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

Task 2
UAS Gap Prioritization, UAS Safety Hierarchy, and Recommendations

August 5, 2022

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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.</td></tr>
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TABLE OF ACRONYMS

ACAS	Automated Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AIA	Aerospace Industries Association
GAMA	General Aviation Manufacturers Association
AOPA	Aircraft Owners and Pilots Association
ARC	Aviation Rulemaking Committee
ATC	Air Traffic Control
BVLOS	Beyond Visual Line of Sight
CA	Controlled Airspace
CFR	Code of Federal Regulations
DAA	Detect and Avoid
DROTAMS	Drone NOTAMs
LAANC	Low Altitude Authorization and Notification Capability
NAS	National Airspace System
NOTAM	Notice to Airman
RPIC	Remote Pilot in Control
RoW	Right of Way
RPIC	Remote Pilot In Command
sUAS	Small Uncrewed Aircraft System
TABS	Traffic Awareness Beacon Systems
UA	Uncrewed Aircraft
UAS	Uncrewed Aircraft Systems
UCA	Uncontrolled Airspace
UPAC	Utilities, Patrol and Construction
UTM	Uncrewed Traffic Management
VLOS	Visual Line of Sight

TABLE OF DEFINITION

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 Uncrewed Aircraft (UA). Available avionics provide the same core intent to identify other aircraft and avoid collisions.
Collision Avoidance	Collision avoidance involves preventing an intruder from penetrating a volume of airspace centered on the aircraft within which avoidance of a collision can only be considered a matter of chance (FAA, 2016; DoD, 2011). Collision avoidance is distinct from well clear, in that well clear provides greater separation than collision avoidance. Collision avoidance can rely on both human and automated systems. The pilot uses proper scanning techniques, sounds (for Uncrewed Aircraft System (UAS) pilots), and vigilance. Automated systems include a sense and avoid system function where the Pilot in Command (PIC) is alerted to a conflict and manually takes action, or the UAS diverts to prevent a collision.
Cooperative intruders	Cooperative intruders carry equipment that allows the ownship to receive state information about the intruder, Electronic transmission of position information to include Mode C or Automatic Dependent Surveillance-Broadcast (ADS-B) are examples of cooperative technology. It'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. (Ramasamy, 2015)
Non-cooperate Intruders	Non-cooperative intruders are "silent" and all state data must be determined by sensors onboard the ownship. (Ramasamy, 2015)
Detect and Avoid (DAA)	The capability of a UAS to remain well clear from and avoid collisions with other aircraft. (Federal Aviation Administration, 2009).
Mid-sized uncrewed aircraft	There is no standard definition of mid-sized UA. However, for purposes of this research, a mid-sized UA is one that is greater than 55 pounds but smaller than an aircraft capable of carrying a person. This can include aircraft such as the RMAX uncrewed helicopter, a ScanEagle, or the RQ-7 Shadow fixed wing drone. The distinction for this research is not necessarily based on weight or size however, but on conspicuity.
Reserved Airspace Concept (RAC)	A volume of airspace with defined boundaries and times within which particular rules apply, and which particular aircraft might be operating within. This supports operations in controlled or uncontrolled airspace and conceptually exists as two types; First, a 3D polygon-shaped block of airspace second, a 3D corridor defined by specified height, width, and length that can support BVLOS operations The intent of the Reserved Airspace Concept (RAC) is to segregate

	aircraft that cannot reasonably detect each other, specifically, to segregate crewed aircraft that are not equipped with ADS-B out, from uncrewed aircraft that cannot detect aircraft that are not equipped with ADS-B out.
Right-of-way (RoW) (FAR 91.113)	The right of a vehicle to proceed with precedence over others in a particular situation. Right of way rules establish which aircraft in any encounter must give way to the other aircraft. 14 CFR § 91.113 is Right-of-way rules: Except water operations.
See and Avoid (FAA-H-8083-3C)	See and avoid refers to the obligation conferred on each person operating an aircraft to maintain vigilance so as to see and avoid other aircraft. See and avoid includes the requirement to give way to aircraft with the RoW, and not pass over, under, or ahead of it unless well clear. 14 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 RoW, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear. This concept relies on knowledge of the limitations of the human eye and the use of proper visual scanning techniques to help compensate for these limitations. Pilots should remain constantly alert to all traffic movement within their field of vision, as well as periodically scanning the entire visual field outside of their aircraft to ensure detection of conflicting traffic. A proposal in the Beyond Visual Line of Sight (BVLOS) Aviation Rulemaking Committee (ARC) Final Report (BVLOS ARC (FAA, 2022), 2022) recommends replacing this term with 'detect and avoid' (DAA).
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.
Sense and Avoid	Sense and Avoid is the capability of a UAS to remain well clear from and avoid collisions with other airborne traffic. Sense and avoid provides the functions of self-separation and collision avoidance to fulfill the regulatory requirement to see and avoid (DoD, 2011).
Shielded Operation	The FAA Drone Advisory Committee defines shielded operations as "flight within close proximity to existing obstacles and not to exceed the height of the obstacle" (Federal Aviation Administration, 2020c, pg. 31). Civil Aviation Authority of New Zealand defines a shielded operation as one in which the "drone remains within 100 meters of, and below the top, of a natural or man-made object" (Civil Aviation Authority (CAA) of New Zealand, 2019).

