THE STATE of ALASKA

GOVERNOR MICHAEL J. DUNLEAVY

Department of Transportation and Public Facilities

DIVISION OF STATEWIDE AVIATION

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June 9th, 2021

SUBJECT: Close Proximity Low Altitude Beyond Visual Line of Sight (CPLA-BVLOS) Operations of the Skydio S2 and X2E Unmanned Aircraft System (UAS)

The Alaska Department of Transportation & Public Facilities (DOT&PF) is requesting approval for adding Close Proximity Low Altitude (CPLA) Beyond Visual line of Sight (BVLOS) to our existing COA #2020-WSA-7610. In support of public UAS operators during emergency and routine inspections of Alaska's critical infrastructure acting in the public interest, we ask that you approve our request based off the following.

Alaska is severely limited on roadway infrastructure and in many cases a single road is the only means of accessibility for hundreds of miles. With our aging infrastructure across the state, it is imperative that we augment our traditional inspection processes with a safe and effective technology that assists the State of Alaska in locating structural anomalies before they become a point of failure. By adding CPLA-BVLOS to our Public operations, our ability to facilitate immediate response to bridge anomalies, natural or manmade, will augment our limited routine inspection services across the entire state under our existing COA, will be greatly increased. The operational request area is within the confines of the State of Alaska within Class C, D, E and G Airspace surface to 400ft and within 2500ft from the remote operator and no more than 400ft laterally from the nearest obstacle or structure.

Alaska DOT&PF acknowledges the following required conditions for operating under a waiver for 91.113(b):

1. DOT&PF will be flying under a valid Part 91 Certificate of Waiver/Authorization (COA 2020-WSA-7610);
2. The approval to conduct such operations will only be applied during critical infrastructure inspections to safeguard human life;
3. The Pilot in Command (PIC) will return to Visual Line of Sight (VLOS) operations as soon as practical or upon the termination of Close Proximity Low Altitude Beyond Visual Line Of Sight (CPLABVLOS);
4. The PIC must not operate any higher than 50 feet above or greater than 400 feet laterally of the nearest obstacle while operating TBVLOS. The 50 feet above an obstacle cannot exceed the 400 feet above ground level (AGL) hard ceiling;
5. The UAS must not exceed 2500 feet laterally from the PIC;
6. The UAS can operate, during an emergency our routine inspection to safeguard human life, CPLA-BVLOS in controlled airspace as long as the location of the operation does not exceed the UAS Facility Map (UASFM) altitude values which should be considered the hard ceiling for the operation;
7. That emergency operations where the operator needs to exceed the 400 feet hard ceiling or the UASFM altitude value will require a Special Governmental Interest COA/Waiver from the FAA's Systems Operations Support Center:https://www.faa.gov/uas/advanced_operations/emergency_situations/

Thank you

Ryan Marlow, CMS
UAS Program Coordinator
DOT&PF, Statewide Aviation

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May 3rd, 2021

SUBJECT: Airworthiness Release (AWR) for Operations of the Skydio S2 Unmanned Aircraft System (UAS)

1. Scope: This document constitutes an Airworthiness release authorizing operation of Skydio 2 and Skydio X2E Unmanned Aircraft System defined by the Federal Aviation Administration (FAA) approved Certificate of Authorization (COA) area throughout the State of Alaska.

2. Validity: This AWR is new and terminates May 3rd, 2023, upon changes to the subject equipment, or upon issuance of later AWR, whichever occurs first. This AWR is valid only for operations within airspace defined by the Federal Aviation Administration (FAA) approved Certificate of Authorization (COA) area throughout the State of Alaska.

3. Compliance: The Alaska Department of Transportation & Public Facilities (ADOT&PF) will maintain a continued Airworthiness program that includes maintenance and training of the Skydio 2 and X2E, which will be will be maintained in an airworthy condition to conduct flights in the National Airspace System. The Alaska Department of Transportation & Public Facilities is responsible for the condition for safe flight of the Unmanned Aircraft Systems (UAS).

4. List of Approved Aircraft:
   1. **Skydio X2E**
   2. **Skydio 2**

5. List of Controlling Documents:

   - Alaska Department of Transportation & Public Facilities UAS GOM
   - Alaska Department of transportation & Public Facilities CPLA-BVLOS CONOPS

6. The point of contact (POC) is Ryan Marlow, Phone (907) 269-0741 or email: Ryan.marlow@alaska.gov

Ryan Marlow,CMS
UAS Program Coordinator
DOT&PF, Statewide Aviation

CONCEPT OF OPERATIONS

Close Proximity Low Altitude
Beyond Visual Line Of Sight
For Bridge Inspection
with Skydio 2 and Skydio X2E

Version 1.0

May 23rd, 2021

Signatures and Revisions

Approved by:____Date___________________

John Binder

Deputy Commissioner

Alaska Department of Transportation and Public Facilities

Version Number	Date	Changes	Revised by
1.0	5/23/2020	First Draft	Ryan Marlow

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1 Introduction

Regular inspection is vital for maintaining transportation infrastructure. Many bridge structures are inspected visually, including deck slabs, beams and diaphragms, bents, piers, abutments, and foundations. Yet, it can be challenging for human inspectors to get close, complete, and clear views of critical components. This is especially true of those components directly underneath the deck. Special equipment, such as snooper trucks, are commonly used to lower human inspectors into position. Traffic control is often required to maintain safety while people and large vehicles are stationed along the bridge. Human inspectors may also need to walk on steep and uneven terrain to gain vantage points of abutments and foundations.

Using small unmanned aircraft systems (sUAS) with highly automated flight capabilities, inspectors can perform close visual examination and documentation from a position within the existing right of way, making the inspection process both more efficient and safer for human inspectors. When executing a complex flight plan in close proximity to a bridge structure, including under or through, the ability to fly beyond the visual line of sight (BVLOS) of the remote pilot in command (RPIC) of the sUAS further enhances efficiency. Waiving the requirement for a visual observer to maintain line of sight and clear the surrounding airspace reduces the number of personnel on site and also reduces the workload on the RPIC.

With numerous critical bridges to be inspected, the Alaska DOT&PF UAS Program seeks to ensure that flights are conducted efficiently and with minimum risk to participants and non-participants. This document describes the concept of operations (ConOps) for Close Proximity Low Altitude (CPLA) Beyond Visual line of Sight (BVLOS) bridge inspection using Skydio 2 and Skydio X2E sUAS. CPLA-BVLOS is a low-risk class of operations characterized by infrastructure masking - a concept that minimizes ground and air risk by operating close to physical objects (within 50 ft) and within a limited range of the RPIC.

2 Alaska DOT & PF sUAS Program Organization

Organizational structure of Alaska DOT&PF sUAS Program.

2.1 Safety

The priority in all DOT&PF sUAS flight operations is the safety of employees, contractors, participants, and the public. The DOT & PF sUAS safety program is documented in Section 7 of the Alaska DOT&PF UAS Operations Manual (Ref 1).

