failures AND **Automatic Mitigations**	User takes no action to resolve hardware issues	DTEM	1E	3E	
System design should include audio and visual alarms AND Training Emphasis on most common critical failures AND **Automatic Mitigations**	User takes no action to resolve DTEM software issues	DTEM	1E	3E	
System design should include audio and visual alarms AND Training Emphasis on ADM AND **Command of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate**	User executes inappropriate procedure given an abnormality or failure	DTEM	1E	2E	
Appropriate crew supervision following initial qualification AND **Audible warnings and alarms** OR C**ommand of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate**	User lacks experience to troubleshoot abnormalities	DTEM	1E	2E	

System Type and Element:	**ABDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Back-up power (e.g. generator)	Brief Power Outage (≤ 5 s)	D	3E	3E	
Back-up power (e.g. generator)	Extended Power outage	D	1E	3E	
Sensor system redundancy	Mechanical failure due to fatigue	D	1E	4E	
Sensor diversification AND additional procedural limitations on environmental conditions	Mechanical failure due to environmental impacts	D	1E	4E	
Sensor diversification/ redundancy	Software failure	D	1E	4E	
Use of additional sensors that do not have the same weather limitations	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	
Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided	Improper identification of real targets among many false targets	D	2B	4D	
Multiple sensors to cross-check/fuse	Refraction causing inaccurate target information	D	2B	4B	

System Type and Element:	ABDAA, Sensor, Passive				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Back-up power (e.g. generator)	Brief Power Outage (≤ 5 s)	D	3E	3E	Same as GBDAA/ABDAA, Sensor, Active
Back-up power (e.g. generator)	Extended Power outage	D	1E	3E	Same as GBDAA/ABDAA, Sensor, Active
Sensor system redundancy	Mechanical failure due to fatigue	D	1E	4E	Same as GBDAA/ABDAA, Sensor, Active
Sensor diversification AND additional procedural limitations on environmental conditions	Mechanical failure due to environmental impacts	D	1E	4E	Same as GBDAA/ABDAA, Sensor, Active
Sensor diversification/ redundancy	Software failure	D	1E	4E	Same as GBDAA/ABDAA, Sensor, Active
Use of additional sensors that do not have the same weather limitations	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	Same as GBDAA/ABDAA, Sensor, Active
Use redundant sensors, which will reduce the number of false targets drastically such that all targets are avoided	Improper identification of real targets among many false targets	D	2B	4D	Same as GBDAA/ABDAA, Sensor, Active
Multiple sensors to cross-check/fuse	Refraction causing inaccurate target information	D	2B	4B	Same as GBDAA/ABDAA, Sensor, Active
Sensor redundancy	Signal used for detection ceases	D	1E	4E	

System Type and Element:	ABDAA, Hardware, Supporting Systems Onboard				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Redundancy in power supply to supporting DAA system hardware onboard	Power failure		1E	5E	
Recurring maintenance plan AND **Supporting system redundancy**	Mechanical failure due to fatigue		1E	5E	
Redundant communication AND Rigorous data integrity checks	Data corrupted -for less than 3 seconds-between onboard DAA system and CS (CS is presumably onboard)		1D	1E	
Redundant communication	Commanded maneuver does not reach CS		1E	5E	

System Type and Element:	**ABDAA, Hardware, Supporting Systems Offboard**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
UPS, back-up power (e.g. generator)	Power failure		1E	5E	
Recurring maintenance plan AND **Supporting system redundancy**	Mechanical failure due to fatigue		1E	5E	
Replacement parts (can include PC) AND procedure action (e.g. RTB, go to ground, loiter)	Mechanical failure due to fatigue		1E	3E	

System Type and Element:	ABDAA, Software, System Management MMI				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Use of alerts within the MMI such that the human is made aware when the aircraft does not maneuver relative to an intruder	Misleading health/status/mode information	T	1E	2D	
Use of alerts within the MMI such that the human is made aware when the aircraft does not maneuver relative to an intruder.	Lack of a Intruder Display System (IDS) to aid in situational awareness for mitigation enactment	T	1E	2E	
Provide redundant information [e.g., direct feed from sensor(s) on a separate display]	Horizontal representation of multiple targets is incorrect (in optional IDS)	T	1E	3E	
Provide redundant information (e.g., from GCS)	Erroneous aircraft altitude displayed for multiple aircraft (in optional IDS)	T	1E	3E	
Provide redundant information [e.g., direct feed from sensor(s) on a separate display]	Sustained loss of multiple targets (in optional IDS)	T	1E	5C	
Health monitoring system to alert accuracy of ownship position (not sure what this will look like) OR Crossreference to an independent display	Horizontal representation of ownship incorrect (in optional IDS)	E	1E	3E	