Small Uncrewed Aircraft	Small Uncrewed Aircraft are small platform and associated elements (including communication links and components that controls the craft) that are required for the safe and efficient operation of such in the National Airspace System (NAS) (AIM, 2021). The actual aircraft must weigh less than 55 lbs. on takeoff including everything on board or otherwise attached (FAA, 2021).
Swarm	Swarms are biologically inspired collective robot systems, operate without centralized control, which uses local interactions with other robots and the environment as control inputs. Swarms use indirect communication from a leader robot to perform complex action or behavior. The disturbance to individual robots may not affect the overall ability or satisfy the collective goal (Leaf 2021).
Multi-Robot system	A multirobot system consist of few agents which are assigned to do a specific task, which they cooperate to complete a goal. In a multi-robot system, each robot is able to do some sub-tasks of a given task. For such multi-robot system, it requires all the nodes (robots/drones) to reach the ultimate goal.
Well Clear	Well Clear is used in 14 CFR §91.113 to define the distance that a pilot must maintain between their aircraft and an aircraft with the RoW. Part 91. states that when encounters occur, the aircraft that does not have the RoW shall give way to the aircraft with the RoW, and may not pass over, under, or ahead of the aircraft with the RoW unless well clear. A recommendation in the BVLOS ARC (FAA, 2022) proposes to replace this term with ‘adequate separation’.

1 EXECUTIVE SUMMARY

The overall purpose of this project is to inform rulemaking and standards development regarding potential Right of Way (RoW) concepts for crewed and uncrewed aircraft in the low altitude environment.

Most of the current RoW rules establish priority among crewed 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 crewed aircraft have the RoW over uncrewed aircraft. Indeed, when only a few small Uncrewed Aircraft Systems (UAS) were 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 (BVLOS) concepts, medium- to large-sized UAS, and the possibility of swarms or multi-robot systems. In these situations, current RoW rules prove to be insufficient. This report seeks to provide initial recommendations for the RoW rules 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 DAA concepts, such as Automated Collision Avoidance System (ACAS) Xu and ACAS sXu for large and small UAS, respectively. Also, Remote ID (RID), although conceived under a security perspective, has the potential to also provide surrounding uncrewed traffic with information on other UAS flying nearby. Automatic Dependent Surveillance-Broadcast (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 technological advancements. At the same time, the technology readiness level of these systems for providing DAA that is an adequate alternate means of compliance to see and avoid has yet to be established. Therefore, new rules must be based on realistic capabilities as well as assumptions that must be made in regard to problems sets that still must be solved.

RoW rules form one aspect of an overall conflict management system (ICAO, 2005). Conflict management is currently provided by segregation of aircraft by category, equipage, conspicuity, flight obstacle, operating rules, 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. Because the possible solution space is quite large, this project intends to narrow that space by identifying the most efficient and realistic solutions to the gaps in RoW rules created by new entrants into the airspace.

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; and UAS operating BVLOS.

This ongoing research project will propose a reasoned and well-founded set of recommendations for new RoW rules. Industry feedback will assist in developing feasible and practical solutions.

To be comprehensive, scenario-based solutions will be used to provide resolution for realistic encounters. The researchers will develop this classification in upcoming phases of the project using the initial recommendations for new RoW rules presented in this report. Recommendations will continue to be refined and updated throughout the research project based on research findings.

2 IDENTIFY GAPS IN RIGHT-OF-WAY RULES

The researchers have identified gaps between what is currently defined in FAA regulations and what is needed to accommodate the planned increase of UAS commercial operations within the National Airspace System (NAS) system below 400 ft Above Ground Level (AGL). The gaps are categorized into 3 distinct areas to accommodate UAS operations: 1) Gaps in current RoW rules, 2) Other Regulatory Gaps, and 3) Research Gaps.

The research gaps and related assumptions are identified and must be agreed upon by researchers and FAA sponsors to effectively provide a framework for creating proposals for new RoW rules that can accommodate UAS operations below 400 ft AGL. These assumptions will continue to be evaluated as additional simulation and flight testing of the existing RoW research is conducted. Together these research gaps and assumptions provide insight to the problem sets that are outside the scope of this research but will need to be solved to move forward with RoW rules.

2.1 Gaps in Current Right of Way Rules Due to Presence of New Entrants in Airspace

As identified within the literature review, current RoW rules for crewed aircraft have garnered success with few accidents attributed to shortcomings in the rules. With UAS operating within the airspace, several gaps have been identified that will need to be bridged in order to allow the continued safety record related to RoW rules and UAS operations.

RoW rules do not address the following:

- UAS greater than 55 pounds except if they operate under Part 91 using existing RoW rules.
- UAS operating BVLOS.
- Encounters between two or more UAS, including differences in maneuverability between different types of UAS. so,
- Encounters between UAS swarms and other aircraft.
- Shielded operations.
- Operations in scheduled, reserved or segregated airspace blocks or corridors.
- The current range of UA sensing methodologies.
- Quantification of well clear for all operational scenarios. BAFR FR 2.1.

Many of these gaps are, in part, being researched in various ASSURE projects.

2.2 Other Regulatory Gaps

In addition to the gaps identified that relate to the established RoW rules, there are several gaps identified that while regulatory, do not directly relate to the RoW rules. These gaps are equally important as a final framework for RoW rules are adopted.

- While there will be a requirement for UAS to transmit RID, there is not yet a requirement for any system to be able to receive RID signals.

- RID is a short-range technology that is transmitted using Wi-Fi and Bluetooth protocols. If RID is included as part of RoW solutions between UAS, a requirement to receive RID information will need to be in place.
- Crewed aircraft do not have an electronic means of detecting UAS. Onboard receipt of UAS RID is not considered an appropriate means of UAS detection for enabling crewed aircraft to remain adequately separated from UAS due to inadequate range and issues with unprotected spectrum.
- There are currently no FAA 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 very high frequency radio or ADS-B In. UA operators need to know whether a crewed aircraft is experiencing an emergency.

2.3 Research Gaps

Research gaps are those gaps that do not directly relate to existing RoW or other regulatory rules but hinder the establishment of a RoW safety hierarchy. While technology continues to mature, additional efforts must be made to enable UAS to be integrated into the NAS. These efforts, while critical, are not yet complete and out of scope for this research project; therefore, the gaps and associated rationale will enable the development of a set of assumptions and subsequent safety hierarchy in Section 4.