2.2 Maintenance

Maintenance includes scheduled and unscheduled overhaul, repair, inspection, modification, replacement, and system software upgrades of all system components necessary for safe flight. The DOT&PF sUAS maintenance program is documented in Section 14 of the Alaska DOT&PF UAS Operations Manual (Ref 1).

2.3 Training

Key to continued safe operations is maintaining a professional level of competency. The DOT & PF sUAS training program is documented in Section 9 of the Alaska DOT&PF UAS Operations Manual (Ref 1).

3 UAS Description

The Skydio S2 and Skydio X2E offer key safety features and capabilities that enable this operation. Rather than relying solely on GPS, Skydio uses advanced computer vision technology for path planning, navigation, and obstacle avoidance. Skydio sUAS can fly a complex three-dimensional pattern around the bridge structure without the risk of a collision with the structure itself. Skydio 3D Scan software aids the RPIC in flying this pattern with aircraft status and position information provided using intuitive interfaces and augmented reality technology.

3.1 Airframe – Skydio 2

The Skydio 2, shown in Figure 1 below, is a rigid airframe quadcopter designed and manufactured by Skydio, Inc. in Redwood City, California USA. The airframe is comprised of magnesium alloy and weighs 755 grams. The Skydio 2 has 3.5 km of range when piloted by its handheld controller. Flight time is 23 minutes. Battery swap is a fast process enabled by Skydio's magnetic battery mount.

Figure 1. Skydio 2 sUAS

The Skydio 2 can fly in winds up to 25 mph, at speeds up to 36 mph, with full obstacle avoidance. The vehicle may be operated at density altitudes up to 15,000 feet, in outside air temperatures of 0 - 40 degrees Celsius. The airframe features thermal interface components, thermal interface material, air ducting features, fan, and environmental monitoring subsystem. The environmental monitoring subsystem monitors temperature and status of various UA subsystems and actuates the fan to regulate temperature of various subsystem components.

Table 1 below lists the dimensions of the Skydio 2 and Table 2 lists the materials used in construction of the airframe.

Table 1. Skydio 2 Dimensions

Size with Battery	8.8” x 10.8” x 2.9” (l x w x h)
Size without Battery	8.8” x 10.8” x 1.7” (l x w x h)
Weight with Battery	1.7 lbs

Table 2. Skydio 2 Construction Materials

Main chassis	Magnesium
Top & bottom chassis	Molded plastic
Motor mounts	Aluminum
Propellers	Molded plastic
Gimbal & payload	Molded plastic
Battery chassis	Molded plastic
Compute & internals	PCBA (FR4) & flex circuits

Loads

Sustained static propulsive loads exceeding maximum peak flight loads were demonstrated on the Skydio 2 airframe. Highly dynamic motor commands recorded from a flight at high altitude have been replayed through the vehicle at sea level. Testing of the fleet leader airframe was discontinued after 4,267 flight replays, totalling 819 flight hours without airframe structural failure.

There were no structural or mechanical failures of the airframe throughout flight testing which included:

- Manual flight demonstrations of dynamic maneuvers including control reversals, climbs, descents during system development.
- Hundreds of hours of developmental flight testing through a broad range of altitudes, airspeeds, wind speeds/gusts, and thermal environments.
- Over 3500 customer fleet flight hours accumulated without any documented in-flight structural failures.

Aircraft Performance Characteristics

The operating and environmental limitations of the Skydio 2 are listed below in Table 3 and Table 4.

Table 3. Skydio 2 Operating Limitations

Maximum altitude from Control device	1,640 ft
Maximum altitude (MSL)	15,000ft density altitude
Maximum endurance	23 minutes
Maximum range of command and control link	3.5km
Maximum rate of climb	10 m/s
Maximum rate of descent	4 m/s
Maximum bank angle	55 degrees
Turn rate limits	N/A
Maximum Flight Speed (Sea Level, No Wind)	36 mph
Slowest speed attainable	N/A or 0 mph
Stall speed (if applicable)	N/A
Nominal cruise speed	<36 mph
Never exceed airspeed	N/A

Table 4. Skydio 2 Environmental Limitations

Maximum Wind Speed Resistance	25mph
Operational Temperature Range	-5°C to 40°C
Turbulence restriction (if any)	N/A
Rain Hail snow resistance (If any)	Flight in weather not suggested
In flight icing (if any)	N/A

Propulsion System

The Skydio 2 propulsion system includes 4 brushless direct current (DC) motors each mounted with 2-bladed propellers. Propulsion system power for the Skydio 2 is provided by a removable, rechargeable Lithium Polymer battery pack. The battery interfaces directly with the 'power board' which contains the electronic speed controllers (ESC) which feed power and control signals to the four electric propulsion motors. Additionally, the ‘power board’ interfaces with the ‘main logic board’. The main logic board contains the primary SoC and flight controller, which take inputs from the onboard sensor suite and the pilot and routes commands to the ESCs.

Table 5. Skydio 2 Propulsion Motor Specifications

Motor type	Brushless DC (BLDC)
Number of motors	Four
Max continuous power output	85W
Max peak power output	135W
Current range	12A

Sensors

The Skydio 2 features seven 4K, visible spectrum light color sensors on-board the aircraft: one 4K 60 fps 12MP sensor mounted on a 3-axis gimbal (“user cam”) and six wide-angle 4K 30 fps rolling shutter sensors mounted on the aircraft in a configuration granting 360-degree obstacle avoidance coverage. The location of these cameras on the airframe is shown below in Figure 2.

Figure 2. Location of Navigation Cameras on Skydio 2

3.2 Airframe – Skydio X2E

The Skydio X2E, shown in Figure 3, is a rigid airframe cruciform quadcopter designed and manufactured by Skydio, Inc. in Redwood City, California. The airframe is comprised of magnesium alloy, carbon fibre, and polycarbonate. It weighs 1325 grams. The Skydio X2E has 3.5km of range when piloted by the handheld controller. Flight time is 35 minutes.

