The DPACS Drone Ground Station
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(U//FOUO)

Note: Before installing DPACS, please contact the author, Rob Ratcliff, at rob@futuretek.com or 512-633-5751 to get the latest version and to be updated on any current issues with the Ardupilot firmware and instructions. The Ardupilot project is moving quickly and behaviors can change with new releases.

The DPACS Drone Ground Station

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Revision History

Version	Date	Action	Pages	Author
2.35.4	4-20-2020	Draft	All	Ratcliff-Clark
2.35.4	8-27-2020	Draft	All	Ratcliff
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Introduction

This document provides step-by-step instructions to install and use the DPACS Drone Ground Station. DPACS is a cross platform application[1] built on the RaptorX platform that commands and controls UASs that use the MAVLink protocol.

MAVLink is a very lightweight messaging protocol for communicating with drones (and between onboard components). MAVLink follows a modern hybrid publish-subscribe and point-to-point design pattern. Data streams are sent /published as topics while configuration sub-protocols such as the mission protocol or parameter protocol are point-to-point with retransmission.

The DPACS plugin resides within RaptorX, a government owned application for global sensor awareness. DPACS is an abbreviation for Distributive Particle Antenna Collaboration System. Development started in 2012 and continues supporting the command and control of Government UASs that focus on elevating antennas to increase radio line-of-sight. RaptorX is free to Government users and commercial users that have Government sponsors.

Features

DPACS provides control of a UAS in a rich, geospatial environment. It verifies pre-conditions and alerts the operator through messages, graphics, sound and voice. DPACS has missions for tethered and non-tethered systems. "Follow-Me" features allow the UAS to follow behind or in front of the operator's reference point. Further, the angle may be specified and the UAS can be "nudged" in the x, y directions.

Operator input may be from mouse clicks, keyboard, special keys, and touch screen. DPACS also senses if an RC is connected and overrides when it is not. DPACS works in conjunction with either a standard RC (wired or wireless) or a wired X-Box controller.

Depending on the situation, the operator may switch from DPACS to RC by simply changing the flight mode of the RC. When an RC transmitter is present, DPACS only overrides a given RC channel such as yaw through software if used within the GUI or via a gamepad controller. If no RC is used, DPACS will override throttle, yaw, pitch and roll RC channels. RC channel override status is displayed clearly to the operator. The operator can quickly release all overrides to pass control the RC operator if needed.

Safety is a strong feature within DPACS. System pre-checks provide audible and visual information on the UAS's readiness for flight. Failsafe parameters are constantly checked and failure status is communicated with loud alerts and visual indicators.

DPACS alleviates pilot's stress by automating flight. At its simplest, the operator uses dedicated keys for the entire mission. A sequence may look like this: cntrl-a (ARM), cntrl-h (Hover), cntrl-u (up), cntrl-right arrow (nudge right), cntrl-l (land) and cntrl-q (quit).

[1] Windows, Linux, OS-X

DPACS provides a simple GUI streamlined for tethered operations and a more detailed one that handles multiple mission types. The choice depends on the mission and pilot's familiarity with DPACS functions.

DPACS interacts with the Ardupilot open-source flight controller that runs on the open architecture hardware known as the "Pixhawk". DPACS performs several fundamental features like calibrating the controller's sensors, testing its motors, and setting parameters. DPACS can also set the controller's gains for throttle, pitch, and yaw. These functions replace having to use separate applications like Mission Planner or Q-Ground Control.

The UAS knows its absolute position using GPS. The position accuracy will improve if we integrate using RTK (real time kinematic) solutions. DPACs has full support for RTK GPS operations including static and moving base modes. For relative positioning, DPACS integrates with a GCS (ground controller) device. This allows the UAS to perform follow-me functions and a guided landing mode on a moving platform.

For non-tethered operations, DPACS allows pre-planning of waypoints and recalling saved missions. In real-time, the pilot can use DPACS to fly to a location or perform a ROI (rotate about object of interest).

DPACS integrates well with SITL (Software-in-the-Loop) simulators. DPACS benefits both in application reliability and robustness. Simulation also offers an excellent training tool.

Finally, DPACS is adaptable. It takes advantage of other features and plugins that reside in RaptorX. One example is the leveraging of the built-in terrain maps to determine a mission's desired radio line-of-sight (R-LOS) or interoperating with the RF link analysis tool Sandbar to determine where a radio on the drone will have a RF link with a radio on the ground.

Definitions

Ardupilot ArduPilot (sometimes known as APM) is an open source autopilot system supporting multi-copters, traditional helicopters, fixed wing aircraft, rovers, submarines and antenna trackers.

ArduCopter This is the full-featured, open-source multicopter UAV controller. A team of developers from around the globe are constantly improving and refining the performance and capabilities of ArduCopter.

DPACS Distributive "Particle" Antenna Collection System.

Elevator Description of a type of mission where the UAS travels in a vertical column with stops at designated "floors".

Failsafe A triggered condition from an event that automates a safe response. One example is a battery failsafe. If the voltage falls below a threshold (the trigger), then an automated action "Land' occurs.

GCS Ground Control Station, a device that passes messages to DPACS about the location for the UAS's base and its altitude. The first allows the UAS to follow a mobile base such as a vehicle or boat. The second provides the aircraft with a relative altitude separation. This permits stable altitude positioning when the atmospheric pressure changes.

LOS Line-of-sight or the distance of a tangent to the horizon. See R-LOS below

MAVLINK Micro Air Vehicle Link is a **protocol** for communicating with small unmanned vehicle. It is designed as a header-only message marshaling library.

Mission Planner Mission Planner is a full-featured ground station application for the ArduPilot open source autopilot project.

Pixhawk Pixhawk open standards provides readily available hardware specifications and guidelines for drone systems development. The full Pixhawk Reference Standards consists of the Pixhawk Autopilot Reference Standard, the Pixhawk Payload Bus Standard, and the Pixhawk Smart Battery Standard. It is the design specification and guidelines for manufactures who want to build PX4 or ArduPilot compatible products. (See https://pixhawk.org/ for more information.)

RaptorX RaptorX is a government-owned, 3D GIS application with a robust application program interface that supports desktop and web variants. A plugin called RaptorTak is available for ATAK to provide a RaptorX API to the ATAK functionalities. Raptor software installers, source code repositories, documentation, and media are all available on the defense intelligence information enterprise (DI2E) and on tak.gov.

RC Remote Controller. A device used to operate a UAS either through wireless or wired communications.

R-LOS Radio Line of Sight Radio wave propagation is affected by atmospheric conditions, ionospheric absorption, and the presence of obstructions, for example mountains or trees. If the earth is assumed to be a perfect sphere, the line-of-sight distance between the top of the antenna to the tangent with the earth can be shown to be:

$$LOS_{kilometers} \approx 3.57 \times \sqrt{antennaHeight_{meters}}$$

$$LOS_{miles} \approx 1.23 \times \sqrt{antennaHeight_{feet}}$$

However, RF signals do not propagate in straight lines. The refractive index must be accounted for, and this will vary. This refraction of the radio wave can be modeled as a flattening of the earth using this equation:

$$RF\_LOS \approx \sqrt{2 \times k \times R \times antennaHeight}$$

Where k is an earth flattening factor or an increase in service range and R is the radius of the earth. Under normal weather conditions, the service range increases to about 15% and so $k\ is\ set\ to\ 4/3$. This assumption leads to these approximations for R-LOS:

$$\text{RF\_LOS}_{kilometers} \approx 4.12 \times \sqrt{antennaHeight_{meters}}$$

$$RF\_LOS_{miles} \approx 1.41 \times \sqrt{antennaHeight_{feet}}$$

ROI Region of Interest. A term used in planning a UAS mission. ROIs can be objects or areas.

RTL Return-to-Launch point. Typically, this is the location where the UAS started its mission.

SITL Simulation in the Loop, a means to validate, test, and train DPACS users by simulating the UAS's hardware with software.

UAS Unmanned Air System, aka "drone" or UAV. Type I UASs are 55 pounds or less. As a system, the UAS consists of the aircraft, payload, and all supporting equipment.

Installation

1. Make sure your Ardupilot firmware on your Pixhawk is at least on version 3.6.12 or 4.0.7. Arducopter 3.5.x and 3.6.6 will work as well, but its recommended to use the latest versions of the firmware. FutureTek has a patched version of ArduCopter that provides the M8P and F9P RTK solution to the GCS and other fixes. We are trying to get those changes merged into the mainline project to eliminate our custom version.
2. If you have the DPACS installer, simply run the installer and answer the questions.
3. If you have a base RaptorX installer and separate plugin jars (uncommon), perform the following steps:
    a. Install RaptorX on Windows, Linux or MacOS X if not installed already
    b. Copy the following jar files to the C:\Program Files\DPACS-2.39.43\plugins directory on Windows.
        i. models.jar
        ii. plugin.tts-2.3.1.jar
        iii. plugin.notification.manager-1.0.0.jar
        iv. plugin.reliance.gamepad-4.32.jar
        v. plugin.dpacs-2.39.43.jar

        On the Mac, use Finder to right click on the RaptorX application icon and select "Show Package Contents". Then navigate to Contents/Resources/dpacs-2.39.43/plugins directory and copy the plugins into that directory. Remove any older duplicates.
    c. Start RaptorX. This may take 2-5 minutes depending on the hard drive type.
    d. Create a project
    e. Navigate to the Apps/Apps button on the ribbon bar and click Install
    f. Select the DPACS and the Gamepad plugins from the plugin list pressing the CTRL key and clicking with the mouse button.
    g. Click on the DPACS entry in the applications list and then click on Config. Select "Automatically start this app" and click OK. Do the same for the Gamepad plugin.
    h. Click on the "Start" button to start the DPACS plugin and for the Gamepad plugin

4. Navigate to the DPACS entry on the menu bar as shown below:

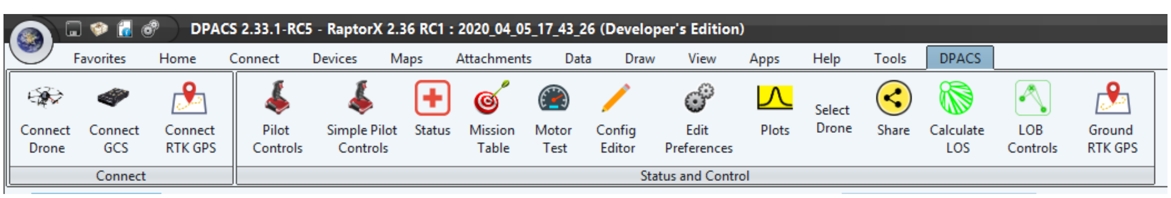


Figure 1 RaptorX panel with DPACS highlighted.

5. The "Simple Pilot Controls" and Globe panels should automatically appear expanded as shown in Figure 2. Other panels can be accessed from the DPACS toolbar. The "Simple Pilot

Controls” are optimized for tethered UAS missions. The “Pilot Controls” are for more multiple mission types including tethered, waypoint and fly-to missions.

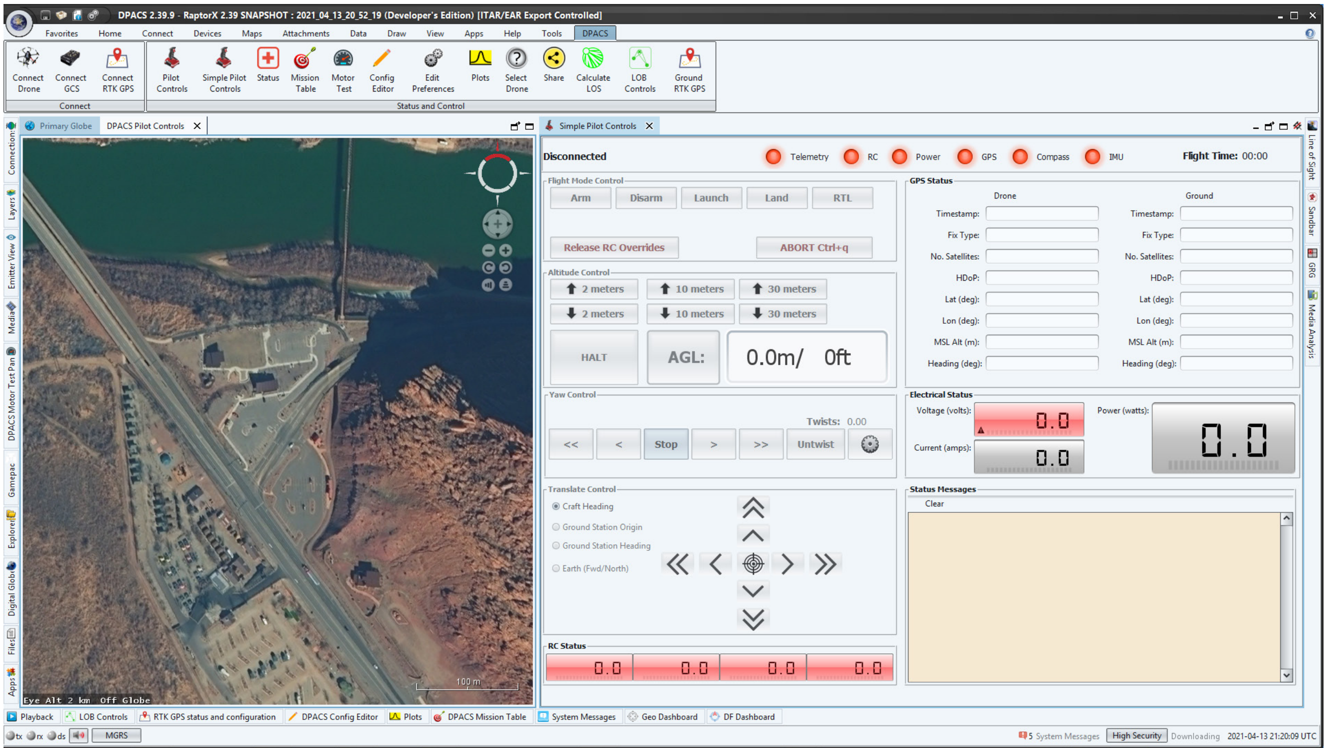


Figure 2 - Initial DPACS display showing the DPACS toolbar, Globe and Simple Pilot Control Panel

External Controllers

All the pilot controls are available from within the DPACS GUI, but it can be convenient or even necessary to override DPACS and take manual control of the UAS using external controls such as a wireless RC, a USB gamepad, a USB RC simulator controller or keyboard shortcuts. These controls are discussed in detail below.

Radio Control (RC)

During normal operations, the copter can be flown without the RC using the DPACS GUI only. But it is ideal to have the RC available as a backup control for certain emergency situations. A typical wireless DX8 transmitter is shown in Figure 3.

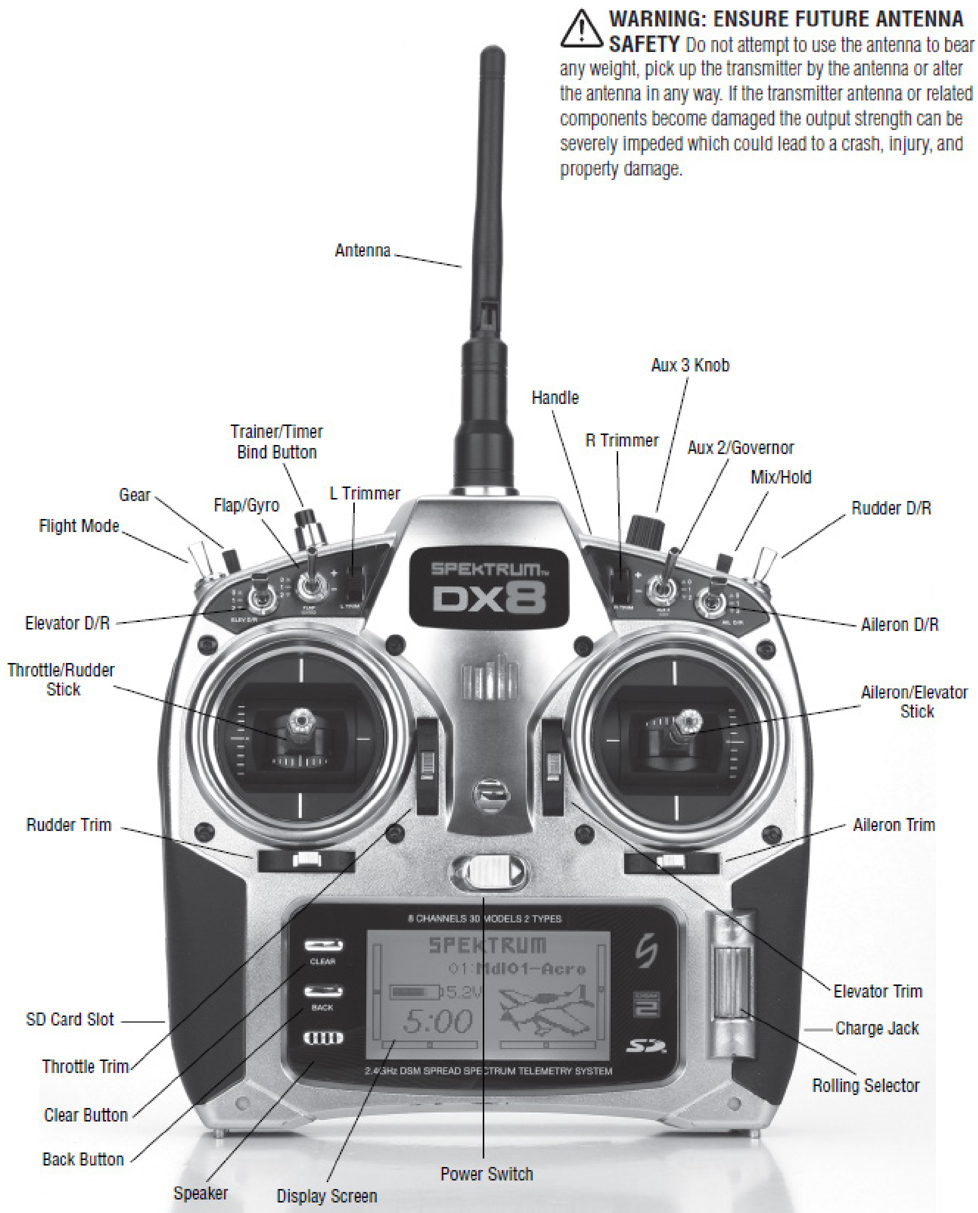


Figure 3 - DX8 RC Transmitter

The most relevant controls on the RC are its Power Switch, the Throttle/Rudder Stick, the Aileron/Elevator Stick and the Flight Mode switch. For a multi-rotor drone:

- Throttle is up/down
- Rudder is yaw clockwise/counter-clockwise
- Aileron is left/right
- Elevator is forward/backward

We assume that the UAS has already been calibrated for the RC and the flight modes have been configured using the Mission Planner software available at:

https://ardupilot.org/planner/docs/mission-planner-installation.html

Some mission operations require no RF transmissions like those originating from a wireless RC. Other times a wireless RC can be turned on and ready should the operator need it.

