University of Colorado Boulder

Final Report

SURGE: Surface-water Reflectometry GNSS Experiment

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May 5th, 2023

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I. Project Overview

A. Background Information

Inland surface water bodies, such as rivers, lakes, reservoirs, and wetlands, are one of the key components of the Earth system. They significantly affect the hydrological cycle, surface energy balance, ecological systems, and human society. Therefore, monitoring surface water extent with high temporal and spatial resolutions is crucial for deepening our understanding of the dynamics of surface water bodies and evaluating their interactions with climate and human society in the context of global warming. Slope measurement with a high spatial resolution and short revisit times is difficult to achieve using existing technologies and as result there is a lack of river slope data on a global scale.

Among other techniques, passive radar reflectometry has been applied to achieve finer spatial resolution. This technique has proven it's feasibility of estimating IWB's with successful research and data to support it's claims as shown in the figure below. Done with low Earth orbiting GNSS satellites however, this accompanies longer revisit times and less coverage than is possible with other platforms.

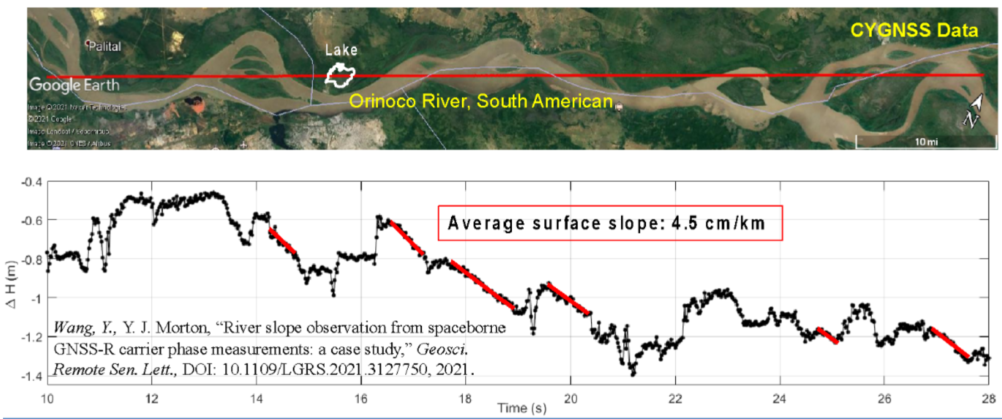


Figure 1: Measurements of the Orinoco River

In a new paradigm of reflectometry techniques, where passive receivers can be disjointed from GNSS satellites, the applicability of small UAV and modern day aircraft becomes apparent. This is where the SURGE (Surface-water UAV Reflectometry GNSS Experiment) project aims to design and test a proof-of-concept UAV-based system that can determine lake and river surface slopes, heights, and dimensions. This will be done by collecting direct GNSS signals and reflected GNSS signals from lake and river surfaces, precisely logging UAV position data, and recording continuous ground footage of the UAV's surroundings. A conceptual overview of how this works is shown in the figure below.

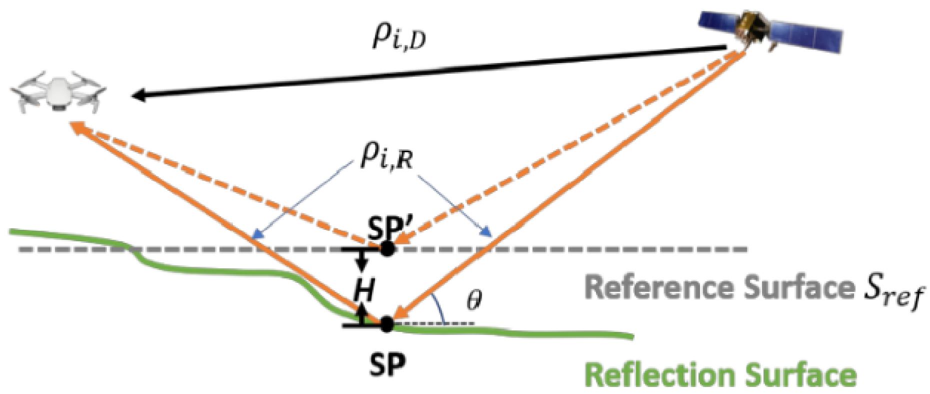


Figure 2: Concept

B. Primary Objectives and Requirements

1. Objectives

- Design a UAV payload that can (1) provide UAV position at 10 cm accuracy, (2) capture and record baseband reflected GPS signals from IWB surface, (3) capture images of IWB and surrounding environment, (4) communicate with a base station to relay the UAV location and operational status, and (5) collect and store UAV position, reflection signal data, and images of IWB during flight.
- Plan for UAV flight path based on GPS satellite orbit information and target IWB geographical information to allow the specular reflection point to follow or across the IWB.
- Explore/find/develop GNC software that will fly the UAV according to the planned flight path.
- Process and analyze the collected data and perform cross validation using measurements obtained from other sources.
- Refine the payload design, flight path planning, and GNC software to optimize the retrieval results.

2. Requirements

The following are a set of high level requirements that define the design space used for this project. It outlines the functionality for all required data that is required to be collected as well as platform performance requirements. For a detailed overview of the design solution and specifications of each requirement being verified, see the system overview section below.

FR1 The GNSS-R payload shall collect and store baseband GPS signals.

