Range Safety Group

RANGE SAFETY GUIDELINES FOR SMALL UNMANNED AIR SYSTEMS

ABERDEEN TEST CENTER
DUGWAY PROVING GROUND
ELECTRONIC PROVING GROUND
REAGAN TEST SITE
REDSTONE TEST CENTER
WHITE SANDS TEST CENTER
YUMA PROVING GROUND

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION PATUXENT RIVER
NAVAL AIR WARFARE CENTER WEAPONS DIVISION CHINA LAKE
NAVAL AIR WARFARE CENTER WEAPONS DIVISION POINT MUGU
NAVAL SURFACE WARFARE CENTER DAHLGREN DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION KEYPORT
NAVAL UNDERSEA WARFARE CENTER DIVISION NEWPORT
PACIFIC MISSILE RANGE FACILITY

96th TEST WING
412th TEST WING
ARNOLD ENGINEERING DEVELOPMENT COMPLEX

SPACE LAUNCH DELTA 30
SPACE LAUNCH DELTA 45

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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RANGE SAFETY GUIDELINES FOR SMALL UNMANNED AIR SYSTEMS

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Preface

This new RCC document provides a common set of guidance and processes for managing small unmanned aircraft systems (sUASs) on the national ranges. The focus is on leveraging the benefits of sUASs without unduly burdening operations. Many current instructions, rules, and policies written for testing UAVs exceed the complexity, risk, and cost of sUASs. However, sUASs have a higher likelihood of operating in closer proximity to people, vehicles, roads, and buildings, which warrants focused guidance to address the hazards they present. This document establishes guidelines useful to range safety and range users with the intent to optimize sUAS safe operations, range containment, and cost effectiveness.

This guidance document benefits all ranges and range users flying sUASs. It promotes consistent protection to the public, range personnel, and assets during the testing and operation of sUASs. The document incorporates standard approaches for assessing and managing safety risks from sUAS flights.

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Acronyms

AVO	air vehicle operator
ASM	airspace manager
ATC	air traffic controller/air traffic control
BVLOS	beyond visual line of sight
BRLOS	beyond radio line of sight
C2	command and control
COA	Certificate of Waiver or Authorization
COTS	commercial off-the-shelf
DoD	Department of Defense
FAA	Federal Aviation Administration
FPV	First Person View
FSS	flight safety system
FTS	flight termination system
GPS	Global Positioning System
IAW	in accordance with
IR	infrared
LiPo	lithium polymer
LOS	line of sight
MC	mission commander
NAS	National Airspace System
OEM	original equipment manufacturing
RCC	Range Commanders Council
RCO	range control officer
RLOS	radio line of sight
RF	radio frequency
RSO	range safety officer
RTB	return to base
SOF	Safety of Flight
SUA	special use airspace
sUAS	small unmanned air system
sUAV	small unmanned air vehicle
UAV	unmanned air vehicle or uninhabited air vehicle
UXO	unexploded ordnance
VLOS	visual line of sight

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CHAPTER 1

Introduction

1.1 Purpose

This document outlines safe operating guidance for the operation and testing of small unmanned air systems (sUASs) on US federal ranges. Many current Air Force, Navy, and Federal Aviation Administration (FAA) instructions, rules, policies, and past experiences written for testing unmanned air vehicles (UAVs) exceed the complexity, risk, and expense of sUASs. As such, when applied to sUAS assets these standards result in costs much greater than that of the UAV itself. There is a higher likelihood of operating sUASs in closer proximity to people, vehicles, roads, and buildings, and therefore focused sUAS guidance must be considered due to the specific hazards that UASs present. This document establishes guidelines useful to range safety officers (RSOs) with the intent to optimize sUAS safe operations, range containment, and cost effectiveness. This guidance also defines the basic parameters, overall strategy, and appropriate responsibilities of the personnel involved with the sUAS test or operation activities. This document will be reviewed, as necessary, to ensure relevancy and currency based on future technological developments, lessons learned, and updates to the FAA Part 107[1] regulations (see Section 1.6).

1.2 Scope

The scope of this document is limited to sUASs as defined in Section 1.4, which can include experimental vehicles, test articles, and expendable targets. While not focused on airworthy sUASs, many of the principles and practices regarding flying within special use airspace (SUA) will apply and hence should be incorporated into the range's tailored safety guidance. These guidelines are not intended to cover counter-sUAS activities, such as bringing down or otherwise rendering an sUAS inoperable; however, this activity should be accounted for in the tailored safety guidance developed at each range. Additionally, this guidance does not cover recreational use of sUASs within SUA. Each range will be responsible for developing proper procedures regarding recreational use of sUASs, and at a minimum should draw upon the framework of FAA Part 107.

While this guidance is principally written for sUAS operations within SUA, in the event that operations occur outside of SUA, the portions of guidance covering protection of people and high-value infrastructure on the ground still apply, per local range operations authority and range safety office requirements. Additionally, the airspace control and de-confliction in the National Airspace System (NAS) under FAA control and FAA Part 107 flight regulations shall apply when operating in airspace outside of SUA.

1.3 Implementation

Individual ranges should seek concurrence where necessary from their respective airworthiness certification authorities or equivalent that sUASs, as defined in this document, will

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[1] Federal Aviation Administration. *Small Unmanned Aircraft Systems*. 14 CFR 107. n.d. May be superseded by update. Retrieved 1 December 2020. Available at https://www.govinfo.gov/content/pkg/CFR-2020-title14-vol2/pdf/CFR-2020-title14-vol2-part107.pdf.

be managed and operated under these adopted principles and procedures once tailored to the respective range. Deviations from procedures developed from this guidance may require a formal Safety Review Board. Depending on the range, seeking concurrence from the following groups should also be considered: local range operations group, airfield management, airspace management, spectrum management, subject matter experts, and similar organizations.

While this document is intended to be guidance, precise language is used in an attempt to capture the intent of the Range Commanders Council's (RCC's) Range Safety Group as follows.

- The words "must", "shall", and "will" indicate a requirement that is strongly recommended. Legitimate alternatives may exist, but each alternative shall demonstrate an equivalent level of safety.
- "Should" indicates an advisory requirement or a highly desirable procedure. The RSG intends that a range will comply to the maximum practical extent, but no equivalent level of safety will be required.
- "Can" and "may" permit a choice and express a guideline.

1.4 Definition

For the purpose of this document, an sUAS is defined as a small, unmanned aircraft (55 pounds or less) with its accompanying ground control station and command links. This definition corresponds to Groups 1 and 2 per US Department of Defense (DoD) UAS classification,[2] which mirrors the FAA sUAS classification defined in FAA Part 107,[3] and the NASA Procedural Requirements NPR-7900.3D.[4] The flight altitude and airspeed limitations for the DoD and FAA sUAS definitions are not included in the definition used in this guidance. For the purposes of this document, the term sUAS will be used interchangeably to refer to either the system as a whole, or the aircraft itself. An sUAS can have many functions including but not limited to; aerial photography, sensor test vehicle, target, package delivery, etc.

Depending on the complexity of the sUAS, various personnel and positions may be required for system operation. The terms *pilot* and *system operator* are also used interchangeably within this document, but generally refer to the sUAS operator who is in control of flight. Other roles that may require additional personnel include mission commander (MC), observer/spotter, and operator in training. Non-participants are considered personnel not involved with the flight activities.

1.5 sUAS Strategy

Ensuring the safety of people, property, and the environment is the primary strategy under which this guidance was developed. Keeping in mind that due to the unmanned, low-cost nature of most sUASs, aircraft recovery can often be considered a secondary mission objective to the data collection or vehicle demonstration. In-flight anomalies that result in erratic or unexpected behavior will likely result in air vehicle loss or damage. The value of the data or

[2] Chairman, Joint Chiefs of Staff. "Joint Air Operations." JP 3-30. 25 July 2019. May be superseded by update. Retrieved 3 June 2020. Available at https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_30.pdf.
[3] Small Unmanned Aircraft Systems. 14 CFR Part 107.
[4] NASA. *Aircraft Operations Management*. NPR 7900.3D. 1 May 2017. Expiration date 1 May 2022. Retrieved 3 June 2020. Available at https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7900_003D_/N_PR_7900_003D_.pdf.

work product can likely be more than that of the vehicle, thus the recovery and repair of the vehicle may not be cost-effective.

The expenditure of time and money for any air worthiness analysis or maintenance analysis may not be cost-effective. However, each range should ultimately make that determination based on the program, the sUASs, and their individual requirements.

Measures taken to ensure public safety for a certified airworthy sUAS will likely be a reduced subset of those required for an sUAS without airworthiness certification. For uncertified sUASs, a cleared area should be established void of any non-participants, property, and assets requiring protection. Operations of an sUAS without airworthiness certification in an uncleared area will likely require a more rigorous risk analysis using the RCC 323[5] guidance, in terms of casualty expectation criteria, property damage criteria, etc. A conservative risk assessment should be considered for approval purposes until the sUAS operational maturity is sufficient to justify reduced conservatism.

1.6 FAA Part 107

The FAA released regulations for the civil operation of sUASs (≤55 lb. class aircraft) in the NAS (see FAA Part 107). The intent of this RCC guidance is to allow sUAS flight, with applicable restrictions, where FAA rules would otherwise prohibit. Ranges should consider the FAA Part 107 flight regulations when developing their requirements, but also be clear on how the SUA differs from the rest of the NAS in regards to such things as airspace deconfliction, frequency authorization, airspace boundaries, classes of airspace, and other general flight restrictions.

[5] Range Commanders Council. *Range Safety Criteria for Unmanned Air Vehicles*. RCC 323-18. June 2018. May be superseded by update. Retrieved 3 June 2020. Available at https://www.trmc.osd.mil/wiki/x/AYy8Bg.

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CHAPTER 2

sUAS Range Safety Fundamentals

2.1 The sUAS Challenge to Range Safety

The Range Safety Program strategy of protecting the general public, test/training area personnel, high-value property, critical assets, and range resources entails providing risk management guidance for sUAS testing and use at an appropriate level of rigor when hazards related to range missions exceed the capability of normal preventive or protective procedures. More specifically, this requires the Range Safety Program to provide the following functions.

- Recognition of hazards associated with the use of sUAS articles on the range;
- Verification of appropriate consequence mitigation when encountering the identified hazards by the employment of proven system safeguards, controls, or existing range barriers;
- Identification of gaps in existing system safeguards, controls, or range barriers;
- Proposal of additional hazard controls to address such gaps; and
- Quantifying/assessing the risk along with any residual risk.

