



RANGE SAFETY CRITERIA FOR UNMANNED AERIAL VEHICLES

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STANDARD 323-18

RANGE SAFETY CRITERIA FOR UNMANNED AIR VEHICLES

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Preface

This document provides a common approach for the range commander to make decisions regarding experimental and test UAV flight operations. The criteria described in this document allow the decision-maker to make an informed and defensible risk decision and provide a tool to help answer the question: “Is this vehicle safe to fly on my range?”

This document represents the collective efforts of both government and contractor personnel and is the result of an extensive cooperative effort.

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Changes to this Edition

This document is an updated version of RCC Document 323-99. The following is a list of changes.

- a. Added introduction to address purpose, scope, implementation, and range responsibilities.
- b. Added acronym list and glossary.
- c. Made substantive changes to criteria.
- d. Corrected administrative errors in standard.

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Acronyms

ATC	Air Traffic Control
DoD	Department of Defense
EUA	exclusive use airspace
FAA	Federal Aviation Administration
FTS	flight termination system
IFR	Instrument Flight Rules
MRTFB	Major Range and Test Facility Base
MRU	military radar unit
NASA	National Aeronautics and Space Administration
RCC	Range Commanders Council
RF	radio frequency
SUA	special use airspace
UAV	unmanned aerial vehicle
UAVC	Unmanned Air Vehicle Committee
VFR	Visual Flight Rules

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CHAPTER 1

Introduction

1.1 Purpose

This document provides a common approach for the range commander to make decisions regarding experimental and test unmanned aerial vehicle (UAV) flight operations. These criteria do the following: allow the decision maker to make an informed and defensible risk decision; and provide a tool to help answer the question: Is this vehicle safe to fly on my range?

Multiple criteria are used to examine flight safety from different perspectives to ensure a thorough review. Different viewpoints reduce the risk of unrecognized hazards and help to quickly identify and isolate deficiencies. The criteria are used to break up the safe to fly question into a series of presuppositions, outlined below.

- a. Are system hazards recognized and risk controls available? The range can use the risk management criteria discussed in [Chapter 2](#) to evaluate the range user's risk management program and answer this question.
- b. How is this range vulnerable to these identified system hazards?
 - (1) Casualty expectation criteria
 - (2) Property damage criteria
 - (3) Midair collision avoidance criteria
- c. If safeguards are needed to reduce risk, will they work? Range can use the adequacy of safeguard criteria to answer this question.

The following chapters describe the five criteria along with the conditions necessary to meet them. The criteria are based on guidance from safety specialists, existing reference standards and policies, and established procedures. The supplement to this document describes rationale and methodology supporting the criteria, as well as examples, definitions, and alternatives to consider if the criteria cannot be met.

1.2 Scope

The criteria in this document are intended for use by members of the DoD national ranges. These policies and criteria apply as follows.

- a. Experimental vehicles and test articles: Experimental and test article UAVs are the primary purpose of these criteria as no airworthiness certification evidence is available as an alternative.
- b. Airworthy vehicles: The criteria are not intended for vehicles certified as airworthy; however, the criteria may be useful in planning for vehicles that are conditionally airworthy.

- c. Small UAVs and model aircraft: Small UAVs¹ and model aircraft² (Section 336 of Public Law 112-95) operated within Federal Aviation Administration (FAA) regulations are out of the scope of these criteria.
- d. Expendable targets: The criteria are not intended for unmanned targets; however, the criteria may be useful in route planning. Additional analysis (such as Range Commanders Council [RCC] 321-17³) may be required when the targets are used in live-fire scenarios.
- e. Ballistic missiles, sub-orbitals, and reentry vehicles: Ballistic missiles and unmanned vehicles such as sub-orbitals and reentry vehicles that are launched by ballistic missiles should typically be analyzed using RCC 321-17 (or current version).

1.3 Implementation

This document is an advisory document. Its content is based on the consensus positions held by the Unmanned Air Vehicles Committee (UAVC) within the Range Safety Group (RSG), which is made up of a broad cross section of the US range safety community. Therefore, the content of this document represents consensus standards. The main body of the document provides consensus standards with the highest levels of priorities, while the supplement contains lower levels of priority requirements, guidelines, and example methods. This document and the supplement both use precise language in an attempt to capture the intent of the UAVC as follows.

The words “must,” “shall,” and “will” indicate a requirement. Legitimate alternatives may exist, but each alternative either shall demonstrate an equivalent level of safety or have a waiver granted by the appropriate risk decision authority.

“Should” indicates an advisory requirement or a highly desirable procedure. When this standard uses “should,” the committee intends that a range will achieve compliance to the maximum extent practical, but no waiver or equivalent level of safety will be required.

“Can” and “may” permit a choice and express a guideline.

In order for a range to effectively implement this document, the range should evaluate the contents of this document and incorporate it accordingly into its local regulations and requirements.