System Type and Element:	ABDAA, Hardware, System Management MMI				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
UPS, back-up power (e.g. generator) OR Procedural action (e.g., land) until management MMI is restored	Power outage		5C	5C	

System Type and Element:	ABDAA, Hardware, Algorithm				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND fusion box system redundancy	Hardware failure with system on which the algorithm (conflict identification and resolution identification) resides		1E	5E	

System Functionality Mitigations

System Type and Element:	GBDAA, Sensor, Active				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	
Real-time propagation modeling during operations	Propagation issues producing detection holes	D	1E	2E	
Real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	
Tracking intruders AND avoiding operations near the edge of your well surveilled volume.	Target is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	
Real-time EM propogation modeling to correct errors in intruder positions	Refraction causing inaccurate target information	D	2B	4B	

System Type and Element:	GBDAA, Sensor, Passive				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
Real-time propagation modeling during operations	Propagation issues producing detection holes	D	1E	2E	Same as GBDAA, Sensor, Active
Real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	Same as GBDAA, Sensor, Active
Tracking intruders AND avoiding operations near the edge of your well surveilled volume	Target is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	Same as GBDAA, Sensor, Active
Real-time EM propagation modeling to correct errors in intruder positions	Refraction causing inaccurate target information	D	2B	4B	Same as GBDAA, Sensor, Active
A means for cleaning the lens in flight	Dirty lens (e.g., EO/IR)	D	1E	5C	
Checks for physical realizability to identify issues with ownship position AND enactment of a procedural mitigation (e.g., land).	Erroneous signal or position data (ownship)		1E	3E	

System Type and Element:	**GBDAA, Hardware, Supporting Systems**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
User indication of target latency (e.g. timestamp or color status) AND procedural action (i.e. RTB and more conservative separation minimums)	Latency exceeds threshold rendering target data unusable	DTEM	1E	4E	
Redundant communication OR l**ogical checks (e.g. filtering impossible aircraft motion)**	Unknown amount of data Comms from sensor is corrupted for less than, or equal to, 3 seconds, and is nonrecurring	T	3B	5C	
Redundant communication AND **logical checks (e.g. filtering impossible aircraft motion)**	Unknown amount of data Comms from sensor is corrupted for longer than 3 seconds	T	1E	5E	
Logical checks (e.g. filtering impossible aircraft motion)	Unknown amount of data Comms from sensor is corrupted for longer than 3 seconds	T	1E	3E	
Redundant communication AND **Rigorous data integrity checks**	High autonomy, commanded maneuver data are corrupted for less than 3 seconds	M	1D	2E	

System Type and Element:	**GBDAA, Hardware, HITL MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
User indication of target latency (e.g. timestamp or color status) AND procedural action (i.e. RTB and more conservative seperation minimums)	Latency exceeds threshold rendering target data unusable	TE	1E	4E	

System Type and Element:	**GBDAA, Software, Algorithm**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
End user is provided a representation of this measurment error and considers for operation (with seperation standards).	Algorithm will always provide imperfect historical and current position (i.e. track) for single target	T	1C	4A	
Send plot data to display	Algorithm fails to provde a track	T	1D	3E	
Send plot data to display	Algorithm fails to provde tracks for multiple targets	T	1D	3E	
System needs to display uncertainties to human user	Algorithm fails to ID conflict with intruder(s) (HITL) at twice the distance of well-clear	E	3D	4E	
Algorthim needs to understand and utilize sensor uncertainties in target positions	Algorithm fails to ID conflict with intruder(s) (HOTL) at twice the distance of well-clear	E	1D	4E	
Algorithm utilizes a DTED and Geospatial data regarding obsticles to define no-fly locations in conjunction with site survey to determine any changes from what is currently in database.	Algorithm provides proper resolution resulting in CFIT/obstacle	E	1D	3E	

System Type and Element:	**GBDAA, Software, MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Uncertainty error is directly communicated to User	Horizontal/Vertical representation of multiple targets has additional uncertainty beyond sensor measurment error	T	1E	4E	
Check categories of known targets (e.g., ownship)	Erronous aircaft category displayed	T	3C	5C	