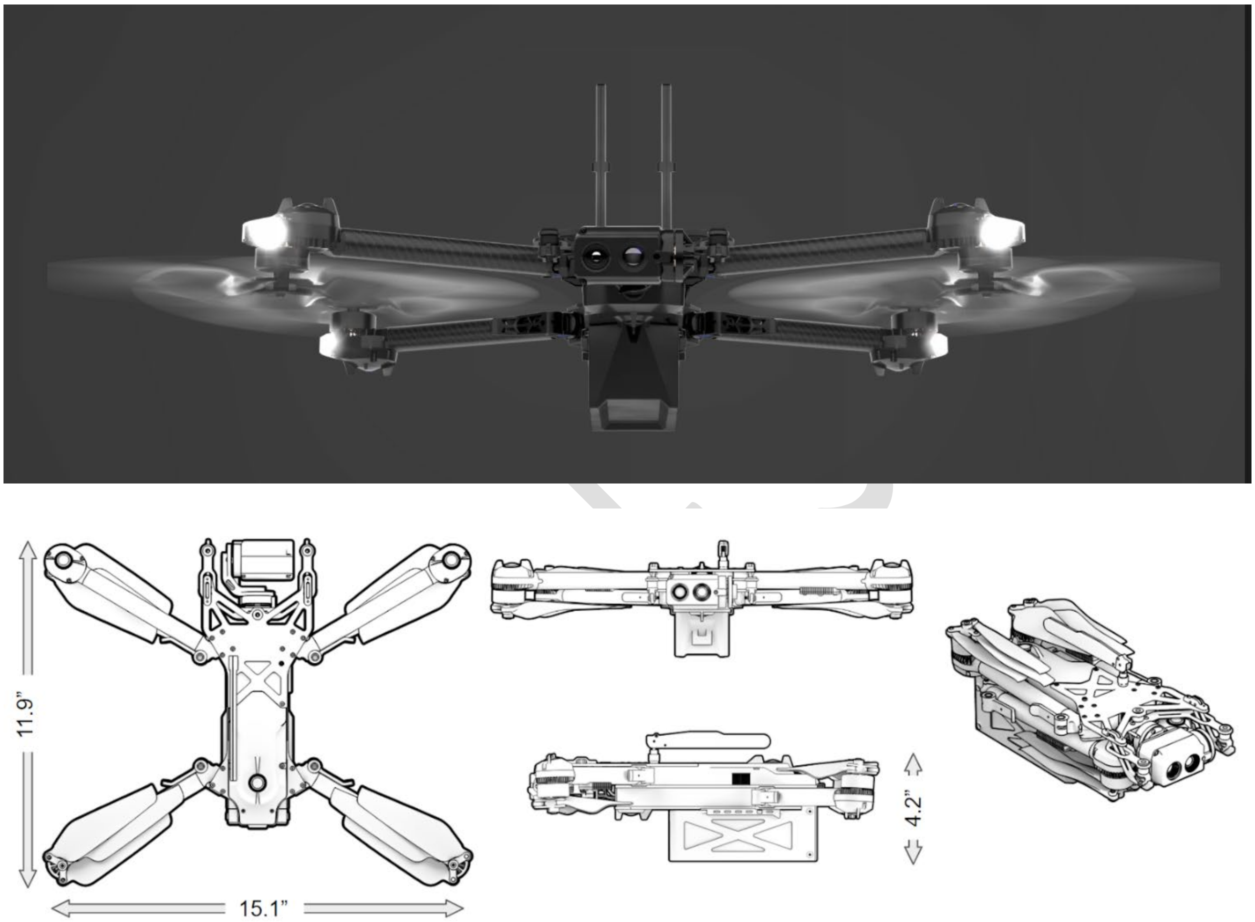

Figure 3. Skydio X2E sUAS

The Skydio X2E can fly in winds up to 23 mph, at speeds up to 25 mph, with full obstacle avoidance. It may be operated at density altitudes up to 12,000 feet, in temperatures of -10 to +43 degrees Celsius. The airframe features thermal interface components, thermal interface material, air ducting features, fan, and environmental monitoring subsystem. The environmental monitoring subsystem monitors temperature and status of various UA subsystems and actuates the fan to regulate temperature of various subsystem components.

Table 6 below lists the dimensions of the Skydio X2E and Table 7 lists the materials used in construction of the airframe.

Table 6. Skydio X2E Dimensions

DIMENSIONS (UNFOLDED, FLYING)	26.1” X 22.4“ X 8.3”
DIMENSIONS (FOLDED, NO BATTERY)	11.9“ X 5.5” X 3.6“
WEIGHT (WITH BATTERY)	1325 g

Table 7. Skydio X2E Construction Materials

Core chassis	Carbon Fibre, Magnesium & Polycarbonate
Motor arm assemblies	Magnesium hinge elbow, Carbon Fibre tube, Aluminium motor base with Polycarbonate enclosure.
Propellers	Carbon Fibre
Gimbal & payload	Magnesium & Polycarbonate
Battery chassis	Polycarbonate
Compute & internals	PCBA (FR4) & flex circuits

Loads

Skydio X2E airframe structural design validation has been performed using analysis, bench testing, and dynamic flight testing. Preliminary finite element analysis was performed to ensure sufficient design margin from expected flight and ground handling loads. On the bench, static thrust was applied at 20% above anticipated in-flight maximum dynamic thrust to weight ratio. No defects were detected when replaying flight logs of dynamic manuvers through a single airframe simulating over 650 flights, totalling over 135 hours of flight time. Numerous test flights at full propulsion system performance were successfully completed without structural failure during motor speed controller tuning development.

Aircraft Performance Characteristics

The operating and environmental limitations of the Skydio X2E are listed below in Table 8 and Table 9.

Table 8. Skydio X2E Operating Limitations

Maximum altitude from Control device	1,640 ft
Maximum altitude (MSL)	11,200 ft MSL, 45°C12,000 ft density altitude

Maximum endurance	35 minutes
Maximum range	3.5km
Maximum rate of climb	10 m/s
Maximum rate of descent	5 m/s
Maximum bank angle	55 degrees
Turn rate limits	N/A
Maximum Flight Speed (Sea Level, No Wind)	25 mph
Slowest speed attainable	N/A or 0 mph
Stall speed (if applicable)	N/A
Nominal cruise speed	<25 mph
Never exceed airspeed	N/A

Table 9. Skydio X2E Environmental Limitations

Maximum Wind Speed Resistance	23 mph
Operational Temperature Range	-10°C to 43°C
Turbulence restriction (if any)	N/A
Rain Hail snow resistance (If any)	Flight in weather not permitted
In flight icing (if any)	N/A

Propulsion System

The Skydio X2E propulsion system includes 4 brushless direct current (DC) motors each mounted with 3-bladed propellers. The Skydio X2E is powered by a removable, rechargeable Lithium Polymer battery pack. The battery interfaces directly with the ‘power board’ which contains the electronic speed controllers (ESC) to power and control the four electric propulsion motors. Additionally, the ‘power board’ interfaces with the ‘main logic board’, containing the primary SoC and flight controller, which take inputs from the onboard sensor suite and the pilot and send commands through the ESCs to the propulsion motors.

Table 10. Skydio X2E Electric Propulsion System Specifications

Motor type	Brushless DC (BLDC)
Number of motors	Four

Max continuous power output of the motor	85W
Max peak power output of the motor	135W
Current range does the motor have	12A

Sensors

The Skydio X2E features seven 4K, visible spectrum light color sensors on-board the aircraft: one 4K 60fps 12MP sensor and an optional thermal sensor are mounted on a 3-axis gimbal ("user cam") and six wide-angle 4K 30 fps rolling shutter sensors mounted on the aircraft in a configuration granting 360-degree obstacle avoidance coverage.

