A54- A11L.UAS.97: PROPOSE UAS RIGHT-OF-WAY RULES FOR UNMANNED AIRCRAFT SYSTEMS (UAS) OPERATIONS AND SAFETY

September 30, 2024

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16. Abstract :

The integration of Unmanned Aircraft Systems into the National Airspace System (NAS) necessitates a comprehensive reevaluation of right-of-way (ROW) rules. This research investigates the safety and operational implications of proposing ROW rules for UAS in low-altitude airspace, encompassing small UAS, UAS encountering other UAS, and swarms of UAS and crewed aircraft. The study employs a systematic approach, integrating literature reviews, gap analyses, simulations, and flight tests to derive data-driven recommendations. The findings highlight the applicability of the existing ROW rules of crewed aircraft to UAS operations and the necessity of updating traditional ROW rules, which have been historically grounded in the "see and be seen" principle and aircraft maneuverability, to accommodate the capabilities of detect-and-avoid (DAA) systems in ensuring safe separation and collision avoidance. The research underscores the significance of Beyond Visual Line of Sight (BVLOS) operations for the UAS industry. It identifies regulatory and research gaps that must be addressed to enable the safe application of ROW rules in BVLOS scenarios. Furthermore, the right-of-way rules for general encounter scenarios have been recommended systematically, along with data-driven maneuverability recommendations, rationale, and required standards. Additionally, the ROW influencers and aircraft handling characteristics have been discussed in detail. The research investigates the efficiency of remote ID to assist in avoidance maneuvers. The study proposes that non-ADS-B reservable airspace (NARA) be used to segregate airspace and mitigate conflicts between UAS and non-cooperative crewed aircraft. The research concludes by presenting recommendations for ROW rules in diverse UAS operational contexts, as well as suggestions for future research and regulatory development to foster the safe and efficient integration of UAS into the NAS.

17. Key Words

Unmanned Aircraft Systems (UAS), Right-of-Way (ROW) Rules, Crash avoidance systems, Detect and Avoid (DAA), Beyond Visual Line of Sight (BVLOS), Reserved Airspace Concept (RAC), Non-ADS-B Reserved Airspace, Remote Identification (RID), Shielded operations.

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Acronym	Meaning
A2C2	Army Airspace Command and Control
AAM	Advanced Air Mobility
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ARC	Aviation Rulemaking Committee
ASSURE	Alliance for System Safety of UAS Through Research Excellence
ASTM	ASTM International
BVLOS	Beyond Visual Line Of Sight
CFR	Code of Federal Regulations
DAA	Detect And Avoid
ERAU	Embry Riddle Aeronautical University
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
GPS	Global Positioning System
KU	University of Kansas
LAANC	Low Altitude Authorization Notification Capability
NARA	Non-ADS-B Reserved Airspace
NAS	National Airspace System
NMAC	Near Mid-Air Collision
sNMAC	Near Mid-Air Collison of sUAV
NOTAM	Notice to Airmen
PIC	Pilot In Command
RPIC	Remote Pilot in Command
RAC	Reserved Airspace Concept
RID	Remote Identification
RoW	Right of Way
SPS	Standard Positioning Service
sUAS	Small UAS
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
UND	University of North Dakota

UTM	Unmanned Aircraft System Traffic Management
WC	Well Clear
sWC	Small Well Clear

TABLE OF DEFINITIONS

Collision Avoidance	Collision avoidance involves preventing an intruder from penetrating a volume of airspace centered on the aircraft within which avoidance of a collision can only be considered a matter of chance (FAA, 2016; DoD, 2011). Collision avoidance is distinct from well clear in that well clear provides greater separation than collision avoidance. Collision avoidance can rely on both human and automated systems. The pilot uses proper scanning techniques, sounds (for Uncrewed Aircraft System (UAS) pilots), and vigilance. Automated systems include a sense and avoid system function where the Pilot in Command (PIC) is alerted to a conflict and manually takes action, or the UAS diverts to prevent a collision.
Cooperative intruders	Cooperative intruders carry equipment that allows the ownship to receive state information about the intruder. Electronic transmission of position information to include Mode C or Automatic Dependent Surveillance-Broadcast (ADS-B) are examples of cooperative technology. It is important to note that not all cooperative intruders are ADS-B equipped. ADS-B equipage is a subset of the larger set of cooperative aircraft. (Ramasamy, 2015)
Non-cooperatitve Intruders	Non-cooperative intruders are "silent," and all state data must be determined by sensors supporting the UAS operation, which may include both onboard and ground-based systems. (Ramasamy, 2015)
Detect and Avoid (DAA)	The capability of a UAS to remain well clear from and avoid collisions with other aircraft. (Federal Aviation Administration, 2009).
Mid-sized uncrewed aircraft	There is no standard definition of mid-sized uncrewed aircraft. However, for purposes of this research, a mid-sized UAS is one that is greater than 55 pounds but smaller than an aircraft capable of carrying a person. This can include aircraft such as the RMAX uncrewed helicopter, a ScanEagle, or the RQ-7 Shadow fixed-wing drone. The distinction for this research is not necessarily based on weight or size, however, but on conspicuity.
Remote Pilot in Command (RPIC)	The RPIC is a person who holds a remote pilot certificate with a small Unmanned Aircraft System (sUAS) rating and has the final authority and responsibility for the operation and safety of an sUAS operation conducted under part 107.
Reserved Airspace Concept (RAC)/Non-ADS-B Reserved Airspace (NARA)	A volume of airspace with defined boundaries and times within which particular rules apply and which particular aircraft might be operating within. This supports operations in controlled or uncontrolled airspace and conceptually exists as two types. First, a 3D polygon-shaped block of airspace; second, a 3D corridor defined by specified height, width, and length that can support beyond visual line of sight operations The intent the RAC or NARA is to segregate aircraft that cannot reasonably detect each other, specifically, to segregate crewed aircraft that are not equipped with ADS-B out, from uncrewed aircraft that cannot detect aircraft that are not equipped with ADS-B out.

Right-of-way (RoW) (FAR 91.113)	The right of a vehicle to proceed with precedence over others in a particular situation. Right-of-way rules establish which aircraft in any encounter must give way to the other aircraft. 14 Code of Federal Regulations (CFR) § 91.113 is Right-of-way rules: Except for water operations.
Right-of-Way Violation (ROWV)	A right-of-way violation occurs when an aircraft, despite having the right of way, is compelled to change its course in order to avoid a collision with another aircraft. This implies that the other aircraft failed to yield as required, thereby infringing upon the right of the first aircraft to proceed on its intended path without obstruction.
See and Avoid (FAA-H-8083-3C)	See and avoid refers to the obligation conferred on each person operating an aircraft to maintain vigilance so as to see and avoid other aircraft. See and avoid includes the requirement to give way to aircraft with the RoW, and not pass over, under, or ahead of it unless well clear. 14 CFR Part B states that when weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the RoW, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear. This concept relies on knowledge of the limitations of the human eye and the use of proper visual scanning techniques to help compensate for these limitations. Pilots should remain constantly alert to all traffic movement within their field of vision, as well as periodically scanning the entire visual field outside of their aircraft to ensure detection of conflicting traffic. A proposal in the Beyond Visual Line of Sight (BVLOS) Aviation Rulemaking Committee (ARC) Final Report (BVLOS ARC (FAA, 2022), 2022) recommends replacing this term with 'Detect And Avoid.'
See and Be Seen	Visual separation of air traffic depends on the principle of see and be seen, which requires that each person operating an aircraft maintain vigilance so as to see and avoid other aircraft and recommends that each person operating an aircraft make their own aircraft as visible as possible to other aircraft. The "See and Be Seen" concept incorporates both detection and conspicuity to enable safe interactions between aircraft. It is foundational to the principles of see and avoid, right-of-way, night lighting, and much of Part 91. The concept also underpins electronic detection and conspicuity systems, including transponders, TCAS, and ADS-B In/Out.
Sense and Avoid	Sense and Avoid is the capability of a UAS to remain well clear from and avoid collisions with other airborne traffic. Sense and avoid provides the functions of self-separation and collision avoidance to fulfill the regulatory requirement to see and avoid (DoD, 2011).
Shielded Operation	The FAA Drone Advisory Committee defines shielded operations as "flight within close proximity to existing obstacles and not to exceed the height of the obstacle" (Federal Aviation Administration, 2020c, pg. 31). Civil Aviation

	Authority of New Zealand defines a shielded operation as one in which the "drone remains within 100 meters of, and below the top, of a natural or man-made object" (Civil Aviation Authority (CAA) of New Zealand, 2019).
Small Uncrewed Aircraft	Small Uncrewed Aircraft are small platform and associated elements (including communication links and components that controls the craft) that are required for the safe and efficient operation of such in the National Airspace System (NAS) (AIM, 2021). The actual aircraft must weigh less than 55 lbs. on takeoff including everything on board or otherwise attached (FAA, 2021).
Swarm	Swarms are biologically inspired collective robot systems, operate without centralized control, which uses local interactions with other robots and the environment as control inputs. Swarms use indirect communication from a leader robot to perform complex action or behavior. The disturbance to individual robots may not affect the overall ability or satisfy the collective goal (Leaf 2021).
Multi-Robot system	A multi-robot system consist of few agents which are assigned to do a specific task, which they cooperate to complete a goal. In a multi-robot system, each robot is able to do some sub-tasks of a given task. For such multi-robot system, it requires all the nodes (robots/drones) to reach the ultimate goal.
Well Clear (WC)	Well Clear is used in 14 CFR 91.113 to define the separation that a pilot must maintain between their aircraft and another aircraft with the RoW so as to not violate or interfere with the other aircraft's RoW. Part 91. states that when encounters occur, the aircraft that does not have the RoW shall give way to the aircraft with the RoW, and may not pass over, under, or ahead of the aircraft with the RoW unless well clear. The intent of Well Clear is to 1) maneuver in a manner that doesn't interfere with another aircraft's right of way and 2) maneuver in a manner that doesn't create a hazardous situation requiring collision avoidance. For DAA systems, a well clear violation also occurs when aircraft come closer than the DAA well clear separation criteria. A well clear violation is an indication that a right-of-way violation may have occured.A recommendation in the BVLOS ARC (FAA, 2022) proposes to replace this term with 'adequate separation.'

EXECUTIVE SUMMARY

The integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS) necessitates a comprehensive reevaluation of Right-of-Way (RoW) rules. This research investigates the safety and operational implications of proposing RoW rules for sUAS in low-altitude airspace, encompassing small Unmanned Aircraft System (sUAS), sUAS encountering other sUAS, swarms of sUAS, and crewed aircraft. The study employs a systematic approach, integrating literature reviews, gap analyses, simulations, and flight tests to derive data-driven recommendations. The findings highlight the applicability of the existing RoW rules of crewed aircraft to sUAS operations and the necessity of updating traditional RoW rules, which have been historically grounded in the "see and be seen" principle and aircraft maneuverability, to accommodate the capabilities of Detect-And-Avoid (DAA) systems in ensuring safe separation and collision avoidance.

The research underscores the significance of future Beyond Visual Line of Sight (BVLOS) operations for the UAS industry. It identifies regulatory and research gaps that must be addressed to enable the safe application of RoW rules in BVLOS scenarios. Furthermore, the right-of-way rules for general encounter scenarios have been recommended systematically, along with data-driven maneuverability recommendations, rationale, and required standards. Additionally, the RoW influencers and aircraft handling characteristics have been discussed in detail. The research investigates the potential use of Remote Identification (RID) technology for electronic conspicuity and detection.

The bulk of the simulations conducted were focused on the required detection distance capability needed to accommodate RoW rules. As such, the focus has been on defining a detection distance that reduces the severity of the encounter, as measured by the avoidance of a right-of-way violation. The determination of risk, then, requires a separate consideration of likelihood.

In one area, the team did not concur with the BVLOS Aviation Rulemaking Committee's (ARC's) initial recommendation to shift the legal burden from the sUAS to the crewed aircraft, requiring the crewed aircraft to give way to sUAS below 400ft Above Ground Level (AGL). The findings in this research address a temporary solution to alleviate the clear safety concerns related to this BVLOS ARC recommendation while still maintaining the position that sUAS should not have RoW below 400ft AGL.

A summary of the key findings in the report includes:

- Proposing Non-ADS-B Reservable Airspace (NARA) be used to segregate airspace and mitigate conflicts between sUAS and non-cooperative crewed aircraft below 400ft AGL.
- RoW safety hierarchy for RoW decision-making between sUAS and various sUAS and crewed aircraft with over 40 recommendations directly related to RoW rules in diverse sUAS operational contexts.
- RoW recommendations below 400ft AGL for interactions between sUAS, multiple-sUAS, and crewed aircraft. In part, recommendations include Head-On, Converging, Overtaking, and Emergency/distress encounters.
- An additional 11 recommendations for future research to include regulatory and standards development are needed to foster the safe and efficient integration of sUAS BVLOS below 400ft AGL into the NAS.

1 INTRODUCTION – RIGHT OF WAY REVIEW

All NAS users and operators have an equal, equitable, and shared legal responsibility ("duty") to know and abide by the applicable and appropriate provisions of the Federal Aviation Regulations (FARs) and Aircrew Information Manual pertaining to their operation. Since 1998, the law in aviation is that those regulations, procedural, and informational documents are evidence of the standard of care among all pilots *(Management Activities Inc. v. US*, 21 F Supp 2d 1157, citing multiple, 1998.) and violations of FARs constitute negligence as a matter of law (*Id.*). The basic assumption in any right-of-way question, absent of special circumstances such as urgent or emergency status or categorical differences in aircraft type, is that all aircraft are assumed to be able to "see and avoid" others, no matter the situation.