These research gaps identify have been classified into five groups:

1. Environmental conditions assessment and impact on DAA
2. Conspicuity
3. Sensors
4. Air traffic density distribution
5. Unequipped aircraft interactions

In Table 1, each gap is categorized with the corresponding group stated and the rationale that has been used to develop the initial RoW rules that include UAS operations below 400 ft. AGL.

2.4 Research Gaps and Rationale

Table 1. Research Gaps and Rationale for Rules.

Gap Group	Gap	Assumptions made to accommodate gaps in research
#1	With BVLOS operations, the operator does not have the same perspective. Some methods of observing clouds and estimating distance will be required to meet the existing cloud clearance requirements.	With BVLOS operations maintaining § 107.51 visibility and cloud clearance requirements, the operator will need some method of observing clouds and estimating distance and visibility This project assumes that remote pilots would have an acceptable method of determining visibility and cloud clearances. .

#3	The required effectiveness of sensors in detecting non-cooperative aircraft for use in maintaining well clear and collision avoidance with UA is not known.	Sensors that can detect non-cooperative aircraft are a critical part of comprehensive DAA solutions, and an essential element of many possible RoW solutions. However, no standards exist for sensors detecting non-cooperative aircraft that are accepted means of compliance by the FAA. For simulations, this project will reference ASTM F3442-20 Standard Specifications for Detect and Avoid System Performance and assumes that sensors can detect non-cooperative aircraft at least as effectively as existing onboard non-cooperative sensor technology advertises (i.e. onboard radar, visual sensors, or acoustic sensors). For flight testing, commercially available sensor performance will be used in conjunction with other mitigations needed for safe flight.
#3	The effectiveness of RID signals for use in maintaining well clear and collision avoidance between UAs is not known.	RID may have applications to DAA in UA to UA encounters. However, the effectiveness of RID as a DAA system is unknown.
#1, 2	The ability of a crewed aircraft to see and avoid a UA under varying environmental conditions, for example rain, snow, glare, haze, etc, is not known.	Additional research is needed to determine whether technologies exist to enable mid-sized UAS to become as conspicuous as a crewed light sport aircraft during daytime. Past conspicuity research has been done on the effect of paint schemes and lighting on visual conspicuity (Wallace et al, 2018; Williams et al, 2022), this research is not sufficiently comprehensive or conclusive, nor does it involve a wide enough range of encounter geometries Conspicuity is assumed to be based on size only. Only FAR § 107.29 rules apply to night operations. The assumption being that conspicuity is raised with strobe lights at night. This project assumes that the only variable influencing the ability of a crewed aircraft pilot to see a UA is the arc-minutes subtended by the UA (i.e. number of degrees in your visual field the UA occupies).
#2	The ability of a crewed aircraft to see and avoid a medium sized UA, defined as larger than 55 pounds but smaller than a crewed aircraft, is not known. Further, the impact of visual conspicuity	This project assumes that a medium sized UAS would have the conspicuity, or technology equivalent to the conspicuity, needed to identify an aircraft similar in size to a light sport crewed aircraft. Further, the project assumes that small UAS will remain highly inconspicuous during

	modifications, such as reflective tape or paint schemes, in helping crewed aircraft pilots visually acquire mid-sized UAS during the day in time to remain well clear is not known.	daytime hours to crewed aircraft even with the aid of conspicuity enhancements. FAR § 107.29 rules apply to night operations and does provide a greater ability to see a UAS similar to that of a crewed aircraft. The assumption being that conspicuity is raised with strobe lights at night.
#4	The density of crewed air traffic in areas where UAS operations are likely to occur, such as linear infrastructure inspections (i.e., inspections of power generation/ transmission/ distribution (electric, gas, oil), rail lines, bridges, surface roads, etc.) precision agriculture, and low-level public safety (i.e., air ambulance, law enforcement and firefighting)) is not known.	This project assumes that crewed air traffic density near natural or artificial obstacles is low when not near crewed aircraft takeoff and landing locations and not near areas that crewed aircraft regularly fly near natural or artificial obstacles
#3	There are no clear solutions for safe interaction or segregation when a UAS and crewed aircraft not equipped with ADS-B out encounter each other during BVLOS. Note: The BAFR (2022) recommendation does not offer a viable solution.	UAS vs. crewed aircraft that are not equipped with ADS-B out is analyzed and possible solutions will be provided throughout this research project's efforts. There is an assumption that crewed aircraft not equipped with ADS-B out pose a higher risk to the souls on board than crewed cooperative aircraft since the aircraft not equipped with ADS-B out is harder to detect unless detection systems for non-cooperative aircraft are mandated by the FAA.

3 PRIORITIZE GAPS BASED ON INDUSTRY NEEDS

3.1 Introduction

Continuous dialogue has been established with the FAA through monthly Technical Interchange Meetings (TIMs) to prioritize the gaps. Researchers will continue to have dialogue with various industry partners such as Iris Automation, Applied Aeronautics, Airtonomy, Bonneville Power Administration, General Atomics, Customs and Border Protection, and SageTech. These conversations have been categorized as generalized company feedback. This research will employ simulation and flight research in an effort to improve and/or validate proposed RoW rules. Researchers may also use field observations or conversations to support the research efforts.

An example of a recent conversation with an aircrew from the Bonneville Power Administration Contract Air Services and in industry discussions with the Utilities, Patrol and Construction

(UPAC) Working Group from the Helicopter Association International (HAI), concerns are as follows:

The researchers were exposed to valuable industry perspectives regarding RoW rules. For reference, one helicopter aircrew is responsible for the construction, maintenance, and inspection of thousands of miles of high-energy transmission lines in the Pacific Northwest, and have fully integrated UAS into their operations. Additionally, UPAC feedback coincides with these examples and RoW is of growing concern from many similar operators.