Several considerations frame the specific challenge to range safety posed by sUASs for the identification of hazards, the characterization of risk, and the development of mitigations to reduce risk to an acceptable level. The following list provides context for sUAS safety considerations.

a. Less robust engineering, fewer redundant and fail-safe systems, and an expendable mentality designed to keep cost, weight, and size down lead to an often abbreviated or lack of formal air worthiness certification. This in turn may contribute to an expectation of higher failure rates and shorter lifetimes of many sUAS vehicles.

b. A common goal of small size is to maneuver where larger aircraft cannot. This means that sUASs are often intended by design to perform operations in closer proximity to people, property, and infrastructure.

c. Damage or injury to people, property, and infrastructure from sUASs can be less about the size and kinetic energy of falling pieces, and more about the punctures, penetrations, and lacerations from smaller yet faster horizontally moving pieces impacting nearby objects more obliquely.

d. Despite their small size, sUAS vehicles still may possess sufficient mass and speed to pose a serious threat to other vehicles within the airspace, but their small size renders it harder for: (1) other aircraft to sense and avoid in time, and (2) traditional ground tracking systems to detect and provide timely warning of potential collision.

As a result of the low-cost, rapid development, and often disposable mentality, sUASs will typically bypass the rigor of airworthiness and reliability assessment of larger, more durable air vehicles. In lieu of such assessments, certifications, and formal data, a less formal assessment of system maturity must often be considered. In common speak, system maturity expresses some degree of confidence in the performance reliability of the system. By definition, a system reflects the aggregate integration of components. Thus, the concept of system maturity level is a function of both the technology readiness level of the system's components and the integration maturity level of interfacing compatible technologies and their behaviors that constitute the system. While there exist standards for assessing technology readiness levels, a common notion of integration maturity and system maturity levels does not yet exist. Furthermore, the functional relation between these two in actually measuring system maturity lacks formal definition. Consequently, the range is left to reviewing available data, documentation, and operational history of the UAS and its constituent parts and technologies to form a level of confidence in the system's performance reliability as the essential assessment of system maturity.

2.2 Building the sUAS Range Safety Case

The safety case concept includes the critical elements of both the GEIASTD0010A[6] and MIL-STD-882[7] techniques. It can thus serve as a convenient approach from which to consider sUAS range safety situations. For the sake of discussion, the basic elements of the sUAS safety case are the sUAS assumptions and the sUAS evidence that feed into the reasoned arguments relating sUAS risk categories to sUAS risk strategies that then satisfy the sUAS safety claims. These elements are depicted in Figure 2-1.

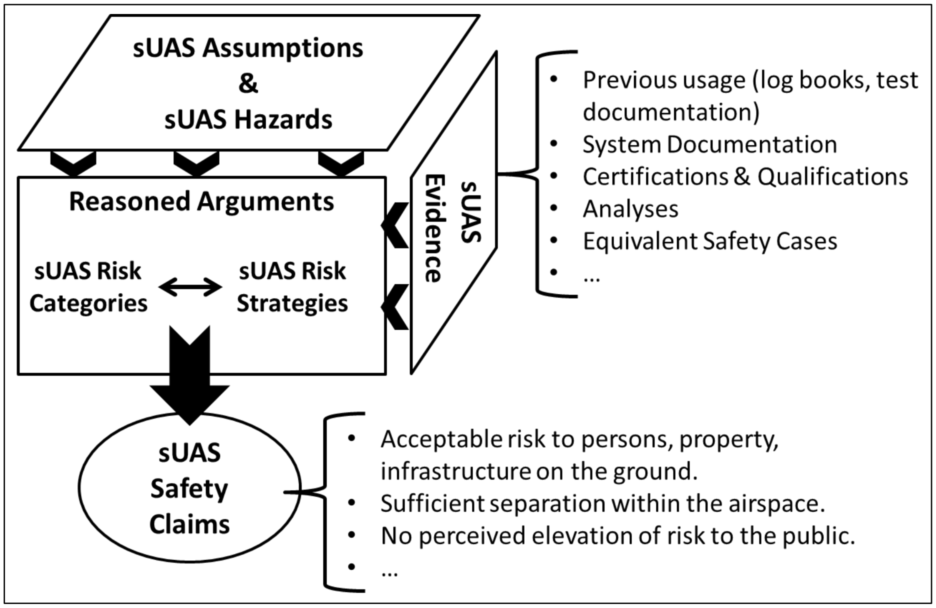

Figure 2-1. Elements of the sUAS Safety Case

Three key sUAS safety claims relevant to range safety are:

- Acceptable risk to participants, non-participants, property, and critical infrastructure on the ground or within proximity of the sUAS vehicle during takeoff, flight, execution of its intended operations, and landing/recovery;

[6] SAE International. *Standard Best Practices for System Safety Program Development and Execution*. GEIASTD0010A. 18 October 2018. May be superseded by update. Retrieved 9 June 2022. Available for purchase at https://www.sae.org/standards/content/geiastd0010a.
[7] Department of Defense. *System Safety*. MIL-STD-882E. 11 May 2012. May be superseded by update. Retrieved 3 June 2020. Available at https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=36027.

- Sufficient separation of the sUAS vehicle and other aircraft within the airspace;
- No perception of elevated risk to non-participants above that which would be considered generally acceptable within the context of the mission.

The sUAS assumptions include the understanding of the operations areas, the operating context, the participants and non-participants, and the common aviation safety assumptions within the context of the challenges already mentioned. In particular, the sUAS operations area may be separated for range safety purposes into five potentially distinct areas.

- sUAS launch and recovery area – This is the area designated for sUAS launch and recovery. It may be located in or adjacent to a designated sUAS work area.
- UAS ground control area – This is the location(s) of the controller personnel and ground transceivers for both UAV control and mission data.
- sUAS work area – This is the designated area within which the sUAS vehicle performs its intended mission operation. Ideally, the work area would be free of non-participant personnel, vulnerable facilities, or sensitive environmental areas. A corresponding airspace should be located away from routes used by other aircraft, and can be scheduled for use by sUAS operations.
- sUAS remote work area – This is an sUAS work area that is not adjacent to the launch and recovery area, thus requiring use of a transit corridor to get to/from the launch and recovery areas.
- sUAS transit corridors – This is a volume of airspace connecting the launch and recovery area(s) to an sUAS remote work area(s).

The operating context of the sUAS on the range can be understood through the following perspectives.

- sUAS Training Context
    - assumes the sUAS and any payload system(s) are operational, i.e., not under experimentation or test; and
    - assumes approved operating instructions and/or procedures for the UAS and any integrated payload(s); and
    - assumes operators unqualified, re-qualifying, or maintaining proficiency.
- sUAS Testing Context
    - assumes the sUAS is under experimentation or test; or
    - assumes the operating payload is under experimentation or test.
- sUAS Target Context
    - assumes the sUAS is operational, i.e. not under experimentation or test; and
    - assumes the sUAS is operating as a target within a larger training or testing context on the range.

The sUAS participants and non-participants include four major categories of personnel from a risk perspective.

- Mission-essential Personnel (Essential Participants)
- Critical-operations Personnel (Non-Essential Participants)

- Neighboring Operations Personnel (Non-Participants with Possible Awareness)
- General Public (Non-Participants with no Assumed Awareness)

Participants include both essential and non-essential personnel associated with the mission. It is generally assumed that they are aware of the mission, have been briefed accordingly, and have the necessary personal protection equipment with respect to the mission role they perform. Mission-essential personnel typically include controllers and ground crew, while observers may fall into the non-essential or critical operations personnel category. Non-participants include both non-mission personnel, such as neighboring operations personnel, and the general public. Neighboring operations personnel are not associated with the mission, but by virtue of their work makes them an unavoidable proximal presence. Non-mission personnel may or may not have some cursory awareness of the mission. The general public, by contrast, is assumed to have no awareness, knowledge, or understanding of the mission. As such, they have no expectation of any heightened risk resulting from the mission, nor the ability to willfully accept such risk that is unbeknownst to them. Conversely, adverse effects to such non-participants can have greater negative repercussions on the range's potential future ability to conduct such missions.

The common aviation safety assumptions can be summarized as follows.

- Airspace boundaries are defined and adequate for routine launch, recovery, and airborne operations as well as emergency operations.
- Surface area is designated for routine launch and recovery, the airborne mission, and potential emergencies.
- Pilots are qualified and certified in vehicle normal and emergency procedures and local airspace procedures.
- Vehicle configuration is approved (hardware and software).
- Vehicle configuration is maintained in accordance with (IAW) approved maintenance procedures.
- Vehicle operating limits have been defined and verified.
- Vehicle standardized operating procedures and emergency procedures have been defined, validated, and approved.
- An aviation safety program exists that tracks all of the above, maintains safety standards, and promotes continuous safety improvement.

While the first three aviation safety assumptions above will generally apply to sUASs, the other assumptions may only partially apply in light of the previously outlined sUAS challenges. Uncertainty in these areas affects the sUAS risk strategies.

Identifying the sUAS hazards will depend on the specifics of a given sUAS, but a general approach could be derived from the degraded states listed in RCC 326-16 for large UASs. Table 2-1 lists possible degraded states for consideration of sUASs. Note that combinations or even sequences of degraded states may be possible.

Table 2-1. Possible Degraded States for sUASs

Takeoff	In Flight	Airspace Ops	Landing	Ground Ops
Abnormal climb-out	Continued controlled flight with damage	Not in assigned airspace	Abnormal runway contact	Collision with obstacle during takeoff or landing
Unguided flight/ erratic flight path on launch	Controlled flight with insufficient resources	Loss of separation assurance	Precautionary landing at alternate site	Ground collision with obstacle
Launcher damages vehicle	Controlled flight into terrain	Near-midair collision	Pilot-induced oscillation	Ground collision with moving vehicle or animal
Wake turbulence resulting in loss of control.	Depart controlled flight	Collision	Runway overshoot/ undershoot	Loss of control - ground
	Ditch/forced landing	Wake turbulence resulting in loss of control.	Arrestment failure	Runway excursion
	In-flight breakup		Parachute recovery failure	Unexpected stop in place on runway or taxiway
	In-flight fire		Wake turbulence resulting in loss of control.	
	Intentional crash in safe location			
	Lost-link routine			
	Transition to parachute recovery (not in recovery area)			
	Uncontrolled impact with terrain or structures			
	Undirected flight (fly away)			
	Undirected glide			

The primary sUAS risk categories from a range safety perspective are as follows.

- Risk of injury to people (participants and non-participants) from a crash or flying debris into a populated area.
- Risk of property damage from a crash or flying debris.
- Risk of damage to critical infrastructure from a collision, crash, or flying debris.
- Risk of collision with other aircraft.
- Risk of negative impact to other range missions or operations.

Examples of potential impacts to overall range operations by the sUAS include the following.

- Unexpected disruption of airspace needed by others.
- Interference of radio frequency (RF) signals.
- Environmental hazards, e.g., risks associated with the handling, use, storage, and disposal of lithium-ion batteries.
- Imposition of additional security controls and OPSEC measures.
- May need to mitigate heightened public perception of danger.

The three major sUAS risk strategies involve managing the ground risk, managing the risks to other aircraft, and managing the risks to range operations.