¹ Code of Federal Regulations, Small Unmanned Aircraft Systems, title 14 sec. 107.

² Special Rule for Model Aircraft. 14 U.S.C. § 336

³ Range Commanders Council. *Common Risk Criteria Standards for National Test Ranges*. RCC 321-17. September 2017. May be superseded by update. Retrieved 30 November 2017. Available at https://www.trmc.osd.mil/wiki/download/attachments/92603631/321-20_Common_Risk_Criteria_Test_Ranges.pdf.

1.4 Range Responsibilities

Department of Defense (DoD) Instruction 3200.18⁴ assigns responsibility to each range commander⁵ (or other risk decision authority for non-DoD facilities) for ensuring that all missions are conducted safely, consistent with operational requirements. Range flight operations typically involve some level of risk. Therefore, an important aspect of the range safety responsibility is to ensure that the risk is properly managed within prescribed limits. To accomplish this, each range commander (or designee) must perform the following.

- a. Establish risk management procedures (including hazard containment) to implement the risk management process described herein.
- b. Establish acceptable risk criteria appropriate to each type of mission flown in consideration of the guidance provided herein.
- c. Accept any risks, including those that exceed the established risk criteria when warranted for a mission in consideration of the operational requirements and national need.
 - (1) Make such decisions based on a thorough understanding of any additional risk that exceeds the risk criteria and the benefits to be derived from taking the additional risk.
 - (2) Ensure such decisions are documented in a formal waiver process (or equivalent), preferably in advance of the mission.
- d. Maintain related range policy and requirements documents.
- e. Maintain records of risk assessments and waivers to established risk criteria.
- f. For a mission involving more than one range, coordinate with the other range(s) to clearly document safety responsibility for each phase of the mission and develop and implement joint plans for controlling the mission risk due to all planned and unplanned events.

⁴ Department of Defense. *SUBJECT: Management and Operation of the Major Range and Test Facility Base (MRTFB)*. DoDI 3200.18. 1 February 2010. Change 1 incorporated 15 November 2017. May be superseded by update. Retrieved 30 November 2017. Available at <http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/320018p.pdf?ver=2017-11-15-142005-213>.

⁵ This document uses “range commander” to refer to the duly authorized risk decision authority.

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CHAPTER 2

Risk Management Criteria

Testing and operations on a range must be conducted safely. To the greatest extent possible, hazards should be identified and managed. Unidentified hazards must be planned for and managed. The operators and test teams must be able and prepared to cope with all potential hazards.

2.1 Risk Management

The goals of risk management criteria are to ensure system hazards that may affect range safety are recognized and to identify control measures. The range can use these criteria to evaluate the range user's risk management program, regardless of what type of approach is used. The following presuppositions describe how each of the criteria are met.

2.1.1 Hazards identified: The hazards associated with the proposed UAV operations have been explicitly stated, based on lessons learned and hazard analysis. Vulnerability to unidentified risk is reduced through hazard analysis efforts.

- A safety history of the UAV is available, describing mishap history, corrective action, mishap rate, or estimate of mishap rate and justification.
- A hazard analysis is completed corresponding in scope to the type of UAV and the nature and location of the flights.
- System failure modes and significant hazards are identified.
- Critical single-point and common-mode failures are identified.
- Hazards related to software are identified.
- Hazards related to operational and training issues are identified.
- Hazards peculiar to the specific range where the test or operation takes place are identified and managed.

In the absence of an acceptable range user's hazard analysis, an independent hazard analysis by Range Safety, System Safety, Aviation Safety, or other pertinent safety representative may be considered.

2.1.2 Hazards assessed: A hazard analysis or similar document describes the level of risk associated with identified hazards.

- Hazard definitions identify the associated level of risk in terms of severity and probability of occurrence.
- Assessment includes the failure probability of critical single-point and common-mode components.
- The severity and probability levels are re-assessed when test range locations are changed.

2.1.3 Control measures and risk decisions: Risk controls are explicitly identified.

- Control measures are chosen to reduce, mitigate, or eliminate the risk.
- Residual risk is accepted by the appropriate authority per the range's risk acceptance process.

2.1.4 Hazard controls: Control measures identified in the hazard analysis are documented during planning.

- Control measures identified in the hazard analysis are incorporated into the design, the test procedures, or the operating plan.
- Safety limits and a plan to monitor them are defined.

2.1.5 Supervision: Follow-up evaluations of the control measures are planned in order to ensure effectiveness. Adjustments will be made before continuing with the test or operation.

- Personnel are assigned with the responsibility for monitoring and documenting the safety control measures of the planned test or operation.
- The assigned safety monitors are empowered to stop operations if control measures are not followed or if safety limits are exceeded.
- The use of safety resources is integrated into the plan to monitor safety limits and to control hazards.

