Final Report
ASSURE A28: Disaster Preparedness and Response Using UAS
Appendix E – Operational Risk Assessment (ORA)

June 1, 2022

NOTICE

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ATC	Air Traffic Control
COA	Certificate Of Authorization
CONOP	Concept of Operation
FAA	Federal Aviation Administration
lUAS	Large Unmanned Aircraft System
ORA	Operational Risk Assessment
sUAS	Small Unmanned Aircraft System
UAS	Unmanned Aircraft System

1. OPERATIONAL RISK ASSESSMENT (ORA)

1.1 Purpose of an Operational Risk Assessment (ORA)

An ORA supports the analysis of a Concept of Operation (CONOP) to identify if mitigation actions are in place to conduct Unmanned Aircraft Systems (UAS) missions with an acceptable level of risk.

An ORA should include specific details to support the authorization of the CONOP for the specific UAS mission. The ORA follows a consistent approach to assess the acceptability of risks and mitigation procedures for mission safety. Mitigation procedures for each risk outlined in an ORA provide details on the best strategy and mitigation action to reduce risk to a level acceptable for safe operations. Mitigation procedures ensure acceptable risk levels for the proposed operations. Federal Aviation Administration (FAA) severity and likelihood decision matrices are used to assess the hazard risk level for operations and the adjusted risk when the mitigation measure is in place.

1.2 Process of Using the ORA along with the CONOP

The methodology of applying the ORA with the CONOP focuses on establishing, with a level of confidence, that the operations can be conducted with an acceptable level of risk. The evaluation process centers on assessing the ground and air risk along with any risk placed on critical infrastructure in and around the mission location. The CONOP is evaluated against the defined hazards in the ORA to check that the CONOP includes mitigation procedures to ensure that the severity and likelihood of the hazard impacting flight operations are at a minimum.

1.3 Risks Associated with UAS Flight Operations

In building an ORA, the hazards that can impact flight operations are collated into six categories that focus on adverse operating conditions, external systems, human factors, the UAS itself, and cyber threats to UAS operations.

<u>Adverse Operating Conditions:</u> These hazards focus on conditions/events outside the aircraft being flown that can impact flight operations. Two hazards included in this category - Collision into Terrain and Terrestrial Entities, and Mid-Air Collision – can be classified as a UAS technical issue or a human error. Since either a UAS technical malfunction and/or human error could cause these hazards, the ORA classifies them under Adverse Operating Conditions. Additional hazards in this category include Inclement Weather Conditions on Site and Unexpected Winds Aloft.

<u>Deterioration of External Systems:</u> These focus on the systems and equipment hazards that can cause an unacceptable level of risk to the mission. In this category, hazards are external to the aircraft or to any payloads or instruments onboard. Examples of hazards include Generator Failure; Loss Function of Tracking Antenna; and Loss of Ground Control Station.

<u>Human Error:</u> These hazards relate to impacts that human operations and error can have on mission safety. This can include human error- from the flight team or anyone near the mission. Hazards include Human Factor Events (such as fatigue and loss of Situational Awareness; Loss of Communications Between crew Members; Loss of Communications between the Flight Crew and Air Traffic Control (ATC); and Non-Crew Member Interruption of Flight Crew.

<u>UAS Technical Issues:</u> This category focuses on the mission UAS and its associated on-board and command and control equipment. All aspects that involve the UAS during a disaster response are

listed within this section. Hazards include Aircraft Fly Away; Engine/Power Failure; Frequency Interference; Global Positioning System Signal Outage; Loss of Navigational Control; Loss of UAS Command and Control link; Stuck Landing Gear (for appropriate UAS); Tire/Brake or Landing Gear Failure; and Unrecoverable Onboard Failure/Malfunctions.

UAS Cyber Threats: This final category focuses on risks that can result from cyber-based attacks to the UAS missions. Three threats are provided: Unmanned Aerial Vehicle hardware, Ground Control System, and Network link cyber-attacks.

1.4 Risk Assessment Table Structure

Each hazard has an associated risk, along with a mitigation procedure and action to minimize the severity of the impact and likelihood of occurrence. The causes and possible effects if the hazard were to occur are included in the ORA. The purpose of the ORA is to determine the hazards that can impact safe flight operations under the CONOP. For these hazards, an ORA assesses the risk they place on operations and classifies them based on severity versus likelihood matrices. Next, the mitigation action and post assessment are defined that reduce the risk to an acceptable level for safe operations. The final task, per hazard, is to classify the final risk on operations that it has given the mitigation actions in place. Below are definitions on the required content within the ORA Hazard and Mitigation Risk Assessment Table. These describe how the table is used to cross reference with the CONOP to evaluate if the proposed mission has an acceptable level of risk.

Risk Category: As defined in the previous section, this defines the category of the specific hazard.

Hazard Description: This description provides sufficient details to ensure that the evaluator of the CONOP can reference to the location of where the hazard impacts the disaster specific CONOP.