An sUAS can operate in close proximity to structures and to the ground, where there is an increased risk of oblique collisions, breakups, and crashes. Therefore, there are four basic strategies for managing risk to people and property on the ground.

- Confine operation to unpopulated areas away from critical infrastructure.
- Avoid transit over populated areas, unless the small unmanned air vehicle (sUAV) has demonstrated a degree of maturity commensurate with some degree of airworthiness.
- Plan for contingencies to avoid recovery of an unhealthy sUAV over populated areas or vulnerable infrastructure.
- Constrain operation to visual line of sight (VLOS) or radio line of sight (RLOS) with appropriate awareness of the vehicle's surroundings.

The small size of sUASs can render them particularly difficult to track and be seen with sufficient time for collision avoidance. Consequently, there are five basic strategies for managing risk to other aircraft.

- Plan to use exclusive use airspace, especially for testing.
- Coordinate transits into and out of exclusive use airspace with air traffic control.
- Plan contingency for loss of link and communicate to all stakeholders.
- Ensure tracking ability by air traffic controller (ATC) of any sUAV with the potential to leave exclusive airspace.
- Constrain operation to VLOS or RLOS with appropriate awareness of other vehicles entering the airspace of the UAV.

There are three major strategies for managing the risks to range operations.

- Coordinate/schedule airspace usage for sUASs, regardless of their size, in order to minimize the chance of vehicles inadvertently occupying the same space and time.
- Engage spectrum management to ensure non-interference of the frequencies used by the sUAS for both control and data streams during the time of its operation.

- Ensure that appropriate battery precautions are observed. The most common power source for sUASs includes lithium-ion batteries. Such batteries impose requirements on their safe use with respect to charging and discharging as well as handling with respect to safe storage and disposal.

Behind the reasoned arguments driving the risk mitigation strategies is the sUAS evidence, which should provide a defensible and traceable basis for the sUAS safety claims being made. The rapid development strategy and often disposable mentality driving the engineering of many sUASs leads to a very different view of certification and airworthiness than traditionally associated with manned aircraft and largescale UASs. In this case, documentation of previous successful use, maturity of system and operations documentation, and prior analyses become invaluable. The operations and qualifications requirements covered in detail in Chapter 3 form a critical backbone for the sUAS evidence. Additionally, equivalent safety cases can help guide the RSO in deciding upon risk mitigation strategies.

2.3 sUAS Range Safety Applied

Since the specifics of each range and each sUAS differs greatly, the application of the sUAS safety case will likewise differ. Nonetheless, one way of applying this concept is to consider the possible degraded states in terms of hazardous conditions and determine for each the vulnerability to people, property, or other aircraft. A review of existing hazard barriers can determine if there is sufficient prevention or protection between each hazardous condition and the exposed people, property, or aircraft. Where a potentially hazardous condition exists, and explicit evidence of adequate barriers between the hazard and exposed people, property, or aircraft do not exist, then additional action is required to ensure additional barriers or controls are put in place, or vulnerable people, property, or aircraft are protected from exposure to hazards.

Barriers are purely protective. They need to be designed to fit the characteristics of the energy flows involved and the “targets,” including people, property, and infrastructure that could be exposed. A barrier is any device or method designed to protect vulnerable targets from sources of harm. The vulnerability of a target is specific to the particular energy flow or environmental condition. Thus, barriers include such mechanisms as machinery guards, personal protection equipment (PPE), and firewalls. Controls, on the other hand, involve any provision taken to reduce the likelihood and/or severity of an adverse event. Controls can include design modifications to address specific risks, modification of procedures, improvements in personnel training, provisions to improve monitoring and oversight, etc.

Table 2-2 through Table 2-5 illustrate examples of mapping preventions and protections to possible hazardous conditions.

Table 2-2. Hazardous Conditions Resulting in Unintended Ground Impact

Hazardous Condition	Prevention	Protection
Erroneous information resulting in controlled flight into terrain	Flight planning accuracy, altimeter, & Global Positioning System (GPS) maintenance/calibration	Situation awareness of terrain vs altitude, navigation accuracy/ redundancy
In-flight breakup	Maintain operating limits	Provide parachute
Unplanned parachute deployment	Parachute system pre-flight	Stay over unpopulated areas
Depart controlled flight (uncontrolled flight)	Employ standard procedures & operating limits	Activation of lost-link protocol or other fail-safe systems.

Inclement weather	Maintain operating limits	Obtain weather forecast and continually monitor. Use wind meter on site for local conditions.

Table 2-3. Hazardous Conditions where Loss of Directed and Controlled Flight is Anticipated

Hazardous Condition	Prevention	Protection
Not enough fuel/lube/battery to return to base (RTB)	Flight planning of resources	Provide alternate landing or ditch sites; employ parachute
Directed glide	Flight contingency planning	Direct glide to alternate landing or ditch sites
In-flight fire	Flight emergency planning	Use safe RTB route to avoid vulnerable areas; use safe landing or ditch site
Reduced controllability	Flight emergency planning; route planning over unpopulated or non-vulnerable areas	Use safe RTB route to avoid vulnerable areas; use safe landing or ditch site
Loss of RF link	Link checks; redundant links; signal strength indication; geo-fence design	Activate geo-fence; employ lost-link routine; monitor signal strength
… results in ditch or forced landing	Identify emergency landing and/or ditch sites	Use alternate landing or ditch site
… results in intentional crash	Identify potential termination sites	Use low-risk termination site

Table 2-4. Hazardous Conditions where Directed Flight is Not Maintained

Hazardous Condition	Prevention	Protection
Undirected powered flight	Redundant RF links; return home software; equip with flight safety system (FSS)	Use redundant RF link; enable return home software; Employ FSS
Undirected glide	Emergency procedures; reserve power for landing; equip with FSS	Clear landing area; deploy reserve power for safe landing; employ FSS

Table 2-5. Hazardous Conditions Related to Airspace Operations

Hazardous Condition	Prevention	Protection
UAV not in assigned airspace	Coordination with ATC; maintain integrity of safeguards assigned in Certificate of Waiver or Authorization (COA)	Notify ATC; monitor common frequency (guard)
Unassigned vehicle in UAV exclusive use airspace	Scheduling of exclusive use airspace; flight planning and routing deconfliction of sUAS; maintain integrity of safeguards assigned in COA	Spot and avoid other aircraft; radio contact with controlling authority; radio contact to offending aircraft
Unexpected loss of exclusive use airspace	Plan for contingencies • (SAR/medevac use) • In-flight emergency	Maintain contact with ATC
Unexpected wake/turbulence along flight path	Use exclusive use airspace	Maintain contact with ATC to ensure safe separation

Considering the sUAS phases of flight, namely ground ops, takeoff, inflight, landing, and airspace control, it is possible to construct strawman tables relating the degraded states to barriers. Table 2-6 through Table 2-10 provide starting points that can be tailored for a specific range.

Table 2-6. Relations between Ground Ops Degraded States and Barriers

Airfield Ground Operation Degraded States vs. Barriers	Collision with Obstacle During Takeoff or Landing	Ground Collision with Obstacle	Ground Collision with Moving Vehicle or Animal	Loss of control - ground	Runway Excursion	Runway Incursion	Stop In Place on Runway or Taxiway
Runway design requirements	●	●					
Runway/taxiway map for operators		●	●				
Clear area on either side of runway	●			●	●		
Standard routes			●				
Fence around runway			●			●	
Arresting barrier options		●		●			
Ground control provides oversight and positive control			●			●	●
Radio control with aircraft & vehicles			●				
Taxi instructions from Ground Control			●				●
UAV Ground ops & takeoff planning & check	●	●					●
UAV emergency procedures documented & briefed	●	●	●	●	●	●	●
Test team video camera observation of ground ops		●	●	●	●	●	●
Vehicle emergency stop procedures		●	●	●	●	●	
Vehicle ground lost-link procedures		●	●	●	●		
UAV ground crew available by radio							●
Contingency runway for other aircraft							●
Alternate airfield for other aircraft							●

Table 2-7. Relations between Takeoff Degraded States and Barriers

Takeoff Degraded States	Abnormal Climbout	Unguided Flight/Erratic Flight Path on Launch	Launcher Damages Vehicle
Clear area on either side of runway	●	●	●
AICUZ clear zone at end of runway	●		
Roadblock options for road at end of runway	●		
Arresting barrier options	●		
Test team video camera observation of ground ops	●	●	
Casualty expectation analysis of departure route	●	●	
wind limits for takeoff (crosswind/tailwind)	●	●	
Vehicle emergency stop capability and procedures	●	●	
UAV emergency procedures documented & briefed	●	●	●
Ditching/parachute options defined for takeoff	●	●	
Pre-launch checklist for vehicle		●	
Pre-launch checklist and visual inspection for launcher		●	●
Launcher heading towards clear area	●	●	●

Table 2-8. Relations between In-flight Degraded States and Barriers

In-flight Degraded States	Continued Controlled Flight Despite Damage	Continued Controlled Flight with Insufficient Resource	Controlled Flight into Terrain	Depart Controlled Flight	Ditch / Forced landing on Non-Runway Surface	Directed Glide	In-Flight Breakup	In-Flight Fire	Intentional crash or FTS termination in Safe Location	Lost-link routine	Transition to parachute recovery (not in recovery area)	Uncontrolled Impact with Terrain	Undirected Flight (fly away)	Undirected Glide
Alternate airfield options	●	●	●											●
Alternate routes for unhealthy vehicle	●		●	●	●	●	●	●	●	●	●	●		
Alternate routes for weather				●			●					●		
Potential ditching/termination sites					●				●		●			
Independent monitoring of ditching/ termination site surface					●				●		●			
Flight planning review			●		●	●			●	●				
Flight planning safety rules		●	●		●	●			●	●	●			
Route minimizes overflight of populated areas	●	●		●	●	●	●	●	●	●	●	●		
vulnerable property identified and avoided	●	●		●	●	●	●	●	●	●	●	●		
Independent TSPI monitoring		●	●		●	●			●	●				
Independent video of vehicle (vehicle health)							●	●						
Independent vehicle TM health monitoring	●	●					●	●		●				
Independent FTS option									●		●		●	●
Geo-fence													●	●
Lost-link route planning			●							●	●			
Lost-link autoland or auto-terminate											●			
Emergency parachute		●		●	●				●		●			
Backup battery preflight check		●												●
Flight planning casualty expectation analysis	●	●		●	●	●	●	●	●	●	●	●		
Flight planning – high-risk test points over low-risk location				●	●	●	●	●	●			●		

