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A11L.UAS.97: Propose UAS Right-of-Way Rules for Unmanned Aircraft Systems (UAS) Operations and Safety Recommendations: Literature Review

June 10, 2022

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. A54_ A11L.UAS.97	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle A11L.UAS.97: Propose UAS Right-of-Way Rules for Unmanned Aircraft Systems (UAS) Operations and Safety Recommendations: Literature Review Draft		**5. Report Date** May 6, 2022 **6. Performing Organization Code** ASSURE: Embry-Riddle Aeronautical University, University of North Dakota, University of Kansas
7. Author(s) M. Ilhan Akbas, Ph.D., https://orcid.org/0000-0002-5450-3522; Kristine Kiernan,PhD https://orcid.org/0000-0001-9673-9464, Scott Burgess, Ph.D. https://orcid.org/0000-0002-7870-8565; Paul R. Snyder https://orcid.org/0000-0003-2417-6388, Ph.D. https://orcid.org/0000-0003-2417-6388; Naima Kaabouch, Ph.D.; Mark Ewing, Ph.D.; Shawn Keshmiri, Ph.D.; Sreejith Vidhyadharan Nair, Ph.D. https://orcid.org/0000-0002-0529-4269 ; Joe Vacek, JDO; Anastasia Byrd; Marcos Fernandez Tous, Ph.D. https://orcid.org/0000-0003-1898-4872		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Embry-Riddle Aeronautical University 1 Aerospace Blvd Daytona Beach FL 32114 University of North Dakota Department of Aviation 4251 University Avenue Stop 9036 Grand Forks, ND 58202 University of Kansas 1450 Jayhawk Blvd Lawrence, KS 66045		**10. Work Unit No.** **11. Contract or Grant No.** 15-C-UAS
12. Sponsoring Agency Name and Address Federal Aviation Administration UAS Integration Office 490 L'Enfant Plaza SW Suite 7225 Washington DC 20024		**13. Type of Report and Period Covered** Draft Literature Review (October 2021 - April 2022) **14. Sponsoring Agency Code** 15-C-UAS
15. Supplementary Notes		

16. Abstract

This literature review provides the necessary background to conduct simulations and flight testing to explore the safety and operational considerations involved in proposing right of way rules for UAS in the low altitude environment, including medium sized UAS, UAS encountering other UAS, and swarms of UAS. Right of way rules have traditionally been based on the see and be seen principle, and generally predicated on the maneuverability of each aircraft. However, the advent of aircraft without an onboard pilot demands an updated approach that accommodates the capabilities of detect and avoid systems to provide well clear and collision avoidance assurance. The UAS industry places great importance on the ability to fly BVLOS. Numerous research gaps and regulatory gaps must be closed to enable safe application of right of way in BVLOS flight.

17. Key Words	18. Distribution Statement
Unmanned aircraft systems, beyond visual line of sight, BVLOS, right of way, well clear, collision avoidance, crash avoidance systems, detect and avoid, see and avoid, see and be seen, shielded operations.	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	73	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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AAM	Advanced Air Mobility.
AC	Advisory Circular
ACAS	Automated Collision Avoidance System
ACAS sXu	Automated Collision Avoidance System for Small Unmanned Aircraft Systems
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AIM	Airman’s Information Manual
AMA	Academy of Model Aeronautics
ARC	Aviation Rulemaking Committee
ASSURE	Alliance for Systems Safety of UAS through Research Excellence
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATM	Air Traffic Management
ATP	Airline Transport Pilot
ATS	Air Traffic Service
BVLOS ARC	FAA BVLOS Aviation Rulemaking Committee Final Report
BVLOS	Beyond Visual Line of Sight
CFR	Code of Federal Regulations
COA	Certificates of Waiver or Authorization
CONOPs	Concept of Operations
DAA	Detect and Avoid
DFR	Digital Flight Rules
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LAANC	Low Altitude Authorization and Notification Capability
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NOTAM	Notice to Airman
RoW	Right of Way
RPIC	Remote Pilot In Command
RTCA	Radio Technical Commission for Aeronautics
SBS	See and Be Seen
sUAS	Small Unmanned Aircraft System
TABS	Traffic Awareness Beacon Systems
UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
USS	UAS Service Suppliers

USC	United States Code
UTM	Unmanned Traffic Management
VFR	Visual Flight Rules
VLOS	Visual Line of Sight
VO	Visual Observer
VTOL	Vertical Take-Off and Landing

TABLE OF DEFINITIONS

Small Unmanned Aircraft	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).
Mid-sized unmanned aircraft	There is no standard definition of mid-sized unmanned aircraft. However, for purposes of this research, a mid-sized unmanned aircraft 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 unmanned helicopter, or the RQ-7 Shadow fixed wing drone. The distinction for this paper is not necessarily based on weight or size however, but on conspicuity.
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.
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 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.
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).
See and Avoid (FAA-H-8083-3C)	See and avoid refers to the obligation conferred on each person operating an aircraft to maintain vigilance to see and avoid other aircraft. See and avoid includes the requirement to give way to aircraft with the right of way, and not pass over, under, or ahead of it unless well clear. 14 Code of Federal Regulations (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 right-of-way, 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. 14 CFR Part 91.113 presents the right-of-way rules for different scenarios outside water operations. A proposal in the Beyond Visual Line of Sight (BVLOS) Aviation Rulemaking Committee Final Report (BVLOS ARC (FAA, 2022), 2022) recommends replacing this term with 'detect and avoid'.
Sense and Avoid	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).
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.
Cooperative intruders	Cooperative intruders carry equipment that allows the ownship to receive state information about the intruder, while non-cooperative intruders are "silent" and all state data must be determined by sensors onboard the ownship. Electronic transmission of position information to include Mode C or ADS-B are examples of cooperative technology. It's 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.
Detect and Avoid (DAA)	The capability of a UAS to remain well clear from and avoid collisions with other aircraft. (Federal Aviation Administration, 2009).
Well Clear	The term used in 14 CFR Part 91.113 to define the distance that a pilot must maintain between their aircraft and an aircraft with the RoW. 14 CFR 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. A recommendation in the BVLOS ARC (FAA, 2022) proposes to replace this term with 'adequate separation'.
Adequate Separation	This proposed concept (FAA, 2022), as a replacement of the term 'well clear', is intended to address the context of a broader range of sensing capabilities available in aviation more specifically. The word 'see' is contextually incorrect

regarding Unmanned Aircraft (UA). Available avionics provide the same core intent to identify other aircraft and avoid collisions.

EXECUTIVE SUMMARY

The overall purpose of this project is to inform rulemaking and standards development regarding potential Right of Way (RoW) concepts for manned and unmanned aircraft in the low altitude environment. The information provided will help identify gaps in current rules regarding new entrants into the airspace, as well as explore options for future rules. This literature review supports the project by organizing the problem space and providing the reader with background for RoW rules and concepts for both manned and unmanned aviation.

The literature review addresses the history and the state of the art for RoW rules and how they may conflict or need to be adapted with the integration of Unmanned Aircraft Systems (UAS) into the National Airspace (NAS). Traditionally, safe separation of aircraft in the NAS has depended upon separation of aircraft by Air Traffic Control (ATC) or by the Pilot in Command (PIC), using the principle of see and avoid and established RoW rules. However, as industry proponents continue to push for increased access of UAS in the NAS, regulations must evolve to allow for new separation methods that better adapt to the UAS reality.

Most of the current RoW rules establish priority among manned aircraft based on aircraft type, maneuverability, relative position, ability to be seen, and emergency status. Supporting regulations also exist that enable adherence to RoW rules, including visibility and cloud clearance requirements. Moreover, RoW rules most often specify that manned aircraft have the RoW over unmanned aircraft. Indeed, when only a few small UAS routinely operated in the NAS and were kept within visual line of sight from the operator, giving RoW to manned aircraft was feasible. However, the demand in the UAS industry is for new operational scenarios, involving beyond visual line of sight concepts, such as medium- to large-sized UAS, and UAS in formation, i.e., swarms. In these situations, current RoW rules prove to be insufficient, and may need to be modified or extended.

Recent technological initiatives are also influencing the way aircraft interact with each other. For example, advances in technology can enable Detect and Avoid (DAA) systems that are intended to meet at least the same vigilance, separation, and collision avoidance capabilities as see and avoid. There is a significant increase in the number of standards addressing Detect and Avoid (DAA) concepts, such as ACAS Xu and ACAS sXu for large and small UAS, respectively. Also, Remote ID, although conceived under a security perspective, has the potential to also provide surrounding unmanned traffic with information on other UAS flying nearby. ADS-B also provides situation awareness and collision avoidance capabilities to some manned aircraft. Current RoW rules assume an onboard pilot who can see and avoid and do not yet account for these UAS technological advancements. At the same time, the technology readiness level of these systems for providing DAA equivalent to see and avoid has yet to be established. Therefore, new rules must be based on realistic capabilities.

RoW rules form one aspect of an overall conflict management system (ICAO, 2005). Conflict management is currently also provided by segregation by aircraft category, equipage, conspicuity, flight obstacle, or time of day. In the future, conflict management could also be provided by airspace access based on level of autonomy, digital flight rules, airspace corridors, airspace property rights, delegated and limited airspace management authority, new equipage requirements, or visual conspicuity requirements. This literature review addresses these concepts by applying them to particular mission sets including linear infrastructure inspection, precision agriculture, package delivery, and low altitude surveillance.

This report also identifies gaps in existing RoW rules for specific scenarios such as: encounters between two or more UAS; encounters between UAS swarms and other aircraft; shielded operations; UAS operating BVLOS; UAS greater than 55 pounds not operating under Part 91. Gaps also exist in regulations that could support RoW in the following areas: display requirements for potential RID utilization; performance standards for non-cooperative sensors; and identifying emergency aircraft electronically. Gaps exist in research in the following areas: methods for estimating cloud clearances; the ability of a manned aircraft to see and avoid a UA under varying environmental conditions; the ability of a manned aircraft to see and avoid a medium-sized UA and the effect of UAS visual conspicuity, non-cooperative sensors, remote ID signals, and ADS-B out in maintaining well clear and collision avoidance.

The results of this report will be used in successive project phases to provide a reasoned and well-founded set of criteria whereby new RoW rules will be proposed. While the aim is to be comprehensive, the researchers acknowledge that a feasible solution must also be practical in nature and certain scenarios will need to be prioritized based on FAA and industry feedback. For instance, it is not practical to establish unique RoW rules for each encounter type identified. The team would need to group similar cases together. This classification will be developed in upcoming phases of the project using the tools that we are presenting in this report. Finally, this work also serves for the working group to build up the field knowledge from which the rest of the project will benefit.

1 INTRODUCTION

1.1 Background

Right-of-Way (RoW) rules govern the interactions between aircraft in order to coordinate aircraft encounters and preserve safety. Ambiguity exists for certain Unmanned Aircraft System (UAS) operations and the RoW rules that they should follow. Thus, exploring the historical or suspected rationale that support existing RoW rules deserves scrutiny.

This report presents a comprehensive exploration of the primary benefits and motivations for RoW rules, and summarizes existing RoW rules and derivative RoW hierarchies, which will help identify safety priorities for aircraft. The literature review is used to identify the key concepts for future exploration such as airspace management, equipage requirements, and conspicuity rules. Then, the report summarizes gaps in RoW rules due to presence of new entrants in airspace, gaps in regulations, and the gaps in research.

1.2 Scope

The literature review includes specific areas that are identified by the sponsor for consideration. The existing RoW rules and their history are explored in detail to present the state of the field. Another important topic for the report is the UAS operations that result in mid-air collision or similar ground situations where an unmanned aircraft interferes with a manned aircraft operation. Emergency situations are also explored regarding existing RoW rules, to include manned aircraft that are in distress.

The aircraft characteristics are included since they are critical for RoW rules. For instance, UAS converging on other UAS, balloons, gliders, aerial refueling and towing, ultralights, airships, airplanes, and rotorcraft, continue to evolve in capability and use while they are addressed by regulation. Therefore, these potential conflicts require further adjudication. The ability for an unmanned aircraft to identify the type of manned aircraft (ultralight, glider, etc.) is not yet mature. In addition, every type of manned aircraft that exists could potentially be converted to an unmanned aircraft thereby creating additional complexity and nuance to consider. Future evolutions of Advanced Air Mobility (AAM), Urban Air Mobility (UAM), Unmanned Aircraft (UA), and their anticipated Concept of Operations (CONOPS) must be a part of this ongoing discussion to facilitate updates to RoW rules. Hence, in this report various segregation concepts are explored by aircraft type, by airspace, by equipage, by flight obstacle, by traffic management, by maneuverability, by automation, and finally, by time of day.

The availability of aircraft characteristics to other traffic is also within the scope of this report as it has a potential impact on decisions taken at aircraft encounters. The FAA, and specifically, Air Traffic Service (ATS), has not allowed the broadcast capability of ADS-B (out) to be a part of the solution for UAS operating under Part 107 in assisting the RoW landscape, although it allows its use in controlled airspace under §91.225i. Additionally, the latency of this technology –of up to 2 seconds allowed under §91.227e– needs to be taken into consideration for UAS collision avoidance. In any case, ADS-B out appears acceptable for certain collision avoidance geometries, such as converging manned aircraft.

The rules for the onboard pilot's ability to see and avoid the UA are derived in part from the See-and-Be-Seen safety concept (See 2.1.3.1), the maneuverability limitations of aircraft types to give way, and other safety considerations. Previous research has supported the challenges to visually acquiring drones in flight by manned pilots. There are various methods that could potentially enhance UA conspicuity for supporting collision avoidance and enabling the pilot of the manned aircraft to see-and-avoid. These solutions have been considered as an added layer of safety that in certain conditions become critical (See 3.9). However, whereas White (2017) shows how fluorescent color schemes contribute to small drones' conspicuity, the study by Wallace et al. (2018) is inconclusive on the use of strobe lights in the daytime for the same purpose. They do address the importance of taking steps to maximize the conspicuity with high-contrast colors and regular maneuvers, but even then, pilot detection from manned aircraft would still be a challenge. Hence, it's difficult to have a conclusive result until more research is conducted in this field. Another important situation to consider in this regard is manned aircraft operations that may transition from having RoW to giving priority to UA. An example might include a declared emergency by a UA.

The cooperative and noncooperative technology capabilities and limitations must be investigated as they pertain to RoW. DAA technology and electronic conspicuity (when approved and so equipped) are vital for safe sUAS BVLOS operations and are a current solution for remaining well clear. However, the technological readiness of DAA solutions for the full range of UAS is not yet known. In regard to visual conspicuity, the role a visual observer plays (when utilized) as a part in shielded operations may assist in the ability to maneuver away from oncoming aircraft. All operators are responsible for the safe operation of their aircraft (see Part 91.3) and hence bear responsibility for collision avoidance. (BVLOS ARC (FAA, 2022))

Aircraft types and their associated RoW rules have certain challenges and impacts. RoW rules on different encounters are studied in this report, such as manned aircraft approaching each other, and unmanned aircraft that are landing with manned aircraft. Balloon/Kites, Amateur Rockets and Model Aircraft under FAR Parts 101.13, 101.23, and 101.41 are other relevant components in the focus of this study. Additionally, the BVLOS ARC (FAA, 2022) includes recommendations for RoW for UA where the intruder is unequipped in rural areas. These recommendations are limited to UA with a mass and speed which result in UA kinetic energy of no more than 800,000 ft.-lbs. to limit the consequences of ground collisions. (FAA, 2022) These comments and others from the BVLOS ARC (FAA, 2022) are not presented as a rationale for adoption, however, they are used to highlight the various viewpoints found in the literature. The recommendations from BVLOS ARC (FAA, 2022) did present controversy as this paradigm shift may cause manned aircraft to yield RoW to UA: The BVLOS ARC (FAA, 2022) makes the following statements:

- The unmitigated risk of mid-air encounter between UA and unequipped General Aviation (GA) aircraft in the below 500'AGL operating environment is assumed to be low in BVLOS ARC (FAA, 2022);
- The risk of a collision fatality between a GA and UA aircraft is very low when compared to the risk of controlled flight into terrain or obstacles involving low altitude operations with human crews (e.g., crop application, power line patrol, etc.);
- The short-term minimal risk of a UA-GA collision in Low Altitude and Shielded airspace is far outweighed by the long-term reduction of the high risk of fatal accidents involving crewed aircraft conducting low altitude missions.

The assumption that the unmitigated risk of mid-air collisions between UA and unequipped GA aircraft is low is not based on actual data of real aircraft operations. The BVLOS ARC (FAA, 2022) does not consider that low-level manned aircraft are not evenly distributed throughout all low-altitude airspace, but are likely concentrated in certain areas, which may in fact be the same areas in which UAS would be operating BVLOS. For example, both manned and unmanned aircraft operations are likely to occur over farms or near infrastructure. Further, the second point, that the risk of collision between a GA aircraft and a UA is comparatively low is mistaken for several reasons: first, the risk of collision fatality between GA and UA aircraft is not actually known; second, the risk is additive to the other identified risks, since those would still be in place; third, accepting a risk without mitigations simply because other risks are greater is not an accepted methodology in aviation.

1.3 Relationship to BVLOS Aviation Rulemaking Committee (ARC) Final Report

In conjunction with this review, the FAA had engaged an ARC, and their report does directly correspond to the literature herein. The Beyond Visual Line of Sight (BVLOS) Aviation Rulemaking Committee Final Report (BVLOS ARC) (FAA, 2022) was released near the end of Task 1 of this project. Hence, this report included BVLOS ARC in literature review on related topics such as the operations mentioned previously, and challenges associated to them.