2.2 **Managing Risk Uncertainty**

Uncertainty and associated hazards of testing new flight critical systems, software, or operating limits must be considered and addressed. The potential for hazards associated with epistemic unknowns must be considered and addressed.

2.2.1 Test hazards: Test events intended to exercise specific subsystems or explore operating limits may pose unique hazards. These risks must be recognized and managed.

- A test hazard analysis has been performed on potentially hazardous test points or test events.
- Precautionary measures and/or corrective actions addressing each identified test hazard have been proposed, evaluated, approved, and implemented.

2.2.2 Maturity and epistemic hazards: Experimental and test vehicles with few flight hours may have unidentified hazards or operating limits or unexercised operating and emergency procedures. The possibility of unexpected flight behavior must be considered.

- Potential hazardous outcomes are identified.
- Hazardous outcomes with inadequate barriers or no acceptable contingency plans are identified.
- Epistemic risk is managed by:

- contingency and risk mitigation plans; or
- adjustment or elimination of test events; or
- recognition and acceptance of the risk of specific outcomes by the authorized decision authoring.

2.3 Personnel Qualifications and Readiness

Personnel performing operations that can directly affect risk must be qualified and ready to perform their functions.

- 2.3.1 Operator qualifications: Vehicle operators have evidence of operating skills and experience corresponding to the difficulty and uncertainty of the flight test.
- 2.3.2 Test team qualifications: The test team has evidence of knowledge, skills, and experience corresponding to the difficulty and uncertainty of the flight test. Test team members are explicitly identified in writing and approved by appropriate test authority
- 2.3.3 Support team readiness: Support personnel providing services such as data acquisition, range clearance, range airspace authority, or remediation support are aware of any unusual hazards peculiar to this flight or test event, and have taken appropriate precautions.
 - Readiness requires identification, understanding, and documentation of unusual safety requirements and procedures.
 - Range personnel should have adequate real-time situational awareness to affect safety of operations.

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CHAPTER 3

Casualty Expectation Criteria

Any UAV test operation must show a level of risk no greater than that for an operation or test of a piloted aircraft.

The range must ensure that the risks to people identified in the hazard analysis are reduced to an acceptable level. Conducting hazardous operations away from populated areas reduces risk by limiting exposure to the hazard.

The criteria are met if the hazard is contained to unpopulated areas (Section 3.1) or if the combined vehicle reliability and population distribution result in an assessed improbable casualty expectation (Section 3.2). A third criterion (Section 3.3) provides for a qualitative approach when there is insufficient data to support quantitative risk analysis and the hazard cannot be contained.

3.1 No Risk to the Public Because Hazard is Contained

The planned route of flight is acceptable because the flight can be contained within unpopulated areas. Considerations include the following.

- Verify that the area is unpopulated through monitoring or exclusion (fence).
- When practical, recognize and mitigate failure modes that could result in the UAV leaving airspace over the unpopulated area. Additionally, review the history of this vehicle or similar designs that encountered these failure modes.
- If necessary, use an independent and highly reliable flight safety system (e.g., flight termination system [FTS]) to ensure the vehicle does not leave assigned airspace.
- Verify that use of “fly home” or “emergency mission” software routines keeps the vehicle inside the assigned airspace over an unpopulated area on loss of control link.
- Consider the level of system maturity. Requirements for additional control measures to keep the UAV inside assigned airspace may be reduced depending on system maturity.

3.2 Casualty Expectation Assessed as Improbable

The average risk to people within the planned area of flight is acceptable and avoidance of high-population-density areas is addressed.

3.2.1 Expected casualties: This must be less than one casualty in a million flight hours.

- Expected casualties are based on UAV crash probability, crash kinetic energy, vehicle dimensions, routing, and population data.
- When empirical data is not available, this condition is met if the route is confined to sparsely populated areas and qualitative methods indicate casualty expectation is negligible.

3.2.2 Route selected to avoid high-population-density area: Routes and altitudes are selected to minimize the possibility of the UAV falling into a congested area in the event of a malfunction. The route avoids densely populated areas, especially during phases of flight with increased risk.

- The route should avoid areas of high population density such as towns, schools, hospitals, stadiums, etc. that would cause the momentary casualty expectation to exceed the acceptable level.
- Typical critical phases of flight with an increased risk of mishap include takeoff and climb-out, approach and landing, and unusual maneuvers that could cause structural failure or loss of controlled flight.
- Unhealthy or damaged vehicles should use alternate routes and actions. Range rules will delineate how to handle unhealthy or damaged vehicles.

3.3 **Qualitative Risk Management**

A qualitative approach may be considered in those cases where there is insufficient information for a quantitative approach, the hazard of a test flight or specific test point cannot be completely contained, or there is a compelling requirement for test data.