Table 2-9. Relations between Landing Degraded States and Barriers

Landing Degraded States	Abnormal Runway Contact	Precautionary Landing at Alternate Site	Pilot-induced Oscillation	Runway Overshoot/undershoot
Clear area on either side of runway	●		●	
AICUZ clear zone at end of runway			●	
Roadblock options for road at end of runway				●
Arresting gear/arresting barrier options				●
Wind limits for landing (crosswind/tailwind)	●		●	●
Waveoff route			●	●
Waveoff decision points defined			●	●
Before landing checklist for vehicle	●			
Independent monitoring of approach parameters (glidescope, etc.)	●		●	●
Test team video camera operation of approach and landing	●		●	●
Casualty expectation analysis of approach route				●
UAV emergency procedures documented and briefed	●	●	●	●
Vehicle emergency stop capability and procedures				●
Ditching options defined for approach	●			●
Alternate landing site contingency plan		●		

Table 2-10. Relations between Airspace Control Degraded States and Barriers

Airspace Operations Degraded States	Not in Assigned Airspace	Loss of Separation Assurance	Near Midair Collision	Collision
Local airspace standard procedures (Air Ops Manual)	●	●	●	●
Airspace routes & boundaries defined	●	●	●	●
Exclusive use airspace		●	●	●
ATC airspace monitoring	●	●	●	●
Independent airspace monitoring by range or test team	●	●	●	●
Vehicle transponder	●	●	●	●
High visibility paint/anticollision lights			●	●
Range/ATC coordination	●	●	●	●
Range or test team brief to ATC	●	●	●	●
AV operator - ATC comm link	●	●	●	●
Backup AV operator - ATC comm link	●	●	●	●
Lost-link planning considers airspace boundaries	●	●	●	●
Undirected flight contingency plans	●	●	●	●

It is also possible to think in terms of sUAS range use scenarios, as shown in the example in Figure 2-2. In this scenario, an sUAS test article is operated within the parameters of a test plan in the sUAS work area. The first part of the scenario safety template characterizes the mission and corresponding assumptions. Next, the safeguards, controls, and barriers with respect to the risks to people & property, risks to airspace, and risks to range mission are listed. Finally, the role of range safety is explicitly spelled out. Appendix C provides additional templates for a variety of sUAS range scenarios. Table 2-6 through Table 2-10 assist with constructing and walking through the use scenarios. Of course, for this purpose, both the scenarios and the tables must be tailored to the specific needs of a given range and situation.

Scenario: Test Article sUAS in sUAS Work Area

Mission

Testing of sUAS addresses a flight-critical issue (envelope expansion, flight critical hardware or software, etc.) within visual range in an sUAS work area

Assumptions

- Test planning identifies potential test hazards; appropriate hazard controls are in place and approved.
- Test team monitors critical parameters for safety to ensure test limits are maintained and safety NOGO thresholds are not exceeded.
- Assume sUAS work area is within line of sight of air vehicle operator (AVO) and observer.
- Assume work area and launch site is within RF line of sight and RF range of sUAS ground station.
- Assume launch and recovery takes place in sUAS work area or adjacent to work area.
- Work area and corresponding airspace scheduled for sUAS testing.
- Qualified test pilots (AVOs) perform testing using documented operating procedures and test procedures.
- AVO verifies safe configuration of sUAS test article, RF links, and safeguards (geo-fence, fly home route, etc)

Risk to people & property

- sUAS work area located in area normally clear of non-participant personnel. (Remote area? Fence?)
- sUAS work area scheduled for sUAS use
- AVO checks sUAS work before launch, visual observer monitors work area continuously
- Test team monitors critical parameters and notifies AVO if remedial action (i.e. RTB etc.) is necessary
- AVO avoids overflight of people & critical property during flight test.

Risk to airspace

- sUAS work area airspace scheduled for sUAS use, ATC monitors continuously
- AVO in contact with ATC, requests airspace before launch
- AVO verifies visually airspace is clear before launch, observer monitors continuously
- AVO gives way to manned aircraft if it unexpectedly enters airspace.

Risk to range mission

Airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users

Range Safety Role

Range safety reviews test plan, ensures test hazards are addressed with appropriate risk controls, and range barriers and test controls are in place.

Figure 2-2. sUAS Safety Scenario Template

CHAPTER 3

Operation and Qualification Requirements

3.1 Preface

This chapter addresses the safe and effective operation of sUAS assets. Many of these sUASs may not have airworthiness certification. The requirements set forth are relevant to systems purchased as commercial off-the-shelf (COTS) or designed and built in-house with COTS or bench-built equipment.

3.2 Logbook

3.2.1 Purpose

Typically, very little data is available in the way of airworthiness or reliability of sUAS assets. While there is no intent to specifically collect this airworthiness information, a logbook may serve as a sufficient means of determining *system maturity*. The logbook is intended to inform the operator and test team of system history and any issues with previous flights.

3.2.2 Requirement

Each sUAS user shall maintain the sUAS logbook while operating within this guidance.

a. The logbook shall contain sufficient detail to ensure safety risks/issues are documented and made fully aware to the operator and test team. This includes any anomalies that occur during flight and any configuration changes made to address the anomaly.

b. The logbook shall contain documentation of current and previous configurations (hardware and software), as well as flight hours, functional checks, maintenance information (major and minor), why changes were made, and any additional information dictated in subsequent sections of this guidance.

c. The Range Safety Office shall periodically review the logbook, as necessary, to ensure compliance and safety.

3.3 System Documentation

Users are required to provide documentation similar to the Micro/Small UAS Survey of New Programs questionnaire (Appendix A) as part of the range's program identification process. This requirement is in place because most sUASs operating on test ranges are not designed to competency-established airworthiness standards and/or there is insufficient data to verify compliance to standards. The office responsible for managing program approvals is also responsible for ensuring users provide this system documentation.

3.4 Test and Safety Documentation

3.4.1 Purpose

Use of any Major Range and Test Facility Base for test will usually require following existing regulations for test conduct, to include safety planning. Users should consult the respective range for the proper documentation required but should include the following at a minimum.

3.4.2 Requirement

The flight manuals (or compilation of appropriate references) shall define nominal and emergency test procedures.

3.4.3 Requirement

Per local test safety review processes, the responsible test organization (such as the sUAS dedicated government test team) shall review the documentation, identify test hazards, and establish both procedures and corrective actions to eliminate or control the hazards. The test team shall also propose an overall risk level and communicate any residual risk to Range Safety for independent review and approval by appropriate authority. If a responsible test organization is not designated, then Range Safety shall review the documents and conduct the safety hazard analysis directly.

3.5 Aircrew Qualifications

3.5.1 Purpose

The protection of people, property, and the environment is the primary concern as described in the sUAS strategy (Section 1.5). Enforcing a minimum level of aircrew qualifications mitigates hazardous sUAS operations and helps to ensure the safety of test participants, general population (non-participants), and high-value assets.

3.5.2 Requirement

Aircrew qualifications shall be presented to and accepted by the range's local airspace management or operations authority, per local process prior to flight. For the purposes of a common framework and terminology, Table 3-1 provides minimum qualifications for the respective roles of sUAS operations. Additional information regarding qualifications and historical information on operators or members of the flight crew shall be provided upon request of the Range Safety Office.

Table 3-1. Minimum Aircrew Qualifications

Qualification Levels	Roles and Responsibilities	Requirements
Operator Under Training	Candidates that will be trained to become a qualified operator.	Be under the direct supervision of a qualified instructor.
Qualified Operator[1,2]	Responsible for flight operations of the air vehicle	1. Knowledge of the air vehicle performance and limitations. 2. Familiar with the air vehicle publications 3. Knowledge of the emergency procedures 4. Knowledge of aviation principles 5. Knowledge of all navigation and guidance modes as it relates to operating of the air vehicle 6. Knowledge of pre-mission planning 7. Knowledge of local operating area.

Project Pilot[1,2]	1. Able to train/mentor new operators and operate air vehicles. 2. Gather weather, tactical, and other information required for mission brief and completion. 3. Perform mission brief and debrief 4. Gather discrepancies and ensure these are addressed or repaired	1. Demonstrate a high level of understanding of sUAS operations and site safety. 2. Demonstrate the ability to efficiently train/mentor new operators.
MC	1. Assume full responsibility of site operations. 2. Does not need to be a qualified operator. 3. Responsible for crew safety and tasking 4. Properly dispose of or secure classified information. 5. Notify team of personnel, equipment, safety, and other issues requiring attention for effective mission completion.	1. During his/her assigned missions, the MC is responsible for the overall safe and professional completion of missions IAW applicable policies, procedures, and priorities. 2. Familiar with the operation and function of air vehicles and payload.
Payload/Subsystem Operator[2]	1. Responsible for payload, sensor, etc. operations. 2. Does not need to be a qualified operator.	1. Knowledge of the payload and/or subsystem under their control. 2. Knowledge of nominal and emergency procedures. 3. Knowledge of air vehicle performance, flight environment, and limitations as it relates to operating the payload/subsystem. 4. Communication with flight team on payload status and operation.
Observer	Assist the operator to see and avoid other air traffic, objects aloft, or ground	1. Competency on radios and radio etiquette. 2. Ability to visually follow air vehicle unassisted and assisted (i.e., binoculars).
[1] FAA Part 107 Remote Pilot certification can cover most, if not all, of these requirements. [2] Medical requirements will be determined by the local range policy		

3.6 Mission/Non-Mission-Essential Personnel

3.6.1 Purpose

As a result of sUAS flight operations in the area, an increased risk to individuals and assets is expected. Two practical ways to mitigate that risk and ensure an adequate level of safety is demonstrated for protection of those individuals and assets, are by having the appropriate quantity of flight operation personnel present and keeping non-essential personnel (i.e. general public) clear of the area.

3.6.2 Requirement

For any flight, there shall be a minimum crew of two personnel, one of which will be the designated operator and the other serving as an observer. Additional crewmembers may be required to support the operator with functions involving spotting, payload operation, air vehicle position monitoring, airspace containment, etc. There may be additional project personnel and observers present if deemed mission-essential by the project manager.

3.6.3 Requirement

Non-mission-essential personnel in the operating area must be approved by the Range Safety Office.

a. The number of personnel will be kept to a minimum in the interest of personnel safety.
b. The onsite project lead will designate an area for non-mission-essential observers that is clear of aircraft operations.
c. The onsite project lead will minimize interference and distractions during sUAS operations/testing.

3.7 Personnel Communications Plan

3.7.1 Purpose

Positive communication between the flight operation personnel and the range or airspace management is critical to ensure a dedicated operating area, alert the team to changes, and improve mission effectiveness for the range.

3.7.2 Requirement

The project lead shall ensure that adequate communications are available (range radio, satellite phone, text, etc.), based on range and airspace requirements, to ensure team members can be contacted by range or airspace management personnel during operations. Prior to flight operations, the project lead is to advise the range control officer (RCO) prior to and upon completion of any event.

3.8 Frequency Approval

3.8.1 Purpose

Frequency approval reduces the risk of unintended effects and/or uncommanded behavior on the sUAS and therefore reduces risk to personnel and assets in the vicinity.