System Type and Element:	**ABDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
Real-time propagation modeling during operations	Propagation issues producing detection holes	D	1E	2E	Same as GBDAA, Sensor, Active
Real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	Same as GBDAA, Sensor, Active
Tracking intruders AND avoiding operations near the edge of your well surveilled volume	Target is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	Same as GBDAA, Sensor, Active
Real-time EM propagation modeling to correct errors in intruder positions	Refraction causing inaccurate target information	D	2B	4B	Same as GBDAA, Sensor, Active

System Type and Element:	ABDAA, Sensor, Passive				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
Real-time propagation modeling during operations	Propagation issues producing detection holes	D	1E	2E	Same as GBDAA, Sensor, Active
Real-time, reliable, accurate monitoring of weather conditions that degrade sensor performance	Weather (rain, clouds, etc.) causing detection holes	D	1E	3E	Same as GBDAA, Sensor, Active
Tracking intruders AND avoiding operations near the edge of your well surveilled volume.	Target is not detected within the well surveilled volume due to temporarly reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	Same as GBDAA, Sensor, Active
Real-time EM propogation modeling to correct errors in intruder positions	Refraction causing inaccurate target information	D	2B	4B	Same as GBDAA, Sensor, Active
A means for cleaning the lens in flight	Dirty lens (e.g., EO/IR)	D	1E	5C	
Checks for physical realizability to identify issues with ownship position AND enactment of a procedural mitigation (e.g., land).	Erronous signal or position data (ownship)		1E	3E	

System Type and Element:	**ABDAA, Hardware, Supporting Systems Onboard**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Redundant communication AND **Rigorous data integrity checks**	Data corrupted-for less than 3 seconds- between onboard DAA system and CS (CS is presumably onboard)		1D	1E	

System Type and Element:	**ABDAA, Software, System Management MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Check categories of known targets (e.g., ownship) OR Procedurally preclude PIC from assuming intruders' performance based on category	Erroneous aircaft ID/category displayed (in optional IDS)	T	3C	5C	

System Type and Element:	**ABDAA, Software, Algorithm**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Algorithm utilizes measurment error and considers for operation (with separation standards).	Algorithm will always provide imperfect historical and current position (i.e. track) for single target	T	1C	4A	
Utilize plot data in algorithm to enforce separation standards and utilize a track prediction algorithm robust enough to handle data drop outs	Algorithm fails to provde a track	T	1D	3D	
Utilize plot data in algorithm to enforce separation standards and utilize a track prediction algorithm robust enough to handle data drop outs	Algorithm fails to provde tracks for multiple targets	T	1D	3E	
Algorthim understands and utilizes sensor uncertainties in calculated target positions	Algorithm fails to ID conflict with intruder(s) (HOTL) at twice the distance of well-clear	E	1D	4E	
Algorithm utilizes a DTED and Geospatial data regarding obsticles to define no-fly locations in conjunction with site survey to determine any changes from what is currently in database	Algorithm provides proper intruder resolution but results in CFIT/obstacle	E	1D	3E	

Pre-Flight Mitigations

System Type and Element:	**GBDAA, HITL, Human Execution Error**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Develop and validate UAS DAA centric phraseology AND Practical performance evaluation AND Place DAA monitor in front of the PIC	Unclear commumication between RPIC and individual providing DAA guidance	T	1D	1E	

System Type and Element:	**GBDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan	Mechanical failure due to fatigue	D	1E	1E	
Health monitoring (e.g. signal to noise ratio) AND **pre-flight interference assessment**.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND **pre-flight interference assessment**.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	
Better definition of needed buffer based on propagation modeling using observed soundings	Propagation issues producing detection holes	D	1E	1E	
Preflight planning takes into consideration weather impacts to the DAA sensors	Weather (rain, clouds, etc.) causing detection holes	D	1E	1E	
Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.	Terrain-induced detection holes	D	2D	4E	
Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.	Sensor cannot provide accurate enough position information	D	3A	5E	

System Type and Element:	GBDAA, Sensor, Passive				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan	Mechanical failure due to fatigue	D	1E	1E	Same as GBDAA, Sensor, Active
Health monitoring (e.g. signal to noise ratio) AND **pre-flight interference assessment**.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND **pre-flight interference assessment**.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
Better definition of needed buffer based on propagation modeling using observed soundings	Propagation issues producing detection holes	D	1E	1E	Same as GBDAA, Sensor, Active
Preflight planning takes into consideration weather impacts to the DAA sensors	Weather (rain, clouds, etc.) causing detection holes	D	1E	1E	Same as GBDAA, Sensor, Active
Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.	Terrain-induced detection holes	D	2D	4E	Same as GBDAA, Sensor, Active
Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.	Sensor cannot provide accurate enough position information	D	3A	5E	Same as GBDAA, Sensor, Active