Critical hazards must be identified and controlled to the satisfaction of the decision authority, which must understand the limitations of the qualitative analysis and accept the residual risk that cannot be mitigated.

If there is no compelling requirement, then the hazardous test operation or test point shall be avoided.

CHAPTER 4

Property Damage Criteria

Critical assets or high-consequence properties that might be damaged in a crash should be avoided. This criterion is met if the critical sites are identified and a route is selected that avoids these locations.

4.1 Identification of Critical Assets and High-Value Property

This section addresses property types where damage would result in unacceptable consequences. Examples include:

- items that could trigger larger hazards if damaged, such as fuel farms, power plants, and ammunition storage sites;
- national assets, such as ground satellite antennas, national satellite systems, and strategic systems;
- costly structures such as expensive range facilities;
- facilities essential to protect health and safety;
- cultural or environmentally sensitive areas.

4.2 Route Selection

The route avoids high-consequence property, especially during phases of flight with increased risk. Examples of critical phases of flight with an increased risk of mishap include:

- takeoff and climb-out;
- approach and landing;
- unusual maneuvers that could cause structural failure or loss of controlled flight;
- continued flight after failure of one leg of a redundant flight-critical subsystem.

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CHAPTER 5

Midair Collision Avoidance Criteria

Collision is avoided by isolating the vehicle from other aircraft or compensating for differences with manned aircraft that increase risk of collision. There are three cases of midair collision avoidance criteria to accommodate different situations:

- exclusive use within restricted airspace or warning area;
- shared use within restricted airspace or warning areas;
- UAV operations outside of special use airspace (SUA).

5.1 Exclusive Use within Restricted Airspace or Warning Areas

The UAV will be flown in restricted or warning areas. Only aircraft that are participating in the UAV's mission or test event will be permitted in the exclusive airspace.

This criterion is met if:

- the UAV is contained inside restricted airspace or a warning area;
- non-participants are excluded;
- participants are adequately briefed; and
- reasonable contingencies exist to address unexpected changes to the first two conditions.

5.1.1 UAV containment: Ensure that the UAV can be contained within the defined restricted or warning area boundaries. Considerations may include:

- recognition of failure modes that could result in the UAV leaving assigned airspace (including the airspace above and below the restricted or warning area) and history of this vehicle or similar designs encountering these failure modes;
- installation of a range-approved independent and highly reliable system (e.g., FTS) to ensure vehicle does not leave assigned airspace;
- verification that on loss of control link, the use of “fly home” or “emergency mission” software routines keeps the vehicle inside the exclusive use boundary and altitude limits;
- recognition that system maturity may or may not support requirements for additional safeguards to keep the UAV inside assigned airspace;
- verification that Air Traffic Control (ATC) or military radar unit (MRU) can monitor vehicle position for containment and communicate with UAV operators in a timely manner;
- demonstration that the ground control station will have positive UAV communication and control and position information during flight.

5.1.2 Exclusion of other aircraft: Ensure other aircraft can be kept out of the airspace dedicated to UAV mission use. Considerations may include the following.

- Boundaries of the exclusive use airspace (EUA) within the restricted airspace or warning areas are explicitly defined, communicated, and recognized by other airspace users and control authorities.
- The EUA within the restricted airspace or warning area is activated.
- Where capabilities exist, demonstrate the ability to monitor the airspace within and near the EUA and communicate with traffic that may conflict.
- Where monitoring capabilities are limited or do not exist, demonstrate the ability to control the airspace through scheduling or standardized local procedures. Potential risks associated with communications and/or monitoring capabilities must be recognized.

5.1.3 Participant coordination: The event coordinator (e.g., test director, mission commander, etc.) ensures that UAV operators, flight crews, and ATC (or MRU or controllers) understand the operation as well as recognize the limitations of the UAV. This coordination may include:

- a local standard operating procedure or process to address routine operations;
- mission briefs and review of UAV peculiar procedures;
- flight crews and ATC following established and approved procedures for that range.

5.1.4 Exclusive use contingencies: Range Operations, UAV operators, and ATC are prepared with reasonable procedures in the event the exclusive use/containment strategy fails. These contingencies should include:

- loss of primary communications between the UAV operator and ATC;
- entry of a non-participant into EUA;
- loss of UAV operator vehicle location data;
- loss of ATC airspace location data for this vehicle;
- loss of both UAV operator and ATC location data for this vehicle;
- loss of control link between the UAV operator and UAV;
- undirected UAV flight within EUA;
- undirected UAV flight leaving EUA.

5.2 **Shared Use within Restricted Airspace or Warning Areas**

The UAV will be flown in restricted or warning areas along with other aircraft that may not be participating in the UAV's mission or test event.

These criteria are met if:

- the UAV is contained inside restricted airspace or a warning area;

- differences between UAVs and manned aircraft that increase risk to other aircraft (e.g., “see and avoid,” response delays, etc.) are accounted for;
- reasonable contingencies exist to address unexpected changes to the first two conditions.