3.8.2 Requirement

Frequency approval for all RF emissions associated with air vehicle operations shall be obtained from Frequency Management via the assigned RCO prior to flight operations. If sUASs operate under FCC Title 47 part 15, this may not necessitate the range's Frequency Management. The Range Safety Office shall inform the risk of using potentially unlicensed frequencies and the interference that may result. The user shall accept this risk. (Note that RF coordination can require long lead time and the corresponding forward planning.)

3.8.3 Requirement

The MC shall ensure all RF emissions are within the frequencies approved during planned operations. Any deviations (intentional or inadvertent) are to be reported to the assigned RCO and Frequency Management authority immediately.

3.9 Schedule Deconfliction

3.9.1 Purpose

Scheduling operations IAW local range policy allows for an operation area within the SUA and considers deconfliction with other range assets. This reduces risk to personnel and assets in the vicinity.

3.9.2 Requirement

The responsible authority for the mission or the MC will coordinate with the assigned RCO to ensure the appropriate information is made available for schedule deconfliction.

3.9.3 Requirement

Primary responsibilities of scheduling and range deconfliction fall with the assigned RCO, or local procedures if delineated.

a. The RCO will coordinate airspace deconfliction via the airspace manager (ASM); any associated Notice to Airmen/Notice to Mariners deemed appropriate by the ASM will be coordinated through the local range scheduling enterprise.

b. The RCO will notify the Range Safety Office of the operation.

3.10 No-Go/Hold Criteria

3.10.1 Purpose

The sUASs addressed in this guidance include systems with potentially minimal flight and operations data and as such the following No-Go/Hold criteria are recommended to provide basic safety measures and reasonable limitations based on practice and lessons learned. These criteria serve to increase mission safety.

3.10.2 Requirement

The team will work with the Range Safety Office to develop No-Go/Hold criteria to include non-participants, weather, visibility, air vehicle, etc. Table 3-2 provides best practice No-Go/Hold criteria for sUASs.

Table 3-2. Recommended No-Go/Hold Criteria

Parameter	Criteria
Non Participants	Non participant conflicting with flight operations

Weather	a. Visible moisture b. Outside air temperature not within safe battery operating temperature limits c. Wind > 10 knots or as defined in the test/safety plan d. Ceiling < 500 feet above desired operating altitude
Visibility*	a. Day < 1 statute mile clear of clouds b. Night < 3 statute mile clear of clouds
Air Vehicle	a. Air vehicle or control station inoperable b. Lost link does not initiate failsafe
*The sUAS should remain within VLOS of the pilot or visual observer who has direct communication with the pilot at all times until the range safety office deems it appropriate to go beyond VLOS (BVLOS). All BVLOS operations will be approved by the range safety office. See Section 3.17 for additional considerations.	

3.11 Safety of Flight

3.11.1 Purpose

Safety of Flight (SOF) checks provide assurance of the SOF features available. Additionally, they validate functionality and air vehicle flight commit criteria (i.e., go/no-go criteria). Once each air vehicle has passed a SOF checkout it will be considered “valid”.

3.11.2 Requirement

Each sUAS will complete a SOF check.

a. The SOF checks performed will be based on original equipment manufacturing (OEM) recommendations and any Range Safety Office requirements. A subset of the sUAS functions and operations that should be verified, based on applicability, include:

- Functional Control Checks (all modes)
    - Autopilot functionality
    - Overall command and control (C2) functionality
- Failsafe Modes
    - Lost Link
    - Range limiting capability such as (geo-fencing, RF range limiting, fly-home function, etc.)
- FSS

b. Completion of SOF checks shall be noted in the air vehicle’s logbook if there is modification or replacement of any item considered to be critical to the SOF. A subsequent SOF check will be required and will follow the process as noted above. A general list of items considered to be major or critical is provided below.

- Structural airframe/part
- Motor/engine
- Any item involved with navigation or flight path control
- All communication/control links with the vehicle
- All control station hardware components necessary for C2

- FSS

3.12 Range Restrictions

3.12.1 Purpose

The Range Safety Office may need to apply additional restrictions on a user to ensure containment or to minimize the risk to personnel and property during sUAS operation.

3.12.2 Requirement

The vehicle operator shall implement range limiting features and lost-link protocols to provide a high level of confidence of maintaining the aircraft in the designated airspace. Range limiting features include geofencing, RF limiting, or forcing the aircraft into flying the lost-link profile if the operator cannot contain the vehicle within the designated operational area by exercising normal vehicle flight control.

a. The geofence shall be chosen to balance operational need against protection of public and property in order to contain the sUAS to the designated airspace.

b. Limiting RF range/power may be a feature of the system that prevents it from flying beyond a certain distance from the controller or operating the controller in a low-power mode, depending on the system being flown.

c. Loss-of-link flightpath shall be approved by the Range Safety Office prior to flight.

d. The loss-of-link timer shall be set to allow time to re-establish the link while the unmanned aircraft continues with its planned mission. Upon expiration of the timer, the aircraft will execute the pre-programmed lost-link procedures. The length of timer is at the discretion of the range but must take into account aircraft flight path at any point during the operation and ensure that no range boundaries will be violated before the timer expires and the lost-link maneuver begins.

e. Loss-of-link flightpath shall be chosen so that the vehicle remains within the designated airspace but also avoids protected buildings, structures, roads, and/or populated areas.

f. Loss-of-link altitude shall be managed to preclude impact with any vertical obstacles as it performs the lost-link maneuver.

g. Loss-of-link flightpaths shall be selected to afford an opportunity for the sUAS to autonomously land, if able.

h. If a terminal holding point is part of the lost-link maneuver, it shall be chosen such that any subsequent ditching occurs in an area designated to minimize risk (e.g., loss of power while in holding or auto-terminate after a set period of time).

i. For sUASs with extended-duration capability and no autoland capability, consideration will be made for the need of an auto-terminate after a set amount of time to avoid extended operation without command link and potentially causing an airspace issue.

3.13 Operations Area Considerations

3.13.1 Purpose

The vulnerability of property is a factor in determining when and where to conduct sUAS operations. With the understanding that some high-value properties are located in otherwise unpopulated areas, proper planning for sUAS operations gives appropriate consideration to these locations. Other aspects of operation area considerations include range assets, high-value areas that may be flown over, and environmental or culturally sensitive sites.

3.13.2 Requirement

The sUAS shall be flown within SUA, or other approved NAS areas, at a location designated for sUAS flying and approved by all pertinent range, airfield management, and airspace authorities.

a. The sUAS flight routes should be planned to avoid overflight of any high-value locations.
b. The area should be free of non-participants and valuable/vulnerable infrastructure.
c. The user should only operate from the pre-determined sites and fly within the airspace designated.
d. The project lead will coordinate all operations through the assigned RCO.

3.14 Flight Management

3.14.1 Purpose

Planned use of specific flight modes (e.g., commanded or autopilot), flight routes, and altitudes are a pertinent aspect of consideration when enforcing safety. It is always crucial to consider personnel safety and range containment. Mitigations exist for certain GPS-equipped sUASs that can, if proven/demonstrated, assist in containment and provide an additional level of safety.

3.14.2 Requirement

The project lead shall coordinate with the assigned RCO to ensure flight planning information (including intended routes, altitudes, etc.) is provided to all support personnel.

3.14.3 Requirement

Air vehicles with GPS/autopilot capability should be operated with a verified pre-programmed failsafe. The failsafe programming can vary; however, the primary range containment feature will be the failsafe automatically activating upon loss of link, either by anomaly or operator initiation, and directing the air vehicle to a designated location. Deviations from the primary containment feature will be subject to approval by the Range Safety Office. Examples that could trigger a failsafe include but are not limited to loss of link, loss of GPS, and loss of primary electrical power.

3.14.4 Requirement

Air vehicles will only operate in flight modes previously verified during SOF.

3.15 General sUAS Safety Precautions

3.15.1 Purpose

Based on experience and lessons learned to date, there exist several general sUAS safety precautions that if properly followed can be quite advantageous to mission success and, more critically, reduce risk to personnel and assets on and off range.

3.15.2 Requirement

The sUAS shall:

a. Not be flown for the first time without conducting a successful radio equipment ground range check as per the manufacturer's recommendation and SOF ground test;

b. Not be flown after major repairs or modifications (Section 3.11) without conducting a SOF check;

c. Not be intentionally flown directly over unprotected/non-mission essential personnel or vehicles unless approved by the Range Safety Office, pre-briefed, and necessary for completion of the event;

d. Not be flown closer than 25 feet to any person other than the user or crewmember active in the operation;

e. Not be touched by any person while in flight except to divert the air vehicle from striking an individual;

f. Not be flown by unqualified personnel (see Table 3-1);

g. Always yield right of way to all manned aircraft;

h. Not be flown with flight stabilization and autopilot systems (onboard flight controllers) unless the operator has the ability to immediately deactivate such systems and return to complete manual control of the air vehicle at any time. If manual control is not a capability, additional flight containment restrictions may be enforced.

i. Not intentionally fly outside the designated airspace or higher than the maximum altitude defined in the event plan prescribed by the ASM. If an inadvertent violation occurs, the project lead will inform the Range Safety Office.

3.16 Night Operations

3.16.1 Purpose

Night operations present additional complexities and hazards due to reduced situational awareness but can in most cases be accomplished by incorporating corresponding risk mitigations. The following requirements in conjunction with any local range safety office requirements improve situational awareness and reduce risk to personnel and property during sUAS night operations.

3.16.2 Requirement

Night Operations

a. Air vehicles flown at night shall have sufficient means to determine vehicle orientation (e.g., lights, distinct infrared profile, etc.).

b. The site will be assessed for lighting needs. The site may require additional controls and safety precautions.

c. Launch and recovery areas must have appropriate lighting or other means to support launch and recovery operations.

3.17 Line of Sight and Beyond Line of Sight Operations

3.17.1 Purpose

Aircraft operating BVLOS and/or beyond RLOS (BRLOS) increase risks associated with mid-air collision as well as collision with ground personnel or structures. This is due to the lack of situational awareness that the operator would typically expect as compared to operating within direct line of sight of the vehicle.

3.17.2 Requirement: VLOS:

The sUAS will be kept within VLOS of the pilot, or a designated visual observer who has direct contact with the pilot, until system maturity and additional resources are sufficient to permit BVLOS operations, per Range Safety Office concurrence. First Person View (FPV) technology cannot be used to satisfy the VLOS requirement, though it may be used to help supplement vehicle situational awareness. While FPV technologies continue to improve, limitations such as the camera field of view, image clarity, range of transmitted video, frequency interference, transmission delay, etc., result in inadequate see-and-avoid capabilities. As a result, having a visual observer with see-and-avoid responsibilities is still preferential. If a safety pilot is utilized, they must have VLOS to the vehicle at the time they assume control and must continue to maintain VLOS.

