NASA/TM-20230010693

Standard Operating Procedure (SOP) for Flight Testing a Radiosonde and 3D Sonic Anemometer Configuration on a Multi-rotor Uninhabited Aerial System (UAS)

Tyler L. Willhite & Jennifer W. Fowler
Uninhabited Aerial Systems Operations Office
Langley Research Center, Hampton, Virginia

August 2024

NASA STI Program Report Series

NASA/TM-20230010693

Standard Operating Procedure (SOP) for Flight Testing a Radiosonde and 3D Sonic Anemometer Configuration on a Multi-rotor Uninhabited Aerial System (UAS)

Tyler L. Willhite & Jennifer W. Fowler
Uninhabited Aerial Systems Operations Office
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

August 2024

The use of trademarks or names of manufacturers in this report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

DOCUMENT HISTORY LOG

Status	Document Revision	Approval Date	Description
Baseline	N/A	March 2024	Standard Operating Procedure (SOP) for Flight Testing a Radiosonde and 3D Sonic Anemometer Configuration on a Multi-rotor Uninhabited Aircraft System (UAS)
Revision	August 2024	August 2024	Section B and G updated with new mount design information

Table of Contents

A. Nomenclature 6

B. Purpose and Applicability 7

C. Summary of Method 9

D. Cautions 9
- 1. Ground Station Receiver 9
- 2. Computers 9
- 3. Radiosonde 9
- 4. UAS 9
- 5. Radiosonde Ground Station 10

E. Interferences 10
- 1. Data Reporting 10
- 2. Initialization 10

F. Personnel Qualifications 11

G. Equipment and Supplies 11
- 1. UAS 11
- 2. Radiosonde 12
- 3. Anemometer 12

H. Procedural Steps 12
- 1. Anemometer 12
- 2. Radiosonde 12
- 3. UAS 18
- 4. Troubleshooting 19

I. Health and Safety Warnings 20
- 1. Weather 20
- 2. Radiosonde Ground Station 20
- 3. UAS 20

J. References 21

K. Acknowledgements 22

L. Appendix 23
- Attachment 1- Launch Equipment Checklist 23
- Attachment 2 – Pre-flight Checklist 24
- Attachment 3 – Programming the Anemometer 26
- Attachment 4 – Anemometer No-Wind Calibration 29

A. Nomenclature

AGL	–	Above Ground Level
ARB	–	Airworthiness Review Board
c.g.	–	Center of Gravity
FFOD	--	First Flight of Day
GCSO	–	Ground Control Station Operator
GPS	–	Global Positioning System
gsf	–	GRAW Simulation File
GS-U	–	Grawmet Ground Station
LaRC	–	Langley Research Center
LiDAR	–	Light Detection and Ranging
NWS	–	National Weather Service
ORR	--	Operational Readiness Review
PIC	–	Pilot in Command
PPE	--	Personal Protective Equipment
RF	–	Radio Frequency
RFA	–	Radio Frequency Authorization
RH	--	Relative Humidity
RSO	–	Range Safety Officer
RTL	--	Return to Launch
SOP	–	Standard Operating Procedure
UAS	--	Uninhabited Aircraft System
UASOO	--	Uninhabited Aerial System Operations Office
UTC	--	Universal Time Coordinate

B. Purpose and Applicability

The purpose of this Standard Operating Procedure (SOP) is to establish a uniform procedure for initialization of a radiosonde, a 3D sonic anemometer, and collection of sounding data with correct sensor integration via a multi-rotor uninhabited aerial system (UAS) within the Langley Research Center's (LaRC) Uninhabited Aerial System Operations Office (UASOO).

The most widely used system for vertical atmospheric profiling is a balloon-borne radiosonde. Radiosondes measure temperature, pressure, relative humidity, wind speed and wind direction every second along its flight path. The engineering goal of this project is to provide a drop-in replacement for a balloon platform using a UAS. The advantage of the change in platform allows for repeated low altitude profiles since the radiosonde is recoverable unlike on a balloon-borne platform. Additionally, wind speed and direction are determined from the balloon drift of the radiosonde therefore when changing the platform an additional anemometer is needed to measure wind speed and wind direction. In this particular setup, the anemometer has the added advantage of being able to measure three dimensional winds unlike the radiosonde on a balloon platform. The radiosonde that is used in this procedure is a GRAW Radiosondes GmbH & Co DFM-17™ radiosonde with a GS-U™ ground station. This particular sonde was selected for three reasons; because of its performance during the World Meteorological Organization's radiosonde intercomparison study[1], the mobility of the ground station, and the ability to attach external sensors whose data is streamed in real-time with the other radiosonde measurements. The anemometer that is utilized is a Anemoment LLC LI-560 TriSonica Sphere Wind Flux Sensor™. This was selected for three reasons as well; because of its ability to measure three dimensional winds, its light weight allowing it to be mounted on a UAS, and the data is capable of being transmitted using the same protocol as the radiosonde. The UAS that these sensors are being flown on is Alta X™ aircraft, manufactured by FreeFly Systems, Inc. This was chosen because of its size to mount a payload at the height required to reduce propellor influence on the sensors and minimize any change in center of mass of the aircraft. The sensors are to be placed on a custom mount atop the aircraft in the shape of a T with one sensor on each end. The first iteration design for this project with the corresponding sensors is shown in figure 1.

Figure 1: Full Assembly First Version

The T shape mount choice is based on best practices for comparing sensors mounted on the same platform. They were placed far enough away from each other so they do not influence each other, and for this first iteration the mount was designed to be tall enough for safe flight and minimal propeller influence. The T mount was oriented on the UAS to minimize cross section of the mount exposed to the forward motion of the aircraft. Since it is being operated only in the z direction it does not matter which side of the mount houses the radiosonde or anemometer.

Figure 2: Full Assembly Second Version

This mount has since been updated for stability, strength and weight using carbon fiber material. It has also been fabricated to be taller, approximately 3 feet high as opposed to the previous design in order to mitigate propeller influence. Currently, this is the final mount design for this sensor suite.