Hazard Assessment: This assessment provides the causes that lead to this hazard occurring during a specific mission. This lists the likely causes of the hazard impacting a mission to support the CONOP evaluation so that the hazard does not put a mission at an unacceptable level risk.

Hazard Assessment Description: This section provides details for each hazard on the effects caused if it occurs and potential knock-on effects to the flight operations. This provides sufficient details on the hazard so that all impacts are catalogued, and the appropriate mitigation action and procedures are defined to mitigate the risk to flight operations.

Original Hazard Risk: This section classifies the severity and likelihood for the hazard. Using the risk matrices in Section 1.9 for both small (sUAS) and large UAS (lUAS), the hazard is classified with an associated code. For example: a code of C1 related to Likelihood: Remote (C) and Severity: Catastrophic (1) with color = Red for a High-Risk Hazards for both sUAS and lUAS. Note for B3 code the color is yellow for sUAS and red for lUAS.

Mitigation Action: This section provides sufficient information on the mitigation procedures performed by the flight team/crew member to minimize the impact of the hazard on the flight operations. When analyzing the CONOP, the detailed mitigation plans from the ORA Hazard and Mitigation Risk Assessment Table should be included if the hazard could impact the flight operations. This ensures that the CONOP is approved with an acceptable level of risk for safe flight operations

Mitigation Post Assessment: This section provides details on the impact that the mitigation action has on the severity of the hazard and likelihood of its occurrence. In evaluating the acceptable risk for safe flight operation, this assessment demonstrates how the procedures benefit safe flight operations

Residual Hazard Risk: This section determines the residual risk on flight operations with the mitigation action and procedure in place using the severity versus likelihood matrices Section 1.9 for both small and large UAS. Here, the residual risk is lower than the original hazard risk. For example: Under the UAS Technical Issue category, there is the hazard of an “Aircraft Flyaway”. The original risk for this hazard is B2 (Severity: Hazardous; Likelihood: Probable) and High-Risk. The mitigation action reduced this to D4 (Severity: Extremely Remote; Likelihood: Minor) and Low-Risk.

1.5 Real-time Hazards to Flight Operations

For specific disaster responses, additional risks may occur during flight operations. These hazards should be evaluated using the ORA Hazard and Mitigation Risk Assessment Table highlighted in Section 1.9 with appropriate mitigation actions to minimize the severity and likelihood of the hazard impacting operations. This ensures the CONOP is completed with acceptable level of risk. Assessing these hazards in real-time as flight operations occurs, the flight crew will determine mitigation actions to minimize the impact of these hazards on the safety of the flight. Adding new hazards to the ORA Hazard and Mitigation Risk Assessment Table, as they occur, supports the building of even more comprehensive risk assessment of operations for each specific disaster response and/or preparedness mission. Updated ORA Hazard and Mitigation Risk Assessment Tables can be used by follow-on UAS missions.

1.6 Adding in Disaster Response Hazards

In building an ORA for each disaster response, the lead organization follows the same procedure for common hazards as defined in the ORA Hazard and Mitigation Risk Assessment Table, Table 1 in Section 1.8, and include specific hazards where appropriate. These disaster-specific hazards are defined following the common design in the ORA Hazard and Mitigation Risk Assessment Table with an original risk for the hazard and defined mitigation actions with a final residual risk for the hazard impact flight operations.

Example: Volcanic-based disaster responses have unique hazards, like impact of ash on aircraft maintenance and/or plumes from cooling lava flows. Such hazards could impact flight operations but would likely not occur in other non-volcanic disaster response.

1.7 ORA Summary

ORAs support the evaluation of CONOPS to ensure that they can be completed with an acceptable level of risk with safe flight operations in the National Airspace System. Severity versus likelihood matrices are used to define the risk for each potential hazard. Once mitigation actions and procedures are defined, the residual risk is outlined for each hazard. With these mitigation actions in place, the CONOP has sufficient procedures for flight operations to occur within the acceptable level of risk.

1.8 ORA Hazard and Mitigation Risk Assessment Table

The risk assessment table which follows is used to define the hazards that could put the mission at risk along with a classification of their risk category using the severity versus likelihood matrices from Figures 1 and 2 in Section 1.9, both for small and large UAS. The right-hand side of the table provides details per hazard on the mitigation action and post assessment that reduces the hazard risk and support safe flight operations under the CONOP. This table provides the common structure to use when developing an ORA per disaster response or preparedness CONOP.

Table 1. ORA Hazard and Mitigation Risk Assessment Table.