Table 11. User Camera Specifications

Primary Camera System	
SENSOR TYPE	Sony IMX577 1/2.3" 12.3MP CMOS
SENSOR ACTIVE PIXELS	4056 (H) x 3040 (V)
LENS APERTURE	f/2.2
LENS FOCAL LENGTH	41mm (35mm format equivalent)
LENS DEPTH OF FIELD	1m - ∞
SHUTTER SPEED	electronic shutter 1 to 1/1920s
ISO RANGE	video 100-6400 photo 100-6400
EXPOSURE CONTROL	-2.0, -1.5, -1.0, -0.5, 0, 0.5, 1.0, 1.5, 2.0
IMAGE SIGNAL PROCESSOR	Qualcomm QCS605
GPU	Adreno™ 615
CPU	64-bit octa-core Kryo™ 300
DSP	Hexagon™ 685, 2x HVX
RESOLUTION AND MODES	3840X2E160 30 fps 3840X2E160 60 fps 1920x1080 30 fps
BITRATE	100 Mbps

VIDEO FORMAT	MPEG-4 (AVC/H.264, HEVC/H.265)
STILL RESOLUTION	4056x3040 (12 MP)
STILL FORMATS	JPEG, DNG (RAW)
STILL MODES	Single, Interval
DYNAMIC RANGE	13 stops
STORAGE	Removable Micro SD Card UHS Speed Class 3 / V30
STABILIZATION MECHANICAL RANGE	pitch ±124°, roll ±120°
PITCH CONTROLLABLE RANGE	-110° to +45° (-110° to +90° with AEF)
Thermal Camera System	
SENSOR TYPE	Uncooled VOx microbolometer
RESOLUTION	320X2E56
LENS APERTURE	1.02
LENS FOCAL LENGTH	9.1mm
LENS DEPTH OF FIELD	2m - ∞
FRAMERATE	30fps

Table 12. Navigation Camera Specifications

CONFIGURATION	6x cameras in trinocular configuration top and bottom
SENSOR TYPE	Sony 1/3” 4K color CMOS
LENS APERTURE	f/1.8
FIELD-OF-VIEW	200°

ENVIRONMENT COVERAGE	True 360°
FRAME RATE	30 FPS

3.3 Electrical System

The Skydio 2 and X2E have similar electrical systems. For both aircraft, all subsystems are powered from the main battery. No power is generated on-board. Battery swap is a fast process enabled by magnetic battery mount. The propulsion system power is electronically isolated from all other subsystem power domains.

A microcontroller-based battery management system (BMS) is monitored by the UA flight controller which implements a watchdog system. This data is made available to the UA ground station software user interface as well as flight logs. The user interface displays battery information in human readable format (example: battery remaining icon on flight screen). There is no automatic or manual load shedding.

Battery management system (BMS) monitors the battery. Motor controller systems monitor the motors and local power domain. The flight controller subsystem monitors the BMS & motor controller subsystems as well as system sensors including inertial, GNSS, & thermal sensors.

The electrical system implements various digital regulators, chargers, analog regulators, power FETs, load switches, and PMU electronics to establish separate power domains which deliver the required power to various subsystems. Figure 4 shows a diagram of the electrical power system.

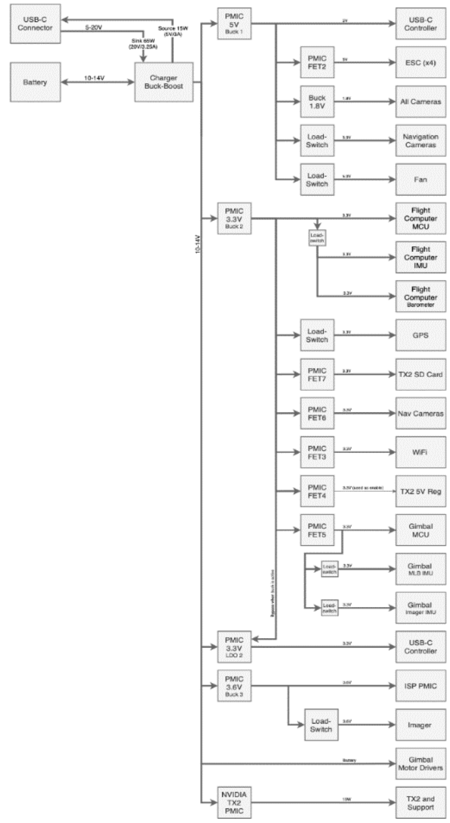

Figure 4. Skydio Power System Diagram

3.4 Navigation and Control

The Skydio 2 and X2EE have similar navigation and control systems. Figure 5 provides a diagram of the avionics architecture.

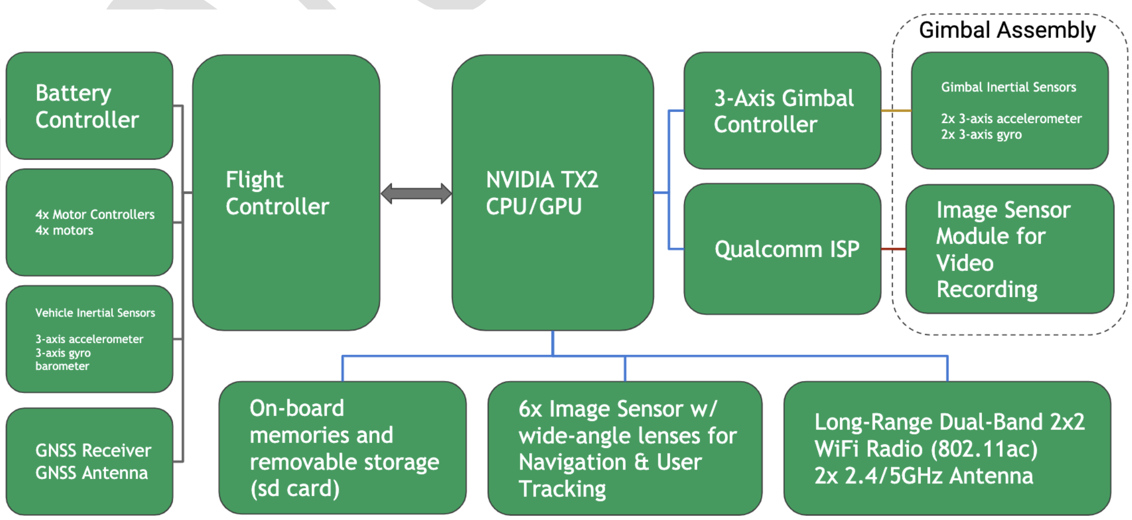

Figure 5. Avionics Architecture

Navigation

To determine location of the aircraft relative to the local environment, as well as globally relative to earth, the Skydio navigation subsystem uses information from the navigation cameras and the flight control subsystem uses information from an IMU (3-axis gyroscope, 3-axis accelerometer), barometer, and GNSS receiver.

Autopilot

The Skydio autopilot is a hardware and software stack which achieves real-time control of the aircraft using a microcontroller-based system with inertial, magnetic, barometric, and GPS sensors, information from the higher-level autonomy system, and Skydio flight control algorithms.

Flight Control System

The flight control system is designed and implemented by Skydio to ensure robust and reliable performance. The system includes a low-level real-time control module that runs on a bare metal microcontroller (Autopilot), and a higher-level model predictive control-based motion planning algorithm that runs on the main navigation computer running the Linux operating system.

The motion planning system sends a 2-second long continuous trajectory to the autopilot system at 15hz. The trajectories are crafted such that the autopilot can safely follow them for their entire length without input from the navigation computer, however in the normal case, new trajectories are swapped in every 66 milliseconds.