That assumption and legal duty are contained in the existing right-of-way rules under 14 Code of Federal Regulations (CFR) 91. However, UASs are a new paradigm as they do not have an onboard pilot to see and avoid other aircraft, and in many cases, the UA is not visually conspicuous. Therefore, the existing legal duties of aircraft pilots to other aircraft do not work with the operations of aircraft to UAS. While the duty to see and avoid other aircraft remains unchanged, it must shift from the parties specified in current regulations to those capable of performing this function. This shift must be reflected in these recommendations.

Ordinarily, a legal duty rests affirmatively with the person acting or performing a task. When driving, for example, a person must act as a reasonable driver and drive safely, not speed, and avoid collisions. Other drivers are presumed to do the same, and the net result for everyone is increased safety. However, the law sometimes shifts legal burdens when special circumstances exist. For example, bicycle riders have a duty similar to that of car drivers to operate their bicycles safely. Some states shift the legal burden onto car drivers to take special care to avoid accidents with the more vulnerable bicyclists. That is one example of a burden shift. Another example of a burden shift—this time in aviation—is that professional flight crews are "charged with the knowledge which in the exercise of the highest degree of care they should have known" (*American Airlines v. US*, 418 F.2d 180, 193 (5th Cir 1969)), while private pilots have only a normal duty of care; i.e. they must act reasonably but might make mistakes. Another example to possibly consider is the shift in burden for Part 107 small drone operations to give way and remain well clear from crewed aircraft since crewed aircraft cannot effectively see-and-avoid small drones.

So, a burden shift of a greater duty onto someone who knows more or has greater technological ability is equally appropriate as shifting a duty away from someone who has less ability or capability. Both these principles apply in assessing the legal duties of UAS operators and other aircraft in the context of examining existing RoW rules and recommending changes to them.

An example of specific legal duties that have been codified into regulation in the RoW context is 14 CFR 91.113(f)-- Overtaking. An overtaking aircraft has the legal duty to avoid the overtaken aircraft by altering course to the right. While the direction of the maneuver is legally arbitrary and defined by regulation, the fundamental legal duty at issue, ordinarily shared equally by the pilots of both aircraft, shifts to the pilot of only one aircraft. That shift is based both upon the greater capacity of the overtaking craft to avoid a collision (i.e., greater information) and the context—in this case, relative positioning. Relative positioning in that the aircraft pilot being overtaken does not have an ability to visually see-and-avoid behind their ownship

In the aircraft overtaking example, both dissimilarities in information and physical location are key to the burden shift. Dissimilarities in information and physical location can also be used to differentiate legal burdens in a sUAS/sUAS or sUAS/aircraft situation and therefore inform appropriate right-of-way rules for new aircraft interactions not contemplated by existing regulations. For example, a sUAS that has DAA capability has different informational capabilities than one that does not, so the legal burden in that context could be different from that of a sUAS that lacks DAA capability. A DAA equipped sUAS and a non-DAA equipped sUAS looks the same to a crewed aircraft, even though they have very different senses and avoid capabilities. Therefore, it is appropriate to rely upon other attributes, such as position, when shifting the legal burden.

The right-of-way rules described in FAR 91.113 are based upon a shift in responsibilities between pilots in command of separate aircraft that may not be in active communication with one another. That shift occurs in response to (1) information dissimilarities (2) physical location, and 3) maneuver dissimilarity. FAR 91.113 standardizes those shifts by prescribing RoW rules between aircraft with varying abilities to avoid other aircraft. Adding sUAS to the existing RoW structure adds a new variable since they are small-uncrewed by definition. FAR Part 107.37 directs sUAS operators to yield the right of way to all other aircraft. Whether operated by a human or autonomous, sUAS must integrate with RoW in such a way that the existing burden shift regime remains predictable to non-communicating aircraft.

These principles applied to the data generated in this research have been used to provide RoW recommendations in consideration of UAS aircraft and emerging technologies.

2 RESEARCH QUESTIONS

During Task 2, the team identified initial recommendations for RoW rules. Three distinct areas were identified to conduct additional simulation and flight testing. These three areas or rounds were 1) Round 1 - General Interactions, 2) Round 2 - Reserved Airspace Concept, and 3) Round 3 - Remote ID. The investigation of these three areas created research questions that were related to, yet different and often more detailed in nature than the original research questions identified in the proposal. These additional questions and related use cases can be found in the simulation plan submitted as a deliverable for Task 3.

Furthermore, upon request by the research team, the FAA reviewed the initial research questions posed in the FAA’s accepted research proposal and organized them by priority to the FAA.The FAA’s reorganization of research questions assisted the research team’s ongoing efforts to focus the work in a manner that maximized results and outcomes for the FAA. While all research questions were meaningful to the FAA, the organization of these research questions provided the degree of impact the questions were anticipated to have on current FAA activities (i.e., a 'tertiary research question' will still have an impact, just not as much of an impact as a 'primary research question').

The following sections provide that list, organized by Primary, Secondary, and Tertiary; Sub-bullets identify reference in either this document or in the FAA submitted "Preliminary/Draft and Interpretations Report for Task 3 and Task 4," herein referenced as "Task 3 and 4 Report" where the research questions were addressed.

2.1 Primary Research Questions

- What is the hierarchy of safety considerations, concepts, and requirements for establishing right-of-way rules for sUAS operations? What is the safety pedigree and the safety justification for right-of-way rules? Under what conditions are right-of-way rules needed? Under what conditions would additional right-of-way rules be unnecessary, burdensome, or overly prescriptive?
    - Hierarchy of Safety Considerations: Safety of Manned Aircraft, Safety of People and Property on the Ground, Safety of the UAS itself.
        - Reference: Final Report Section 2 and Section 9 - Introduction
    - Safety pedigree: The safety justification lies in the ability of the proposed rules to enable UAS to maintain safe separation distances from other aircraft, thereby mitigating the risk of mid-air collisions.
        - Reference: Task 3 and 4 Report, Section-4: Conclusion/Interpretation Of Simulation And Flight Testing Data; Final Report, Section 9
    - Under what conditions are right-of-way rules needed?
        - Reference: Task 3 and 4 Report, Section: 1; Final Report Section 1 and 9.
- What are the industry priorities for updating or creating new right-of-way rules to better integrate sUAS operations? What should regulators consider in the near-term vs in the longer term?
    - Reserved Airspace Concept (RAC) / Non-ADS-B Reserved Airspace (NARA)
        - Reference: Task 3 and 4 Report, Section 1.3 Reserved Airspace Concept (ROUND 2)
        - Reference: Task 3 and 4 Report, 3.2 Reserved Airspace Concept
        - Reference: Final Report, Section 8
- What are recommended right-of-way rules for unmanned aircraft that may be slightly less conspicuous than other manned aircraft in the airspace? What are the conspicuity metrics and thresholds for determining sUAS right-of-way? Consider the different DAA field of regard requirements for sUAS operating under Part 107.37 and UAS operating under Part 91.113 right-of-way rules. What data exists or can be measured to inform decisions?

- The report does not explicitly define "conspicuity metrics and thresholds" but discusses factors that contribute to conspicuity and how these might influence right-of-way decisions.
  - Reference: Task 3 and 4 Report, Section 1 sUAS vs Crewed
  - Reference: Task 3 and 4 Report, Section 1 - Single and Multiple sUAS vs Crewed
  - Reference: Task 3 and 4 Report, Section 1 sUAS Encounters with a Crewed Aircraft
  - Reference: Task 3 and 4 Report, Section 4 CONCLUSION/INTERPRETATION OF SIMULATION AND FLIGHT TESTING DATA
  - Reference: Final Report, Task 9

- What rules are recommended for interactions between two unmanned aircraft? Consider visual conspicuity, electronic conspicuity, visual operation, BVLOS operation, Remote Identification, maneuverability, altitude, participation in Unmanned Aircraft System Traffic Management (UTM), whether the aircraft is operating under Part 107 or Part 91, and other factors. What data exists or can be measured to inform decisions?
  - Remote Identification (RID)
    - Reference: Task 3 and 4 Report, Section 1.4 Remote ID (Round 3), 3.3 REMOTE ID – ROUND 3
  - Handling characteristics
    - Reference: Task 3 and 4 Report, Section 3 FLIGHT TESTS
    - Reference: Task 3 and 4 Report, Section 3 sUAS vs sUAS and Crewed Aircraft - CA vs sUAS
    - Reference: Task 3 and 4 Report, Section 1 sUAS vs. sUAS
    - Reference: Task 3 and 4 Report, Section 1 sUAS vs Crewed
    - Reference: Final Report, Section 8 and 9
- For sUAS operations below 400ft AGL or below Low Altitude Authorization Notification Capability (LAANC) altitudes, there may be maneuvering constraints due to terrain or obstacles. How do these maneuvering constraints apply to right-of-way rules for interactions between two unmanned aircraft? Should there be additional speed limits or other constraints for operations near terrain or obstacles in order to better accommodate safe interactions between two low altitude unmanned aircraft?
    - Reference: Section 1.3 RESERVED AIRSPACE CONCEPT (ROUND 2)
    - Reference: 3.2 RESERVED AIRSPACE CONCEPT
    - Reference: Section 1 - Estimated Saturation point for sUAS with noncooperative crewed aircraft
    - Reference: Final Report, Section 8 and 9

- UAS do not have an onboard pilot to see-and-avoid other aircraft per Part 91.113. As such, UAS DAA systems require a waiver when operating under Part 91. What recommendations should be considered for updating, revising, or creating new rules to accommodate UAS DAA systems? Should Part 91.113 be updated to allow for UAS DAA systems, or should an entirely new rule be created for UAS operations?
    - The simulations and flight tests conducted in the report provide empirical evidence for the effectiveness of DAA systems in various scenarios.
        - Reference: Task 3 and 4 Report, Section 1 SIMULATIONS
    - The report addresses the question of whether Part 91.113 should be updated or a new rule should be created.
        - Reference: Final Report, Task 9
- Part 107.37 right-of-way rules applies to sUAS visual operations. Should these same right-of-way rules apply to all sUAS regardless of altitude or if they are operated BVLOS?
    - The research highlights the need for alternative solutions, such as DAA systems and RAC/NARA to ensure safe separation in BVLOS scenarios.
        - Reference: Task 3 and 4 Report, Sections 1.2.3, 1.2.4, 1.3.3, 3.1.2, 3.2.2.
    - The study emphasizes the need for robust DAA in addition to RID
        - Reference: Task 3 and 4 Report, Section 3.3 RID
        - Reference Final Report, Section 8 and 9

2.2 Secondary Research Questions:

- Can sUAS that are in proximity to structures take advantage of "shielded" concepts in a similar way as kites in Part 101.13? Does the kite shielded concept have potential applicability to drone operations or is kite shielding used for a different purpose or have a significantly different definition? How much does a visual observer play a part in the shielded kite definition? (Coordinate with the ASSURE DAA Shielded Operations research.)
    - The research explores the RAC/NARA, while not directly equivalent to kite shielding, RACs could potentially be used to create controlled environments where drones operate near structures with reduced risk, similar to the concept of shielded operations.
        - Reference: Task 3 and 4 Report, Section 1.3.
    - The report details flight tests conducted in some scenarios with proximity to structures (e.g., powerline inspections and grid survey missions). The inferences could provide insights into practical challenges
        - Reference: Task 3 and 4 Report, Section 1.3.7, Section 1.3.4
- sUAS that are operated BVLOS do not conform with Part 107, which was written for visual operations. What recommendations should be considered for updating, revising, or creating new rules to accommodate sUAS DAA systems that operate BVLOS? Should Part 107 be

updated to include non-visual operations like DAA or should an entirely new rule be created for UAS operations?