Risk Category	Hazard			Original Hazard Risk - sUAS	Original Hazard Risk - lUAS	Mitigation		Residual Hazard Risk - sUAS	Residual Hazard Risk - lUAS
	Description	Assessment	Assessment Description			Action	Post Assessment		
Adverse Operating Conditions	Collision into Terrain and Terrestrial Entities	This hazard would be caused through a collision with a structure or people. A structure is any item on the ground, both stationary (such as a building) or mobile (such as a vehicle). Those people who could lead to a collision with an unmanned system include the public and mission crew.	Possible effects are extensive damage to structures impacted by the UAS as well as minor to severe injuries to humans. In addition, collisions can lead to vehicular collisions and road accidents for those mobile structures.	C2	C2	The Pilot in command (PIC) will perform a controlled descent towards the terrain, population, built-up structures and/or vehicles/vessels. The choice of mission location will mitigate this risk through enclosing an area with sparse population and structures, avoiding built-up areas and heavily trafficked airways. The mission PIC will invoke a return to base (RTB) or return to landing (RTL). This suspends the onward flight path and commands the UAS to return to base. The mission PIC will invoke a Divert Land Immediately (DLI), which suspends the onward flight path and commands the UAS to land at a designated landing zone, in a controlled manner at the maximum safe descent rate.	The risk that the hazard can have on operations is reduced by pre-defined flight paths, which are chosen in advance of operations and verified, prior to first flight.	E3	E3
Adverse Operating Conditions	Mid-Air Collision	This hazard would result from participating or non-participating aircraft failing to comply with See-and-Avoid requirement, non-participating aircraft fail to monitor appropriate air traffic control (ATC) frequency, and/or non-participating aircraft operating well below airway altitude.	Possible effects resulting from an event are loss of UAS and damage or loss of participating or non-participating aircraft.	C1	C1	As a part of the safety case, the operators will submit details on the airspace characterization. The mission team will navigate with lights on UAS, use Automatic Dependent Surveillance-Broadcast (ADS-B) compliant transponders, display ATC/ADS-B traffic maps for local traffic awareness, and immediately land or terminate flight. If the non-participating aircraft approaches unmanned aircraft (UA), such that UA cannot avoid approaching aircraft's flight path, the team will conduct potential air traffic/airspace briefing with all crewmembers and participants and comply with ATC separation instructions. Under Part 107 operations, a visual observer would support the PIC to monitor the aircraft and airspace around it to minimize potential impact and have continued communications throughout the mission. Once the ATC (or VO) has identified traffic and an encounter is likely, the PIC will determine the exact avoidance maneuver to be utilized and will initiate that maneuver. The preferred order for invoking the avoidance maneuvers, in decreasing order of preference, will be used: Divert and Loiter (DAL) > Return to Base (RTB) > Divert Land Immediately (DLI) > Terminate Flight (TER). For BVLOS operations in uncontrolled airspace, radar systems (or other sensors to detect non-cooperative traffic) will be needed.	This hazard remains a severe hazard and including mitigation actions will focus on reducing likelihood of occurrence to extremely unlikely.	E1	E1
Adverse Operating Conditions	Rapid Onset of Inclement Weather or Disaster Specific Weather	This hazard can be caused by a lack of or not current weather briefing and/or localized winds due to terrain. Additionally, disasters like Wildland Fires, Volcanic Eruptions, or Nuclear Dispersion can cause beyond line of sight (BVLOS) operations or instrument flight rules (IFR) conditions.	Possible effects are potential loss of UAS control resulting in loss of lift, followed by uncontrolled descent into terrain/terrestrial entities or loss of line-of-sight operations and visual line of light (VLOS) flights becoming BVLOS or visual flight rules (VFR) conditions rapidly becoming IFR only.	B3	B3	During flight, if weather conditions deteriorate suddenly, the PIC assess if DLI is required or if they can invoke RTB resulting in a suspension of the onward flight path. DLI will ensure that the flight lands safely as close as possible to the original location. If the PIC can determine that flight can still operate with the RTB in place, then the UAS will follow this pattern, i.e., its launch/landing point. If this is not possible given the weather conditions, the mission will use the defined landing zones developed in the CONOP for divert land immediately. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	The action to RTB if weather conditions prevent safe flight operations minimizes the risk of this hazard impact the mission.	E3	E3
Adverse Operating Conditions	Unexpected Winds Aloft	This hazard can be a result of wind gusts and/or sustained winds exceeding UAS operating specifications.	Possible effects are loss of aircraft due to turbulence or inability to attain accurate performance data. Current operations would be to have a forced landing at unsurveyed landing location and/or Loss Link during the landing that may result in UAS attempting RTL.	D3	D3	The mission team will request a local Pilot Report (PIREP) from any aircraft in the vicinity and/or flight team will obtain briefings every hour of the flight operations or obtain local weather data including winds aloft from accredited source such as National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) for U.S. NAS missions.	The PIREPS and abbreviated weather briefings will increase the situational awareness of the flight crew and reduce the occurrence of unforeseen weather events impacting flight operations.	E3	E3
Deterioration of external systems	Generator Failure [on-board]	This hazard can be caused by engine component failure and/or rotor failure, depending on if large fixed-wing or small rotor UAS respectively.	Possible effects resulting from the occurrence of this hazard are a reliance on a backup battery or loss of aircraft. Current operations would be to check both generators pre-flight and ensure backup batteries are charged and checked before flight.	C3	C3	Mitigation would include assigning ditch points for the UAS in the concept of operation (CONOP) so that the team is prepared for safe landings if unable to return to home. Also, crew member responsible for mission team safety and the ground control station (GCS) should inform the PIC or mission manager on loss of power. Depending on the vehicle capabilities, it may not be possible to reach a prescribed ditch point during a power loss. However, if the vehicle can reach the ditch point, these points should be monitored for pedestrian/ground traffic to ensure safe landing is possible. VO's in place for VLOS operations will be used to support the PIC in understanding any risks on the ground below the aircraft's location when power is lost. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	The pre-flight checks of available power and backups will minimize the risk and reduce the likelihood of this risk impacting flight operations.	D4	D4