This SOP will aid in ensuring credibility, accuracy, and completeness of all flight and sensor data retrieved. The procedures outlined in this SOP are applicable to all personnel involved in the planning, coordination, preparation, execution, and reporting of UAS based upper air soundings. The procedures outlined in this SOP may be useful outside NASA LaRC, but do not take precedence over applicable manufacturer procedures and/or specifications.

C. Summary of Method

For more information on this instrument suite and why it was selected and produced, refer to AIAA SciTech publication AIAA-2024-2092[2].

D. Cautions

1. Ground Station Receiver

- DO NOT operate the ground station without a proper antenna attached. A proper antenna is the antenna supplied with this ground station by the manufacturer or antenna specifically authorized by the manufacturer for use with this ground station.

2. Computers

- Keep all electrical equipment stored in a cool, dry place. While the computers are being used in the field they may be exposed to adverse conditions.

3. Radiosonde

- While preparing the radiosonde, be careful not to bend the boom or touch the sensor head.
- Any contact to the sensors from the skin can leave oil residue which will result in spotty or inaccurate data retrieval.
- Before initializing, make sure the anemometer is connected to the radiosonde and powered.
- Make sure initialization plug is connected correctly and all of its drivers are installed.

4. UAS

- Before flight of any UAS, a pre-flight checklist will need to be completed (Attachment 2). Make sure all personnel are trained and mentally/ physically prepared for flight.
- Stand clear from UAS propellers until verbal verification from GCSO that vehicle is disarmed, this can be verified by seeing if orientation lights have dimmed on aircraft.[3]
- Two UAS batteries allow for approximately 45 minutes of flight time. Peak battery voltage is 50.4 V,[4] when battery voltage reaches at or below 44 V(~30%), ground the vehicle and swap batteries.
- Ensure UAS battery charger limits are appropriate for the battery type, number of cells and overall capacity.
- Only utilize batteries in verified operating temperatures, do not overheat or overcharge or fire may erupt.
- Communication protocols for pilot intervention in automated flights or other emergencies will be established in the Operational Readiness Review (ORR) conducted by NASA Langley.
- As per the ORR, the aircraft heading will be established into the wind.
- It is recommended to only take off in Manual Mode or alternatively use mission mode for autonomous takeoff. This experiment is solely done in mission mode. UAS must have a GPS lock before takeoff to set a valid home position in order to start a waypoints mission.[3]
- UAS will only Autoland if the battery exhaustion failsafe is set to RTL.[3]
- Do not exceed vehicle flight limits as defined by the Eastern Region Airworthiness Review Board for the airwothiness review criteria set by the project as:

  Max deck angle: 25 degrees
  Max wind speed: 20 knots (10.3 m/s)
  Ascent rate: 10 knots (5.1 m/s)
  Descent rate: 5 knots (2.5 m/s)
  Geofence: Flight range, RSO and PIC discretion

NOTE: limits are only valid with current aircraft configuration, any changes will need new analysis and airworthiness review approvals.

5. Radiosonde Ground Station

- Prior to operation outdoors, the ground station can be earthed with an earthing cable.
- Do not use a higher voltage than recommended in the Technical Data. Otherwise, the device may be damaged, and the warranty shall immediately be rendered null and void.[5]

6. Anemometer

- Be sure the data connections have been made correctly before powering the unit.
- Be sure a proper battery is being applied to the anemometer (14.8V LiPoly).

E. <u>Interferences</u>

1. Data Reporting

- Monitor both the raw data and profile data screens for inaccurate and missing data. If the flight altitudes are high enough, graph a skew-t plot using the Grawmet software during flight to view any problems that may occur. (In the software at the top of the screen, there is a button that says "skew-t plot").
- Minimize the probability of data loss due to obstructions.
  - Heights of obstructions should be less than tracking antenna if possible.
  - Ensure maneuvering room.
- Analyze data to detect system noise or signal dropouts.
- To avoid loss of data, save radiosonde data to both the computer used and to a thumb drive.
- For UAS specific data or connectivity concerns please see the ORR and Hazards document attached to the ORR.

2. Initialization

a. Radiosonde

- Acclimate the radiosonde to ambient air for 10 minutes before making comparisons. Ground values (pressure, temperature, and humidity) from a ground weather station. The comparison values to the radiosonde should be within these ranges: +/- 2°C for temperatures, +/- 10% for RH, or +/- 5 mbar for pressure. If the radiosonde values fall outside these limits, allow it to acclimate for another 2 minutes before rechecking; if it fails again, use another sensor.
- Before initializing, check the transmission frequency of the radiosonde to avoid interference (see Procedural Steps- Radiosonde- Initialize Radiosonde). When a ground station is used, the frequency band is continuously scanned for interference. Disconnecting the radiosonde and reading the frequency will indicate if any other signal is on the same frequency. Choose new frequency if one currently in use is occupied.
- Three attempts should be made to properly initialize the radiosonde. If after three attempts the radiosonde is still not properly initializing, discard the radiosonde and use a new one.
- Confirm any radiosondes not initialized for flight have been turned off to avoid interference.

b. GRAWMET

- Exact GPS coordinates allow the time packets to arrive almost immediately. If the coordinates are for the broad region of flight it takes time for Grawmet to find the radiosonde and can result in lost data.

NOTE: North America is **negative** longitude

c. Anemometer

- Confirm that the wind sensor has been properly programmed and base-lined in a zero-wind condition before use. (Refer to Attachment 3 and 4 for instructions on doing this).

F. Personnel Qualifications

This SOP is written specifically for those individuals who are participating on any level with a flight test at NASA Langley Research Center with a radiosonde sensor payload. Certification and training provided by both UASOO and the project are necessary for all personnel actively assisting. Minimum personnel necessary for a flight test include an RSO, spotter/observer, pilot, data analyst, and a GCSO.

Basic knowledge of electronics and sensors are only necessary for data analysts but may be helpful to other personnel involved.

G. Equipment and Supplies

1. UAS

a. UAS Storage

- This UAS collapses to 30% its full size.[6] It can be unfolded and refolded when time for storage after final flight tests when the mount is removed as shown in figure 3.