2 LITERATURE REVIEW

2.1 Right of Way Rules and History

2.1.1 *History and Background*

The history of RoW rules dates back to 1927, when the Department of Commerce, Aeronautics Branch, pursuant to the Air Commerce Act of 1926, promulgated the first set of aircraft flight rules, which took effect in March 1927. These rules included the provision called "give-way duties" which stated that "300 feet [is] the minimum distance within which aircraft, other than military aircraft of the United States engaged in military maneuvers and commercial aircraft engaged in local industrial operations, may come within proximity of each other in flight." The minimum distance was increased to 500 feet by 1945, but this requirement was deleted in 1946 in recognition that 500 feet could be insufficient separation for larger aircraft. In 1947, an amendment was issued stating that "no person shall operate an aircraft in such proximity to other aircraft as to create a collision hazard." (Anderson et al., 2015). This rule remains essentially unchanged.

In 2015, a thorough and comprehensive analysis of the legal history of FAR Part 91 see and avoid rules, which includes RoW rules, was performed by researchers at the University of North Dakota, who reached two broader conclusions: "1. The duty to see and avoid is not limited to seeing and avoiding other aircraft. There is a broader responsibility to also see and avoid other hazards, including terrain and obstacles. 2. The duty to see and avoid has a long history not confined solely to the operation of aircraft. Regulation of other forms of transportation also emphasizes the see and avoid concept, including maritime and surface transportation." (Anderson E. E., Watson, Marshall, & Johnson, 2015)

A search of the National Transportation Safety Board case files over the past 30 years for RoW violations yields only 9 cases, none of which occurred in the last decade. (Anderson et al., 2015; search updated 2022) Nonetheless, several of those are directly relevant to the report at hand:

- Hinson v. Blanc, EA-4112 (1994). "FAR 91.113(b) prescribes pilot vigilance so as to see and avoid other aircraft." Absent some explanation why [a pilot does not see another aircraft], he cannot be found to have performed up to a reasonable standard of care.
- Administrator v. Ferguson, 1 National Transportation Safety Board 328 (1968), in which the respondent could have and should have avoided the near collision, because "responsibility to maintain proper lookout is not avoided because of limited cockpit vision; pilot must take measures to compensate for restricted vision."
- Administrator v. Kuhn, 13 CAB 139 (1949), aff'd, Kuhn v. CAB, 183 F.2d 839 (1950), in which the Civil Aeronautics Board (CAB) stated that the directional relation of two planes and their respective courses at the point of intersection are not the sole determinant of whether a situation involves an overtaking or a convergence. The CAB concluded that Kuhn involved an overtaking and not a convergence, despite the fact that the aircraft collided at an angle of 74 degrees, because the pilot of the faster aircraft, though on the right and thus arguably entitled to the RoW under the rules of convergence, knew that he would ultimately pass the slower aircraft ahead of him and the other aircraft had no such knowledge.

Given the relatively few published appellate cases of violations of FAR 91.113, it appears the existing RoW rules are very stable and there is little question about definition of terms used within the RoW rules vis-a-vis traditional piloted aircraft. It is significant to note that none of the legal history or published, appellate cases to date involve UAS. However, it is likely that the addition or integration of UAS into the NAS will result in occurrences where right of way between UAS and traditional piloted aircraft will be litigated. Even though no UAS cases have yet yielded legal precedent, FAA has pursued enforcement actions in several instances. Enforcement actions, unless appealed, are not in the public record.

The following list contains examples of encounters between manned aircraft and UAS:

- Army UH-60/DJI Phantom, September 2017. The operator of the sUAS flew the aircraft beyond visual line of sight and was unaware that the sUAS struck the helicopter. ((ASN Aviation Safety Wikibase, 2017)
- Hot Air Balloon/DJI Mavic, August 2018. The sUAS was operated within 5 miles of an airport without FAA authorization when the operator lost sight of the sUAS and was unaware that the sUAS struck the balloon. (Tellman, 2022)
- AS350 Helo/DJI Mavic. February 2020. While filming an off-road car race, the operator of the sUAS failed to give way to a helicopter, resulting in a midair collision. (Aerossurance, 2022)
- LAPD helicopter/DJI Mavic, September 2020. The sUAS was being operated in a reckless manner. The helicopter saw the sUAS and attempted to maneuver but struck the sUAS. (Winton, 2020)

In the case of the Army UH-60 and DJI Phantom, the FAA has "taken action against Vyacheslav Tantashov for his actions that resulted in damage to a military helicopter (without seeing the actual action, it is a reasonable assumption that the action will be a §91.13 or a §107.23 (hazardous operation)." (Eagle, 2018). In the case of the LAPD helicopter and DJI Mavic, "the FAA has recently initiated actions against Masih Mozayan for flying his aircraft near a helicopter and taking no avoidance action." (Eagle, 2018). Whether this certificate action is under Part 91.13 or 107.23 is unknown.

Reliable data on encounters between manned aircraft and UAS is an area of active research. The ASSURE A50 Small UAS Traffic Analysis Project is designed to fill the gap in knowledge regarding actual sUAS flights and their relationship to ADS-B tracks of actual aircraft. Using ADS-B and Aeroscope data over a three-year period at Dallas-Fort Worth Airport, Wallace et al. (2022) reported 24 cases of Near Midair Collisions (NMAC), in which a sUAS detected by the Aeroscope came within a 500-foot proximity sphere of a manned aircraft transmitting an ADS-B signal at the same point in time. However, only three cases met the DAA definition of a NMAC, in which the volume of airspace surrounding the aircraft is a cylinder, not a sphere.

Sighting reports have also been used to analyze encounters between sUAS and manned aircraft. Pyrgies (2019) mined sighting reports and news reports to identify 124 NMACs between sUAS and manned aircraft worldwide. In 24 cases, the manned aircraft engaged in evasive maneuvers (Pyrgies, 2019). Wang and Hubbard (2021) analyzed the FAA sightings database and determined that 3.3% of reported sightings resulted in evasive action on the part of the manned aircraft pilot (Wang & Hubbard, 2021). Gettinger and Michel (Gettinger & Michel, 2015) also analyzed sighting reports and concluded that 35.5% of reports consisted of close encounters, in which a drone came within 500 feet of a manned aircraft, or a pilot took evasive action, or the pilot described the sUAS as being dangerously close. However, sighting reports have numerous shortcomings that make them unreliable as the single source of data (Loffi et al., 2016).

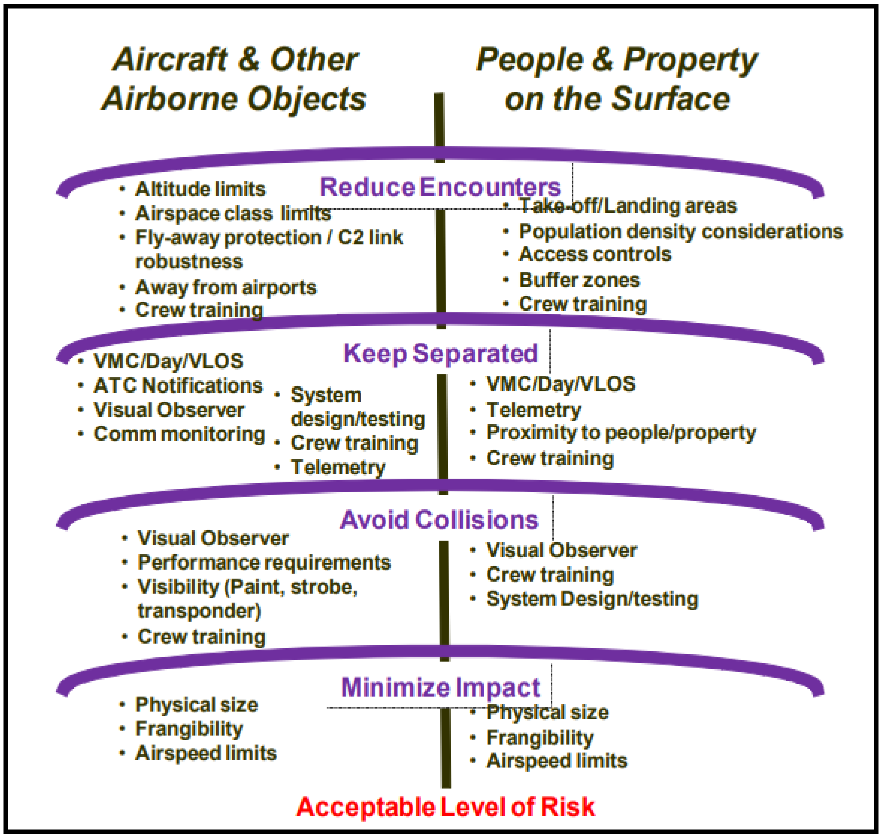
In summary, RoW rules have been in place since 1927, and have evolved as aircraft technology has changed. The rules have not measurably changed since 1947, and litigation has reinforced the responsibility of the pilot in command to maintain vigilance and see and avoid other aircraft.

2.1.2 *Layers of Conflict Management*

International Civil Aviation Organization (ICAO) distinguishes three layers of conflict management to mitigate the risk of hazardous interactions between aircraft: strategic conflict management; separation provision; and collision avoidance (ICAO, 2005). Strategic conflict management is provided by ATC through airspace organization and management, demand and capacity balancing, and traffic synchronization. Separation provision between aircraft is provided either by ATC or the airspace user, depending upon the situation. When there is no ATC support, well clear (defined in section 2.1.3.4) and RoW (defined in section 2.1.8) become part of the separation provision layer (pilot self-separation) in the general conflict management concept. Collision avoidance is the last layer of conflict management, which activates when the separation mode has been compromised.

The sUAS ARC formed in 2008 focused on making recommendations regarding sUAS commercial operations used a similar concept in the layered approach to safety, shown in Figure 1. In this case, the layers had the same intent of reducing the level of risk of collision to an acceptable level. The layers consisted of reducing encounters through airspace management, keeping aircraft separated primarily through the actions of the sUAS operator, avoiding collisions through the actions of the sUAS operator, and minimizing severity of the collision through design and operation (Federal Aviation Administration [FAA], 2008).

Figure 1. Layered approach for ensuring safety.



Note. From Small Unmanned Aircraft System Aviation Rulemaking Committee [See Figure 1], by FAA, 2008. https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/suasarc-4102008.pdf

2.1.2.1 Strategic Conflict Management

Strategic conflict management consists of airspace organization and management, demand and capacity balancing, and traffic synchronization. Airspace organization and management involves the "flexible allocation and use of airspace [...] based on the principles of access and equity" (ICAO, 2005, 2-5). An example of strategic conflict management through airspace organization is the establishment of restricted or prohibited areas in the NAS. ICAO recognizes that under some circumstances, airspace will be subjected to service limitations, based on safety issues, but that airspace should not be organized in a way that permanently precludes mixed use and mixed equipage operations. In practice, this indicates that while restrictions on use of airspace based on type of operation or equipage are permissible, the goal is full access to airspace by all users.

Demand and capacity balancing relates primarily to minimizing the effects of Air Traffic Management (ATM) system constraints, which are not yet relevant to UAS operations, as they take place for the foreseeable future outside the locations where the ATM system is at capacity. However, this will be a relevant feature in UAS Traffic Management (UTM) scenarios. Similarly, traffic synchronization is most applicable to airspace and airports where optimizing the sequencing of traffic is critical to accommodating demand. This may be a relevant feature for UTM but will not play a role for UAS in the near term.

In summary, strategic conflict management for UAS in the near term will involve airspace organization and management but not demand and capacity balancing or traffic synchronization.

2.1.2.2 Separation provision

Separation provision can be provided by ATC or by the airspace user. Where ATC does not provide separation provision, self-separation depends upon the principles of see and be seen (SBS) as well as see and avoid, and adherence to RoW rules to maintain well clear. Numerous rules exist to support self-separation, including the requirement to maintain visual line of sight with a small UAS, and cloud clearance and visibility requirements for both manned and unmanned aircraft. These supporting rules are discussed further in Section 2.1.4. In the BVLOS ARC (FAA, 2022) there is a recommendation on existing RoW rules to allow a range of sensing methods in clarifying adequate separation. The BVLOS ARC (FAA, 2022) acknowledged the potential for future challenges where strategic deconfliction would rely on all parties in a congested area to cooperate with appropriate equipage. Further, it was identified that a framework may be necessary for the sharing of information between users for deconfliction.

2.1.2.3 Collision Avoidance

Collision avoidance becomes necessary when the other layers of safety have failed to assure safe separation. Manned aircraft equipped with TCAS can coordinate collision avoidance with other TCAS-equipped aircraft during an encounter. While some large UA DAA systems incorporate TCAS as a piece of the DAA system, however, TCAS in its current form is not a viable solution for collision avoidance in encounters between manned and unmanned aircraft because not all aircraft are required to have TCAS, and the aircraft characteristics and collision geometries preclude use of TCAS in encounters between manned aircraft and some UAS (Dalamagkidis et al., 2012, p. 184). TCAS is discussed further in Section 2.3.1.2. ACAS X is a possible solution for automatic collision avoidance for unmanned aircraft. For encounters with non-cooperative traffic (not using TCAS, ADS-B or ACAS X), collision avoidance depends on either see and avoid or non-cooperative sensors. In these cases, at least one aircraft must maneuver to avoid a collision.

2.1.2.4 Minimize Impact

The sUAS ARC also included a final layer of safety, which is akin to survivability requirements in manned aviation. In other words, minimizing impact assumes that a collision has occurred, and seeks to mitigate the severity of the outcome.

2.1.3 *Safety Concepts of RoW*

2.1.3.1 See and Be Seen

The separation provision of the layers of conflict management depends upon ATC when ATC services are provided, and upon the airspace user when ATC services are not provided. When ATC services are not provided, self-separation of manned aircraft depends upon the ability to SBS. The concept of SBS leads directly to the requirement to see and avoid other aircraft, and to supporting rules, such as RoW, VFR weather minima, cloud clearances, cruise altitudes, aircraft lighting, and ADS-B equipage requirements. According to Anderson et al. (2015), compliance with RoW and collision avoidance rules requires a three-step process: be vigilant, detect target, and avoid.

2.1.3.2 See and avoid

See and avoid refers to the capability of an onboard pilot to remain well clear of other aircraft with the right-of-way and avoid collisions with other aircraft. Manned aircraft pilots have a regulatory responsibility to see and avoid other aircraft. Aircraft general operating rules found in 14 CFR Part 91 require that when weather conditions permit, pilots shall maintain vigilance to see and avoid other aircraft. Section 5-5-8 of the Airman's Information Manual (AIM) (U.S. Department of Transportation, FAA, 2021) further explains that this responsibility exists regardless of type of flight plan or whether the aircraft is under positive ATC. Rules governing minimum flight visibility and distance from clouds for VFR flight, outlined in 14 CFR Section §91.155, have been adopted to assist the pilot in meeting the responsibility to see and avoid other aircraft. The Airplane Flying Handbook (Federal Aviation Administration, 2021) also addresses the requirement to see and avoid, stating that the pilots must maintain a vigilant lookout regardless of type of aircraft being flown and purpose of the flight. The Airplane Flying Handbook and FAA advisory circular AC90-48d (Federal Aviation Administration, 2016) provide information about human visual perception and proper visual scanning techniques.

While see and avoid is used to maintain separation provision and collision avoidance, the BVLOS ARC (FAA, 2022) questioned the effectiveness of see and avoid, stating:

> "The effectiveness of see and avoid has been estimated at 0.6975, averaging alerted and un-alerted encounters. Only about 70% of aircraft within the pilot's field of view would be detected by a GA pilot prior to a loss of separation. Using the number of aircraft in the field of view does not account for the fact that no aircraft has a constant 360° field of view for the pilot, so there will be even fewer detections of the total population of potential intruders."
>
> "Likelihood of see and avoid:
>
> 1. ~70% of intruders visibly detected (Andrews, LL Study)
> 2. ~25% of airspace visible from generic cockpit (Assumes a fixed wing cockpit where the pilot cannot see behind or below due to the aircraft structure blocking the view which yields 90° vertical and 180° horizontal field of view)
> 3. ~17.5% (70% x 25%) of intruders detected and avoided (Current level of collision risk accepted by GA) (Andrews, 1989)"

The BVLOS ARC (FAA, 2022) interpretation of the Andrews study has some serious limitations. First, the assertion that only 70% of intruders within the pilot's field of view would be detected prior to loss of separation is not accurate. The value is based on flight tests that simply had another aircraft visible in the field of view, not encounters that were carried out until loss of separation occurred. The BVLOS ARC (FAA, 2022) also assumes that the percentage of airspace visible to the pilot is the same as the percentage of relevant traffic visible to the pilot, which is not the case. Instead, the amount of traffic within the field of regard is critical.

The Flight Safety Foundation has called into question the relevance of see and avoid as a RoW and collision avoidance tool for modern high-speed aircraft, but maintains that the concept remains useful for slower aircraft operating in uncontrolled airspace, or in airspace in which ATC does not provide VFR traffic separation (Loss of Separation: See and Avoid, n.d.).

The sUAS Notices of Proposed Rule Making expressed concern over the use of see and avoid for small UAS operations, (2015) stating:

> "The operation of sUAS presents challenges to the application of the traditional right-of-way rules. The smaller visual profile of the small unmanned aircraft makes it difficult for manned pilots to see and, therefore, avoid the unmanned aircraft. This risk is further compounded by the difference in speed between manned aircraft and the often slower small unmanned aircraft. (p.9561) (Federal Aviation Administration, 2015)"

In the recently released BVLOS ARC (FAA, 2022), there is a recommendation to "allow automatic means for see-and-avoid responsibility". Further, this report recommends language clarifications between the term see and avoid and others as explained below.

2.1.3.3 Right of way

ROW rules are explained in depth in Section 2.1.4.

2.1.3.4 Well Clear

The term well clear is used in 14 CFR Part 91.113 to define the separation required that a pilot must maintain when maneuvering ahead of, above, or below another aircraft with the RoW. Well clear provides greater separation than collision avoidance. 14 CFR 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. Historically, the concept of well clear was not quantified, but rather was a judgement of the pilot that the aircraft with the RoW would not have to maneuver to avoid the aircraft without the RoW (Anderson et al., 2015).