System Type and Element:	**GBDAA, Hardware, Supporting Systems**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND Supporting system redundancy	Mechanical failure due to fatigue	DTEM	1E	5E	
Recurring maintenance plan AND fusion box system redundancy	Fusion box failures	T	1E	5E	

System Type and Element:	GBDAA, Hardware, HOTL MMI				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND MMI system redundancy	Mechanical failure due to fatigue		1E	5E	

System Type and Element:	**GBDAA, Hardware, HITL MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND MMI system redundancy	Mechanical failure due to fatigue	TE	1E	5E	

System Type and Element:	**GBDAA, Software, Algorithm**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
End user is provided a representation of this measurment error and considers for operation (**with seperation standards**).	Algorithm will always provide imperfect historical and current position (i.e. track) for single target	T	1C	4A	
Algorithm utilizes a DTED and Geospatial data regarding obsticles to define no-fly locations **in conjunction with site survey to determine any changes from what is currently in database**.	Algorithm provides proper resolution resulting in CFIT/obstacle	E	1D	3E	

System Type and Element:	GBDAA, Software, MMI				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Separation standards (for nominal conditions) plus a buffer is employed as a condition of current CONOPs (e.g. 3-5 NM with ASR-11) AND Alert from health monitoring system regarding latency	Horizontal/Vertical representation of multiple targets has additional uncertainty beyond sensor measurement error	T	1E	4E	
Procedurally preclude PIC from assuming intruders' performance based on category AND **additional separation standards**	Erroneous aircraft category displayed	T	3C	5C	

System Type and Element:	**ABDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan	Mechanical failure due to fatigue	D	1E	1E	Same as GBDAA, Sensor, Active
Health monitoring (e.g. signal to noise ratio) AND **pre-flight interference assessment**.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND **pre-flight interference assessment**.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
Better definition of needed buffer based on propagation modeling using observed soundings	Propagation issues producing detection holes	D	1E	1E	Same as GBDAA, Sensor, Active
Preflight planning takes into consideration weather impacts to the DAA sensors	Weather (rain, clouds, etc.) causing detection holes	D	1E	1E	Same as GBDAA, Sensor, Active
Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.	Terrain-induced detection holes	D	2D	4E	Same as GBDAA, Sensor, Active
Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.	Sensor cannot provide accurate enough position information	D	3A	5E	Same as GBDAA, Sensor, Active

System Type and Element:	ABDAA, Sensor, Passive				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan	Mechanical failure due to fatigue	D	1E	1E	Same as GBDAA, Sensor, Active
Health monitoring (e.g. signal to noise ratio) AND **pre-flight interference assessment**.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Monitor natural sources of interference (e.g. solar flares) AND health monitoring (e.g. signal-to-noise ratio) AND **pre-flight interference assessment**.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
Better definition of needed buffer based on propagation modeling using observed soundings	Propagation issues producing detection holes	D	1E	1E	Same as GBDAA, Sensor, Active
Preflight planning takes into consideration weather impacts to the DAA sensors	Weather (rain, clouds, etc.) causing detection holes	D	1E	1E	Same as GBDAA, Sensor, Active
Detailed modeling of sensor coverage relative to terrain and structures prior to flight to define appropriate operational buffers.	Terrain-induced detection holes	D	2D	4E	Same as GBDAA, Sensor, Active
Define MOPS for connecting sensor to visualization system such that operating characteristics are understood for sensors being used.	Sensor cannot provide accurate enough position information	D	3A	5E	Same as GBDAA, Sensor, Active

System Type and Element:	ABDAA, Hardware, Supporting Systems Onboard				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND Supporting system redundancy	Mechanical failure due to fatigue		1E	5E	

System Type and Element:	ABDAA, Hardware, Supporting Systems Offboard				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND supporting system redundancy	Mechanical failure due to fatigue		1E	5E	

System Type and Element:	**ABDAA, Hardware, Algorithm**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Recurring maintenance plan AND fusion box system redundancy	Hardware failure with system on which the algorithm (conflict identification and resolution identification) resides.	TE	1E	5E	