Here is how to use the RC for a CONOP that allows RC transmissions during the entire mission:

1. Turn on the RC using its Power Switch.
2. Connect the DPACS GUI to the UAS
3. Toggle the Flight Mode switch to different positions and watch the response in DPACS. Remember the position of the switch corresponding to Loiter, Altitude-Hold and Land if it is labeled on the controller.
4. Switch the Flight Mode to Loiter
5. Move the throttle stick to the lowest position
6. Arm the UAS using DPACS
7. Within 10 seconds, click the "Launch" button or use Ctrl+h on the keyboard.
8. Once the UAS is flying, **raise the throttle to halfway**. DPACS has throttle control so this is a safety measure should you need to take manual control. The safety procedure involves using the RC to switch flight modes. When this happens (depending on the chosen flight mode) and the throttle is down, the UAS will not have any power and will fall quickly to the ground. Therefore, we raise the RC throttle to half-way. DPACS will remind you every minute to raise the throttle to prevent this situation from occurring.
9. When DPACS has control, the RC can be used to rotate the UAS in yaw using the rudder stick (left stick moving left or right) unless the yaw function has been used within DPACS and not released.
10. For normal operations, nothing else needs to be done using the RC.
11. Perform one of the following steps during failure situations:
    a. If telemetry communications fail, GCS failsafe will not automatically land the UAS if the RC is on unless you are using the patched firmware. If this occurs, simply switch the Flight Mode to Land using the RC.
    b. If the UAS starts drifting away quickly and does not appear to be recovering, it is possible that its GPS has lost lock or has been jammed or spoofed. In this case, use the RC to switch the Flight Mode to Altitude-Hold and slowly lower the throttle until

the UAS is on the ground. Move the Throttle Stick to the lower left to turn off the motors if the motors do not turn off automatically.

c. If the UAS does not stop ascending when it hits the target altitude specified in the mission, switch the Flight Mode to Land. When the UAS touches the ground move the Throttle Stick to the lower left to turn off the motors if the motors do not turn off automatically.
d. If you need more control over the UAS, switch the Flight Mode to Loiter. Use the Pitch/Roll stick to move the UAS around laterally. When you are ready to land, lower the throttle slowly until the UAS is on the ground. Move the Throttle Stick to the lower left to turn off the motors if it does not happen automatically.

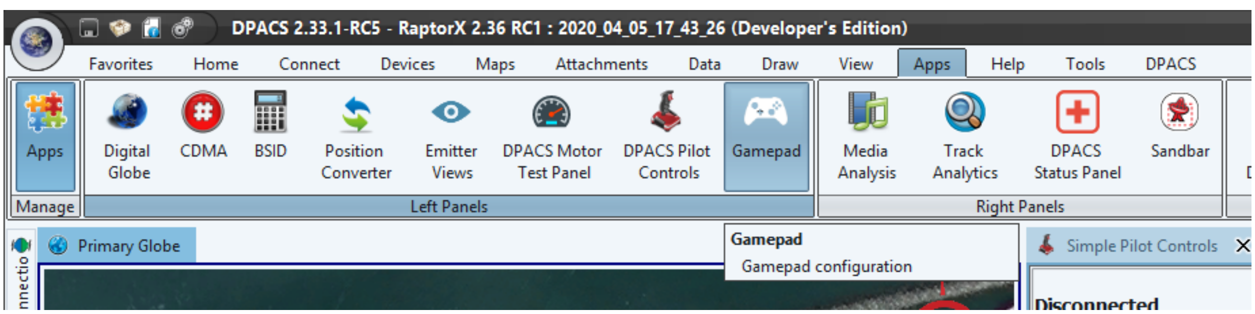
If the CONOP does not allow the RC to transmit during normal operations, the process to take over control of the flight with the RC is a little more complicated:

1. RC is turned off.
2. DPACS is used to pilot the UAS to altitude.
   Note: Since the RC is turned off, DPACS is required to override all the RC stick controls.
3. To Land with the RC
   a. Move the Throttle Stick to halfway and switch the RC Flight Mode to Land.
   b. Turn on the RC
   c. Click the "Release All Controls Button" in DPACS. If DPACS can detect that the RC was turned on, it will automatically release the RC overrides.
   d. The mode should switch to Land and the UAS should start descending. If not, toggle the Flight Mode switch to another mode and back to Land.
4. To fly using Loiter with the RC
   a. Move the throttle stick to halfway and switch the RC flight mode to Loiter.
   b. Turn on the RC
   c. The mode should switch to Loiter in DPACS. If not, toggle the Flight Mode switch to another mode and back to Loiter.
   d. Click the "Release All Controls Button" in DPACS. If DPACS can detect that the RC was turned on, it will automatically release the RC overrides.
   e. Adjust the throttle stick to stabilize the altitude of the UAS
   f. Move the UAS to the desired location using the Pitch/Roll Stick
   g. Slowly lower the throttle stick until the UAS is on the ground

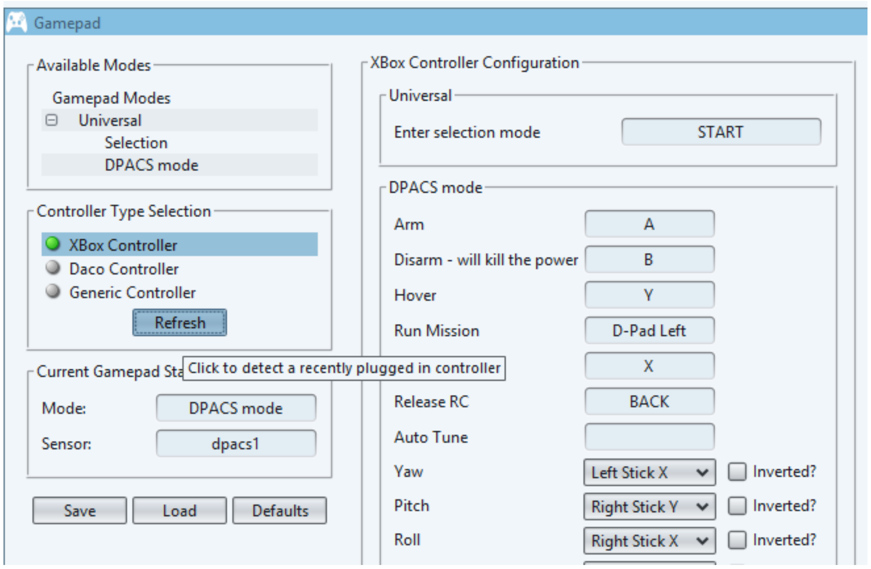
XBox Controller

An XBox gamepad controller can be used as a convenient way to control the drone from within DPACS in addition to the GUI controls and the RC controls. The current mappings between the gamepad controller and the drone functions are shown in Figure 4. If audio is available on the computer, an audio description of the function will played on the speakers when any of the buttons are clicked once. The function will execute when a given button is double clicked, except for the disarm function that requires three rapid clicks. The "Release RC" button is useful if control needs to be passed to the RC controller after using the gamepad controller. The RC controls are overridden by DPACS if the RC is not detected or if the gamepad controller is used. Once the controls are overridden, they need to be released to use the RC stick controls.

To use the gamepad controller if it was not plugged in before starting DPACS, plug the gamepad into the USB port and then navigate to the Gamepad App by clicking on the Gamepad button located in the Apps ribbon bar shown in Figure 5.



Click on the “Refresh” button to poll for new controllers shown in Figure 6. The radio button next to the XBox Controller should turn green when the controller is detected.



RC Flight Simulator Controller

DPACS supports a second type of USB interface that simulates the familiar RC interface shown in Figure 1.

The currently implemented mappings for the RC simulator are:

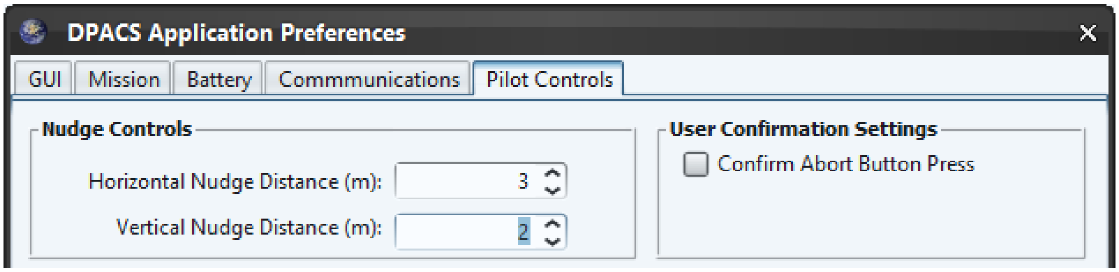
1. Left stick -X to +X direction is yaw
2. Left stick -Y to +Y direction is throttle
3. Right stick -X to +X direction is roll left to right
4. Right stick -Y to +Y direction is pitch forward to backward
5. CH 5 switch down is loiter
6. CH 5 switch up is altitude hold
7. CH 6 knob is gimbal pitch
8. CH 7 switch is RTL
9. CH 8 is currently unmapped

Keyboard Shortcuts

Another way to fly besides the GUI controls, the XBox gamepad controller and RC is to use keyboard shortcuts. The shortcuts offer a quick way to access functionality, especially on bright days where it can be difficult to see some laptop's screens or if the touchpad and screen are wet from rain. The shortcuts are listed here:

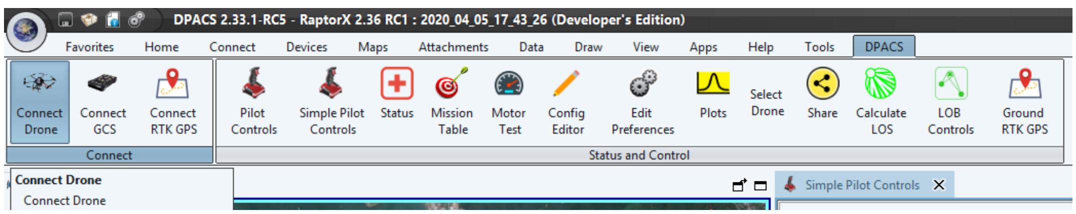
1. Ctrl+A - Arm
2. Ctrl+H - Hover
3. Ctrl+Home - Return to Launch
4. Ctrl+Q - Abort (**WARNING: THIS WILL IMMEDIATELY STOP ALL MOTORS!**)
5. Ctrl+L - Land
6. Ctrl+S - Brake (Pause)
7. Ctrl+F - Fly Mission
8. Ctrl+R - Resume Mission
9. Ctrl+Left-Arrow - Nudge Left
10. Ctrl+Shift+Left-Arrow - Big Nudge Left
11. Ctrl+Right-Arrow - Nudge Right
12. Ctrl-Shift+Right-Arrow - Big Nudge Right
13. Ctrl+Up-Arrow - Nudge Forward
14. Ctrl-Shift+Up-Arrow - Big Nudge Forward
15. Ctrl+Down-Arrow - Nudge Back
16. Ctrl+Shift+Down-Arrow - Big Nudge Back
17. Ctrl+U - Increase altitude by the preferred altitude change
18. Ctrl+Shift+U - Increase altitude by twice the preferred altitude change
19. Ctrl+D - Decrease altitude by the preferred altitude change
20. Ctrl-Shift+D - Decrease altitude by twice the preferred altitude change
21. Ctrl+Alt+R - Remotely reboot the Pixhawk (**WARNING: THIS SHOULD ONLY BE PERFORMED WHILE THE AIRCRAFT IS ON THE GROUND!**)

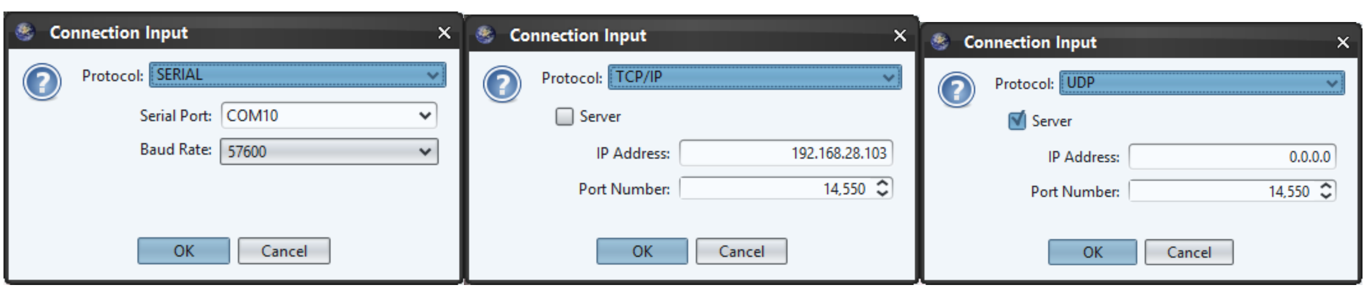
Note: The horizontal and vertical nudge values can be changed in the DPACS preferences as shown in Figure 7.



Connecting to Drone

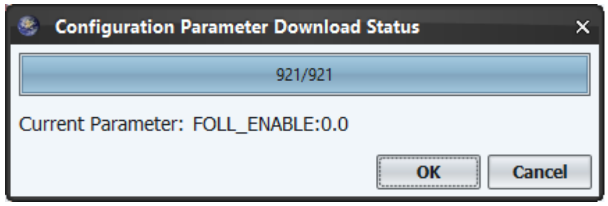
To connect to the drone, click the “Connect Drone” button in the DPACS ribbon bar shown in Figure 8. DPACS supports multiple methods to connect the drone including: serial, TCP/IP client or server and UDP client or server as shown in Figure 9. Only use the connection buttons in the DPACS ribbon bar and not the RaptorX connections.

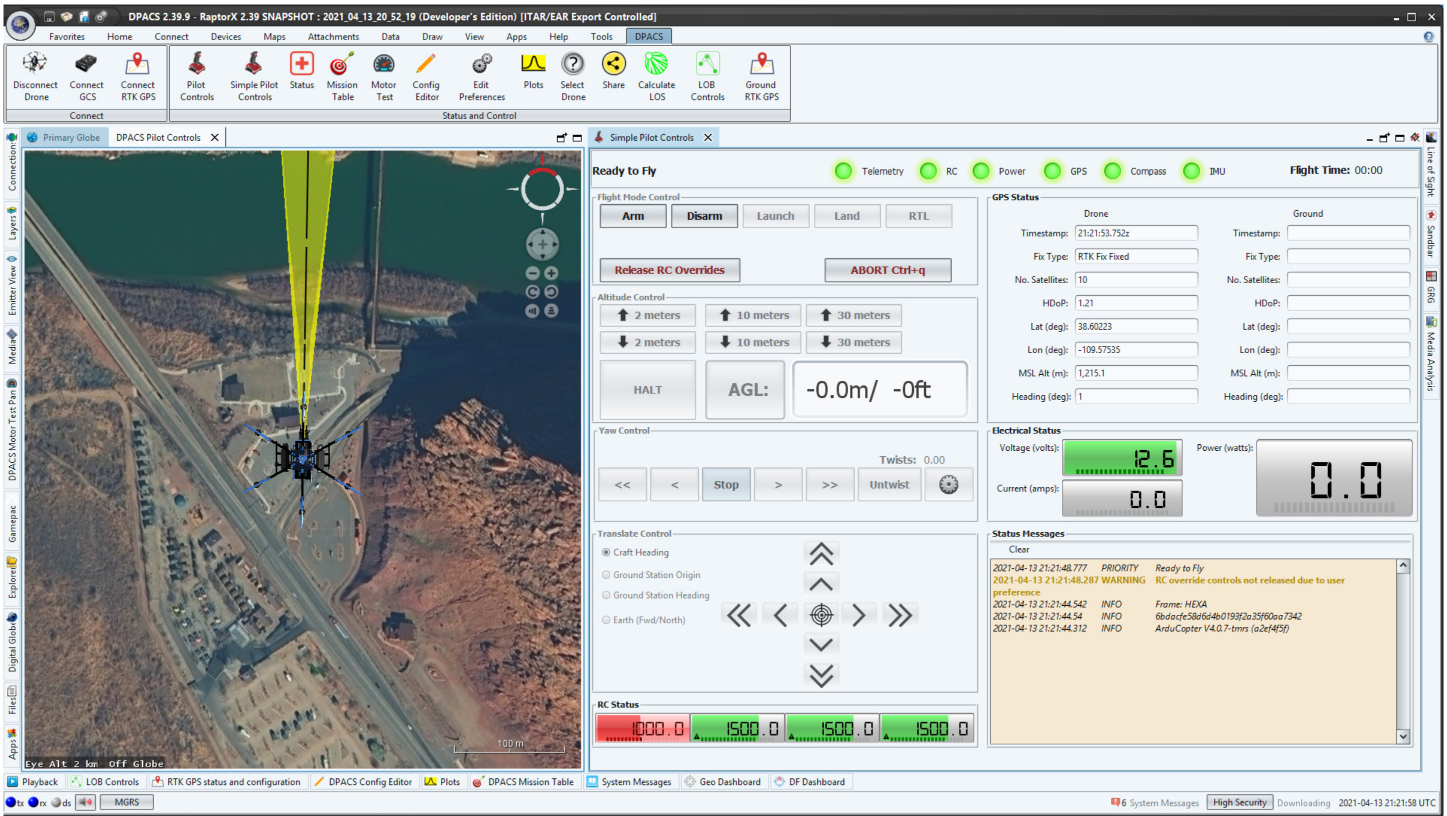




For example, click on the “Connect Drone” button in the DPACS “Connect” ribbon bar to connect to the drone using the 3DR USB Radio. Select the correct “Serial Port” and ensure that the “Baud Rate” is 57,600. If connecting to the ArduCopter simulator or a Solo controller, use the UDP settings shown in the figure as well.