Listed below are a generalized collection of industry feedback:

- Pilots of crewed aircraft believe that UAS operators flying Visual Line of Sight (VLOS) are better able to recognize an impending encounter than pilots of crewed aircraft.
- Pilots of crewed aircraft agree that UAS should always give the right of way.
- Publishing LAANC authorizations (location and times) or mandating NOTAM/DROTAMS for shielded operations (publicly) should occur as soon as possible.
- There should be a tiered system of notification levels for crewed aircraft pilots when there is UA operating in controlled airspace they are transitioning. This tiered system would inform crewed aviation assets of relative size of nearby UA traffic that enumerates impact energy (similar to operations over people studies).
- The Helicopter Association International (HAI) UPAC Working Group has recently discussed a 'highway in the sky system' principle for scheduling or reserving air space for BVLOS UA aircraft and is supportive of this concept.

3.2 BVLOS Aviation Rulemaking Committee and Dissenting Statements

The BVLOS ARC made numerous recommendations. Only those recommendations relevant to RoW rules below 500 ft AGL are summarized in this report. The ARC report generated considerable dissent among the participating members. Dissenting viewpoints are presented where applicable.

Air & Ground Risk Recommendations (AG) 2.1: "The acceptable level of risk for UAS should be consistent across all types of operations being performed, and no more restrictive than the accepted fatality rates of general aviation" (BVLOS ARC report p. 65). The ARC report states that the acceptable level of risk should be set at the fatality rate of GA operations. A group of ARC members consisting of AIA, Aircraft Owners and Pilots Association (AOPA), Air Line Pilots Association (ALPA), GAMA, HAI, and Praxis Aerospace dissented from this opinion, stating that the ARC misused the safety continuum, and mischaracterized the level of GA midairs as "acceptable" when in fact vast resources have been expended to lower the GA midair rate. In the experience of the A54 ASSURE team, identifying a particular mishap rate as acceptable simply because it exists is not an accepted approach in aviation safety. Rather, a data-driven determination of 'As Low As Reasonably Practical' (ALARP) or its general equivalent is used (Skybrary, 2022).

Flight Rules Recommendations (FR) 2.1: "The FAA should amend § 91.113(b) to allow a range of sensing methodologies and clarify adequate separation." The ARC report further recommends that the term 'see and avoid' be changed to 'detect and avoid' to allow aircraft to "utilize technical or non-technical means to detect other aircraft" (BVLOS ARC, 2022, p. 75). No dissents were filed to this recommendation. This recommendation reflects the realities of modern traffic awareness and would benefit both crewed and uncrewed aircraft operations. However, the ARC report goes on to state "Enabling operations that do not require a non-cooperative sensor will accelerate the approval of UA that will replace higher risk operations and activities" (BVLOS ARC, p. 76). This statement goes beyond the amendment of § 91.113 and is inadequately justified from a risk management perspective.

FR 2.2: "The ARC recommends that UA operations in Non-Shielded Low Altitude Areas (i.e., below 400 ft AGL) yield right of way to crewed aircraft equipped with ADS-B or Traffic Awareness Beacon Systems (TABS) and broadcasting their position." and

FR 2.3: "The ARC recommends that UA operations in Non-Shielded Low Altitude Areas (i.e., below 400 ft AGL) have right of way over crewed aircraft that are not equipped with an ADS-B out as specified in 14 CFR § 91.225 or TABS. The AOPA, dissented, stating that the recommendations fail to "recognize the reality of aircraft operations at lower altitudes, and the unsafe and unfeasible requirements it will place on crewed aircraft" (BVLOS ARC, Appendix F Combined Voting Ballots). Citing fixed wing, rotorcraft, lighter than air, powered parachute, ultralight, antique, agricultural, and other operations at low altitude, AOPA questions the ARC's assumption that very few aircraft operate below 400 ft AGL. Further, AOPA highlights what it views as the ARC's "unsafe and unfeasible reliance on electronic conspicuity" (BVLOS ARC, Appendix F Combined Voting Ballots), stating that ADS-B is not required in the majority of the NAS below 10,000 ft. Indeed, requiring an aircraft that is not obligated to transmit ADS-B to give way to a more maneuverable aircraft that is difficult to visually acquire does not seem a fair or prudent approach, but rather increases overall risk in the system. Airbus echoed AOPA's concern about over-reliance on electronic conspicuity in their dissent. AOPA's recommendation is to require uncrewed aircraft to have DAA equipment when operating BVLOS, and to keep RoW rules based on maneuverability.

HAI also dissented stating, "What the recommendations in the Report attempt to do is relieve uncrewed (sic) system operators of the foundational responsibility for detecting and avoiding other aircraft. Amending FAR § 91.113 right of way rules in no way mitigates risk. Essentially, it increases risk to other airspace users and transfers legal liability away from BVLOS operators." (BVLOS ARC Appendix F Combined Voting Ballots). HAI pointed out that detection capability is foundational to RoW rules, and that RoW should not be granted simply because an aircraft is unable to detect an intruder.

IRIS Automation also dissented, stating that all users of the NAS have a responsibility to avoid collisions, and that a crewed aircraft will likely be unable to give way to Small Uncrewed Aircraft System (sUAS) because of the difficulty of visually detecting sUAS.

ASTM International also dissented, stating that transferring responsibility to only crewed aircraft is a risk that is not in the best interest of the industry.

Airbus and ALPA also dissented stating that UA should not have the RoW over non-cooperative crewed aircraft.