However, with the advent of unmanned aircraft, "well clear" must be quantified in order to establish appropriate performance requirements for DAA equipment. Multiple separation criteria may exist for different types of UAS operations. RTCA SC-228 has defined Detect and Avoid Well Clear (DAAWC), quantifying the requirements that certain DAA systems must meet in order to keep an aircraft well clear of both cooperative traffic (equipped with transponders) and noncooperative traffic (not equipped with transponders). The quantification of DAAWC for cooperative and noncooperative aircraft is based on distance, time, and velocity, similar to TCAS. The quantification of DAAWC for small UAS is still in progress with RTCA SC-228.

The recently released BVLOS ARC (FAA, 2022) suggests that the term 'well clear' be replaced with 'adequate separation', which would allow different levels of separation in different situations. The BVLOS ARC (FAA, 2022) states that, "Implementation of this change requires a different approach to determining collision risk that is not dependent on a volume of airspace, but rather on an acceptable level of collision risk appropriate for the airspace." (p. 33). This suggests that the

BVLOS ARC (FAA, 2022) authors potentially envision a scenario based not on distance, time, and velocity relative to a volume of airspace, but rather a level of risk based on assumptions about the collision risk in particular airspace.

2.1.3.5 Detect and Avoid

Detect and avoid (DAA) refers to the capability of a UAS to remain well clear from and avoid collisions with other aircraft. (Federal Aviation Administration, 2009). DAA fulfills the same function as see and avoid in manned aviation ICAO RPAS conops for international IFR ops. (ICAO, 2017). Like see and avoid, DAA is used in both the separation provision layer of conflict management to maintain well clear, and the collision avoidance layer of conflict management. Just as see and avoid is limited by human visual system capabilities, DAA is limited by technological capabilities. DAA is a concept, rather than a specific technology. DAA surveillance can be provided by a variety of individual sensors, or by sensor fusion. A variety of avoidance algorithms may also exist to support a diversity of UAs and operating concepts. DAA technologies are discussed in Section 2.3. DAA capabilities also include avoiding other hazards such as obstacles or terrain. However, for the purposes of this project, the conflict management aspect of DAA for separation and collision avoidance from other aircraft is most relevant. The maturity of DAA technology is a key factor in proposing modifications to RoW rules or alternate means to meet the intent of RoW rules.

The flight rules recommendation contained in the BVLOS ARC (FAA, 2022), recommends some language changes, specifically from 'see and avoid' to 'detect and avoid'. In its proposed text revision to §91.113(b), the BVLOS ARC (FAA, 2022) recommends the following revision:

> **General**. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules, visual flight rules, ***or automated flight rules,*** vigilance shall be maintained by each person operating an aircraft so as to ***detect and avoid*** other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under or ahead of it unless able to maintain ***adequate separation.***

2.1.3.6 Explicit vs implicit coordination.

Separation provision provided by the airspace user, and conflict avoidance can either be explicit or implicit. Explicit coordination means that the aircraft in the encounter are actively coordinating with each other, for example via two-way communication and maintaining specified altitudes. Implicit coordination (like Right-of-way rules) does not require active radio communication between aircraft; hence one pilot may not always know exactly how the other aircraft will maneuver.

2.1.4 *Current RoW Rules*

2.1.4.1 Pilot in Command responsibilities

14 CFR Section §91.3 (Federal Aviation Administration, 1963) and §91.11 (Federal Aviation Administration, 2016) mandate that a pilot in command has final authority over the safe conduct of a flight, and that no pilot shall operate an aircraft so as to create a collision hazard.

All manned aircraft must comply with Section §91.113 RoW rules except water operations, which address the following scenarios:

- In distress: Aircraft in distress have the RoW over all other traffic.
- Converging: When aircraft of the same category are converging at approximately the same altitude, the aircraft to the right has the RoW. When aircraft are of different categories, the order of precedence is as follows:
    - A balloon has the RoW over any other category of aircraft.
    - A glider has the RoW over an airship, powered parachute, weight-shift-control aircraft, airplane, or rotorcraft.
    - An airship has the RoW over a powered parachute, weight-shift-control aircraft, airplane, or rotorcraft.
    - An aircraft towing or refueling other aircraft has the RoW over all other engine driven aircraft.

  These rules appear to be categorized based on a safety hierarchy informed by the maneuver limitations of certain aircraft to give way and avoid with less maneuverable aircraft having the RoW in converging scenarios. These regulations also require the ability to visually classify aircraft types, which has a direct impact on DAA system requirements if UAS are to operate exactly like manned aircraft.

- Approaching head on: When aircraft are approaching head-on, each aircraft shall alter course to the right.
- Overtaking: When an aircraft is overtaking another, the aircraft being overtaken has the RoW, and the overtaking aircraft shall alter course to the right to pass well clear of the aircraft being overtaken. This is presumably because the pilot in the aircraft being overtaken does not have the ability to visually see an approaching aircraft from behind. This rule appears to be based on visual limitations.
- Landing: Aircraft on final approach or while landing have the RoW over other aircraft. When two or more aircraft are on approach to land, the aircraft at the lower altitude has the RoW. Landing rules are also based on maneuverability and safety, though not on the inherent capabilities of the aircraft but rather the capabilities resulting from the phase of flight and proximity to the ground. It is safer to give the lower aircraft the RoW, in part because a lower aircraft has less room to maneuver. Lack of maneuverability leads to a safety risk, but safety is the priority and maneuverability in this case is due solely to proximity to the ground.
- The above rules are relevant for low altitude manned aircraft operations. Using the logic behind the RoW rules based on maneuverability, overall safety, and visual limitations rationale exists for future rules to give a manned aircraft conducting low altitude flight RoW because of its proximity to the ground and limited space to maneuver near terrain and

flight obstacles. A small UA can more easily maneuver in close proximity to flight obstacles than a manned aircraft. In addition, an onboard pilot cannot easily see small UAs leading to a visual limitation argument. The harm severity of a small UA colliding with terrain is less than the harm severity of a manned aircraft colliding with terrain or flight obstacles. Hence, the rationale behind existing RoW would appear to favor giving a manned aircraft the RoW over a small UA when in proximity to terrain or flight obstacles in order to maximize safety.

Although RoW rules explain who should give way in an encounter, the Airman's Information Manual (AIM) advises pilots who have RoW, to give way instead of waiting for the other pilot to respect the RoW if they believe the other aircraft is too close. Overall safety takes precedence over strict adherence to RoW rules.

2.1.4.2 14 CFR Part 101

14 CFR Part 101 addresses operating rules for moored balloons, kites, amateur rockets, and unmanned free balloons.

- 14 CFR Part §101.7 (Federal Aviation Administration, 2002) Balloon, kite, amateur rocket or unmanned free balloons cannot create a hazard to people or property.
- Part §101.23 (Federal Aviation Administration, 2009a) Amateur rockets must be operated in such a way as to not preclude safe flight operations.
- Part §101.25 (Federal Aviation Administration, 2009b) Class 2 and Class 3 amateur rocket launch activity is prohibited in controlled airspace or within 5 miles of airports without FAA authorization.

2.1.4.3 Part §103.13

All ultralights shall yield RoW to all aircraft. This rule does not appear to be based on maneuverability or safety, but might recognize the recreational aspect of ultralight activity, or perhaps be based on the reduced visual conspicuity of ultralights compared to many other categories of aircraft. The rule also states that powered ultralights shall yield RoW to unpowered ultralights which does appear to be based on maneuverability. (Federal Aviation Administration)

2.1.4.4 Part §107.37

Small UAS operated under Part 107 must yield RoW to all aircraft. This is based largely on the low visual conspicuity of small UAS. Further, small UAS operating for commercial purposes must usually remain below 400' AGL (with exceptions around towers and buildings). Operations in controlled airspace require FAA authorization. (Federal Aviation Administration). . The aircraft must be flown within the visual line of sight of the person operating the aircraft or a VO co-located and in direct communication with the operator. (Federal Aviation Administration, 2019) Part 107 is the only FAR that specifically addresses RoW for unmanned aircraft.

2.1.4.5 49 USC 44809

Small UAS operated for recreational purposes must yield RoW to all aircraft. Further, small UAS operating for recreational purposes must remain below 400’ AGL. Operations in controlled airspace require FAA authorization. Further, the aircraft must be flown within the visual line of sight of the person operating the aircraft or a VO co-located and in direct communication with the operator. (Federal Aviation Administration, 2019)

2.1.4.6 Supporting Rules (enabling RoW)

To support the requirement to SBS for safe interactions between aircraft, weather minimums and cloud clearances are established for flight operations for both manned and unmanned aircraft.

- 14 CFR Part §91.155 To operate under visual flight rules manned aircraft must maintain visibility and cloud clearance limits appropriate to the airspace category.
- 14 CFR Part §107.51 *(Federal Aviation Administration, 2016)* Minimum visibility for operating sUAS is three statute miles. To operate sUAS, the platform must fly no less than 500 feet below the clouds and 2000 feet horizontally from clouds. Because Part 107 rules require the UAV to remain within visual line of sight of the operator, the assumption is that the operator will be able to see both the UAV and the clouds in the area. With BVLOS operations, the operator will not have the same perspective, and some method of observing clouds and estimating distance will be required to meet the cloud clearance requirements.

Further, sUAS must be flown within visual line of sight.

- 14 CFR Part 107.31 (Federal Aviaiton Administration, 2016) Small UAS flown for commercial purposes must be flown within the visual line of sight of the remote pilot in command, the person operating the aircraft, or a VO.
- 49 USC 44809 (Federal Aviation Administration, 2019) Small UAS operated for recreational purposes must yield RoW to all aircraft.

In addition, sUAS must be operated according to the lighting rules.

- 14 CFR Part 107.29 (Federal Aviaiton Administration, 2016) The small unmanned aircraft has lighted anti-collision lighting visible for at least 3 statute miles that has a flash rate sufficient to avoid a collision. The remote pilot in command may reduce the intensity of, but may not extinguish, the anti-collision lighting if he or she determines that, because of operating conditions, it would be in the interest of safety to do so.

14 CFR Part 107.29 (Federal Aviaiton Administration, 2016) No person may operate a small unmanned aircraft system during periods of civil twilight unless the small unmanned aircraft has lighted anti-collision lighting visible for at least 3 statute miles that has a flash rate sufficient to avoid a collision. The remote pilot in command may reduce the intensity of, but may not extinguish, the anti-collision lighting if he or she determines that, because of operating conditions, it would be in the interest of safety to do so.

2.1.4.7 Strategic Conflict Management Rules

As discussed in Section 2.1.2, conflict management relies on a layered approach to mitigate the risk of hazardous aircraft interactions. In addition to RoW rules which operate at the collision avoidance layer, regulations also exist to enforce strategic conflict management. These rules involve segregating aircraft by category or equipage, as described below. This list is not comprehensive, but rather serves to show examples of strategic conflict management based on aircraft category or equipage.

- **Category: Small UAS**: 14 CFR §107.41 (Federal Aviation Administration, 2016) No person may operate a small UAS for commercial purposes in Class B, Class C, or Class D airspace or within the lateral boundaries of the surface area of Class E airspace designated for an airport unless that person has prior authorization from Air Traffic Control (ATC). Small UAS operating under Part 107 must remain below 400' AGL unless operating within 400 feet of the radius of a structure, in which case the aircraft must not fly higher than 400 feet above the structure.
  49 USC 44809 (Federal Aviation Administration, 2019) No person may operate a small UAS for recreational purposes in Class B, Class C, or Class D airspace or within the lateral boundaries of the surface area of Class E airspace designated for an airport unless that person has prior authorization from Air Traffic Control (ATC). Small UAS operating for recreational purposes must remain below 400' AGL.
- **Category: Ultralights** 14 CFR §103.17 (Federal Aviation Administration, 1982) No person may operate an ultralight in Class A, B, C, or D airspace or within the lateral boundaries of the surface area of Class E airspace designated for an airport unless that person has prior authorization from ATC.
- **Equipage:** 14 CFR §91.215 (Federal Aviation Administration, 2021) No person may operate a manned aircraft in Class A, B, or C airspace or in certain areas unless the aircraft has an operating transponder with altitude encoding capability or has been authorized by ATC to operate without a transponder.
  14 CFR §91.225 (Federal Aviation Administration, 2021) No person may operate an aircraft in Class A, B, or C airspace or in certain areas unless the aircraft is equipped with ADS-B out. Exceptions are made for certain airspace for aircraft that were not initially certified with electrical systems, and for balloons and gliders.

2.1.4.8 Use of transponder by UAS

14 CFR §91.215 (Federal Aviation Administration, 2021) ATC Transponder and altitude reporting equipment and use. Sub section (e) authorizes a UA to use a transponder in the airspace defined in sections §91.215.b1 to b5 if either the UA operates under a flight plan and a two-way communication with ATC are established, or directly authorized by ATC.

2.1.4.9 Remote Identification

14 CFR Part 89 - Remote Identification of Unmanned Aircraft. Part 89 (Federal Aviation Administration , 2022) Remote identification rules established in 14 CFR Part 89 mandate that any

unmanned aircraft required to be registered under 14 CFR part 47 or part 48, except those operating under Part 91 and transmitting ADS-B out pursuant to §91.225, continually broadcast its serial number, latitude, longitude and altitude of the control station, latitude/longitude and altitude of the aircraft, velocity of the aircraft, time, and emergency status. Remote identification was initially conceived with security and identification of the drone and operator in mind, not collision avoidance. While RID transmissions will be required in accordance with 14 CFR Part 89, there is no corresponding requirement for manned aircraft or UAS to be able to receive RID information.

2.1.4.10 Emergency Authority

CFR14 91.3 gives the pilot in command of a manned aircraft the authority to deviate from FARs to handle emergencies.

2.1.5 *Related Standards*

2.1.5.1 ASTM

F3442: Standard Specification for Detect and Avoid System Performance Requirements. This specification applies to UA with a maximum dimension (for example, wingspan, disc diameter) ≤25 ft, operating at airspeeds below 100 kts, and of any configuration or category. (ASTM Standard F3442, 2020) It is meant to be applied in a "lower risk" low- and medium-risk airspace as described by Joint Authorities for Rulemaking on Unmanned Systems (JARUS) airspace environment with assumed infrequent encounters with manned aircraft; this is typically in classes G and E airspace (below about 1200 ft AGL), Class B, C, D (below about 400 to 500 ft AGL), below obstacle clearance surface (FAA Order 8260.3, as amended), or within Low Altitude Authorization and Notification Capability (LAANC) designated areas below the altitude specified in the facility map.

WK62669: New Test Method for Detect and Avoid. The objective is to define test methods for DAA systems and sensors applicable to smaller UAS BLVOS operations for the protection of manned aircraft in lower altitude airspace. (ASTM Standard WK62669, 2018)

F3411: Standard Specification for Remote ID and Tracking. This specification covers the performance requirements for remote identification (Remote ID) of unmanned aircraft systems (UAS). Remote ID allows governmental and civil identification of UAS for safety, security, and compliance purposes. The objective is to increase UAS remote pilot accountability by removing anonymity while preserving operational privacy for remote pilots, businesses, and their customers. Remote ID is an enabler of enhanced operations such as beyond visual line of sight (BVLOS) operations as well as operations over people. (ASTM Standard F3411, 2020)

2.1.5.2 RTCA

RTCA DO-365B (Detect and Avoid Systems: Ready for Takeoff with DO-365B, 2021) Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems. This standard establishes the minimum performance requirements for a DAA system to ensure well clear while operating under IFR in Class D, E, and G airspace above 400' and when transiting Class B and C airspace. The MOPS includes encounter geometries that may be useful for this project, as well as extensive examples, and models for visual acquisition. The MOPS also discusses quantified RoW, which as the name suggests involves quantifying RoW maneuvers such as “alter course to the right”.

DO-385 Vol I and II, Minimum Operational Performance Standards for Airborne Collision Avoidance System X (ACAS X) (ACAS Xa and ACAS Xo), 2018, specifies collision avoidance standards for the ACAS Xa and Xo variants.

DO-387 (RTCA Standard DO-387, 2021) MOPS for Electro-Optical/Infrared (EO/IR) Sensors for Traffic Surveillance. This standard provides MOPS for EO/IR systems that are part of a DAA system. This standard applies to Unmanned Aircraft Systems (UAS) transiting through Class B, C, D, E and G airspace and performing extended operations higher than 400' AGL in Class D, E (up to Flight Level 180 (FL180)), and G airspace, and in TA for approach and departure. It does not apply to sUAS operating below 400’, or to operations in the VFR traffic pattern.

DO-386 Vol I and Vol II, Minimum Operational Performance Standards for Airborne Collision Avoidance System Xu (ACAS Xu), 2020. These standards define the minimum operational performance standards (Vol I) and Algorithm Design Descriptions (Vol II) for Airborne Collision Avoidance System Xu (ACAS Xu) equipment.

DO-366A-Minimum Operational Performance Standards (MOPS) for Air-to-Air Radar for Traffic Surveillance. These standards specify the radar system characteristics relevant to detect and generate tracks for all airborne traffic within the radar detection volume. The onboard radar complements other airborne surveillance sensors by providing detection of non-cooperative traffic. These standards ensure that the track is established at sufficient range and with sufficient accuracy to enable the system to plan and execute a maneuver to keep the Unmanned Aircraft (UA) well clear of other traffic and avoid collisions.

2.1.5.3 EUROCAE

EUROCAE has a number of new standards in development relevant to detect and avoid and often collaborate with RTCA. Many of these are situated among the systems and subsystems area. These standards appear to address flight visibility conditions (IFR/VFR), low level flight.

2.1.5.4 ISO/CD

In March 2021 ISO initiated a Detect And Avoid Advisory Group (AG5) under the auspices of ISO/TC20/SC16 Unmanned Aircraft Systems committee. However, they do not have published standards on DAA.

