The FAA's Center of Excellence for UAS Research

ASSURE

Alliance for System Safety of UAS through Research Excellence

Final Report
ASSURE A28: Disaster Preparedness and Response Using UAS
Appendix F - Risks, Waivers and Mitigation Report

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TABLE OF ACRONYMS

ATC	Air Traffic Control
BVLOS	Beyond Visual Line-of-Sight
C2	Command and Control
CONOP	Concept of Operation
DLI	Divert Land Immediately
FAA	Federal Aviation Administration
GCS	Ground Control Station
GPS	Global Positioning System
IFR	Instrument Flight Rules
lUAS	large Unmanned Aircraft System
NAS	National Airspace System
ORA	Operational Risk Assessment
PIC	Pilot in Command
PIREP	Pilot Report
RTB	Return to Base
RTL	Return to Landing
SA	Situational Awareness
SMS	Safety Management System
SRM	Safety Risk Management
sUAS	small Unmanned Aircraft System
TER	Terminate Flight
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line of Sight
VO	Visual Observer

1. RISKS, WAIVERS AND MITIGATION REPORT

1.1 Overview

Each Unmanned Aircraft System (UAS) organization will have their own Safety Management System (SMS) or a Safety Risk Management (SRM) approach that defines the organizations policies for its team to follow during UAS missions. A SMS/SRM enables the UAS operator to fly safely and ensures safe integration of its UAS mission in the National Airspace System (NAS). When building a SMS/SRM, the operator's organization will include all aspects of their safety polices such as identify the hazards that would impact mission safe and the safety measures to follow. One aspect of safe UAS missions for a disaster preparedness and response is defining the specific hazards and the mitigation plans to reduce the severity and likelihood of the risk. In building a successful UAS Concept of Operation (CONOP) to support disaster preparedness and response, operators will develop an Operational Risk Assessment (ORA).

1.2 Hazard Identification

There are three stages to build a successful CONOP and provide an ORA that can support evaluating the safety measures needed for UAS integration into the NAS. These stages are: (1) identify the hazards; (2) analyze the safety measures, and (3) identify the mitigation plan per hazard. As the ORA accompanies the CONOP, the hazards will be directly associated with the scope of the UAS mission.

As defined in Federal Aviation Administration (FAA) Order 8040.4B, a hazard that can impact UAS operations is "a condition that could foreseeably cause or contribute to an aircraft accident". When identifying the hazards, the operator will define the outcomes that the hazards will have on operations, ensuring that all sources for the hazard are documented. Additionally, connecting each hazard to an associated category will assist the operator in ensuring that no potential hazard is missed and support those reviewing an ORA and comparing ORA's for different CONOPs. Example categories include but are not limited to the following:

- Weather Conditions
- External Systems
- Human Factors/Errors
- UAS Technical Issues
- UAS Cyber Threat

1.3 Risk Assessment

In assessing the risk, an operator will use a severity and likelihood matrix. The severity scale provides a tool to define the type of impact to the operations from minimal, to minor, to major and from hazardous to catastrophic. The likelihood scale is defined based on the potential occurrence of the defined hazard starting with extremely improbable through extremely remote to remote and then probable to frequent, as shown in Figures 1 and 2 in Appendix E for small and large UAS respectively.

FAA Order 8040.4B states: Severity is the potential consequence or impact of a hazard in terms of degree of loss or harm. It is a prediction of how bad the outcome of a hazard can be.

Likelihood is the estimated probability or frequency, in quantitative or qualitative terms, of the outcome(s) associated with a hazard. It is an expression of how often an outcome of a hazard is predicted to occur in the future.

Once the risk has been defined for each hazard then the mitigation plan can be defined to reduce the severity and likelihood to a residual level that is acceptable for safe operations.

1.4 Defining the Hazard Assessment Process and Mitigation Action Planning

To better understand the different hazards to safe integration of UAS into the NAS during disaster preparedness and response, the hazards have been collated into six categories that focus on adverse operating conditions, external systems, human factors, the UAS itself, and cyber threats to UAS operations.

Adverse Operating Conditions: 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.

Deterioration of External Systems: 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 (GCS).