FR 2.4: "The FAA should amend FAR Rule § 91.113(d) to give UA Right of Way for Shielded Operations." AOPA, HAI, GAMA, Praxis, and Airbus again dissented, stating that RoW rules should continue to be based on maneuverability. HAI went on to recommend the FAA more clearly define shielded operations. OneSky Systems concurred with the BVLOS ARC report, but highlighted the lack of method for avoiding UA to UA encounters, and lack of methods for equipping crewed aircraft under 400 ft.

ALPA further stated that BVLOS should only occur in Class G airspace below 400 ft.

In addition to the specific recommendations, The BVLOS ARC makes the following statement:

- "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., agriculture 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 crewed 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 crewed and uncrewed 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.

4 DEVELOP UAS HIERARCHY RELATED TO THE GAPS IDENTIFIED

Based on findings in the background report as well as further analysis in Task 2, an initial hierarchy has been developed to enable use cases to be developed and tested in Tasks 3 and 4. This initial hierarchy has been developed by constructing matrices between the various aircraft that operate below 400 ft AGL to reduce the RoW gaps within the current regulatory framework. Furthermore, these matrices are complementary to the textual description of the RoW rules with each encounter. The rationale for these RoW rules is predicated by the methodology listed as well as the assumptions that were made as a result of the research gaps identified. These identified research gaps reflect unsettled topics such as conspicuity, DAA capability, training, navigational integrity and other considerations that need to be determined before RoW rules can be safely implemented.

4.1 Introduction/ Methodology

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

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

- Crewed aircraft equipped with ADS-B out
- Crewed aircraft not equipped with ADS-B out
- UAS

- Swarm
- UAS in specified shielded operations
- UAS in specified reserved airspace operations

Note that some of these combinations are symmetrical. For instance, an approaching head-on between a crewed aircraft cooperative and a UAS is the same as an approaching head-on between a UAS and a crewed aircraft cooperative. On the contrary, in the case of overtaking geometries, it is important to make a distinction between which aircraft is overtaken and which aircraft overtakes. Similarly, in a landing geometry the results may be different depending on which aircraft is landing and which one is not.

The following proposed rules were adopted to resolve the RoW for each encounter. In each case below, it must be assumed that deconfliction rules apply to BVLOS conditions as none of these should be applicable in a VLOS situation. Note that resolving these encounters has some common sense in it, which require aeronautical decision making upon the precedence between two potential, conflicting rules. For instance, apply §107.37, which indicates that UAS yields to any other aircraft. By extension, it is assumed that swarms also yield in any encounter with non-UAS aircraft. Where reserved airspace is enabled, this signals other aircraft that they have a responsibility to remain well clear or that RoW may be impacted. The case of UAS/UAS encounters is resolved by providing a symmetric solution. Thus, for instance, in UAS/UAS converging geometries, both would turn right, so that, no preference is given. Since a swarm is less maneuverable than a single UAS, any swarm encounter with a single UAS would lead to the single UAS yielding the RoW. In the case of ultralight encounters, §103.13 applies: Ultralights always yield.]The recommended update for UAS/ultralights encounters are resolved by giving the ultralight the RoW.

Encounters in reserved airspace will only be between UAS and UAS, UAS and crewed aircraft transmitting ADS-B, UAS that are able to sense crewed aircraft not equipped with ADS-B and aircraft not equipped with ADS-B, or crewed aircraft and crewed aircraft. No encounters will occur between UAS that cannot sense aircraft not equipped with ADS-B and crewed aircraft not transmitting ADS-B out, because these aircraft will be segregated. UAS in shielded operations are less maneuverable because of the presence of a structure. In order to avoid sudden, unexpected maneuvers, some texts recommend that UAS flying near structures do so leaving the structure always to the same side, with respect to the direction of the flight. It is recommended that the spirit of §91.113 apply. When both aircraft are of the same type (i.e., both UAS in shielded operations, or flying in reserved airspace, or both swarms) that the UAS fly on the right side of the structure. When one sUAS is overtaking another, it would pass on the right of the slower sUAS.

A "common sense" rule is also imperative: Saving human lives is more important than a UAS. Thus, the researcher understands that any maneuver that could minimize the risk or eliminate it altogether, even if it contradicts the rules above, is imperative. Last minute maneuvers cannot be discarded, but the results are influenced by the reflexes and experience of the pilots involved.

4.2 Reserved Airspace Concept (RAC)

This new concept is intended to assist in segregation and RoW identification in both Controlled (CA) and Uncontrolled Airspace (UCA). The RAC is a 3D polygon or corridor of airspace with the added dimension of date/time. The reserved space measurements would be defined with floor and ceiling altitudes, widths and lengths from a center, and finally, day(s) of operation and associated length of time. The airspace could be reserved by crewed or uncrewed aircraft alike. RAC is intended to be used in areas outside UTM services.

The primary intent of RAC is to segregate aircraft that have no realistic means of detecting each other. Specifically, the main purpose of RAC is to segregate crewed aircraft not equipped with ADS-B out from BVLOS uncrewed aircraft that are not capable of detecting non-cooperative aircraft. RAC would enable safe operations of BVLOS drones and crewed aircraft not equipped with ADS-B out by creating reservable airspace blocks or corridors which would be available to aircraft that can safely operate in the same airspace as the aircraft reserving the airspace, but would restrict operations from aircraft that cannot safely operate in the same airspace as the aircraft reserving the airspace. For example, if a BVLOS uncrewed aircraft reserves the airspace, only crewed aircraft transmitting ADS-B or uncrewed aircraft transmitting an electronic signal may operate in the airspace, however, non-cooperative aircraft, crewed or uncrewed, cannot. If a crewed aircraft not equipped with ADS-B reserves the airspace, all other aircraft may operate in the airspace except a BVLOS drone without the ability to detect and avoid non-cooperative aircraft. The scenarios in Table 1 illustrate RoW in and outside RAC.

Note. Precision Ag can be traditional crop duster aircraft or helicopter. NCA is a non-cooperative aircraft of any type (crewed or uncrewed). A non-cooperative crewed aircraft is an NCCA. Cooperative crewed aircraft is CCA.