For the customers seeking Range Safety Office concurrence for BVLOS operations, one must consider C2 signal strength, the range of the RLOS, monitoring systems that provide the operator enhanced vehicle situational awareness, see-and-avoid capabilities, and return-to-start features. Additional considerations should be paid to mitigating increased see-and-avoid risks inherent with the use of sUASs in BVLOS operations.

3.17.3 Requirement: RLOS:

All sUAVs will be kept within RLOS of the control station during all flight operations, unless otherwise approved by the Range Safety Office. The RLOS shall be approved by the Range Safety Office and can be achieved using any device or combination of devices (e.g., ground-based repeater networks, satellite uplink) that ensure the operator is able to maintain or regain control of the sUAS with a demonstrated reliability that meets or exceeds the capabilities of line of sight (LOS) C2 systems that are commonly employed for an equivalent VLOS mission (e.g., COTS radio systems). Factors to consider when assessing the reliability of a non-traditional RLOS system include bandwidth vulnerability, signal encryption, link margin, repeater reliability, system redundancy, and performance when used for similar yet not identical applications.

For the customers seeking Range Safety Office approval for BRLOS operations, one must consider reliability of containment measures such as flight time longevity, maximum range, geofence, return-to-start features, and autonomous collision avoidance capabilities. Additionally, the probability of impacts to public persons, vulnerable structures, or protected property should be considered. If the primary BRLOS method is utilizing a GPS-reliant system, operators should verify satellite coverage during the proposed operational time frame and be aware of any satellites that are predicted to become unavailable during the flight (e.g., GPS jamming).

3.18 Pre-Flight Briefing

3.18.1 Purpose

A pre-flight briefing IAW local range policy promotes safe, effective mission. This reduces risk to personnel and assets in the vicinity.

3.18.2 Requirement

The user shall hold a pre-flight briefing with all crewmembers and support personnel. Pre-flight briefings shall address the following topics as applicable to the operation.

1. Mission objectives
2. Intended mode of flight (i.e. FPV, LOS, etc.)
3. Limitations and restrictions
4. Airspace constraints
5. Concurrent operations that may interfere, impact, or constrain the mission
6. High risk/high workload points
7. Possible project-related emergency procedures
8. Special precautions, personal protection equipment, safety equipment
9. Personnel requirements, roles, and responsibilities
10. Review of applicable hazards
11. Review of go/no-go criteria
12. Aircraft, payload(s), and control station configuration
13. Current and/or forecast weather conditions
14. Take-off and landing plan
15. Containment procedures/methods (i.e., lost-link procedures, failsafe modes, etc.)
16. Medical emergencies/pre-existing medical conditions
17. Mission loaded into flight controller for waypoint locations/mapping
18. Mishap plan and assignment of responsibilities

3.19 Pre-Flight Checklist

3.19.1 Purpose

Pre-flight checks validate functionality of safety-critical systems prior to flight.

3.19.2 Requirement

Pre-flight checks will be performed by qualified operators for every flight IAW the customer's pre-flight checklist that is approved by the range. This serves to help validate safety-critical systems. A general suggestion for a pre-flight checklist is provided in Appendix B.

3.20 Post-Flight Checklist

3.20.1 Purpose

Completing a post-flight checklist confirms the status of the sUAS, safes the systems, and identifies any defects/issues experienced during the flight.

3.20.2 Requirement

After landing, the user or designated team member shall conduct the range-approved post-flight checklist. A general suggestion for tasks is provided in Appendix B.

3.21 Post-Flight Briefing

3.21.1 Purpose

A post-flight briefing IAW local range policy promotes identifying lessons learned and improved test execution. Identifying how to improve the mission may reduce risk to personnel and assets in the vicinity.

3.21.2 Requirement

The user shall hold a post-flight briefing with all crewmembers and support personnel. Post-flight briefings shall address the following topics.

1. Mission objectives status

2. Any unexpected results
3. Any safety implications
4. Accuracy of planning
5. Air vehicle status
6. Maintenance status
7. Lessons learned and ways to improve the next operation

3.22 Air Vehicle Monitoring

3.22.1 Purpose

Real-time air vehicle monitoring IAW local range policy ensures SOF and may reduce risk to personnel and assets in the vicinity.

3.22.2 Requirement

Air vehicle operations shall be monitored when operating in automatic flight modes with a control station when available. Flights incapable of control station monitoring functionality will result in flights limited to LOS operations that are adequate to inform the operator of the vehicle's attitude and orientation.

3.23 Mishap Plan

3.23.1 Purpose

For the purposes of this document, a mishap is an unplanned event or series of events resulting in death, injury, occupational illness, or damage to or loss of equipment or property. Consequently, any incident in which aircraft control or containment was lost or in which personnel or property were endangered is considered a mishap. A mishap plan is a documented response plan to minimize further negative effects of hazards associated with the mishap.

3.23.2 Requirement

A mishap plan should be developed for each program respective to the range being utilized prior to commencing operations. It should be developed by the test team, receive concurrence of the Range Safety Office, and detail investigative roles and responsibilities. In the event of a mishap the plan should take precedence and the procedures from the plan should be followed until it has been determined by all parties (e.g., customer, Range Safety, Program Manager) that it is safe to return to normal operations.

3.24 Reportable Event

3.24.1 Purpose

Mishap reporting serves as a critical feedback tool to understanding the system's limitations, reassessing previous hazards for any discrepancies, and adding or optimizing risk mitigations to increase the level of safety.

3.24.2 Requirement

The owner should provide all prior relevant information to the Range Safety Office using the sUAS Survey (a general example is provided in Appendix A) or similar documentation.

a. Any mishaps or unusual events relating to the containment of vehicle during operations will be reported to the Range Safety Office prior to continuing operations. The event will be reviewed by that office before the user is allowed to return to operations. The event will be logged in the vehicle's logbook.

b. All landings outside the approved recovery areas shall be reported to the Range Safety Office, documented in the logbook, and reported as a mishap.

c. Any collisions with other aircraft shall be reported to the Range Safety Office and documented as a mishap.

d. Any collision with any moving or fixed object is to be reported to the Range Safety Office and documented as a mishap.

e. The Range Safety Office shall be informed of any vehicle that fails to properly execute a loss-of-link routine.

f. Any flight outside the approved operation area shall be reported to the Range Safety Office.

g. Any other information required by the Range Safety Office shall be provided by the user.

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APPENDIX A

Micro/Small UAS Survey for New Programs

- Top level vehicle description (include a picture)
    - Name/ID Number
    - Dimensions
    - Construction materials
    - Empty/Gross Weight
    - Propulsion
    - Glide ratio and speed
    - Fuel type/amount
    - Battery types/quantities
    - RF requirements
    - Payload/explosives/high energy (laser, radar, etc.)
    - Hazardous materials/equipment (cryogens, pressure vessels, chemicals, etc.…)
    - Launch/Recovery methodology
    - Vehicle limitations (airspeed, altitude, wind limits, stall speed, etc.…)
- C2 system
    - Vehicle control capabilities: automated, remotely piloted, autonomous, etc.
    - How many C2 links do you have? What are they?
    - List any required ground control/sensor systems
    - What navigation redundancies do you have?
    - Discuss loss-of-position and/or navigation data procedures
    - Discuss lost-link procedures
- Containment and residual risk methods
    - What are the containment procedures for this vehicle/test? (will need to see some method of verification of containment method)
    - Does the system have an independent flight termination system (FTS)?
    - If no FTS, what other containment methods or contingency management systems do you have? Examples include:
        - Deadman switch
        - Geofence
        - Return home logic
        - Motor/engine cut-off
        - Auto-terminate
    - What happens in a loss of propulsion event?
        - What is your battery backup timeframe if loss of propulsion occurs, if applicable?
        - What is the autopilot response?
- sUAS history/maturity
    - Describe system maturity to include the following information as applicable: documented or estimated flight hours, engine failures, crashes/collisions, mishaps, near-misses
    - List any prior FAA/DoD/other entity certifications or flight clearances and any associated limitations required by the certification authority.

    - Frequency management demonstration and electromagnetic interference/ electromagnetic compatibility testing if applicable
- Describe UAV operator history/maturity
- Planned events/test description
    - Type of test requested (first flight, auto-land mode, proof of concept, autonomous flight demo, etc.)
    - How many vehicles in flight simultaneously?
    - Flight duration estimates (time and range)
    - If going beyond LOS or several vehicles airborne simultaneously, are there any tracking sources available for vehicle (i.e., FAA radar, beacon, visual observer)?
    - Are there any unique ground sensors or systems required to use in addition to the pilot station?
    - Airspace and range needed for test/operations (altitude, geographical area, etc.)

APPENDIX B

General Pre/Post Mission Checklist

B.1 Pre-Flight Checklist

Environmental

- Notify airspace authority of your intentions and obtain clearance via predetermined/pre-planned communication methods.
- Clear people, animals, and obstructions in flight vicinity as required.
- Notify all mission-essential personnel of your intentions.
- Set up the operational site IAW safety guidance.
- Verify a First Aid kit on hand, stocked, readily accessible, and visible to anyone in the area.
- Ensure a charged class A, B, and C fire extinguisher is present and visible.
- Conduct pre-flight briefing with support personnel.

Hardware/Equipment

Visually Inspect The Air Vehicle

- Inspect launch and recovery systems for damage and verify operational readiness.
- Inspect for cracks (especially in high stress areas like joints).
- Inspect for loose or damaged screws/fasteners/bands/straps/ties.
- Inspect for loose or damaged wiring.
- Inspect for loose or damaged connections (solder, plugs, etc.).
- Inspect prop mounts and screws.
- For FPV, inspect/clean FPV and/or capture camera lens and ensure that cameras are secured.
- Ensure the vehicle battery/batteries are fully charged, properly seated & secured, and undamaged.
- Ensure control station, including transmitter, batteries are fully charged, properly installed, and undamaged.
- Test failsafe behavior (if applicable).
- Verify that props are smooth and free of damage/defect (check blade, surface, & hub).
- Tighten prop adapters IAW OEM recommendations.
- Ensure voltage alarm is connected (if applicable).
- Ensure arming/idle timeout is properly configured (6 - 15 seconds) (if applicable).
- Check the transmitter to ensure proper mode is selected.
- Check the transmitter to ensure range and centering for all sticks is good.
- Check the transmitter/receiver frequencies to ensure operating within approved/scheduled frequencies.
- Check consumables (e.g. fuel, lubricants, coolants, etc.).