Risk Category	Hazard Description	Hazard Assessment	Assessment Description	Original Hazard Risk - sUAS	Original Hazard Risk - lUAS	Mitigation Action	Mitigation Post Assessment	Residual Hazard Risk - sUAS	Residual Hazard Risk - lUAS
Deterioration of external systems	Generator Failure [ground-based for GCS]	This hazard can be caused by a lack of power in the generator to support the GCS equipment when mains power is unavailable. Tt will impact other mission equipment that will need to operate on battery power until a backup generator power source is found.	Possible effects resulting from the occurrence of this hazard are a reliance on a backup battery for any ground-based equipment. Current operations would be to check all ground-based power sources pre-flight and ensure backup batteries are charged and checked before flight.	C3	C3	Mitigation include continued communication between PIC, VO's, mission lead and engineering team on the available backup battery power for all GCS systems to ensure that flight can be completed before unsafe conditions occur. Additionally, flight checklists ensure that backup generator power is available in remote locations where mains power is unavailable. If battery power for GCS systems is running low, the PIC will follow mitigations plans for DLI if unable to return to the landing zone. If the aircraft can return, the RTB will be invoked when the PIC determines it is needed to ensure safe operations and that the aircraft can return.	The pre-flight checks of available power and backups will minimize the risk and reduce the likelihood of this risk impacting flight operations.	D4	D4
Deterioration of external systems	Loss Function of Tracking Antenna	Causes include tracking antenna losses either its GPS position or the aircraft's, antenna becomes disconnected from Control Station subsystem, and/or antenna subsystem mechanical failure.	Possible effects are that when outside of omni-directional range, aircraft must rely on satellite link for C2 requirements, and some UAS do not have this function. Testing of any tracking antenna equipment in mission planning stage to reduce likelihood of this hazard.	C3	C3	GCS parameters are set to ensure the aircraft returns to the assigned point in the event of loss link.	Utilization of a satellite link will minimize safety of flight impact for large UAS while emergency landing zone for small UAS will ensure no UAS fly away when tracking lost.	D5	D5
Deterioration of external systems	Loss of the Ground Control Station (GCS	This hazard could be caused by computer reboot, loss of power, frozen screen, or cold conditions leading to GCS shutdown.	Possible effects to flight operations are inability to effect maneuvers when required.	C3	C3	Upon loss of the GCS, the PIC will intervene and take control of the UAS using a separate hand-held radio controller, operating on a different command-and-control (C2) link frequency, and command it to return to base. Additionally, for beyond visual line of sight (BVLOS) operations, a loss of the GCS will result in a loss of the C2 link from the GCS. At this point, the flight team will use the lost link contingency procedures. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	The severity of this risk is lowered using backup GCS systems to ensure C2 links along with RTL options support a safe mission and lower risk on the operations.	E3	E3
Human Factors	Physiological Human Factors Event	This hazard would result from a loss of situational awareness (SA), crew miscommunication, and crew fatigue.	Possible effects to safe flight operations are an inability to effect timely avoidance maneuvers, if required.	C3	C3	During the pre-flight brief, the PIC will check to ensure that the flight team are able to complete the planned flight. Only a flight team that can complete the CONOP will be able to be a part of the mission. Pre-flight briefings will be used to ensure all crew members are aware of their responsibilities.	The likelihood of this risk is lowered with flight checklist and pre-flight briefings to all the crew.	E4	E4
Human Factors	Loss of Communications Between Crew Members	This hazard results from communications equipment failure, insufficient battery power, and/or radio interference from external source.	Possible effects include crewmembers unable to notify each other of abnormal operations and/or a potentially hazardous situation is not communicated. This has a minor severity as existing procedures require aircraft to stay in place in the event of loss of communications between aircraft and flight team.	C3	C3	The mission team will ensure that UAS PIC, Crew, ATC communications plan, call sign and protocols are briefed at each pre-flight briefing. Also, the team will ensure spare batteries are available for all communication devices. Note that loss of communications between PIC's, VO's (or personnel used for SAA requirements), and/or ATC may be grounds for termination of flight operations. The PIC will assess this based on the mission and their situational awareness on the location of the airspace and aircraft. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	A pre-flight briefing including flight checklists and confirmation that all checks have occurred before flight will reduce the likelihood of this hazard occurring and impacting safe flight operations	E4	E4
Human Factors	Loss of Communications Between Flight Crew and Air Traffic Control (ATC)	This hazard would result from communications equipment failure, insufficient battery power, and/or radio interference from external source.	Possible effects are loss of ability to notify ATC of potentially hazardous or unplanned flight operation and/or loss of ability of ATC to provide UAS crew traffic advisories. Minor severity as aircraft will ground if loss of communications between flight crew and ATC.	C3	C3	Mission team will ensure that UAS PIC, Crew, ATC communications plan, call signs, and protocols are briefed at each pre-flight briefing. Including a satellite phone in the mission checklist will ensure that additional communication equipment will mitigate this hazard impacting flight operations. Note that loss of communications between PIC's, VO's (or personnel used for SAA requirements), and/or ATC may be grounds for termination of flight operations. The PIC will assess this based on the mission and their situational awareness on the location of the airspace and aircraft. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	Hazard is only minor severity and extremely improbable.	D5	D5
Human Factors	Non-crew Member Interruption of Flight Crew	Causes for this hazard occurring and impacting operations include spectators watching the mission asking questions or getting too close to the crew members who are performing the mission.	Possible effects on safe flight operations are a loss of aircraft control by the PIC, if being flown manually and/or if being used the loss of visual line of sight on the aircraft by the VO. Current operational procedures ensure sterile control station procedures along with safety equipment including no crossing cones, tape to cordon off the mission location, and a preflight briefing from PIC to highlight the sterile control station briefing.	C3	C3	Prior to take-off, the PIC will remind those present of the sterile control station requirements. Also, a crew member not performing PIC or VO duties is assigned to brief any approaching spectator. This role should be laid out in the roles and responsibilities section of the CONOP. Finally, prior to the landing the PIC should rebrief the mission team and its vicinity on the sterile control station procedure and environment.	The briefings and assigned crew member reduce likelihood impacting operations and support the team to react if a non-crew member approaches the flight crew.	D4	D4