The system has extensive health monitoring on both the main navigation computer and the autopilot. In the case of a significant fault on the navigation computer, the autopilot is able to hover and/or land the vehicle safely without any input from the navigation computer.

Skydio Autonomy Engine

The Skydio Autonomy Engine is a hardware and software stack which enables the aircraft to achieve trustworthy autonomous operations. It includes high performance and product hardened real-time motor, gimbal, and flight control systems as well as full 360° sensing via 6 fish-eye cameras arranged in a trinocular configuration on the top and bottom of the airframe. These cameras enable world mapping and obstacle avoidance. Skydio obstacle avoidance is based on the output of several deep neural networks (DNNs) which have been trained to detect difficult objects in varied lighting conditions, including tree branches, wires, and textureless surfaces. These DNNs, which run in real-time on an NVIDIA Jetson TX2E at up to 1.33 trillion operations per second, are used to build up a 3D map of obstacle locations and allow Skydio sUAS to plan collision-free paths through complex obstacles (such as trees, trusses, and pylons).

The Skydio Autonomy Engine enables operation with centimeter-level precision in GPS-denied environments, while integrating GPS information when it is available. It also enables person, vehicle, and object classification, identification, trajectory prediction, and tracking in GPS-allowed and GPS-denied environments. It includes state of the art light log generation, including navigation and user camera video.

The Figure 6 below depicts some of the main building blocks of the Skydio Autonomy Engine - depth estimation, state estimation, and object identification and tracking capabilities.

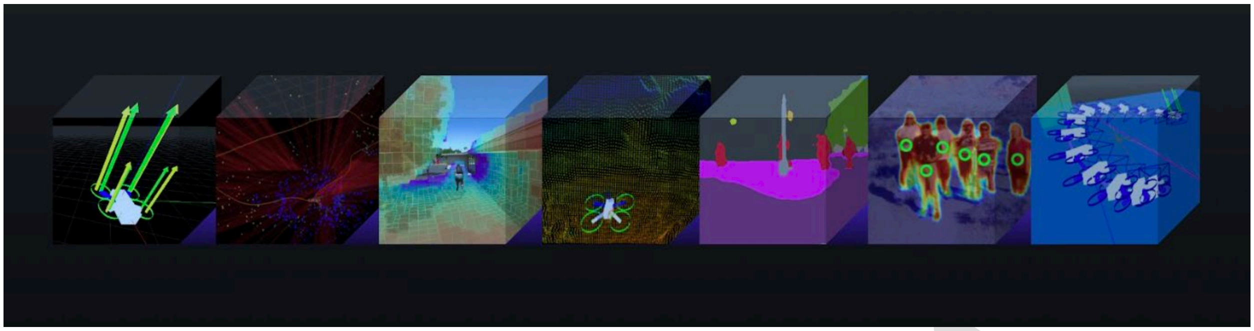

Figure 6. Building Blocks of Skydio Autonomy Engine

The autonomy engine performs the following while in flight:

- Visual SLAM (simultaneous localization and mapping) for centimeter-level motion estimation in GPS denied environments
- Dense 3D mapping for obstacle avoidance and environment relative control
- Semantic scene understanding for more robust navigation
- Visual detection and tracking of objects of interest (currently people and vehicles)
- Uses all perception information and predicts 4 seconds into future to make intelligent decisions

***Note that the sUAS only responds to instructions given by the pilot through the mobile application.**

3.5 Control Station (CS)

The control station of the Skydio 2 and X2E is a mobile device application and an optional handheld controller as shown in Figure 7.

Figure 7. Handheld Controllers – Skydio 2 Controller and X2E Enterprise Controller

The controls on each handheld controller are depicted in Figure 8.

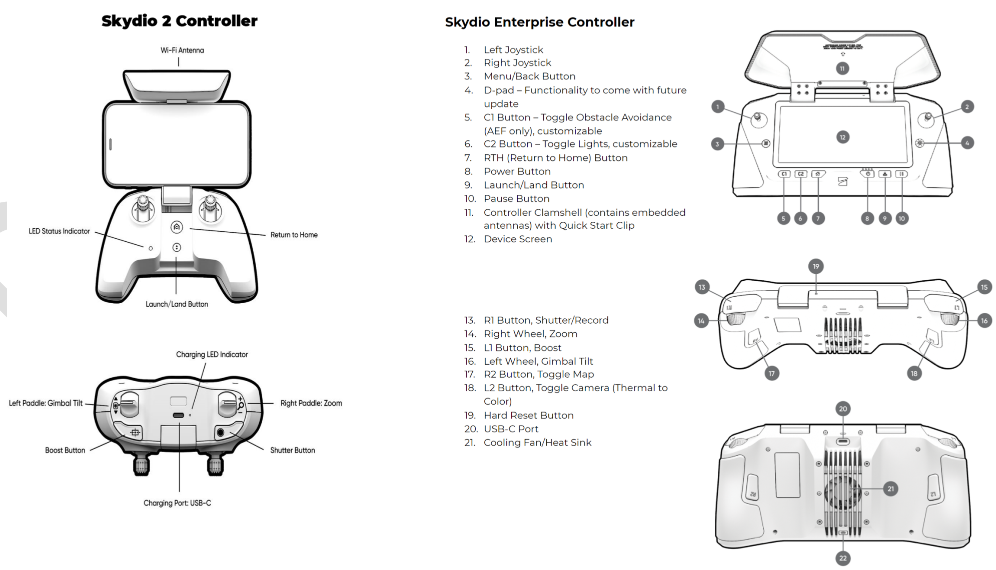

Figure 8. Diagram of Controls – Skydio 2 Controller and X2E Enterprise Controller

Using the CS software application, the RPIC can determine attitude, altitude, speed, position, and system health status of the aircraft.

On the mobile application, the RPIC is provided with three levels of battery/power alerts:

1. BATTERY LOW (~15% battery capacity)
2. BATTERY LOW (Auto landing start, ~10% battery capacity, pilot can cancel landing)
3. BATTERY CRITICAL (Auto landing starts, ~5% battery capacity, pilot cannot cancel landing)

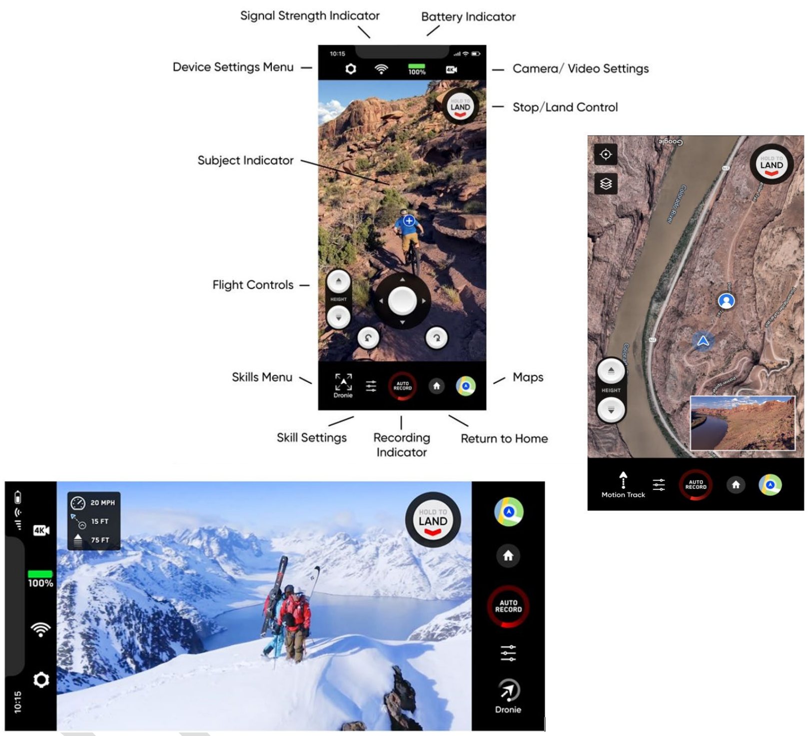

Figure 9. Controller Application Screenshots – Flight Controls, Aircraft Status & Health, Moving Map, User Camera Video Feed