Figure 3: UAS Folded without Mount

b. UAS Battery Storage

- Batteries must be stored in a Lithium Polymer (LiPo) bag for storage, then placed in a fireproof locker.

2. Radiosonde

a. Radiosonde Storage

- The box the sondes are shipped in, provide enough cushion to protect the sensor and antenna. Keep radiosondes in the shipping box until ready to use.
- Store units in a dry place, away from direct sunlight.

3. Anemometer

a. Anemometer Storage

- Keep the anemometer in its case until ready to use.
- Store in a dry place, away from direct sunlight.

4. For a list of remaining equipment see Attachment 1.

H. <u>Procedural Steps</u>

1. Anemometer

a. Anemometer Setup

- Complete programming and calibration instructions shown in Attachment 2 and 3 in the appendix. This only needs to be completed **once**.
- Once completed, the anemometer is ready for use.

NOTE:
The anemometer operates in the 60kHz ultrasonic frequency range.
When mounting the anemometer onto the mount assembly there is a "north" indicator "N" marked on the cap of the top of the mounting post. When air flows directly into the "N" the data streams reports "zero" degrees for wind direction, regardless of the physical orientation of the Sphere.[7]

i. <u>Confirming proper connection</u>

- Connect the anemometer to the XDATA port of the radiosonde (the black arrow on the connector from the anemometer goes to the red wire on the XDATA cable).
- Connect the power to the anemometer.
- Confirm static sound from the anemometer.
- Power ground station on (section H.2.a.iii) and begin Radiosonde initialization procedure (H.2.b.i). If an earthing connection is required, do section H.2.a.ii prior to powering ground station on.

ii. <u>Data Interpretation</u>

- Any setup questions can be referred to the anemometer Manual.[7]
- The anemometer needs to be running BEFORE initializing the radiosonde.

2. Radiosonde

a. Ground Station Setup

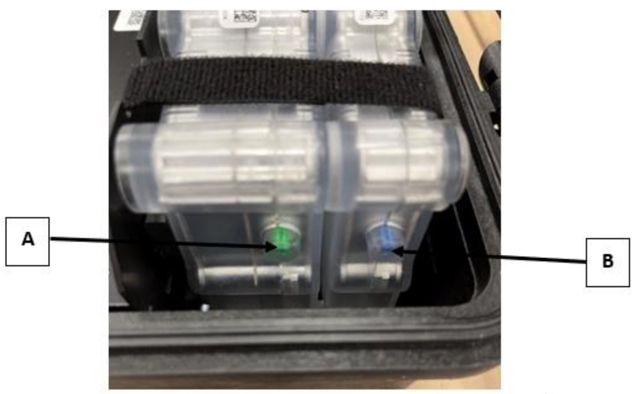
i. <u>Charging Ground Station</u>

NOTE: Charge status only shows when the battery is switched on. The LED on the front of the battery describes the status. Status lights are shown in figure 4.

LED indicator	Status
Green	Battery charge status 75 - 100%
Yellow	Battery charge status 50 - 75%
Orange	Battery charge status 35 - 50%
Red-orange	Battery charge status 20 - 35%
Red	Battery charge status 10 - 20%
Red flashing	Battery charge status < 10%; connect power supply as soon as possible
BC / orange / BC / dark flashing (BC + green to red, depending on charge status)	The AC/DC adaptor does not provide enough current to operate the receiver and change the portable current source at the same time. (The receiver runtime is increased by using the portable current source, but the battereis on the portabl ecurrent source are gradually discharged).
Orange flashing	Battery is charging: mains operation is running
Green flashing	Battery is fully charged; mains operation is running
Red flashing	Error - check temperature, overlaoad or short circuit at the output

Figure 4: LED Indicator table

- Connect the adapter to the power supply unit and then connect to a socket outlet.
    - Power supply is 100-240 V/AC 12 V/DC.
- Press the button on the front of the battery (B in figure 5).
    - The ground station should start flashing orange.



Legend:

A Receiver On/Off switch

B Battery On/Off switch

Figure 5: Ground Station Receiver

ii. <u>Earthing connection</u>

- Loosen the wing screw by twisting it off the threaded rod counter-clockwise. (Port D in figure 6).

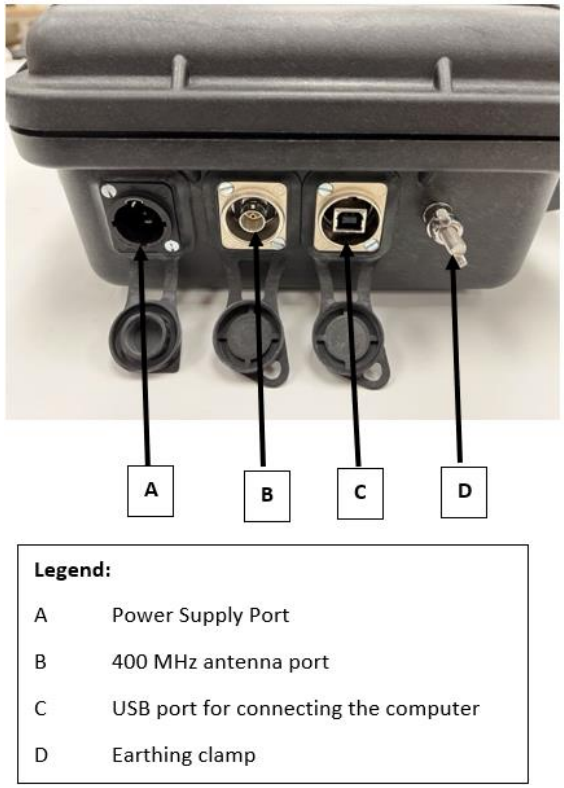


Figure 6: Ground Station Ports

- Take one of the two shims off the thread.
- Push the closed cable lug onto the thread.
- Screw the earthing cable with the wing screw clockwise until hand tight.
- Attach an earthing lug to a suitable earthed object.

iii. <u>Powering Ground Station on</u>

- Connect the antenna to port B (Refer to figure 6 in section H.2.a.ii for all port connections).
- Connect the USB port on the ground station to a computer (port C in figure 6).
- Turn on the ground station.
    - Press BOTH the battery and receiver buttons (refer to figure 5).
    - Receiver frequency range is 400-406 MHz.

b. Radiosonde Setup in Grawmet

NOTE: Grawmet software should be installed properly prior to beginning these steps, follow the instructions from the company after radiosonde purchase for installation requirements.

i. <u>Connect to Power</u>

- Open the radiosonde – be careful to *not touch the end of the sensor*.