  - The simulations and flight tests conducted in the report provide empirical evidence for the effectiveness of DAA systems in various scenarios.
    - Reference: Task 3 and 4 Report, Section 1 SIMULATIONS
  - The report addresses the question of whether Part 91.113 should be updated or a new rule should be created.
    - Reference: Task 3 and 4 Report, Executive Summary
    - Reference: Final Report, Section 1,8, and 9
- Is there a potential difference for UAS right-of-way rules based on whether the other manned/unmanned aircraft is cooperative or non-cooperative? (Reference RTCA DO-365 and RTCA DO-366)
  - Simulations focused on different scenarios involving intruder aircraft, both manned and unmanned. These scenarios specifically looked at whether the intruding aircraft were following right-of-way rules or not following right of way rules. This helps to differentiate between cooperative aircraft, which follow these rules, and non-cooperative aircraft, which do not.
    - Reference: Task 3 and 4 Report, Sections 1.2.2, 1.2.3, 1.3.2
    - Reference: Final Report, Section 1,8, and 9

2.3 Tertiary Research Questions:

- What are the recommended criteria for determining whether an unmanned aircraft that is converging with or being overtaken by a manned aircraft should follow Part 107.37 right-of-way rules or Part 91.113 right-of-way rules? How can industry know whether their DAA systems should be built with 360 degrees of non-cooperative surveillance or only forward and side surveillance?
  - Outside RAC/NARA, the simulations and flight tests conducted in the report primarily focus on scenarios where the sUAS is required to yield the right-of-way to the manned aircraft, regardless of the specific encounter type. Part 91.113 right-of-way rules were generally found to be applicable.
    - Reference: Task 3 and 4 Report, Sections 1, 3, and 4
    - Reference: Final Report, Task 1,8, and 9
  - Within RAC/NARA, Crewed aircraft operating without ADSB-Out in RAC/NARA does not have RoW. Crewed aircraft operating without ADSB-Out are prohibited from operating in the RAC/NARA reserved by sUAV.
    - Reference: Final Report, Task 1,8, and 9
  - The report emphasizes the importance of clear separation standards for DAA systems to provide sufficient warning and prevent collisions. This could indirectly suggest that the required type of surveillance for a DAA system (360-degree vs.

forward and side) may vary based on the specific right-of-way rules and encounter scenarios in which the UAS is expected to operate.
        - Reference: Reference: Final Report, Task 1,8, and 9
- What are recommended updates to Part 91.113 right-of-way rules to include different sized UAS?
    - The report highlights the need to take into account the performance capabilities of both manned and unmanned aircraft when assessing right-of-way rules.
        - Reference: Final Report, Task 1,8, and 9
        - Reference: Task 3 and 4 Report, Section 4, Conclusions
- What right-of-way rules are recommended for different types of unmanned swarms or multi-UAS operations?
    - The report highlights the need to take into account the performance capabilities of both manned and unmanned aircraft when assessing right-of-way rules.
        - Reference: Final Report, Task 1,8, and 9
        - Reference: Task 3 and 4 Report, Section 4, Conclusions
- How well do Advanced Air Mobility (AAM) and Urban Air Mobility (UAM) concepts fit into Part 91.113 right-of-way rules? Are any right-of-way rule updates recommended?
    - The report does discuss AAM and UAM concepts in relation to Part 91.113 right-of-way rules. The proposed recommendations in the report might be applicable to AAM and UAM concepts as well.
        - Reference: Final Report, Task 1,8, and 9
- Are right-of-way rules needed for UAS that are landing or taking off from an area where there may be people, cars, animals, and so forth?
    - The report doesn't specifically discuss the need for right-of-way rules for UAS when they land or take off in areas with people, cars, animals, and so on. Instead, it concentrates on conflicts in the air between crewed and uncrewed aircraft, rather than interactions at ground level.
        - Reference: Final Report, Task 1,8, and 9
- Smaller unmanned aircraft are just as conspicuous as manned aircraft at night if they are equipped with lighting that has the same luminous output. Under what conditions is it safe for smaller unmanned aircraft to operate like manned aircraft following Part 91.113 right-of-way rules at night? Consider the reduced spacing between wingtip lights, differences between unmanned rotorcraft and unmanned fixed wing aircraft, potential optical range illusions, color blending effects of closely spaced lights of different colors, and so forth.
        - References: Final Report, Task 1,8, and 9

Throughout the final report, each of these questions have been addressed and answered through narrative as well as the final RoW recommendations made in the conclusion and recommendations section of this document.

3 TASKS

As per the FAA's accepted research task plan, for execution of the research efforts within the project "A11L.UAS.97: Propose sUAS Right-of-Way Rules for small-Unmanned Aircraft Systems Operations and Safety Recommendations" (hereinafter A54), the primary tasks of this project were as follows:

0. Project Management
1. Literature Review
2. sUAS Gap Prioritization, sUAS Safety Hierarchy, and Recommendations
3. Research Planning
4. Execution of research, Demonstration, and Flight Test Plans
5. Final Briefing and Final Report

The research was primarily focused on sUAS operating and interacting with crewed aircraft in the NAS below 400ft AGL BVLOS. Various interactions between sUAS, multiple sUAS, and crewed aircraft were addressed. Subsequent tasks described within this document are summaries of the reports submitted throughout the entirety of the research project. Task 5 is completed with the submission and acceptance of this report and the final briefing to the FAA completed as required by the research task plan.

This report provides well-reasoned and well-founded research outcomes that can potentially assist in developing recommendations for RoW involving various interactions between sUAS and crewed aircraft.

Table 1. The submitted deliverables.

Tasks and Deliverables Submitted	**Date Submitted to FAA**
Task 0: 1st Draft Research Task Plan (RTP)	Initial RTP: 30 NOV 21 Final RTP: 18 JUL 23
Task 1: Literature Review	06 MAY 2022
Task 2: sUAS Gap Prioritization, sUAS Safety Hierarchy, and Recommendations	11 AUG 2022
Task 3 – Research Planning Task 3D1: Simulation Plan Task 3D2: Task 3 Initial/Draft Flight Test Plan	 01 November 2022 01 October 2023
Task 4: Flight Test Completed Task 4D1: Preliminary/Draft Results and Interpretation	28 June 2024 28 July 2024
Task 5: Final Briefing and Final Report Project Closeout	16 August 2024 30 October 2024

4 TASK 1: LITERATURE REVIEW AND RISK IDENTIFICATION

4.1 Objectives

The literature review presented a comprehensive exploration of the primary benefits and motivations for RoW rules and summarized existing RoW rules and derivative RoW hierarchies, whose intent was to help identify safety priorities for aircraft. The literature review also identified the key concepts for future exploration, such as airspace management, equipage requirements, and conspicuity rules. The report summarized gaps in RoW rules due to the presence of new entrants in airspace, gaps in regulations, and the gaps in research that were further expanded on in Task 2.

4.2 Methods

This task was completed through a teamwork approach with Embry Riddle Aeronautical University (ERAU) as the lead of the compilation. ERAU assisted with subject matter expertise, periodic reviews, and collaboration with the remaining teams. Other ASSURE project research and expertise were utilized to assist in the development of the literature review.

4.3 Summary of Results

Results are summarized by Akbas et al. (2023). A high-level overview is provided herein. The conclusion confirms RoW rule governance, especially with conflict management and separation. The team found a lack of clarity on operations for sUAS integration. Additionally, the challenge is that RoW rule changes likely depend upon information that is not yet known.

5 TASK 2: UAS GAP PRIORITIZATION, UAS SAFETY HIERARCHY, AND RECOMMENDATIONS

5.1 Objectives

The purpose of Task 2 was to identify the sUAS RoW gaps, prioritize those gaps, and establish initial recommendations for new RoW rules. In the Task 2 report, the team considered the possible categorization of RoW-related gaps, which included 1) gaps in the current RoW rules, 2) other regulatory gaps, and 3) additional research gaps. There were assumptions created in response to the identified research gaps, and these were evaluated in subsequent tasks. Through collaboration within the team and the FAA, the gaps were prioritized. Based on the identified gaps and subsequent assumptions, the team developed an initial safety hierarchy to enable the use cases to be developed and tested in the subsequent sessions.

The team established a gap categorization in the following areas;

RoW Rule Gaps Due to New Entrants in NAS (sUAS). RoW Rules do not address:

- UAS > 55 pounds except if they operate under Part 91 using existing RoW rules.
- UAS operating BVLOS.
- Encounters between multiple UAS, including maneuverability differences.

- Encounters between UAS swarms and other aircraft.
- Shielded operations.
- Operations in scheduled, reserved or segregated airspace blocks or corridors.
- The current range of sUAS sensing methodologies.
- Quantification of well clear for all operational scenarios. BAFR FR 2.1.

Other Regulatory Gaps that do not relate to RoW rules:

- sUAS must transmit RID, however no system must yet receive RID signals.
- If RID will be a RoW solution between sUAS, there is not yet an interrogation rule.
- Crewed aircraft cannot detect sUAS. sUAS RID data transmission is currently inadequate for this purpose.
- FAA has no accepted performance requirements for non-cooperative sensors in the low altitude regime.
- Remote Pilot in Command (RPICs) cannot detect aircraft with an emergency.

Research Gaps that do not directly relate to existing RoW or other regulatory rules but hinder the establishment of a RoW safety hierarchy.

- Environmental conditions assessment and impact on DAA.
- Conspicuity.
- Sensors.
- Air traffic density distribution.
- Unequipped aircraft interactions.
- Capabilities of autonomous systems.

Gaps Based Upon Industry Needs. These were identified through collaboration with low airspace crewed entities.

- Crewed Pilots in Command (PICs) believe RPICs flying in a visual line of sight can better recognize impending encounters.
- Crewed PICs agree that RPICs should always yield right of way.
- Publishing LAANC authorizations (location and times) or mandating NOTAM/DROTAMS for shielded operations (publicly) should occur as soon as possible.
- Implement tiered notification system for crewed PICs of UAS operating in controlled airspace they are transitioning. Notification shows the relative size of nearby UAS and impact energy (similar to operations over people studies).
- The Vertical Aviation International UPAC Advisory Group recommended a ‘highway in the sky system’ for scheduling or reserving air space for BVLOS sUAS operation.

5.2 Methods

This task was completed through research and analysis in the gaps of RoW rules. The research gaps and related assumptions are identified and must be agreed upon by researchers and FAA sponsors to effectively provide a framework for creating proposals for creating proposals to assist in potential ROW policy changes that can accommodate UAS operations below 400 ft AGL.

In order to consider all possible scenarios, several matrices were constructed. Each matrix corresponded to a specific geometry identified in FAR §91.113, i.e., in distress, converging, approaching head-on, overtaking, and landing.

For each of these geometries, scenarios were defined as a combination of the following aircraft and/or operations:

- Crewed aircraft equipped with ADS-B out
- Crewed aircraft not equipped with ADS-B out
- sUAS
- Multiple sUAS flying in formation
- sUAS in specified shielded operations
- sUAS in specified reserved airspace operations

Several of these combinations were deemed symmetrical. These matrices helped the team's analysis and shaped the focus of follow-on tasks and were approved by the sponsor.

5.3 Summary of Results

Overall, Task 2 recommended that an RPIC has a method of determining visibility and cloud clearances. Research in visual conspicuity enhancements was found insufficient or inconclusive for mid-sized drones. The recommended research was to address a wide range of environmental conditions related to conspicuity and that DAA systems remain the long-term solution for lack of conspicuity due to the size and various shapes of UAS. Further study on the visual acquisition of a sUAS was recommended. It was believed that training could not alleviate conspicuity issues surrounding sUAS, and thus is a lower priority research topic for this project. The efficiency of a DAA systems (to detect cooperative and non-cooperative) aircraft (crewed or uncrewed) requires further research. Research on air traffic density of crewed aircraft near an artificial and natural obstacle was identified as a gap. Finally, the most important finding of Task 2 was the need for an airspace reservation system to separate non-cooperative crewed traffic from uncrewed traffic without a non-cooperative DAA capability. Crewed PICs must be able to see this information in planning or as they access low-level airspace.

6 TASK 3: RESEARCH PLANNING

6.1 Objectives

To evaluate the initial recommendations for RoW rules developed in Task 2, research questions were proposed to evaluate the rules through analysis and simulations in order to validate and identify gaps in the initial recommended rules and guide the development of flight test plans in Task 4. Three areas were simulated and analyzed for these purposes. General Interactions focus on head-on, converging, and overtaking geometric traffic encounters as outlined in FAR Part 91.113. The Reserved Airspace Concept, a construct developed in part as a result of Task 2, is intended to assist the separation of sUAS and noncooperative crewed aircraft when operating BVLOS. Finally, Round 3 (i.e. Remote Identification) seeks to identify whether RID could be an effective tool for maintaining RoW as well as whether it can assist in the execution of RoW rules.

6.2 Methods

A variety of simulation platforms were used to conduct simulation testing for RoW rules. These include 1) Fast-time Simulation Testbed – a high fidelity six-degree freedom flight dynamics software package that performs sweeps on high-performance computing clusters across several aircraft and sensor performance parameters to generate metric data; 2) Anylogic – a commercial software platform that can be used to develop multimethod simulation modeling; and 3) High-Fidelity Multi-Agent Heterogeneous sUAS Simulation – an in-house simulator developed by KU that uses high fidelity six degrees of freedom dynamic model of sUAS (instead of a point mass) and autonomous guidance and navigation.

6.3 Summary of Results

6.3.1 *General Interactions*

In the case of sUAS vs sUAS interactions, proposed RoW rules are adequate for maintaining a sNMAC under the assumption that the performance of both aircraft is similar. From the simulation results, if the aircraft has a reasonable vertical performance of 500ft per minute or greater and a Global Positioning Service (GPS) uncertainty of Standard Positioning Service (SPS) (5.64ft Horizontal, 11.22ft Vertical) or better, the aircraft can maintain a sNMAC distance with a detection range of 1,641ft for a nominal 5s pilot response time. This distance is also adequate if the intruder sUAS fails to give way, assuming that the operator of the own aircraft sUAS can determine that the intruder will fail to give way at the required detection range of 1,641ft (Page 16, University of North Dakota (UND)).

For sUAS vs crewed interactions, placing the avoidance burden on the sUAS requires it to have a longer-range sensor or cooperative/DAA system capable of handling reliable detection at distances of 12,451 ft or greater in order to remain Well Clear volume of 2000 ft horizontal by 250 ft vertical for the set of geometries and encounters tested in simulation. This is due to the larger performance delta between the crewed and sUAS aircraft, given the requirements of the well clear safety volume. If the sUAS cannot meet this requirement, it may be appropriate for the sUAS to minimize interactions with crewed aircraft by operating in areas that are restricted for crewed aircraft, such as reserved airspace (Page 24, UND).

Round 1 helicopter vs sUAS experiments aimed to evaluate the performance of standard and non-standard RoW procedures for sUAS versus helicopters. In standard RoW scenarios, crewed vehicles have priority, and sUAS must maintain safe separation. This study highlighted that a right-hand turn by a sUAS is not always a safe avoidance maneuver, necessitating alternative strategies. Parameters explored included start, stop, steps, and unit, with low, middle, and high values tested for most parameters, while drone response distance was examined more granularly. Results showed that in head-on and overtaking scenarios, about 50% of simulations, without safety margins, would have resulted in well clear violations with a mean severity of 52%. Converging scenarios had higher severity, particularly converging right at 65% severity and 40% well clear violation rate. Reduced well clear violations correlated with increased response distance, significantly decreasing from 31.3% at 3000ft to 1.6% at 10,000ft in head-on scenarios.