- **DR1.1** The GNSS-R payload shall collect and store direct baseband L5 GPS signals
- **DR1.2** The GNSS-R payload shall collect and store reflected baseband L5 GPS signals from water
- **DR1.3** The GNSS-R payload shall collect and store direct and reflected baseband GPS L5 signals at a sampling rate of at least 22MHz.
- **DR1.4** The GNSS-R payload should collect and store direct baseband L1 GPS signals.
- **DR1.5** The GNSS-R payload should collect and store reflected baseband L1 GPS signals from water
- **DR1.6** The GNSS-R payload should collect and store direct and reflected baseband GPS L1 signals at a sampling rate of at least 10 MHz.

FR2 The SURGE UAS shall record video of the inland water body and surrounding environment

- **DR2.1** The recorded video shall be stored on the camera payload
- **DR2.2** The recorded video shall be exportable from the camera payload after a mission has been fully completed
- **DR2.3** The recorded video shall be saved as a .MP4 format

FR3 The SURGE UAS PPK receiver shall store correlated time and location data

- **DR3.1** The stored correlated time and location data shall contain time series of longitude, latitude, and altitude of the UAV, and GNSS time stamp
- **DR3.2** The receiver shall record data in a format that can be used to perform Post Processing Kinematics (PPK)
- **DR3.3** The receiver shall sample correlated time and location data at a rate of 1 Hz
- **DR3.4** The receiver shall achieve a PPK accuracy of 10 cm

FR4 The SURGE UAS shall operate autonomously

- **DR4.1** The autonomous control system shall follow an operator defined flight path
- **DR4.2** The operator defined flight path shall be followed within 5 meters of the desired location
- **DR4.3** The operator defined flight path shall be based on GPS ephemeris and IWB location and shape
- **DR4.4** The autonomous control system shall be capable of taking off
- **DR4.5** The autonomous control system shall be capable of landing
- **DR4.6** The autonomous control system shall be capable of return to home flight mode
- **DR4.7** The SURGE UAS shall be capable of flight near Inland Water Bodies (IWB) with installed GNSS-R payload to collect reflected signals
- **DR4.8** The SURGE UAS shall be capable of flying autonomously for 1 km of distance

FR5 The SURGE UAS shall be capable of communicating with a ground station

- **DR5.1** The SURGE UAS shall transmit GNSS-R payload operational status to a ground station
- **DR5.2** The SURGE UAS shall transmit its operational status to a ground station
- **DR5.3** The ground station shall be capable of receiving signals from the SURGE UAS
- **DR5.4** The ground station shall be capable of transmitting a signal that switches the SURGE UAS from autonomous flight control to be manual flight control
- **DR5.5** The SURGE UAS shall communicate with the ground station within FCC guidelines

FR6 The processed GNSS-R payload data shall be capable of being processed.

- **DR6.1** The processed GNSS-R payload data shall be analyzed to determine the relative surface height of IWB's
- **DR6.2** The processed GNSS-R payload data shall be analyzed to determine the absolute water slope of IWB's
- **DR6.3** The processed GNSS-R payload data shall be analyzed to determine the boundaries of IWB's
- **DR6.4** The camera and satellite images shall be capable of validating location of IWB's

C. CONOPS

A snapshot of the concept of operations is below, showing the primary steps of the procedure along the top.

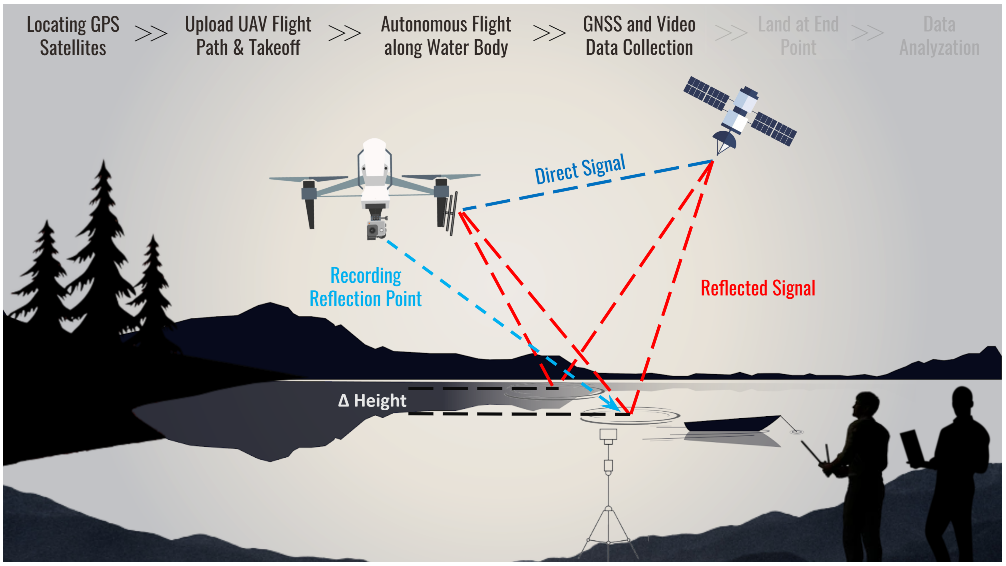


Figure 3: Concept of Operations

II. System Overview

A. System Design

1. CAD Rendering

The full system design layout is provided by the CAD rendering in the figure below. Each major component can be identified in its respective position attached to the UAV frame. Position-sensitive components include the science antenna, PPK antenna, and camera, otherwise, the rest of the components are in their positions due to space claims available on the UAV frame. The antennas are contingent on not interfering with any structures or material from the UAV. Details on each specific subsystem are to follow in the sections below.

