



RANGE SAFETY GROUP

DOCUMENT 323-99

RANGE SAFETY CRITERIA FOR UNMANNED AIR VEHICLES

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RANGE SAFETY CRITERIA FOR UNMANNED AIR VEHICLES

INTRODUCTION

The Range Safety Criteria for Unmanned Air Vehicles (UAVs) document provides a common approach for the Range Commander to make decisions regarding UAV flight operations. These criteria 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?"

The use of this tool depends on the needs of the Range Commander. Examples of when the tool might be used include First Flight Readiness Reviews, new types of missions or tests, or to help review existing procedures.

Multiple criteria are used to examine flight safety from the perspective 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:

- a. Are system hazards recognized and risk controls available?
 1. Risk management criteria
- b. How is this range vulnerable to these identified system hazards?
 2. Casualty expectation criteria
 3. Property damage criteria
 4. Midair collision avoidance criteria
- c. If safeguards are needed to reduce risk, will they work?
 5. Adequacy of safeguards criteria

The five criteria are described in the following sections, along with the conditions necessary to meet the criteria. The criteria are based on guidance from safety specialists, existing reference standards and policies, and established procedures. The supplement to this document, "RANGE SAFETY CRITERIA FOR UNMANNED AIR VEHICLES RATIONALE AND METHODOLOGY," describes rationale and methodology supporting the criteria, as well as examples, definitions and alternatives to consider if the criteria cannot be met.

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1. RISK MANAGEMENT CRITERIA

The goal of risk management criteria is to ensure system hazards which may affect range safety are recognized, and have control measures available. The range can use this criteria to review the range user's risk management program, regardless of what type of risk management approach is used. For the risk management criteria to be met, the following conditions must be satisfied:

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 corresponding in scope to the type of UAV and the nature and location of the flights has been performed.
- 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 addressed.
- In the absence of a hazard analysis, an independent hazard analysis by Range Safety, System Safety, Aviation Safety, or other safety representative may be considered.

1.2 Hazards Assessed: *A hazard analysis or similar document describes the level of risk associated with identified hazards.*

- The level of risk associated with the hazards has been identified in terms of severity and probability of occurrence.
- The probability of critical single-point and common-mode failure components has been assessed.
- The severity and probability levels are valid on the specific range where the test or operation will take place. Hazards assessment has been reviewed for each new

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range to be flown to ensure risk exposure does not increase to an unacceptable level.

- Hazards which are "accepted risk" have been identified as such.

1.3 Control Measures and Risk Decisions: *Control measures to reduce risks to an acceptable level are identified.*

- Control measures are chosen to reduce, mitigate, or eliminate the risk.
- A review and decision process has been followed for hazards which exceed the acceptable level of risk at the appropriate level of management.

1.4 Hazard Controls: *Control measures identified in the hazard analysis are incorporated.*

- Safeguards 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.

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.*

- The range organization has identified personnel 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. CASUALTY EXPECTATION CRITERIA

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

The hazards associated with a specific UAV are defined in the hazard analysis (risk management criteria). 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.

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The criteria is met if the hazard is confined to unpopulated areas (2.1) or if the combined vehicle reliability and population distribution results in a risk is no greater than that for manned aircraft operations (2.2).

2.1 No Risk to Human Life Because Hazard is Contained: *The planned route of flight is acceptable, because the flight can be confined to unpopulated areas. Considerations include:*

- Verification that the area is unpopulated through monitoring or exclusion (fence).
- Recognition of failure modes which could result in the UAV leaving airspace over the unpopulated area, and history of this vehicle or similar designs encountering these failure modes.
- If necessary, an independent or highly reliable system (e.g., Flight Termination System) is used to ensure the vehicle does not leave assigned airspace.
- Verification that use of "fly home" or "emergency mission" software routines keeps the vehicle inside the assigned airspace over unpopulated area boundary on loss of control link.
- System maturity may or may not support requirement for additional safeguards to keep the UAV inside assigned airspace.

2.2 Equivalent Risk to Manned Aircraft: *A prediction of the average risk to people within the planned area of flight or along the planned route of flight is acceptable, and avoidance of high population density "hot spots" is considered.*

2.2.1 Casualty Expectation: *Must be less than one casualty in a million flight hours.*

- Casualty expectation is based on UAV reliability predictions or mishap history, crash kinetic energy, vehicle dimensions, routing, and population census 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.