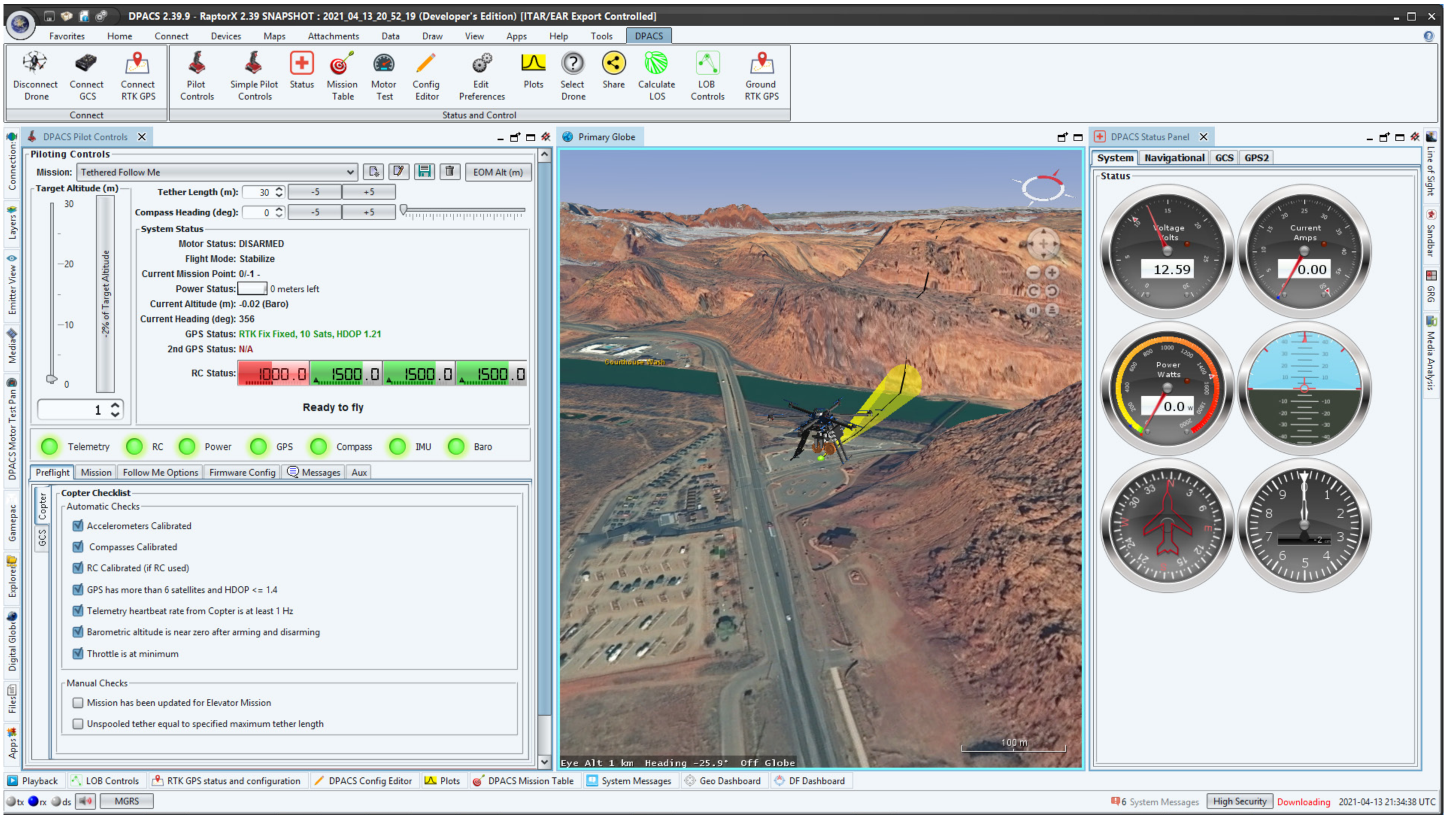
If the connection is successful, the configuration parameters will begin to download as shown in Figure 10. After the parameter download is complete the globe will zoom to the current position of the drone and the arm button will enable as shown Figure 11.



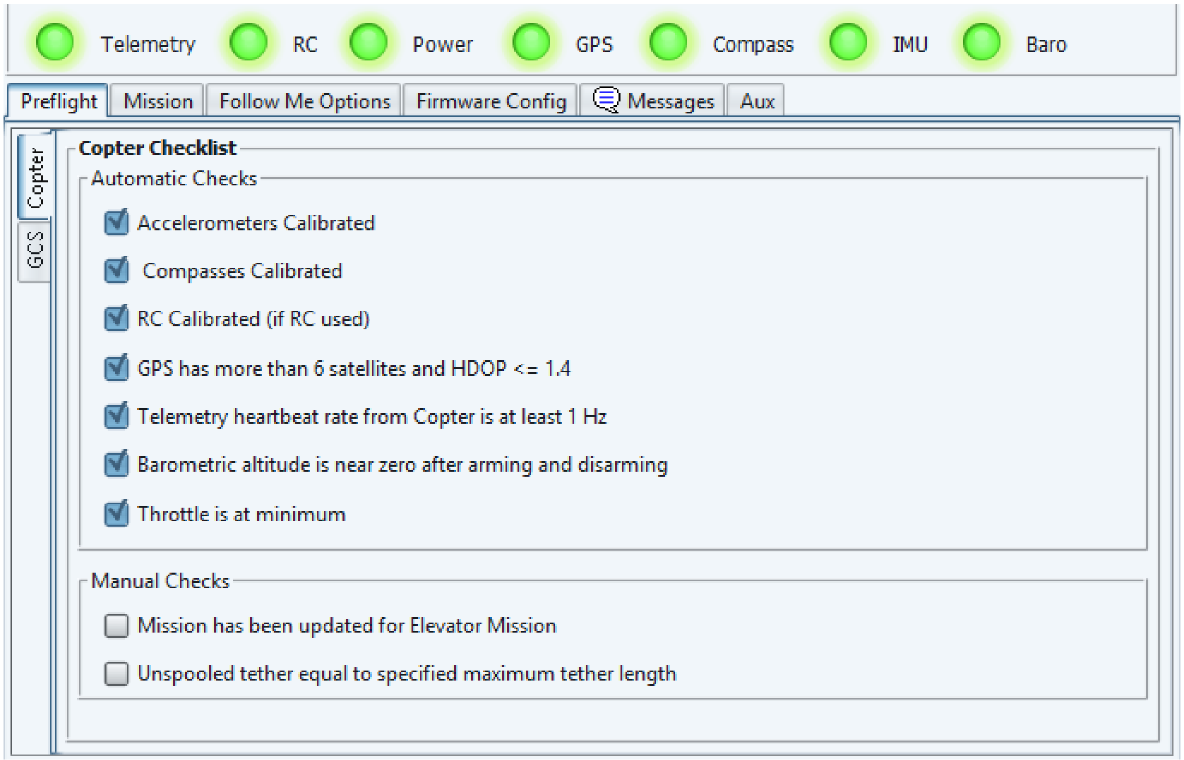


The Simple Pilot Controls panel is optimized for Elevator and Follow-Me tethered drone operations. Only guided commands are used to control the UAS from this panel. Nearly all the functionalities can be accessed on a touch screen with simple screen presses. This is the preferred interface for tethered drone operations.

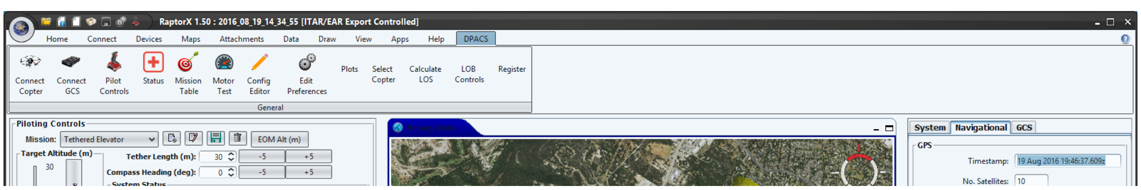
The multi-mission "Pilot Controls" panel shown in Figure 12 can be used for all supported mission types including: Elevator, Follow-Me and Waypoint missions. The Waypoint and Elevator missions are executed using Auto mode rather than guided, whereas the Follow-Me missions are executed in guided mode identically to the "Simple Pilot Controls" panel. This panel also has subpanels that allow easy access to commonly used firmware parameters and inputs that impact the Follow-Me mission behavior.

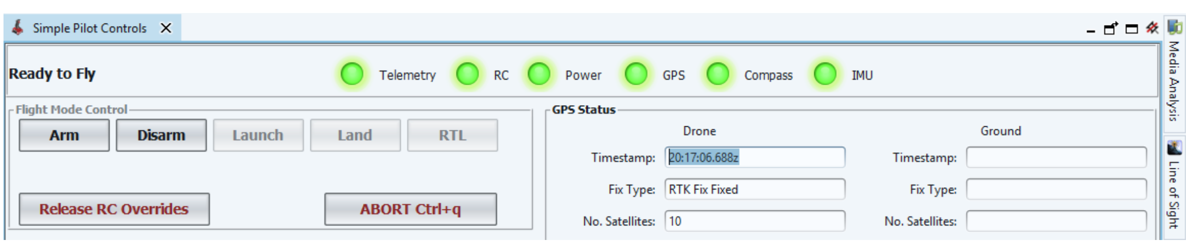


Navigate to the “Preflight” tab of the Pilot Controls panel and ensure that all steps are checked or will be accomplished before arming as shown in Figure 13. Only error codes are checked for the Accelerometer and Compass checks. RC is checked to make sure that the RC range is not the default (exactly 1100 to 1900).   If all steps are checked, the status summary lights should all be green as well.



A sanity check to ensure that the navigation telemetry data is coming in is to monitor the "Telemetry heartbeat rate" checkbox or switch to the Navigation tab of the DPACS Status panel or the GPS Status panel of the Simple GUI and observe that the timestamp highlighted is changing at least once a second.



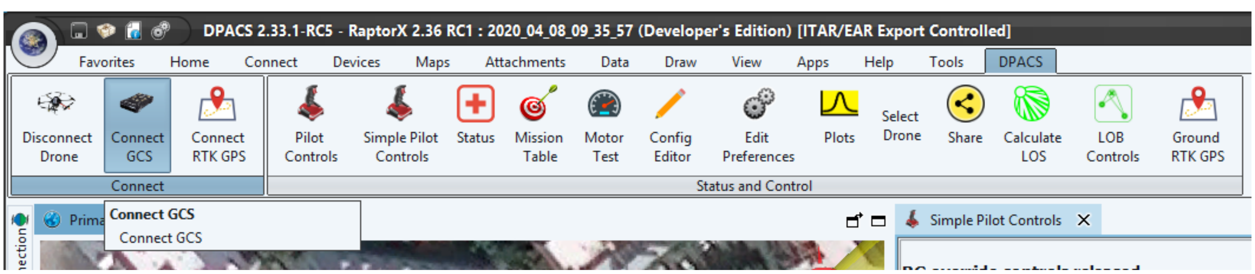


Connecting to a Ground Control Station (GCS)

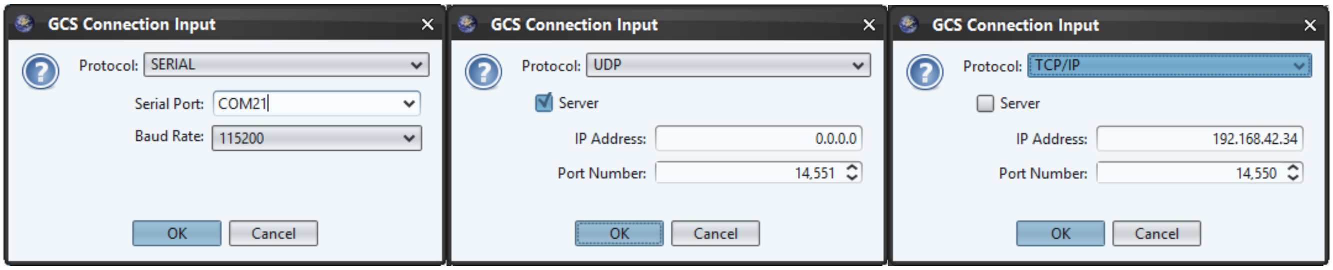
1. If you are going to be using "Follow Me" mode where the orientation of the truck or boat is considered, you will need to have a Pixhawk connected to the laptop as shown in Figure 15.

Production systems will likely have this GCS Pixhawk, GPS and Compass embedded in the tether reel.

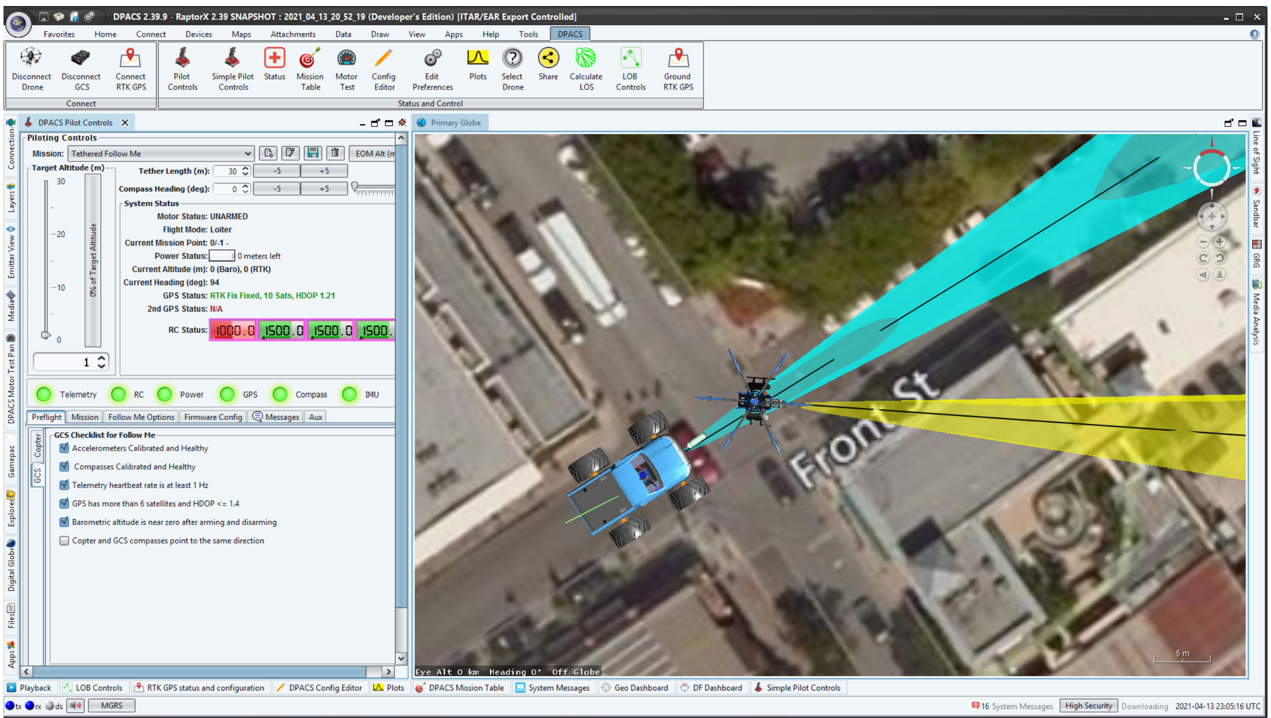
2. Connect to the GCS using "Connect GCS" button shown highlighted in Figure 16.

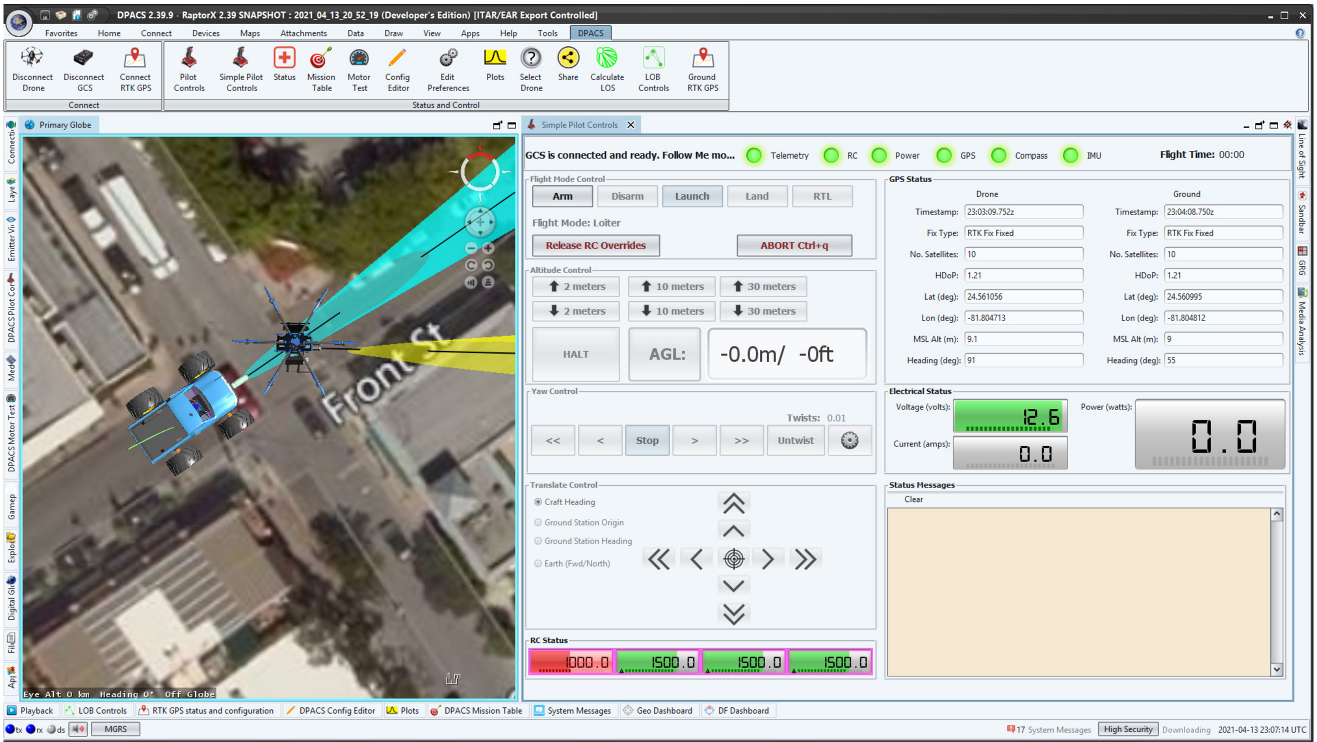


3. Select the protocol and input the required parameters for that protocol as shown in Figure 17. For a locally connected Pixhawk using serial over USB, select the 115200 baud rate and the correct COM port.