3.6 Obstacle Avoidance System

Skydio 2's obstacle avoidance is based on the output of several deep neural networks (DNNs) which have been trained to detect difficult objects in varied lighting conditions, including tree branches, wires, and textureless surfaces. These DNNs, which run in real-time on an NVIDIA Jetson TX2E capable of up to 1.33 trillion operations per second, are fused with geometric algorithms to build up a 3D map of obstacle locations and allow the Skydio 2 to plan collision-free paths through complex obstacles (such as trees, trusses, and pylons) all without relying on GPS positioning. Autonomy is a core facet of the Skydio product and allows the drone to be piloted more safely with less training to avoid collisions with structures and terrain features.

3.7 3D Scan

Skydio 3D Scan is a suite of software tools for autonomously capturing visual imagery of a wide range of structures like bridges, building facades, and energy infrastructure. Users can capture data to build complex 3D models.

With an AI-driven workflow, 3D Scan provides comprehensive flight plan generation and builds a live 3D model of the scene as the Skydio sUAS flies. A path is planned to image all surfaces with overlap to get data for inspections and photogrammetry. 3D Scan operates with no reliance on prior maps, internet connectivity, or GPS. The automation level makes execution of this complex flight plans reduces the workload on the RPIC. The RPIC is then better able to maintain situation awareness of all factors impacting the flight.

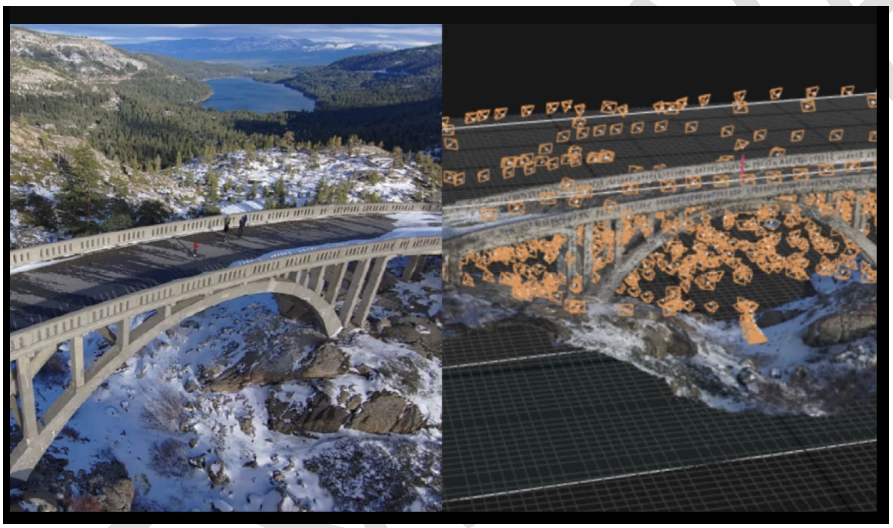

Figure 10. 3D Reconstruction of a Bridge with Skydio 3D Scan

3.8 Airspace Geo-Fencing

Skydio does not have an airspace geofencing capability. The RPIC must ensure each flight is authorized in the local airspace. Use of an airspace awareness service such as the B4UFLY is recommended.

3.9 Command and Control Link (C2 link)

The characteristics of the command and control (C2) links used by Skydio sUAS are listed in Table 11. The C2 system has been optimized to minimize latency, constantly adapting the video and telemetry bitrate to remain within the link budget. This adaptation monitors a wide variety of factors, including signal strength, channel utilization, packet error rate, and real-time queue depth. C2 link characteristics

Table 13. C2 Link Characteristics

Range	~3.5km
Operating frequencies	2.4-2.483 GHz 5.18-5.24 GHz

	5.725-5.85 GHz
Channel Width (Standard WiFi)	20, 40, and 80 MHz
Channel Width (Skydio Link)	5 and 10 MHz

3.10 C2 Link degradation

The Skydio mobile app plays an important role in the command and control system. Link health metrics are summarized and displayed through the Skydio app. The RPIC is given an indication when the link is degraded. In addition to the real time video feed, the telemetry feed provides the distance and altitude of the vehicle relative to the take-off location. THE RPIC may use the moving map display to gain further awareness of the location of the vehicle. The displayed location is computed using a fusion of computer vision and GPS, enabling location updates **even when the vehicle is operating in a GPS-denied environment, such as underneath the deck of a bridge.**

4 Operation

The following section describes the BVLOS operation in close proximity to bridge structures.

4.1 Background

Alaska DOT&PF has identified a need for a waiver for beyond visual line of sight requirements when flying in close proximity to bridge structures including under or through (truss members, for example). Waiving the requirement for a visual observer maintaining line of sight of the UAS and clearing the airspace will reduce the time spent exposed to roadway traffic, total amount of personnel on site as well as reducing the workload on the pilot.

Key Terms

Term	Definition
Close Proximity Low Altitude (CPLA)	A low-risk class of operations characterized by infrastructure masking, a concept that minimizes ground and air risk by operating in close proximity to physical objects (within 50ft) and within a limited range of the RPIC.
Area of Interest (AOI)	The physical area or asset to be inspected. For the purpose of the required FAA waiver the asset will be a bridge. The area of interest will determine the scope of the "operational area."
Operational Area (OA)	Refers to a space no more than 50 feet above the highest point of the area of interest; and no more than 50 feet laterally from the edges of the area of interest; and no more than 2,500 feet laterally from the RPIC. This area consists of areas where the aircraft is both within visual line of sight and BVLOS. All the BVLOS portion of the operational area will be at or below the height of the bridge; no more than 50 feet laterally away from the bridge; and no more than 2,500 feet laterally from the operator. The UAS will remain within the operational area at all times.

4.2 Location

Operations will be conducted primarily within the boundaries of the state of Alaska over or near state owned bridges of various types including highway, rail, pedestrian, etc. The maximum AGL height of bridge to be inspected will be no more than 100ft.