The study also evaluated non-standard RoW compared to standard RoW procedures. Vertical maneuvers, in particular, significantly reduced risk, with the highest observed risk at 17% for head-on scenarios, much lower than the lowest risk in standard RoW tests. Horizontal maneuvers generally showed lower risk, with some scenarios as low as 3-4%. Risk for vertical maneuvers decreased from 45.5% at 3000ft to 0.0% at 10,000ft, while horizontal maneuvers showed a decrease from 12.6% at 3000ft to 0.0% at 10,000ft. These findings indicate that non-standard RoW maneuvers, especially horizontal ones, can substantially enhance safety and reduce violation rates.

6.3.2 *Reserved Airspace Concept*

In sUAS vs. sUAS interactions in a transiting corridor scenario, the proposed RoW rules are adequate for maintaining an sNMAC separation. The addition of the corridor restriction increased the required distance compared to general interaction results but was not an overlarge increase and did not significantly affect the conclusions and recommendations presented in the general interactions section (Page 52, UND).

Given an aircraft capable of sustaining at least a vertical performance of 500fpm or greater and a GPS uncertainty of SPS or better, the the aircraft can prevent incursion of a 100ft horizontal by 25ft vertical safety volume (sNMAC) with a detection range of 1,641ft given a 5s pilot response time for both following and not-following RoW rules. This also assumes that the aircraft is not restricted to a horizontal-only maneuver for the overtaking geometries for the not-following RoW scenario.

In an emergency corridor scenario where the sUAS in distress is using the corridor for landing purposes, results can be applied for a subset of emergency interactions to find an estimate of the range required for the sUAS to prevent incursion of a 100ft horizontal by 25ft vertical safety volume (sNMAC) from a sUAS in emergency while staying within the corridor. Because the emergency aircraft will most likely be transitioning through altitudes toward the ground, it is regarded as a column of avoidance, and vertical maneuvers are not practical in this situation. These assumptions mean that sUAS vs sUAS encounters, when not following RoW rules, horizontal-only results may still be applied to this specific emergency scenario (Page 56, UND).

Given the general corridor results, the required detection range for a sUAS avoiding an aircraft in distress would require 1,772ft to prevent incursion of a 100ft horizontal by 25ft vertical safety volume (sNMAC) and 2,330ft in an overtaking geometry. This means the sUAS would require at least a 2,330ft detection range to maintain a sNMAC distance against another sUAS in an emergency that is using the corridor as an approach/landing area.

In Round 2 of the experiments, the RAC was introduced, allowing pilots to reserve a specific region for their operation, constraining drone flights to this area. The experiments involved two RAC types: a Rectangular RAC (4600ft by 3000ft, 0ft to 400ft altitude) and a Narrow RAC (5200ft by 1700ft, 0ft to 400ft altitude), each with a 2000ft buffer zone around its perimeter. sUAS patrolled the RAC interiors on pre-defined missions with varying scenarios depending on the encounter points with helicopters. Helicopters had one of four paths intersecting the RAC, exploring different angles and paths.

Two maneuvers were compared: the standard RoW right-hand turn maneuver and the safe-zone maneuver. In the RoW maneuver, drones took a 90° right turn, traveling to the RAC edge and then orbiting until the simulation ended. The safe-zone maneuver involved navigating to the nearest safe zone and orbiting there, aiming to avoid crossing the helicopter's path unless no safe zones were available on the current half of the RAC.

The results showed that in the rectangular RAC, the RoW maneuver had a much higher risk than the Safe Zone maneuver. For instance, in head-on scenarios, the RoW maneuver resulted in a 67% violation rate and a 35% risk metric, compared to the Safe Zone maneuver's 18% violation rate and 5% risk. Similar trends were observed in overtaking and converging scenarios. In the narrow RAC, the RoW maneuver also showed higher risk and violation rates compared to the Safe Zone maneuver. Despite slight variations in risk levels between the two RAC types, the horizontal maneuver consistently maintained a significant safety advantage over the RoW maneuver.

6.3.3 *Remote ID*

In sUAS vs sUAS interactions, the Remote ID transmitter standards and their tested ranges proposed in ASTM International (ASTM) F3411 provide sufficient range to allow an sUAS to properly follow the proposed RoW rules and prevent the incursion of a 100 ft horizontal by 25 ft vertical safety volume. The ranges used in testing are based on the tested ranges of the underlying proposed transmitters and may vary depending on the transmitter, antenna, and external factors such as interference and noise. Simulation results indicated that Bluetooth 4.0 was acceptable for certain configurations, but using conservative assumptions, a Bluetooth 5.0 or WiFi 14dBm Remote ID transmitter would allow the aircraft to reliably prevent the incursion of a 100 ft horizontal by 25 ft vertical safety volume (sNMAC).

In sUAS vs crewed cases, Remote ID is not intended to be used for deconfliction, but simulation results do show that it can aid in deconflicting sUAS vs sUAS using the longest-range transmitter defined in ASTM F3411 in cases where one aircraft has a much higher performance delta. Otherwise, segregating either high-performance UAS or crewed aircraft will be necessary (Page 94, UND).

7 TASK 4: EXECUTION OF RESEARCH, DEMONSTRATION, AND FLIGHT TEST PLANS

7.1 Objectives

Based on the outcomes from Tasks 1, 2, and 3 the research team, consisting of the UND, ERAU, and (KU), developed a project-wide flight test plan to support all testing, and each team developed their own specific flight test cards to execute flight tests of sUAS and crewed aircraft encounters for the predetermined use cases at their individual locations. UND near Grand Forks, ND, ERAU at Knox City, TX, and KU near Lawrence, KS. The intent of testing and demonstrations was to refine and validate initial recommendations. There were three rounds of testing. Round 1 reflected the continuation of the simulation efforts each university accomplished in Task 3. The focus in Round 1 addressed "standard types of geometric encounters, including head-on, converging, and overtaking with both aircraft following proposed right-of-way rules." This was done considering a variety of crewed aircraft (airplane and helicopter) vs sUAS, sUAS vs sUAS, multiple sUAS vs crewed airplane, and crewed helicopter. Round 2 focused on the Reserved Airspace Concept (RAC), also identified in conceptual development as NARA. Round three focused on RID supported by simulation and flight testing. Flight tests often occurred where simulation did not sufficiently answer knowledge gaps. Terminologies may vary between school teams due to standardization at each location. The overall flight test plan was a working document to enable clear communication between the FAA, the researchers and a general standardization for aviation safety. As additional simulation efforts were completed as outlined in the simulation plan (Task 3), the flight test plans were updated to reflect the flight testing that was to be accomplished.

7.2 Methods

This task was completed through a centralized concept of operation (and under the consolidated and approved Flight Test Plan), and a decentralized execution according to approved flight test cards.

During Task 3, the team collaborated in tandem with the progress of Task 3 simulation to begin to formulate how the researchers would conduct flight testing based upon those Task 3 results and interests, and with the guidance of the sponsor (FAA). This made the A54 team ready to take immediate action and begin flight tests quickly as there was a significant delay (close to 12 months) in the project due to the inability of technology integration, which was to support data collection, decision making, and overall aviation safety. An alternative methodology was rapidly integrated which led to several human factors discoveries and recommendations shown in the following section.

Flight testing for the three rounds of testing occurred between February-July of 2024. The team agrees that by supporting three separate testing operations, with variations in aircraft, environments, and crews, the final research results were able to better resemble the broad perspective of the sUAS industry.

7.3 Summary of Results

Results are summarized by Snyder et al. (2024) in the Task 3 and 4 Report (Pages 100-205). In general, flight test results supported Task 2 recommendations and gaps and expanded them with the addition of the Task 3 simulation results, ultimately leading to specific Task 4 goals.

Several themes stand out from Task 4 and helped the A54 Team address RoW rules in the recommendations below. As discussed, the previous tasks guided the team; the efforts planned for flight testing were prompted by a need to address the following areas in support of the original research questions derived from the request for proposal and research task plan;

- General interactions
  - between (cooperative and noncooperative) crewed and uncrewed aircraft,
  - between uncrewed versus uncrewed aircraft,
- Concepts for reserved airspace interactions
  - between (cooperative and noncooperative) crewed and uncrewed aircraft,
  - between uncrewed versus uncrewed aircraft and
- Remote Identification viability in supporting any RoW recommendation.

The A54 Team believed that there were several themes that would influence final recommendations, and they were:

- Specifications on maneuverability and handling characteristics of unmanned aircraft to ensure separation standards are met.
- Specification on the accuracy of the sUAS technology to operate BVLOS, for example, maintaining a given altitude or location accuracy.
- Specifications on crew reaction times to accomplish a collision avoidance maneuver such as a descending turn to remain well clear.
- Clear separations standards for DAA systems to provide adequate warning of collision based on the speed of two aircraft, including two sUAS or an sUAS and crewed aircraft that will result in a Near Mid-Air Collison (NMAC) or well clear violation.
- Specifications on the reservation of certain airspace to allow for the short-term commercialization of sUAS operations yet also enable fair use of the airspace to all users.
- Current minimum regulatory requirements for remote ID systems are not adequate to separate sUAS from other sUAS traffic in BVLOS scenarios.

- Well Clear (WC) and NMAC distances, vertically and horizontally, need to be identified for sUAS when passing manned aircraft and other sUAS.
- Crewed aircraft are unable to effectively visually identify sUAS; therefore, the burden must be left to the BVLOS sUAS aircraft to detect and avoid.

With these interpretations, guided by simulation and flight testing, the A54 team had a path to providing viable RoW recommendations to the FAA.

8 RESERVED AIRSPACE CONCEPT / NON-ADS-B RESERVABLE AIRSPACE – RECOMMENDATION

8.1 Reservable Airspace Concept (RAC)

Airspace Segregation with Equitable Access below 400ft AGL, BVLOS, as NARA: Applicable Scenarios:

- UAS vs Crewed (Fixed wing and Helicopter)
- UAS vs UAS
- Multiple UAS vs UAS

8.2.1 UAS Volume Reservations

The term "Non-ADS-B Reservable Airspace (NARA)" refers to the general Reserved Airspace Concept whereby a volume of airspace is reservable by users (similar to UAS Volume Reservations from UTM ConOps 2.0). The NARA label reinforces that this airspace is only relevant to crewed aircraft not equipped with ADS-B Out and sUAS that do not have the capability to detect crewed aircraft that do not have ADS-B Out and that are operating in low-level airspace (below 400ft AGL). If NARA is reserved by a crewed aircraft, other crewed aircraft would be allowed to transit this airspace under normal Part 91.113 rules provided the crewed aircraft had ADS-B Out. BVLOS sUAS operating in the NARA would need a full DAA system capable of identifying non-cooperative crewed aircraft. These sUAS would also be required to have ADS-B In. If the NARA is reserved by sUAS going BVLOS, then the crewed aircraft entering a NARA would be required to have ADS-B Out to allow the BVLOS sUAS flying to identify the crewed aircraft using one of the two required DAA capabilities. VLOS SUAS would not be impacted by NARA as separation would be maintained visually under current rules and VLOS sUAS would have to give way to all crewed and BVLOS sUAS in the NARA. This concept differs slightly from UAS Volume Reservations discussed in the UTM ConOps 2.0 document published in 2020 in respect to applicability, primarily public safety vs all airspace users below 400ft AGL.

8.2.2 New Category of Reserved Airspace

Through an internal White Paper developed in 2023 (Burgess and Kiernan), the A54 team recommended that a new category of reservable airspace be created. The intent of the RAC/NARA is to keep aircraft that cannot realistically detect each other from occupying the same airspace. UAS may reserve airspace requiring crewed aircraft not equipped with ADS-B Out to be restricted from entering the RAC/NARA for the duration of the reservation, and crewed aircraft that are not equipped with ADS-B Out may reserve airspace in which sUAS that cannot detect non- ADS-B equipped crewed aircraft may not enter for the duration of the reservation (See 8.2.3 NARA Sample System). In all cases, a sUAS reserving this airspace would be required to have ADS-B In.

This concept would allow both BVLOS UAS (with ADS-B In) without a means to detect non-ADS-B equipped crewed aircraft and for non-ADS-B equipped crewed aircraft such as Part 137 (typically ADS- B exempt aircraft) to have equal access to airspace that may have sUAS operating provided the sUAS have a preflight authorization which has reserved the airspace for their use. Likewise, crewed aircraft can only enter the NARA if they are transmitting ADSB Out or if they have a preflight authorization that has reserved the airspace for their use. sUAS can only enter the NARA if they can detect and avoid non-cooperative aircraft. It is believed that this concept would be very helpful in providing “equity in access” to airspace for UAS conducting BVLOS, such as package delivery or inspections, or a crewed aircraft conducting low-level flight operations with no ADS-B or equivalent technology available.