System Type and Element:	**ABDAA, Software, Algorithm**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Algorithm utilizes measurment error and considers for operation (**with separation standards**).	Algorithm will always provide imperfect historical and current position (i.e. track) for single target	T	1C	4A	
Utilize plot data in algorithm to enforce **separation standards** and utilize a track prediction algorithm robust enough to handle data drop outs.	Algorithm fails to provde a track	T	1D	3D	
Utilize plot data in algorithm to enforce **separation standards** and utilize a track prediction algorithm robust enough to handle data drop outs.	Algorithm fails to provde tracks for multiple targets	T	1D	3E	
Algorithm utilizes a DTED and Geospatial data regarding obsticles to define no-fly locations **in conjunction with site survey** to determine any changes from what is currently in database.	Algorithm provides proper intruder resolution but results in CFIT/obstacle	E	1D	3E	

Training and Performance Evaluation Mitigations

System Type and Element:	GBDAA, HITL, Human Execution Error				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Practical performance evaluation added to training	User(s) is poorly trained on the man-machine interface	T	1D	1E	
Practical performance evaluation added to training AND visual cues (e.g. trail information of intruders) AND Aural and Visual alerts	Misinterpretation of target data	T	2D	2E	
Practical performance evaluation added to training AND required reporting of colorblindness.	User is colorblind when the Man-Machine interface uses color	T	1E	5E	
Develop and validate UAS DAA centric phraseology AND **practical performance evaluation** AND place DAA monitor in front of the PIC.	Unclear communication between RPIC and individual providing DAA guidance	T	1D	1E	
Practical performance evaluation added to training AND required reporting of hearing limitations.	User is deaf when the Man-Machine interface uses aural alerts	E	2E	5E	
Practical performance evaluation.	User has low proficiency in recognizing conflict	E	1E	5E	
Practical performance evaluation.	User has low proficiency in identifying conflict resolutions	E	1E	5E	
PIC is trained to recognize ghost targets and to validate with procedure turns	Pilot becomes fixated during maneuvers from a ghost target of ownship resulting in diminished Situational Awareness	M	3D	4D	

System Type and Element:	**GBDAA, HOTL, Human Management Error**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
System design should include audio and visual alarms AND **training emphasis on most common critical failures** AND automatic mitigations.	User takes no action to resolve hardware issues	DTEM	1E	3E	
System design should include audio and visual alarms AND **training emphasis on most common critical failures** AND automatic mitigations.	User takes no action to resolve DTEM software issues	DTEM	1E	3E	
System design should include audio and visual alarms AND **training emphasis on ADM** AND command of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate	User executes inappropriate procedure given an abnormality or failure	DTEM	1E	2E	

System Type and Element:	**GBDAA, Software, MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
User is trained on sensor capabilities AND alert from health monitoring system regarding latency.	Horizontal/Vertical representation of multiple targets has additional uncertainty beyond sensor measurement error	T	1E	4E	
Training for PIC to recognize ghost targets.	False target	T	4B	4B	

System Type and Element:	ABDAA, HOTL, Human Management Error				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
System design should include audio and visual alarms AND **training emphasis on most common critical failures** AND automatic mitigations.	User takes no action to resolve hardware issues	DTEM	1E	3E	Same as GBDAA, HOTL, Human Management Error
System design should include audio and visual alarms AND **training emphasis on most common critical failures** AND automatic mitigations.	User takes no action to resolve DTEM software issues	DTEM	1E	3E	Same as GBDAA, HOTL, Human Management Error
System design should include audio and visual alarms AND **training emphasis on ADM** AND command of execution override is available, but message includes reasoning for why the automated system believes another mitigation is appropriate	User executes inappropriate procedure given an abnormality or failure	DTEM	1E	2E	Same as GBDAA, HOTL, Human Management Error

System Type and Element:	**ABDAA, Software, System Management MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Training for PIC to recognize ghost targets.	False target (in optional IDS)	T	4B	4B	

Health Monitoring Mitigations

System Type and Element:	GBDAA, Sensor, Active				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring for environmental threats	Mechanical failure due to environmental impacts	D	1E	1E	
Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	
Monitor natural sources of interference (e.g. solar flares) AND **health monitoring (e.g. signal-to-noise ratio)** AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	
More detailed health monitoring of sensor data.	Partial target data are provided	D	3C	4C	
More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.	Degraded sensor performance such that no positional target data are provided	D	2C	3C	

System Type and Element:	**GBDAA, Sensor, Passive**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring for environmental threats	Mechanical failure due to environmental impacts	D	1E	1E	Same as GBDAA, Sensor, Active
Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Monitor natural sources of interference (e.g. solar flares) AND **health monitoring (e.g. signal-to-noise ratio)** AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
More detailed health monitoring of sensor data.	Partial target data are provided	D	3C	4C	Same as GBDAA, Sensor, Active
More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.	Degraded sensor performance such that no positional target data are provided	D	2C	3C	Same as GBDAA, Sensor, Active
Health monitoring of signal AND procedural mitigation (e.g., land)	Signal used for detection ceases	D	1E	3E	
More detailed health monitoring of sensor data.	Signal used for detection degrades	D	3C	4C	