Risk Category	Description	Hazard Assessment	Assessment Description	Original Hazard Risk - sUAS	Original Hazard Risk - lUAS	Mitigation Action	Post Assessment	Residual Hazard Risk - sUAS	Residual Hazard Risk - lUAS
UAS Technical Issue	Aircraft Fly Away	For this hazard, causes include pilot error, UAS subsystem failure, and/or interference from external source.	Possible effects to operations are inadvertent flight into the path of nonparticipating aircraft resulting in mid-air collision; Inadvertent flight into terrain; UAS departing the operating area; and/or loss of UAS.	B2	B2	The PIC will ensure that the flight plan coordinates are verified prior to uploading to the aircraft. Additional equipment available to the PIC will be used to communicate with those leading the disaster response, any nearby general traffic in the airspace and/or other UAS support a disaster response. If the fly away extends beyond the disaster response area, then any local ATC will be informed using the same channels used to connect when briefing them of UAS operations.	Detailed workflow to ensure that all flight plans are correctly uploaded will ensure that the probability of occurrence is lowered as to present no unacceptable residual risk.	D4	D4
UAS Technical Issue	Engine/Power Failure	With this hazard, causes include component failure, power starvation, or improper engine/motors tuning and operations.	Possible effects to flight operations include a loss of thrust/altitude and/or UAS impact with the ground and uncontrollable flight.	C3	C3	The mission team will leave at least 1 hour of reserve fuel on board throughout entire flight profile if large UAS or sufficient power for return to home for battery based small UAS. The mission team will ensure that the flight checklists include details on population density and communities along their flight route. Also, alternative landing sites will be identified so that the PIC can manually fly the UAS to the new landing zone or the aircraft can be assigned to a new landing site if automated flight is still possible under safe operations. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	With proper maintenance and fuel/power management will lower the likelihood.	C4	C4
UAS Technical Issue	Frequency Interference	This hazard causes include entities transmitting on or near UAS frequencies at high power level.	Possible effects include a loss C2 or video link condition resulting in inability to complete testing regimen and GPS inaccuracy resulting in loss of navigational accuracy.	D2	D2	The mission team will track the C2 frequency strength between GCS and aircraft. Additionally, the PIC will ensure that the flight checklist has information on the C2 coverage throughout the flight route.	Through a continued monitoring of frequency strength, the team will lower the risk and likelihood of loss in C2.	E5	E5
UAS Technical Issue	GPS Signal Outage	The hazard could be a result of a loss of lock on GPS satellite, aircraft flies into GPS denied area, aircraft flies into area where GPS signal is blocked by terrestrial entities, like buildings and vehicles.	Possible effects to flight operations are loss of UAS navigation capabilities potentially followed by deviation from approved flight path and/or breach of the operational range boundaries.	C3	C3	If a loss of GPS signal occurs during the in-flight phase of the operations, the UAS will begin to loiter in place. If the UAS has not reestablished a GPS link in 1 minute, the PIC will command avoidance DLI. This will suspend the onward flight path and cause the UA immediately to descend, at its maximum safe descent rate, from the current location to land in a controlled manner. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	Safe pre-flight briefings on procedures to follow will ensure the flight team are aware of what to do and safe emergency landing zones will minimize risk from this hazard.	E3	E3
UAS Technical Issue	Loss of Navigational Control	The hazard would be caused by Pilot error, UAS subsystem error, ground control system error, interference from external source.	Possible effects to flight operations are an inadvertent flight into the path of nonparticipating aircraft resulting in mid-air collision, as well as inadvertent flight into structure, vehicle, or person and/or loss of UAS.	D2	D2	Navigational coordinates will be verified prior to uploading to the UAS. UAS will be commanded to return to landing zone immediately if loss of navigation control to minimize time spent dead reckoning. For beyond visual line of sight (BVLOS) operations, the PIC will divert and land/land immediately (DLI), suspending the onward flight path and commanding the UAS to descend and land from its current location, in a controlled manner, at its maximum safe descent rate. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights.	The probability of occurrence is lowered as to present no unacceptable residual risk.	E2	E2
UAS Technical Issue	Loss of UAS Command and Control Link	With this hazard, causes include pilot error, UA system error, ground control system error, interference from external source.	Possible effects include an inadvertent flight into structure, vehicle, or person outside of the operating area, and/or loss of UAS.	C2	C2	There are four actions here to support safe flight operations: 1. ensure that the loss of C2 link return home routing does not conflict with air traffic routes including altitudes; 2. monitor common area traffic frequencies, 3. publish a NOTAM a minimum of 24 hours prior to flight, and 4. notify known airspace uses of UAS flight activity. Additionally, the PIC will ensure that the flight checklist has information on the C2 coverage throughout the flight route.	Severity is lowered as to constitute no unacceptable residual risk due to return home routing and landing will result in minimal asset damage.	E2	E2
UAS Technical Issue	Stuck Landing Gear	For this hazard, causes include damaged linkages and failed equipment that leads to landing gear stuck in one position. Note that this hazard is more likely for a large fixed wing UAS but depending on the type of small UAS, the landing gear may retract upon take-off and so may get stuck.	Possible effects to safe operations are that the mission team need to perform a manual landing with expected damage to the airframe.	C3	C3	The team will have the aircraft loiter over the landing zone while still staying within safe fuel/battery power limits. This will allow the team to assess a safe landing location and process.	Briefs by the PIC to the flight crew during pre-flight briefing on the procedure on how to react if landing gear gets stuck to prevent landing or impact a safe landing will minimize the risk.	D4	D4
UAS Technical Issue	Tire/Brake or Landing Gear Failure	Causes of this hazard include tire under/over inflation as well as wear for appropriate fixed-wing UAS. For other UAS that use landing gear rather than tires then cracks in the landing gear or failure to engage can lead to failure.	Possible effects on safe operations are loss of positive control either during take-off or landing.	D3	D3	Performing safe flight tests before the mission will support the mission team to check the landing gear safety as well as pre-flight checks of the airframe will allow the team to assess any maintenance issues and minimize the likelihood of this risk impacting flight operations.	Pre-flight checks of the airframe will assist in minimizing the risk.	E3	E3