8.2 RAC/NARA Introduction

NARA (refer to figures below) is intended to create a system whereby 1) any crewed aircraft that does not have ADS-B Out (Figure 1 – left side), or 2) UAS being operated BVLOS that are not able to detect and avoid crewed aircraft that do not have ADS-B Out (Figure 2 – right side), can both reserve a volume of airspace (first-come; first-served), therefore, providing equitable access opportunity to airspace while maintaining desired levels of safety. This would allow certificated UAS Operators that cannot detect and avoid crewed aircraft (without ADS-B Out) to fly BVLOS in the NAS while remaining segregated from these non-ADS-B equipped crewed aircraft. This concept is intended to apply only to altitudes below 400ft AGL (inferring a vertical buffer) and below UAS facility map altitudes. Other airspace restrictions would require adjudication. Non-ADS-B equipped crewed aircraft that fly above 400ft AGL (i.e. above the NARA) are not affected. Crewed aircraft transmitting ADS-B Out are also not affected. The assumption is that BVLOS flights outside of NARA, and flights inside NARA without a reservation will only be permitted for UAS that are able to detect and avoid non-cooperative crewed aircraft. UAS with a reservation is still required to detect and avoid aircraft that are transmitting ADS-B Out. The reservation concept only segregates them from aircraft that are not transmitting ADS-B Out. A visual depiction of NARA is shown in the Figures 1 and 2. The figures communicate scenarios of aircraft with a NARA reservation (one UAS and the other crewed) and what other aircraft would simultaneously be allowed in the NARA and what aircraft would not be allowed (circle-slash symbol) based upon DAA and ADS-B Out configurations. It should be noted that for short-term solutions, only UAS would be required to have DAA technologies and crewed aircraft would have ADS-B Out. In the future, using autonomous air taxis or UAS with exceptions to having ADS-B Out, may require operational requirements to be adjusted, assuming the UAS aircraft could have a means to identify which aircraft have souls on board.

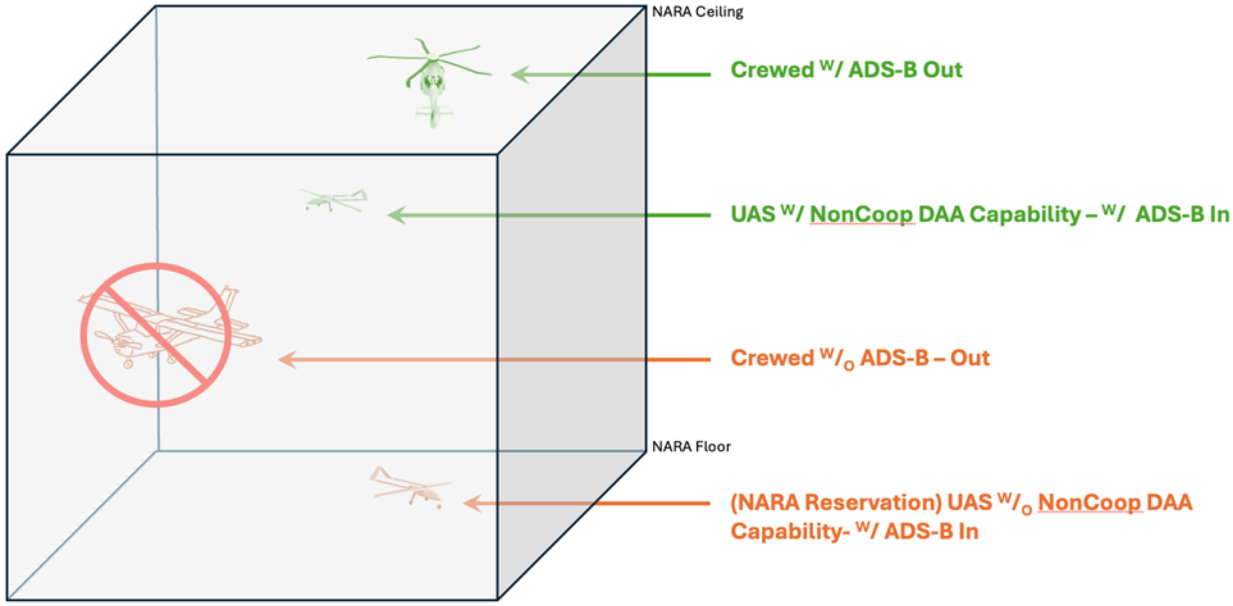

Figure 1. NARA Reservation by sUAS that cannot detect and avoid crewed aircraft not equipped with ADS-B Out.

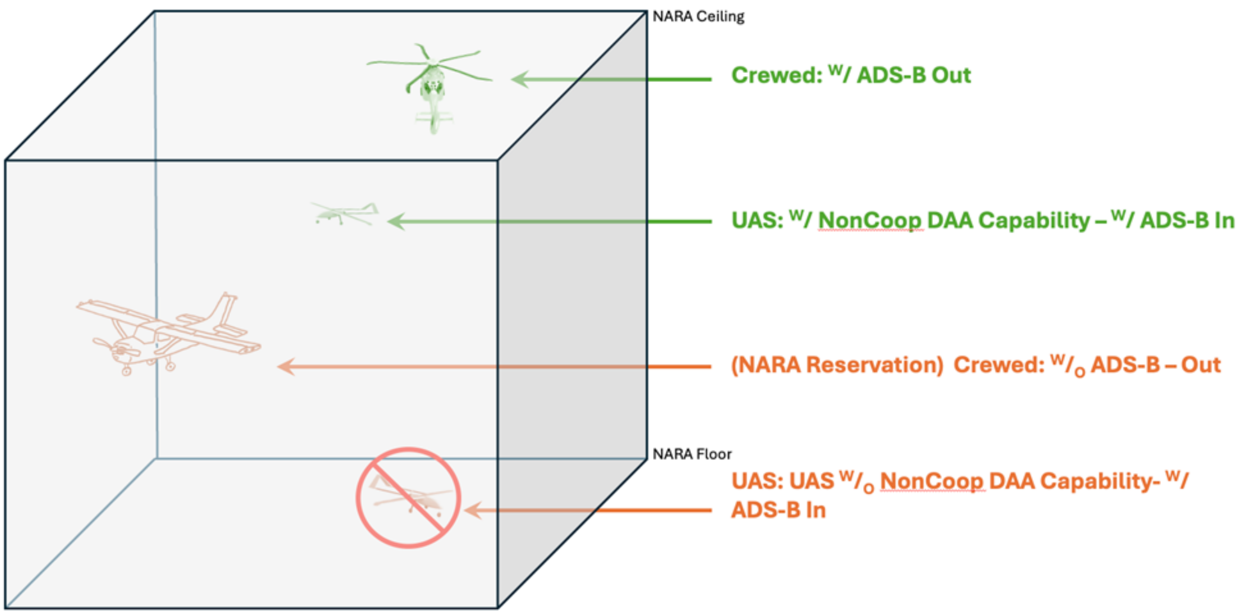

Figure 2. NARA Reservation by crewed aircraft not equipped with ADS-B Out.

8.2.3 NARA Sample System

NARA would be a somewhat new concept in civil airspace, though it has been working in the military with an example in place for decades called the Army Airspace Command and Control (A2C2) system. The A2C2 system involves ensuring separation through segregation in actual or simulated wartime operations. It is employed (in peacetime – in the NAS) within the US Department of Defense Special Use Airspace but is intended to operate in or out of an existing airspace structure. Ultimately, the A2C2 system deconflicts crewed and uncrewed aircraft, artillery, and other airborne conflicts. This system is centrally coordinated/monitored/managed and uses a decentralized scheduling system. The closest existing systems in the NAS are the Notice to Airmen (NOTAM) or Special Use Airspace systems.

A NARA system could potentially enable multiple entities (crewed/uncrewed or uncrewed/uncrewed), depending on the type of DAA capability of the sUAS, to share a NARA (in a stacked or overlapping fashion) through some type of pre-flight coordination or in active communication during flight. Separation in a sharing situation could be maintained via four-dimensional parameters (width, length, height, and time), but specific parameters must be established to reduce the chance of a scheduled airspace conflict situation. Should there ever be an sUAS requirement for full DAA (with ADS-B In, and ability to DAA non-cooperative Crewed Aircraft), this would greatly enhance safety in all classes of airspace.

It is important to also identify that the NOTAM system, while present, is not utilized well by crewed aircraft pilots within the NAS. Conversations by the researcher with low altitude (crewed) airspace users (electrical distribution, agriculture) suggest that integration of NARA would encourage the usage of the NOTAM system in general, or could elevate the importance of the NOTAM system. This method could encumber more resources to manage. Alternatively, like the LAANC system, NARA could become an integrated online system that provides four-dimensional authorizations.

It must be noted there are several machinations of a similar airspace system for separation between sUAS and crewed aircraft. One example is provided in the UTM ConOps 2.0. In our example herein, the concept could enable NARA pre-authorizations of BVLOS flights for UAS that cannot detect non-cooperative crewed aircraft, or conversely, non-cooperative crewed aircraft outside of exempted areas. In this methodology, pre-authorizations would not be required for crewed aircraft transmitting ADS-B Out, or BVLOS drones with DAA equipage capable of detecting non-cooperative crewed or uncrewed aircraft.

8.2.4 NARA Scheduling and Notifications.

NARA would operate as a system whereby UAS Operators or crewed aircraft pilots could reserve a block of airspace below 400' AGL for a period of time and space to accomplish flight operations. As an example, a linear infrastructure inspection reservation would include segmentized four-dimensional blocks of airspace so as not to disrupt other flight operations that may occur adjacent to or across (for linear configurations) the intended reservation blocks. This is similar to the UTM Concept of Operation 2.0 (2020). These reservations could be facilitated through updates to the existing NOTAM system and/or the existing LAANC system. Planned reservations could also be segmented and identified in blocks of space that are not all active at the same time but sequentially to support linear inspections, for example. There will need to be a mechanism for communications (including contact information for operators who reserve NARA to aid in facilitating communications between airspace users) for users to deconflict and present opportunities for co-use, or near co-use. The concept reservation system provides a preflight authorization, and the NARA only exists when the airspace is reserved. There should be no such thing as “inactive” NARA, as the airspace is created by the reservation.

8.2.5 NARA Elements of Safety

The addition of a safety buffer would also enhance safety. Currently, UAS under part 107.51 are limited to 400ft AGL (Part 107.51), while most crewed aircraft are held to a minimum altitude of 500ft (FAR 91.119) while enroute and in theory, this only allows for a 100ft vertical safety buffer. An additional requirement to maintain separation with additional lateral buffer could be regulated to enhance NARA scheduled airspace.

The team’s RAC test flights utilized a 2000ft horizontal buffer. This was added to support a well clear volume for the test that allowed for enhanced air safety for these research flight tests. In most cases even the 2000ft horizontal buffer was found inadequate (primarily due to environmental conditions). Non-cooperative crewed aircraft should not enter a NARA they did not have authorization for as they would be an active threat to their own safety and possibly damage to property or persons on the ground. sUAS with full DAA who can detect other sUAS (but have not reserved the NARA) and intend to enter the NARA, must have active communication with the reserving sUAS and coordinate entry. This is a decision for the FAA if such a condition warrants labeling it a safety of flight hazard.

A regulation change that requires non-ADSB crewed aircraft to adhere to these proposed rules would help to ensure their safety by preventing hazardous interactions. It would encourage greater sUAS ADS-B In equipage without requiring it. Non-ADSB equipped crewed aircraft would either remain above 500' AGL or they would need to obtain a preflight authorization that reserved the low altitude airspace for their own safe operation. NARA could also potentially enable wide-scale limited BVLOS operations without the challenge of integrating non-cooperative DAA. The concept provides equitable airspace access to aviation communities and equitable burden for use of the airspace.

If the NARA system becomes unavailable, no preflight authorizations are provided and the system is fail-safe. The NARA system would build on existing NAS management tools (LAANC, ADAPT, UTM 2.0, NOTAMs and TFRs). NARA could expand BVLOS by building upon DAA availability and requirements, and it could inform future AAM/UAM airspace deconfliction rules.

Alternatively, as a related element of safety, should all airborne platforms (crewed and uncrewed) be equipped with ADS-B In and Out and powered at levels that support missions, the NARA may be modified even further and be easier to manage. Low-flying UAS and Part 137 aircraft (<4-500' AGL), for example, do not need to see aircraft at FL25 and 100nm distance but rather see 2-5 miles in order to detect and maneuver to successfully avoid an encounter with an intruder.

As an aside, if all crewed aircraft were required to transmit ADSB Out in a region of airspace thereby disallowing and permanently segregating non-ADSB aircraft, then that is an alternate concept to the NARA that would also facilitate UAS integration without burdensome non-cooperative DAA technologies. The NARA concept was intended to address non-ADSB aircraft need for access to the airspace and for equitable access by both non-ADSB aircraft and UAS without a means to detect and avoid non-ADSB aircraft.

The US Helicopter Safety Team published a 2019 research report titled "Identifying How UAS/OPA Can Reduce Fatal Accidents in High-Risk Manned Helicopter Operations" for the Helicopter Safety Enhancement (H-SE 90) (Colborn, Burgess, and Keeton, 2019). By default, this report indirectly supports the NARA very well. The report identifies that crewed aircraft could be supplanted by UAS when safety risks are too high (marginal weather conditions, etc.), thus reducing the risk to humans, and potential airspace conflicts between crewed and uncrewed aircraft.

8.2.6 Implementation

Another important consideration for NARA is its possibility to be integrated into existing airspace management tools, such as the LAANC system. While LAANC is widespread and responsive, it is still not fully deployed but is seemingly expandable. Similarly to LAANC authorization, it would seem possible to integrate NARA into or parallel with LAANC. This could extend the LAANC methodology for authorizations similarly for NARA in any airspace. If additional airspace intelligence is necessary, connecting this possible system with the NOTAM process (perhaps only for commercial UAS BVLOS and public safety) would together enable far better airspace information for NAS users, thus enhancing aviation safety.