System Type and Element:	GBDAA, Hardware, Supporting Systems				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring and replacement parts (can include PC) AND procedure turn if needed	Fusion box failures	E	1E	3E	
Ping across LAN components (i.e. health monitoring) to identify issues AND Procedural action (e.g. RTB, decend and loiter, go to ground)	Data communication failure within DAA supporting systems	E	1E	3E	

System Type and Element:	**GBDAA, Software, MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Separation standards (for nominal conditions) plus a buffer is employed as a condition of current CONOPs (e.g. 3-5 NM with ASR-11) AND **alert from health monitoring system regarding latency**	Horizontal/Vertical representation of multiple targets has additional uncertainty beyond sensor measurement error	T	1E	4E	
Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) AND apply a mitigation like return-to-base or land	Incorrect horizontal target positions displayed	T	1E	3E	
Provide health monitoring such that the user is alerted that latency has become too large. This mitigation would be provided within the MMI.	Latency exceeds threshold rendering target data unusable	T	1E	3E	
Provide health monitoring that alerts to loss of targets on display (e.g. inclusion of reference to a fixed relative target) apply a mitigation like return-to-base or land	Sustained loss of multiple targets	T	1E	3E	
Health monitoring system to alert accuracy of ownship position (not sure what this will look like)	Horizontal representation of ownship incorrect	E	1E	3E	

System Type and Element:	**ABDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring for environmental threats	Mechanical failure due to environmental impacts	D	1E	1E	Same as GBDAA, Sensor, Active
Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Monitor natural sources of interference (e.g. solar flares) AND **health monitoring (e.g. signal-to-noise ratio)** AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
More detailed health monitoring of sensor data.	Partial target data are provided	D	3C	4C	Same as GBDAA, Sensor, Active
More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.	Degraded sensor performance such that no positional target data are provided	D	2C	3C	Same as GBDAA, Sensor, Active

System Type and Element:	**ABDAA, Sensor, Passive**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring for environmental threats	Mechanical failure due to environmental impacts	D	1E	1E	Same as GBDAA, Sensor, Active
Health monitoring (e.g. signal to noise ratio) AND pre-flight interference assessment.	Brief loss of target(s) due to interference (≤ 5 s)	D	3E	3E	Same as GBDAA, Sensor, Active
Monitor natural sources of interference (e.g. solar flares) AND **health monitoring (e.g. signal-to-noise ratio)** AND pre-flight interference assessment.	Sustained loss of target(s) due to Interference (> 5 s)	D	1E	1E	Same as GBDAA, Sensor, Active
More detailed health monitoring of sensor data.	Partial target data are provided	D	3C	4C	Same as GBDAA, Sensor, Active
More detailed health monitoring of sensor data resulting in earlier identification of the degraded system.	Degraded sensor performance such that no positional target data are provided	D	2C	3C	Same as GBDAA, Sensor, Active
Health monitoring of signal AND procedural mitigation (e.g., land)	Signal used for detection ceases	D	1E	3E	Same as GBDAA, Sensor, Passive
More detailed health monitoring of sensor data.	Signal used for detection degrades	D	3C	4C	Same as GBDAA, Sensor, Passive

System Type and Element:	**ABDAA, Software, System Management MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) AND apply a mitigation like return-to-base or land	Horizontal representation of multiple targets is incorrect (in optional IDS)	T	1E	3E	
Provide health monitoring that alerts to loss of targets on display (e.g. inclusion of reference to a fixed relative target)	Sustained loss of multiple targets (in optional IDS)	T	1E	5C	
Health monitoring system to alert accuracy of ownship position (not sure what this will look like)	Horizontal representation of ownship incorrect (in optional IDS)	E	1E	3E	

System Type and Element:	ABDAA, Hardware, Algorithm				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring (MMI) and procedural mitigation (e.g., RTB or land)	Hardware failure with system on which the algorithm (conflict identification and resolution identification) resides.		1E	3E	

Procedural Mitigations

System Type and Element:	GBDAA, HITL, Human Execution Error				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Assume all targets are real and mitigate appropriately.	Pilot becomes complacent failing to maneuver from an actual intruder believing it is a false target	M	1D	5E	
PIC is trained to recognize ghost targets and to **validate with procedure turns**.	Pilot becomes fixated during maneuvers from a ghost target of ownship resulting in diminished Situational Awareness	M	3D	4D	