Table 2: Example Scenarios using RAC Concept

Aircraft Encounter	No ADS-B out Precision Ag and BVLOS drone without sensors to detect NCA (can detect CCA)	No ADS-B out Helo conducting inspection and BVLOS drone with sensors to detect NCCA and CCA	CCA and BVLOS drone without sensors to detect cooperative aircraft	CCA and BVLOS drone with sensors to detect cooperative aircraft
Unreserved, unshielded airspace	BVLOS drone without sensors to detect NCA would not be allowed in this airspace	Both aircraft allowed in airspace, crewed aircraft have the RoW	BVLOS drone not allowed in this airspace	Both aircraft allowed in airspace, crewed aircraft have the RoW
Unreserved shielded airspace	TBD	Both aircraft allowed in airspace, crewed aircraft have the RoW	BVLOS drone not allowed in this airspace	Both aircraft allowed in airspace, crewed aircraft have the RoW
Reserved unshielded airspace	Aircraft reserving airspace gets	Aircraft reserving airspace gets	BVLOS drone not allowed in this airspace	Both aircraft allowed in airspace,

	access, other aircraft type in this scenario may not enter.	access, other aircraft type in this scenario may not enter		crewed aircraft have the RoW
Reserved shielded airspace	Aircraft reserving airspace gets access, other aircraft type in this scenario may not enter	Aircraft reserving airspace gets access, other aircraft type in this scenario may not enter	BVLOS drone not allowed in this airspace	Both aircraft allowed in airspace, crewed aircraft have the RoW

An online reservation system would be used by both crewed and uncrewed aircraft to reserve sections of low-altitude airspace within a boundaries area and time. The approval process for reserving airspace would need to include oversight to prevent one user from dominating the system unfairly, for example a homeowner reserving airspace to prevent anyone from using it, or one operator reserving airspace to deny use to a competitor. The reservation must include a point of contact and frequencies (as applicable) to permit other aircraft to contact the reserver of the airspace prior to the block time. Where practical, communication could occur during flight operations to assist in deconfliction. Airspace reservations under RAC would need to be submitted in a timely fashion (hours ahead) in order to assist in deconfliction and coordination to enable separation, and not force an unsafe situation in flight. This assumes BVLOS drone aircrew are authorized to communicate via VHF radio. Reservation information would be transmitted to other airspace users via the NOTAM system. While recreational drone users are not likely to consult NOTAMs, UAS companies that contract services for inspections or perform package delivery would be the most probable users of the reservation system, and therefore might be more likely to check NOTAMs. Additionally, local users in rural areas may not frequent the NOTAM system and frequently operate at low altitudes (precision agriculture). NOTAMs are not a perfect notification system, and the FAA would be advised to enhance the distribution of this airspace intelligence to likely users. While graphical NOTAMs are helpful, it is the best method available and further establishing 4-dimensional identification through the system is essential.

Questions still must be resolved regarding RAC including:

- Who should be allowed in shielded non-reserved airspace?
- On what criteria would approval of a reservation request be based?
  - As in public safety, infrastructure safety, commerce, or personal/private
- How would the request and approval process be operationalized?
  - Would the request be based on lat/long and altitude, or by geographic reference, or by selecting points on an interactive map?
  - By criteria? By time (first come/served)?
- Is a reservation per agency/company, per aircraft, or per operator?
- What priority warrants issuance of airspace?

- Such as a critical infrastructure inspection vs. a package delivery

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4.3 Summary of Initial Assumptions

In the development of initial RoW solutions for aircraft below 400 ft AGL, a series of assumptions were made to further account for the gaps in information or research. These assumptions allow for a uniform approach to develop proposed RoW rules and remain within the scope of the project. This project is not intended to determine acceptable means of compliance for UAS to maintain cloud clearance, determine an adequate DAA or meet a variety of other gaps previously mentioned. The intent is to create a framework, with realistic assumptions, that would allow for the logical implementation of proposed RoW rules for aircraft that operate below 400 ft. AGL. Once these proposed RoW rules are tested through simulation and flight testing, final recommendations can be submitted to the FAA for consideration and to inform the industry of expectations for future systems that may fill the research gaps.

Listed below is a summary of those assumptions. These apply to encounters in BVLOS situations. It should be noted that for any assumption that is changed, a decision tree will be impacted that will alter the initial proposed RoW rules. It is intended that through continued dialogue with the FAA and industry, as well as simulation testing, assumptions and subsequent RoW rule recommendations will need to be modified or changed.

1. UAS has to remain clear of clouds and ensure flight visibility remains in accordance with FAR § 107.51.
2. sUAS operating during daytime hours are largely inconspicuous. Mid-sized UAS operating during daytime hours are assumed to be less conspicuous than a light sport aircraft. The question of whether mid-sized UAS conspicuity can be adequately improved with the use of technological solutions will be known through future research.
3. IAW with ASTM F3442-20 Standard Specification for Detect and Avoid System Performance Requirements, DAA Sensors used by UAS are effective for tracking cooperative and non-cooperative aircraft.
4. Cooperative aircraft will provide location, identification of aircraft (i.e. N#, category (UAS/swarm/airplane/balloon etc.) and status (normal, emergency, unknown).
5. Navigational performance of (BVLOS) UAS is equivalent to crewed aircraft when enroute and has improved performance in shielded operations and areas that normally have degraded navigational performance.
6. All UAS are cooperative, as described in #5, unless otherwise noted. Examples of uncooperative UAS could be VLOS or under proposed RID rules.
7. This project assumes that crewed aircraft air traffic density near natural or human-made obstacles is often low except in special areas such as landing and take-off locations and areas of known manned traffic near flight obstacles (shielded operations).
8. Reserved airspace operations are a form of segregated airspace to prevent encounters between UAS BVLOS operations and non-cooperative crewed aircraft, Recommendations will be focused on UAS BVLOS Operations restricted to below 400 ft AGL.
9. Crewed aircraft missions include low-level commercial operations (i.e. construction, precision agriculture, infrastructure inspections, tourism), public safety (fire, law

enforcement, air ambulance), and recreational operations (ultralights, gliders). This list is not intended to be exhaustive.