- Connect the initialization cable into the sonde as shown in figure 7. There is a section on the end of the sonde near the power switch that is cut to fit the cable. Do not turn it on until section iv “Start a Sounding.” Then connect the USB end into the computer.

Figure 7: Initialization Plug into Radiosonde

- Open Grawmet 5.15
    - You may receive a warning regarding weather station not found -- disregard.

ii. <u>Check Communications</u>

- Click on the tab to the left of the Start tab.
- Click Program Options.
- Click on the Communications tab.
- Click Detect under Ground station.
    - Should be GSE.
- Click Detect under Com Ports.
    - Make sure COM shows up correctly.
- Click OK.
    - May receive error “TEMP/BUFR will be invalid” – disregard.

iii. <u>Initialize Radiosonde</u>

    - Be sure the anemometer is on BEFORE initializing the radiosonde.
- Click Sounding/Simulation in the ribbon near the top of the screen.
- Click Initialize Radiosonde.
    - Wizard is optional and not recommended - if using Wizard follow instructions.
    - In Wizard when it asks for initials- must be at least 3 letters long to be valid.
- After initialization completes, click the arrow next to Advanced and click Set Frequency.
- Set the frequency according to the frequency allocation list or find an open channel free of interference as shown in figure 8.
    - A channel without interference will not have high dbm peaks.

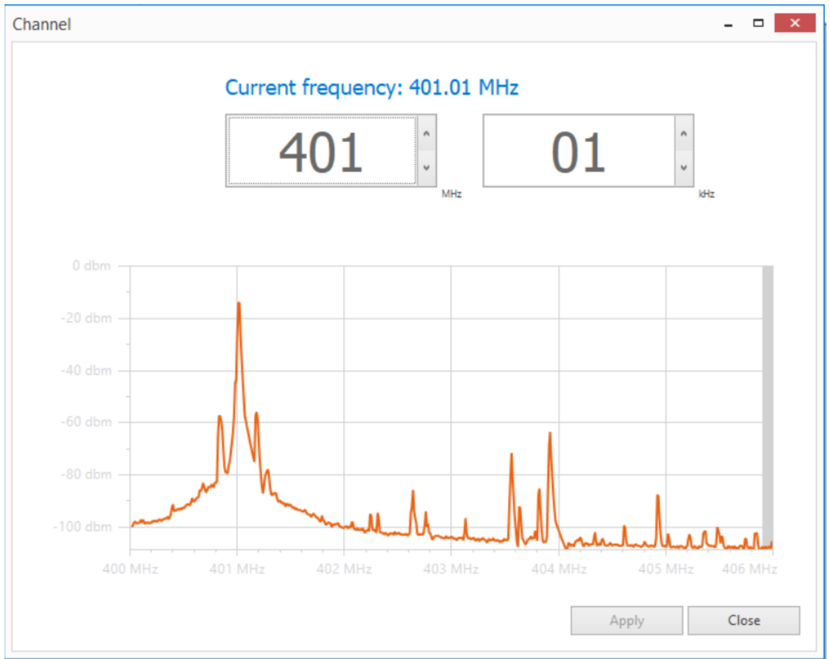


Figure 8: Changing Channel Frequency Display

- Click apply
  - If the error "Interference Found" is received, repeat the last step and choose a different frequency.
  - It may be necessary to disconnect the radiosonde to see if any other frequencies are in use and then reconnect.
- Double check Battery and Status both have a green check mark next to them (shown in figure 9) and that XDATA is available under Radiosonde Information.

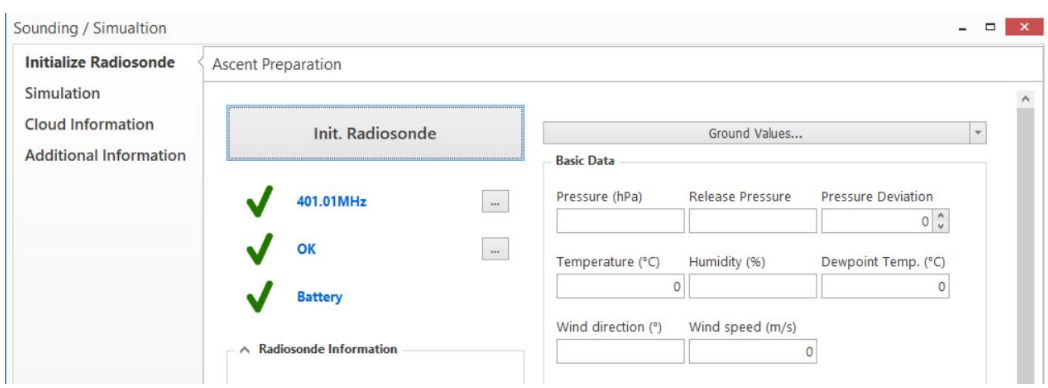


Figure 9: Sounding/Simulation Status Check Marks

- Input ground conditions into their respective fields as shown in figure 9 (click the arrow next to Ground Values to choose a Read-in method).
  - Temperature, humidity, and pressure are required. Cloud information, and wind conditions are optional.
  - Values can be gathered from the internet, weather station (recommended) or from the radiosonde if outside.

- The radiosonde may not be equipped with a pressure sensor (it measures pressure via GPS values using the hypsometric equation), therefore the inputted surface pressure value must be as accurate as possible.
- Make sure all values are as accurate as possible to insure immediate data retrieval. Initial values can be updated post-flight and data rerun if necessary.