Human Error: 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.

UAS Technical Issues: This category focuses on the mission UAS and its associated on-board and Command and Control (C2) equipment. All aspects that involve the UAS are listed within this section. Hazards include Aircraft Fly Away; Engine/Power Failure; Frequency Interference; Global Positioning System (GPS) Signal Outage; Loss of Navigational Control; Loss of UAS C2 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 Arial Vehicle (UAV) hardware, Ground Control System, and Network link cyber-attacks.

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. Below are definitions when defining the hazards that could impact a safe flight operation. These definitions are then used per hazard in the following section

to demonstrate the type of mitigation, if in place, that will reduce the risk severity and likelihood and be sufficient to support a safe CONOP for a disaster response mission.

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 Figures 1 and 2 of Appendix E 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 in Appendix E. 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.

For specific disaster responses, additional risks may occur during flight operations. For example: Volcanic-based disaster responses have some unique hazards, like the impact of ash on aircraft maintenance and/or steam plumes from cooling lava flows. Such hazards could impact flight operations but would likely not be seen in a pandemic-based or other, non-volcanic disaster

response. Assessing these hazards in real-time as flight operations occurs, the flight crew determines mitigation actions to minimize the impact of these hazards on the safety of the flight.

1.5 Hazards to UAS Safe Flight Operations

1.5.1 Adverse Operating Conditions

1.5.1.1 Collision into Terrain and Terrestrial Entities

Assessment: 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.

Original Hazard Risk: C2 (Yellow for sUAS and Red for lUAS)

Mitigation Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.1.2 Mid-Air Collision

Assessment: This hazard would result from participating or non-participating aircraft failing to comply with See-and-Avoid requirement, non-participating aircraft fail to monitor 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.

Original Hazard Risk: C1 (Red for both sUAS and lUAS)

Mitigations Action: 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 UAS, such that UAS 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 (VO) 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 > RTB > DLI > Terminate Flight (TER). For Beyond Visual Line of Sight (BVLOS) operations in uncontrolled airspace, radar systems (or other sensors to detect non-cooperative traffic) will be needed.

Mitigation Outcome: This hazard remains a severe hazard and including mitigation actions will focus on reducing likelihood of occurrence to extremely unlikely.

Residual Hazard Risk: E1 (Yellow for sUAS and Red/Yellow for lUAS)

1.5.1.3 Rapid Onset of Inclement Weather or Disaster Specific Weather

Assessment: 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 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 Sight (VLOS) flights becoming BVLOS or visual flight rules conditions rapidly becoming IFR only.

Original Hazard Risk: B3 (Yellow for sUAS and Red for lUAS)

Mitigations Action: During flight, if weather conditions deteriorate suddenly, the PIC will invoke RTB resulting in a suspension of the onward flight path and commanding the UA to return to base, i.e., its launch/landing point.

Mitigation Outcome: 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.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.1.4 Unexpected Winds Aloft

Assessment: This hazard can be a result of wind gusts and/or sustained winds exceeding UAS operating specifications. Possible effects are a loss of aircraft due to turbulence or inability to attain accurate performance data. Current operations would lead to a forced landing at an unsurveyed landing location and/or Loss Link during the landing that may result in UAS attempting RTL.

Original Hazard Risk: D3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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/National Weather Service for NAS missions.

Mitigation Outcome: 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.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.2 Deterioration of External Systems

1.5.2.1 Generator Failure [on-board]

Assessment: 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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 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.

Mitigation Outcome: The pre-flight checks of available power and backups will minimize the risk and reduce the likelihood of this risk impacting flight operations.

Residual Hazard Risk: D4 (Green for both sUAS and lUAS)

1.5.2.2 Generator Failure [ground-based for GCS]

Assessment: This hazard can be caused by a lack of power in the generator to support the GCS equipment when mains power is unavailable. This 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: The pre-flight checks of available power and backups will minimize the risk and reduce the likelihood of this risk impacting flight operations.