8.2.7 Equitable NAS Access

Equitable NAS Access enables equal access to both UAS and crewed aircraft communities by allowing either to reserve airspace on a first come, first served basis. The equitable access and equitable burden of obtaining a preflight authorization would help to safeguard low altitude non-ADSB crewed aircraft operations from collisions. This may reduce the cost of entry burden to commercial and individual use. It also enables more BVLOS UAS operations and encourages greater UAS DAA integration. It encourages ADS-B equipage if flight below 500ft AGL is desired. Non-cooperative aircraft will have equal opportunity to reserve airspace as do UAS. NARA could be modified to allow preflight coordination between NARA users.

NARA Example: Crop dusters, while they should transit above 500ft AGL to their area of operation, do not always do so, and additionally, are non-cooperative (lacking ADS-B Out). NARA would allow these operators to either reserve a direct route to a series of NARA blocks over fields or fly above 500ft AGL in transit to/from a NARA block of airspace for spraying. Non-DAA equipped UAS could not transit this area. Non-DAA equipped VLOS UAS could operate within a NARA, and yield RoW to all others. There should be no scenario where BVLOS UAS would not have full non-cooperative DAA equipage. Likewise, if a UAS Operator scheduled a route through an intended NARA reservation area for a low airspace user (such as a crop duster), preflight coordination could occur or the crop-dusting operator would have to reserve the airspace before or after the UAS operator has cleared the NARA (determined by coordination) or their reservation time has expired.

8.2.8 Intruder treatment

There should be no scenario where an sUAS that cannot detect non-cooperative crewed aircraft (without ADS-B Out) is allowed to schedule a NARA. A crewed aircraft not equipped with ADS-B Out, or an sUAS without full DAA equipment (and is not operating VLOS), entering a NARA without a reservation is instigating a flight hazard and aircraft should not enter. If a UAS enters a NARA (not scheduled by their crew) and has full DAA capability, they could potentially be able to safely and legally transit this area.

8.2.9 Right-of-way

Right-of-way rules and emergency procedures are unchanged by NARA.

8.2.10 NARA Recommendation Summary

Due to the reference to NARA in various recommendations, the researcher's first recommendation is for the development of a reserved airspace system to provide a short-term solution for sUAS to operate effectively in BVLOS environment as well as provide safety for non-cooperative crewed aircraft who also desire to reserve airspace and not be impacted by sUAS that do not have the ability to electronically identify non-cooperative crewed aircraft. This short-term solution could be monitored through FAA safety assurance processes to validate its success in Class G airspace and could be expanded to more complex airspace that may contain non-cooperative (non-ADS-B) crewed aircraft.

The research team discussed the FAA could also negate the need for NARA by requiring ADS-B out for all crewed aircraft. As this idea would take time to occur, and as an interim near-term step, it could allow time for all crewed aircraft to equip with ADSB in areas where there are current ADSB exemptions. For example, while most aircraft under a Mode C Veil are required to have ADSB equipage, not all are. If the FAA was interested in removing those exemptions and requiring all crewed aircraft to transmit ADSB Out, the reserved airspace concept could be an interim step that also enabled drone operations.

Enabling ADS-B Out equipage on all BVLOS UAS, while also different than NARA, integrates UAS BVLOS more broadly in the near term. Other parts of the NAS may require some capability for non-ADSB aircraft to operate and hence the reserved airspace concept would be a permanent solution in those areas.

As indicated in the Preliminary/Draft and Interpretation Report for Task 3 and 4 Data, simulation data as well as actual flight testing validated that sUAS need only identify crewed aircraft at distances no greater than two miles for all general interactions related to FAR Part 91.113.

8.2.10.1 FAA concerns

While there may be concerns over the use of an ADS-B only DAA system, it performed well in-flight tests. The RPIC was able to identify (when the best configuration was established) a cooperative crewed aircraft with excess time in encounters. It was discussed that the use (in this case) of a low-power ADS-B Out on the crewed aircraft in a pattern altitude was observable to the RPIC during the flight tests. If all crewed aircraft transmitted , ADS-B Out and possibly certain sUAS operations (in certain complex airspace), it theoretically could significantly enhance flight safety.

9 CONCLUSIONS AND RECOMMENDATIONS FOR ROW RULES

9.1 Safety Hierarchy for Establishment of RoW Rules for UAS Operations

Current regulations aim to distribute the responsibility of avoiding collisions equitably between all aircraft. This means that the burden of taking evasive action can shift between aircraft depending on factors like who has better information about the situation or who is in a better position to maneuver. However, the current system is built on the assumption that small unmanned aircraft systems (sUAS) don't carry human passengers. In cases where an AAM aircraft has humans on board, the new recommendation would need to be developed to place the entire burden of avoiding collisions on the sUAS, even if it means the sUAS might be lost.

For autonomous UAS or air taxis, right-of-way rules should prioritize the safety of both their occupants and those in other aircraft, ensuring that no loss of life is acceptable. Current regulation already addresses aircraft operator duties with humans onboard, such as those contained within 14 CFR 135 or 121. Recall also that the law places the “highest duty of care” on Part 135 or 121 operators. It is assumed that autonomous air taxi operators would be subject to the same duty of care. However, without a human operator on board to make those decisions (and consequent loss of “skin in the game”), allowing an algorithm to make right-of-way decisions that may result in the loss of human life is unacceptable to most people.

This question has been addressed in other non-aviation contexts, however. The right of way decision matrix may be addressed by a simple safety hierarchy. Within our recommendations, this safety hierarchy was applied to shifting the burden to avoid and give way by adhering to an order of precedence. The order of precedence is as follows:

1. Protection of human life - A sUAS may not allow a human onboard or in another aircraft to be harmed through maneuvering or inaction.
2. The burden to avoid shifts to the aircraft or person who has the ability to see/sense and avoid. Generally, a crewed aircraft can not see a sUAS, so the burden shifts to the sUAS to give way. A sUAS with only ADS-B In can not see a sUAS who is capable of identifying non-cooperative traffic, so the burden to avoid shifts accordingly.
3. Ensures consistency with existing RoW rules and allows safe integration of the sUAS into the National Airspace System (NAS).
4. Considers environmental/external influences, such as the boundary of operations. For example, if all operations are below 400 ft AGL, certain maneuvers are not feasible due to terrain. Also, boundaries can be created to use separation as a method to collision avoidance. This example would be reflected within the recommendation of creating a RAC/NARA.

In summary, sUAS must give way in such a way that it does not violate the other crewed aircraft's expectations under FAR 91.113, preserves humans, is possible given the technology present, and lastly, preserves self.

These laws and 91.113 suggest a possibility that DAA or similar equipment must be mandatory at all times, especially for the AAM/UAM applications. A sUAS must make a decision to give way in such a way that it does not violate the other crewed aircraft's expectations under FAR 91.113 and also preserves itself and its (potential) human passengers.

The scenario below further validates the logical sequence that shifts the burden to the sUAS because it has the ability to "sense and avoid" unlike the crewed aircraft. If the sUAS is able to "sense and avoid," then it has the burden of giving way to the crewed aircraft that is unable to see and avoid or give way. The scenario is depicted in the case of Admin. v. Roderick, EA-4803 (1999). In this case, a fixed-wing airplane and helicopter had a mid-air collision in a mountain pass in Alaska. No one was killed, but the pilot was charged with a violation of FAR 91.113 for failure to alter course to the right (he pulled up and turned left). The judge dismissed the charge since the pilot testified he didn't even see the helicopter until too late. So, while the pilot failed to "see and avoid" he didn't violate the right of way rule under 91.113(e) because he wasn't able to see the helicopter and so couldn't give right of way.

Furthermore, this case, when applied to UAS right of way means that the first priority is sense and avoid by any means necessary, and specific right of way rules are secondary to that. You must first see or sense the other aircraft before any specific maneuver (to the right, well clear, etc). So, a UAS that senses a crewed aircraft before the crewed aircraft can visually identify it and maneuver in any way to avoid the crewed aircraft.

9.2 Recommendations for RoW Rules

The distances outlined in this report are based on a series of specific assumptions and operational parameters as detailed in the Task 3 and 4 report. These parameters include, but are not limited to, aircraft speeds, bank angles, vertical speed limits, turn rates, GPS uncertainties, pilot response delays, track update rates, and detection range increments. While distances may vary, they provide the foundation for RoW rules based on the development of adequate separation rules adopted for sUAS vs UAS, Multiple sUAS, and sUAS and Crewed Aircraft.

9.2.1. Head On – sUAS vs sUAS Scenario

a. **Recommendation:** When aircraft are approaching each other head-on, or nearly so, each pilot of each aircraft shall alter course to the right.

b. **Rationale**
    i. The horizontal maneuver of altering course to the right is recommended due to its predictability and simplicity. It has been the standard practice in manned aviation for many years.
    ii. The horizontal maneuver is preferred over the vertical maneuver because of the limited altitude between terrain and 400 ft AGL, potential altitude reporting inaccuracies and varying handling characteristics that may prevent adequate vertical separation.
    iii. Simulation results and flight test results showed that when both aircraft followed the rule and altered course to the right, they were able to maintain a sNMAC and avoid collisions.

c. **Research Reference** – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data
    i. Altitude inaccuracies – Section: 1.1.1 (Simulations) and 3.1.1.4 Flight Test Results - UAS vs sUAS
    ii. Handling Characteristics – Section: 3.1.1 sUAS vs sUAS and CA vs sUAS
    iii. Simulations results – Section: 1.2.2.1.1 sUAS vs. sUAS
    iv. Flight test results – Section: 3.1.1.4 Flight Test Results - UAS vs sUAS
    v. Standard rule for manned aviation – CFR § 91.113

9.2.2. Head On – CA vs Tight Swarm (with 500 ft. Lateral separation)/multi-sUAS Scenario

a. **Recommendation:** Crewed Aircraft has right of way. Avoidance maneuver of sUAS will be to turn right.
    i. Note: Crewed aircraft operating without ADSB-Out are prohibited from operating in the RAC/NARA reserved by sUAV.

ii. Note: For multiple sUAS in a tight formation, both head-on and overtaking encounter angles require a slightly higher detection distance to perform a successful avoidance maneuver; thus, a multiple sUAS is more susceptible to RoW violations, especially higher crewed aircraft speeds (Ref: Page-35, Report for Task 3 and 4).

b. Rationale

i. Aircraft maneuvering to the right keeps rules/maneuvers simple for both crewed and uncrewed pilots by keeping consistent with previously mentioned recommendations.

i. Altitude reporting inaccuracies, varied handling characteristics, and limited altitude available between terrain and 400ft AGL to possibly prevent adequate separation.

ii. Simulation results and flight test results showed that when both aircraft followed the rule and altered course to the right, they were able to maintain a WC and avoid collisions.

c. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

i. Altitude inaccuracies – Section: 1.1.1 (Simulations) and 3.1.1.4 Flight Test Results - UAS vs sUAS

ii. Handling Characteristics – – Section: 3.1.1 sUAS vs sUAS and CA vs sUAS

iii. Simulations results – Section: 1.2.2 sUAS vs. sUAS

iv. Flight test results – Section: 3.1.1.4 Flight Test Results - UAS vs sUAS

v. Standard rule for manned aviation – CFR § 91.113

9.2.3. Head On – sUAS vs Crewed Aircraft Scenario

a. Recommendation

i. Crewed Aircraft has the right of way. The avoidance maneuver of sUAS will be to turn right.

i. Note: Crewed aircraft operating without ADSB-Out are prohibited from operating in the RAC/NARA reserved by sUAV.

ii. Note: sUAS must have a means of detecting the crewed aircraft.

iii. Note: Based on simulations, when flying with a single sUAS, to stay within the prescribed corridor, the required size of the corridor is a function of the relative speeds. Corridors should have an adequate buffer that allows for avoiding ADS-B aircraft without exiting the corridor. (Task 3 and 4 Report Appendix A).

b. Rationale

i. The burden to avoid is shifted to sUAS as testing shows crewed aircraft is likely NOT to be able to see a sUAS to avoid.

ii. Horizontal maneuvering to the right is recommended due to its predictability and simplicity. This consistency benefits both sUAV pilots and onboard pilots of manned aircraft. In the event an onboard pilot visually identifies a sUAV, they can react as they would to any other aircraft, without needing to alter their avoidance maneuvers based on the sUAV's unique characteristics.
iii. The horizontal maneuver is preferred over the vertical maneuver because of the limited altitude between terrain and 400 ft AGL, potential altitude reporting inaccuracies and varying handling characteristics that may prevent adequate vertical separation.

c. Research Reference –See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

i. Altitude inaccuracies – Section: 1.1.1 (Simulations) and 3.1.1.4 Flight Test Results - UAS vs sUAS
ii. Handling Characteristics – Section: 3 sUAS vs sUAS and CA vs sUAS (ERAU, UND)
iii. Simulation results – Section: 1.2.3.1.1 sUAS vs Crewed
iv. Flight test results – Section: 3. Flight Test Results - sUAS vs CA
v. Crewed aircraft not sighted sUAS until they passed – Section: 3 Flight Test Results - sUAS vs CA and Fig 88, Page 143

9.2.4. Converging – sUAS vs sUAS Scenario

a. Recommendation: When two sUAS are converging at approximately the same altitude (except head-on or nearly so), the sUAS to the other's right has the right-of-way.

i. Note: The simulation results of the research suggest that the best maneuver is horizontal avoidance for lower vertical performance and/or higher GPS uncertainty configurations. However, higher vertical performance and lower GPS uncertainty privilege vertical maneuvers (Page 13, Ref: Report for Task 3 and 4).