- [ ] Enter Latitude, Longitude and Altitude.
    - If outside, the radiosonde can pick up a GPS signal that may populate this field automatically.

iv. <u>Start a Sounding</u>

- [ ] Click Start Sounding.
- [ ] Click Next through additional windows, then click Apply.
- [ ] Check the status bars at the bottom of the screen and make sure they are all green.
- [ ] Turn on the radiosonde and then unplug the initialization cable from the sonde.
    - To power on, hold the radiosonde power button until a solid yellow light appears (Red: error, Yellow: on).
- [ ] Double check data is being received by clicking the Sensor/GPS data table. Data should be populating on the left table; data will populate on the right table if GPS lock has been achieved.
- [ ] Click Start Launch Manually in the Start tab for UAS operations.
    - ONLY click this button if RSO has given the "go ahead" to launch.

v. <u>Data Collection</u>

- [ ] Navigate to the Visualization tab and click Sensor/GPS data table.
    - This is the raw data.
    - Note that this radiosonde transmits every second.
- [ ] Click Profile Data Table.
    - This is corrected data (might come in slow since calculations are being done in the background for the corrections).
- [ ] Click Skew-t Diagram (if skew-t plot is necessary).
- [ ] Save raw data tables (Save Active View button in the Sensor/GPS data table tab)
    - First window will prompt user to save raw sensor data first, second window is raw GPS data
    - Mm_dd_yy_hhmmss_UTC_Raw_Sensor/GPS.
- [ ] Wait for the flight to finish then click Terminate.
    - If raw data is needing to be saved, click Save Active View in the Visualization tab BEFORE clicking Terminate. File Explorer will open twice prompting for a file name input, the first is saving the sensor data, the second is saving the GPS data.
    - For more resources on navigating the user interface, utilize the manual provided by the company.

vi. <u>Saving Data</u> (D = Date; mm_dd_yy; hhmmss_UTC = time of flight termination)

- Wait for data to finish compiling before saving.

- [ ] Save XDATA (Document>Grawmet5>data).
    - **Save XDATA after every flight!** File will be overwritten each flight.
- [ ] Save Profile data table (Reports Tab>Profile Data>Export Document > Save as .csv).
    - Mm_dd_yy_hhmmss_UTC_profile.
- [ ] Save Simulation files if necessary (Documents>Grawmet5>Data>.gsf and .gsf1 file).

  - Choose the .gsf and .gsf1 files that correspond with correct time of when the flight was terminated.
- ☐ Upload flight data to an external hard drive, thumb drive, or Box.
- ☐ Upload flight data onto a shared teams folder.
- ☐ Turn off the radiosonde between flights.
- ☐ Unplug power to the anemometer if all flights are completed for the day.
- ☐ Unplug remaining cords to the ground station and computer and store accordingly.

NOTE: Refer to User Manuals in References for questions not answered in this SOP.[7,8]

c. Running Two Computers with One Radiosonde

NOTE: For the use of two computers, two ground stations are needed. It is not possible to use two computers with only one ground station.

- ☐ Initialize the radiosonde on the first computer using Section iii above.
- ☐ Click on “Start sounding” to put the software to reception mode using Section iv above.
- ☐ Wait until the raw data table is being filled as shown in Section v above.
- ☐ Disconnect the cable without switching on the radiosonde.
- ☐ Initialize the radiosonde on the second computer.
  - Make sure the same frequency is in use on both computers.
- ☐ Click on “Start sounding” to put the software to reception mode.
- ☐ Wait until the raw data table is being filled at both computers.
- ☐ Switch on the radiosonde.
- ☐ Disconnect the initialization cable.
  - During the time of initializing the radiosonde on the second computer, data reception will stop even on the first computer. After initializing and setting the same frequency the signal should return.

3. UAS

a. Before Flights Begin

- ☐ Confirm that the Airworthiness Review Board (ARB), ORR, Radio Frequency Authorization (RFA), Hazards documents, and Airworthiness statement have been signed.
- ☐ Confirm request to be on the monthly flight schedule with UASOO.
- ☐ Section H.1.a should be completed.
- ☐ The ground station and accompanying computer should be charged the day before the flights.
  - Refer to section H.2.a.i for how to charge the ground station.

b. Pre-Flight (Day of Launch)

i. <u>UAS Setup and Pre-Flight Checklist – see Attachment 2</u>

NOTE: For more information and details about this UAS and its capabilities and procedures see the company wiki page.[3]

- ☐ Once the radiosonde is outside, keep it shaded and ventilated as best as possible (refer to figure 10).

Figure 10: Radiosonde Shaded and Ventilated

c. Post-Flight

i. Post-Flight Checklist

Verify:

- ☐ Motors have stopped and are disarmed (confirm with GCSO).
- ☐ Turn off radiosonde once flight termination confirmed with the data analyst.
- ☐ When sensors are no longer needed, unplug power to the radiosonde FIRST and then unplug the ground station, laptop, etc.

d. Emergency Responses – See UAS, and Sensor Documentation[3,7,8]

NOTE: For more information and details about this UAS and its capabilities and procedures see the company wiki page.[3]

4. Troubleshooting

a. Radiosonde

- Attempt initialization no more than three times before using a new radiosonde.
- If the batteries are low, replace them or use a new radiosonde.

b. GRAWMET

- If the error "Does not recognize radiosonde type" is thrown, navigate to General Settings, then Program Settings, then the Communications tab. Click Detect under COM ports. If this fails, try reinitializing, and check the COM ports again. Remember to shut down Grawmet between each initialization to minimize chance of software error.

c. GPS

If raw data received but GPS is not:

- First check GPS values.
  - Negative signs matter.
- Move the ground station as far from the computer/sonde as possible.
- Eliminate any obstructing metal objects around the sonde.
- Wait for between 15-30 minutes with the sonde placed in view of satellites to see if it begins filling (consider replacing depending on time requirements).
- Check ground connections are correct.
- Check LEDs of radiosonde. If light is flashing then the sonde is receiving GPS, but no data is being received by Grawmet. Double check the radio and connections and the initial condition GPS.
- Reinitialize the sonde. Using a different USB port on the computer can also be attempted.
- Try initialization no more than three times before discarding the sonde and trying a new one.