2.2.2 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 electronic or material malfunction. Route avoids densely populated areas, especially during phases of flight with increased risk.*

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- Route should avoid areas of high population density such as towns, schools, hospitals, stadiums etc., which would cause the momentary casualty expectation to exceed the acceptable level.
- Typical critical phases of flight with an increase risk of mishap include takeoff and climb-out, approach and landing, and unusual maneuvers that could cause structural failure or loss of controlled flight.

3. PROPERTY DAMAGE CRITERIA

Identify high value properties or high consequence sites to avoid. This criteria is met if the critical sites are identified and a route is selected that avoids these locations.

3.1 High Value Property Identified: *High value property which, if damaged, would result in an unacceptable consequence are identified. Examples include:*

- Items which could trigger larger hazards if damaged, such as fuel farms, power plants, and ammunition storage sites
- National assets such as ground satellite antennas to national satellite systems, strategic systems
- Costly structures such as expensive range facilities
- Locations containing Native American and environmentally sensitive areas.

3.2 Route Selection: *Route avoids high consequence property, especially during phases of flight with increased risk.*

- Route should avoid high consequence property such as fuel tank farms, nuclear power plants, etc.
- Examples of critical phases of flight with an increase risk of mishap include:
 - takeoff and climb-out
 - approach and landing
 - unusual maneuvers which could cause structural failure or loss of controlled flight
 - continued flight after failure of one leg of a redundant flight-critical subsystem
- Orbiting over these sites should be avoided.

4. MIDAIR COLLISION AVOIDANCE CRITERIA

Collision is avoided by isolating the vehicle from other aircraft or compensating for differences with manned aircraft which 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 in other than Restricted and Warning Areas.

4.1 Midair Collision Avoidance Criteria: 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 UAVs mission or test event will be permitted in the exclusive airspace.*

This criteria is met if the UAV is contained inside restricted airspace or a warning area, non-participants are excluded, and participants are adequately briefed.

4.1.1 UAV Containment: *Assurance that UAV can be contained within the restricted or warning area boundaries defined. Considerations may include:*

- Recognition of failure modes which could result in the UAV leaving assigned airspace, and history of this vehicle or similar designs encountering these failure modes. This includes consideration of airspace above and below the restricted or warning area.
- Installation of a Range approved independent and highly reliable system (e.g., Flight Termination System) 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 requirement for additional safeguards to keep UAV inside assigned airspace.
- Verification that Air Traffic Control (ATC) or military radar unit (MRU) can monitor vehicle position for containment, and to communicate with UAV controllers in a timely manner.

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4.1.2 Exclusion of Other Aircraft: *Assurance that other aircraft can be kept out of the airspace dedicated to UAV mission use. Considerations may include:*

- Boundaries of the restricted airspace or warning areas are explicitly defined and recognized by other airspace users.
- The restricted area or warning area is activated.
- Where capabilities exist, demonstrate ability to monitor the airspace within and near the restricted or warning area and communicate with traffic which may conflict.
- Where monitoring capabilities are limited or do not exist, demonstrate ability to control the airspace through scheduling or standardized local procedures. Potential risk associated with limitations of the ability to monitor and communicate with traffic in the restricted or warning areas must be recognized.

4.1.3 Participant Coordination: *UAV operators ensure that flight crews and ATC (or MRU controllers) understand the operation as well as recognize the limitations of the UAV. A local "standard operating procedure" may address routine operations. This coordination may include:*

- Mission briefs, review of UAV peculiar procedures.
- Flight crews and ATC following established and approved procedures for that range.

4.2 Midair Collision Avoidance Criteria: Shared Use within Restricted Airspace or Warning Areas - *The UAV will be flown in restricted or warning areas along with other aircraft which may not be participating in the UAV's mission or test event.*

This criteria is met if the UAV is contained inside restricted airspace or a warning area, and differences between UAVs and manned aircraft that increase risk to other aircraft (e.g. "see and avoid," response delays, etc.) are accounted for.

4.2.1 UAV Containment: *Assurance that UAV can be contained within the restricted or warning area boundaries. Considerations may include:*

- Recognition of failure modes which could result in the UAV leaving the restricted or warning area, and history of this vehicle or similar designs encountering these failure modes. This includes consideration of airspace above and below the restricted or warning area.