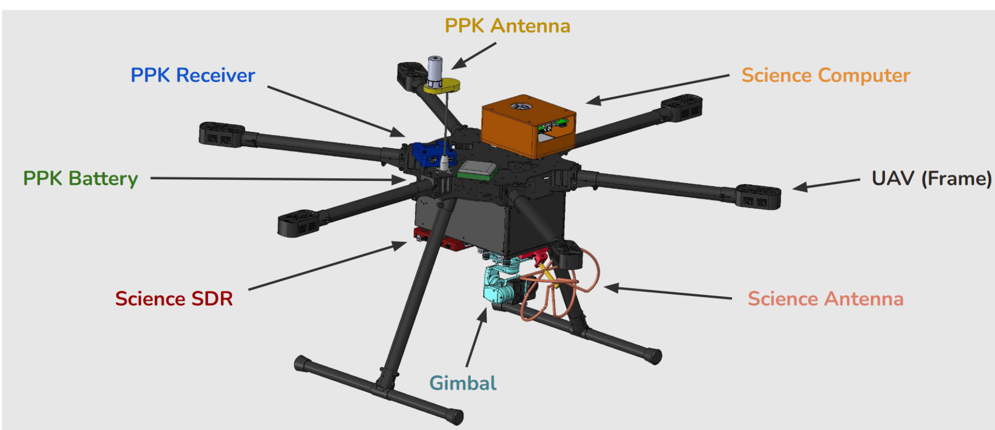


Figure 4: System

2. *Functional Block Diagram*

A more functional and in-depth view of the full system is shown below. This figure shows how each subsystem and component is interfaced with each other and the whole system. See the legend for labeling on wireless communication, power, mechanical, and data interfaces.

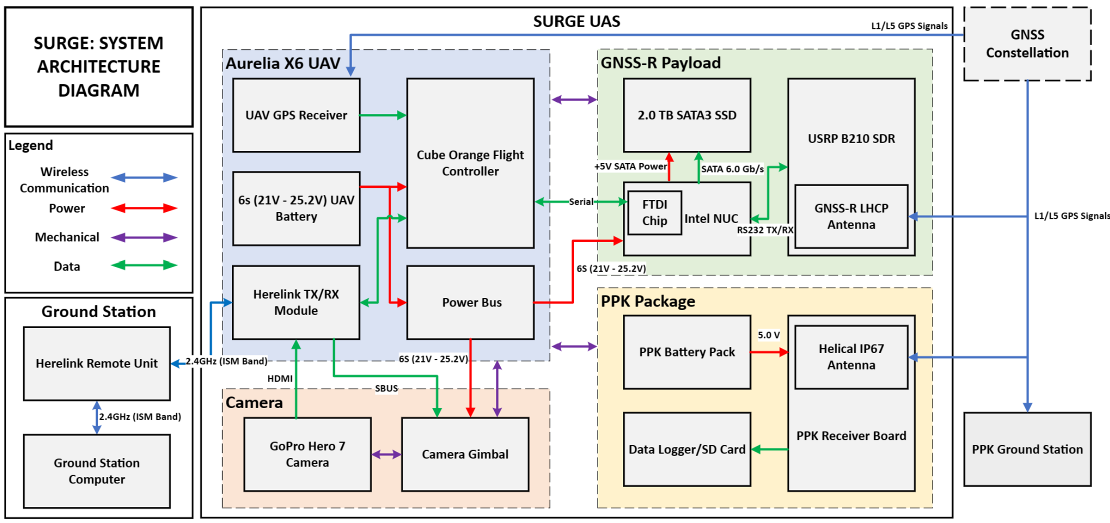


Figure 5: Functional Block Diagram

3. *Bill of Materials*

For a list of parts and purchasing links, please refer to the Bill of Materials spreadsheet in the Appendix for a comprehensive list of all components purchased.

B. GNSS Payload

1. *Components*

The GNSS Payload is the primary science payload and provides the functionality required for collecting and storing L5 direct and reflected GPS signals. It consists of a central processing unit, software-defined radio, power amplifiers, storage drives, and an L5 capable left-hand circular polarized GPS antenna. All component and specification details are found in the table below.

GNSS Payload Items		
Item	Comments	Datasheet
L5 LHCP Antenna	Sense Lab manufactured antenna capable of collecting L5 GPS Signals	N/A
Intel NUC Board/Kit NUC7i3DN	Science computing providing interfacing between SDR, flight controller and storage drives.	NUC Datasheet Link
USRP B200 SDR	Powered by data collection computer via USB3	Ettus Research Datasheet
2.0 TB SSD WDS200T1R0A	Red 2.0 TB 2.5" SATA3 SSD	Western Digital Datasheet

The GNSS Payload collects data on startup of the guided flight mode on the UAV flight controller. This is set such that no unwanted data is collected while powered on and awaiting take-off.