I. Health and Safety Warnings

1. Weather

- Fly only under approved limits stated in the project's ORR. Do NOT fly during poor weather conditions that have the potential for lightning. If there are questions about the weather conditions, reference the latest weather conditions from NWS.

2. Radiosonde Ground Station

- This ground station has exposed battery terminals and can be an electric shock hazard if not handled with caution. Once the battery terminals are connected and the unit is powered, the front cover should be latched closed to protect from electric shock and damage to unit.

3. UAS

- The aircraft's props spin at a high RPM and the ends of the blades move at high speeds. These props can cause severe injury or death or case damage to objects while rotating. All participants must participate in the pre-flight safety brief.[5] (Refer to section D- Cautions for more detailed safety warnings).

J. References

1. World Meteorological Association, P. (n.d.). WMO Intercomparison of high quality radiosonde systems. Library. https://library.wmo.int/index.php?lvl=notice_display&id=15531
2. Willhite, T., Fowler, J. and Medina, A. (2024) ‘Uninhabited aerial system drop-in balloon-borne radiosonde alternative for lower tropospheric flights’, AIAA SCITECH 2024 Forum. doi:10.2514/6.2024-2092.
3. Alta X.” ALTA X – Freefly Public, https://freefly.gitbook.io/freefly-public/products/alta-x/features.
4. Alta X Procedures. Procedures – Freefly Public. (n.d.). https://freefly.gitbook.io/freefly-public/products/alta-x/untitled-6
5. Technical specs. Technical Specs – Freefly Public. (n.d.). https://freefly.gitbook.io/freefly-public/products/alta-x/untitled-3/technical-specs
6. Alta X Features. Features – Freefly Public. (n.d.). https://freefly.gitbook.io/freefly-public/products/alta-x/features
7. Anemoment. (n.d). TriSonica Sphere User Manual. https://anemoment.com/wp-content/uploads/2022/03/TriSonica-Sphere-Manual-2022-03-03.pdf
8. GRAW Radiosondes. (n.d.). Grawmet User Manual. GRS-KD-0002-en_V05.12_GRAWMET_User Manual.pdf
9. GRAW Radiosondes – DFM-17. DFM-17 | NORIS Group GmbH. (2019, April 17). https://www.graw.de/products/radiosondes/dfm-17/

K. Acknowledgements

The authors would like to acknowledge Carl Spangrude for the initial outline of this Standard Operating Procedure.

L. Appendix

Attachment 1- Launch Equipment Checklist

Launch Checklist													
Radiosonde (x4)													
Radiosonde initialization cable (x2)													
Radiosonde ground station													
Computer w/ Grawmet software & connecting cables (x3)													
UAS ground station – coordinate with PIC													
UAS items – coordinate with PIC													
Radios for all team members – coordinate with RSO													
Anemometer													
Mount													
Power inverter if working remotely from a vehicle													
First aid kit – coordinate with RSO													
Tool Box: coordinate with PIC													
Scissors													
Duct Tape													
Wire Cutters													
Electrical Tape													
Lighter/Matches													
Zip Ties (x10+) and Velcro straps													
Extension cord													
Plug strip													
Water – coordinate with RSO													
Possible Additional Items: coordinate with RSO													
Canopy													
Table													
Chairs													
PPE													

<u>Attachment 2 – Pre-flight Checklist</u>

Authored by: Jacob Revesz of NASA Langley Research Center

1. **(FFOD)** EXTEND ARMS
2. **(FFOD)** CLOSE BOTH SAFETY LATCHES
3. **(FFOD)** VERIFY TOAD IN THE HOLE LEVERS ARE FULLY LATCHED
4. **VERIFY** FLIGHT BATTERY <u>QUALIFICATION DATE</u>
5. **VERIFY** FLIGHT BATTERY IS <u>FULLY CHARGED</u>
6. **INSTALL** BATTERIES
    a. BATTERY LEAD EXTENSION CABLE
7. **VERIFY** THAT ALL BATTERY TREY STRAPS ARE SECURED
8. **VERIFY** MAX FLIGHT TIME WITH 30% RESERVE
9. **VERIFY** THAT 900MHZ ANTENNA IS SECURED
10. **VERIFY** THAT GPS ANTENNAS ARE SECURED
11. **CHECK** THE CONDITION OF PROPELLER HUBS, MOTORS, BLADES, AND BOOMS
12. **CHECK** THE CONDITION AND FIT OF EACH BOOM BRACE (X4)
13. **VERIFY** **<u>RC TX</u>** **<u>THROTTLE IS SET TO ZERO</u>**, AND SWITCHES ARE IN CORRECT POSITION.
14. **POWER** ON THE TRANSMITTER VERIFY MODEL AND VOLTAGE >5.6V
15. **<u>VERIFY CREW PPE</u>**
16. **CONNECT** FLIGHT BATTERIES WHILE KEEPING THE VEHICLE STILL
17. **VERIFY** STATUS LIGHTS ON MOTORS: 2 GREEN / 2 RED
18. **VERIFY** STATUS LIGHT ON GPS BUTTON: <u>SINGLE RED</u> (DISARMED), <u>DOUBLE RED</u> (ARMED)
19. **VERIFY** 900 MHZ GROUND RADIO **<u>IP ADDRESS AND PORT NUMBER</u>**
20. **CONNECT** GROUND CONTROL STATION TO VEHICLE, VERIFY GOOD CONNECTION
21. **(FFOD)** VERIFY ORIENTATION ON GCS (PITCH, ROLL, YAW)
22. **(FFOD)** PERFORM RANGE CHECK ($\geq$ 30 PACES)
    a. **POWER** OFF RC TX TO VERIFY LOST LINK
    b. **CHECK** FLIGHT MODES IN REDUCED POWER MODE
    c. **VERIFY** MODES WITH GCS