2.1.5.5 AMA

The Academy has long published their set of community guidelines for the safe practice of recreational model aircraft flying. Their efforts have been safety conscience over everything else. They have provided significant input to collision avoidance since the inception of Part 107.

2.1.5.6 Other

The following standards developing organizations were also reviewed but did not have published or in development standards relevant to RoW: APSA, UL, Consumer Technology Association , NFPA, IEEE, ITU, 3GPP, ACI, ASD, ASO, AIAA, ASME, ASSP, ATIS, ETSI, NACE, NATE, and OGC.

2.2 International RoW Rules

2.2.1 *EASA RoW Rules*

European RoW rules are outlined in the Standardised European Rules of the Air (SERA). SERA.3210 RoW follows ICAO guidance for the RoW of aircraft. Protocols of hierarchy covered in these rules cover approaching head-on, converging, overtaking, landing, takeoff and surface movement. The document does not address UAS specifically.

The European rules for UAS suggest that it is the UAS operator's responsibility to define the how collision avoidance will be assured: Their annex D to Article 11, "Rules for conducting an operational risk assessment" indicates that, lest a RTCA SC-228 or EUROCAE WG-105 -compliant 'see and avoid' system is in place, the operator should have a documented deconfliction scheme, in which the criteria for avoidance traffic should be described. These criteria will have to be defined in terms of safety and performance for the UAS operation (EASE eRules, 2021).

In their discussion of UAS ATM flight rules, EASA states that RoW should be given to manned aircraft based on the difficulty of seeing and avoiding a small UAS. However, the discussion goes on to say, "EASA position is that, in principle, manned aircraft should have priority over unmanned, but they realize that the issue of priority could, however, be quite complex e.g., should an UA engaged in a search and rescue mission, or transporting life-safety equipment or transplants, give the right of way to a GA aircraft on a joy-riding flight." (EASA, 2018, p. 15) (EUROCONTROL, 2018)

Differences between SERA.3210 and Part 91.113 are not significant. SERA.3210 includes the case of taking-off aircraft, which have the RoW with respect to taxiing aircraft. SERA.3210 also includes cases involving surface movement.

U-space regulation released by EUROCAE and EASA aims to enable safe and secure drone traffic management. It offers fair, flexible, and open access to the airspace for the UAS operators. Regulatory authorities maintain control over airspace, protect safety and security in critical areas, drone identification, etc. The objective of the U-space is to create a harmonized condition for the drones and the manned aircraft to operate safely in the airspace, to prevent collision between aircrafts and to mitigate the ground risk and air risk. This includes defining RoW procedure for pilots knowing that a pilot flying its drone in visual line of sight will have to determine the relative level, heading and distance of an incoming flight. Similarly, a pilot in the cockpit would have trouble visually identifying a small drone even if it is only 50 m away (CORUS Consortium, 2019).

EU Regulation 2021/664 (Regulation 2021/664, 2021) provides the following definition of U-space airspace (Art. 2, def. 1): "A UAS geographical zone designated by [EU] Member States, where UAS operations are only allowed to take place with the support of U-space services." In addition to EU Reg. 2021/664, which provides the regulatory framework for U-space, U-space regulations include EU Reg. 2021/665 (Regulation 2021/665, 2021)on complementary/amended requirements for the service providers in the U-space airspace and EU Reg. 2021/666 on additional requirements for manned aircraft operating in U-space airspace. It noted that the European approach is not to segregate, but to integrate airspace users; in this sense, U-space airspace is not an exclusive space for UAS operators.

None of the three U-space regulations indicated above mention RoW rules explicitly. Art. 3.4.c of EU Reg. 2021/664, the framework regulation, commends Member States to determine the applicable operational conditions and airspace constraints for each U-space airspace, but they do not mention which operational conditions are these. It is implicitly assumed that RoW rules presented in SERA.3210 are applicable there.

A notice of proposed amendment NPA 2021-14 to the three U-space regulations has been issued. It develops acceptable means of compliance and guidance and supporting material. With respect to art. 3 of EC Reg. 664/2021, the NPA presents the elements that Member States should include in a risk assessment prior to establishing a U-space airspace.

2.2.2 *ICAO RoW Rules*

International RoW rules are addressed in ICAO Annex 2, Chapter 3, Section 3.2 (ICAO, 2005) The goal of ICAO in addressing unmanned aviation is to provide the fundamental international regulatory framework through Standards and Recommended Practices (SARPs), with supporting Procedures for Air Navigation Services (PANS) and guidance material, to underpin routine operation of UAS throughout the world in a safe, harmonized and seamless manner comparable to that of manned operations (ICAO, 2011).

With the introduction of UAS, Cir 328 section 5.4 emphasizes the need for [all] pilots to continue seeing other aircraft to avoid collision hazards and recognizes the need to develop alternate means of identifying these hazards in appropriate SARPS in the future, the RoW rules remaining essential for the safe operation of aircraft.

ICAO rules reflect avoidance guidance adopted by the FAA and delineate the convergence and overtaking protocols. Annex 2 does not directly address UAS. However, ICAO has created model UAS regulations to aid member states in creating their own UAS regulations. ICAO’s Model UAS Regulations, Parts 101 and 102, state that RPICs are responsible to “give way to and remain clear of all manned aircraft on the ground and in flight” (Section 101.33), to which philosophy 14 CFR 107.37 aligns. These model regulations are not prescriptive, and each member nation may use them as they see fit.

Differences between SERA.3210 and ICAO Annex 2, 3.2.2 are minimal. Even though most of the sections are identical, an exemption is SERA.3210 section on surface movements, which provides complementary information to its ICAO counterpart in Annex 2.

2.2.3 *International Examples of Conflict Management*

2.2.3.1 Rwanda

In 2019, Rwanda had the most extensive drone delivery operation in the world (Lockhart et al, 2021). Rwanda’s approach to UAS operations has been two-fold: tight regulation on most commercial sUAS operations, combined with a pathway for certain commercial BVLOS flights.

The regulatory structure to enable this was enacted by the 2018 "Regulations related to unmanned civil aircraft systems" which allows commercial BVLOS flights if: "(1) the operation is approved by ATC; (2) drones have appropriate Detect and Avoid technology and capacity to respond to changing weather conditions; (3) flights are operated from established aerodromes, droneports, or locations meeting specified standards; and (4) direct telephone communication is maintained between pilots and ATC" (Lockhart et al, 2021, p 9).

Rwanda has worked closely with US-based startup Zipline to create a delivery network for blood transfusions that mirrors the existing road network. The low-level corridors, which avoid population centers, consist of trunk lines with branches to more remote areas. Although this approach has proven highly successful for Zipline, the corridors have so far not been opened to other companies or operators. The development of the corridors was greatly assisted by close cooperation between government officials, and by high-level commitment to proving the concept and showcasing Rwandan innovation. Tanzania attempted the same type of operational concept in the late 2010's without success, but Ghana is making progress in a similar approach to enabling commercial UAS operations while guaranteeing deconfliction for RoW and collision avoidance.

Zipline (Instant Logistics, 2022) uses a fully autonomous system to retain collision avoidance between their own aircraft. Avoidance between a 'Zip' and manned aircraft is conducted by ATC who clears each flight. One Zipline operator can control 24 simultaneous flights. They claim this is done by removing the human from judgement calls on a per-flight basis (Simmie, 2021).

Zipline recently integrated operations into Ghana and will expand soon to the Ivory Coast and possibly Nigeria. In the US, Zipline is integrating delivery in Arkansas (Walmart), North Carolina (Cardinal Health), California and Utah (Intermountain Healthcare). International partnerships are being organized.

2.3 Technologies Enabling RoW, Maintaining Well Clear and Collision Avoidance

While the fundamental principles of RoW, well clear, and collision avoidance depend upon visual contact, there are existing technologies that aid in adhering to RoW rules. Further, there are DAA technologies in development that can replace visual contact for adhering to RoW rules, maintaining well clear, and collision avoidance.

Although there are numerous candidate technologies, there are currently no FAA regulations that mandate a particular technology, or that mandate performance requirements for any technologies. An aircraft that is transmitting their altitude or position information is considered cooperative, while an aircraft that is not transmitting is considered non-cooperative.

DAA surveillance systems themselves can be classified by detection type as either cooperative, in which detection depends on a transmitted signal from a cooperative aircraft, or non-cooperative, in which detection does not depend on a transmitted signal. Guan et al. (2020) provide a summary of technologies that enable or assist see and avoid or DAA in Table 1. Table 2 contains a summary of the DAAWC systems. These technologies and systems are discussed below.

Table 1. Collision avoidance and security technologies that can enable See And Avoid or DAA.

System	Detection Type	Detection Range (km)[a]	Detection Information[b]	Comparison
TCAS	Cooperative	160	Distance, altitude	Heavy, impractical for small UAS, for collision avoidance only, not well clear
ADS-B	Cooperative (ADS-B In is permitted for UAS ADS-B Out is not)	240	Location, altitude, speed	Not permitted on UAS due to clutter and interference concerns, except when 91.225i applies. Used by ACAS Xa/Xo
ACAS Xa/Xo	Cooperative	160	Distance, altitude	Performance standards defined, drop in TCAS replacement
Remote ID	Cooperative	Dependent upon transmission strength	Location, altitude, speed	Associated display for receiving aircraft are not yet defined. Not universally accepted as DAA means. May have potential for sUAS avoidance of other sUAS.

Note. Adapted from Guan et al (2020).

Table 2. DAA Technologies.

System	Detection Type	Detection Range (km)[a]	Detection Information[b]	Comparison
ACAS Xu	Cooperative			Performance standards defined, some products available
ACAS sXu	Cooperative			Performance standards in progress. No commercially available products
Electro-Optical	Non-cooperative			Size weight and power concerns for small UAS, not suitable in limited visibility. Has potential for ground-based or airborne surveillance applications, not a stand alone

				solution but could be useful within an integrated suite.
Acoustic	Non-cooperative			Not yet commercially viable for air-to-air application. Some success with ground-based applications.
Radar	Non-cooperative			Size weight and power concerns for small UAS. Some success with ground-based applications.

Note. Adapted from Guan et al (2020).

2.3.1 *Existing Cooperative Technologies*

2.3.1.1 ADS-B Automatic Dependent Surveillance Broadcast (ADS-B)

ADS-B is a means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position, and additional data, as appropriate, in a broadcast mode via a data link. ADS-B is a surveillance airspace management technique that relies on aircraft or airport vehicles broadcasting their identity, position and other information derived from on board systems (Global Navigation Satellite System etc.). This signal (ADS-B Out) can be captured for surveillance airspace management purposes on the ground or on-board other aircraft in order to facilitate airborne traffic situational awareness, spacing, separation and self-separation (ADS-B In). ADS-B is automatic because no external stimulus is required; it is dependent because it relies on on-board systems to provide surveillance information to other parties. Finally, the data is broadcast, the originating source has no knowledge of who receives the data and there is no interrogation or two-way contract. (ICAO, 2016)Source: ICAO Doc 4444 PANS-ATM. As with TCAS, ADS-B information may be transmitted through an SSR transponder using the Extended Squitter version (FAA AC 90-114). (Federal Aviation Administration, 2019). Other ADS-B technologies such as Universal Access transceiver (UAT) work in a different frequency, 978 megahertz, and therefore does not depend on SSR, but their deployment is limited outside Alaska. 1090ES ADS-B MOPS can be found in RTCA DO-260B, whereas UAT ADS-B MOPS can be found in RTCA DO-282.

While ADS-B is a very effective tool for surveillance and aiding in collision avoidance for encounters between manned aircraft, its utility is limited in encounters between UAS and manned aircraft, and encounters between UAS. As discussed in Section 2.5.2, the use of ADS-B Out transmitters on UAS is not permitted without ATC coordination, due to concerns about spectrum saturation, interference with manned aircraft signals that are used by ATC in providing positive air traffic control and cluttering of controller scopes with UAS not under positive air traffic control. However, UAS may use ADS-B In for detecting and avoiding manned traffic in the area.

2.3.1.2 Traffic Awareness Beacon System

Traffic Awareness Beacon System (TABS) devices are designed for voluntary installation on aircraft that are not required to carry a transponder or ADS-B device, such as gliders, balloons, and aircraft without an electrical system. Since the TABS devices do not meet the transponder or ADS-B standards described in 14 CFR §91.215 and 14 CFR §91.225, they must first be approved and meet the minimum performance standards (MPS) as defined per the FAA standards. The TABS thus provides an easy-to-install, low-cost surveillance option for such aircraft by making the aircraft visible to others equipped with collision avoidance systems such as TAS, TCAS I, TCAS II, and ADS-B In.

Equipment that meets only the minimum TABS standards will allow other aircraft equipped with traffic advisory systems to detect it but will not support detection by ground surveillance systems that rely on complete transponder functionality. The capability of TABS is divided into four categories: transponder, altitude source, ADS-B Out, and position source which provides compliance with MPS criteria. (Federal Aviation Administration, 2014).

2.3.1.3 Airborne Collision Avoidance System

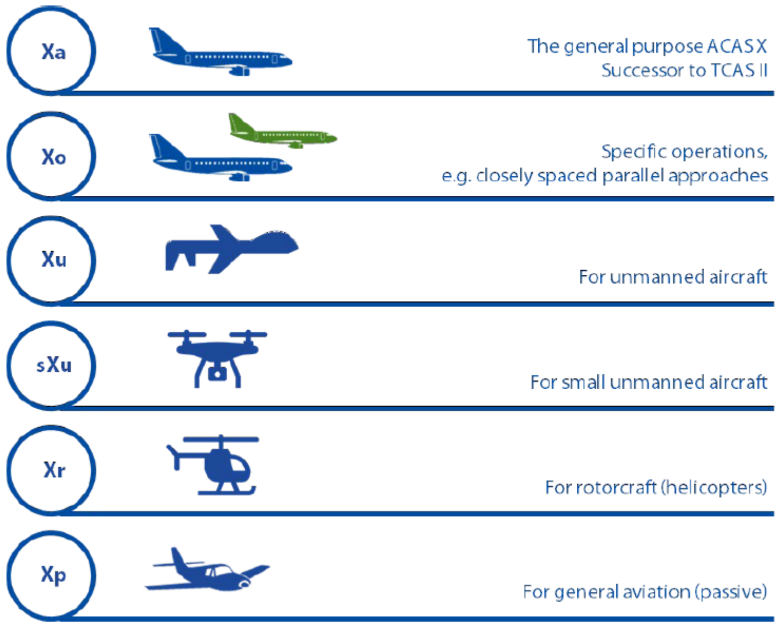
Traffic Alert and Collision Avoidance System (TCAS) is an Airborne Collision Avoidance System that functions independently of the ground-based air traffic control (ATC) system and provides collision avoidance protection for a broad spectrum of aircraft types. TCAS works independently of the aircraft navigation, flight management systems, and Air Traffic Control (ATC) ground systems. (Loss of Separation: See and Avoid, n.d.) (Skybrary, n.d.; EUROCONTROL, 2017).

All TCAS systems provide some degree of collision threat alerting, and a traffic display. TCAS I and II differ primarily by their alerting capability (Federal Aviation Administration, 2011). While TCAS is intended to be a collision avoidance technology for when separation provision is lost, it can also be used to help pilots visually acquire traffic by providing bearing, distance, and altitude information about other aircraft also equipped with TCAS. However, TCAS is not a viable solution for collision avoidance in encounters between manned and unmanned aircraft, because aircraft characteristics and collision geometries preclude use of TCAS in encounters between manned aircraft and some UAS (Dalamagkidis et al., 2012, p. 184), (Federal Aviation Administration, 2016). TCAS can however, be part of a DAA system for larger UA. TCAS limitations are that it does not provide resolution advisories below an altitude of 1,000’ AGL. TCAS resolution advisories are vertical maneuvers, and the system does not have knowledge of ground terrain elevation.

TCAS II MOPS can be found in RTCA DO-185 mentioned above.

ACAS X was developed as a successor to TCAS. ACAS X differs from TCAS in terms of the surveillance source, and the collision avoidance logic. ACAS X systems detect conflicts with other aircraft and provide alerts and guidance to resolve encounters. There are several ACAS X variants, designed for different users. All ACAS X variants provide collision avoidance functionality. ACAS X variants intended for unmanned aircraft are intended to function as DAA systems that provide collision avoidance and well clear (RTCA, 2020) Further, all ACAS variants use ADS-B data in some form. ACAS variants are shown in Figure 2. (EUROCONTROL, 2021).

Figure 2 ACAS variants.



Note. Adapted from *Airborne Collision Avoidance System (ACAS) Guide*, by EUROCONTROL, 2021, p. 24 (https://www.eurocontrol.int/publication/airborne-collision-avoidance-system-acas-guide)

ACAS Xa/Xo is designed for current TCAS users. ACAS Xa/o is a drop-in replacement for TCAS, and relies only on Mode S and ADS-B input for surveillance (EUROCONTROL, 2021),

ACAS Xu is an extension of the ACAS Xa/Xo system, designed for fixed wing UAS operating under Part 91 or Part 135. ACAS-Xu MOPS are published in RTCA DO-386.

ACAS sXu is designed for small UAS flying under Part 89 Remote ID requirements. ACAS sXu MOPS are under development by a joint ASTM/RTCA working group, with publication expected in late 2022 (RTCA, 2021).

ACAS Xu and ACAS sXu will be able to use a variety of surveillance sources, including electro-optical, radar, satellite, and infrared sources (skybrary). (EUROCONTROL, 2013) MOPS for ACAS Xr for rotorcraft and VTOL aircraft, such as will be engaged in AAM, are expected in 2025 (RTCA 2021).