2. *SDR Configuration*

The SDR is configured according to the configuration file found on the Intel NUC. Two files are critical for running SDR data collection: `b210_split_settings_balloon.xml` and `rx_multi_to_file.cpp`. Configuration for SDR data collection is found in the script b210_split_settings_balloon.xml. In this file, the few parameters that need to be examined when using a new SDR are: serial, sampling rate, osc_source, antenna, dev_name, and path_name. The SDR Collects data at a rate of 22MHz, internal osc_source, and data is being captured in a directory named /media/DataStore/usrp3. Raw data is stored as an sc8 file.

3. *Intel NUC and PPK Scripts*

The Intel NUC contains software for managing communication with the CubeOrange, saving PPK data, and monitoring whether SDR data is being written to the hard drive. These scripts start when the UAV is powered on. This automatic startup is handled in the /etc/rc.local file. The PPK and NUC have two main.py files that are launched in this file. The NUC script handles the startup of the SDR collection and mavlink serial communications. The PPK main script handles the processing of PPK data. The link to the GitHub repository can be found in the appendix of the document.

The CubeOrange communication software manages the mavlink serial communication between the CubeOrange and the NUC. It first establishes a heartbeat with the CubeOrange and then exchanges data. The NUC obtains information about the UAV's current flight mode, which is utilized by the PPK software. It also sends a boolean value to the CubeOrange, indicating whether SDR data is being collected. This message is displayed in Mission Planner, as described in the ground station section of this document.

The PPK data saving software establishes serial communication with the PPK board using Python's serial library. The NUC receives data from the PPK board, which is then saved to a timestamped file. The file's storage location is detailed in the PPK Payload section.

The SDR writing software monitors the SDR folder for size increases, indicating that SDR data is being written. The specific folder being checked is specified in the SDR section of this document. The SDR software only begins collecting data when the UAV is in "AUTO" mode, signifying fully autonomous flight. This prevents unnecessary data collection during pre-flight or while the UAV is grounded.

C. Post-Processed Kinematics (PPK) Payload

Post-Processed Kinematics (PPK) is a GNSS correction technology used to correct the location data after it is collected and uploaded. PPK allows the SURGE system to calculate more precise positional data that can be used to give better estimations for when the height, slope, and water boundaries are calculated for the IWBs. To gather PPK data, the SURGE system uses the ArduSimple simpleRTK2B board.

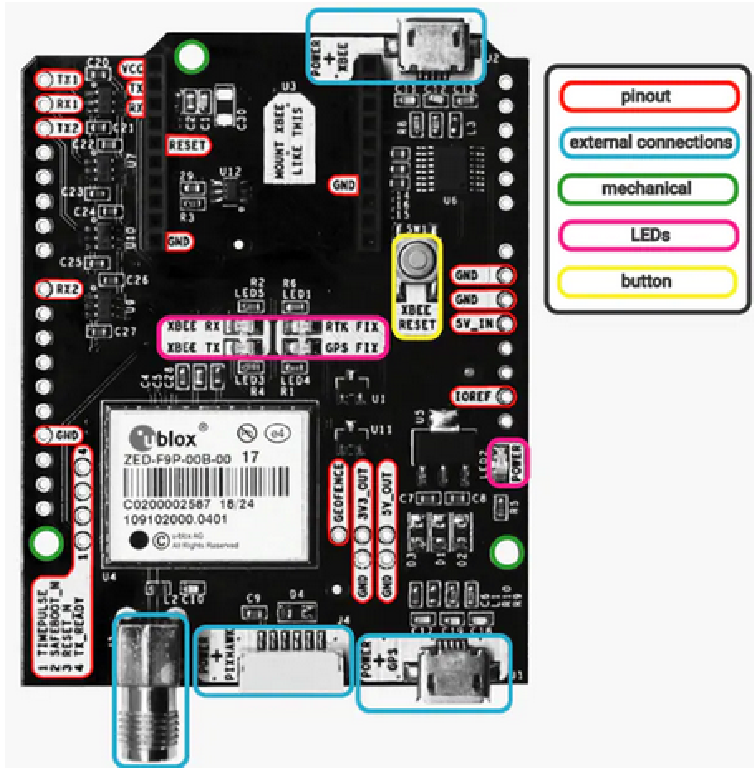


Figure 6: PPK ArduSimple simpleRTK2B

This board supports the capability of writing the collected data to either an on board SD card or a connected computer. If the data is written to a computer, it can either be saved via the U-blox software or saved to a file using a script that reads in the binary serial data. The SURGE system uses two boards. The first is a ground station board which is connected to a ground station computer via U-blox. This provides base station positional information that can be used to correct the drone's positional data. The second board is on the drone and is used to gather the positional data during flight. This system gathers data via a script that reads in the serial information via the science computer on the drone. Due to limitations in the PPK data processing speed, the data is collected at a frequency of 1 Hz.

1. *PPK Board Configuration*

The base station board is connected to a Trimble Zephyr III on a tripod via a 3m RF cable. The board itself is powered by connecting a USB C cable to a laptop base station via the Power + GPS plug as seen in Figure 6

The drone PPK board is connected to an ArduSimple Lightweight helical antenna for multiband GNSS via an RF cable. The board is powered by connecting a USB C cable to the NUC and plugging into the Power + GPS port on the Ardusimple board.