23. **VERIFY** GPS: **> 8 SATS**, VERIFY HDOP: **<2.0**
24. **VERIFY** VEHICLE HEADING ON THE GCS MATCHES ACTUAL VEHICLE HEADING
25. **ENSURE** GCS REPORTING NO RELIEVENT WARNINGS
26. **CYCLE** FLIGHT MODES AND VERIFY ON GCS DISPLAY
27. CREATE FLIGHT PLAN:
    a. **VERIFY** TAKEOFF LOCATION AND ALT
    b. **VERIFY** ALL WAYPOINTS (ALT, SPEED)
    c. **VERIFY** FLIGHT PLAN HAS GEOFENCE
28. **REVIEW** FLIGHT PLAN WITH CREW AND RSO
    a. **UPLOAD** FLIGHT PLAN TO VEHICLE
29. **VERIFY** VEHICLE FAILSAFE SETTINGS
    a. RC LINK LOSS
    b. GCS LINK LOSS
    c. GEOFENCE ACTIVATED (CHECK BOX) ENABLED
    d. GEOFENCE ALTITUDE
30. **VERIFY** GCSO REPORTING NO FLIGHT CRITICLE WARNINGS
31. **PIC VERIFY** SINGLE RED FLASH ON GPS PUCK
32. **GCSO VERIFY** VEHICLE IS REPORTING DISARMED
33. CARRY VEHICLE TO THE FLIGHT LINE
34. REQUEST TAKEOFF FROM THE RSO
35. PIC PRESS ARM BUTTON ON THE GPS PUCK, **VERIFY DOUBLE RED BLINK**
36. PIC ARMS VEHICLE VIA TRANSMITTER
37. TAKEOFF

<u>Attachment 3 – Programming the Anemometer</u>

- This should only need to be done once.
- Refer to the manual at any time during this procedure for further details. (Page 17)[9]

a. USB Adapter Setup

- ☐ Open the USB adapter box top cover.
  - There are several additional wires that will not be used - only use the 5 shown below.
  - Do not follow the color labeling on the USB adapter circuit board.
  - To insert the wire, press the orange tab into the select block hole and insert each wire as far as it allows then release the button. (Refer to figure 3-1 for this process).
- ☐ Insert the Brown wire to terminal block hole 1.
- ☐ Insert the Blue wire into terminal block hole 2.
- ☐ Insert the Yellow wire into terminal block hole 3.
- ☐ Insert BOTH the Red and Black wires to terminal block hole 4.
- ☐ Replace the USB adapter box top cover.
- ☐ Plug the mini-usb cable into the now wired adapter.
- ☐ Turn on the anemometer.

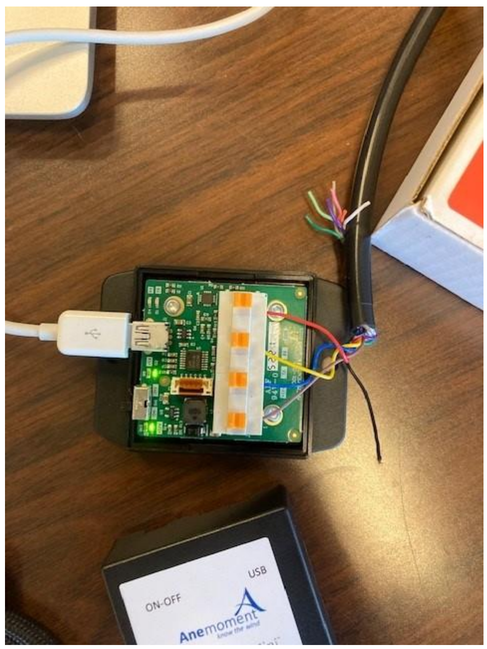


Figure 3-1: Wire inputs into USB Adaptor

b. Data Output

- ☐ Run the Terminal Emulator app: Tera Term.
  - Data should be streaming in, if not, then command "systemreset."
- ☐ Connect the black wire with the red wire and the proper baud rate for the USB port should be set. "Settings of 115200,8,N,1 regardless of the software settings of the instrument."
- ☐ Once data is streaming, press ESC to get to the sensor menu to set up settings of the instrument to attach to the radiosonde. Choose the letter from the below list of options (figure 3-2).

- Radiosonde settings: LLVT, 9600 baud rate, 8 bits, no parity, 1 stop bit, 1 hz.

MAIN MENU OPTION	FUNCTIONS AVAILABLE WITHIN SERIAL MENU OPTION
A. Serial Setup	Serial Baud, Parity, and Serial Protocol Selection
B. Data Output Setup	List of Output Parameters, indicating whether they are Enabled, how man Decimals are displayed, the Units for the parameters, and the data Tag. From this menu, press the menu letter key to access submenus that control these Output Parameters.
C. Instrument Setup	Data Output Rate, Orientation, and Trigger parameters
D. Calibration	Walks the User through calibration steps for User-performed wind, and level calibration. • To calibrate the wind sensor, the User places the instrument in a zero-airflow chamber equipped with a temperature sensor, and the User enters a value for local humidity. • The level sensor calibration requires the Sphere to be attached to a pole that is known to be vertical
E. Diagnostic	Runs built-in diagnostics and displays the results.
G. Instrument Reset	Resets the instrument, clearing all volatile memory, restoring the nonvolatile memory settings.
X. Exit without storing cha	Exits the menu with the changes the User has made, allowing the User to apply the changes temporarily. These changes are not stored in the non-volatile memory and will be lost after a system reset/system power-down.
0. Exit	Exits the menu and stores changes in non-volatile memory. These changes are retained even after a system reset/system power-down.