2.3.1.4 SSR. Secondary Surveillance Radar

The radar antenna rotates –usually at 5-12 rpm– and transmits a pulse which is received by the onboard equipment –transponder–. The transponder sends back a reply containing at least ICAO code –if operating in Mode A– but more often this is combined with flight level –Mode C– or other information, e.g. Mach number, selected vertical intent, etc. –Mode S–. The information received depends on the interrogation mode (A, C or S) and the transponder capability. (ICAO, 2016)

2.3.1.5 Remote Identification (RID)

Remote identification (RID) is the capability of an unmanned aircraft in flight to provide certain identification, location, and performance information that people on the ground and other airspace users can receive with a personal device. The final rule requiring RID went into effect on April 16, 2021 and amends the following 14 CFR parts, i.a.: 91, 89, and 107. The rule requires most drones operating in US airspace to transmit (1) the serial number of the broadcast module assigned by the producer; (2) an indication of the latitude, longitude, geometric altitude, and velocity of the unmanned aircraft; (3) an indication of the latitude, longitude, and geometric altitude of the unmanned aircraft takeoff location; and (4) a time mark. 14 CFR Part 89 mandates that all UAS greater than .55 pounds must comply with these provisions or operate in an FAA-Recognized Identification Area (FRIA). All aircraft covered by the regulation must comply by September 16, 2023. RID can be accomplished via broadcast or network ID, as discussed below, but the final rule for RID mandates broadcast ID. Although RID was intended to assist the FAA and public safety agencies in identifying drones that are operating in an unsafe manner, the system has potential to be used for collision avoidance between two drones as well. Broadcast RID is transmitted via Bluetooth or Wi-Fi signals. The usable range of the RID signals is an active area of research, and depends upon variables such as message interference, characteristics of the transmission signal (power output, antenna pattern, broadcast rate, etc.) and characteristics of the receiving device (antenna gain, orientation of the receiver, how often a message is needed to support a use case, etc.). For example, the effective range of RID for a use case that requires an update every five seconds may be greater than the effective range of RID for a use case that requires an update every two seconds. The RID rule and the ASTM standard that serves as the means of compliance requires one transmission per second with an output power of 5dBm for Bluetooth.

Research done in ASSURE A40 suggests that Bluetooth performance exceeds Wi-Fi, and that better receivers, including potentially directional receivers, could improve the effective range at which signals can be received. Additionally, operational limitations that affect the required update frequency, such as speed limits, might reduce the required range for effective RID.

Remote ID displays for personal devices will be available through remote ID display applications such as ScaleFlyt or OpenSkies (ScaleFlyt Remote ID: smart solution to allow safe and secure drone operations, n.d.). Remote ID displays are not required equipment and it is not expected that Remote ID displays will be part of future manned collision avoidance avionics equipment.

2.3.1.6 Network ID

In the Notice of Proposed Rulemaking (NPRM), the FAA proposed requiring standard remote identification UAS and limited remote identification UAS to transmit remote identification message elements through a network connection. To comply with this proposed requirement, UAS would have had to transmit the remote identification message elements through the Internet to a third-party service provider, referred to as a Remote ID UAS Service Supplier (USS). Remote ID USS would have collected and, as appropriate, disseminated the remote identification information through the Internet.

In response to the NPRM, the FAA received significant feedback about the network requirement identifying both public opposition to, and technical challenges with, implementing the network requirements. The FAA had not foreseen or accounted for many of these challenges when it proposed using the network solution and USS framework. After careful consideration of these challenges, informed by public comment, the FAA decided to eliminate the requirement in this rulemaking to transmit remote identification messages through an Internet connection to a Remote ID USS.

2.3.1.7 Remote ID Final Rule with Public Comments and FAA Responses

Most commenters in support of the rule cited improvements to safety and privacy. Commenters expressed that with UAS becoming increasingly widespread, the rule would make identification easier, increase the safety of airspace, particularly for manned aircraft operating at the same altitudes as unmanned aircraft, and protect citizens' privacy.

The FAA acknowledges the support of commenters and finalized this rule and related policies to implement a remote identification framework that provides near-real time information regarding unmanned aircraft operations and increases situational awareness of unmanned aircraft to the public, operators of other aircraft, law enforcement and security officials, and other related entities.

On the other hand, many of the commenters opposed the concept as a whole, while others expressed opposition to specific aspects, concepts, or proposed in the NPRM. Most comments surrounded negative affect upon the hobby and recreational industry, as well as the impact to future UAS innovation. The proposed alternative is the application-based interface to permit self-declaration of an operational area outside Low Altitude Authorization and Notification Capability (LAANC) zones.

The FAA considered the alternative approaches proposed by commenters and assessed whether they met the needs of the FAA, law enforcement, and national security agencies to ensure the safety and efficiency of the airspace of the US sufficient to enable unmanned aircraft to fly over people and at night. The Agency agrees with commenters that a retrofit option could enable operators to meet the remote identification requirements of this rule.

2.3.2 *Non-cooperative Technologies*

2.3.2.1 Electro-optical

Electro-Optical (EO) sensing is comprised of a set of mounted camera lenses to view a specified field of view whereby an algorithm processes pixel changes and movements in order to identify an intruder. This information is then presented in a Graphical User Interface to inform the Remote Pilot in Command (RPIC). Some systems may include an autopilot interface which engages automatic avoidance maneuvering.

Challenges with airborne EO systems are the minimum altitudes that the systems can support are often significantly above the height of structures used for shielding concepts. Minimum altitudes help to prevent airborne systems cueing off the ground clutter. Airborne EO systems are often immature technologies. Ground-based EO systems have the potential for greater performance near the ground than airborne systems due to their ability to filter out areas of known ground clutter and moving objects such as cars on a road. There are limited examples of Ground based EO systems being developed for DAA on the market. Ground based EO systems would provide a limited operational area based on the range of each ground sensor in the ground sensor network.

EO detection methods often have poor range performance, poor range resolution, and difficulties with clutter and tracking aircraft below the horizon. These challenges are greater when equipped onboard an aircraft.

2.3.2.2 Acoustic

Acoustic sensing technology for DAA application on a drone is a newer and immature technology. Although research and development for airborne acoustic sensing applications is ongoing, currently no standalone airborne system exists in the commercial sector. Challenges with airborne acoustic systems often come down to poor track accuracy in determining the intruder position and heading. These same challenges do not necessarily exist for ground-based acoustics that triangulate signals.

The example found is a platform called the Scout System from American Robotics. This system uses an acoustic, AI ground based proprietary system to perform DAA. The drone is a multirotor device and requires a base station to house the drone in between flights, charge the drone, and provide the remote connectivity between a home station and the remotely located air and ground-based systems.

2.3.2.3 Primary Surveillance Radar

Airborne radar systems must be able to contain an antenna, transmit a pulse, and receive the reflected pulse from a target. This can give a somewhat accurate direction, distance from and speed of an intruder. The challenge is getting these systems small enough to fit on a sUAS. Ground based systems are segregated from the airborne radar for communicating conflicts, and of course, size is not a negative influence to flight. These systems are accurate though have challenges with limits to a targets' altitude and potential masking behind natural or manmade obstacles.

EchoFlight is an airborne radar designed for airspace DAA on unmanned aircraft. (Unmanned Airspace, 2019) With output choices for onboard or ground-controlled guidance and unique hooks for integration with other sensors, EchoFlight can detect and track cooperative and non-cooperative aircraft. The field of view is at 120º (horizontal), and 80º (vertical), and the weight is 730g. DeTect's Harrier BVLOS system is a relatively large ground-based surveillance radar providing long-range airspace monitoring with risk advisories including uncooperative aircraft detection. It is large and has functionality out to 20 miles. As another example, Fortem Technologies offers a ground based active electronically scanned phased array radar with 16 channels.

2.3.2.4 Electronic Signal Detection

DJI Aeroscope is able to identify DJI sUAS by monitoring and analyzing their electronic signals to gain critical information, allowing users to protect the integrity of their flight-sensitive environment. This method of detection is akin to Remote ID specifically for tracking DJI sUAS.

2.4 Alternatives to RoW Rules

Existing RoW rules assume integration of aircraft types in shared airspace. However, there are alternatives that keep aircraft separated without resorting to RoW rules. Thus, these methods achieve safe interactions between aircraft through alternative means. Many of these concepts involve a type of segregation. Various forms of aircraft segregation including those originally intended for purposes other than to keep aircraft separated, might also be part of future concepts that enable safe drone operations. This section reviews existing strategic conflict management approaches that may inform future concepts to safely enable drone operations.

2.4.1 *Segregation by Aircraft Category*

In some circumstances, aircraft are not allowed in certain airspace due to the aircraft category. For example, ultralight aircraft cannot operate in controlled airspace without advanced approval or fly over congested areas (FAR §103.15, §103.17). Similarly, sUAS currently have the following restrictions:

- FAR §107.41 (Federal Aviation Administration, 2016) Operation in certain Airspace; "no person may operate a sUAS in Class B, Class C, or Class D airspace or within the lateral boundaries of the surface area of Class E space designated for an airport unless that person has prior authorization from ATC." Low Altitude Authorization and Notification Capability (LAANC) is a FAA-industry initiative to facilitate these ATC authorizations below 400'. UAS facility maps inform users on the maximum altitude around airports that FAA may grant authorizations without further safety analyses.
- FAR §107.43 (Federal Aviation Administration, 2016) Operation in the vicinity of airports: "No person may operate a SUAS in a manner that interferes with operations in traffic patterns at any airport, heliport, or seaplane base."
- FAR §107.45 (Federal Aviation Administration, 2016) Operation in prohibited or restricted areas. No person may operate a SUAS in prohibited or restricted areas unless that person has permission from the using or controlling agency, as appropriate.
- FAR §107.47 (Federal Aviation Administration, 2019) Flight restrictions in the proximity of certain areas designated by a notice to airmen. A person acting as a remote pilot in command must comply with the provisions of §91.137 through §91.145 and §99.7 of this chapter.
- FAR §107.41. (Federal Aviation Administration, 2022). The altitude of the sUAS cannot be higher than 400 feet above ground level, unless it is flown within a 400-foot radius of a structure; and it does not fly higher than 400 feet above the structure's immediate uppermost limit.
- FAR §91.119. (Federal Aviation Administration, 2022). Restricts flight over congested and non-congested areas to above 500 feet AGL, which contributes to segregation from UAS. This restriction, however, does not apply to helicopters, powered parachutes, or weight-shift control aircraft when they operate without hazard to persons/property as per §91.119(d), or agricultural aircraft engaged in dispensing operations, as per §137.49 and §137. Arguably, the UAS being flown over an intended landing zone where the pilot has

no knowledge of the manned pilot's intentions ahead of a landing sequence presents a conflict.

2.4.2 *Segregation by Equipage*

In some circumstances, aircraft are not allowed to operate in certain airspace without particular equipment. For example, with certain exceptions, manned aircraft may not operate in Class A, B, or C airspace, or within 30 NM of the primary airport in Class B airspace, or at an altitude of over 10,000 MSL without an operating transponder that encodes altitude information (CFR 91.215)

- FAR §91.215 ATC transponder and altitude reporting equipment and use. "Unless otherwise authorized or directed by ATC, and except as provided in paragraph (e)(1) of this section, no person may operate an aircraft in the airspace described in paragraphs (b)(1) through (5) of this section, unless that aircraft is equipped with an operable coded radar beacon transponder."

2.4.3 *Segregation by Conspicuity*

In some circumstances, aircraft are not allowed to operate without features that enhance visual conspicuity. For example, in order to operate at night, both manned and unmanned aircraft must have a functioning anti-collision lighting system (§91.209 and §107.29).

2.4.4 *Segregation by Ground Population*

In some circumstances, aircraft access to airspace depends upon characteristics of the surface over which the flight is conducted. For example, sUAS and ultralights may not fly over assemblies of people, which minimizes the probability of striking an individual on the ground. This minimization is necessary since sUAS and ultralights are not subject to aircraft certification requirements.

- FAR §103.15 states: "No person may operate an ultralight vehicle over any congested area of a city, town, or settlement, or over any open-air assembly of persons."
- FAR §107.39, sUAS Operations Over People. No flights over people unless they are participants in the operation, are located under cover, or meet the operational categories specified.

2.4.5 *Segregation by Time of Day*

In some circumstances, aircraft are restricted from operating during night time.

- FAR §203.11 (Ultralight) Daylight Operations. "No person may operate an ultralight vehicle except between the hours of sunrise and sunset."
- FAR §107.29 sUAS Operation at night. Knowledge and testing is required. Anti-Collision lighting visible for 3SM is required. Civil Twilight flight rules.

2.5 Operations and Associated Challenges

Current RoW rules are sufficient for two manned aircraft but there are operational, human factor, environmental, and functional challenges that are specific to manned vs unmanned flight in the same space, or with encounters between two unmanned aircraft or swarms. Methods of awareness and recognition must be equivalent to those of current manned operations. Listed below are examples of the current gaps and challenges related to existing RoW regulations.

2.5.1 *Operation Type*

This section explores operational scenarios for which current rules and procedures may be insufficient to meet the challenges of new entrants.

2.5.1.1 Emergency

FAR §91.113c specifies that an aircraft in distress has RoW over all other aircraft. This rule was developed under the historical circumstance that all aircraft in close geographic proximity were communicating on party line radio frequencies, so that when one aircraft declared an emergency, all aircraft in the vicinity would hear the transmission. In the future, datalink and automated operations will change the nature of radio communications, making reliance on situation awareness derived from a party line impractical. For continued provision of RoW to emergency aircraft, DAA systems should incorporate some method of identifying emergency aircraft. The DAA Minimum Operational Performance Standards (MOPS) for large UA operating under IFR (DO-386B) addresses this point by stating that the DAA system will maneuver a UA well clear if a conflicting aircraft that does not have RoW fails to maneuver to remain well clear. Therefore, the DAA MOPS asserts that the UA does not need to identify an emergency aircraft, because the DAA system will eventually maneuver to remain well clear of any aircraft that fails to yield RoW, whether that aircraft is entitled to RoW or not (RTCA DO-365B, 2021, p. H-1).

2.5.1.2 Converging

FAR §91.113d specifies that when two aircraft are converging in other than 180^{o} angle, the aircraft to the right has the RoW. This article also indicates priorities when different types of aircraft are involved: balloon, glider, airship, parachute, etc. The classification provided, which does not consider sUAS, are based on maneuverability. Thus, for instance, a balloon has the RoW over any other aircraft category. Part §107.37 specifies that sUAS must yield the RoW to any other aircraft. Two scenarios have not been specifically addressed and would need further consideration: UAS/swarm and UAS/UAS encounters. The role of DAA also needs further consideration. For instance: Should a non-DAA equipped UAS yield the RoW always when approaching a DAA-equipped sUAS to its left? In other words, should RoW between two UAS depend on equipage?

FAR §91.113 requires aircraft type categorization and the rule is defined for both manned and unmanned vehicles. This adds a technical challenge to unmanned vehicles for categorizing other aircraft detected during flight. Similarly, it is challenging for an onboard pilot since they will need not only to detect but also categorize other aircraft and decide whether other aircraft is manned or unmanned.

2.5.1.3 Head-On and Overtaking

Head on or overtaking a small UAS: Under FAR Part 107, sUAS must yield RoW to all manned aircraft. If these RoW rules are maintained for BVLOS operations, requirements must be in place that mandate that sUAS can detect both cooperative and non-cooperative traffic approaching from any angle.

Head on or overtaking a medium UAS: A medium UAS is defined by sponsor as > 55 lbs and < human cargo capable. Under existing Part §91.113 right-of-way rules, a medium UAS operating under Part 91 would have RoW if being overtaken by a manned aircraft. However, a medium UAS may not be as visually conspicuous as an aircraft large enough to carry a human. The ability of a human to visually detect a medium UAS is not known. The transition between an sUAS that must give way to a manned aircraft in Part §107.37, and medium UAS that operate under Part 91 is a grey area in terms of visual detection. The distance at which an object can be visually detected depends upon numerous factors, including object size, visual angle, obstructions, visual acuity, visual accommodation (focus), contrast, background, search time, and apparent motion (Williams & Gildea, 2014). In an empirical study of manned aircraft encountering sUAS with various encounter geometries, (Loffi et al., 2016) found that manned aircraft pilots flying in a Cessna 172 visually detected a hovering or transiting quadcopter sUAS in 37% of encounter cases. Manned aircraft pilots visually detected a fixed wing sUAS with a 6-foot wingspan orbiting with a head on aspect relative to the aircraft course in 84% of encounter cases.

A manned aircraft pilot requires 12.5 seconds for detection, decision, and beginning evasive action (FAA, 2016b). Based on the rate of closure and distance at which the manned aircraft pilot visually detected the vehicles, (Loffi et al.,2016) found that manned aircraft pilots would have had insufficient reaction time to avoid quadcopter sUAS. However, manned aircraft pilots would have had sufficient reaction time to avoid a fixed wing sUAS of six-foot wingspan with a head on aspect in 10 out of 16 encounters. The reaction time was based on the time required to avoid a direct collision, not avoid NMAC nor remain well clear. This study was limited in generalizability since most of the factors that affect visual detection range were invariant. Further, the closure rate of 100 knots does not reflect the range of airspeeds at which aircraft may encounter sUAS. While a medium UAS would presumably be required to carry DAA equipment, the manned aircraft would have no such requirement beyond what is already required for ADS-B out. A further unresolved issue is the FAR Part under which medium UAS would operate. The above discussion assumes a medium UAS would be operating under Part 91. Ongoing ASSURE Research conducted by Mississippi State University is measuring the ability of pilots to visually acquire other aircraft and is expected to provide more insights into this topic.

Head on or overtaking a Large UA: Defined by sponsor as human cargo capable, a large UA is likely operating under a COA or LOA, Part 91, 135, or 137 FAR rules. RTCA DAA MOPS addresses this situation from a standards perspective and proposes to give RoW to the UA only when the large UA is being overtaken by a non-cooperative intruder. (RTCA DO365B 2021, p. A-106).