2. *U-blox Firmware Overview*

Both simpleRTK2B boards have the same firmware installed for their respective ZED-F9P receivers. Each board is currently running version 1.13 of the ZED-F9P firmware. The directions to upload a file to the board, and the files themselves, can be found by following this link

3. U-blox Sampling Parameters

Both simpleRTK2B boards have the same sampling parameters. Each board is currently running with the following parameters: NMEA, NAV-PVT, NAV-SAT, MON-SPAN, RXM-RAWX, and RXM-SFRBX messages enabled with Target" to "3-USB" under Configuration - PRT. The rate is set to 1 Hz. These sampling parameters configure the boards to collect RAW ubx measurements which are used in Post Processing later.

4. Software Overview

To operate the PPK system on the drone during flight, software was written to start and store data collection. This software uses Python's pyserial library to read in the binary output from the PPK board. The serial rate to read in the board data at a baud rate of 38400 with each byte size being eight bits. When data is collected, the system writes the PPK data to the /media/PPK_data/ folder on the science computer in a file with the date and time of collection. The science computer is currently configured to start the script when powered on. This configuration is defined in the /etc/rc.local file on the science computer.

D. Power System

1. Batteries

Two batteries were used as the main source of power for the system. The batteries used are the Aurelia X6 MAX Batteries. These are LiPo 6S 22.2V, 27,000 mAh batteries. With these batteries the UAV can fly up to 70 minutes with no external payload. With the SURGE payload installed, the drone has approximately a max flight time of 40 minutes. These batteries need to be charged using a LiPo battery charger with a balancing connector. When connected, the batteries can be charged at a rate up to 27 amps. Though this is the case, the current charger in the SENSE lab can only do up to 20 amps.

2. Power Distribution

The system utilizes the two LiPo batteries that are connected in series to provide the primary power to the system. This setup powers the essential components, including the NUC computer, GoPro camera gimbal, and the cube orange flight controller. The NUC computer is responsible for distributing power to the PPK payload and the SDR payload, which ensures that all components receive the required power. These systems powered through the NUC computer are powered via a USB connection. Additionally, the system is designed to support the GoPro camera, which has an internal battery that is charged to power it.

E. Aurelia UAV & Flight Controller

The UAV platform is the Aurelia X6 Standard. It is a hexacopter rated for a 30-minute flight time while carrying a 5kg payload. It is foldable and is able to be stored safely with propeller restraints. The Aurelia X6 includes a Cube Orange flight controller running Ardupilot. The Cube Orange communicates with the ground system through a Herelink transmitter, which supports RC, telemetry, and video transmission.

F. Camera Payload

The specular point visual observation system, otherwise known as the camera payload, provides visual assertion of the specular point recording site. In order to verify the received data from the GNSS Payload to the actual recording site, a GoPro Hero 3 camera is attached to the base of the UAV and records the location of the data we receive. The camera is attached to a gimbal which provides accurate pointing direction and reduces vibration from the UAV during flight. Although the gimbal is unable to be controlled during flight, it may be programmed prior to flight through the TarotXYZ gimbal software to the desired pitch and yaw angles. The camera must be manually started before flight to record video to its onboard SD card.

G. Ground Station

The ground station serves as a way to monitor the flight of the UAV via a computer to assist the pilot. The ground station runs a program called Mission Planner and connects to the herelink controller to receive data from the UAV. In order to receive data, the herelink controller needs to enable its hotspot and launch the QGroundControl software, and the ground station computer needs to connect to the hotspot named "SURGE" with the password "AndreasBad". Once connected mission planner should automatically detect and display the data on the screen.

The Mission Planner screen will also display whether the SDR is writing data to the NUC. To view whether data is being written, go to setup>advanced>MAVLink Inspector. Then select vehicle 255> Mavlink Severyity and look at the emergency messages string, it should say "Disk Writing" or "Disk Not Writing".

III. Operation Guide

A. Flight Planning

This section will outline the team's current procedure for planning the flight path and uploading this to the UAV prior to actual flight. It is up to the discretion of the team how this should be done, however this will provide insight into future team's operation of this UAV.

For the purpose of flights that collect reflected GPS signals, it starts with identifying satellite position and path, and determining based on geometry where the UAV needs to be at certain times throughout the flight. This is done currently through Matlab scripts which take in a GPS broadcast file and returns a waypoint file containing the correct format to be read into the ground station software Mission Planner. Once this waypoint file has been generated with the desired flight path, it is uploaded to Mission Planner where it can be verified on the map and written to the UAV if a connection has been established. The "write" button under the plan tab in Mission Planner will achieve this. After it has successfully written, the flight plan should display on the Herelink controller. If it has not been updated on the Herelink controller, a restart of the QGroundControl software on the Herelink controller may need to completed.

The UAV may also be operated manually, however may be less precise with respect to position and attitude throughout flight.

B. Checklist

The following is the operational checklist that should be followed pre-flight, during-flight, and after-flight for all flight testing. Included are procedures in case of emergency behaviour such as fly aways.