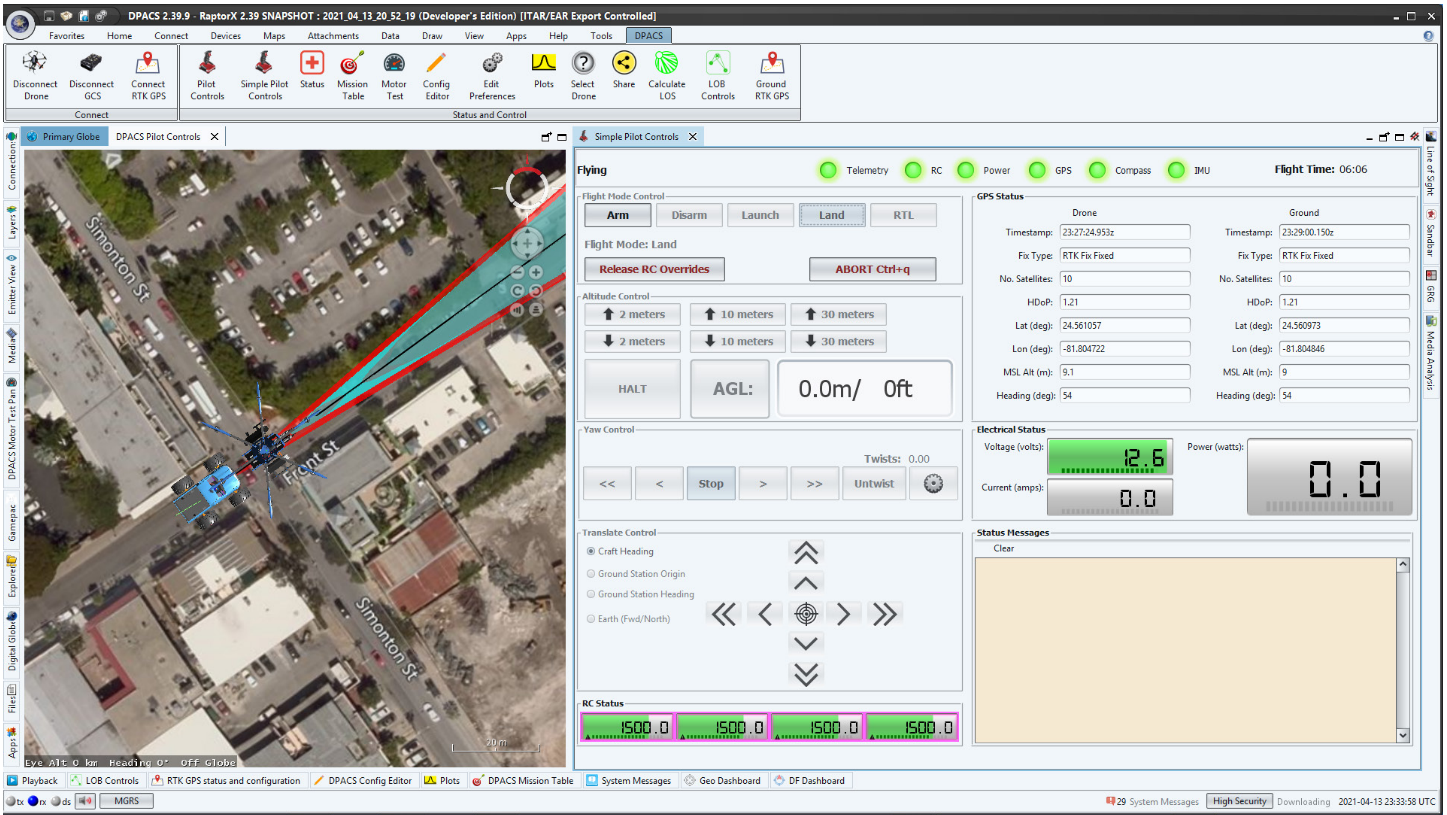
4. Once the GCS is connected, the checkboxes should all be checked except for the last one in the GCS tab of the Preflight panel. The GPS timestamp should also be changing rapidly in the GCS tab of the DPACS Status Panel as shown in Figure 18 and in the Ground GPS timestamp in the GPS States panel of the Simple Pilot Panel shown in Figure 19.





Wait for both the GCS and aircraft to achieve a good GPS lock (at least 8 satellites and an HDOP less than 1.0)

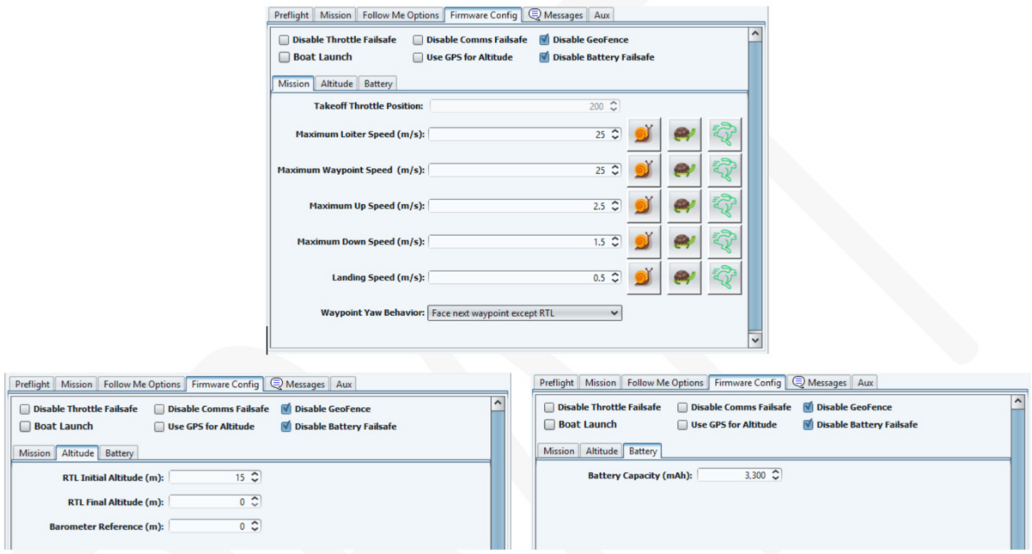
Rotate the drone and the GCS so they are physically pointing to the same direction such as North. Verify that the direction arrows and cones point to the same direction as shown in Figure 20. This step is not required but makes it easier to ensure that both compasses are working correctly by visually verifying that the drone and vehicle are pointing in the same direction.



If the arrows do not line up, the GCS's or the UAS's compass may be near some iron or one of them needs to have their compass recalibrated. It is important that the compasses are operating accurately since they are used to ensure that the drone maintains the same orientation to the GCS as the GCS moves and turns.

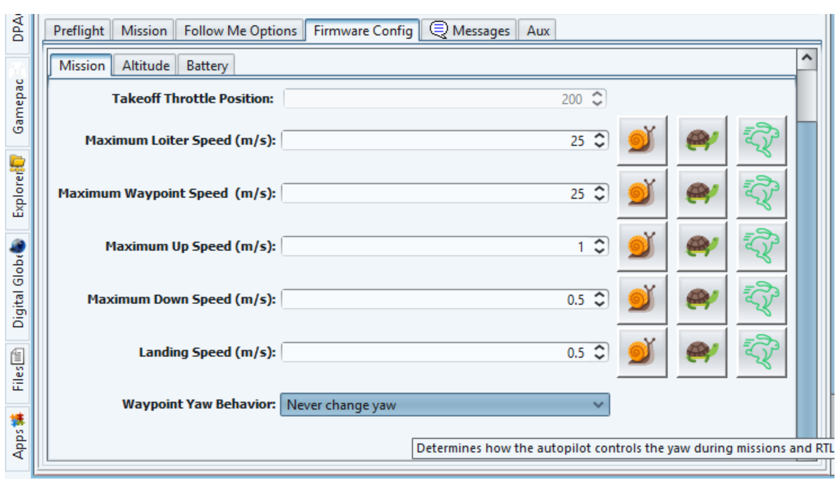
Configuration Setup

Some of the commonly used flight control firmware configuration parameters are available in the DPACS GUI as shown below:



For follow-me tethered flights, be sure to disable the GeoFence and Battery Failsafe's since those will cause the UAS to land or RTL. If you are moving in a boat for example, disable the battery fail safe to avoid landing in the sea if the battery is low. You will receive a warning message that the battery is low and can tell the captain to stop the boat so you can land the UAS.

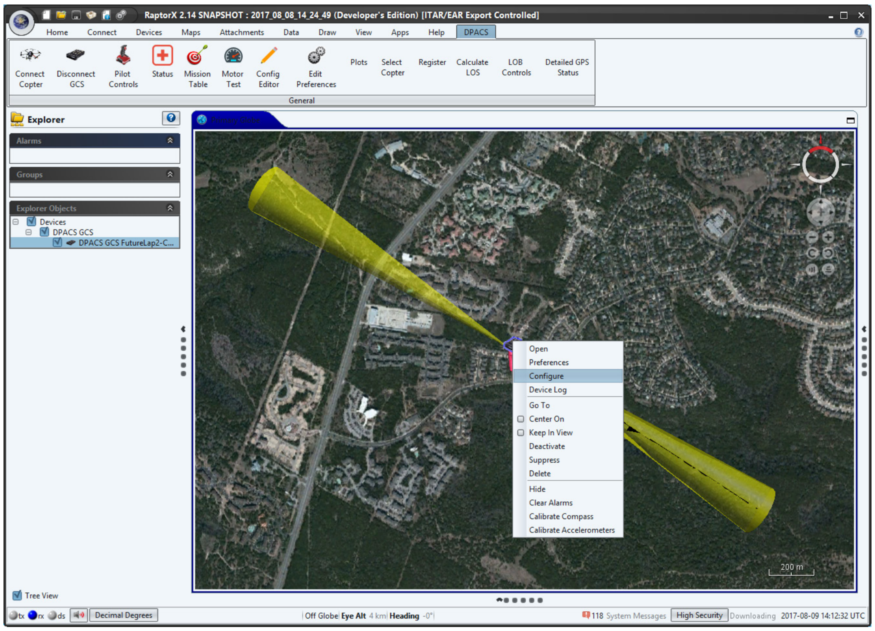
For elevator, waypoint, follow-me or fly-to missions where you do not want the UAS to rotate to the next waypoint, be sure to select "Never change yaw" in the "Waypoint Yaw Behavior" pulldown. This is especially important if you'd like to point the UAS to an arbitrary heading to point a camera or antenna to desired location.

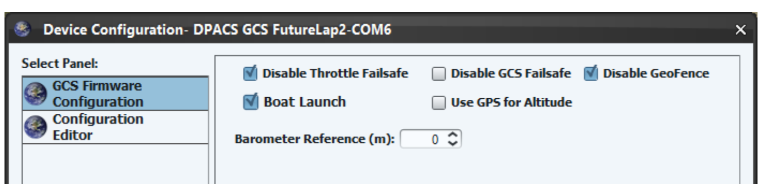


Boat Operations

If you will be launching from a moving vehicle like a boat, be sure that "boat launch" is checked in the "Firmware Config" panel. If not, check it and cycle the power or reboot using Ctrl+Alt+R and then re-connecting.

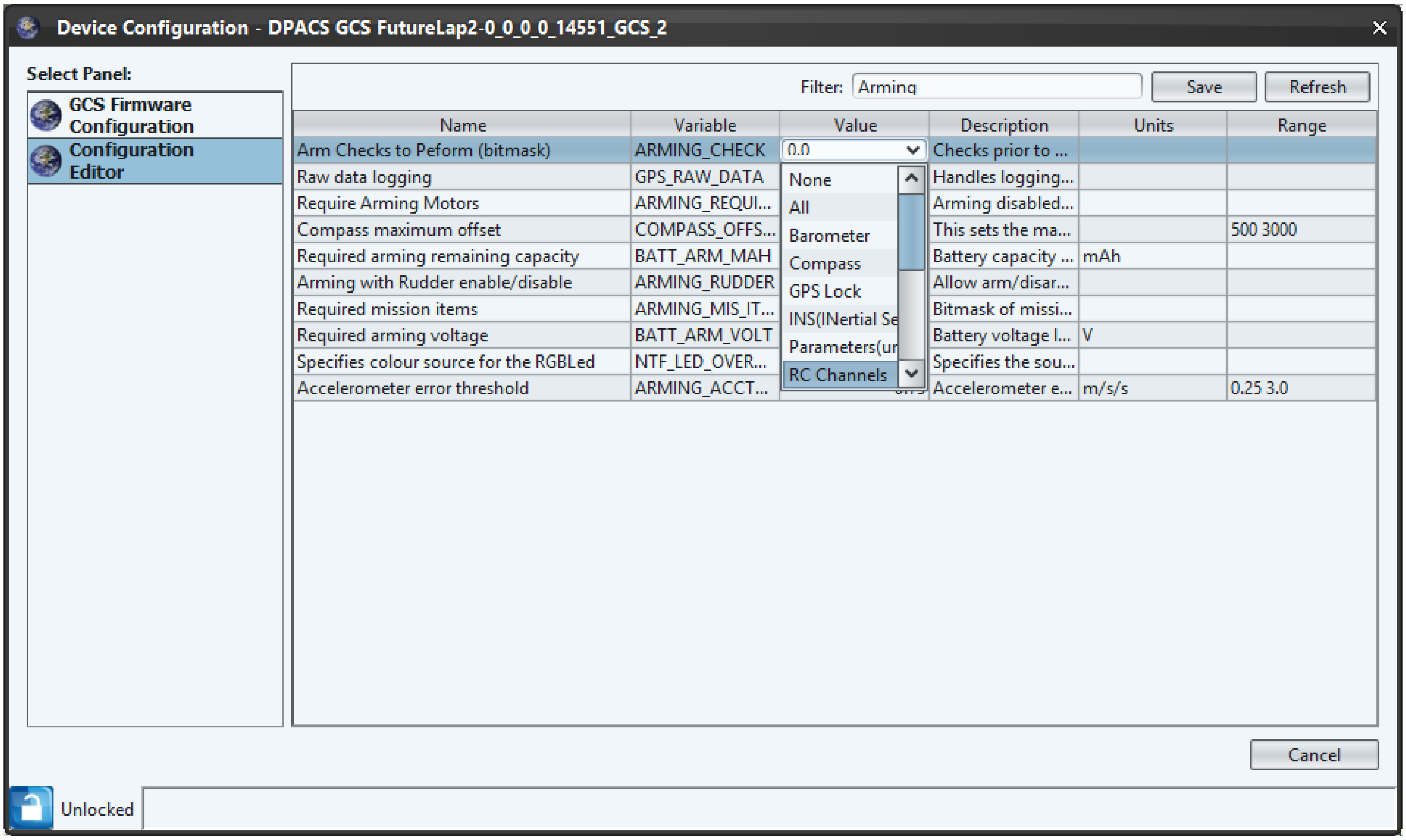
If you are using a GCS, make sure that it is in "boat launch" mode by right clicking on the device and choosing the "Configure" menu:





GCS Configuration

Any of the parameters for the GCS can also be accessed from the Device Configuration panel as shown below. Just change the desired parameter and click the “Save” button.



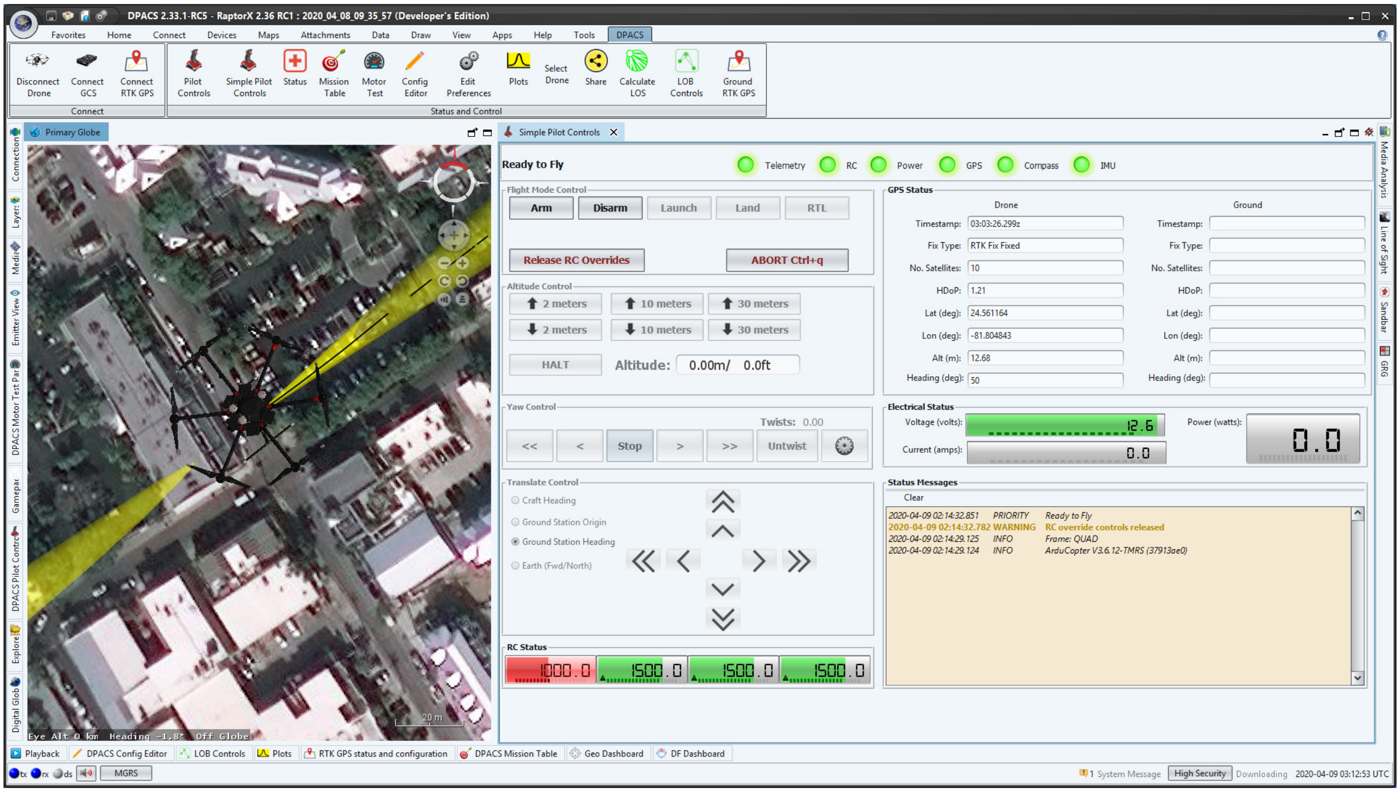
Missions

There are four types of missions that DPACS currently supports:

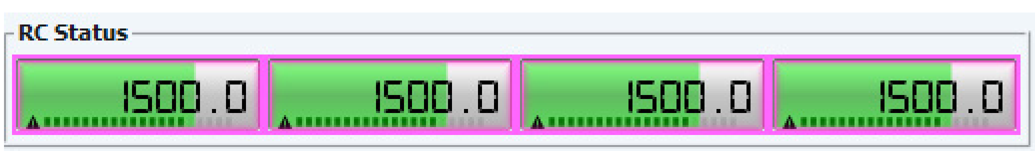
- “Tethered/Untethered Elevator”,
- “Route”,
- “Tethered/Untethered Follow Me”
- Ad hoc “Fly to” mission types.