The BVLOS ARC (FAA, 2022) proposes that UAS could be given RoW over crewed non-cooperative aircraft in a non-shielded low-altitude area (under 400’ AGL and >100’ separation from a structure or critical infrastructure). Additionally, where there is ‘adequate separation’ giving way and passing would be acceptable. Further recommendation of a new regulation under the identification of Part 108 to address UAS BVLOS was presented. Challenges with the BVLOS ARC (FAA, 2022) to support safe aircraft interactions include an inability for onboard pilots to see drones approaching them from behind and documented extremely poor performance in seeing small converging drones within the cockpit field of regard with adequate time to yield and give way. Hence, the BVLOS ARC (FAA, 2022) recommendation would require onboard pilots to do something that they are not able to do for certain geometries and may not be able to do well for other encounter geometries. Hence, the BVLOS ARC (FAA, 2022) proposal as written does not appear viable since it does not appear to support safe interactions when a drone and crewed non-cooperative aircraft encounter one another. Safer concepts include segregation or continuing to give the crewed aircraft priority and RoW.

2.5.1.4 Approach and Landing

If manned and unmanned pilots follow the published rules and related knowledge when operating near any published airfield, there should not be a scenario that would negatively affect RoW in an approach and landing condition. The addition of the LAANC authorized areas near Class D and above airports does provide additional safety enhancements by restricting sUAS operations to not operate where they might interfere with traffic patterns, approach and departure paths from the airport.

2.5.2 *Shielded DAA Operations*

Currently, the concept of shielded operations applies to moored balloons and kites and specifies that these aircraft must comply with cloud clearance and visibility limitations, except when within 250 feet of a structure, and below the top of the structure (CFR Part 101.13). The concept of shielded operations applied to sUAS suggests that future rule changes could be made to allow sUAS to be exempt from certain requirements or to have differences compared to balloons and kites when operating in close proximity to ground-based structures. Defining requirements for shielded operations may help reduce the DAA requirements for airborne-based DAA technologies. Therefore, sUAS operations carried out near man-made structures could serve as a mechanism to contain sUAS operations within a specific operational volume that essentially presents a shield to reduce the risk of a potential collision with a conventional aircraft, as is proposed in the BVLOS ARC Report. Shielded operations present a potential avenue for conducting BVLOS flight operations with UAS in a manner that reduces the likelihood of a traffic conflict with manned aircraft. While this may assist, additional RoW rules must be considered for when aircraft do encounter one another and also where precision agriculture operations such as crop dusting may be prevalent. The BVLOS ARC (FAA, 2022) recommends the establishment of low altitude shielded and non-shielded areas and how those would operate.

The airspace boundaries that would contain shielded operations are not yet defined. Some sources identify the definition of shielded operations for small UAS to the operational limitations set up in §107.51b to fly within a radius of 2,000 ft of a structure and not higher than 400 ft above it (Edmonds et al., 2021). In ASTM standard F3442/F3442M (ASTM 2020, as cited in Edmonds et al., 2020) the vertical margin is reduced to 250 ft, as long as the airspace is considered to be ‘low risk’, which is commonly associated with non-congested airspace.

In other sources, the reference to shielded operations is more vague. For instance, the Joint Authorities for Rulemaking of Unmanned Systems (JARUS) Specific Operations Risk Assessment’s (SORA) Annex I (JARUS, 2017) includes the definition of “atypical airspace”, as that portion of the airspace “where normal manned aircraft cannot go” and gives the example of flying within 100 ft of buildings and structures. From this definition, it logically follows those operations within 100 ft of a building or structure might be considered atypical. This distance is considerably less than the already reduced distance in American Society for Testing and Materials (ASTM) definition. It remains unclear what “normal manned aircraft” is, and whether the concept of “atypical” operations would include, in this context, “shielded operations.”

ICAO model UAS regulations Parts 101 and 102 (ICAO, 2020) defines shielded operations as: operations “of an aircraft within 100 m of, and below the top of a natural or man-made object” (p. 7).

The BVLOS ARC (FAA, 2022) defines shielded airspace as the “volume of airspace that includes 100’ above the vertical extent of an obstacle or critical infrastructure and is within 100 feet of the lateral extent of the same obstacle or critical infrastructure as defined in 42 U.S.C. § 5195c (Critical Infrastructures Protection Act of 2001).” (UAS BVLOS Arc Final Report, 2022).

Whereas the safety distances differ depending on the source, the concept of “shielded operations” is always related to an operation near a structure. As long as the UA is kept within a certain distance to the structure –for instance, for inspection purposes– the risk of an encounter with another aircraft might be reduced, since manned aircraft are often kept away from them for safety reasons. This is the case of sUAS under Part 107, authorized to fly within a 400 ft radius and above a flight obstacle (§107.51). In Part §91.119, certain manned aircraft cannot be closer than 2,000 ft horizontally and 1,000 ft above the structure in congested areas, which in the worst-case scenario would leave a well-clear distance of 600 ft. In cases other than congested areas, the manned aircraft vertical distance above the top of the structure can be as low as 500 ft. Such a worst-case scenario results in a minimum segregation buffer where sUAS and certain manned aircraft can fly of 100 ft. These minimum vertical distances of 100’ between manned aircraft and sUAS may be insufficient to guarantee safety operations. Further, this analysis does not account for manned aircraft that are exempt from minimum altitudes or are intentionally close to the obstacle for mission-related purposes such as agricultural spraying, tree cutting, infrastructure inspection, emergency medivac, or other allowable reasons. Lower minima could apply in sparsely populated areas for powered parachutes or weight-shift-control aircraft.

The BVLOS ARC rendered much attention to the concept of shielded operations of UA with respect to low altitudes where manned and unmanned aircraft will have encounters. Specifically, they recommend a categorization for RoW rules in low altitude operations as Shielded and Non-Shielded Low Altitude Operations. There are situations where current RoW conflicts will be possibly further exacerbated by some of the BVLOS ARC (FAA, 2022) recommendations regarding shielding rules. This can be best explained in a recent near-miss incident in Arizona between a Western Area Power Administration Bell 407 conducting a (100’ AGL) power line inspection, and an sUAS that was identified conducting a type of structural inspection and shielded by the line and had LAANC authorization (Class D airspace). There are countless locations where multiple entities would have legal right to operate in the area and/or LAANC authorizations for the same time and place; Perhaps best termed as an infrastructure corridor, these do and may include co-located power lines, rail lines, bridges, and towers, or more, as an example. These situations are not isolated. Additionally, ATS does not publish LAANC authorizations for public access (i.e., useful for manned flight planning).

The following is quoted from the BVLOS ARC (FAA, 2022), and provided here for background:

> **<u>Low Altitude Operations</u>**
> The ARC selected the altitude limits for the application of the proposed RoW rules that most closely align with widely understood controlling altitudes for both traditional and unmanned aviation. The ARC clarified that this recommendation is primarily for Class G airspace and recommends that the FAA create a method to authorize coordination with ATC for operations in controlled airspace (e.g., LAANC), Letter of Authorization (LOA), or other approval).
>
> 1. 500' AGL is the minimum safe altitude for aircraft operating away from airports and over other than congested areas as defined in 14 CFR §91.119(c), and well below the minimum safe altitude for aircraft operating away from airports and over congested areas as defined in §91.119(b). Exceptions to this rule are limited to specific types of aircraft operations as defined in §91.119(d) (for helicopters and weight shift control aircraft); and in §137.49 and §137.51 (for agricultural aircraft during actual dispensing operations). This **substantially limits the number of aircraft that are authorized to operate** in the limited altitude strata from the surface to 500' AGL, and therefore would **substantially limit the number of aircraft that might be affected by the rule change**– particularly as many of these aircraft are already equipped with ADS-B out or TABS capability.
> 2. 400' AGL is the current altitude limit for UA operating under Part 107. It is widely understood and accepted by the aviation community and has proven to support the vast majority of sUAS Use Cases.
>
> The difference between the altitude cap for UA (at 400' AGL) and the altitude floor for traditional aircraft (at 500' AGL) affected by the rule change provides an altitude "buffer" of up to 100' AGL that provides:
>
> 1. Traditional unequipped aircraft descending into this stratum the opportunity to scan the area for potential traffic conflicts **before** the UA is co-altitude;
> 2. UA equipped with ADS-B in collision avoidance the opportunity to detect descending converging traditional aircraft **before** the aircraft is co-altitude;
> 3. Sufficient safeguard for altitude accuracy errors (with up to 75' allowable under §91.411 and as specified in Appendix E of Part 43).

The ARC recommends § 91.113 (d) be amended to give UA right of way over all aircraft for Shielded Operations. The recommended definition of shielded is:

> **<u>Shielded Operations – UA Have Right of Way</u>**
> Shielded Area is defined as a volume of airspace that includes 100' above the vertical extent of an obstacle or critical infrastructure and is within 100 feet of the lateral extent of the same obstacle or critical infrastructure as defined in 42 U.S.C. §5195c. A Shielded Operation is an operation within a Shielded Area. (FAA, 2022)

Further, the ARC recommends adding to §91.113 (d)(4) this stipulation; UA conducting BVLOS Shielded Operations have right of way over all other aircraft. They argue to "maximize the utility of the existing "bubble" of airspace near structures and other obstacles that crewed aircraft are already in the habit of avoiding" (FAA, 2022). They also address that the

> "…likelihood of UA-GA encounters to be minimal in shielded airspace because crewed aircraft typically do not conduct operations near obstacles, and the existing regulations prohibit a significant portion of helicopters and non-agricultural GA aircraft from operating at low altitudes except for takeoff or landing….no crewed aircraft should be within 100 feet of a structure for the vast majority of low altitude operations. The limited crewed operations in this volume of airspace provides a strategic mitigation that allows UA operators to obtain the full benefits of shielded operations, and increase safety without any additional cost or technology. The intent is to capitalize on structures that pilots are already trained to avoid under existing VFR operating rules." (FAA, 2022).

Current efforts on shielded operations include the ASSURE A45 project on shielded UAS operations. ASSURE A45 work aims to identify risks and recommend solutions to FAA that enable shielded UAS operations and to what degree UAS Detect and Avoid requirements is needed. The project also aims to address recommendations on UAS standoff distances from manned aviation flight obstacles. International shielded operation efforts include shielded operation rules from Civil Aviation Authority (New Zealand) which allows an operator to fly a drone within the height of 100 meters and below the top of a natural (such as a tree) or man-made object. Civil Aviation Authority shielded operations rules also allow an operator to fly during night as well as to operate in controlled airspace without ATC clearance. Even though current shielding concepts mostly leverage a type of segregation concept, in the future there may be different categories of shielded operations that provide varying levels of segregation or soft segregation that only limits the rate of interactions for one or more aircraft categories.

2.5.2.1 Relationship of shielded operations to RoW

Small UAS flying under Part 107 are already authorized to operate within a 400' radius, and above a flight obstacle (§107.51). Certain manned traffic is informed to remain a distance of 2000 ft horizontally, however, FAR Part 91.119 allows flight that may in fact be as close as 1000 ft above a structure where a UA is flying in shielded configuration in congested airspace, whereas in non-congested airspace distances can be reduced to 500 ft horizontally and vertically. This could easily become a conflict to well clear and thus RoW.

Within the distances to a structure imposed by §107.51 and considering that common fixed-wing aircraft do not fly near them for safety reasons, using segregation and keeping non-ADS-B equipped aircraft out of shielded areas can be a viable option for safety. RPIC situational awareness to not exit this airspace block is essential and should be a part of the flight planning. Additionally, the manned aircraft flying near vertical structures are also advised by FAR §121.657 and AIM 7-6-3 Obstructions to Flight where manned pilots are required to maintain a minimum 1000 ft. vertical separation from structures in non-mountainous areas when flying IFR.

Per FAR §107.29, anti-collision lighting requirements combined with the fact that some obstacles like towers and some buildings are compulsorily already lit as a warning to nearby manned air traffic. Together, these proximity relationships combine as visual warnings and enhance safety.

Night operation of sUAS near obstacles might be public safety missions or inspection operations utilizing thermal sensors. However, night operations may also include any drone as they may fly near structures if shielded areas are open to them.

2.5.3 *UAS Encounters with Other UAS*

2.5.3.1 Encounters between BVLOS sUAS & VLOS sUAS

Applying RoW rules for UA aircraft under VLOS rules versus UA under BVLOS waiver requirements can be a challenge operationally. Due to environmental issues such as low visibility (Wallace et al., 2019), or human factors such as being distracted (Woo, 2017; Lamb, 2019); the sUAS remote pilot may misjudge the location of a sUAS operating in the vicinity or react in a way contrary to the UA operating with DAA equipment under BVLOS waiver requirements. Functional challenges are also apparent in that there is no clear way to communicate between two sUAS. Some type of broadcast capability seems the most logical pathway to remaining well clear in a conflict scenario between two UA.

Operational challenges may also be addressed through advancement of a national UAS Traffic Management (UTM) system. A UTM system would enable established routes and a centralized airspace management system, that would enable separation and UA collision avoidance. This effort would create a challenge in obtaining participation from recreational users if user-fees were imposed. Additionally, since cellular coverages are limited in areas, UTM will have built-in deficiencies.

2.5.3.2 VLOS sUAS encountering VLOS sUAS

Section §107.31 states:

> "(a) With vision that is unaided by any device other than corrective lenses, the remote pilot in command, the VO (if one is used), and the person manipulating the flight control of the small unmanned aircraft system must be able to see the unmanned aircraft throughout the entire flight in order to:
>
> 1. Know the unmanned aircraft's location;
> 2. Determine the unmanned aircraft's attitude, altitude, and direction of flight;
> 3. Observe the airspace for other air traffic or hazards; and
> 4. Determine that the unmanned aircraft does not endanger the life or property of another."

§107.31 provides direct guidance regarding how a UAS operator must 'see' the UAS and §107.37 provides the RoW guidance regarding the UAS operator's responsibility to give way to all other aircraft. While the RoW regulation instructs a yielding requirement, there is no identification of how that maneuver is performed as it is described under §91.113, nor is there a priority given for sUAS encountering sUAS.

2.5.3.3 sUAS BVLOS & sUAS BVLOS

Similar to an encounter between two VLOS sUAS, there is no defined rule for two BVLOS sUAS operating under Part 107 encountering each other.

2.5.4 *Swarm Operations*

FAA's "Air Traffic Organization Policy: Unmanned Aircraft Systems (UAS)." Order JO 7200.23C, defines a swarm of UA as "an operation of more than one UA in which all UAs operate in unison to commands from one pilot in command, who commands them all through a common link". The Headquarters Airspace Authorization Procedures defines the waiver process for operations of multiple UASs (§ 107.35).

Currently, RoW rules regarding drone encounters between drone formations vs. drones are not found in FAR parts §107.37 and §91.113. Drone NOTAMs are certainly an available tool that could enhance safety; however, the effectiveness of Drone NOTAMs depends upon operators actually reading them and being familiar with their contents. All scenarios are different, and any regulatory solution would need to consider the method of detection, whether the encounter is entered into knowingly, if the encounter is an immediate reaction, and encounter flight profiles of all UA in the event. The possibility that both the formation and single UA are in autonomous modes of flight creates extra challenges that may only be avoided by enhanced sensors.
Maneuvering to maintain collision avoidance is an established instruction –yield to the right in head-on approaches– that can continue to provide for safety when there is advanced warning such as that which can be obtained from onboard sensing capabilities –infrared, optical etc. –. In any conceivable situation, advanced notice of the potential conflict would be essential, regardless of the presence of proximity sensors.

2.5.5 *Operation of Multiple Drones by One Operator*

Scenarios involving one operator to many drones depend upon automation of DAA functions. The BVLOS ARC (FAA, 2022) suggested that training and qualification areas and thresholds for the BVLOS rating reflect different use cases, capabilities, and operational concepts unique to operations enabled under the new rule. The BVLOS ARC further recommends the need to conduct multiple simultaneous (a.k.a. "one-to-many") UAS BVLOS operations at more advanced levels of automation.

2.5.6 *Recreational UAS*

Recreational flights at airfields owned and operated by the Academy of Model Aeronautics (AMA) are not necessarily a threat due to strict community guidelines and their rules for collision avoidance, remaining well clear of manned traffic, and RoW considerations. AMA members have flown safely in a rules-conscious environment for decades. Not all recreational pilots are members of the AMA with its knowledge and compliance discipline. There are numerous examples of pilots flying drones (with and without a remote pilot certificate) in controlled airspace and certainly, the potential for drone caused airspace conflict in uncontrolled airspace is equally present.

The BVLOS ARC was not clear on whether the scope of their work included recreational UAS or not. If the intent is to allow recreational BVLOS flight, rulemaking will have to be clear on requirements for recreational operators.

3 CONCEPTS TO EXPLORE

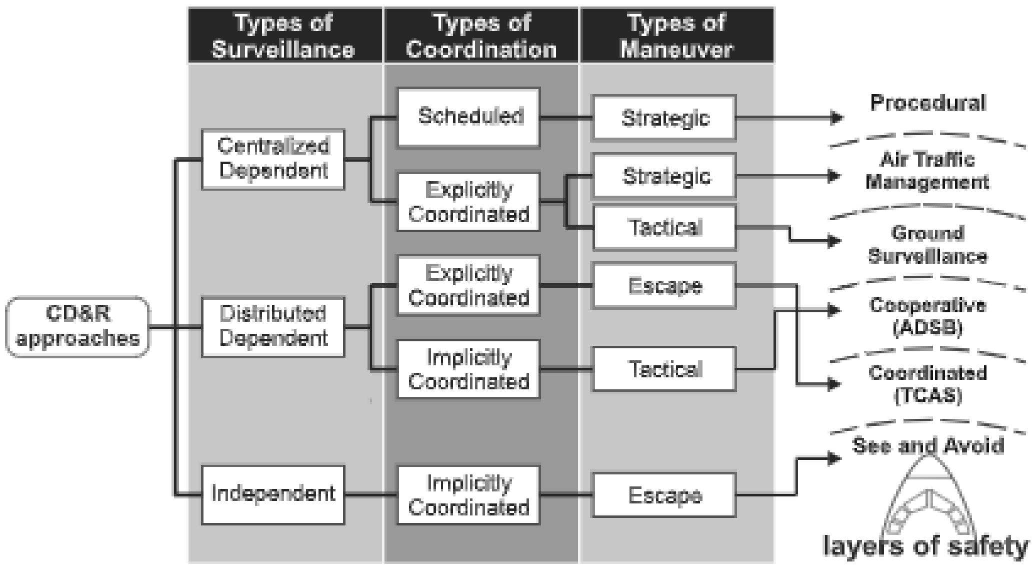
As demonstrated below, various stakeholders have attempted to explore airspace concepts as well as implement missions sets that partly address the full integration of unmanned aircraft into the

NAS. These concepts include changes to property rights, airspace management, RoW rules, flight rules, equipage requirements, and conspicuity rules.