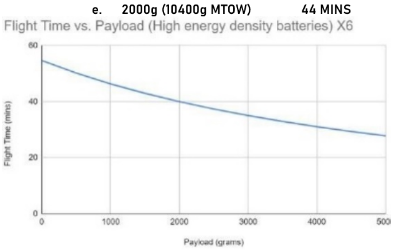
CHECKLIST FOR SURGE SYSTEM – AURELIA X6 UAV

Airport Info Frequencies:

Boulder	
Pattern	6300 ft
Boulder AWOS	118.825
Boulder CTAF	122.725
Rocky Mountain Metro	
Pattern	6700 ft
Metro ATIS	126.25
Metro Tower	118.6
Metro Tower Phone Number	720.633.8610
Fort Morgan	
Pattern	4595.3 ft
Fort Morgan CTAF	123.05
Fort Morgan Phone Number	970.867.4823

Critical Drone Parameters:

1. Max Estimated Flight Time
   a. 0g (8400g MTOW) — 58 MINS
   b. 500g (8900g MTOW) — 54 MINS
   c. 1000g (9400g MTOW) — 50 MINS
   d. 1500g (9900g MTOW) — 47 MINS
   e. 2000g (10400g MTOW) — 44 MINS



2. Max Flight Speed — 12.5 m/s
3. Max Ascent Speed — 2.5 m/s
4. Max MTOW 12170g
5. Max Range 5km
6. Dimensions — 42 x 42 x 24in

EQUIPMENT LIST

Mission Items

1. UAS Airframe
2. Flight Battery (4)
3. LIPO Bags
4. RC Transmitter
5. Aviation Handheld Transceiver
6. Ground Station Computer
7. Spare Propellers

Tool Items

1. Table
2. Chairs (2)
3. Tool Kit
4. Anemometer
5. Fire Extinguisher
6. First Aid Kit
7. Shovels (2)

Documentation

1. Part 107 Certification
2. Checklist (3)

Preflight Checks

Weather/Logistics

1.	Remote PIC Health	CHECKED
2.	Remote PIC License	CHECKED VALID
3.	Visibility (METAR)	> 3 MILES
4.	Wind (METAR)	< 10 MPH
5.	Wind (6000 ft)	< 10 MPH
6.	Wind (Anemometer)	< 10 MPH
7.	Gusts (METAR)	< 5 MPH
8.	Temperature (METAR)	5C – 40C
9.	Temperature (6000 ft)	5C – 40C
10.	Current METAR (METAR)	RECORDED
11.	Forecast TAF (METAR)	RECORDED
12.	ATIS (303.466.8744 or 126.25)	RECORDED
13.	NOTAMS	CHECKED
14.	TFRs	CHECKED
15.	Airspace	CHECKED
16.	Flight Waivers (if applicable)	CHECKED VALID
17.	Any Questions/Concerns?	DISCUSS

Vehicle Preflight Inspection

1.	Registration Marking	LEGIBLE
2.	Arms Deployed and Locked	CHECKED
3.	Motors	FREE & CLEAR
4.	Propeller Condition	CHECKED
5.	Propellers	INSTALLED/OPEN
6.	Propeller Directions	CHECKED
7.	Battery Condition/Swelling	CHECKED
8.	Wiring Condition	CHECKED
9.	Wiring Clear of Props	VERIFIED
10.	Landing Gear	SECURE
11.	GPS Mast	SECURE
12.	Compass Mast Direction	CHECKED
13.	GPS Antennas	SECURE
14.	Telemetry/RC Antennas	SECURE
15.	All Fasteners/Bolts	SECURE
16.	Miscellaneous Components	SECURE
17.	Battery Charge	CHECKED FULL
	Verify that Paired Batteries have Same Voltage +/- 0.2V	
18.	Wire Connections	SECURE
18.	Herelink Transmitter	BATTERY >80%
19.	Batteries	INSTALLED
20.	Battery Straps	SECURE
21.	Center of Gravity	CHECKED
22.	Any Questions/Concerns?	DISCUSS

Payload Preflight Inspection

1.	Front Camera	INSERT SD
2.	Bottom Camera	INSERT SD
3.	Bottom Camera	INSERT BATT.
4.	Bottom Camera	BATTERY 100%
5.	Bottom Camera	POWER OFF
6.	NUC to battery connection	CHECKED
7.	NUC to SDR connection	CHECKED
8.	Antenna to Amplifier conn.	CHECKED
9.	Amplifier to SDR connection	CHECKED
10.	Board to Amplifier connection	CHECKED
11.	Any Questions/Concerns?	DISCUSS

Crew Briefing

1.	Remote Pilot in Command	VERBALLY NOTED
2.	Ground Station Operator	VERBALLY NOTED
3.	Visual Observer	VERBALLY NOTED
4.	Air Traffic Monitor	VERBALLY NOTED
5.	Fire Extinguisher Operator	VERBALLY NOTED
6.	**Fire Procedures**	**VERBALLY NOTED**
	1. Attempt to extinguish the Fire	
	2. Notify all Personnel/Bystanders	
	3. Call Fire Department if Unable to Extinguish	
7.	Non-Participating Personnel	INSTRUCTED
8.	Type of Flight	VERBALLY NOTED
9.	Purpose of Flight	VERBALLY NOTED
10.	Direction & Path of Flight	VERBALLY NOTED
11.	Roles Throughout Flight	VERBALLY NOTED
12.	Site	
	1. Permissions	VERBALLY NOTED
	2. Boundaries	VERBALLY NOTED
	3. Obstacles	VERBALLY NOTED
	4. Special Restrictions	VERBALLY NOTED
	5. Airport/Air Traffic	VERBALLY NOTED
13.	Emergency Landing Locations	VERBALLY NOTED
14.	**Flyaway Procedures**	**VERBALLY NOTED**
	1. Notify Personnel	
	2. Maintain Visual Contact	
	3. Verify Remote Control ON	
	4. Toggle Return to Home	
	↓↓ If Drone Fails to Return ↓↓	
	e. Contact ATC/Traffic	