10. Shielded operations are defined for this research as "flight within close proximity to existing obstacles and not to exceed a height of 100 ft above of the obstacle" (Federal Aviation Administration, 2020c, pg. 31). Outcomes from the ASSURE A45 Project on shielded Detect and Avoid operations may refine recommended standoff distances.
11. The integrity of navigation performance during shielded operations can be maintained.
12. When planning a route, a pilot or Remote Pilot In Command (RPIC) will have to have method to differentiate what airspace has been classified as shielded under 42 U.S.C. § 5195c and the UAS reserved airspace concept.
13. It is assumed that all other things being equal during daytime hours, a crewed aircraft is more conspicuous than a sUAS. Research is needed with respect to drone lighting at night and whether onboard pilots can recognize and respond to drone lighting the same as aircraft lighting at night.
14. It is assumed that a UAS below 400 ft AGL is more maneuverable than any other crewed aircraft.
15. It is assumed for a swarm, that a swarm is more conspicuous than a single UAS, in the case of shielded operations, the aircraft (crewed, uncrewed, or swarm) maneuverability is partially impaired by proximity to infrastructure.
16. It is assumed that a BVLOS or VLOS UAS will detect crewed aircraft before the onboard pilot of a crewed aircraft visually detects the UAS.
17. It is assumed that during VLOS operations with a UAS, the UAS will detect (by sound or sight) the crewed aircraft before the crewed aircraft sees the UAS.
18. Onboard pilots do not visually see-and-avoid aircraft approaching from behind.
19. All uncrewed BVLOS aircraft will be able to detect and avoid aircraft equipped with ADS-B out or similar location technology.

4.4 RoW Scenarios and Initial RoW Rules

4.4.1 RoW Description

Using the safety hierarchy established for crewed aircraft, additional RoW rules are established below for each of the common geometries found which include 1) Converging, 2) Approaching Head On, 3) Overtaking, 4) Landing, and 5) Emergency.

The proposed rules have been established to provide a textual description. After the proposed rules, a basic rationale is displayed. This rationale provides supplemental information that further informs the methodology previously explained.

4.4.2 Converging - Proposed Rule Changes Summarized

The BVLOS ARC recommends that UAS yield RoW to crewed aircraft equipped with ADS-B out. The A54 team concurs with this recommendation. The BVLOS ARC further proposes that crewed aircraft not equipped with ADS-B out yield RoW to UAS operating BVLOS away from airports or helipads. The A54 team disagrees with this recommendation for two reasons: A BVLOS drone with no capability to detect a non-cooperative aircraft is incapable of exercising the fundamental requirement for vigilance in detecting and avoiding other aircraft. Further, visually locating small UAS from the cockpit of a crewed aircraft in time to avoid the UAS has been shown to be extremely difficult. However, BVLOS drones without the ability to detect non-cooperative aircraft can reserve airspace which non-cooperative aircraft cannot enter. Reserving airspace allows fair access to all airspace users without compromising safety, and distributes the burden of reserving airspace or adding equipage equally to the crewed and uncrewed communities.

The BVLOS ARC recommends that all crewed aircraft yield RoW to UAS conducting shielded operations. As the ARC report points out, very few crewed aircraft operations occur in shielded airspace. However, among those operations are public safety crewed aircraft operations, including police and medevac. Therefore, the A54 team recommends that crewed aircraft not equipped with ADS-B out yield RoW to UAS in shielded operations, but that UAS yield RoW to crewed aircraft equipped with ADS-B out. Although as stated above, visually locating a small UAS from the cockpit of a crewed aircraft is extremely difficult, electing to stay away from shielded airspace unless reserved by that crewed aircraft is not difficult. The difficulty remains that uncrewed aircraft (regardless of cooperativity) in shielded operations will be required to give way to crewed aircraft equipped with ADS-B out. This may create a situation in which an uncrewed aircraft must maneuver to avoid an overtaking crewed aircraft, which could result in the uncrewed aircraft having no room to remain well clear without risking collision with the structure or nearby obstacle. This scenario must be tested in simulation to determine if other solutions must be developed. Other solutions could involve temporary flight restrictions that would restrict access to shielded airspace to all other users.

The A54 team recommends that a new category of reservable airspace be created. The intent of RAC is to keep aircraft that cannot realistically detect each other from occupying the same airspace. UAS may reserve airspace which aircraft not equipped with ADS-B out may not enter for the duration of the reservation, and crewed aircraft that are not equipped with ADS-B out may reserve airspace in which UAS that cannot detect non-ADS-B aircraft may not enter for the duration of the reservation.

General comments regarding the recommended updates to 91.113, when weather conditions permit, regardless of whether an operation is conducted under applicable instrument flight rules or visual flight rules, vigilance will still be required by each person operating an aircraft, crewed or uncrewed, so as to detect and avoid the other aircraft. In the event the aircraft is uncrewed (single or swarm UAS), the RPIC shall use the UAS's approved DAA system or through means of visual observation, remain well clear of other aircraft at all times by altering course, altitude, or speed before well clear boundary is reached (or adequate separation is lost). When a rule of 91.113 as amended gives another aircraft the right-of-way, the pilot or RPIC shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

4.4.3 Converging - Rationale

UAS does not have souls on board and has reduced conspicuity; therefore, every effort should be made to remain well clear of less maneuverable as well as cooperative aircraft. The intent is for UAS DAA systems to have algorithms that help the UAS remain well clear at all times by altering course, altitude, or speed before well clear boundary is reached.