b. Rationale

i. Aligns with the standard rule that has been followed by manned aviation.
ii. The horizontal maneuver is preferred over the vertical maneuver because of the limited altitude between terrain and 400 ft AGL, potential altitude reporting inaccuracies and varying handling characteristics that may prevent adequate vertical separation.

c. Research Reference

i. See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

ii. Altitude inaccuracies – Section: 1.1.1 (Simulations) and 3.1.1.4 Flight Test Results - UAS vs sUAS
iii. Handling Characteristics – – Section: 3.1.1 sUAS vs sUAS and CA vs sUAS
iv. Simulations results – Section: 1.2.2.1.2 sUAS vs. sUAS
v. Flight test results – Section: 3.1.1.4 Flight Test Results - UAS vs sUAS
vi. Standard rule for manned aviation – CFR § 91.113

9.2.5. Converging – CA vs Tight Swarm (with 500 ft. Lateral separation)/multi-sUAS Scenario

a. **Recommendation** Outside RAC/NARA, when sUAS and crewed aircraft are converging at approximately the same altitude (except head-on, or nearly so), the crewed aircraft has the right-of-way.
  i. Note**:** Maneuver criteria recommended to prevent sNMAC for multiple sUAS, both head-on and overtaking encounter angles require a higher detection distance to perform a successful avoidance maneuver; thus, a multiple sUAS is more susceptible to RoW violations, especially higher crewed aircraft speeds (KU, Page 35, Ref: Report for Task 3 and 4).

b. Rationale
  i. Aircraft maneuvering to the right keeps rules/maneuvers simple for both crewed and uncrewed pilots by keeping consistent with previously mentioned recommendations.
  ii. Simulation results and flight test results showed that when sUAS followed this rule and altered course, they were able to maintain a WC and avoid collisions.
  iii. The horizontal maneuver is preferred over the vertical maneuver because of the limited altitude between terrain and 400 ft AGL, potential altitude reporting inaccuracies, and varying handling characteristics that may prevent adequate vertical separation.
  iv. Tight formation swarming UASs typically involves multiple UASs, often guided by one or more leader UASs that direct the collective movement. Swarm communication can occur either with the leader node or directly among the UASs themselves. However, this communication hierarchy can introduce latency and operational delays. In a hierarchical setup, the leader communicates with its subordinates, who then relay messages further down the hierarchy. This communication delay poses a challenge when attempting to safely maneuver the entire SWARM, particularly in scenarios where an intruder aircraft is encountered. While partial movement of UASs within the SWARM can mitigate this issue, it may still result in a Well clear violation due to the space required to

avoid the crewed aircraft. Additionally, environmental factors such as weather, moisture, and radio interference can further impact communication between UASs in the SWARM, may increase the delays.

c. **Research Reference** – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data
   i. Altitude inaccuracies – Section: 1.1.1 (Simulations) and 3.1.1.4 Flight Test Results - UAS vs sUAS
   ii. Handling Characteristics – – Section: 3.1.1 sUAS vs sUAS and CA vs sUAS
   iii. Simulations results – Section: 1.2.2 sUAS vs. sUAS
   iv. Flight test results – Section: 3.1.1.4 Flight Test Results - UAS vs sUAS
   v. Standard rule for manned aviation – CFR § 91.113

9.2.6. Converging – sUAS vs Crewed Aircraft Scenario

a. Recommendation #1 – Outside RAC/NARA, when sUAS and crewed aircraft are converging at approximately the same altitude (except head-on, or nearly so), the crewed aircraft has the right-of-way.

b. Recommendation #2 – RAC/NARA Reserved by sUAS - When operating in RAC/NARA, and the sUAS and crewed aircraft are converging at approximately the same altitude (except head-on, or nearly so), the crewed aircraft with ADS-B Out has the right-of-way.
   i. Note: Non-ADSB aircraft are prohibited from entering the RAC/NARA when it has been reserved by sUAS.

c. Recommendation #3 – RAC/NARA Reserved by Noncooperative Crewed Aircraft (i.e. no ADSB-Out) - Operating in RAC/NARA, when sUAS and crewed aircraft are converging at approximately the same altitude (except head-on, or nearly so), the crewed aircraft has the right-of-way.
   i. Note**:** sUAS operating within RAC/NARA reserved by Noncooperative Crewed Aircraft must be properly equipped to safely Detect and Avoid noncooperative crewed aircraft within the RAC/NARA. The reserved space must be large enough to accommodate sudden sUAS avoidance maneuvers when affected by performance and environmental conditions.

d. Rationale
   i. The burden to avoid is shifted to UAS as testing shows crewed aircraft is likely NOT to be able to see a sUAS to avoid.
   ii. The horizontal maneuver is preferred over the vertical maneuver because of the limited altitude between terrain and 400 ft AGL, potential

altitude reporting inaccuracies and varying handling characteristics that may prevent adequate vertical separation.

iii. Flight test and simulation results demonstrate that sUAS can effectively avoid head-on collisions with crewed aircraft by maneuvering horizontally, even when the crewed aircraft does not alter its course.

e. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

i. Simulation results – Section: 1.2.3.1.2, 1.2.3.2.3 sUAS vs Crewed

ii. Flight test results – Section: 3 Flight Test Results - sUAS vs CA

iii. Crewed aircraft not sighted sUAS until they passed – Section: 3 Flight Test Results - sUAS vs CA and Figure 88, Page 136

9.2.7. Overtaking – sUAS vs sUAS Scenario

a. Recommendation Each BVLOS sUAS that is being overtaken has the right-of-way, and each pilot of an overtaking BVLOS sUAS shall alter course by altering course to the right.

b. Rationale

i. The recommendation is to caution for sUAS or NonCooperative Aircraft who is confined by the RAC/NARA to avoid overtaking scenarios when approaching the RAC/NARA boundaries. This is due to flight test results showing that aircraft approaching RAC/NARA boundaries frequently exited those established boundaries before completing the overtaking maneuver (See Figure 96, page 157, Task 3 & 4 report). This is attributable to the limited speeds and linear boundaries naturally created by a RAC/NARA.

ii. The intent is not to limit the size of the RAC/NARA, but the recommendation further warrants research to identify warning mechanisms such as in DAA software, that assist the pilot to remain well clear while not exiting the RAC/NARA.

iii. Altitude reporting inaccuracies, varied handling characteristics, and limited altitude available between terrain and 400ft AGL to possibly prevent adequate separation.

c. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

i. See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

ii. Simulation results: 1.2.2.1.3 Overtaking

iii. Flight test results: – Section: 3.1.1. Flight Test Results - sUAS vs sUAS

9.2.8. Overtaking – sUAS vs Crewed Aircraft Scenario

a. **Recommendation #1** – Outside RAC/NARA, when any crewed aircraft is overtaking a sUAS or inside a RAC/NARA when the crewed aircraft, with ADS-B out, is overtaking a sUAS at approximately the same altitude, the crewed aircraft has the right-of-way.
    i. Note: The burden to avoid is shifted to sUAS as testing shows crewed aircraft is likely NOT to be able to see a sUAS to avoid
    ii. Note: Simulation results, with assumed simulation parameters, indicate when a sUAS initiates a descending turn to remain well clear of the crewed aircraft, the descent should be made with a constant descent of 500ft/min or greater while turning. It is suggested that a turn to the left would be optimal as crewed aircraft normally turn right when overtaking an aircraft; they positively identify. While the likelihood of positive identification of the UAS by the crewed aircraft is low, turning right would further separate the two aircraft. As the crewed aircraft would have the right of way, it would not be required to alter course; the burden would shift to the sUAS.
    iii. Note: When crewed aircraft are interacting with sUAS, to remain within the prescribed corridor, the required size of the corridor is a function of relative speeds.

b. **Recommendation #2** – Outside RAC/NARA, when any sUAS aircraft is overtaking a crewed aircraft or inside a RAC/NARA when the sUAS is overtaking a crewed aircraft, with ADS-B Out, at approximately the same altitude, the crewed aircraft has the right-of-way.
    i. Note: The research suggests that the best avoidance maneuver is horizontal avoidance, which involves the sUAS altering course to the right upon identifying the intruder and passing to the right. The report mentions that this maneuver is preferred for lower vertical performance or higher GPS uncertainty configurations (Ref: Report for Task 3 and 4 , Page 13).

c. **Recommendation #3** – RAC/NARA Reserved by sUAS - Noncooperative Crewed Aircraft (i.e., no ADSB-Out) in RAC/NARA reserved by a sUAS operator does not have RoW. Crewed aircraft operating without ADSB-Out are prohibited from operating in the RAC/NARA reserved by sUAV.

d. **Recommendation #4** – RAC/NARA Reserved by Noncooperative Crewed Aircraft (i.e., no ADSB-Out) - Operating in RAC/NARA, all crewed aircraft has right of way over sUAS. sUAS operating within RAC/NARA reserved by Noncooperative Crewed Aircraft, the sUAS must be properly equipped to safely Detect and Avoid any crewed aircraft within the RAC/NARA.

e. Rationale

i. The burden to avoid is shifted to sUAS as testing shows crewed aircraft is likely NOT to be able to see a sUAS to avoid

ii. When the sUAS is not limited by altitude, vertical-only and unrestricted maneuvering is generally favored when overtaking (as per simulations) (Ref: Page-23, Report for Task 3 and 4).

iii. Because the sUAS is limited to operating below 400ft AGL, horizontal-only is recommended to maintain adequate separation.

iv. Overtaking as an avoidance maneuver often extends beyond the RAC/NARA boundary. This was more prevalent in windy conditions.

v. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data.

f. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

i. Simulation results: 1.2.2.1.3 Overtaking

ii. Flight test results: – Section: 3.1.1.5 Flight Test Results - CA vs sUAS

9.2.9. In distress– sUAS vs sUAS Scenario or sUAS vs multi-sUAS Scenario

a. Recommendation - An sUAS in distress has the right-of-way over all other sUAS traffic that can detect and avoid.

i. Note: General results from non-emergency corridor interactions can be applied to estimate the necessary actions for maintaining a sNMAC in this emergency scenario.

ii. Note: The emergency sUAS will use the corridor for approach and landing (Page 56, Ref: Report for Task 3 and 4).

b. Rationale

i. An sUAS in distress may have limited maneuverability or control, increasing the risk of a collision.

ii. The pilot of the distressed sUAS might be preoccupied with the emergency and have reduced situational awareness.

iii. In some cases, an sUAS in distress could be carrying out critical tasks (like search and rescue or medical delivery), making granting it right-of-way crucial for the successful completion of these vital missions.

c. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

i. Reference: Section 1.3.2.5 Emergency

9.2.10. In distress – sUAS vs Crewed Aircraft Scenario (inside and outside RAC)

a. Recommendation – Crewed aircraft in distress has the right-of-way over all other air traffic that can see and/or detect and avoid.

i. Note**:** Maneuver criteria recommended to remain WC. In all cases for all aircraft (crewed and uncrewed), maintaining aircraft control is the initial and most important action. Maneuvering to remain WC is essential and in most cases, immediate avoidance maneuvering may require a manual RPIC action.

b. Rationale

i. The burden to avoid is shifted to sUAS as testing shows crewed aircraft is likely NOT to be able to see a sUAS to avoid.
ii. The pilot of the distressed sUAS might be preoccupied with the emergency and have reduced situational awareness.
iii. This situation does not change from any other flight operation where the sUAS must still remain WC.
iv. In some cases, communicating ownship emergencies to crewed aircraft in the vicinity may not be possible. This may be a consideration for future research regarding BVLOS operations.
v. Crewed aircraft in distress may be communicating their emergency and the sUAS crew may not be receiving their distress communication and must be vigilant in observing DAA/ADS-B information to react in a timely fashion (which should already be happening) to remain WC.
vi. Maneuvering within a NARA with a sUAS in distress, may compromise safety of flight due to conditions.
vii. RPICs should be prepared to conduct immediate action in communicating a loss of visual line of sight where a UAS exits the NARA with presence of crewed aircraft in the vicinity.

c. Research Reference – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data

9.3. ROW Influencers

The following recommendations do not direct a RoW distinction, but they each would support RoW rules and advance safe separation, thus adding to aviation safety on the whole. Additionally, they each inform further research efforts.

9.3.1. Use of RID

a. Recommendation – Minimum RID standards are not sufficient for RID devices to be used for the execution of RoW avoidance maneuvers or being used to maintain separation standards.

b. Rationale

i. RID is on an unprotected spectrum and may receive interference; therefore, it shouldn't be relied on for the safety of life applications.

ii. For sUAS vs sUAS encounters, a collision is not a direct safety of life event.
iii. There are few low-burden mature technology options for a BVLOS drone to detect and avoid a Part 107 drone operation. RID is one potential technology that is a low burden to the Part 107 community but may require updates for RID-based DAA to be more effective.
iv. In the case of sUAS vs sUAS simulations, RID is able to provide enough range to allow sUAS to maintain adequate separation. In the case of sUAS vs Crewed simulations, RID is not sufficient to be used to determine RoW or to assist in avoidance maneuvers. During actual flight testing of sUAS vs sUAS as well as sUAS and Crewed aircraft , the Bluetooth 4.0 was ineffective.
v. In the case of sUAS vs sUAS a minimum of a Bluetooth 5.0 or WiFi 14dBm transmitter is able to provide enough range for the sUAS to maintain an adequate separation.
vi. For sUAS vs Crewed interactions, the maximum range transmitter proposed is able to barely provide enough range but would potentially experience heavy interference or low update rates and would not be practical for maintaining a safe separation.
vii. At maximum range of the transmitters, the update rate can decrease to unusable amounts of time due to packet loss from a weak signal from path loss and other factors.

c. Research Reference

i. Simulation Results: 1.4
ii. Flight Test Results: 3.3 Remote ID – Round 3

9.3.2. Human Factors

a. Recommendation #1:

i. Separation standards need to consider human reaction time.
ii. Note**:** The average human reaction time observed by UND is 3.43, and ERAU is 5.15 seconds, which are based upon on varying systems complexities involved in completing a maneuver.

b. Recommendation #2:

i. Recommend that the DAA graphic interface be integrated as it enhances the RPIC’s situational awareness to execute avoidance maneuvers expeditiously in the effort to remain WC.

c. Rationale

i. Increasing separation standards to compensate for longer reaction times provides a greater safety buffer to accommodate potential delays in response.
ii. The report acknowledges that this data is not statistically significant enough to draw definitive conclusions or make specific recommendations on human reaction times.
iii. Specific graphic interface was included in several of the test locations (ERAU and UND). In the interface, distance rings followed the ownship and more rapidly enabled RPIC's to initiate avoidance maneuvers. Besides enhancing decision-making, it also helped shorten and improve human reaction time.

d. **Research Reference** – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data
i. See Section 3.1.2 Assessment of Flight Test Objectives and Section 3.1.4 Helicopter vs sUAS, Round 1 Objectives Assessment.