3.1 Categorization of Conflict Detection and Resolution

A discussion of concepts regarding full integration of unmanned aircraft into the NAS should begin with an explanation of the categorization of conflict detection and resolution. (Jenie et al., 2016) provides such a categorization system, which is shown in Figure 3.

Figure 3. Taxonomy of Conflict Detect and Resolution approaches in manned flight.



Note. Adapted from "Taxonomy of Conflict Detection and Resolution Approaches for Unmanned Aerial Vehicle in an Integrated Airspace," by Y. I. Jenie, E. V. Kampen, J. Ellerbroek & J. M. Hoekstra, 2016, *IEEE Transactions on Intelligent Transportation Systems*, p. 559.

As per Figure 3, conflict detection and resolution can be defined by the type of surveillance, coordination, and maneuvering used to maintain well clear. Surveillance can be centralized and dependent, in which data is received from a common central station; distributed and dependent, in which every vehicle cooperatively broadcasts information to others, as with aircraft equipped with TCAS or ADS-B, or independent, in which data is obtained independently from an onboard sensor, as with see and avoid (Jenie et al., 2016). Coordination in turn can be scheduled; explicitly coordinated as with TCAS or ACAS Xu; implicitly coordinated as via right-of way rules, or uncoordinated, when each aircraft acts alone. Maneuvering can be thought of as either strategic, involving a significant deviation from the flight path while still far away from the other aircraft: tactical, involving a small deviation from the flight path usually closer to the other aircraft; and escape, involving maneuvering the aircraft without regard to flight path, only safety. Use of the terms 'strategic' and 'tactical' in reference to maneuvering should not be confused with similar language used to discuss the levels of safety. Consiglio et al (2010) outline alternatives to see and avoid as shown in Figure 4.

Figure 4. Summary of See and Avoid Alternatives from Consiglio et al. (2010).

	When	Approach	Costs	Development Risks	Stakeholder Impact
Small UAS Line-of-sight Regulations	+2 yrs	Establish regulations & certification standards for aircraft and crew that would enable small UAS (<25 kgs) to operate for commercial purposes	Low	Low • Regulations & standards • Safety case	Low Glass G users may encounter small UAS
Ground-based Sense & Avoid (GBSAA) Dedicated Sensor	1-2 yrs	Deploy dedicated 3D air surveillance radars to enable UAS flight crews to monitor traffic	Medium	Medium • Installation of radar • Operational concept • Decision-support system & display • Safety Case – Highly dependent on C2 link	Low UAS operators need to remain well-within surveillance range
GBSAA Repurposed Sensors	2-3 yrs	Operate within coverage of existing ground sensors (e.g., ASR-9/11) which will enable UAS flight crews to monitor traffic	Medium	Medium • Radar post processing accuracy • Operational concept • Decision-support system & display • Safety Case – Highly dependent on C2 link	Low Broader surveillance area
Airborne-based Sense & Avoid (ABSAA) Cooperative	10+ yrs	Airborne equipment receives signals from *cooperative* aircraft (ADS-B). Traffic situation info sent to UAS pilot or used by automation on-board the UAS to autonomously sense and avoid	High	High • Avoidance algorithm development and validation • Policy requiring equipage in specific airspace • Decision-support system & display • Safety Case – Dependent upon C2 link or autonomous software	High • Reduces access for legacy airspace users unless appropriately equipped • Technology could be extended to manned aviation
ABSAA Non-cooperative	12+ yrs	Airborne equipment uses non-cooperative sensor technologies to locate other aircraft and hazards. Situation info sent to UAS pilot or used by automation on-board the UAS to autonomously sense and avoid	Very High	High • Requires the development of new non-cooperative sensor technology which is able to be certified for the purpose of Sense and avoidance • Decision-support system & display • Safety Case – Dependent upon C2 link or autonomous software	Low Technology could be extended to manned aviation

3.2 Segregation by Airspace Property Rights

One possibility for strategic conflict management using airspace management is to invoke airspace property rights to restrict entrance into certain airspace. It is well settled that landowners possess property rights in the airspace superjacent to their property, per US v. Causby. The vertical extent of those property rights is not defined either by statute or by legal precedent, although the Court in Causby held that a landowner owns as much of the airspace above his or her property to which he or she can reasonably use, and any invasion of that airspace is a trespass subject to damages. Likewise, that airspace above the "immediate reaches above the land" is part of the public domain, not subject to trespass. FAA has statutory authority to regulate "navigable" airspace, per 49 US Code Sec. 40103. While there has never been a statutory, regulatory, or legal definition of the term "navigable" it is reasonable to assume that airspace within the "immediate reaches of the land" is not navigable, and is privately owned, per US v. Causby. Thus, for example in a situation where a drone was used to inspect a powerline, the owners or lessees of the property would have standing to claim legal ownership of the airspace in the immediate reaches of the ground and surrounding the powerline, as the powerline's physical presence above the land is a superjacent and reasonable use of the land. That property owner or lessee would also have legal standing for the authority to either grant or refuse permission for a third party to access that airspace and might have a state law trespass claim against non-permitted parties.

While FAA, under its enabling statutes in 49 USC 40103, has the legal authority to designate and regulate navigable airspace for public use, that authority does not extend to non-navigable airspace. The legal distinction between navigable airspace and non-navigable airspace in the context of property ownership has not been addressed either by statute, regulation, or legal precedent. However, the term "navigable airspace" has been defined by regulation in the context of airport airspace designation. Airports are designated as navigable by regulation—and usable by the general public—down the ground, or runway, so the definition does not apply outside that context, but it may be helpful by analogy. In the airport context, "navigable airspace" is defined as "the airspace at or above the minimum altitudes of flight that includes the airspace needed to ensure safety in the takeoff and landing of aircraft." The implication may be that, once legal aerial trespass issues are resolved, some minimum level of flight needed to ensure safety—likely pertaining both to flight and ground safety—would be included in the definition of navigable airspace pertaining to drone operations around privately owned structures such as powerlines.

A pending case in the DC Circuit, RaceDayQuads v. FAA, illustrates the tension present in airspace property rights. The plaintiff argues that the Remote ID rule will violate their right to privacy under the 4th Amendment because the rule would require broadcast of personally identifiable information even when flying in their own, private, non-public airspace. While the definition of navigable airspace is not central to the plaintiff's argument, its presence highlights the lack of a definition for "navigable" in the federal statutes and regulations.

3.2.1 *Changes to Airspace Property Rights for Flight Near Obstacles*

Current airspace property rights are best understood by referencing the US v. Causby case, from the US Supreme Court in 1949. There, not long after the passage of the Air Commerce Act and the gradual acceptance of air travel, the Court was faced with a question of ownership of airspace above private property. In this case, the US Army Air Force conducted frequent low-level flights right above Causby's farm. Causby sued, arguing such low-level flights entitled him to just compensation under the 5th Amendment. The US claimed a public right to fly over Causby's farm. The Court agreed a taking occurred and nullified the ancient doctrine that ownership extends indefinitely upward, affirmed that navigable airspace was public domain, and concluded flights so low and frequent as to be a direct and immediate interference with the enjoyment and use of the land constitute a taking. The Court, however, explicitly declined to state a specific altitude at which private property ended.

While further cases since 1949 have refined concepts such as "air easements" and defined government powers to zone property to restrict property rights in adjacent airspace, there has been no federal or state statutes that address airspace ownership directly. The FAA has statutory authority to regulate navigable airspace under federal law, but the legal question remains whether privately owned airspace is "navigable" for purposes of regulation. Some commentators have suggested that FAA simply define certain low altitude airspace as "navigable" to provide clarity for regulation, but there does not exist such authority in federal law or regulation.

Establishing restrictions on use of airspace based on property rights would certainly enable segregation and safe separation of aircraft. However, the regulatory structure for this does not yet exist, and would likely face legal challenges.

3.3 Segregation by Delegated Airspace

The FAA can delegate management of airspace to other entities. In this approach, the FAA would delegate management of airspace that is normally managed by the FAA to a landowner or facilities operator, for example a farmer or critical infrastructure operator. Delegation of airspace currently only occurs between nations for the purposes of ATC, for example the FAA delegates airspace management to Canada in certain border regions (Federal Aviation Administration, n.d.) and ICAO delegates certain international oceanic airspace to the FAA (Federal Aviation Administration, 2019) Current delegation of airspace however is just for aircraft control, with no changes to regulations in the delegated airspace. Delegation of airspace that involves different regulations or restrictions would likely meet with numerous legal challenges.

3.4 Segregation Through Reserved Airspace

For purposes of this discussion, 'reserved' airspace per se means a volume of airspace with defined boundaries and times within which particular rules might apply, and which particular aircraft might be operating within. This airspace exists as two types; First, a 3D polygon-shaped block of airspace such as is found in a LAANC authorization, second, a 3D corridor defined by specified height, width, and length that can support BVLOS operations (akin to UTM volume segment concepts). The UTM CONOP example explains what would become in effect 'reserved' as a planned operational volume of airspace for a specified time. (Federal Aviation Administration, 2020) For example, flight approvals granted under certain circumstances by the FAA to UA users who wish to fly in controlled airspace below 400 ft. Also, a preponderance of BVLOS waivers include air corridors whereby UA are confined to volumes of airspace segmented routing with limits to vertical and horizontal maneuver boundaries.

As discussed in Section 2.2.3.1, Rwanda has used this approach by creating dedicated air corridors for sUAS activity. The concept of reserved airspace is part of the UTM concept of operations, in which UAS could be assigned routes or operating areas from which manned aircraft are restricted in non-UTM airspace. Restriction of freedoms for manned aircraft would likely meet with significant opposition from current airspace users.

In the spring of 2021, NASA Langley and LONGBOW partnered to develop BVLOS testing with flight corridors (UAS transit corridors and highway lanes in the sky). The test is intended to include a supporting infrastructure, data sharing, and other capabilities to prototype a UAM ecosystem (Ball, 2021; Reichman, 2021; Stonor, 2021).

3.5 Segregation by Levels of Autonomy

Pang et al. (2021) describe a concept of operations for small UAS operating in both segregated and integrated airspace. The CONOPS is based on small UAS meeting required levels of autonomy (LoA) for each flight segment. "LoA capability of the (UAS) onboard separation assurance system and/or procedure would also need to be assessed for cooperative (E3, E4, E5) and non-cooperative (E4, E5, E6, E10) operations; the former assumes that all traffic tracking data are available through the data link to the automated UTM backend with no ATC involvement, while the latter depends on the sensors suites available and capability of Unmanned Aircraft Flight Management System." (Pang et al., 2021). The LoA elements that would need to be evaluated include planning and scheduling (E3), risk-aware system (E4), decision making and acting (E5), detect and avoid (E6), and sensing and perceiving (E10).

The concept of levels of autonomy ensures that only aircraft with a level of autonomy appropriate to the full mission would be allowed to operate. Many hurdles would have to be cleared to realize this concept, beginning with a universally accepted autonomy definition and its corresponding taxonomy. Further, as the authors note, "The development of the certification for LoA-based operation would also be needed, possibly using simulation-based method to evaluate the LoA using role-based or performance-based thresholds.” (Pang et al., 2021). Finally, CONOPS based on LoA does not address RoW for encounters involving non-cooperative aircraft.

3.6 Changes to RoW Rules

The BVLOS ARC (FAA, 2022) recommends amending §91.113 to accommodate:

- allowing automatic means for see-and-avoid responsibility;
- giving UA right of way in Shielded Areas;
- giving UA right of way over crewed aircraft not equipped with ADS-B or Traffic Awareness Beacon System (TABS) in Non-Shielded Low Altitude Areas; and
- giving crewed aircraft that are equipped with ADS-B or TABS (and broadcasting their position) the right of way in Non-Shielded Low Altitude Areas.

The BVLOS ARC (FAA, 2022) recommends that UAS have the RoW over non-cooperative traffic in operating environments with minimal GA activity, which the BVLOS ARC (FAA, 2022) defines as below 500’ AGL and away from airports or heliports. The BVLOS ARC (FAA, 2022) states that “The unmitigated risk of mid-air encounter between UA and unequipped GA aircraft in the below 500’ AGL operating environment is low.” However, this statement does not account for the fact that the density of GA aircraft operating below 500’ AGL is not actually known, nor is it evenly distributed. For example, in particular operating environments like agricultural operations or infrastructure inspections, manned aircraft may be operating in exactly the airspace in which a UAS would be likely to operate. In their statement of non-concurrence to the BVLOS ARC (FAA, 2022), the Aircraft Owners and Pilots Association (AOPA) states, “AOPA strongly disagrees with the ARC leadership’s characterization that very few aircraft operate at these lower altitudes. In fact, the FAA recognized the realities of aircraft operations at lower altitudes.” (BVLOS ARC (FAA, 2022) Appendix F, 2022, p. 44). Further research is needed to determine the actual density of GA traffic in low-level environments.

Roughly half of the GA fleet, or 113,000 out of 220,000 active aircraft, are not currently equipped with ADS-B (Federal Aviation Administration, 2022). These aircraft, when operating below 500’ away from an airport or heliport, would be responsible for seeing and avoiding UAS, which has proven to be difficult to do visually, as explained in section 2.5.1.3.

The BVLOS ARC (FAA, 2022) also recommends changes to RoW rules to give UAS right of way over all aircraft for shielded operations, where the shielded area includes a “volume of airspace 100’ above the vertical extent of an obstacle or critical infrastructure and is within 100 feet of the lateral extent of the same obstacle or critical infrastructure.” (BVLOS ARC (FAA, 2022), 2022, p, 37).

3.6.1 *Changes to the Requirement to See And Avoid or DAA*

The BVLOS ARC (FAA, 2022) also recommends a change to FAR Part 91.113(b) to read:

“When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules, visual flight rules, *or automated flight rules*, vigilance shall be maintained by each person operating an aircraft so as to *detec*t and avoid other aircraft.” (italics indicate changes).

In its dissent from the BVLOS ARC (FAA, 2022), the Helicopter Association International states, "Right of way is not possible without detection. Detection capability is the foundational element that enables right of way rules to be effective" (Appendix F)

If UA operating BVLOS have right of way over non-cooperative manned aircraft yet there is no requirement for the UA to be able to detect non-cooperative aircraft, it is impossible for the operator of the UA to comply with the requirement to detect and avoid all other aircraft. Hence, there still may be the responsibility for drones avoiding collision whenever possible if aircraft are not segregated.

3.7 Integration via Digital Flight Rules or Automated Flight Rules

In their 2020 paper, Wing and Levitt propose an additional set of flight rules known as Digital Flight Rules (DFR) that supplement VFR and IFR. (Wing & Levitt, 2020) VFR offers flexibility of operations, but restrictions based on visibility, while IFR provides access to airspace even with reduced visibility, but at the cost of operational flexibility. VFR and IFR evolved in a world before modern connectivity, satellite navigation, and surveillance methods. DFR however would capitalize on connectivity, precision three-dimensional navigation, and decentralized surveillance mechanisms such as ADS-B to allow flexibility of operations along with airspace access in limited visibility. DFR would accomplish this goal without overloading ATC by shifting separation provision largely to the operator.

According to Wing (p. 12), "One way shared-airspace operations could be achieved, but not necessarily the only way, is for DFR aircraft to give RoW to IFR aircraft in essentially all encounters and to VFR aircraft until visually acquired, at which point VFR RoW rules are applied." Inherent in the notion that DFR aircraft would give way to IFR aircraft is the requirement that all aircraft would transmit information about the rules under which they are operating at any given moment. Manned aircraft often switch between IFR and VFR while airborne, for example, aircraft can depart VFR and pick up an IFR clearance enroute, or can depart IFR and cancel when enroute, or more commonly when the airport is in sight and Visual Meteorological Conditions can be maintained until landing. Further, aircraft can operate on an IFR clearance using VFR on top rules, in which the aircraft is still on an IFR flight plan but may select an altitude and heading that keeps them in Visual Meteorological Conditions.

DFR would offer the possibility of full integration of manned and unmanned traffic using rules applied equally to all airspace users and allowing equal access to all traffic based on minimum equipage required for connectivity, navigation, and surveillance. However, the equipage requirements could be considerable, and impose a cost, size, weight, and power burden on small UAS. Further, the path forward for DAA required by the concept of DFR is not yet agreed upon. Finally, the concept of DFR does not address RoW for encounters between two aircraft operating under VFR beyond what is already specified in 14 CFR §91.113 and Part 107.

The BVLOS ARC (FAA, 2022) also included reference to Automated Flight Rules (AFR), though the BVLOS ARC (FAA, 2022) only defined the categories within AFR according to the level of autonomy and risk (BVLOS ARC (FAA, 2022)). No equipage requirements or RoW rules related to AFR were articulated.

3.8 New Equipage Requirements

New equipage requirements can be imposed either on manned aircraft or on unmanned aircraft.