4.4.4 Approaching Head-On - Proposed Rules Summarized

(e)Approaching head-on. When cooperative and/or non-cooperative aircraft are approaching each other head-on, or nearly so, each pilot or RPIC of each aircraft shall alter course to the right. Due to conspicuity and depth perception between a UAS and crewed aircraft, if a UAS or Swarm approaches a crewed aircraft, the UAS or Swarm will turn right; a crewed aircraft will turn right.

4.4.5 Approaching Head-On - Rationale

A UAS that is operating BVLOS would be expected to be cooperative as well as having an effective DAA system that would enable the acquisition of cooperative traffic. A single UAS or Swarm would be expected to give way to a crewed aircraft.

4.4.6 Overtaking - Proposed Rules Summarized

(f)Crewed aircraft encounters with crewed aircraft remain the same. Crewed aircraft encounters with UAS remain the same (crewed aircraft have right of way). The only exception is in shielded airspace, in which the UAS has RoW over a non-ADS-B out crewed aircraft. In that case, the non-ADS-B out crewed aircraft shall alter course to the right to pass well clear.

4.4.7 Overtaking - Rationale

A UAS that is operating BVLOS would be expected to have an effective DAA system that would enable acquisition of cooperative traffic. This technological advantage requires the UAS to use all available means to remain adequately separated from a crewed aircraft regardless of RoW rules.

It is the researcher’s recommendation that reserved airspace become a form of segregated airspace by time/dimension which includes shielded airspace, LAANC, and DROTAMs. Further, shielded airspace approval, as defined, should consist of only one operator at a time.

4.4.8 Landing - Proposed Rules Summarized

(g)Landing. At FAA designated airports for both crewed or uncrewed aircraft; aircraft, while on final approach to land or while landing, have the right-of-way over other aircraft in flight or operating on the surface, except that they shall not take advantage of this rule to force an aircraft off the runway surface which has already landed and is attempting to make way for an aircraft on final approach. When two or more aircraft are approaching an airport for the purpose of landing, the aircraft at the lower altitude has the right-of-way, but it shall not take advantage of this rule to cut in front of another which is on final approach to land or to overtake that aircraft.

4.4.9 Landing - Rationale

UAS operating in a Class G airport environment must have effective DAA sensors to operate as a normal aircraft, this is due to traffic flow where crewed and uncrewed aircraft are approaching to land. The addition of “FAA designed airports for both crewed and uncrewed aircraft is to identify that not all airports will be conducive to integrating crewed and uncrewed aircraft. UAS operating in controlled airport, such as Class D or Class C will also be required to meet additional equipage requirements such as two-way radio communications as well as have the ability to comply with ATC for safety of flight.

4.4.10 Emergency - Proposed Rules Summarized

91.113 (c) In distress. A crewed aircraft who in distress has the right-of-way over all other air traffic regardless of shielded operations or other reserved airspace. Regardless of RoW rules, a UAS or Swarm must use effective DAA systems and give way to an aircraft that has declared an emergency (emergency status) or their immediate flight path reflects that of an aircraft in distress. A UAS or Swarm in distress has right-of-way over other UAS or Swarm, but does not have right-of-way over crewed aircraft.

4.4.11 Emergency - Rationale

Any crewed aircraft, regardless of category or maneuverability, must be given RoW when an emergency is declared. While all operators must remain vigilant and strive to maintain adequate separation, a crewed aircraft in distress must be free to deviate to ensure a safe outcome is attained.

5 CONCLUSIONS AND RECOMMENDATIONS FROM TASK 2

The purpose of Task 2 is to identify the UAS RoW gaps, prioritize those gaps, and establish initial recommendations for new RoW rules. The Task 1 report helped to identify many of the gaps related to RoW as well as provide a framework to create a new safety hierarchy for RoW rules that included UAS. The Task 2 report attempted to consider the possible categorization of RoW related gaps, which included: 1) gaps in the current RoW rules, 2) other regulatory gaps, and 3) additional research gaps. The assumptions created in response to the identified research gaps will need to be agreed upon by the sponsors and the performer team prior to moving to Task 3. These assumptions mentioned in the report will continue to be evaluated in the forthcoming tasks. The team will continue to seek FAA inputs and industry feedback along with the ARC BVLOS report to prioritize the gap. Based on the gaps identified and subsequent assumptions, the team has developed an initial safety hierarchy that will enable the use cases to be developed and tested in the subsequent sessions.

5.1 Recommendations

Overall, Task 2 recommends that the remote pilots have a method of determining visibility and cloud clearances. Research in visual conspicuity enhancements is not sufficient or conclusive for mid-sized drones. The research needs to address a wide range of environmental conditions related to conspicuity, but it is the researcher’s recommendation that DAA systems remain the long-term solution for lack of conspicuity due to size and various shapes of UAS. The effectiveness of training a pilot on visual acquisition of a UAS needs to be further studied, but it is the researcher’s recommendation that training will not alleviate the issues surrounding conspicuity of UAS. Hence research into pilot training is a lower priority research topic for this project focused on exploring right-of-way. Efficiency of a DAA systems that can detect not only cooperative, but non-cooperative aircraft need to be further researched. This research may include modeling scenarios to determine whether the RoW scenario can be avoided through electronic means. Research needs to focus on determining the air traffic density of crewed aircraft near an artificial and natural obstacle. A digital system needs to be developed and available for a RPIC to reserve airspace when planning operations. This capability should clearly differentiate UAS Reserved Airspace as shielded, LAANC, under a DROTAM/NOTAM, or a combination of these. This Reserved Airspace must also be visible to crewed aircraft pilots as they begin their planning or otherwise find themselves in low-level airspace.

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