5.2.1 UAV containment: Ensure the UAV can be contained within the defined restricted or warning area boundaries. Considerations may include:

- recognition of failure modes that could result in the UAV leaving the assigned SUA (including airspace above and below it), and history of this vehicle or similar designs encountering these failure modes;
- installation of a range-approved independent and highly reliable system (e.g., FTS) to ensure vehicle does not leave assigned airspace;
- verification that on loss of control link, the use of “fly home” or “emergency mission” software routines keeps the vehicle inside the restricted or warning area boundary and altitude limits;
- recognition that system maturity may or may not support requirements for additional safeguards to keep UAV inside assigned airspace;
- verification that ATC or MRU can monitor vehicle position for containment and communicate with UAV operators in a timely manner;
- demonstration that the ground control station will have positive UAV communication and control and position information during flight.

5.2.2 Compensating for see-and-avoid limitations: Ensure positive separation of aircraft by recognizing and compensating for see and avoid limitations of the UAV. For example, onboard cameras may have limitations (field of view, sensitivity) and a small UAV may be difficult to see from other aircraft. Considerations may include:

- use of a chase aircraft to augment UAV operator situational awareness and to increase visibility to other aircraft;
- use of bright colors or lights to increase the visibility of the UAV;
- use of radar surveillance in UAV flight area and verification that both communications and radar coverage are adequate;
- use of a ground observer for low-flying UAVs;
- use of a plan to actively avoid conflicts that considers the performance limitations of the vehicle.

5.2.3 Compensating for delays with ATC instruction: Vehicles with limited or no see-and-avoid capability are dependent on ATC or MRU for deconfliction. Communication and control delays may be greater than those of manned aircraft. Vehicle response must match airspace conditions and requirements. Considerations may include:

- increased coordination and pre-planning with ATC or MRU;

- use of locally established deconfliction procedures.

5.2.4 Contingencies in shared use SUA: The UAV operators and ATC are prepared with reasonable procedures in the event the airspace strategy for operating shared use within SUA fails. These contingencies should address:

- loss of control link between the UAV operator and UAV;
- loss of communications between the UAV operator and ATC;
- loss of UAV operator vehicle location data;
- loss of ATC airspace location data for this vehicle;
- loss of both UAV operator and ATC location data for this vehicle;
- undirected flight within SUA;
- undirected flight leaving SUA;
- chase unable to monitor or follow the UAV;
- chase unable to communicate with ATC and/or the UAV operator;
- radar and ground observers are unable to provide position data.

5.3 UAV Operations Outside of SUA

This section addresses events in which a UAV will operate outside of SUA. The FAA is responsible for aircraft separation during Instrument Flight Rules (IFR) conditions and for regulations regarding aircraft separation in Visual Flight Rules (VFR) conditions. The FAA must authorize and approve the flight.

These criteria are met if:

- documentation of FAA approval and review exists;
- approval has been granted by the accountable government sponsor; and
- verification that conditions for approval of the first two conditions can still be satisfied in the event of degraded system or environmental conditions.

5.3.1 FAA approval: All UAVs operating outside of active restricted, prohibited, or warning areas shall conform with FAA regulations and gain approval from the regional FAA representative. A Certificate of Authorization is required.

5.3.2 DoD/NASA review: A government sponsor (i.e., the DoD or NASA) must also review and approve if there is any DoD or NASA liability. FAA Notice 7610.71 states: “The proponent and/or its representative shall be noted as responsible at all times for collision avoidance maneuvers with nonparticipating aircraft and the safety of persons or property

on the surface.” Differences between UAVs and manned aircraft (e.g., “see and avoid,” response delays) must be accounted for.

5.3.3 UAV containment: Ensure the UAV can be contained within the boundaries of the pre-planned route of flight defined in the flight plan and approved by the FAA.

Considerations may include:

- recognition of failure modes that could result in the UAV leaving the assigned route of flight or assigned altitude limits and history of this vehicle or similar designs encountering these failure modes;
- installation of a range-approved independent and highly reliable system (e.g., FTS or flight safety system) to ensure the vehicle does not leave its assigned route of flight;
- verification that on loss of control link, “fly home” or “emergency mission” software routines keep the vehicle on its assigned route and within its assigned altitude limits;
- verification that the use of “fly home” or “emergency mission” software routines will not increase risk to other aircraft or persons on the ground due to loss of control link;
- recognition that system maturity may or may not support requirements for additional safeguards to keep the UAV on its assigned route and within assigned altitude limits;
- verification that ATC can monitor the vehicle position and communicate with UAV operators in a timely manner.

5.3.4 Compensating for see-and-avoid limitations: The limitations of the UAV are recognized and compensated for. For example, onboard cameras may have limitations (field of view, sensitivity) and the size of the UAV may make it difficult for other aircraft to see.