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- Installation of a Range approved independent and highly reliable system (e.g. flight termination system) 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 requirement for additional safeguards to keep UAV inside assigned airspace.
- Verification that ATC or MRU can monitor vehicle position for containment and to communicate with UAV controllers in a timely manner.

4.2.2 Compensating for See and Avoid Limitations: *The see and avoid 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 vision of UAV controller and to increase chance of being seen by 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 is adequate.
- Use of a ground observer for low flying UAVs.
- A plan to actively avoid conflicts which considers performance the limitations of the vehicle.

4.2.3 Compensating for Delays with ATC Instruction: *Vehicles with limited or no see and avoid capability are dependent on ATC or MRU for safe separation. Communication and control delays may increase in comparison with 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 local established deconfliction procedures.

4.3 Midair Collision Avoidance Criteria: *UAV Operations in other than Restricted and Warning Areas - UAV plans to enter National Airspace, other than restricted area or warning area. FAA is responsible for aircraft separation during Instrument Flight Rules*

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(IFR) conditions, and is responsible for regulations regarding aircraft separation in Visual Flight Rules (VFR) conditions. The FAA must authorize and approve the flight.

This criteria is met with documentation of FAA approval and review and approval by the accountable government sponsor.

4.3.1 FAA Approval: *UAVs which plan to enter the National Airspace System shall conform with FAA regulations and gain approval from the regional FAA representative. A Certificate of Authorization is required.*

4.3.2 DoD / NASA Review: *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.*

4.3.2.1 UAV Containment: *Assurance that 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 which 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., flight termination system) to ensure vehicle does not leave assigned route of flight.
- Verification that on "loss of control link," use of "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 requirement for additional safeguards to keep the UAV on assigned route and within assigned altitude limits.
- Verification that ATC can monitor vehicle position and communicate with UAV controllers in a timely manner.

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4.3.2.2 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 vision of UAV controller and to increase chance of being seen by other aircraft.
- Use of bright colors or lights to increase the visibility of the UAV.
- Use of radar surveillance in UAV flight area.
- Use of a ground observer for low flying UAVs
- A plan to actively avoid conflicts which considers the performance limitations of the vehicle.

4.3.2.3 Compensating for Delays with ATC Instruction: *Vehicles with limited or no see and avoid capability are dependent on ATC for safe separation. Communication and control delays may increase in comparison with those of manned aircraft. 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. CRITERIA FOR RELIABILITY AND ADEQUACY OF SAFEGUARDS

There must be evidence to show that required 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 safeguards include, but are not limited to:

- Emergency remote pilots
- Flight termination systems
- Software "fly home" routines
- Parachutes

Additional guidance is provided below.

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5.1 Hardware Safeguards: *Evidence shows that the reliability of required hardware safeguards are adequate. The range may require one or more of the following:*

- Evidence reliability is 0.999 at 95% confidence level in a representative environment.
- Verification the FTS subsystems meet the current RCC flight termination standard (i.e. RCC Document 319-99 or equivalent)
- Proof the safeguard subsystem meets an established reliability standard for that type of safeguard.
- Evidence the system or safeguard has been tested and can be monitored in flight or will be explicitly checked before flight.

5.2 Software Safeguards: *Evidence shows that 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.
- Hazard control measures identified in the software hazard analysis have been implemented and are adequate.

5.3 Procedural Safeguards: *Evidence shows 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 by the Range Commander or delegated representative.

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CRITERIA CHECKLIST

1. RISK MANAGEMENT CRITERIA

For the risk management criteria to be met, the following conditions must be satisfied:

Condition	condition met / not met / comment
1.1 Hazards Identified: <i>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.</i>	
1.2 Hazards Assessed: <i>A hazard analysis or similar document describes the level of risk associated with identified hazards.</i>	
1.3 Control Measures and Risk Decisions: <i>Control measures to reduce risks to an acceptable level are identified.</i>	
1.4 Hazard Controls: <i>Control measures identified in the hazard analysis are incorporated.</i>	
1.5 Supervision: <i>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.</i>	

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2. CASUALTY EXPECTATION CRITERIA

The criteria is met if the hazard is confined to unpopulated areas (2.1) or if the combined vehicle reliability and population distribution results in a risk no greater than manned aircraft operations (2.2).