Risk Category	Description	Hazard Assessment	Assessment Description	Original Hazard Risk - sUAS	Original Hazard Risk - lUAS	Mitigation Action	Post Assessment	Residual Hazard Risk - sUAS	Residual Hazard Risk - lUAS
UAS Technical Issue	Unrecoverable Onboard Failures/Malfunction	Causes of this hazard include power issues with onboard navigation, loss of power to motors if rotary small UAS, and or lack of response from onboard payload.	Possible effects in operations are loss of capability to control the UAS, potential loss of lift and/or deviation from the approved flight path, eventually followed by a controlled or uncontrolled descent into terrain/terrestrial entities.	C3	C3	BVLOS operations will be contingent on the airspace situation, i.e., depending upon whether surveillance systems detect an intruder. The PIC will suspend the flight and invoke RTB, commanding the UAS to return to base; or DLI, commanding the UAS to suspend the current plan, divert to the nearest safe area, and descend at its maximum safe descent rate to controlled landing. If there are multiple UAS flights at the same time and in the same airspace supporting a disaster response, then pre-mission coordination on each flights alternative landing zones will occur to mitigate any mid-air collisions from DLI or RTB flights. On the other hand, if the failure/malfunction onboard the UAS during flight leads to an unrecoverable loss of control state, then If the C2 link continues to be available (contingent on the airspace situation) the PIC will command either DLI, commanding the UAS to descend from its current location at its maximum safe descent rate to a controlled landing, or TER, resulting in a shutdown of the UAS engines. However, if the C2 link is also unavailable, the emergency procedures applicable for a sustained loss of the C2 link will be utilized.	Contingencies for emergency landing zones or RTB options included in the CONOP will reduce the severity of this hazard. The likelihood of occurring will be minimized with a maintenance check included in pre-flight, pre-deployment, and mission planning checklist to ensure multiple instances to detect an issue before it could occur during flight.	E3	E3
UAS Cyber Threat	UAV Hardware Cyber Attack	Causes of this hazard, like all cyber threats, are from direct intentional action by a hostile entity. The threat itself may be immediately recognizable as a threat or may be masked as another type of system issue or failure.	Cyber hardware attacks generally take the form of spoofing or jamming the flight hardware systems. This can include spoofing or jamming the GPS, actuators, ADS-B, the remote ID, and other sensors. It could also impact via firmware flashing. The issues may present themselves directly to the users/operators, but more than likely present as a "UAS Technical Issue" with an unknown source.	D3	D3	Depending on the specific way the cyber-attack manifests, operationally the mitigation actions would follow the same approaches outlined above for each specific UAS Technical Issue. For hardware cyber-attacks, see the mitigations for Aircraft Fly Away, Engine/Power Failure, and Unrecoverable Onboard Failures/Malfunction.	Cyber attack issues are generally not identified real time in operational scenarios. The issues look like other common technical issues. Post flight/mission assessment is generally where the attacks are identified, if they are identified, as the source of the issues.	D3	D3
UAS Cyber Threat	Ground Control System Cyber Attack	Causes of this hazard, like all cyber threats, are from direct intentional action by a hostile entity. The threat itself may be immediately recognizable as a threat or may be masked as another type of system issue or failure.	Ground Control System (GCS) Attacks are in several forms including remote access, forced quitting application, data exfiltration, password breaking, reverse engineering GCS application/software (not likely during an active operation), and social engineering. Remote access of flight system and controls threatens safe operation, and forced quitting of the control application mid flight is also a safety of flight issue. Incorrect information during a flight can lead to issues with social engineering in the relay of false or contradictory information during a mission an either lead to incorrect decision or loss of trust in the information collected.	D3	D3	Depending on the specific way the cyber-attack manifests, operationally the mitigation actions would follow the same approaches outlined above for each specific UAS Technical Issue. For GCS cyber-attacks, see the mitigations for Frequency Interference, GPS Signal Outage, Loss of Navigational Control, and Loss of UAS Command and Control Link.	Cyber attack issues are generally not identified real time in operational scenarios. The issues look like other common technical issues. Post flight/mission assessment is generally where the attacks are identified, if they are identified, as the source of the issues.	D3	D3