Figure 3-2: Menu of Available Functions

- Once data is streaming, press Ctl+C to go to command line and type “display”.
  - This will show a table of the values available for output.
  - Only the values marked as enabled in the table are output.
  - They are output in order from top to bottom.
- Click U, V, W, and T.
  - U: west to east wind flow.
  - V: south to north wind flow.
  - W: Pitch. (now we know if it’s level)
  - T: Roll.

c. Setup XDATA 3 or XDATA 4

  - XDATA 3 and XDATA 4 have different formats for data interpretation.
- Type “expert enable” then hit enter.
- Type “dataformat xdata3” (or 4) then hit enter.
- Type “nvwrite” then hit enter.
- Setup instrument ID.
  - Cannot be 00, e.g. trisonica 23.
- Check the setting is written by typing “trisonicaid.”

d. Connect to Radiosonde with Open Wiring

- Connect Red wire from anemometer to GND (pin1) on the Radiosonde.
  - Red wire is ground.
- Connect Light Green wire (3.3V LVTTL-UART Serial Data Output) from anemometer to RX (receive pin 2) on the Radiosonde.
- Connect Red wire from the anemometer to ground wire from battery.

- Red wire is ground.

- Connect Brown wire (Voltage Input of 9V to 36V) from the anemometer to the battery.

e. Connect to Radiosonde with plug

- Connect GND (pin1) on the Radiosonde XDATA cable (Red wire) to pin with black arrow on plug. Refer to figure 3-3.

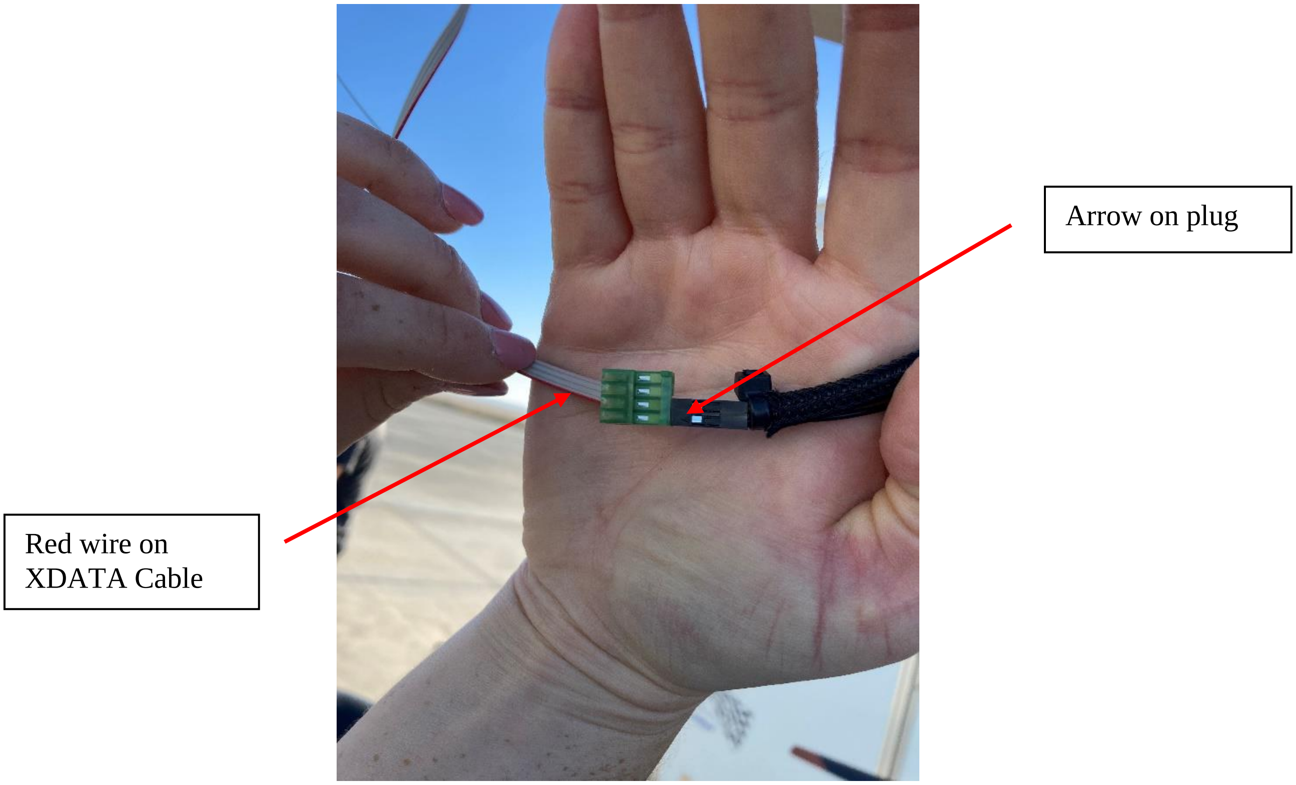


Figure 3-3: XDATA cable to anemometer cable Connection

Attachment 4 – Anemometer No-Wind Calibration

- All Sphere's come tested and pre-calibrated prior to shipping, but users can re-calibrate it to acclimate to unique test cases.
- This should only need to be done once.
- Refer to the manual at any time during this procedure for further details. (Page 27) Alternately, the user may go to the sensor menu utilized previously in Attachment 3 (Figure 3-2), and type letter D as shown below.

D. Calibration	Walks the User through calibration steps for User-performed wind, and level calibration. • To calibrate the wind sensor, the User places the instrument in a zero-airflow chamber equipped with a temperature sensor, and the User enters a value for local humidity. • The level sensor calibration requires the Sphere to be attached to a pole that is known to be vertical

Figure 4-1: Calibration Function in Menu

a. Calibrating Anemometer – only do this if getting erroneous values and after communication with company engineers.

- ☐ Place the anemometer in a container or underneath a cloth to make the airflow as close to zero as possible.
  - "Care must be taken to eliminate acoustic reflections from hard sides and to not block the acoustic pathways. There should be some sound absorbing material on any flat walls that could reflect sound back towards the Sphere. A small box with acoustic absorption foam is ideal."[9]
- ☐ In Tera Term, type "calibrate <temp> [<rh>].
  - Temperature is in Celsius, and humidity is relative humidity both to 1 decimal place (humidity will be 50% if not supplied).
  - Calibration takes 10 seconds.
- ☐ Type "nvwrite" to store the calibration values.
- ☐ Level may be calibrated by placing the Sphere on a vertical pole and typing "levelcalibrate."
- ☐ Type "nvwrite" to store new level values.
  - Tilt data is not used for calculating the wind vector data.