ADS-B In & Out: While FAA ATS has not supported the use of UAS broadcasting an ADS-B signal due to potential saturation in the communications link and cluttering of both ATC and cockpit traffic screen, it did not provide an alternative solution either. The use of filters to reduce the system load does not appear to have been discussed nor researched as a potential option.

UA could be required to be equipped with sensors that could detect both cooperative and non-cooperative traffic. While manned aircraft are required to be equipped with ADS-B out in airspace with a high density of manned aircraft traffic, manned aircraft in most low-level airspace where UAS are likely to be found are not required to be equipped with ADS-B. Therefore, UAS operating BVLOS would need to have some way of detecting non-cooperative traffic in order to comply with current RoW rules that give RoW to manned aircraft. However, any requirement to equip UAS with non-cooperative detection technology would be met with strong resistance from the UAS industry.

The BVLOS ARC (FAA, 2022) addresses non-shielded UAS BVLOS operations by recommending ADS-B or TABS-equipped manned aircraft to have RoW. As in this type of operation, UAS conducting BVLOS would be required to have an approved DAA or other systems that could detect ADS-B or TABS-equipped aircraft.

Collision avoidance (optical sensor): An optical sensor enables an algorithm to identify airborne targets (intruders) that would render feedback to the PIC. It also has automatic maneuver and SAA/DAA capabilities. Optical sensors have enabled several FAA BVLOS waivers and were recently identified as a BVLOS solution by transport Canada. However, the technological readiness of these systems is not certain.

3.9 Impacts of Visual Conspicuity to RoW

Color standards: There are several companies that sell skins, stickers or wraps customized the shape of the drone and are available in high visibility colors and hues. These are a part of many public safety entity fleets.

High reflectivity: Certain skins are a highly reflective chromed or mirrored finish. These offer a high degree of conspicuity. In a field observation by a researcher in this project, worked with a regional power provider who used sUAS to inspect transmission infrastructure. The company used a mirrored decal to highlight the body of a DJI Phantom 4 which offered high reflectance in sunlight, yielding visibility out to extended ranges (Burgess, 2019).

Integrated day/night strobe: As a current rule under §107.29, strobe use is established for night flight. Strobes enhance conspicuity during nighttime; however, daytime use of strobes is challenged by ambient conditions. Research has been inconclusive on the impact of strobe lights on sUAS detection during the day (Wallace, 2018).

The BVLOS ARC (FAA, 2022) recommends imposing conspicuity requirements on UAS, but further research is needed to determine what, if any, types of modifications result in improved visual acquisition of UAS by manned aircraft pilots, whether the modifications aid manned aircraft pilots in maintaining well clear, and under what environmental conditions these modifications are effective.

4 SAMPLE MISSION SETS

Currently, each sample mission set below is fully integrated with the use of the UA in applicable industries. The energy sector has integrated the use of UAS in the primary use of inspections (oil and gas, electrical transmission, hydroelectric, solar fields, wind towers). The transportation sector also utilizes UA to inspect bridges, rail-lines, etc. Telecommunications uses of UA include cell towers and radio towers. Industry uses continue to surface and as aircraft become more capable, their utility expands. As a note, there are a number of research projects through the FAA ASSURE COE that addressed the possibility of the following mission profiles and in most cases, tested their efficacy.

4.1 Long-line Linear Infrastructure Inspections

The US Department of Energy has facilitated the integration of using drones to inspect the power transmission grid. Traditionally a manned flight function, the use of UA for this task has been elevated in recent years. (Federal Aviation Administration, 2020) The US Helicopter Safety Team published a recommended safety mitigation to utilize UA in the conduct of this type of inspection operation. (Colborn et al., 2019). Many examples exist in the use of UA for inspecting all parts of electric power production from generation to transmission and finally, distribution. (Drones in T&D, n.d.).

The most obvious conflict management solution for long-line linear infrastructure missions is strategic conflict management through ‘reserved’ airspace corridors, airspace property rights, delegated airspace management, or separation provision through shielded operations. All three of these approaches are discussed in Section 3. Challenges in long-line linear infrastructure inspection include operation BVLOS, the existence of power lines on fields that might have manned agricultural aircraft activity, and the potential conflicts between long-line linear infrastructure inspections and other infrastructure inspections (Burgess, 2022).

4.2 Precision Agriculture Operations Including Crop Spraying

Drone use for Precision Agriculture (PA) was first seen in broad use with the Yamaha RMAX introduced in the late 1990’s. The concept was simply to facilitate treatment of the numerous amounts of small farms that did not have the overhead to utilize helicopters. This example led later to the application of the UA to similar applications in other locations globally. The primary uses of the UA in PA is determining plant health using multispectral sensors, and precision spraying. (Precision Agriculture: A Day on the Farm, 2021)

Conflict management for PA operations could be achieved through ‘reserved’ airspace corridors, airspace property rights or delegated airspace management. Challenges in PA include the presence of manned aircraft, and the difficulty of imposing additional equipage requirements on manned agricultural aircraft.

4.3 Package Delivery (Urban/Rural)

Package delivery has long been an industry milestone in the integration of UA. From concept to research and development, to state approved commercial operations (outside the US), these missions are considered to be safely possible from an industry perspective. There is extraordinary global effort in trying to perfect consistently safe UA package delivery. As discussed previously, Zipline is conducting daily operations in Africa. Several companies (Wing Aviation and UPS) have received the Part 135 certification to deliver packages in the US. (Federal Aviation Administraiton , 2021) More companies are in the process of obtaining this approval**.**

Strategic conflict management through established ‘reserved’ flight corridors has been used in Rwanda for package delivery and a variation adapted for U.S. operations may be a solution for unmanned package delivery. Challenges in package delivery abound from safety of flight, privacy, and airspace property rights perspectives, but from a conflict management and RoW perspective, the chief challenge is in airspace that is utilized by GA, for example rural areas with manned agricultural aviation, or areas with helicopter traffic. Urban areas in which GA aircraft do not operate are not yet a concern. However, when passenger transport in UAM scenarios becomes a reality, conflict management will likely need to go beyond flight corridors to separation provision and RoW rules that address operations in low level urban airspace.

4.4 Low Altitude Surveillance, Industrial Aerial Data Gathering

These missions are typically flown on site and are more aligned with a platform matched to the mission. UA-Airplane configurations are usually chosen for long duration missions like area reconnaissance at private or sensitive (critical infrastructure) locations (similar to military operations of intelligence, surveillance, and reconnaissance). Multi-rotor platforms are used when structural inspections of infrastructure are necessary. Hovering in place with high-quality sensors (Red, Green and Blue or Light Detection and Ranging) as would be seen scanning a nuclear power plant cooling tower in a structural integrity inspection, are ideal platforms in this and similar employment.

The most obvious conflict management solution for low altitude surveillance is strategic conflict management through ‘reserved’ airspace, airspace property rights, delegated airspace management, or separation provision through shielded operations. All three of these approaches are discussed in Section 3. Challenges in low altitude surveillance include operation in areas with heavy GA traffic.

5 GAPS IN ROW RULES AND RESEARCH GAPS

The gaps identified in the preceding analysis are summarized in this section for better assessment. References there are made to the BVLOS ARC (FAA, 2022), which was published during the development of this report and included important aspects related to RoW rules. Acronyms used in the list are: AG: Air & ground risk recommendations. FR: Flight rules recommendations. AS: Aircraft & systems recommendations. OQ: Operator qualifications recommendations. GP: General & procedural recommendations:

Gaps in RoW rules due to presence of new entrants in airspace:

- RoW rules do not address UAS greater than 55 pounds except if they operate under Part 91.
- RoW rules do not account for UAS operating BVLOS.
- RoW rules do not address encounters between two or more UAS, including differences in maneuverability between different types of UAS.
- RoW rules do not address encounters between UAS swarms and other aircraft.
- RoW rules do not address shielded operations.
- RoW rules do not address operations within 'reserved' blocks of airspace or corridors.
- RoW rules do not address the current range of UA sensing methodologies,

RoW rules address well clear, but this concept does not have an accepted FAA quantification for all operational scenarios. BVLOS ARC (FAA, 2022) FR 2.1. Other regulatory gaps

- While there will be a requirement for UAS to transmit Remote ID, there will not be a requirement for any aircraft to be able to receive Remote ID signals.
- There are no accepted performance requirements for non-cooperative sensors in the low altitude regime.
- Emergency aircraft have RoW over all other aircraft, but there is no requirement for UA operators to have or use equipment that would allow them to know whether an aircraft is experiencing an emergency, for example VHF radio or ADS-B in.

Research Gaps

- With BVLOS operations, the operator will not have the same perspective, and some method of observing clouds and estimating distance will be required to meet the cloud clearance requirements.
- The effectiveness of UAS visual conspicuity modifications in helping manned aircraft pilots visually acquire UAS in time to remain well clear is not known.
- The effectiveness of training manned aircraft pilots how to visually search for sUAS in maintaining well clear and collision avoidance is not known.
- The effectiveness of non-cooperative sensors for use in maintaining well clear and collision avoidance with UA is not known.
- The effectiveness of Remote ID signals for use in maintaining well clear and collision avoidance with UA is not known.
- The effectiveness of ADS-B for use in maintaining well clear and collision avoidance for UA-UA encounters is not known.

- The ability of a manned aircraft to see and avoid a UA under varying environmental conditions is not known.
- The ability of a manned aircraft to see and avoid a medium sized UA, defined as larger than 55 pounds but smaller than a manned aircraft, is not known.
- The density of air traffic in areas where UAS operations are likely to occur, such as long line linear infrastructure inspections, precision agriculture, and low-level surveillance is not known.
- The support for safe interactions when a drone and crewed non-cooperative aircraft encounter each other. The BVLOS ARC (FAA, 2022) recommendation does not offer a viable solution.
- The effectiveness of BVLOS ARC (FAA, 2022) recommendations for traditional unequipped aircraft descending into low altitude to scan the area for potential traffic conflicts**.**

The BVLOS ARC (FAA, 2022) encompasses a broad range of aspects of UAS BVLOS operations, and as such goes beyond identifying gaps in existing RoW rules. Thus, in accordance with ASSURE A54's objectives and in order to avoid digression of the ensuing discussions, the gaps will be strictly streamlined during the analysis in Task 2. To scope this analysis, a classification of different encounter cases is proposed, depending on the type of aircraft or operation involved. Each of these cases is further classified in a series of encounter geometries, following §91.113. Generic assumptions for these cases are:

- Operations are restricted to airspace below 400 ft AGL.
- Manned aircraft missions include precision agriculture, air ambulance, and infrastructure inspections (BVLOS ARC (FAA, 2022) FR2.7).
- sUAS swarm use §107.205.e waivers over §107.35.
- For these purposes, shielded operations means any operation within 400 ft of a structure horizontally, and up to 400 ft vertically. No limits are defined for a shield operation below a structure. BVLOS ARC (FAA, 2022) FR2.4 considers that a sUAS in shielded operations within 100 ft of a structure is safe enough to maintain adequate separation from manned aircraft.
- Operations within a given volume of airspace with no physical boundaries surrounding it are 'reserved' using LAANC authorizations or through BVLOS corridor waivers as found in the UAM concept of operations (Federal Aviation Administration, 2020a).

RoW between UAS and ultralights (§103.13), manned free balloons, gliders (including sailplanes), airships, powered parachutes, weight-shift-control aircraft should also be reviewed, and gaps assessed, additionally, when these platforms were converted to UA. Moored-type aircraft (such as moored balloons and kites), amateur rockets and model aircraft are considered out of the scope of the proposed analysis.

Encounter cases are as follows:

- Manned aircraft versus sUAS. A distinction is made between cooperative and non-cooperative aircraft (BVLOS ARC (FAA, 2022) 2.2 and BVLOS ARC (FAA, 2022) FR2.3).
- Manned aircraft versus sUAS swarm (also known as formation flying).
- Manned aircraft versus sUAS in shielded operations.

- Manned aircraft versus sUAS in operations within ‘reserved’ blocks of airspace or corridors.
- sUAS versus sUAS.
- sUAS versus sUAS swarm.
- sUAS versus sUAS in shielded operations.
- sUAS versus sUAS in operations within ‘reserved’ blocks of airspace or corridors.
- sUAS swarm versus sUAS swarm.
- sUAS swarm versus sUAS in shielded operations.
- sUAS swarm versus sUAS in operations within ‘reserved’ blocks of airspace or corridors.
- sUAS in shielded operations versus sUAS in shielded operations.
- sUAS in shielded operations versus sUAS in operations within ‘reserved’ blocks of airspace or corridors.
- sUAS versus sUAS where both are flight operations within the same ‘reserved’ blocks of airspace or corridors.

Two sUAS configurations may be considered:

- VTOL.
- HTOL.

For each of these cases, the following encountering geometries are considered (see §91.113):

- Emergency.
- Converging.
- Approaching head-on.
- Overtaking. This geometry distinguishes two cases, depending on which aircraft is overtaking and which aircraft is being overtaken.
- Landing. This geometry also distinguishes two cases: a) one landing aircraft and the other in flight or operating on the surface, and b) two landing aircraft at different altitudes.

The encountering cases will be combined with the encounter geometries and the final list will be organized in a hierarchy attending to safety and priority aspects. Safety aspects will in turn be determined by aircraft conspicuity and maneuverability, as well as the risk assumed by passengers onboard (BVLOS ARC (FAA, 2022) AG2.2).

The potential use of the following DAA should be considered in the analysis of the encounter scenarios for the use cases presented above (§91.113):

- For UAS, the use of transponder-based DAAs, such as ADS-B and TCAS, are restricted to certain airspace and operations: UA may carry a transponder in ATC airspace if either it has a flight plan and has established two-way communications with ATC, or else it has been authorized by ATC (§91.215e).
- The use of TCAS II is not deemed suited to UAS, but updates from this standard has been released recently, such as ACAS Xu for UAs (RTCA DO-386) and ACAS sXu for sUASs.
- DAA ASTM standards for smaller UAS are described in F3442, whereas RTCA DO-365B contains DAA standards forlarger unmanned aircraft.

- The use of ADS-B out in UAS is sanctioned by §91.225.i (which refers to §91.227 for the equipment requirements).
- Regulated in the rule published under the Billing Code 4910-13-P, RID has the potential to be used for certain types of surveillance in a larger DAA system for enabling drone-to-drone avoidance.
- Electro-optical and acoustic-based airborne DAA solutions have limited maturity for implementation in the short term.

6 CONCLUSION

RoW rules that govern the interactions between aircraft that encounter one another are largely based on the responsibility to see, and be seen by, other aircraft. These have been in place since the earliest days of aviation. However, the entrance of aircraft without onboard pilots into the national airspace demand a hard look at RoW rules and their underlying principles to determine if existing rules are sufficient. Enforcement actions by the FAA have clearly demonstrated the responsibility that pilots must maintain vigilance in searching for other aircraft. However, BVLOS flight with UA makes vigilance and conflict management through visual search impossible. Other means must be found to meet the intent of the requirement to see and avoid other aircraft.

Conflict management has three layers: strategic, provided by air traffic management; separation provision, provided by air traffic control and the airspace user; and collision avoidance, which is generally the realm of the airspace user. Separation provision, when provided by the airspace user, depends on the principle of SBS, and adherence to RoW rules to maintain well clear. Collision avoidance becomes necessary when the other layers of safety have failed to assure safe separation. RoW operates at the separation provision layer. However, strategic conflict management tools can also be used to ensure conflict management. Currently, airspace is segregated for conflict management based on aircraft category, equipage, conspicuity, flight obstacle, altitude and time of day. The segregation is used for managing airspace and for operational limitations. Some types of segregation might also span both of these (e.g. ultralights cannot fly at night). Additional segregation also exists primarily for other purposes such as operations over congested areas, operations over people, or minimum altitudes for conventional fixed wing aircraft. Future options include segregation based on ‘reserved’ route corridors, airspace property rights, airspace delegation, or levels of autonomy. ‘Reserved’ route corridors appear to be the most viable of these approaches. These new or different forms of segregation may impact the types of interactions that are possible between aircraft.

Along with clearly articulating the requirement to maintain vigilance, RoW rules establish which aircraft has priority and which aircraft must give way to the other. Existing RoW rules govern the interactions between aircraft. They are largely supported with a variety of safety rationale that trace to the ability or limitations to be seen by another aircraft, the ability or limitations to see and avoid another aircraft, maneuver limitations, and emergency situations. Hence, many RoW rules are based on maneuverability as determined by the aircraft type, but also on maneuverability as determined by the position and emergency status of the aircraft. For example, when two aircraft are landing, the aircraft at the lower altitude has the RoW, presumably because it is less able to maneuver than the aircraft at the higher altitude. Further, some RoW rules are based on position, due to limits of human visual perception. For example, aircraft being overtaken have the RoW presumably because the onboard pilot cannot be expected to see and avoid an aircraft approaching from behind.

Current RoW rules do not address operations that are necessary for full integration of UAS into the NAS, or situations that are likely to occur with full integration, including operations with UAS greater than 55 pounds (except those operating under Part 91), operations with UAS BVLOS, encounters between two or more UAS including differences in maneuverability between different types of UAS, encounters between manned aircraft and UAS swarms, shielded operations, or technological means by which to achieve the intent of SBS.

Future options for conflict management that involve full integration in shared airspace include changes to the requirement to see and avoid, changes to RoW rules, digital flight rules, equipage requirements, or visual conspicuity requirements.

Modifications to RoW rules depend on information that is not yet known, including the efficacy of: improved visual conspicuity of UAS, manned aircraft pilot training, Remote ID, non-cooperative sensors, and ADS-B on maintenance of well clear and collision avoidance. The ability of a manned aircraft pilot to detect an sUAS or a medium sized UAS under varying environmental conditions is not known. Finally, the density of non-cooperative GA traffic in areas where UAS operations are likely is not known.

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