B.2 Pre-Flight Run-Up

Power Up

- Verify batteries (vehicle and transmitter) are charged, secured, and operating.
- Position airframe in a level, safe location for takeoff.
- Power up ground station, video receiver, goggles, etc. as appropriate.
- If using on-board video capture camera, turn on camera.
- Verify all transmitter controls move freely in all directions.
- Set all transmitter trims in neutral position.
- Verify all transmitter switches in correct position (away).
- Set the transmitter throttle at zero.
- Verify the radio transmitter is on.
- Check flight and engine control for freedom of movement and synchronization with transmitter.
- Obtain final flight clearance from range control.
- Perform communications check with all relevant mission-essential personnel.
- Connect power on battery to airframe.
- Ensure light-emitting diode indicators and audible tones are all correct (as applicable).
- Calibrate air vehicle compass per OEM instructions.
- Turn on the timer (if applicable).
- For FPV, check video.
- Scan for nearby people or animals.
- Perform weather and wind limits check.
- Arm flight controller (if applicable).
- Stand clear - audibly, loudly announce the word "CLEAR!".
- Set throttle slightly above idle, and turn off transmitter - verify failsafe mode functionality.

B.3 Post-Flight Checklist

- Ensure throttle is set to "zero".
- Disarm flight controller (if applicable).
- Ensure flight controller is in manual mode (if applicable).
- Disconnect battery (if electric power).
- Kill engine (if internal combustion).
- Turn off capture cameras.
- Safe/inert payload and support equipment (if applicable).
- Ensure fire extinguisher is present.
- Remove lithium polymer batteries (if applicable).
- Place lithium polymer batteries in fire-safe container.
- Defuel aircraft (if applicable).
- Report any mishaps to range safety office.
- Record significant flight events in the logbook.
- Conduct post-flight briefing.

APPENDIX C

sUAS Safety Scenarios

SCENARIO 1: Operational Vehicle Proficiency Training in sUAS Work Area

- Assume work area is within line of sight of AVO and observer.
- Assume work area and launch site are within RF line of sight and RF range of sUAS ground station.
- Assume launch and recovery takes place in work area or adjacent to work area.
- Schedule work area and corresponding airspace sUAS proficiency training.
- Qualified pilots (AVOs) perform proficiency training using documented operating procedures.
- The AVO verifies safe configuration of vehicle, RF links, and safeguards (geofence, fly home route, etc)

<u>Risk to people & property</u>:

- Choose a work area located in an area normally clear of non-participant personnel. (Remote area? Fence?)
- Schedule the work area for sUAS use.
- The AVO checks before launch and the observer monitors continuously.
- The AVO avoids overflight of people & critical property during flight.

<u>Risk to airspace</u>:

- Schedule a work area airspace for sUAS use; it is expected that ATC typically monitors this area continuously.
- The AVO, who is in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, and the observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

<u>Risk to range mission</u>:

- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.

<u>Range Safety Role</u>:

- There is no action for range safety for operational vehicle using standard operating procedures and established local airspace and range procedures

SCENARIO 2: Operational Vehicle Proficiency Training in sUAS Remote Work Area

The vehicle launches from launch area and uses transit corridor to go to sUAS remote work area, then returns via the same transit corridor.

- If sUAS remote work area is not within sight of the AVO and observer, a handoff to a remote visual observer in contact with AVO is necessary to maintain situation awareness.
- If sUAS remote work area is beyond sUAS control link RF range or RF horizon, then control handoff to another AVO at the remote work area must be pre-coordinated. Both AVOs must be in contact with each other and ATC.
- Schedule launch and recovery site, transit corridor, and sUAS remote area and corresponding airspace for sUAS proficiency training.
- Obtain "acceptable risk" and "necessary risk" approval for transit corridor.
- Qualified pilots (AVOs) perform proficiency training using documented operating procedures.
- The AVO verifies safe configuration of vehicle, RF links, and safeguards (geofence, fly home route, etc.).

<u>Risk to people & property</u>:

- Choose an sUAS remote work area located in an area normally clear of non-participant personnel.
- The AVO verifies a healthy vehicle before entering transit corridor.
- The AVO checks launch area before launch and the observer monitors continuously.
- The AVO avoids unnecessary overflight of people & critical property during flight by planning.

<u>Risk to airspace</u>:

- Schedule the transit route and remote work area airspace for sUAS use; it is expected that ATC monitors this area continuously.
- The AVO, in contact with ATC, requests transit route and remote work area airspace before launch.
- The AVO verifies visually airspace is clear before launch and the observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

<u>Risk to range mission</u>:

- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.

<u>Range Safety Role</u>:

- There is no action for range safety for operational vehicle using standard operating procedures and established local airspace and range procedures

SCENARIO 3: Test Article sUAS in sUAS Work Area
Testing of sUAS addresses a flight-critical issue (envelope expansion, flight-critical hardware or software, etc.) within visual range in an sUAS work area.

- Test planning identifies potential test hazards; appropriate hazard controls are in place and approved.
- Test team monitors critical parameters for safety to ensure test limits are maintained and safety NOGO thresholds are not exceeded.
- Assume sUAS work area is within line of sight of AVO and observer.
- Assume work area and launch site are within RF line of sight and RF range of sUAS ground station.
- Assume launch and recovery take place in sUAS work area or adjacent to work area.
- Schedule the work area and corresponding airspace for sUAS testing.
- Qualified test pilots (AVOs) perform testing using documented operating procedures and test procedures.
- The AVO verifies safe configuration of sUAS test article, RF links, and safeguards (geo-fence, fly home route, etc.).

Risk to people & property:

- Choose an sUAS work area located in area normally clear of non-participant personnel. (Remote area? Fence?)
- Schedule an sUAS work area for sUAS use.
- The AVO checks sUAS work before launch, visual observer monitors work area continuously.
- The test team monitors critical parameters and notifies AVO if remedial action (i.e., RTB etc.) is necessary.
- The AVO avoids overflight of people & critical property during flight test.

Risk to airspace:

- Schedule an sUAS work area airspace scheduled for sUAS use; it is expected that ATC monitors this area continuously
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch and the observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

Risk to range mission:

- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.

Range Safety Role:

- Range Safety reviews test plan, ensures test hazards are addressed with appropriate risk controls, and confirms range barriers and test controls are in place.

SCENARIO 4: sUAS as Target in sUAS Work Area

An sUAS is used in a cleared area as a target for weapons test or counter-UAS testing.

- Assume remote work area is within line of sight of AVO and observer.
- Assume remote work area and launch site are within RF line of sight and RF range of sUAS ground station.
- Assume launch and recovery take place in work area or adjacent to work area.
- Schedule work area and corresponding airspace for sUAS target operation.
- Define a Hazard area to contain sUAS debris within the work area.
- Qualified pilots (AVOs) perform target presentation using documented operating procedures and test event script.
- The AVO verifies safe configuration of vehicle, RF links, and safeguards (geofence, fly home route, etc.).

Risk to people & property:

Safety requirement: Hazard areas where the target vehicle might crash must be clear of vulnerable people or property.

- Choose a work area that is located in an area normally clear of non-participant personnel.
- Schedule the work area for sUAS use.
- Verify the target debris hazard area within sUAS work area is clear.
- The AVO checks before launch, and the observer monitors continuously.
- The AVO avoids overflight of people & critical property during flight.
- Establish ditch area for damaged or otherwise unhealthy vehicle.

Risk to airspace:

- Schedule the work area airspace for sUAS use; it is expected that ATC typically monitors this area continuously.
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, and the observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

Risk to range mission:

- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.

Range Safety Role:

- Verify airworthiness of vehicle prior to RTB.
- Range safety verifies hazard area and hazard airspace contain sUAS, sUAS target debris, and weapon projectile or energy.
- Range safety verifies range is clear.

SCENARIO 5: sUAS Provides Laser Designator in sUAS Remote Work Area

A laser designator-equipped sUAS performs designating testing or training in a certified laser range.

- Ensure that the sUAS work area is a certified laser range.
- Assume remote work area is within line of sight of AVO and observer.
- Assume remote work area and launch site are within RF line of sight and RF range of sUAS ground station.
- Assume launch and recovery take place in work area or adjacent to work area.
- Schedule a work area and corresponding airspace for sUAS target operation.
- The laser hazard area within work area is defined.
- Qualified pilots (AVOs) perform lasing operation using documented operating procedures and test plan or training brief.
- The AVO verifies safe configuration of vehicle, RF links, and safeguards (geofence, fly home route, etc.).
- Laser is approved for use by the Laser Systems Safety Working Group and appropriate certification authority and have a current Laser Safety Review Board letter.
- The laser system is boresighted before flight.

<u>Risk to people & property</u>:

- Safety requirement: Laser hazard areas must be clear of vulnerable people. Test participants in or near laser hazard area must have appropriate personal protective equipment.
- Schedule the work area for sUAS use.
- Verify the target debris hazard area within sUAS work area is clear.
- The AVO checks area before launch, and an observer monitors continuously.
- The AVO avoids overflight of people & critical property during flight.

<u>Risk to airspace</u>:

- Schedule the sUAS work area airspace for sUAS use; it is expected that ATC monitors this area continuously.
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, and an observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

<u>Risk to range mission</u>:

- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.

<u>Range Safety Role</u>:

- Range safety verifies laser hazard area and hazard airspace are defined by appropriate laser safety authority.
- Range safety verifies laser hazard area is clear.
- Range safety verifies laser safety personal protective equipment is adequate and used.

SCENARIO 6: sUAS Operations in a Confined Work Area
An sUAS is confined within a physical structure.

- Assume sUAS cannot physically escape confined area (e.g., a closed hangar or room).
- Assume work area is within line of sight of AVO and observer.
- Assume work area and launch site are within RF line of sight and RF range of sUAS ground station.
- Assume launch and recovery take place in work area.
- Verify the hazard area to contain sUAS debris within work area is defined.
- The AVO verifies safe configuration of vehicle, RF links, and safeguards (e.g., bladeguards).

<u>Risk to people & property</u>:
Safety requirement: Hazard areas where the vehicle might crash must be clear of vulnerable people or property.
- Chose a work area that is clear of non-participating vehicles, equipment, or structures susceptible to damage (e.g. hangared aircraft, windows).
- Work area clear of non-participant personnel.
- Work area scheduled for sUAS use.
- Debris hazard area within sUAS work area verified clear.
- The AVO checks before launch, and a observer monitors continuously.
- The AVO avoids overflight of people & critical property during flight.

<u>Risk to airspace</u>:
- None.

<u>Risk to range mission</u>:
- None.

<u>Range Safety Role</u>:
- Range safety coordinates with facility manager for confined space use.
- Range safety assesses vulnerable articles/structures/personnel within work area.
- Range safety verifies confined area is clear and restrictions in place.

SCENARIO 7: sUAS Swarm Operations
Simultaneous Operations of Multiple sUASs.

- Identify number of sUASs in swarm and number of vehicle controllers; may incorporate multiple control units and frequencies.
- Identify contingency plan for control loss of single, multiple, and entire swarm of vehicles.
- Identify hazards generated by single sUAS and swarmed sUASs.
- See Scenario 3, “Test Article sUAS in sUAS Work Area” for additional guidance.