Considerations may include:

- use of a chase aircraft to augment the UAV operator’s situational awareness and to increase visibility to other aircraft;
- use of bright colors or lights to increase the visibility of the UAV;
- use of radar surveillance in UAV flight;
- use of a ground observer for low flying UAVs;
- use of a plan to actively avoid conflicts that considers the performance limitations of the vehicle.

5.3.5 Compensating for delays with ATC instruction: Communication and control delays may be greater than those of manned aircraft and must be reviewed and compensated for.

Vehicles with limited or no see and avoid capability are dependent on ATC for deconfliction. Vehicle response must match airspace conditions and requirements.

Considerations may include:

- increased coordination and pre-planning with ATC;
- use of FAA-established deconfliction procedures.

5.3.6 Contingencies outside SUA: The UAV operators and ATC are prepared with reasonable procedures in the event the airspace strategy for operating within shared SUA fails.

- Alternatives to contingencies in FAA Certificate of Authorization are available in the event system failure or environmental change prevents compliance.
- Control link between UAV operator and UAV is lost.
- The UAV operator loses communication with ATC.
- The UAV operator loses vehicle location data.
- The ATC personnel loses airspace location data for the vehicle.
- Both the UAV operator and ATC lose location data for the vehicle.
- The UAV is no longer being directed by an external operator or pre-planned emergency routine.
- Chase aircraft are unable to monitor or follow the UAV.
- Chase aircraft loses communication with ATC and/or the UAV operator.

CHAPTER 6

Criteria for Reliability and Adequacy of Safeguards

There must be evidence to show that required vehicle safeguards will mitigate critical hazards. Safeguards must be provided if the hazard analysis requires it or if the UAV or test operation does not meet other safety criteria (e.g., casualty expectation, property damage, collision avoidance) without it.

Typical systems that may be considered as vehicle safeguards include, but are not limited to:

- flight safety systems;
- FTSs;
- software “fly home” routines;
- parachutes.

New vehicles with enhanced performance may exceed the range’s capacity to provide an additional layer of safety. Range safeguards include range geography, independent vehicle situational awareness capability to support the test team, weather and radio frequency (RF) environment monitoring, and independent flight termination capability.

6.1 UAV System Safeguards

6.1.1 Hardware safeguards: Evidence shows that the reliability of required hardware safeguards is adequate. The range may require one or more of the following:

- verification that the FTS subsystems meet the current RCC flight termination standard;⁶
- proof that the safeguard subsystem meets an established reliability standard for that type of safeguard;
- evidence that the system or safeguard has been tested and can be monitored in flight or will be explicitly checked before flight.

6.1.2 Software safeguards: Evidence must prove the reliability of required software safeguards is adequate. Examples of software safeguards may include “fly home” or “emergency mission” routines in the event of lost link and some “emergency remote pilot” components.

- Software used in safeguard functions must show evidence of an approved software safety program by which software hazard analysis has been performed.

⁶ Range Commanders Council. Flight Termination Systems Commonality Standard. RCC 319-14. September 2014. May be superseded by update. Retrieved 30 November 2017. Available at https://www.trmc.osd.mil/wiki/download/attachments/92603511/319-19_FTS_Commonality.pdf.

- The software analysis has identified sufficient hazard control measures that have been implemented.

6.1.3 Procedural safeguards: Evidence must show procedural safeguards are adequate. Examples of procedural safeguards are emergency procedures, checklists, operator certification, and training. Operator procedures, which will be used as a safeguard, must be documented, reviewed, and approved.

6.2 Range Safeguards

Review of existing range capabilities may be required to ensure they are adequate for safety support of a new vehicle or a new test.

6.2.1 Independent situational awareness: Ensure range video and instrumentation systems are adequate to support safety critical decisions.

- Review range-independent situational awareness systems to verify vehicle health or to support abort, return to base, or terminate decisions.
- Review performance and coverage of time-space-position information, telemetry, and optical systems to show they are adequate to support a specific event.

6.2.2 Independent command systems: Ensure independent FTSSs, if used, are adequate to support safety-critical decisions.

6.2.3 Range environment: Ensure capability to monitor the range environment is adequate to support safety-critical decisions.

- Verify that the capability and accessibility of weather forecasting/monitoring is adequate to support safety-critical decisions.
- Verify that RF scheduling/monitoring capabilities are adequate to detect interference that may affect a test flight or other safety-critical local RF link.

6.2.4 Range airspace & geography: Ensure range airspace and geography are adequate to support surface hazard patterns, flight test operations, and contingencies.

6.2.4.1 Range geography surface: The following are the topography-based concerns.

- Hazard areas are adequate for risk.
- Surface surveillance capability and strategy are adequate.