Tethered Elevator- Simple GUI

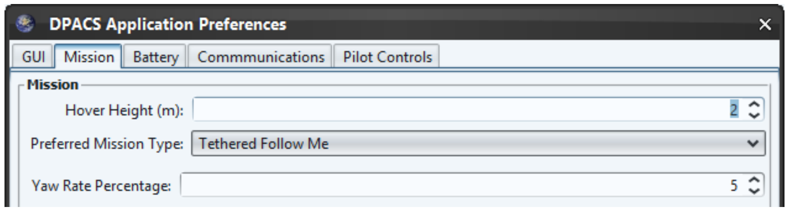
The Simple Pilot Controls Panel shown in Figure 25 was designed to easily perform simple tethered elevator missions. The drone is controlled using guided mode almost exclusively except for landing and pausing.



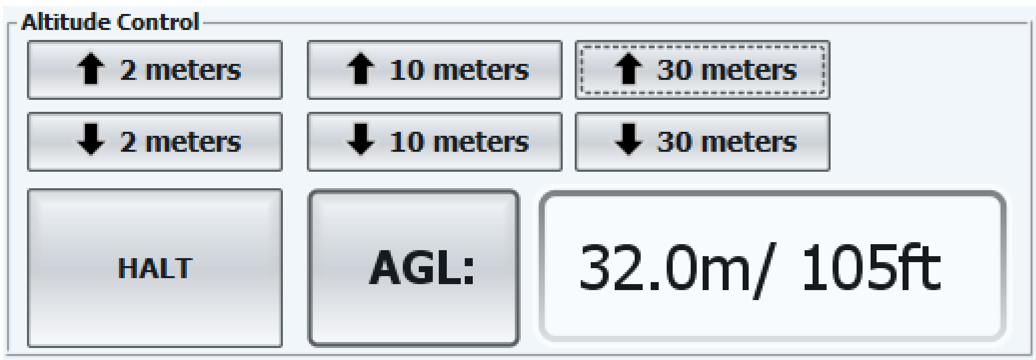
1. After connecting to the drone, wait for all status lights to go green.
2. The RC status channels should be all green except for the first one, which is the throttle. The throttle will turn green once the drone is flying and the pilot raises the throttle value to midway. If the XBox game controller is used, the control sticks should be moved around for DPACS to force overrides. Purple borders will appear for every overridden channel. The values should change as the sticks are moved around. If no RC or XBox controller is used, DPACS will override all four channels (throttle, roll, pitch and yaw) with RC channel ranges and trim values present in the downloaded configuration parameters.



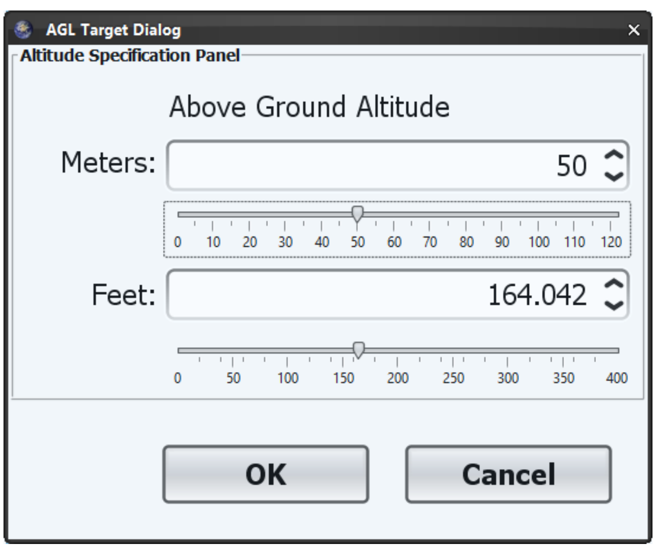
3. Click the “Arm” button to turn on the motors. If the RC or XBox game controller is being used, the throttle needs to be fully lowered before clicking the “Arm” button.
4. Within 10 seconds, click the “Launch” button to command the drone to hover at the hover height once it is enabled. The hover height defaults to 2 meters and can be changed in the DPACS preferences shown in Figure 27.



5. If the drone appears to be stable in hover, the altitude can be increased by clicking on the Altitude Control buttons shown in Figure 28.



6. To quickly stop the motion of the drone, click on the "Halt" button. This changes the mode to "Brake" which stops all movement. Cntrl-h also halts the aircraft's vertical position.
7. To go to an exact altitude in meters or feet, click the AGL button to show the dialog shown Figure 29.



8. To rotate the drone, click on the arrow buttons in the Yaw Control panel shown in Figure 30. The ">" and "<" buttons will rotate the drone to the right and left respectively at the "Yaw Rate

Percentage" speed specified in the DPACS preferences. The ">>" and "<<" buttons will rotate the drone to the left and right at double the preferred yaw rate. Before landing the drone, click the "Untwist" button to remove all the twist in the tether so that it reels without getting tangled.

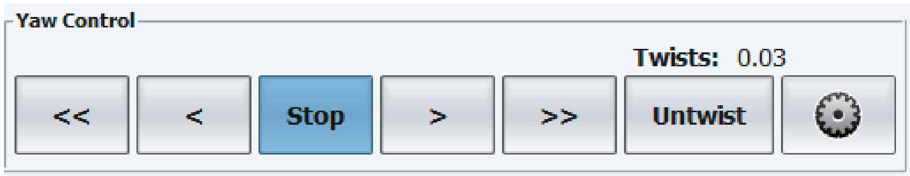


Figure 30 - Yaw direction and rate controls

9. Use the translate controls shown in Figure 31 to adjust the position of the drone. The single arrow ">" will move the drone by the "Horizontal Nudge Distance" preference located under the "Pilot Controls" tab. The double arrow ">>" will move the drone by twice the nudge distance.

   The translations can be performed in different coordinate systems. The "Craft Heading" option is relative to the front of the drone. The "Ground Station Origin" defines forward along the line between the GCS GPS position and the drone. The "Ground Station Heading" defines forward as the compass direction the GCS is facing. If there is no GCS, the default coordinate system will be "Craft Heading". The "Earth" setting defines forward as North. The bullseye button re-centers the drone back to the original takeoff location.

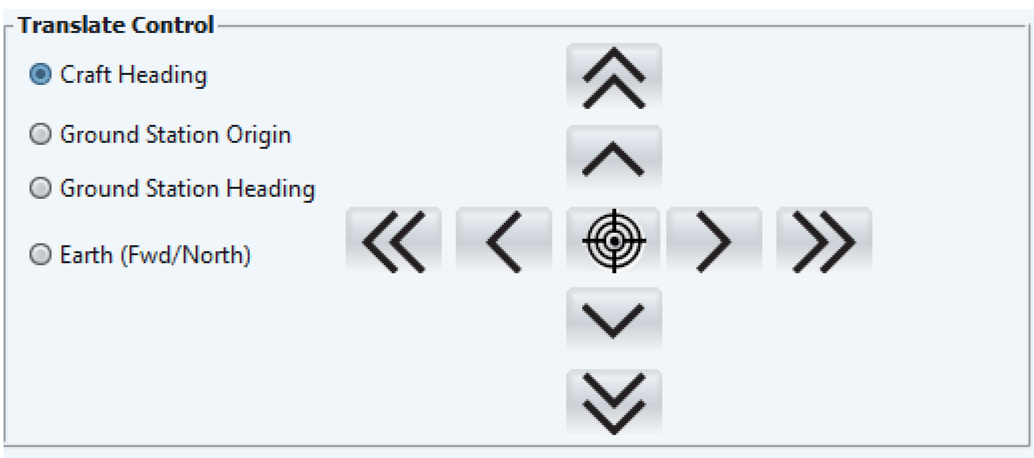


Figure 31 – Translate or "Nudge" Controls Panel

Tethered Elevator – Pilot Controls GUI (Multi-Mission GUI

1. Select "Tethered Elevator" in Mission Selector shown highlighted below:

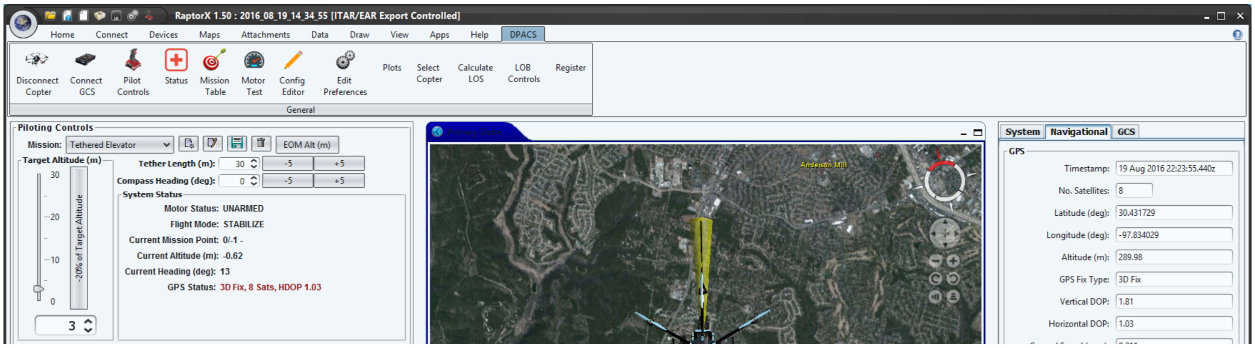


Figure 32 "Pilot Controls" Tethered Mission

2. Specify the maximum tether length available in the "Tether Length" field. This field just limits the maximum altitude that can be specified for the UAS.
3. Ensure that the "Flight Mode" is in Loiter. If not, click on the Abort button or type Cntrl+Q to reset the state to Loiter. The drone may not arm when in the wrong flight mode.
4. The tethered elevator mission can be executed by simply specifying the altitude with the "Target Altitude" slide or typing in a specific value then clicking on the "Update Mission" button. You should see 4 mission commands show up in the "Mission Table" at the bottom of the screen as shown in Figure 33 with the last one being "LOITER UNLIMITED".

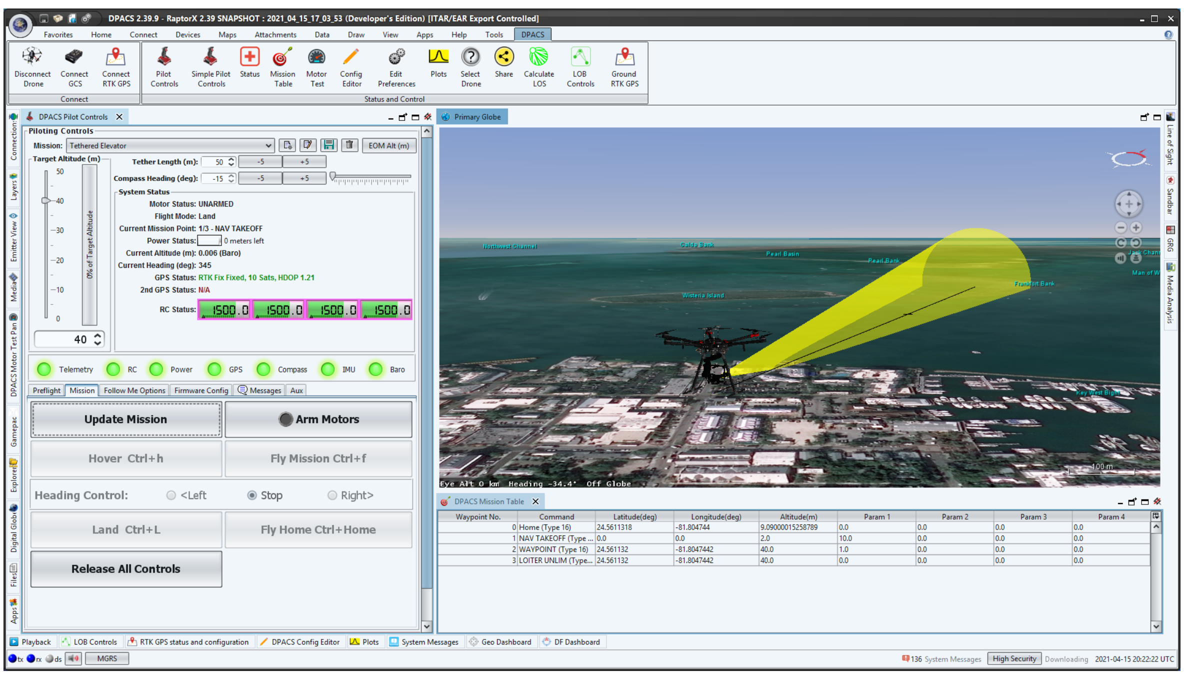


Figure 33 - Mission Table shown after updating the mission

5. Verify that the altitudes are correct in the Mission Table. Make sure all the waypoints appear in the correct order and the total count is correct.
6. Then click on "Arm Motors" and wait for the motors to spin.[2]

[2] If the failsafe settings of your RC receiver has not been configured correctly, the throttle position stored may be the last throttle position set before the RC transmitter was turned off. This can lead to a surprising launch if the throttle was not at the

7. Click the “Hover” button and wait for the UAS to stabilize in hover. [3] The default hover altitude is 2 meters, which can be changed in the DPACS preferences.
8. Click the “Fly Mission” button. The UAS should rise immediately to the designated target altitude and loiter.
9. To change altitude or compass heading during flight, simply change the target altitude or compass heading in the Pilot Controls Panel or by right clicking on the 3D model and selecting the “Set Heading” menu option. You can also use the Yaw slider control the heading of the UAS by slowly moving the slider left or right and moving it back to zero when the UAS is at the desired bearing.
10. At the end of the mission, click the “Land” Button to land the drone. (You can also enter Ctrl+L.) The landing algorithm is reliable and will auto-detect a landing plus turn off the motors, but always be ready to type Ctrl+Q or click on the ABORT button to quickly power off the motors if it looks like the drone is not powering down fast enough after landing or looks like it is about to teeter over.
11. Click on ABORT to reset and turn the motors off. The ABORT (Ctrl+Q) is also useful if the drone is out of control and switching to altitude hold on the RC does not work either. (Be sure and increase the throttle to midway before turning on the RC.) It will shut off all power to the motors immediately causing the drone to freefall and crash, so abort is a last resort step when the drone is airborne.

Route Planning Using Waypoints

Figure 34 when the save button is click (i.e. no handles on the route). The mission will be saved to disk as well so that it can be retrieved in the future by name.

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minimum at the end of the last flight and would bypass the Ardupilot RC failsafe check if it is enabled. Please see this article for instructions on how to setup failsafe for a Spektrum receiver: http://diydrones.com/profiles/blogs/spektrum-dx8-and-ar8000-failsafe-setup.

[3] Do not release the controls from the GUI until the RC is turned on and the throttle is positioned mid-way.

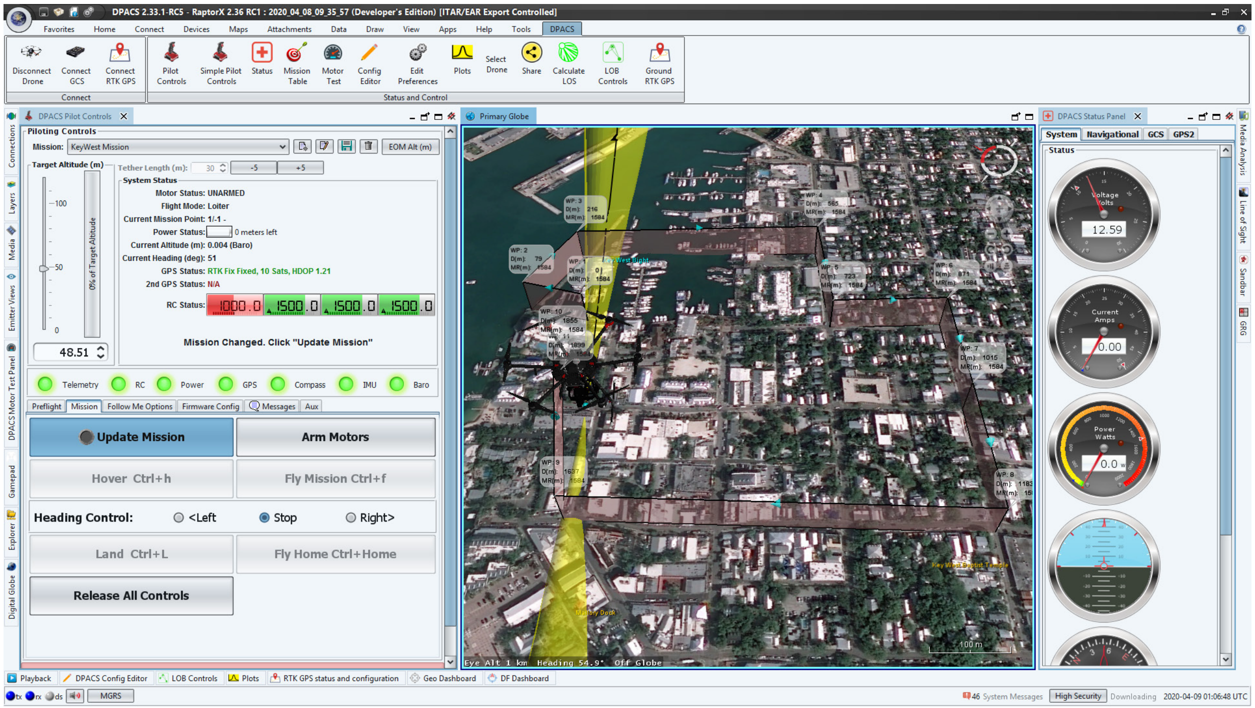


Figure 34 – The display of waypoints associated with the waypoint mission

Note: Currently the lat/lon location cannot be specified by value in DPACS. If that is needed, add a pin to the map using Home/Icons/PushPins and change Lat/Lon of the pin to your desired location and then put a waypoint on top of the pin.