<u>Risk to people & property</u>:
- Risks to personnel and property must be assessed for single vehicles and the swarm.
    - single vs. massed kinetic energy potential
    - confusion/dazzle effect of swarm
    - larger debris/hazard area potential
    - probability of vehicle collision with another member of swarm
- In potential loss (without recovery) of micro vehicles, would a find by non-participants create a hazard to persons/property/vehicles? (e.g., similar to an unexploded ordnance [UXO])

<u>Risk to airspace</u>:
- See people & property risks above.
- Schedule an sUAS work area airspace for sUAS use; it is expected that ATC typically monitors this area continuously.
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, and an observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

<u>Risk to range mission</u>:
- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.
- Lost vehicles may create a hazard to non-participants (similar to UXO).

<u>Range Safety Role</u>:
- Range safety reviews test plan, ensures test hazards are addressed with appropriate risk controls, and range barriers and test controls are in place.

SCENARIO 8: Operation of High-Hazard sUAS
Operation of sUAS with elevated potential for serious injury, death or property damage.

- Weaponized sUAS
- - vehicle has bomb/missile/projectile
- - vehicle has laser/dazzler/electromagnetic emitter
- High-kinetic-energy sUAS, i.e. - vehicle has sufficient speed and mass to generate lethal kinetic energy
  Typically > 150 ft-lbs of kinetic energy. (e.g., a 2-lb UAS @ 48 MPH = 150 ft-lb)
- Lacerating, piercing, penetrating sUAS
  - vehicle has unguarded blades, pointed shape or sharp edges
- Vehicle contains toxic substance (e.g. a hypergolic)

Risk to people & property:
- Risks to personnel and property must be assessed for both vehicle and weapon.
  - footprint analysis of hazard areas for vehicle + weapon (e.g. WDZ/LSDZ-type analysis)
  - larger debris/hazard area potential

Risk to airspace:
- Schedule an sUAS work area airspace for sUAS use; it is expected that ATC typically monitors this area continuously.
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

Risk to range mission:
- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.
- Vehicles may create a UXO hazard.

Range Safety Role:
- Range Safety must generate and supply a footprint to sUAS operators of weaponized vehicles.
- An on-site RSO must be assigned.
- Range safety reviews test plan, ensures test hazards are addressed with appropriate risk controls, and range barriers and test controls are in place. Enhanced containment measure such as physical barriers, geofence or FTS may be required.

SCENARIO 9: Autonomous sUAS Operations
Operation of sUAS with the ability to act autonomously.

- Vehicle has the ability to independently alter flight parameters to accomplish an assigned objective.
- Identify contingency plan for deviation of flight path into prohibited areas.
- Vehicle will require elevated tracking capabilities and continuous monitoring.
- See Scenario 3, "Test Article sUAS in sUAS Work Area" for additional guidance.

Risk to people & property:
- Choose a work area that is clear of non-participating vehicles, equipment, or structures susceptible to damage (e.g. hangered aircraft, windows)
- Ensure the work area is clear of non-participant personnel.
- Schedule the work area for sUAS use.
- Verify that the debris hazard area within sUAS work area is clear.
- The AVO checks before launch, and an observer monitors continuously.
- The AVO avoids overflight of people & critical property during flight.

Risk to airspace:
- Schedule an sUAS work area airspace for sUAS use; it is expected that ATC typically monitors this area continuously.
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

Risk to range mission:
- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.

Range Safety Role:
- Range safety reviews test plan, ensures test hazards are addressed with appropriate risk controls, and range barriers and test controls are in place. Enhanced containment measures, such as physical barriers, geofence, or FTS may be required.

SCENARIO 10: Operation of sUAS in Critical or Hazardous Work Areas
Operation of sUAS may pose elevated potential for serious injury, death, or property damage.

- sUAS flying in close proximity to people, high-value assets, critical operations, hazardous areas/conditions, or critical infrastructure.
  - An sUAS operation may increase risk in hazardous work area.
  - Hazardous areas/conditions may pose increased risk to sUAS operation.
- The sUAS or payload poses a hazard, e.g. debris, toxic, laser, electromagnetic emitter, etc.
- The sUAS has unguarded blades, a pointed shape, or sharp edges that pose lacerating, piercing, or penetrating hazards.
- The AVOs perform mission objectives using documented operating procedures.
- The AVO verifies safe configuration of vehicle, RF links, and safeguards (geofence, fly home route, etc.).

Risk to people & property:
- Risks to personnel and property must be assessed for both vehicle and payload.
  - Analyze hazard area footprint for vehicle and payload.
  - Determine debris/hazard area potential.

Risk to airspace:
- Schedule an sUAS work area airspace for sUAS use; it is expected ATC typically monitors this area continuously.
- The AVO, in contact with ATC, requests airspace before launch.
- The AVO verifies visually airspace is clear before launch, and an observer monitors continuously.
- The AVO gives way to manned aircraft if it unexpectedly enters airspace.

Risk to range mission:
- The airspace/range scheduler ensures no schedule conflicts between sUAS and other range or airspace users.
- The sUAS may create a toxic, electromagnetic, laser, or other hazard.
- Any sUAS impact may damage critical range infrastructure or high-value assets.

Range Safety Role:
- Range safety must generate and supply a footprint to sUAS operators.
- An on-site RSO may be assigned.
- Range safety reviews operations plan, ensures hazards are addressed and appropriate mitigations are in place. Enhanced containment measures such as physical barriers, controls, geo-fence, or FTS may be required.

APPENDIX D

Glossary

Airspace Manager - The individual with primary responsibility for coordinating, integrating, and regulating an airspace.
Casualty Expectation - The mean number of casualties predicted to occur as a result of an operation if the operation were to be repeated many times.[8]
Containment - The range safety strategy of ensuring risk is minimized by keeping hazardous operations within hazard areas verified to be clear of vulnerable personnel or property.
Contingency Management System - A system designed to manage the vehicle that provides a controlled response under the full set of circumstances defined by the mission's risk assessment. The system may be comprised of a set of elements within the vehicle, including but not limited to: manual control, autonomous control, and recovery capability. A contingency management system is a type of flight safety system. (See also *Flight Termination System* and *Flight Safety System*).
Control Station - An air-, land-, or sea-based control center that provides the facilities for human control of unmanned aerial vehicles (UAVs or drones).
Equivalent Level of Safety - An approximately equal level of safety as determined by quantitative or qualitative means. (C.F.R. 14 §401.5)
Flight Safety System - Includes airborne and ground safety systems, tracking safety system, and telemetry data transmission systems that must meet flight safety and user requirements, as well as established reliability and single-point failure requirements. The flight safety system provides a means of preventing a vehicle and its hazards, including any payload hazards, from reaching any populated or other protected area in the event of a vehicle failure (See also *Flight Termination System* and *Range Safety System*).
Flight Termination System - Terminates the flight of a vehicle. In addition to disabling thrust, the goal of the FTS is to result in a termination action that minimizes the debris footprint. The FTS shall minimize significant lateral or longitudinal deviation in the impact point. The FTS consists of the entire system on an airborne vehicle used to receive, decode, and execute a flight termination. (*See also Flight Safety System* and *Range Safety System*).
FTS Fail safe - A method built into FTSs that will activate a termination output upon the loss of positive FTS control due to conditions such as loss of power, RF signal, tone, or command message.
Ground Control Station - *(See Control Station)*
Hazard - Any real or potential condition that can cause mission degradation, injury, illness, or death to personnel or damage to or loss of equipment or property.[9]
Hazard Area - A geographical or geometric surface area that is susceptible to a hazard from a planned event or unplanned malfunction. (RCC, 321-20)
Mishap - An unplanned event or series of events resulting in death, injury, occupational illness, or damage to or loss of equipment or property. (AFPAM 90-803, MIL-STD-882E)

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[8] Range Commanders Council. *Common Risk Criteria Standards for National Test Ranges*. RCC 321-20. May 2020. May be superseded by update. Retrieved 6 December 2021. Available at https://www.trmc.osd.mil/wiki/x/-Yu8Bg.
[9] Secretary of the Air Force. *Risk Management (RM) Guidelines and Tools*. AFPAM 90-803. 11 February 2013. May be superseded by update. Retrieved 6 December 2021. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afpam90-803/afpam90-803.pdf.

Mission Commander (MC) - The MC is responsible for the overall safe and professional completion of the UAS mission IAW applicable policies, procedures, and priorities.
National Airspace System (NAS) - The common network of U.S. airspace-air navigation facilities, equipment and services; airports or landing areas; aeronautical charts; information and services; rules, regulations and procedures; technical information; and manpower and material. (FAA Glossary of Terms 2016-06-05)
Operator - Responsible for flight operations of the air vehicle through autonomous control of the unmanned aircraft by means of a ground-based computer interface with an onboard flight management system.
Range Control Officer - The Range Control Officer (RCO), or equivalent is the primary interface to the user for planning and test execution. This person oversees the range readiness to meet the range schedule. The RCO identifies range and data processing support requirements and peculiarities.
Range Safety Officer - Range Safety Officer (RSO) is a generic term used in this document to designate the individual or individuals responsible for making range safety decisions, particularly flight termination decisions. During real-time, the RSO is delegated the authority to execute the range commander's range safety policies and has sole responsibility for making range safety decisions. (Other RCC member range equivalents include mission flight control officer or flight safety officer.)
Range Safety System - The ground-based portion of the flight safety system. An integrated system of hardware, software, and human operators that is necessary to provide mission safety support. Includes instrumentation and communication infrastructure needed to fulfill safety's flight control responsibility. *See also Flight Safety System* and *Flight Termination System)*
Residual Risk - The remaining risk that exists after all mitigation techniques have been implemented or exhausted. (MIL-STD-882D)
Risk - An expression of mishap consequences in terms of probability of an event occurring, the severity of the event and the exposure of personnel or resources to potential loss or harm. (AFPAM 91-214)
Safety Pilot - A qualified operator who assumes command of the vehicle in the event the operator loses control of the vehicle.
Special Use Airspace (SUA) - Defined dimensions within the NAS wherein activities must be confined because of their nature, or wherein limitations are imposed upon aircraft operations that are not a part of those activities, or both. (Aeronautical Information Manual AIM 3-4-1) SUA encompasses a group of airspace types: restricted areas, prohibited areas, warning areas, alert areas, military operation areas, national security areas, controlled firing areas, ATC assigned airspace, and any other designated airspace areas. SUA includes defined vertical and lateral dimensions that alert users to areas of unusual flight hazards and separates those activities from other airspace users to enhance safety. Certain limitations or restrictions may be placed on non-participating aircraft.
System Maturity - Assessed level of the performance reliability of a UAS. System maturity is assessed using local guidance established by each range.
UAS Fail Safe Mode - Autonomous, pre-programmed software that takes over vehicle control when control link to the operator is interrupted. Examples are lost link and range limiting capabilities such as geo-fencing, RF range limiting, fly-home function, etc.
User - The range user can be a commercial or government entity using the federal range for test or training purposes.

APPENDIX E

Citations

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