9.3.3. Safety Volumes: sNMAC

a. **Recommendation**
i. The current research does not quantitatively assess the dimensions of the sNMAC nor the small well clear (sWC) distances, recommendation for future research in this area.
ii. Simulations and Flight testing for sUAS vs sUAS used the following criteria for NMAC. These distances were based on GPS inaccuracies in various sUAS.
- sUAS-sUAS: 100ft horizontally and 25ft vertically (Ref: Page 3, 10, 283 in Task 3 & 4 report)
- Simulations and Flight testing for sUAS vs CA used the crewed well clear volume instead of the sNMAC volume. Well clear is defined as 2000ft horizontally and 250 ft vertically (Ref: Page-20 in Task 3 & 4 report).

b. **Rationale**
i. Simulation results showed that the initial value of 50 t horizontal and 15ft vertical is too small and could potentially be eclipsed by the GPS uncertainty.
ii. The simulation results show that the 100ft horizontal and 25ft vertical sNMAC performs better than the initial value.
iii. It provides a larger buffer for the GPS uncertainty and the physical size of the aircraft itself.

c. **Research Reference** – See Preliminary/Draft and Interpretation Report for Task 3 and 4 Data
   i. Section: 1.1 Configuration
   ii. Section: 1.2.3 sUAS vs. Crewed
   iii. Section: 1.1.3 Embry-Riddle Aeronautical University
   iv. Appendix D – small NMAC

9.3.4. Technology Recommendations

a. **DAA**: The research underscores the essential role of DAA systems in ensuring safe BVLOS operations and adhering to RoW rules. This is particularly crucial in situations with non-cooperative aircraft or when Remote ID alone is insufficient. The research recommends that DAA systems must reliably detect and alert (at a minimum) but preferably steer clear of other aircraft at WC distance to prevent collisions (Refer to Pages 43, 142, 145, Ref: Report for Task 3 and 4).

b. **GUI**: The impact of the operator's graphical user interface on reaction times, suggesting that optimizing the interface design could help minimize reaction times and improve decision-making during critical avoidance maneuvers (Refer to Figures 92 and 93, Ref: Report for Task 3 and 4).

c. **Cooperative Systems**: The research suggests exploring the development and implementation of cooperative systems that enable communication and coordination between UAS and other airspace users. Such systems could enhance situational awareness, facilitate the implementation of RoW rules, and enable more efficient airspace management (Refer to Pages 25, 95v).

d. **High-Precision GPS**: The simulations demonstrate the importance of accurate positioning information for the effective implementation of RoW rules. The research suggests that high-precision GPS, such as RTK or WAAS-enabled GPS, could be crucial for ensuring precise navigation and maneuvering, especially in BVLOS operations (Refer to Pages 3, 27, Ref: Report for Task 3 and 4).

e. **Enhanced Remote ID Systems**: The research acknowledges the limitations of current Remote ID systems, particularly in BVLOS scenarios. It recommends developing enhanced Remote ID systems with improved capabilities, such as extended range, faster update rates, and potentially more detailed information sharing (Refer to Section 3.3 Remote ID – Round 3, Ref: Report for Task 3 and 4).

9.3.5. RAC/NARA Recommendations

a. **Recommendation #1**. Integrate NARA into the NAS as a fully functional airspace reservation system for crewed aircraft that do not have ADS-B Out and for BVLOS ADSB-only DAA drone operations (i.e. without non-cooperative DAA).
   i. When flying with a single sUAS, to stay within the prescribed corridor, it is recommended that the corridor be wide enough to enable successful

avoidance maneuvers and remain within the corridor based upon UAS performance capability and environmental conditions.

b. **Recommendation #2**. Expand the knowledge base needed to support the integration of the RAC/NARA beginning with, but not limited to, the research questions below as related to the challenges addressed in this report for the reservation of airspace;

i. Within what classes of airspace NARA can exist?
ii. Where could NARA not exist, i.e., known airfields, designated take-off/landing locations, ultralight parks etc.?
iii. What parameters would be used to identify the boundaries of NARA both for operators reserving airspace and other users being notified?
iv. If preflight coordination was enabled, could a sUAS operator with non-cooperative DAA capability allow a non-cooperative crewed aircraft to occupy their reserved airspace?
v. What metrics determine the volume of airspace that can be reserved?
vi. Should NARA airspace buffers be required? How would these be integrated?
vii. Regarding a NARA block, what factors determine the length of time for which airspace can be reserved? Possibly by type of category new Part 108 specifications; such as type of certificate or category of operation?
viii. What determines the limits to an airspace reservation both geographically and temporally?
ix. What reservation vehicle would be used?
x. If a Company A UAS has full DAA (cooperative and noncooperative) capability, then they might be fine with sharing the airspace with Company B to access the same NARA (that was reserved). Also, if I reserve the RAC/NARA as a sUAS with ADS-B In, and another sUAS company wants to overlap reservations, when would that be acceptable?
xi. Would a reservation system be paired with an existing system (such as the LAANC system does for controlled airspace UAS operators or the NOTAM system)?
xii. Notes recommended to prevent sNMAC or remain WC
   - Scheduling RAC/NARA
   - Use of Shared UTM services such as Key site in Texas NTAP
   - Boundary limitations and Buffer zones
   - Use for Shielded operations
   - RPICs should be prepared to conduct immediate action in communicating any loss of link should an sUAS exit a NARA when crewed aircraft are in the vicinity.

9.3.6. UAS above 400ft AGL Scenario

a. **Recommendation:** Consideration should be given to the mission types present in the industry where terrain or separation challenges may be better supported through the encouragement of waivers to the Part 107.51 altitude restrictions.
    i. Note**:** Given terrain in certain areas, to reduce controlled flight into terrain on BVLOS flights or where environmental conditions prompt flight at higher altitudes, operators may seek to fly higher than 400’AGL
    ii. Note: Maneuver Criteria recommended preventing sNMAC or remaining WC-supported climbs or descents as a better avoidance maneuver, but due to the low altitude challenges presented for the UAS, and altitude restriction of 400ft AGL, horizontal maneuvers were deemed the least restrictive to all airspace users.
    iii. Note: At higher altitudes, vertical separation could be used by required aircraft to either descend or climb based on flight direction similar to VFR cruising altitudes above 3000ft AGL.
    iv. Note: In areas like the pacific northwest, where terrain altitudes rapidly change, and the vast amount of forested areas and their standard-sized trees reach the 150-200’+ heights, the adherence to maintaining realistic flight enroute altitudes is a challenge.

9.3.7. Recommendations sUAS Attributes/Handling Characteristics

The following sUAS attributes/handling characteristics do not directly dictate right-of-way rules, but they will influence the maneuverability of sUASs and may, in turn, influence right-of-way rules. These areas warrant further research.

9.3.7.1.Speed

a. **Recommendation:**
    i. Expanded Safety Margins: Given the observed airspeed variability, RoW rules should incorporate wider safety buffers. The dynamic aspect of airspeed, influenced by environmental factors, necessitates a conservative approach to distance calculations. This concept requires further research.
    ii. Note: The purpose is to express increased speed, sometimes caused by tailwinds that can cause an sUAS to quickly exit a boundary area created by a RAC/NARA. To protect the current well clear rules between crewed aircraft outside the RAC/NARA, a safety buffer should be created around a RAC/NARA, with consideration given to remaining well clear or preventing an NMAC.

iii. Note: Assumption Reassessment: The common practice of assuming constant airspeed might not adequately mitigate the risk associated with these fluctuations.

b. Rationale

i. Speed Variability: Both the ScanEagle and Albatross sUAS demonstrate significant deviations from their designated airspeeds.

ii. Environmental Influence: Wind speed and turbulence substantially impact the sUASs' airspeeds.

iii. Airspeed variations are linked to fluctuations in altitude and vertical speeds during maneuvers.

9.3.7.2.Rate of Turn

a. Recommendation

i. Classify UAS by their turn performance (e.g., high rate, medium rate, low rate). This classification would aid in optimizing minimum separation distance.

ii. Require manufacturers to publish the rate of turn specifications for RPICs to reference when conducting collision avoidance.

iii. Early detection of another UAS is critical. The sooner a potential conflict is identified, the more time there is to execute an avoidance maneuver, regardless of the turn rate.

b. **Rationale**:

i. The rate of turn performance of each sUAS is within a given range

ii. The turn performance may be specific to the UASs evaluated and not necessarily applicable to the broader spectrum of UAS types.

9.3.7.3.Vertical Speed

a. **Recommendation**

i. Vertical Speed Limits: Establish maximum vertical speed limits based on airspace classification and operational scenarios to mitigate the risk of rapid altitude changes.

ii. Manufacturers are required to publish vertical speed specifications for RPICs to reference when conducting collision avoidance.

iii. Altitude-Based RoW: Implement altitude-based RoW rules where higher-altitude UASs may yield to lower-altitude UASs.

iv. Safety Buffer: Incorporate a safety buffer to account for variations in vertical speed.

v. Combined Maneuvers: Consider utilizing combined horizontal and descending maneuvers for increased vertical speed when operationally appropriate. For future research, further flight tests should be conducted in similar environmental conditions to validate the effectiveness of combined horizontal and descending maneuvers for achieving higher vertical speeds.

b. **Rationale**:
   i. Maximum vertical speed for Albatross: approximately 408 ft/min, Maximum vertical speed for other ScanEagle: 522 ft/min
   ii. Highest vertical speeds achieved during combined horizontal and descending maneuvers
   iii. Wind speed and turbulence significantly impact vertical speed and altitude

9.3.7.4.Maintaining altitude

a. Recommendation:
   i. Altitude Buffer: Establish a safety buffer for UAS flight altitudes to account for environmental variations.
   ii. Wind Gust Considerations: Incorporate wind gust forecasts into sUAS flight planning, particularly for avoidance maneuvers.

b. Rationale:
   i. sUAS Altitude Deviations: Unintended and significant variations in sUAS altitude were observed during flight.
   ii. Environmental Impacts: Wind speed and turbulence significantly affected sUAS altitude stability.

9.3.7.5.GPS Inaccuracies:

a. **Recommendation**:
   i. DAA Planning: Incorporate observed GPS inaccuracies into DAA calculations for a safety margin.
   ii. Sensor Fusion: Consider integrating additional sensors with GPS data to improve position accuracy.

b. Rationale:
   i. A 30-minute comparison flight between uBlox M9N and QStratZ GPS systems on the Albatross sUAS revealed an average difference of ~19 feet in horizontal distance and ~6 ft in altitude. The maximum difference in horizontal distance is ~36.2 ft and the maximum difference in altitude is 17.2 ft.

9.4. Additional Recommendation for Research, Standards and regulation development to support RoW in BVLOS below 400ft AGL

Based on research efforts, the research team has recommended the following items: additional research, standards and regulation development to support RoW in BVLOS below 400ft AGL.

a. **Recommendation**:

i. Standards for minimum GPS accuracy requirements for sUAS
ii. Standards for terrain data on GUI or aircraft autonomously avoiding
iii. Develop sNMAC and sWC for sUAS to allow for vertical separation maneuvers to maintain adequate separation.
iv. Standards for RID minimum capability to be used as a means of separation between sUAS in flight.
    i. Enhanced Remote ID System Capabilities: Extended range, faster update rates, and potentially more detailed information sharing which may assist in distress and priority situations.
v. sUAS Minimum performance standards for handling characteristics.
    i. Require predictable maneuverability and handling specifications to ensure converging aircraft can anticipate intruder reaction and also be able to execute the necessary maneuvers to maintain separation standards in various encounter scenarios.
vi. Require minimum crew or autonomous reaction times to execute advoidance manuevers.
vii. Recommendation for training and proficiency requirements for RPIC operators.
viii. DAA Interface Design: The impact of the operator's GUI on reaction times, suggests that optimizing the interface design could help minimize reaction times and improve decision-making during critical avoidance maneuvers.
ix. RAC/NARA requirements: Crewed aircraft to have ADS-B Out and RPIC must have location data from sUAS usingADS-B In capability. Consider expanding ADS-B Out for certain sUAS operations.
x. Long Term ADS-B requirements: All crewed aircraft to have ADS-B out to allow burden shift to be on sUAS and eliminate the need for RAC/NARA.
xi. Additional research related to Multi-Robot response vs Swarm Response.

10. REFERENCES

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