i. Metro Tower – 118.6
ii. SW Practice – 122.75

15. Any Questions/Concerns? DISCUSS

POWER UP

1. Herelink Transmitter POWERED ON
1. Batteries (x2) CONNECT
2. Drone Power Noise VERIFY
3. Leave Still for 30 Seconds VERIFY
4. Check Status LEDs CHECKED
5. Safety Switch PRESS & HOLD
6. Front Camera POWER ON
7. Front Camera CONNECT HDMI
8. Bottom Camera POWER ON
9. Bottom Camera CONNECT HDMI
10. Camera Feed VERIFY
11. Gimbal Control VERIFY POSITION
12. PPK Payload VERIFY ON
13. NUC Fan/FTDI Light VERIFY ON

The motors should stop beeping, if any of the motors continues beeping, after the safety switch LED is solid red, disconnect the batteries and contact Aurelia Aerospace for support.

14. Mission Planner to Herelink CONNECTED
15. MP Receiving Data VERIFY
16. Heading in MP VERIFY

If the actual heading of the UAS is different to the heading in MP, perform re-calibration process of the UAS compass.

Flight Path

1. Herelink Hotspot On VERIFY ON
1. Connect GSC MP to Herelink CONNECTED
2. Flight Path in MP VERIFY PATH
3. Write Mission to Herelink CHECKED
4. Verify Mission on Herelink VERIFY

TAKEOFF

1. Bottom Camera BEGIN RECORDING
1. Propellers/Area VERIFY CLEAR
2. Flight Mode Check VERIFIED
3. Crew VERBAL "READY"
4. Flight Mode LOITER ©
5. Begin Timer BEGIN
6. Push Restart Button RESTART BUTTON

VERIFY CAN CHANGE INTO ALL FLIGHT MODES
NUC and PPK will automatically start recording data immediately after pushing the button.

8. PPK Payload BEGIN RECORDING
8. NUC Payload BEGIN RECORDING
9. Vehicle ARM

LEAVE RIGHT STICK CENTERED WHEN ARMING

10. Controls TEST
11. Fly 5m HIGH
12. Flight Mode AUTO
13. Mission EXECUTE

Before Landing

Flight Mode RTL (Long B)

LEAVE RIGHT STICK CENTERED WHEN LANDING
If the landing zone is not clear or there is erratic behavior with the UAS while it is landing, regain manual control

After Landing

Disarm THROTTLE DOWN (Bottom Left)

Shutdown and Secure

1. Transmitter DISCONNECTED
1. Mission Planner DISCONNECTED
2. Batteries (x2) DISCONNECTED
3. Place Batteries in LiPo Bag CHECKED

Fly Away

1. Notify Personnel VERBALLY NOTED
1. Visual Contact MAINTAIN
2. Remote Control ON VERIFY
3. Return to Home TOGGLE

↓↓ If Drone Fails to Return ↓↓

4. ATC/Traffic CONTACT
    1. Return to Home TOGGLE
    2. SW Practice – 122.75

Figure 7: SURGE UAV Checklist

C. Personnel Details

In order to conduct flight tests of the UAV platform, it requires a number of roles to be filled within the team. There should be (1) a visual observer (VO), (2) Remote Pilot-in-Command (RPIC), (3) Ground station operator. The visual observer needs to keep a visual assessment of the UAV and other potential hazards during flight, such as obstacles, other UAVs, or aircraft. The RPIC will be in command of the UAV during flight and is the main point of contact and provides decision making in case of emergency or hazards. The RPIC should have knowledge of the system to take full manual control of the system if needed to avoid hazards or retain constant safety of the platform. Finally, the ground station operator will be constantly verifying real-time health and telemetry data of the UAV from the ground station in Mission Planner during flight. The ground station operation shall maintain UAS location, altitude AGL, attitude, and direction of flight through the duration of all flights.

Our Remote Pilot in Command (RPIC) and Visual Observer (VO) shall be located in places to maintain visual assurance of the UAV during the entire flight. This may change based on location and path of flight. The team also purchased a secondary DJI mavic drone that can be controlled by a secondary pilot to provide additional awareness of the Surge UAV when far away. The VO's will assist the RPIC in order to avoid potential non-participating aircraft should they enter the geo-fenced area. Shall another aircraft enter the operational area, sighted by either the VO or RPIC, the RPIC shall either maintain 400 ft AGL or lower the UAS to 50 feet AGL depending on an immediate visual assessment of the hazard until it has passed. If necessary, the RPIC will assume manual control of the UAS to perform avoidance maneuvers to potential hazards within these altitudes. In addition to this, VO's will monitor air traffic via a handheld VHF aviation radio, further increasing situational awareness.

D. Data Recovery and Translation

To achieve actual results of water body surface height and boundaries, the data will need to be extracted from the UAV and processed through acquisition and data analysis. This requires taking the PPK payload and GNSS payload data that was collected during flight and determining if it is adequate for performing analysis on. The PPK data will output positional results of the UAV during flight and will assign a confidence number that determines how accurate the system is recording data. For processing data, it is best to use all the "good" data that has an assigned confidence level of "1". For the GNSS data, this will be recorded to the Intel NUC. These files provide sc8 data type of GNSS signals that were collected from L5 satellites during flight and will need to be processed. From here, refer to data processing scripts to translate the data, perform acquisition, and height determination of the surface of the water.