3. Click the “EOM Alt (m)” button to set the final loiter altitude. (The original CONOP was to have the drone fly to the target and then descend to the target altitude. Then a pilot would land the drone using FPV to help guide him.)
4. Ensure that the “Flight Mode” is in Loiter mode. If it is not in Loiter mode, click on the Abort button or type Ctrl+Q to reset the state to Loiter.
5. Click on the “Update Mission” and verify the altitudes and the general waypoint positions in the Mission Table as shown in Figure 35.

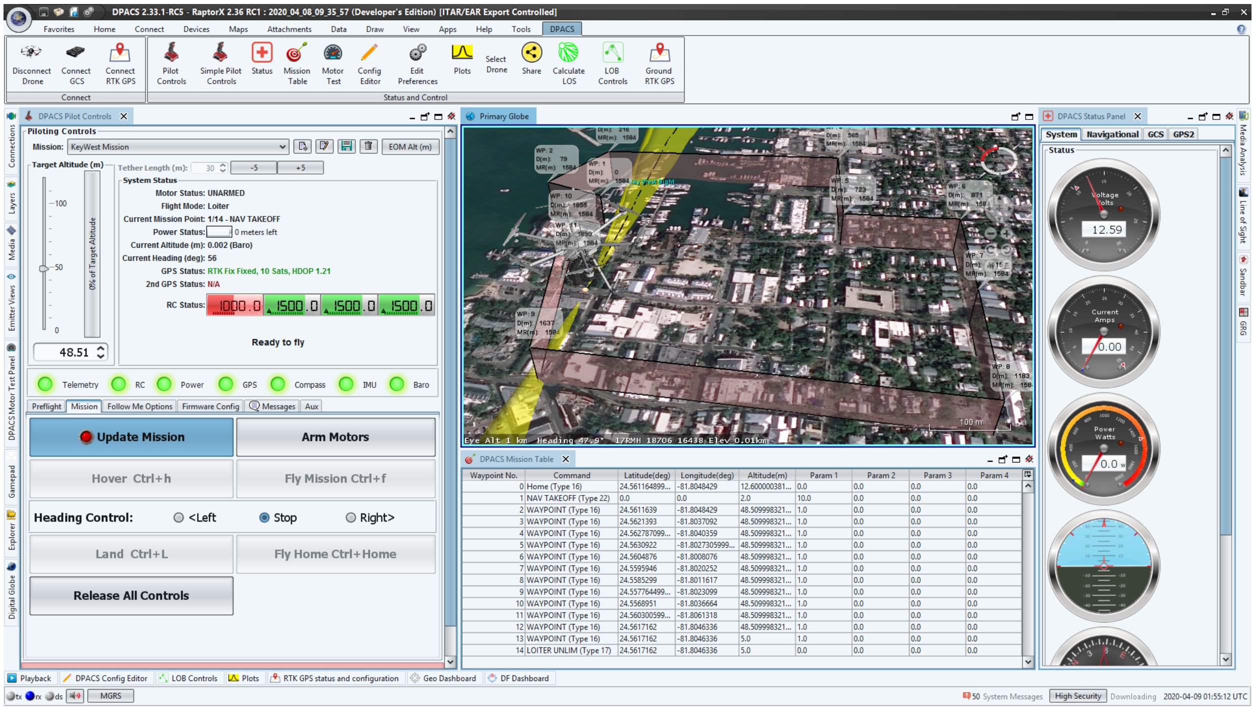


Figure 35 - DPACS Mission Table displayed after updating mission

6. Then click on "Arm Motors" and wait for motors to spin up. The Armed state will timeout in 10 seconds if you do not perform the next step.
7. Click on "Hover" to command the UAS to fly 2m off the ground. (Initial hover height is specified in the DPACS preferences.)
8. When it appears that the UAS is stable in hover, click "Fly Mission".
9. When the UAS arrives at the destination and finishes the last point, the pilot can take over to land with the RC using FPV to help guide him or click the "Land" button. Here is an explanation of the Land behavior: http://copter.ardupilot.com/wiki/land-mode/
10. Click on ABORT once it has landed to ensure that the motors are turned off and that the GUI is reset for the next mission.

Tethered/Untethered Follow-Me

The Follow Me Mission is used for two main cases: long flying elevator missions where the GCS's barometer is used to correct for altitude drift and for instances where the UAS is chasing the GCS either on land or water.

1. Connect the Copter
2. Connect the GCS
3. Verify that the connections are active by looking at the Timestamps in the Navigation and GCS tabs (updating at least once a second or faster)

4. Verify that the GPS fix is good (3D fix, HDOP < 1, Number of Satellites > =8) for both the GCS and the UAS
5. Verify that the Barometric Altitude is near 0 for both the GCS and the UAS. If the altitude is not near 0, Arm and then Disarm to verify that both altitudes went to near 0. If the barometric altitude is not near 0 (less than 1.0) after arming and disarming, cycle the power on the UAS and GCS.
6. Verify that both UAS and the GCS are pointing to the expected direction by looking at the arrows in the 3D map and comparing against known landscape features or compass direction:

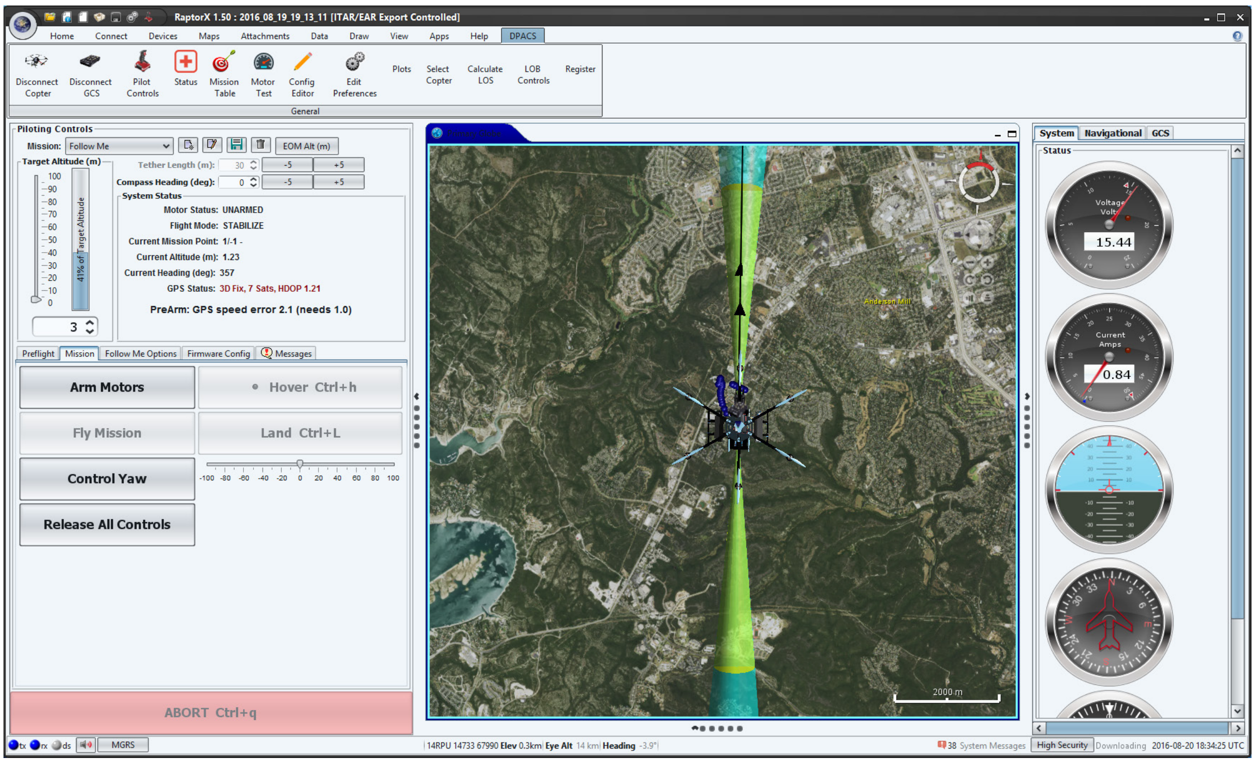


Figure 36 – Drone and GCS headings aligned

7. Select “Tethered Follow Me” mission for a tethered UAS or “Follow Me” for untethered in the mission selector as shown here:

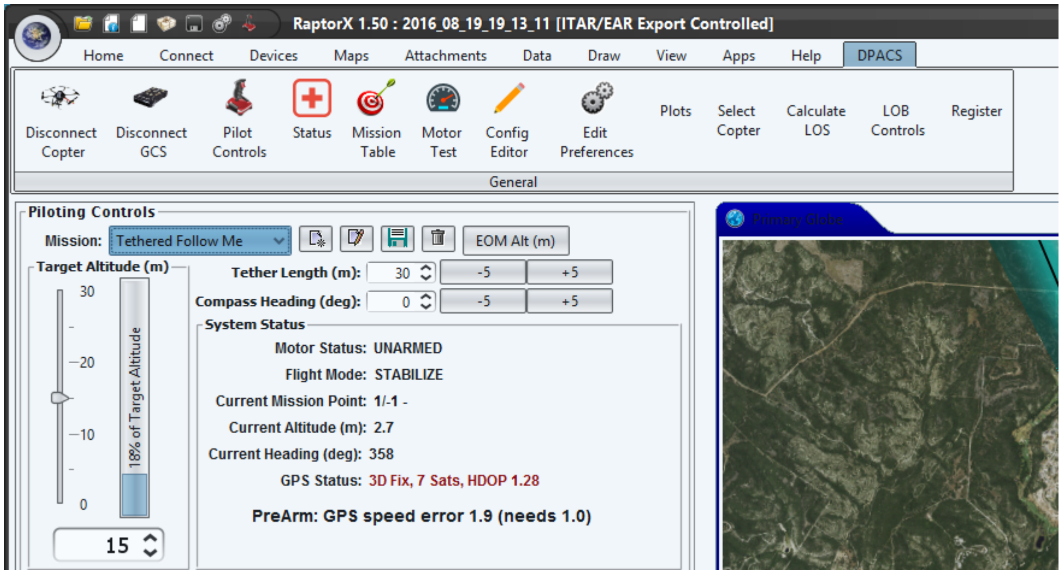


Figure 37 - Tethered Follow Me mission option selected

8. Specify a target altitude by using the slider or typing in a value
9. Ensure that "Takeoff Orientation" is selected in the Follow Me Options panel so that the current UAS orientation to the vehicle is chosen.

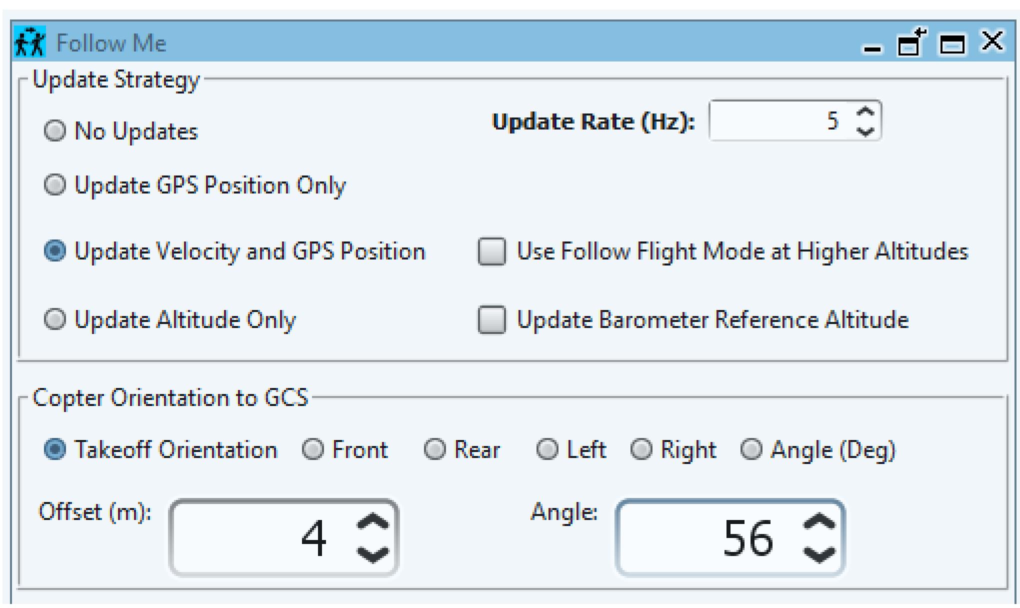


Figure 38 – Takeoff Orientation selected to set offset and angle based on physical orientation between the copter and the GCS.

10. Arm UAS and verify that Barometric Altitude is near 0 for the UAS and GCS
11. Click Hover to launch the UAS 2 meters off the ground and set its mode to guided
12. If the RC is on, move the throttle on the RC to mid position in case the RC operator is required to switch to stabilize or loiter mode to takeover control.
13. Click "Fly Mission" to start following waypoints from the local GCS

14. Raise the GCS a meter or move the GCS towards the UAS and verify that the UAS moves accordingly.
15. If you would like the UAS to maintain a given relative orientation to the GCS, select the preset angles corresponding to “Front”, “Rear”, “Left”, “Right” or the “Angle” option for a specific orientation in the “Follow Me Options” as shown below. (All of these settings can be changed while the UAS is flying as well.)

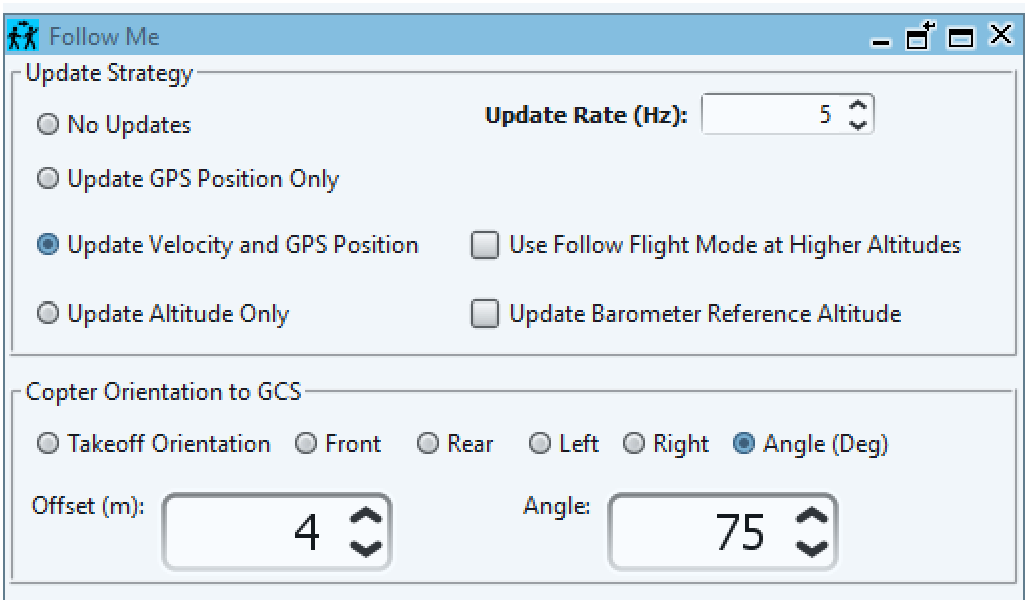


Figure 39 – Angle option selected for Follow Me to allow general angle orientation and offset between the drone and the GCS. The initial values are set by the orientation and the offset between the drone and the GCS at the time of arming.

16. Change the Offset in meters and Angle in degrees to move the UAS to the desired location relative to the GCS. **Slowly** rotate the GCS to verify that the UAS follows the orientation.
17. Change the target altitude by typing in a value or moving the target altitude slider.
18. If you want to RTL while moving, ensure that the “Use Guided RTL instead of normal RTL when connected to the GCS” option shown in Figure 40.
19. When Fly Home (RTL) is selected, this mode will raise the drone to the RTL altitude and then fly to the original takeoff position relative to the GCS. Guided RTL will then lower the drone at the high altitude land rate and then reduce the landing speed to the low altitude land rate land when it hits the low altitude landing setting.[4] Once the altitude is at the “Final Landing Height” shown in Figure 40, the mode will switch to “Land”. If the drone does not appear to switch to landing mode click the Land button (Ctrl+L) and then Ctrl+Q once the drone touches the ground to avoid any mishaps while moving.

[4] If you do not have an automatic tether tensioning system, be sure to manage (manually reel in) your tether while the copter is landing to avoid getting the tether tangled in the vehicle such as in the boat’s propeller.