6.2.4.2 Range airspace: The concerns with airspace are as follows.

- Airspace is compatible with proposed test operation.
- Airspace surveillance capability and strategy are adequate.

Appendix A

Glossary

Activated: To make special use airspace available for the assigned using agency (i.e., a military airfield).⁷

Casualty: A serious injury or worse, including death, for a human. For the purposes of this standard, serious injury is defined as Abbreviated Injury Scale Level 3 or greater except where prior general practice at the range has been to protect to a lesser level of injury than Abbreviated Injury Scale level 3, such as eardrum protection (RCC, *Common Risk Criteria*).

Casualty Expectation: See *Expected casualties*

Chase: 1. An aircraft assigned to follow and monitor a UAV. An airborne observer. 2. An aircraft flown in proximity to another aircraft normally to observe its performance during training or testing.⁸

Containment: The range safety strategy of minimizing risk to the maximum extent practical by keeping hazardous operations within defined hazard areas that are unpopulated or where the population is controlled and adequate protection can be provided to highly valued resources; to stop, hold, or surround a hazard (RCC, *Common Risk Criteria*).

Critical Asset: A resource requiring protection. It normally includes property/ infrastructure that is essential to protect the public health and safety, maintain the minimum operations of the range, or protect the national security or foreign policy interests of the United States (RCC, *Common Risk Criteria*).

Decision Authority: The range commander or senior official designated by the range commander to make risk decisions on his or her behalf (RCC, *Common Risk Criteria*).

Epistemic: Pertaining to the degree of knowledge. From the Greek *episteme* (knowledge)⁹

Exclusive Use: The assignment of only one event within a block of airspace.

Expected Casualties: The expected number of individuals who will be casualties. Used to define Collective Risk. This risk is expressed with the following notation: $1E-7 = 10^{-7} = 1$ in ten million (RCC, *Common Risk Criteria*).

Exposure: The number of persons or resources affected by a given event, or over time, repeated events. This can be expressed in terms of time, proximity, volume, or repetition. This

⁷ Federal Aviation Administration. *Air Traffic Organization Policy*. SUBJ: *Unmanned Aircraft Systems (UAS)*. JO 7200.23. 3 October 2016. May be superseded by update. Retrieved 30 November 2017. Available at https://www.faa.gov/documentLibrary/media/Order/FAA_JO_7200_23_2.pdf.

⁸ Federal Aviation Administration. *Aeronautical Information Manual*. AIM. 12 October 2017. May be superseded by update. Retrieved 30 November 2017. Available at https://www.faa.gov/air_traffic/publications/media/AIM_Basic_dtd_10-12-17.pdf.

⁹ National Aeronautics and Space Administration. *NASA Risk-Informed Decision Making Handbook*. Office of Safety and Mission Assurance, NASA Headquarters. Version 1.0. April 2010. May be superseded by update. Retrieved 8 May 2018. Available at <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100021361.pdf>.

parameter may be included in the estimation of severity or probability, or included separately.¹⁰

Flight Safety System: A system designed to limit or restrict the hazards to public health and safety and the safety of property presented by a launch vehicle or reentry vehicle while in flight by initiating and accomplishing a controlled ending to vehicle flight.¹¹

Flight Termination System: All components onboard a UAV that provide the ability to end the vehicle's flight in a controlled manner. An FTS consists of all command destruct systems, inadvertent separation destruct systems, or other systems or components that are onboard a UAV and used to terminate flight (Definitions, 14 CFR 401.5).

Fly Home: Software routine(s) that ensure the UAV returns to the launch site or other designated safe area in the event of lost radio control link.

Hazard: A real or potential condition that could lead to an unplanned event or series of events (i.e., mishap) resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.¹²

Hazard Area: A geographical or geometric surface area that is susceptible to a hazard from a planned event or unplanned malfunction (RCC, *Common Risk Criteria*).

High Value Property: A property where the severity of potential damage or loss caused by a UAV would be unacceptable to the range commander or stakeholder.

Mishap: An event or series of events resulting in unintentional death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment (Department of Defense, *System Safety*).

Mitigate: Action required eliminating the hazard or when a hazard cannot be eliminated, reducing the associated risk by lessening the severity of the resulting mishap or lowering the likelihood that a mishap will occur (Department of Defense, *System Safety*).

Observer: A trained person who assists the unmanned aircraft pilot in the duties associated with collision avoidance and navigational awareness (FAA, *Air Traffic Organization*).

Probability: An expression of the likelihood of occurrence of a mishap (Department of Defense, *System Safety*).

Residual Risk: The remaining risk that exists after all mitigation techniques have been implemented or exhausted (Department of Defense, *System Safety*).