Residual Hazard Risk: D4 (Green for both sUAS and lUAS)

1.5.2.3 5.2.3. Loss of Function of Tracking Antenna

Assessment: This hazard can be caused from the tracking antenna losing either its GPS position or the aircraft's, antenna becomes disconnected from Control Station subsystem, and/or antenna subsystem mechanical failure. Possible effects resulting from this hazard, when outside of omni-directional range, mean the 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: GCS parameters are set to ensure the aircraft returns to the assigned point in the event of loss link.

Mitigation Outcome: 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.

Residual Hazard Risk: D5 (Green for both sUAS and lUAS)

1.5.2.4 Loss of the Ground Control Station

Assessment: 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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 C2 link frequency, and command it to return to base. Additionally, for 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.

Mitigation Outcome: 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.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.3 Human Factors

1.5.3.1 Physiological Human Factors Event

Assessment: This hazard would result from a loss of SA, crew miscommunication, and crew fatigue. Possible effects to safe flight operations are an inability to effect timely avoidance maneuvers, if required.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: The likelihood of this risk is lowered with flight checklist and pre-flight briefings to all the crew.

Residual Hazard Risk: E4 (Green for both sUAS and lUAS)

1.5.3.2 Loss of Communications Between Crew Members

Assessment: 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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, VOs (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.

Mitigation Outcome: 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.

Residual Hazard Risk: E4 (Green for both sUAS and lUAS)

1.5.3.3 Loss of Communications Between Flight Crew and Air Traffic Control

Assessment: 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. There is minor severity as the aircraft will ground if loss of communications between flight crew and ATC.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: The 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.

Mitigation Outcome: Hazard is only minor severity and extremely improbable.

Residual Hazard Risk: D5 (Green for both sUAS and lUAS)

1.5.3.4 Non-crew Member Interruption of Flight Crew

Assessment: 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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 will be 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 brief the mission team and its vicinity on the sterile control station procedure and environment.

Mitigation Outcome: 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.

Residual Hazard Risk: D4 (Green for both sUAS and lUAS)

1.5.4 UAS Technical Issues

1.5.4.1 Aircraft Fly Away

Assessment: 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.

Original Hazard Risk: B2 (Red for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: A 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.

Residual Hazard Risk: D4 (Green for both sUAS and lUAS)

1.5.4.2 Engine/Power Failure

Assessment: 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: With proper maintenance and fuel/power management will lower the likelihood of this hazard.

Residual Hazard Risk: C4 (Green for sUAS and Yellow lUAS)

1.5.4.3 Frequency Interference

Assessment: This hazard's 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.

Original Hazard Risk: D2 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: Through a continued monitoring of frequency strength, the team will lower the risk and likelihood of loss in C2.

Residual Hazard Risk: E5 (Green for both sUAS and lUAS)

1.5.4.4 GPS Signal Outage

Assessment: The hazard could be a result of a loss of lock on GPS satellite, aircraft flight into GPS denied area, or aircraft flight 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.4.5 Loss of Navigational Control

Assessment: 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.

Original Hazard Risk: D2 (Yellow for both sUAS and lUAS)

Mitigations Action: 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 BVLOS operations, the PIC will 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.

Mitigation Outcome: The probability of occurrence is lowered as to present no unacceptable residual risk.

Residual Hazard Risk: E2 (Green for sUAS and Yellow lUAS)

1.5.4.6 Loss of UAS Command and Control Link

Assessment: With this hazard, causes include pilot error, UA system error, ground control system error, and 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.

Original Hazard Risk: C2 (Yellow for sUAS and Red for lUAS)

Mitigations Action: 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 Notice to Airman 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. 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.

Mitigation Outcome: Severity is lowered as to constitute no unacceptable residual risk due to return home routing and landing will result in minimal asset damage.

Residual Hazard Risk: E2 (Green for sUAS and Yellow lUAS)

1.5.4.7 Stuck Landing Gear

Assessment: 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 get stuck. Possible effects to safe operations are that the mission team need to perform a manual landing with expected damage to the airframe.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: D4 (Green for both sUAS and lUAS)

1.5.4.8 Tire/Brake or Landing Gear Failure

Assessment: 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, cracks in the landing gear or failure to engage can lead to failure. Possible effects on safe operations are loss of positive control during either take-off or landing.