Condition	condition met / not met / comment
2.1 No Risk to Human Life Because Hazard Is Contained: <i>The planned route of flight is acceptable, because the flight can be confined to unpopulated areas.</i>	
2.2 Equivalent Risk to Manned Aircraft: <i>(2.2.1) Casualty Expectation less than one casualty in a million flight hours.</i>	
2.3 Equivalent Risk to Manned Aircraft: (2.2.2) <i>Routes and altitudes are selected to minimize the possibility of the UAV falling into a congested area in the event of electronic or material malfunction. Route avoids densely populated areas, especially during phases of flight with increased risk.</i>	

3. PROPERTY DAMAGE CRITERIA

This criteria is met if the critical sites are identified and a route is selected to avoid vulnerable locations.

Condition	condition met / not met / comment
3.1 High Value Property Identified: <i>High value property which if damaged would result in an unacceptable consequence are identified.</i>	
3.2 Route Selection: <i>Route avoids high consequence property, especially during phases of flight with increased risk.</i>	

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4. MIDAIR COLLISION AVOIDANCE CRITERIA

There are three cases of midair collision avoidance criteria to accommodate different situations. Consider those cases which apply:

4.1 Midair Collision Avoidance Criteria: Exclusive Use within Restricted Airspace or Warning Areas - *This criteria is met if the UAV is contained inside restricted airspace or a warning area, non-participants are excluded, and participants are adequately briefed.*

Condition	condition met / not met / comment
4.1.1 UAV Containment: <i>Assurance that UAV can be contained within the boundaries defined as restricted airspace.</i>	
4.1.2 Exclusion of Other Aircraft: <i>Assurance that other aircraft can be kept out of the airspace dedicated to UAV mission use.</i>	
4.1.3 Participant Coordination: <i>UAV operators ensure flight crews and ATC (or MRU controllers) understand the operation as well as recognizing the limitations of the UAV.</i>	

4.2 Midair Collision Avoidance Criteria: Shared Use within Restricted Airspace or Warning Areas - *Meet the following conditions:*

Condition	condition met / not met / comment
4.2.1 UAV Containment: <i>Assurance that UAV can be contained within the restricted or warning area boundaries.</i>	
4.2.2 Compensating for See and Avoid Limitations: <i>The see and avoid limitations of the UAV are recognized and compensated for.</i>	
4.2.3 Compensating for Delays with ATC Instruction: <i>Vehicles with limited or no see and avoid capability are dependent on ATC or military radar unit (MRU) for safe separation. Communication and control delays may increase in comparison with those of manned aircraft. Vehicle response must match airspace conditions and requirements.</i>	

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4.3 Midair Collision Avoidance Criteria: UAV Operations in other than Restricted and Warning Areas - Meet the following conditions:

Condition	condition met / not met / comment
4.3.1 FAA Approval: <i>UAVs which plan to enter the National Airspace System shall conform with FAA regulations and gain approval from the regional FAA representative. A Certificate of Authorization is required.</i>	
4.3.2.1 UAV Containment: <i>Assurance that UAV can be contained within the boundaries of the pre-planned route of flight defined in the flight plan and approved by the FAA.</i>	
4.3.2.2 Compensating for See and Avoid Limitations: <i>The limitations of the UAV are recognized and compensated for.</i>	
4.3.2.3 Compensating for Delays with ATC Instruction: <i>Vehicles with limited or no see and avoid capability are dependent on ATC for safe separation. Communication and control delays may increase in comparison with those of manned aircraft. Vehicle response must match airspace conditions and requirements.</i>	

5. CRITERIA FOR RELIABILITY AND ADEQUACY OF SAFEGUARDS

5.1 Hardware Safeguards: The range may require one or more of the following:

Condition	condition met / not met / comment
Evidence reliability is 0.999 at 95% confidence level in a representative environment.	
Proof FTS subsystems meet the current RCC Flight Termination System standard (i.e., RCC Document 319-99 or equivalent).	
Verification the safeguard subsystem meets an established reliability standard for that type of safeguard.	
Evidence the system or safeguard has been tested and can be monitored in flight or will be explicitly checked before flight.	

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5.2 Software Safeguards: Meet both of the following conditions:

Condition	condition met / not met / comment
Software used in safeguard functions must show evidence of a software safety program in which software hazard analysis has been performed.	
Hazard control measures identified in the software hazard analysis have been implemented and are adequate.	

5.3 Procedural Safeguards: Meet both of the following conditions:

Condition	condition met / not met / comment
Operator procedures, which will be used as a safeguard, must be documented.	
Procedures must have been reviewed and approved by the Range Commander or delegated representative.	