System Type and Element:	**GBDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Sensor diversification AND **additional procedural limitations on environmental conditions**.	Mechanical failure due to environmental impacts	D	1E	4E	
Avoid all targets	Improper identification of real targets among many false targets	D	2B	5A	
Tracking intruders AND **avoiding operations near the edge of your well surveilled volume**.	Target is not detected within the well surveilled volume due to temporarly reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	

System Type and Element:	**GBDAA, Sensor, Passive**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Sensor diversification AND **additional procedural limitations on environmental conditions**.	Mechanical failure due to environmental impacts	D	1E	4E	Same as GBDAA, Sensor, Active
Avoid all targets	Improper identification of real targets among many false targets	D	2B	5A	Same as GBDAA, Sensor, Active
Tracking intruders AND **avoiding operations near the edge of your well surveilled volume**.	Target is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	Same as GBDAA, Sensor, Active
Health monitoring of signal AND **procedural mitigation (e.g., land)**	Signal used for detection ceases	D	1E	3E	
Procedural mitigation (e.g., land)	Dirty lens (e.g., EO/IR)	D	1E	3E	
Checks for physical realizability to identify issues with ownship position AND **enactment of a procedural mitigation (e.g., land)**.	Erroneous signal or position data (ownship)		1E	3E	
Procedural mitigation such as return to base or land.	Loss of signal and position data (ownship)		1E	3E	

System Type and Element:	**GBDAA, Hardware, Supporting Systems**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
User indication of target latency (e.g. timestamp or color status) AND **procedural action (i.e. RTB and more conservative separation minimums)**	Latency exceeds threshold rendering target data unusable		1E	4E	
Replacement parts (can include PC) AND **procedure action (e.g. RTB, go to ground, loiter)**	Mechanical failure due to fatigue		1E	3E	
Health monitoring and replacement parts (can include PC) AND **procedure turn if needed**	Fusion box failures		1E	3E	
Ping across LAN components (i.e. health monitoring) to identify issues AND **procedural action (e.g. RTB, decend and loiter, go to ground)**	Data communication failure within DAA supporting systems		1E	3E	

System Type and Element:	**GBDAA, Hardware, HOTL MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Replacement parts (can include PC) AND procedure turn if needed	Mechanical failure due to fatigue		1E	3E	

System Type and Element:	**GBDAA, Hardware, HITL MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Replacement parts (can include PC) AND **procedure turn if needed**	Mechanical failure due to fatigue	TE	1E	3E	
User indication of target latency (e.g. timestamp or color status) AND **procedural action (i.e. RTB and more conservative separation minimums)**	Latency exceeds threshold rendering target data unusable	TE	1E	4E	

System Type and Element:	GBDAA, Software, MMI				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Apply a procedural mitigation such as checking aircraft altitudes via radio communications AND apply a mitigation like return-to-base or land	Erronous aircraft altitude displayed for multiple aircraft	T	1E	3E	
Check categories of known targets (e.g., ownship) AND additional separation standards	Erronous aircaft category displayed	T	3C	5C	
Procedurally preclude PIC from assuming intruders' performance based on category AND additional separation standards	Erronous aircaft category displayed	T	3C	5C	
Provide redundant information [e.g., direct feed from sensor(s) on a separate display] AND apply a mitigation like return-to-base or land	Incorrect horizontal target positions displayed	T	1E	3E	
Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) AND apply a mitigation like return-to-base or land	Incorrect horizontal target positions displayed	T	1E	3E	
Provide redundant information [e.g., direct feed from sensor(s) on a separate display] AND apply a mitigation like return-to-base or land	Sustained loss of multiple targets	T	1E	3E	
Provide health monitoring that alerts to loss of targets on display (e.g. inclusion of reference to a fixed relative target) AND apply a mitigation like return-to-base or land	Sustained loss of multiple targets	T	1E	3E	

System Type and Element:	ABDAA, Sensor, Active				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Sensor diversification AND **additional procedural limitations on environmental conditions**.	Mechanical failure due to environmental impacts	D	1E	4E	Same as GBDAA, Sensor, Active
Avoid all targets	Improper identification of real targets among many false targets	D	2B	5A	
Tracking intruders AND **avoiding operations near the edge of your well surveilled volume**.	Target is not detected within the well surveilled volume due to temporarily reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	