Risk Category	Hazard			Original Hazard Risk - sUAS	Original Hazard Risk - lUAS	Mitigation		Residual Hazard Risk - sUAS	Residual Hazard Risk - lUAS
	Description	Assessment	Assessment Description			Action	Post Assessment		
UAS Cyber Threat	Network Link Cyber Attack	Causes of this hazard, like all cyber threats, are from direct intentional action by a hostile entity. The threat itself may be immediately recognizable as a threat or may be masked as another type of system issue or failure.	Network Link Attacks can disrupt the entire UAS operation information flow. These attacks include Black Hole/Gray Hole, Wormhole, Sybil, Sinkhole, Radio Frequency (RF)-based Jamming, Protocol-based Jamming (Message Flooding), Deauthentication, Packet Sniffing/Analysis, Password Breaking, Person-In-The-Middle, Command Injection, Masquerading, Replay Attack, Relay Attack, and Fuzzing. Many of these are complex and may not apply during the actual disaster response operational phases, but of most concern are the Radio Frequency based jamming, message flooding, person in the middle, and masquerading which all can lead to loss of asset operational control.	D3	D3	Depending on the specific way the cyber-attack manifests, operationally the mitigation actions would follow the same approaches outlined above for each specific UAS Technical Issue. For the network cyber-attacks, see the mitigations for Aircraft Fly Away, Frequency Interference, GPS Signal Outage, Loss of Navigational Control, and Loss of UAS Command and Control Link.	Cyber attack issues are generally not identified real time in operational scenarios. The issues look like other common technical issues. Post flight/mission assessment is generally where the attacks are identified, if they are identified, as the source of the issues.	D3	D3

1.9 Risk Severity versus Likelihood Matrix

Risk severity versus likelihood matrices are used to define the original and residual hazard risk in the ORA. These matrices come from FAA Order 8040.4B: Safety Risk Management Policy. Included with the two matrices are the page numbers within the FAA order.