Once signal peaks are detected, one can analyze those peaks by determining its code delay. By knowing the drone and satellite positions, specular point position on the water body can be determined. Finally, one can compare signal travel time with code delay and sampling frequency to determine drone height above the water surface. A matlab script for this processing can be found on our github repository under the branch “Data_Processing”.

IV. Future Work

A. General

Immediate future work that could be conducted is flying the aircraft above 400ft to acquire L1 GPS signals. This requires an FAA waiver, which had been processed and approved on May 3rd, 2023 and will expire on May 4th 2025. Unfortunately, no test flights were able to be completed in this altitude block since this waiver was only approved during finals week and the team had minimal time to test. The GPS antenna also can be changed out to an L1 GPS antenna (which should be available in the lab) prior to flying up to 800ft which should achieve more accurate results. Additional work to be done is fixing the forward camera and GoPro gimbal. With both specular point observing sensors not working, the specular point was not able to be recorded for verification. This could be fixed with part replacements or some further troubleshooting.

B. Lessons Learned

Modeling and predicting RF behavior is difficult. Beyond a point, there is no substitute for experimentation.

When operating in high risk environment such as over bodies of water, be confident in the design to reduce risk of of adverse behavior causing the system to be damaged.

Software processing and creation take a significant portion of time needed for creation and testing. Writing software and data scripts proved to be difficult without guidance and mentorship from field experts. Some software packages that needed to be used relied heavily on heritage packages (MAVLINK) with poor documentation. SDR configuration scripts were also used based on heritage flights of a previous satellite data collection experiment–mentorship and guidance was necessary to be able to get testing and operations running quickly. Prior knowledge of satellite signal acquisition and processing was necessary in being able to generate scripts needed for signal processing.

C. Data Processing

Our acquisition process must be confirmed to track a consistent satellite signal across a certain length of time. Once our acquisition process have proven to be reliable, water-body characteristics can be calculated. Initial acquisition scripts as well as specular point and drone height calculations can be found on our github repository.

The data collected from future flights must then be able to determine parameters of a water-body such as slope, height, and boundaries. As a first test, the drone should be flown over a water and shore to be able to determine water boundaries in post-processing. Then, water height and slope can be calculated.

V. Appendix

A. Github Repository

The GitHub repository can be found at `https://github.com/jamiestankiewiz/SURGE`

SDR configuration files can be found at `https://github.com/jamiestankiewiz/SURGE/tree/main/NUC_scripts/SDR_backup_files`

Data Processing scripts can be found at `https://github.com/jamiestankiewiz/SURGE/tree/main/Data_Processing`

B. Bill of Materials

`https://docs.google.com/spreadsheets/d/1aU-oNnlAp5RBdQ3QMPX__wG4rHO70fivSRhbpG5-o20/edit#gid=0`

C. Ardusimple Sampling Configuration Procedure

Sampling Parameters Procedure

- Connect Ardusimple board to base station antenna
- Connect ardusimple board to computer via the USB-C port labeled “Power + GPS” (This will power the receiver so ensure an antenna is connected)
- Open u-center 1 (not 2) application
    - https://www.u-blox.com/en/product/u-center
- Select serial port
- Enable NMEA, NAV-PVT, NAV-SAT, MON-SPAN, RXM-RAWX, and RXM-SFRBX messages
- Select “Target” to “3-USB” under Configuration - PRT
- Set Configuration - RATE to 1 Hz
- Receiver - Action - Save Configuration

Drone/Rover Data Collection Procedure

- Ensure main.py is uncommented in /etc/rc.local so it launches on startup.
- Ensure rover board is secured to the drone
- Connect ardusimple board to NUC via the USB-C port labeled “Power + GPS”
    - Port on same side as SMA (antenna) cable
- Power on the drone and the ppk system should start collecting data.

Ground System Data Collection Procedure

- Connect base antennas to Ardusimple boards
- Connect ardusimple board to computer via the USB-C port labeled “Power + GPS”

        - Port on same side as SMA (antenna) cable
- Open u-center 1 (not 2) application
    - https://www.u-blox.com/en/product/u-center
- Select correct serial port
- Set baudrate to 57600 Hz
- Begin recording base station
    - Ensure the file is saved as a .ubx

Post-Processed Kinematic Procedure

- Use RTKLIB “Demo 5” version
    - https://github.com/rtklibexplorer/RTKLIB/releases
    - https://drive.google.com/drive/folders/15VmOHDXc8sPmXHOSNZBmVzR2BsNj7qL7?usp=sharing
- Obtain log.txt file from SD card
    - rename to .ubx
- Open RTKconv.exe to convert from .ubx to .obs+.nav files
    - Under “Options” include L1, L1/E5b, GPS, GLO, all observation types
    - Convert base station and rover .ubx files
- Open RTKpost.exe to post-process data
- RTKpost Options:
    - Setting 1: Kinematic, L1+L2E5b, Combined - no phase reset, include GPS+GLO, 15 degree elevation mask
    - Setting 2: fix and hold + fix and hold integer ambiguity res
- Input rover .obs, base .obs, and base .nav into RTKpost, execute
    - This will create a .pos file with the final position solution.