System Type and Element:	**ABDAA, Sensor, Passive**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Sensor diversification AND **additional procedural limitations on environmental conditions**.	Mechanical failure due to environmental impacts	D	1E	4E	Same as GBDAA, Sensor, Passive
Avoid all targets	Improper identification of real targets among many false targets	D	2B	5A	Same as GBDAA, Sensor, Passive
Tracking intruders AND **avoiding operations near the edge of your well surveilled volume**.	Target is not detected within the well surveilled volume due to temporarly reduced S/N ratio (e.g. detection nodes, partial beam blockage)	D	2A	2D	Same as GBDAA, Sensor, Passive
Health monitoring of signal AND **procedural mitigation (e.g., land)**	Signal used for detection ceases	D	1E	3E	Same as GBDAA, Sensor, Passive
Procedural mitigation (e.g., land)	Dirty lens (e.g., EO/IR)	D	1E	3E	Same as GBDAA, Sensor, Passive
Checks for physical realizability to identify issues with ownship position AND **enactment of a procedural mitigation (e.g., land)**.	Erronous signal or position data (ownship)		1E	3E	Same as GBDAA, Sensor, Passive
Procedural mitigation such as return to base or land.	Loss of signal and position data (ownship)		1E	3E	Same as GBDAA, Sensor, Passive

System Type and Element:	**ABDAA, Hardware, Supporting Systems Onboard**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Procedure action (e.g. RTB, go to ground, loiter)	Mechanical failure due to fatigue		1E	3E	

System Type and Element:	ABDAA, Hardware, Supporting Systems Offboard				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Replacement parts (can include PC) AND procedure action (e.g. RTB, go to ground, loiter)	Mechanical failure due to fatigue		1E	3E	

System Type and Element:	**ABDAA, Software, System Management MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Provide redundant information [e.g., direct feed from sensor(s) on a separate display] AND **apply a mitigation like return-to-base or land**	Horizontal representation of multiple targets is incorrect (in optional IDS)		1E	3E	
Provide health monitoring system that alerts to this issue (e.g. monitor position relative to a fixed reference target) AND **apply a mitigation like return-to-base or land**	Horizontal representation of multiple targets is incorrect (in optional IDS)		1E	3E	
Provide redundant information (e.g., from GCS) AND **apply a mitigation like return-to-base or land**	Erroneous aircraft altitude displayed for multiple aircraft (in optional IDS)		1E	3E	
Apply a procedural mitigation such as checking aircraft altitudes via radio communications AND apply a mitigation like return-to-base or land	Erroneous aircraft altitude displayed for multiple aircraft (in optional IDS)		1E	3E	
Check categories of known targets (e.g., ownship)	Erroneous aircaft ID/category displayed (in optional IDS)		3C	5C	
Procedurally preclude PIC from assuming intruders' performance based on category	Erroneous aircaft ID/category displayed (in optional IDS)		3C	5C	

System Type and Element:	**ABDAA, Hardware, System Management MMI**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Procedural action (e.g., land) until management MMI is restored.	Power outage		5C	5C	
Procedural action until management MMI is restored.	Mechanical failure due to fatigue		5D	5D	

System Type and Element:	ABDAA, Hardware, Algorithm				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Health monitoring (MMI) and **procedural mitigation (e.g., RTB or land)**	Hardware failure with system on which the algorithm (conflict identification and resolution identification) resides.		1E	3E	

Medical Mitigations

System Type and Element:	GBDAA, HITL, Human Execution Error				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Practical performance evaluation added to training AND required reporting of colorblindness.	User is colorblind when the Man-Machine interface uses color	T	1E	5E	
Practical performance evaluation added to training AND required reporting of hearing limitations.	User is deaf when the Man-Machine interface uses aural alerts	E	2E	5E	

Software Standards Mitigations

System Type and Element:	GBDAA, Sensor, Active				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
DO178 B standard	Software failure	D	1E	1E	

System Type and Element:	**GBDAA, Sensor, Passive**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
DO178 B standard	Software failure	D	1E	1E	Same as GBDAA, Sensor, Active

System Type and Element:	**ABDAA, Sensor, Active**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
DO178 B standard	Software failure	D	1E	1E	Same as GBDAA, Sensor, Active

System Type and Element:	**ABDAA, Sensor, Passive**				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
DO178 B standard	Software failure	D	1E	1E	Same as GBDAA, Sensor, Active

System Type and Element:	ABDAA, Software, Algorithm				
Mitigation:	Hazard:	Function:	Initial Risk (Worst Credible):	Residual Risk (Worst Credible):	Notes:
Build and test software to an agreed level within DO-178C	Software lacks robustness/maturity	E	1D	1E	