Original Hazard Risk: D3 (Yellow for both sUAS and lUAS)

Mitigations Action: Performing safe flight tests before the mission will support the mission team checking the landing gear safety. 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.

Mitigation Outcome: Pre-flight checks of the airframe will assist in minimizing the risk.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.4.9 Unrecoverable Onboard Failures/Malfunction

Assessment: Causes of this hazard include power issues with onboard navigation, loss of power to motors if rotary small UAS, and 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.

Original Hazard Risk: C3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: E3 (Green for both sUAS and lUAS)

1.5.4.10 UAV Hardware Cyber Attack

Assessment: 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.

Original Hazard Risk: D3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: D3 (Yellow for both sUAS and lUAS)

1.5.4.11 Ground Control System Cyber Attack

Assessment: 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. 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 midflight 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 and either lead to incorrect decision or loss of trust in the information collected.

Original Hazard Risk: D3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: D3 (Yellow for both sUAS and lUAS)

1.5.4.12 Network Link Cyber Attack

Assessment: 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.

Original Hazard Risk: D3 (Yellow for both sUAS and lUAS)

Mitigations Action: 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.

Mitigation Outcome: 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.

Residual Hazard Risk: D3 (Yellow for both sUAS and lUAS)

1.5.4.13 Summary

This section on risks and mitigation plans to UAS support for disaster preparedness and response lays out the different categories of hazards along with definitions of their impact and expected outcomes along with the original risk the hazard places on operations. Per hazard, the mitigation plans are defined along with the outcomes that would occur to minimize the risk severity and likelihood of its occurrence. The defined risks and mitigations are then transitioned into an operational risk assessment that accompanies a CONOP.

1.6 Federal Aviation Administration Orders

To supplement the analysis performed here on the hazards to safe flight operations and the mitigation plans to minimize the risk, FAA orders are referenced that provide more details on conducting SRM in the FAA (Order 8040.4B) and the FAA Policy on Unmanned Aircraft Systems Safety Risk Management (Order 8040.6). Note that each of these orders could have updates as amendments are made and an operator and/or their organization FAA Order 8040.4B: Safety Risk Management Policy, effective: May 2, 2017.

Chapter 2, Pages 9 – 16, provides details on how the FAA conducts a SRM in the operational environment and the process to identify the hazards, assess the risk, and safety performance monitoring and hazard tracking. Appendix C, Pages 27 – 32, provides details on the severity and likelihood definitions used in the risk and mitigation analysis described here and are in the ORA's that accompany the CONOP. Figure C-1 and C-2 are effective risk matrices, used by the A28 team in its ORA development and can be used by other organizations to define the mitigation action plans per hazard to accompany their disaster preparedness and response CONOP.

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

This order defines the methods that the FAA uses to assess a request to operate UAS and how the FAA performs SRM in accordance with FAA Order 8040.4 for UAS requests to operate. Chapter 3, Pages 7 – 9, focus on the process of how FAA reviews UAS requests for operations. and

highlights the request governance and triage steps to ensure safe operations. Chapter 4, Pages 10 – 14 describes aspects reviewed in the FAA SRM analysis. Should continue to follow the online links for each order.

1.7 Conclusion

In planning a concept of operations to support a disaster response with an unmanned aircraft system, the risks and hazards to safe flight operations need to be defined along with the impact that they could have on the mission. Building mitigation action plans provides mechanisms for the lead organization to demonstrate that it has safety management processes in place to mitigate the severity of the risk caused by the hazard and likelihood that it would occur and impact mission safety. The different hazards that could occur and impact the safety of a UAS mission are highlighted, and the causes and effects are detailed if the hazard was left alone to impact operations.

With mitigation action plans recorded in a CONOP, the lead organization demonstrates that if the hazard does occur during a flight that they have the capabilities to react and put their mitigation plan into action. The hazard definitions and mitigation action plans documented in this report can be included in a disaster preparedness and response ORA along with any disaster specific hazards. Together with the CONOP and the flight checklists these three documents can be used by the lead organization for the mission to demonstrate they have sufficient safety measures in place to support a disaster response and integrate the UAS in the NAS.