4.3 Airspace

Operations will not be conducted within 1 mile of any airport or helipad published on a VFR Sectional Chart without ATC or Anchorage Center Approval as outline in DOT&PF's COA

4.4 Aircraft System

As noted in Section 3, Skydio 2 and X2E sUAS will be used with the Handheld Controllers and a iOS device connected to the Skydio App which includes a first person view (FPV) from the aircraft. The RPIC will primarily use the 3D Scan automated flight and data capture capability.

4.5 Operating Procedures

An RPIC will conduct a site inspection to identify the area of interest (AOI) around the bridge to be inspected. Once the AOI is identified, the RPIC will identify the limits of the operational area (OA).

The BVLOS portion of the operations will be conducted no more than 50 feet laterally away from the bridge and no more than 2,500 feet laterally from the operator. Any operations at or above bridge level will be conducted within visual line of sight. The RPIC will be located at bridge deck level.

Prior to the operation start, the RPIC will ensure that the area below the OA is free of non-participants.

4.5.1 Pre-flight:

The RPIC will ensure the following are met:

1. Airmen
    a. Trained – RPIC is familiar with Skydio sUAS including use of handheld controllers and 3D Scan software.
    b. Current and proficient - RPIC is in compliance with Section 9 of the Alaska DOT&PF UAS Operations Manual.
    c. Fit for duty - The RPIC has made a risk assessment for the operations, including personal factors.
2. Air Risk
    a. BVLOS operations will remain within the operational area—no more than 50 feet laterally from the bridge and no higher than the highest point of the bridge. That carefully confined area close to the structure of the bridge substantially limits the air risk of the operation, as manned aircraft should not be flying within 50 feet laterally of a bridge, and the UA will not fly higher than the bridge itself.
    b. There are no private or public airport/airstrip/helipad, as identified on a sectional chart, within 1 mile of the OA.
    c. RPIC has identified local FAA ATC contact.
3. Ground Risk
    a. The area under the OA is a controlled ground area.
    b. To the extent necessary, Alaska DOT & PF personnel will take steps to physically block pedestrian and vehicular access to the area under inspection.

In addition, the RPIC conducts manufacturer recommended pre-flight steps and recommended pre-flight operations procedures to confirm mission readiness.

1. Establish best take-off/landing location
2. Establish contingency landing location
3. Establish best location for RPIC given environmental constraints while maximizing the visual sight lines of the UAS
4. Preflight UAS checklist
5. Weather check
6. Coordination and radio check with traffic control point of contact if assigned

4.5.2 Airborne:

Figure 11 illustrates a typical bridge inspection mission path and the boundaries of the OA. The RPIC will use Skydio 3D Scan for photogrammetric mapping and 3D reconstruction and when necessary fly manually within the OA using the onboard camera to photograph or video the structure. The RPIC will utilize a handheld controller connected to an iOS device hosting the Skydio App. If the RPIC notices a degradation in UAS performance, including C2 connectivity, the RPIC will end the inspection and return the aircraft to the take-off location for landing.

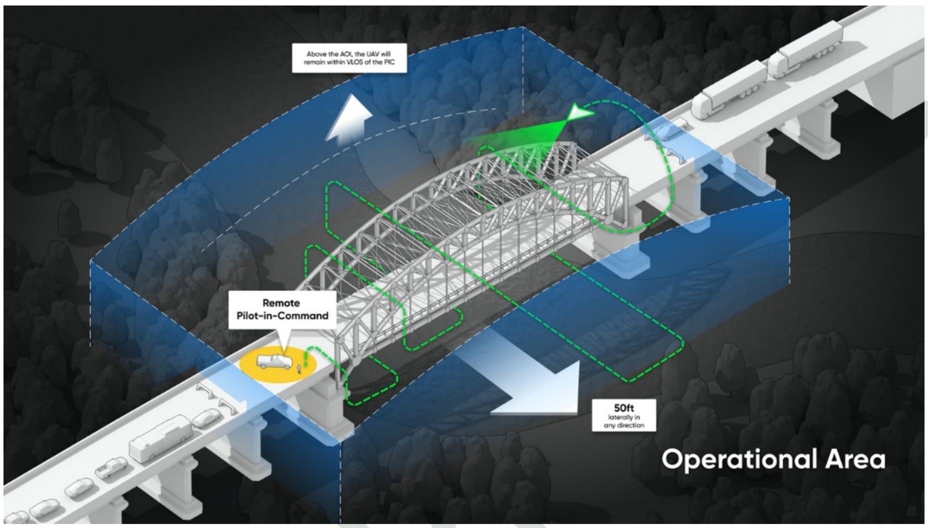

Figure 11. Typical Bridge Inspection Mission and Operational Area

Figure 12 illustrates the maximum distance the UAS will be operated from the RPIC. This maximum distance of 2,500 feet should be well within the range of the command and control link. Note that the RPIC is not required to be stationed in the center of the bridge. The intent of this illustration is to show that a large structure can be inspected in segments, over multiple flights. The maximum distance of 2,500ft can be maintained by repositioning the RPIC (and launch point) between flights.

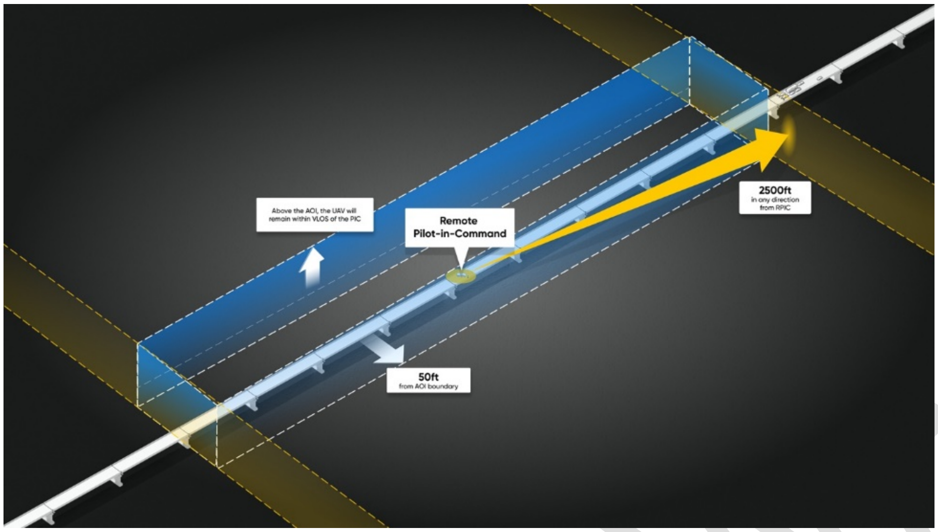

Figure 12. Maximum Range of BVLOS within Operational Area

4.5.3 Weather Conditions

Weather information will be collected from aviation sources in the surrounding area. The RPIC will make the final decision to execute or continue a flight based on all the latest weather information. Flights are short in distance and duration. The RPIC will be present at the operational area and able to assess local weather, weather minimums, and operating limits.

4.5.4 Airspace Awareness and Containment

During BVLOS operations, the sUAS will be flying above and below state-owned bridges. The close proximity of the operations to the structure of the bridge substantially minimizes air risk. Manned aircraft will not be operating within the airspace occupied by these operations. Again, the OA is limited to **within 50 feet of the bridge laterally and no higher than the height of the bridge**. If the UAS leaves the OA, the RPIC will be able to visually identify the UAS and execute contingency procedures based on VLOS rules. This concept is depicted in Figure 13.