Restricted Airspace: Airspace designated under 14 CFR Part 73¹³, within which the flight of aircraft, while not wholly prohibited, is subject to restriction. Most restricted areas are designated joint use and IFR/VFR operations in the area may be authorized by the

¹⁰ Secretary of the Air Force. *Risk Management (RM) Guidelines and Tools*. AFPAM 90-803. 11 February 2013. May be superseded by update. Retrieved 15 May 2018. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afpam90-803/afpam90-803.pdf.

¹¹ Code of Federal Regulations, Definitions, title 14, sec. 401.5.

¹² Department of Defense. *System Safety*. MIL-STD-882E. 11 May 2012. May be superseded by update. Retrieved 30 November 2017. Available at <http://quicksearch.dla.mil/Transient/5E5E55D9BB0C409D9F21945218FDE1EC.pdf>.

¹³ Code of Federal Regulations, Special Use Airspace, title 14, sec. 73.

controlling ATC facility when it is not being utilized by the using agency (FAA, *Aeronautical...*).

Risk: 1. A combination of the severity of the mishap and the probability that the mishap will occur (Department of Defense, *System Safety*). 2. 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 (Secretary of the Air Force, *Risk Management (RM)...*).

Safeguard: Hardware component, software routine, operator procedure, or some combination intended to mitigate risks.

Safety: Freedom from conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment (Department of Defense, *System Safety*).

Safety Critical: A term applied to a condition, event, operation, process, or item whose mishap severity consequence is either catastrophic or critical (e.g., safety-critical function, safety-critical path, and safety-critical component) (Department of Defense, *System Safety*).

See and Avoid: The requirement that, when weather conditions permit, pilots operating IFR or VFR observe and maneuver to avoid other aircraft. Right-of-way rules are contained in 14 CFR Part 91¹⁴ (FAA, *Aeronautical...*).

Severity: 1. The magnitude of potential consequences of a mishap to include: death, injury, occupational illness, damage to or loss of equipment or property, damage to the environment, or monetary loss (Department of Defense, *System Safety*). 2. The expected consequences of an event in terms of degree of impact on the mission, injury, or damage (Secretary of the Air Force, *Risk Management (RM)...*).

Special Use Airspace: Any airspace with defined dimensions within the National Airspace System wherein limitations may be imposed upon aircraft operations. This airspace may be restricted areas, prohibited areas, military operations areas, air ATC assigned airspace, and any other designated airspace areas (FAA, *Aeronautical...*).

Stakeholder: An individual or organization that is materially affected by the outcome of a decision or deliverable but is outside the organization doing the work or making the decision. (NASA, *NASA Risk-Informed Decision...*)

System Maturity: A measure of the ability of an unmanned aerial system to consistently and safely perform all normal flight and emergency procedures in a variety of conditions based on test evidence and/or flight history.

Uncertainty: The absence of perfectly detailed knowledge. Uncertainty includes incertitude (the exact value is unknown) and variability (the value is changing). Uncertainty may also include other forms such as vagueness, ambiguity, and fuzziness (in the sense of borderline cases) (RCC, *Common Risk Criteria*).

Variability: Observed differences attributable to true heterogeneity or diversity. Variability is the result of natural random processes and is usually not reducible by further

¹⁴ Code of Federal Regulations, General Operating and Flight Rules, title 14, sec. 91.

measurement or study (although it can be better characterized) (RCC, *Common Risk Criteria*).

Unmanned Aircraft: An aircraft operated without the possibility of direct human intervention from within or on the aircraft (FAA, *Air Traffic Organization*). See also *Unmanned Air Vehicle*

Unmanned Aircraft System: An unmanned aircraft and associated elements, including communication links and the components that control the aircraft that are required for the pilot in command to operate safely and efficiently in the national airspace system (FAA, *Air Traffic Organization*).

Unmanned Air Vehicle: The aircraft portion of the unmanned aircraft system. See also *Unmanned Aircraft*.

Undirected Flight: 1. The vehicle continues to maintain powered flight but is not responsive to operator commands.¹⁵ 2. An interruption or loss of the control link, or when the pilot is unable to effect control of the aircraft and, as a result, the UA is not operating in a predictable or planned manner. Also *flyaway* (FAA, *Air Traffic Organization*).

Waiver: Granted use or acceptance of an article that does not meet the specified requirement (RCC, *Flight Termination*).

Warning Area: A warning area is airspace of defined dimensions extending from three nautical miles outward from the coast of the U.S. that contains activity that may be hazardous to nonparticipating aircraft. The purpose of such warning areas is to warn nonparticipating pilots of the potential danger. A warning area may be located over domestic or international waters or both (FAA, *Aeronautical...*).

¹⁵ Range Commanders Council. *Unmanned Aerial Vehicle Mishap Taxonomy for Range Safety Reviews*. RCC 326-16. February 2016. May be superseded by update. Retrieved 30 November 2017. Available at https://www.trmc.osd.mil/wiki/download/attachments/91390743/326-16_UAV_Mishap_Taxonomy.pdf

Appendix B

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