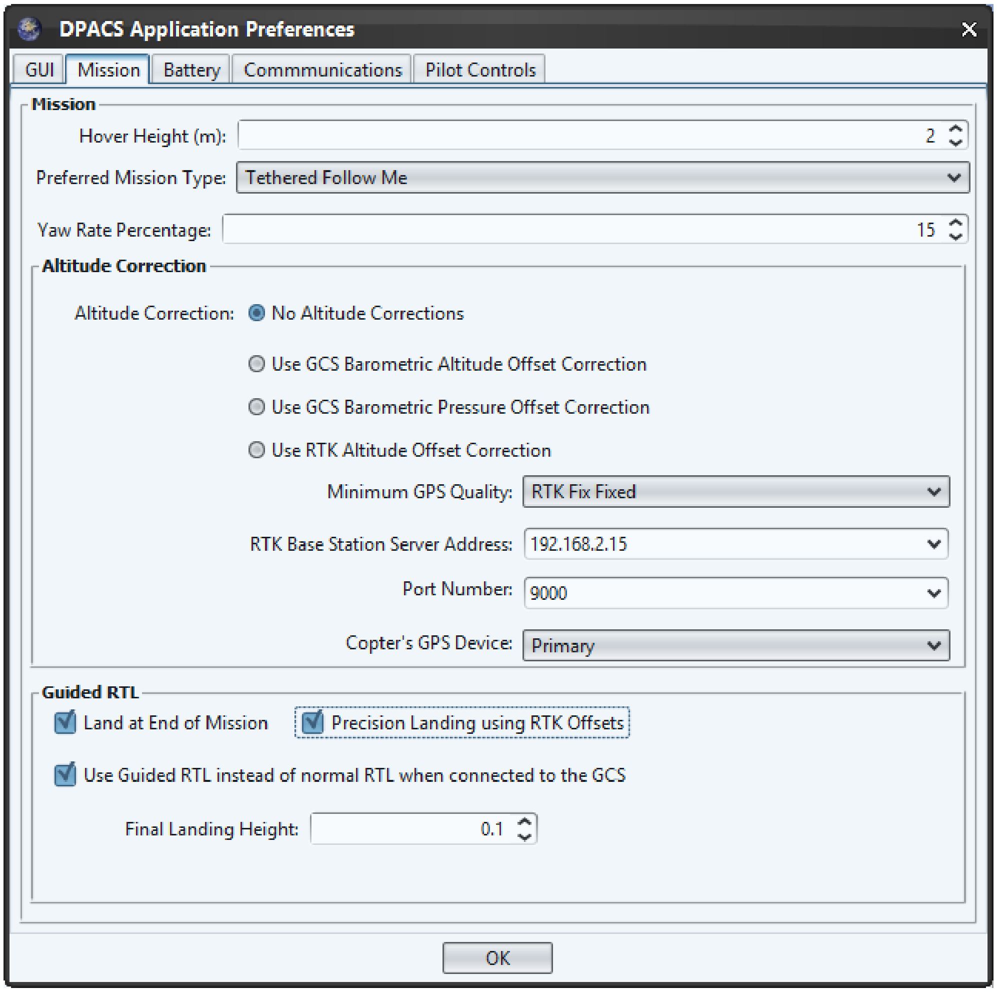


Figure 40 – Guided RTL preferences

The UAS can also just be brought within grabbing distance of an assistant by reducing the offset distance and angle or using the nudge operations. With the tether power turned off, the assistant would grab the landing gear and then the operator would kill power to the UAS by clicking “Abort” or typing Ctrl+q or triple clicking the abort button on the XBox controller.

Note: A new option to use the ArduCopter “Follow” flight mode is available as well if the user prefers. It will only be allowed at altitudes above 10m since it does not use precision RTK information and does not follow as accurately or aggressively as the DPACS follow mode. This mode can be selected at any time in the “Follow Me” settings panel as shown in Figure 41

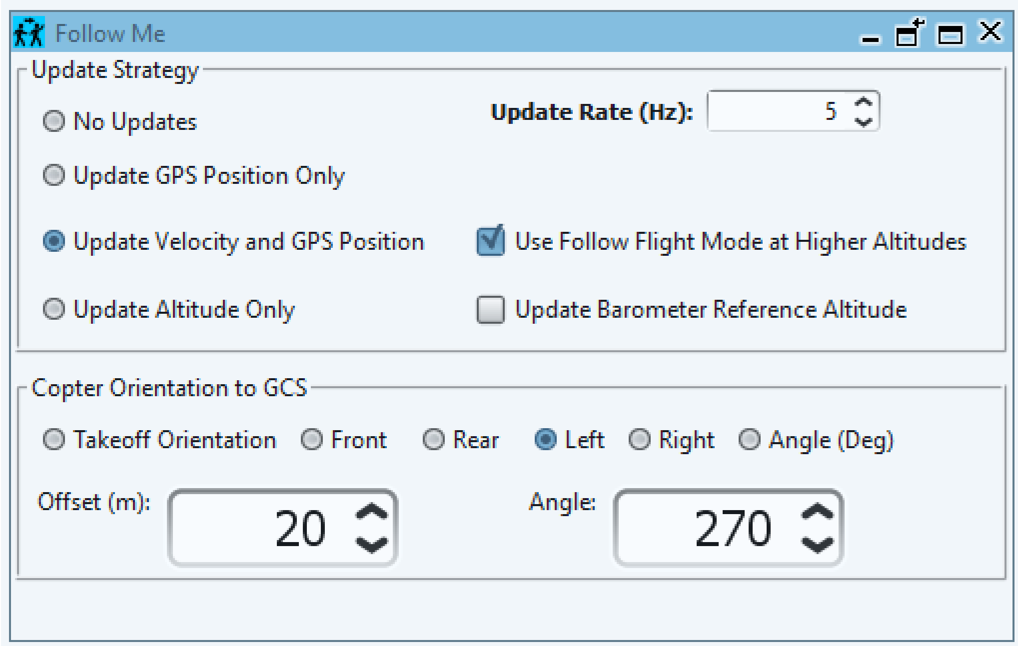


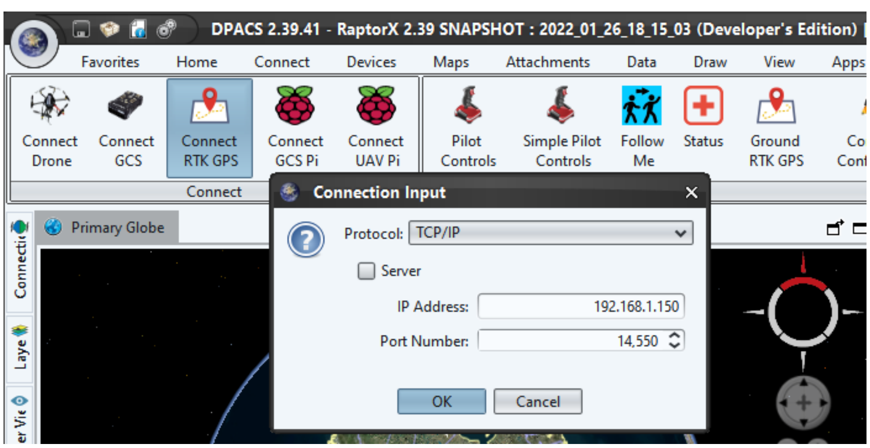
Figure 41- Using ArduCopter Follow flight mode when flying at altitudes higher than 10m.

Precision Follow Me using the Simple Pilot Panel

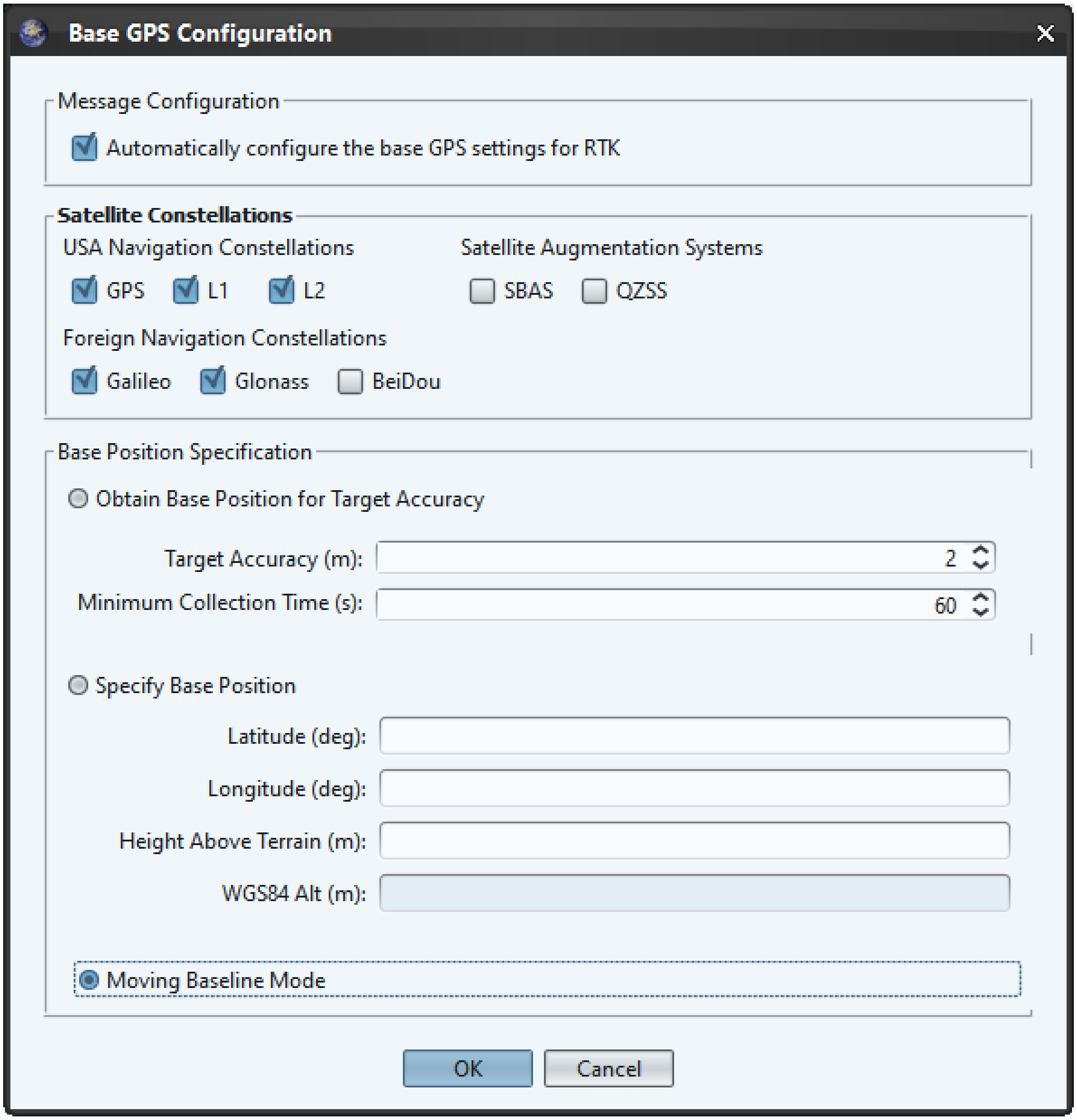
When using the Simple Pilot Panel to control the copter, it will automatically switch the copter to follow me mode when clicking the launch button and the rest of the controls will work as expected as the copter follows the vehicle. If F9P RTK GPS and the custom firmware, the follow me mode will use the delta offsets calculated by the RTK GPS to perform follow me and precision landing while moving.

Here are the usual steps to accomplish follow me with precision guided RTL:

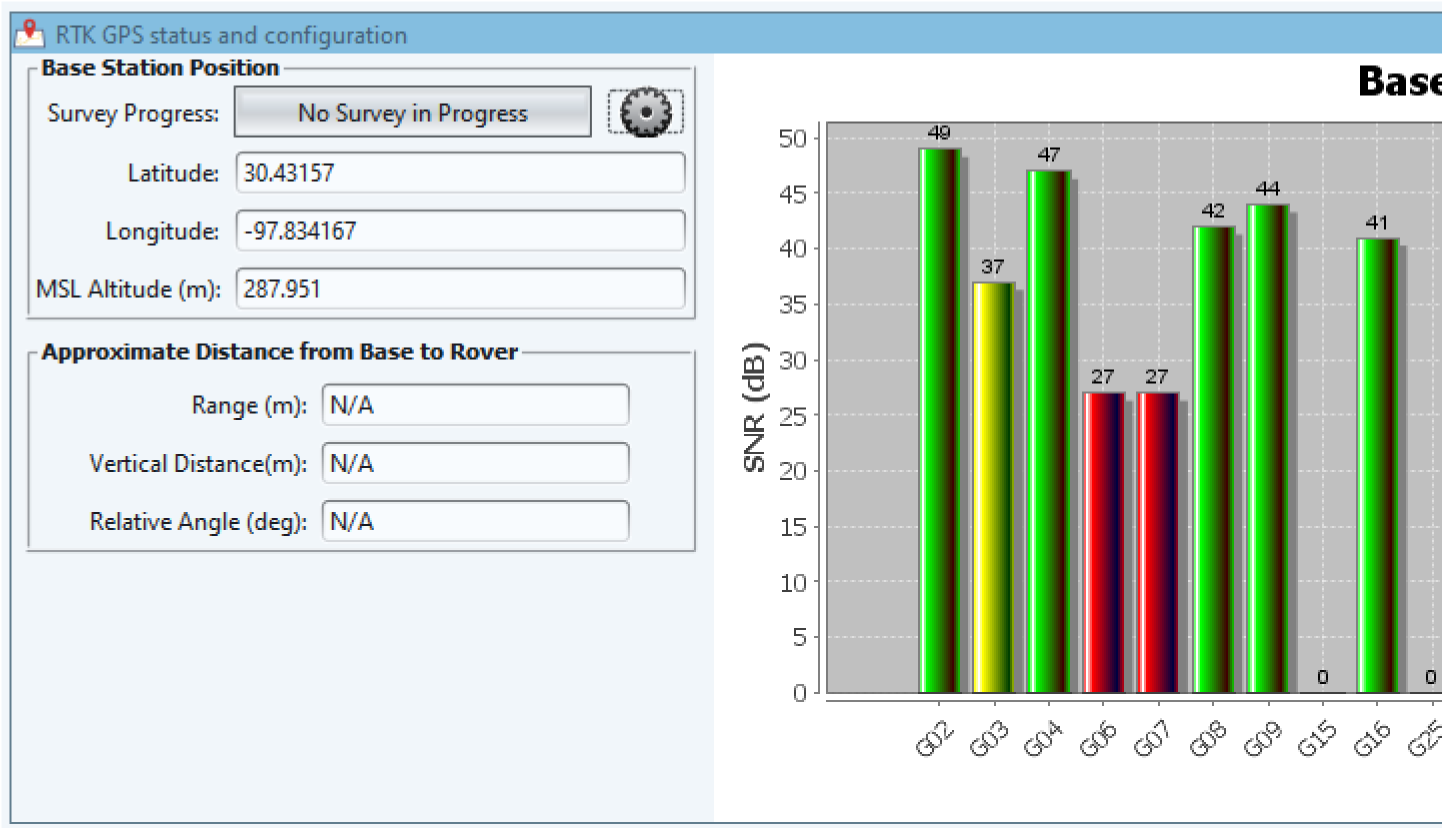
1. Connect to the RTK GPS



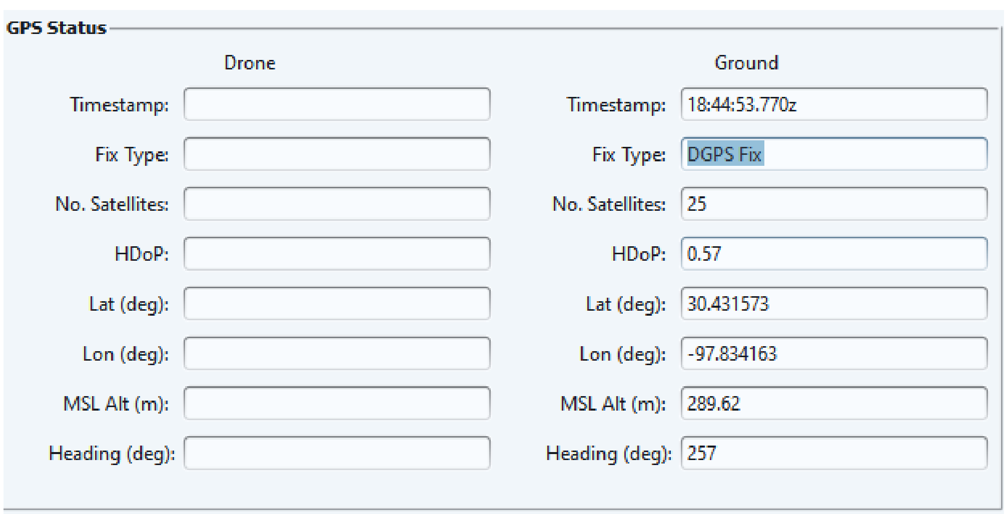
2. Display the "Ground RTK GPS" panel and select the gear icon to configure the GPS for moving baseline mode



There should be 10 or more satellites with SNRs above 40.



3. Connect to the GCS using the “Connect GCS” button in the ribbon bar. The GCS’s GPS Fix type should be 3D or DGPS Fix and not “Static Fix”.



4. If the copter is powered and a non-moving baseline mode was used to achieve an RTK Fixed Fix, cycle the power on the copter to clear the static base mode in the GPS. The copter’s GPS will not switch to moving baseline mode if it was ever in static base mode.

5. Connect to the copter using the “Connect Drone” button in the ribbon bar. Make sure that the 3D cones for the copter and the GCS line up on the map when they are both

pointed in the same direction. If they are not lining up, recalibrate the compasses on both or make sure that the each compass are a foot or two off any iron source.

6. The GPS Fix type should switch almost immediately to “RTK Fixed Fix”. If the fix type is not “RTK Fixed Fix” there is likely a communication problem or there are blockages such as buildings that are creating multi-path or blocking satellites. UBlox recommends setting all the serial port communication rates (drone and GCS) to 460,800 baud including the telemetry and the GPS baud rates. Most of the testing was done with this rate, but successful moving base solutions were obtained with 230,400 baud for telemetry and 460,800 for the GPS. If there are continuous “Bad GPS” warning messages, that indicates that the communication rates are not fast enough. The custom ArduCopter firmware relaxed the expected GPS solution rate from 5Hz to about 2Hz. This lower rate was achievable with a wireless telemetry link using the RFD900X radio. More performant comms links will support faster than 2Hz solution rates, but 2Hz appears to be sufficient for this use case. The solution rate can be verified by plotting the GPA.Delta field from the

ArduCopter log file as shown in Figure 42 and Figure 43. As shown, the GPS solution rate is between .2 seconds or 5Hz and .4 seconds or 2.5Hz.