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	[Green]	[Yellow]	[Red]	[Red]	[Red]
Probable B	[Green]	[Yellow]	[Red]	[Red]	[Red]
Remote C	[Green]	[Yellow]	[Yellow]	[Red]	[Red]
Extremely Remote D	[Green]	[Green]	[Yellow]	[Yellow]	[Red]
Extremely Improbable E	[Green]	[Green]	[Green]	[Yellow]	[Red] [Yellow]

Risk Matrix – Commercial Operations/Large Transport Category	* = High Risk with Single Point and/or Common Cuase Failures
Referenced from Figure C-1: FAA Order 8040.4B, Appendix C, C-3 [Page 29 of PDF]	

Figure 1. Severity versus Likelihood Matrix for Large UAS.

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	[Green]	[Yellow]	[Red]	[Red]	[Red]
Probable B	[Green]	[Yellow]	[Yellow]	[Red]	[Red]
Remote C	[Green]	[Green]	[Yellow]	[Yellow]	[Red]
Extremely Remote D	[Green]	[Green]	[Yellow]	[Yellow]	[Red] [Yellow]
Extremely Improbable E	[Green]	[Green]	[Green]	[Green]	[Yellow]

Risk Matrix – General Aviation Operations/Small Aircraft and Rotorcraft	* = High Risk with Single Point and/or Common Cuase Failures
Referenced from Figure C-2: FAA Order 8040.4B Appendix C, C-4 [Page 30 of PDF]; Figure C-1: FAA Order 8040.4B, Appendix C, C-1 [Page 21 of PDF]	

Figure 2. Severity versus Likelihood Matrix for Small UAS.

The following color scale is used for both matrices.

High Risk [Red]
Medium Risk [Yellow]
Low Risk [Green]

1.10 MISHAP Response Checklist

Immediately after an incident or accident, and before additional flights in the operation, the initial notification of the following information should be relayed to the FAA via the UAS Certificate of Authorization (COA) On-Line forms (Incident/Accident) must be submitted.

1) All accidents/mishaps involving UAS operations where any of the following occurs:
   a. Fatal injury, where the operation of a UAS results in a death occurring within 30 days of the accident/mishap;
   b. Serious injury, where the operation of a UAS results in a hospitalization of more than 48 hours, the fracture of any bone (except simple fractures of fingers, toes, or nose), severe hemorrhage or tissue damage, internal injuries, or second- or third-degree burns;
   c. Total unmanned aircraft loss;
   d. Substantial damage to the unmanned aircraft system where there is damage to the airframe, power plant, or onboard systems that must be repaired prior to further flight;
   e. Damage to property, other than the unmanned aircraft.
2) Any incident/mishap that results in unsafe/abnormal operation including but not limited to:
   a. A malfunction or failure of the unmanned aircraft's on-board flight control system (including navigation);
   b. A malfunction or failure of ground control station flight control hardware or software (other than loss of control link);
   c. A power plant failure or malfunction;
   d. An in-flight fire;
   e. An aircraft collision;
   f. Any in-flight failure of the unmanned aircraft's electrical system requiring use of alternate or emergency power to complete the flight;
   g. A deviation from any provision contained in the COA;
   h. A deviation from an ATC clearance and/or Letter(s) of Agreement/Procedures;
   i. A lost control link event resulting in fly-away, or execution of a pre-planned/unplanned lost link procedure.

3) Initial reports contain the information identified in COA On-Line Accident/Incident Report.
4) Follow-on reports describing the accident/incident/mishap(s) submitted by providing copies of proponent aviation accident/incident reports upon completion of safety investigations. Such reports must be limited to information only where privileged safety or law enforcement information is included in the final report.
5) Public-use agencies other than those which are part of the Department of Defense are advised that the above procedures are not a substitute for separate accident/incident reporting required by the National Transportation Safety Board under 49 CFR Part 830 §830.5.
6) Any COA issued with the provision that the FAA permitted involvement in the proponent's incident/accident/mishap investigation as prescribed by FAA Order 8020.11, Aircraft Accident and Incident Notification, Investigation, and Reporting.

1.11 Federal Aviation Administration Relevant Orders

Below are FAA orders that apply to safety risk management and safety management systems. The orders can be used as reference material for the ORA development and were used to develop the original and residual risk classifications for the ORA hazards.

Rather than include the original multi-page documents, hyperlinks are inserted so that those developing the ORA to accompany their CONOP can access the FAA Order. These hyperlinks allow the lead organization access to the FAA Safety Management Systems and Management Policies as they develop the ORA including disaster-specific hazards.

FAA Order 8040.4B: Safety Risk Management Policy, effective: May 2, 2017

FAA Order 8000.369C: Safety Management System, effective: June 24, 2020

FAA Order 8040.6: Unmanned Aircraft Systems Safety Risk Management Policy, effective: October 4, 2019