Figure 13. Maintaining Awareness

4.5.5 Emergency Response Procedures

Emergency situations require immediate action from the RPIC in order to ensure public safety and avoid potential damage to the UAS or to other property. This could be triggered by:

- Degraded C2 Link
- UAS System Failure
- Deteriorating weather conditions

In the event of a loss link or failure of the controlling device, Skydio sUAS will automatically perform a 'Return to Home' action. Skydio sUAS will automatically return to the 'Home Point' or 'Rally Point' (if either one was specified), or the original launch point (if no 'Home Point' was specified). If at any time the C2 link is regained, the sUAS will continue the current action (RTH). However, the RPIC is given the opportunity to cancel RTH and send a new command to re-route the sUAS.

The RPIC will exercise aeronautical decision making and use knowledge of the Skydio sUAS systems to manage the situation. Procedures and guidance in Section 12 of the Alaska DOT&PF UAS Operations Manual will be followed. In the event of a system failure, the RPIC can elect to land immediately in the nearest safe area. Under most circumstances, Skydio autonomy collision avoidance will remain active, preventing the sUAS from impacting obstacles during manual or automated flight.

If the weather conditions appear to be deteriorating, the RPIC will cease operations and return the sUAS to the landing location.

4.6 Hazards and Safety Mitigations

This section describes common hazards experienced during BVLOS operations and the existing safety mitigation measures for CLPA-BVLOS bridge inspection. Skydio sUAS feature automated contingency behaviors and offer options for pilot control during off nominal events.

4.6.1 Summary

At any time, the RPIC may command the sUAS to return to the launch point, or land in place. The live camera feed enables the RPIC to view the landing area.

Onboard systems automatically monitor health. Based on critical faults and system state, the aircraft system may abort launch, execute an emergency landing, or return to the home point.

If sUAS experiences a propulsion system component (ESC) failure, the below mitigations are in place:

1. attempt to resync
2. attempt to restart
3. shut down all motors

If the sUAS has low battery power remaining, the below mitigations are in place:

1. At 15% battery capacity remaining, warn pilot that battery is low
2. At 10% battery capacity remaining, engage an automated landing, pilot can cancel and reposition UA
3. At 5% battery capacity remaining, engage an automated landing, **pilot cannot cancel landing**

If the sUAS has loses signal from the control station, the below mitigations are in place:

1. attempt to reestablish connection
2. automated return to rally point
3. land in place

4.6.2 Loss of C2 Link

While the C2 system has been optimized to maintain a link whenever possible, all wireless systems are subject to interference and/or attenuatinon. As such, it is important that the vehicle has a well-defined lost link procedure that enables the RPIC to safely re-establish the link, or safely recover the aircraft.

Skydio autonomy engine plans a safe path using its knowledge of the surrounding environment, allowing it to traverse complex environments. Even if the vehicle is operating in a GPS-denied environment, it is capable of returning to a using visual state estimation capability. In the event of loss of link, the sUAS will return directly towards one of the following:

- A pre-specified 'Home Point',
- The last known location of the controller, or
- The takeoff location.

<u>In the event of a link loss or failure of the controlling device, Skydio sUAS will automatically return to the Home Point or the original launch point.</u>

4.6.3 Loss of Propulsion System

Table 6 provides the most critical propulsion-related failure modes/conditions and their impact on system operation.

Table 14. Skydio Critical Propulsion-Related Failure Modes/Condition

Cause	Result
Propeller failure	Loss of ability to control the UA resulting in system shut-off
Motor failure	Loss of ability to control the UA resulting in system shut-off
Motor Controller failure	Loss of ability to control the UA resulting in system shut-off
Power PCB failure	Loss of ability to control the UA resulting in system shut-off
Battery management system (BMS) failure	Loss of power to the UA as well as loss of control
Battery failure	Loss of power to the UA as well as loss of control

4.6.4 Loss of Electrical Power / Low Battery Procedures

If a Home Point was specified for the flight, the UA will notify the pilot on the mobile app and offer to return to the Home Point when its battery reaches the level where the Home Point is at the edge of its expected flight range. This notification may be ignored by the pilot if they wish to continue flying. The UA will not automatically return to the home point. At 10% battery capacity remaining the UA will engage an automated landing which can be cancelled by the pilot. At 5% battery capacity remaining the UA will engage an automated landing which cannot be cancelled by the pilot.

If no Home Point was specified for the mission, the UA will display a warning to the pilot when it has 2 minutes of flight time left (~16% battery capacity) on the mobile app. At 10% battery capacity remaining the UA will engage an automated landing which can be cancelled by the pilot. At 5% battery capacity remaining the UA will engage an automated landing which cannot be cancelled by the pilot.

4.6.5 Loss of Navigation Systems

The Skydio system relies primarily on the navigation cameras and IMU (accelerometer + gyroscope) data together in a process called Visual Inertial Odometry (VIO). VIO is the process of estimating the state (pose and velocity) of an agent (e.g., an aerial robot) by using only the input of one or more cameras plus one or more Inertial Measurement Units (IMUs) attached to it. Using VIO allows the Skydio to ensure safe navigation and automated RTH procedures in GPS-denied environments.

In addition to the visual navigation cameras and IMU, the Skydio system uses a barometer and GPS positioning (when available) to assist in navigation.

If the system detects the loss of GPS or the navigation cameras it will respond by relying on the other instruments for safe navigation. If for example GPS lock is lost during flight, the UAS will rely on the VIO system to navigate. Conversely, if the system is to be flown at night when the vision-based navigation system will not be effective, the system will rely on GPS for navigation. Sophisticated checks for quality of visual features and GPS health are used to fuse the signals with appropriate noise models. Additionally, the VIO system can use semantic information about the scene around it to decide on which signal to use and to define a safe flight envelope.

If the system suffers a complete navigation failure, the UAS will engage a recovery or landing sequence based on the nature of the failure. If visual sensing is available, the system will attempt a “smart landing” in which the UAS will look for a flat surface clear of obstacles on which to land. If the planning subsystem has failed, the UAS will engage a vision or GPS-based emergency landing sequence straight down. If the main Tegra X2E processor has failed, a lower-level system will hover the drone on GPS while recovering the main processor. If there is no visual or GPS state estimate available, the UAS will engage a barometer+IMU emergency landing sequence.

If GPS position information is available, the vehicle will hover and then land using the GPS information. If GPS is not available, the vehicle will descend vertically via an emergency landing utilizing barometer data to control rate. If functionality of the navigation computer is restored during descent, the emergency landing will be aborted, and the mission may be resumed at operator discretion. GPS signal strength is provided to the pilot, and degraded system performance or emergency landing notifications are also displayed.

5 References / Attachments

1. Alaska DOT&PF UAS Operations Manual Version 1.3
2. Skydio 2 User Guide Version 1.0
3. Skydio X2E User Guide Version 1.0
4. Skydio 3D Scan User Guide Version 1.0