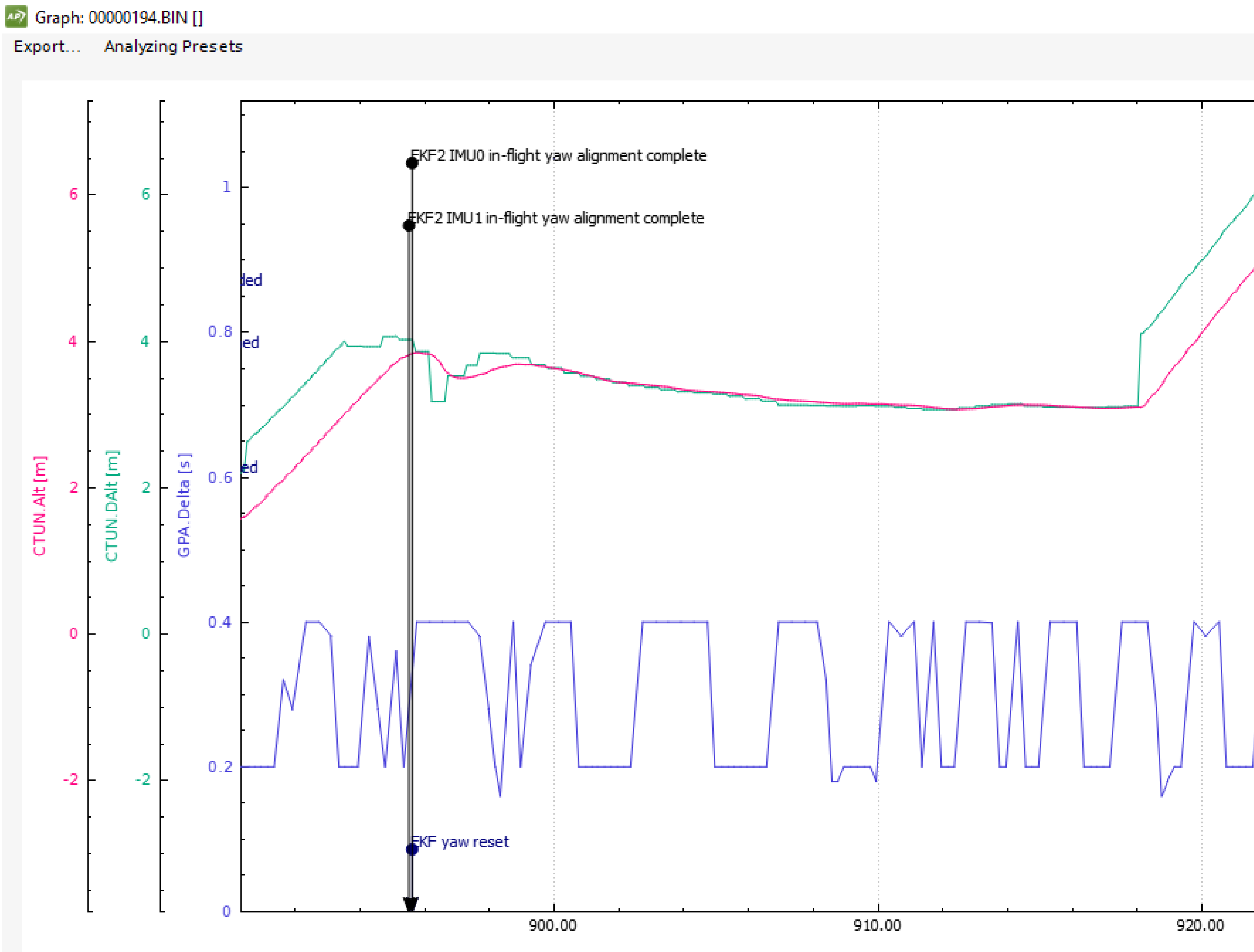


Figure 42 – Typical time between solutions for the Moving Baseline RTK mode using the RFD900X telemetry radio with all baud rates set to 460,800.

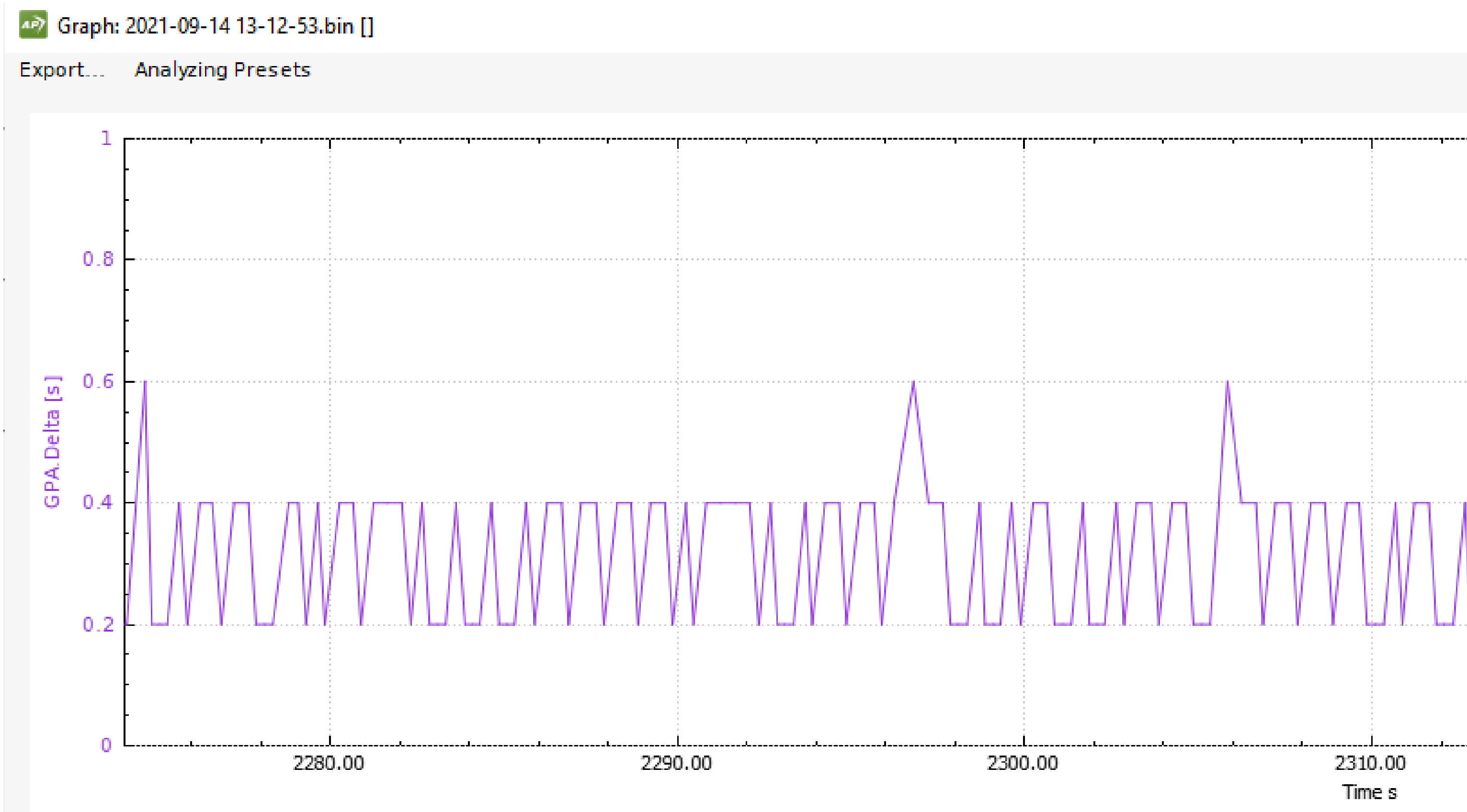


Figure 43 - Typical time between solutions for the Moving Baseline RTK mode using Ethernet over the tether to the drone with the serial telemetry rate being set to 230,400 and the GPS baud rate set to 460,800.

5. The Follow Me mode is automatically used upon takeoff using the Simple Pilot Control Panel if the "Automatically Enable Follow Me When Possible" setting is enabled in the DPACS preferences as shown in Figure 44.

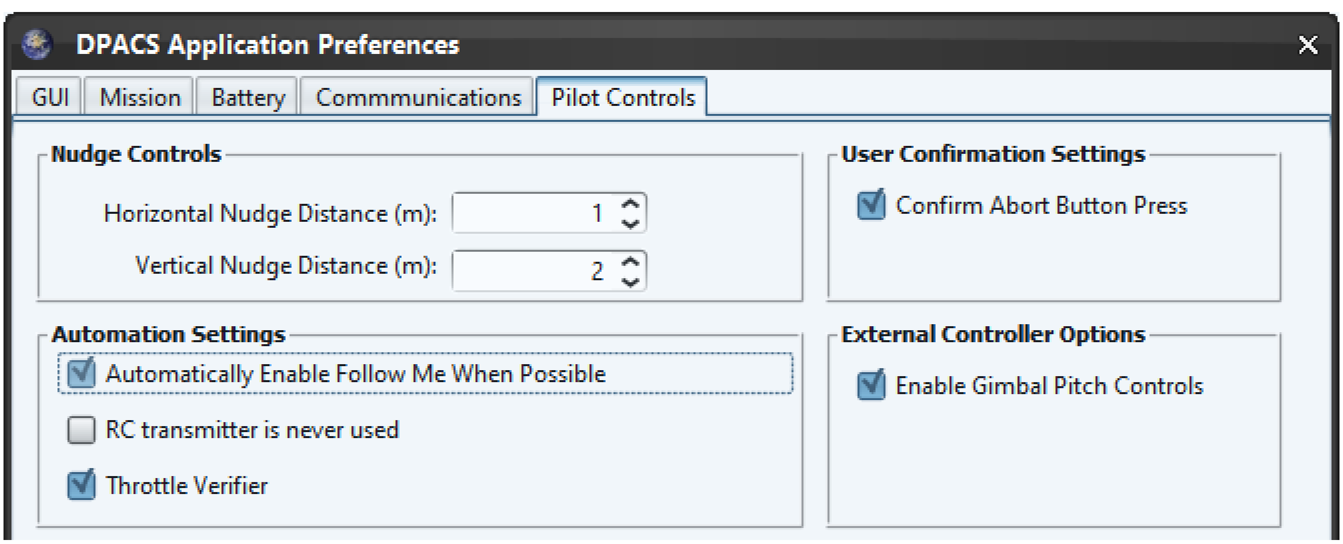


Figure 44 – Automatic Enable Follow Me preference enabled

6. A special mode called Guided RTL is used instead of RTL for follow me missions. This mode guides the drone to the original takeoff orientation relative to the GCS box on the vehicle during landing. RTL would return to the original takeoff location. Guided RTL is enabled by selecting the “Use Guided RTL instead of normal RTL when connected to the GCS” preference in the DPACS preferences shown in Figure 45. The 2 cm accurate RTK offset solution will also be used for precision follow me and Guided RTL if the “Use RTK Offsets for Precision Guidance” is selected in the DPACS preferences also shown in Figure 45.

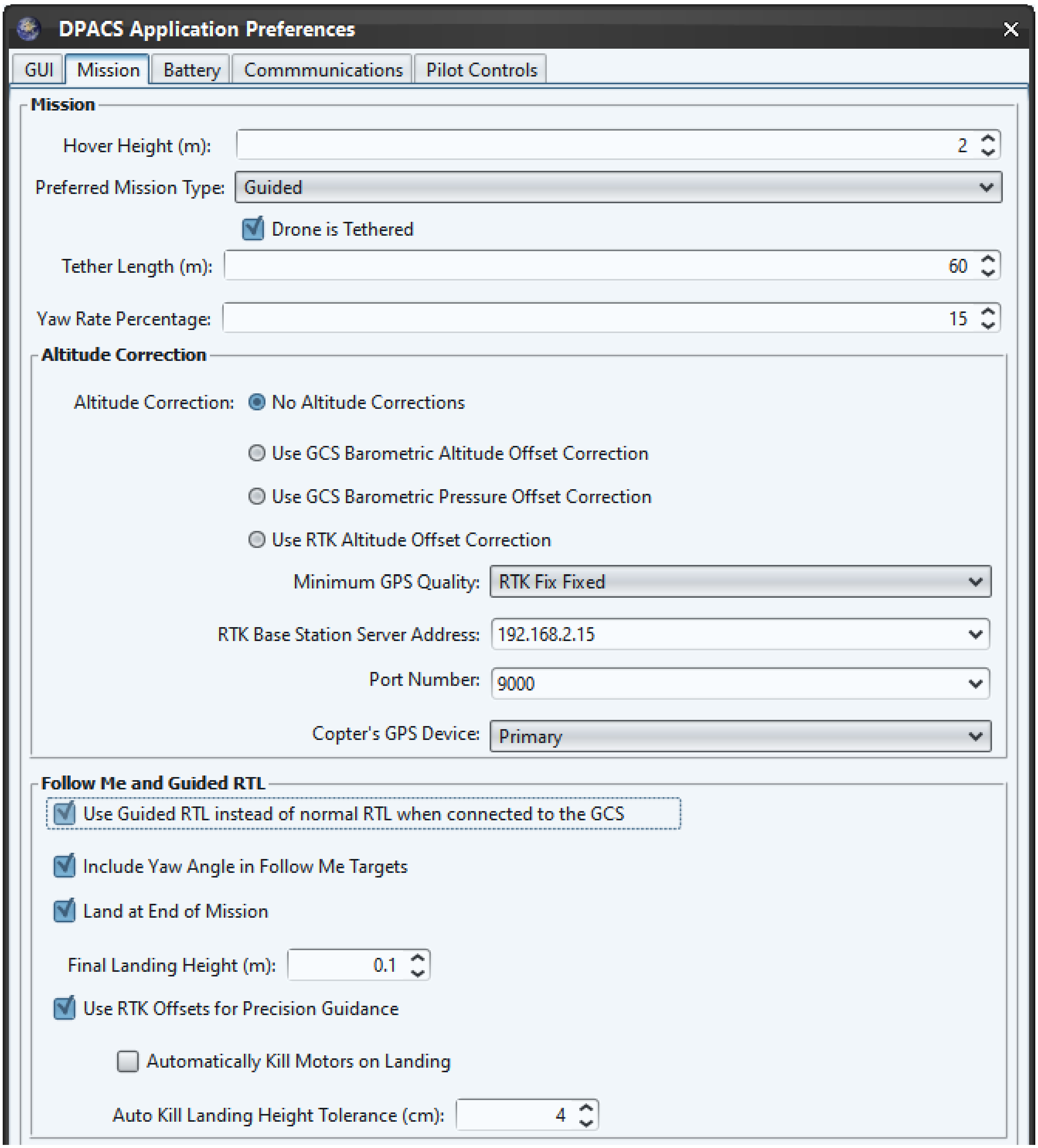


Figure 45 – Enabling Guided RTL and RTK Offset for Precision Guidance

7. The performance of the precision follow-me is affected by a few of the WP firmware parameters such as WPNAV_ACCEL and WPNAV_SPEED. If they are too high, the copter will overshoot the target position using the current approach. Use the settings shown in Figure 46 as a start. The fail safes are disabled since landing or normal RTLing during a failsafe could be catastrophic while following a boat. The operator will need to take over or force a guided RTL if there is a failure.

Figure 46 – Typical firmware settings for a precision follow me scenario

8. Test the setup in a stationary situation to ensure that everything is working as expected by arming, launching, increasing the altitude 2 meters and then Guided RTLing. The copter should not be jerking too much during hover and it should land at the original relative takeoff orientation to the GCS GPS antenna. If there is too much jerking, reduce the maximum waypoint acceleration and velocity a bit and retry.

9. Once the settings are tuned, perform another test with arm, launch, increase altitude and nudge to another position, change the relative orientation and offset using the "Follow Me" panel shown in Figure 47. Click on the RTL to initiate Guided RTL and verify that the copter landed at the original relative orientation to the GCS GPS antenna.

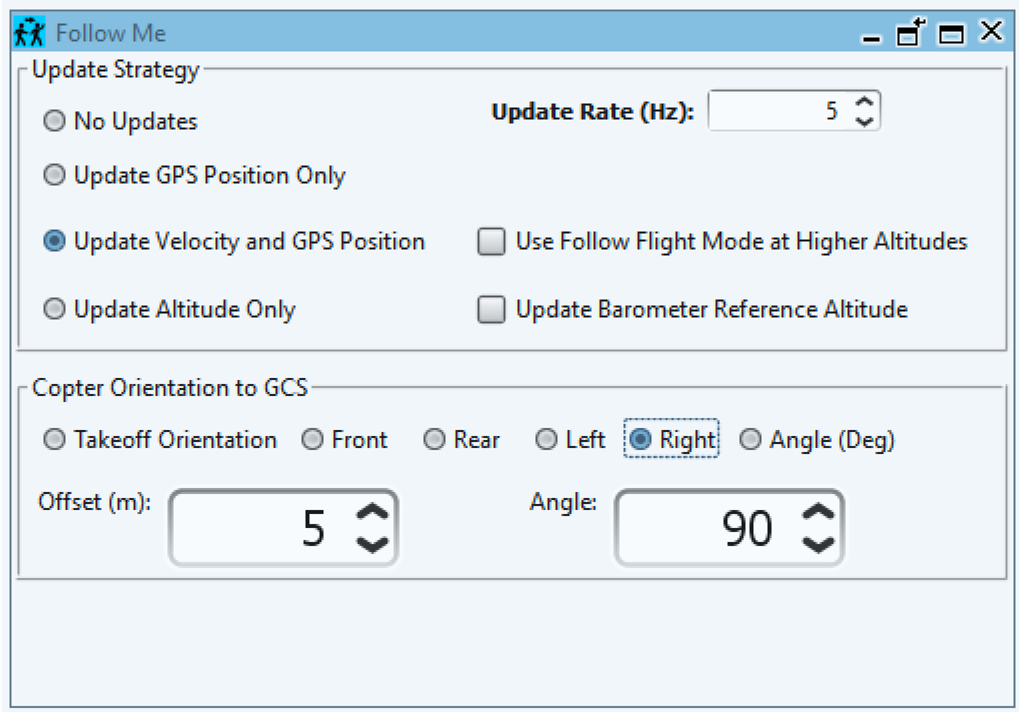


Figure 47 – Follow Me settings panel

10. If everything seems to be working correctly, perform a test where the copter is launched and taken to the desired altitude and then start moving the vehicle slowly. The copter should follow the vehicle immediately. Stop the vehicle and initiate RTL and verify that the copter lands at the original relative position to the GCS GPS antenna.
11. The final test will test landing on the vehicle while moving. Arm and launch the copter and raise it to say 5 to 10 meters and start moving the vehicle slowly (less than 5 MPH). While the vehicle is moving, click on the RTL to initiate Guided RTL. If it appears that the copter is going to miss the vehicle, the guided RTL can be paused by clicking the "Stop RTL" button (same as RTL button) and then resumed by clicking the RTL button. This capability is useful in situations where the platform, like a large ship, cannot be stopped quickly and the automatic landing needs to be stopped temporarily while the drone continues to follow the ship. The nudge operations can also be used during Guided RTL if there a small position error noticed during landing or if the relative landing position needs to be changed.
12. Continue the tests at higher speeds to determine the limits of operation.

Pointing Copter at an ROI

Use the Region of Interest (ROI) point to command the copter to continuously yaw to align with the ROI point as it moves along its waypoint mission for instance. This capability is useful for taking video around a feature like a bell tower or surveying the RF around an antenna.

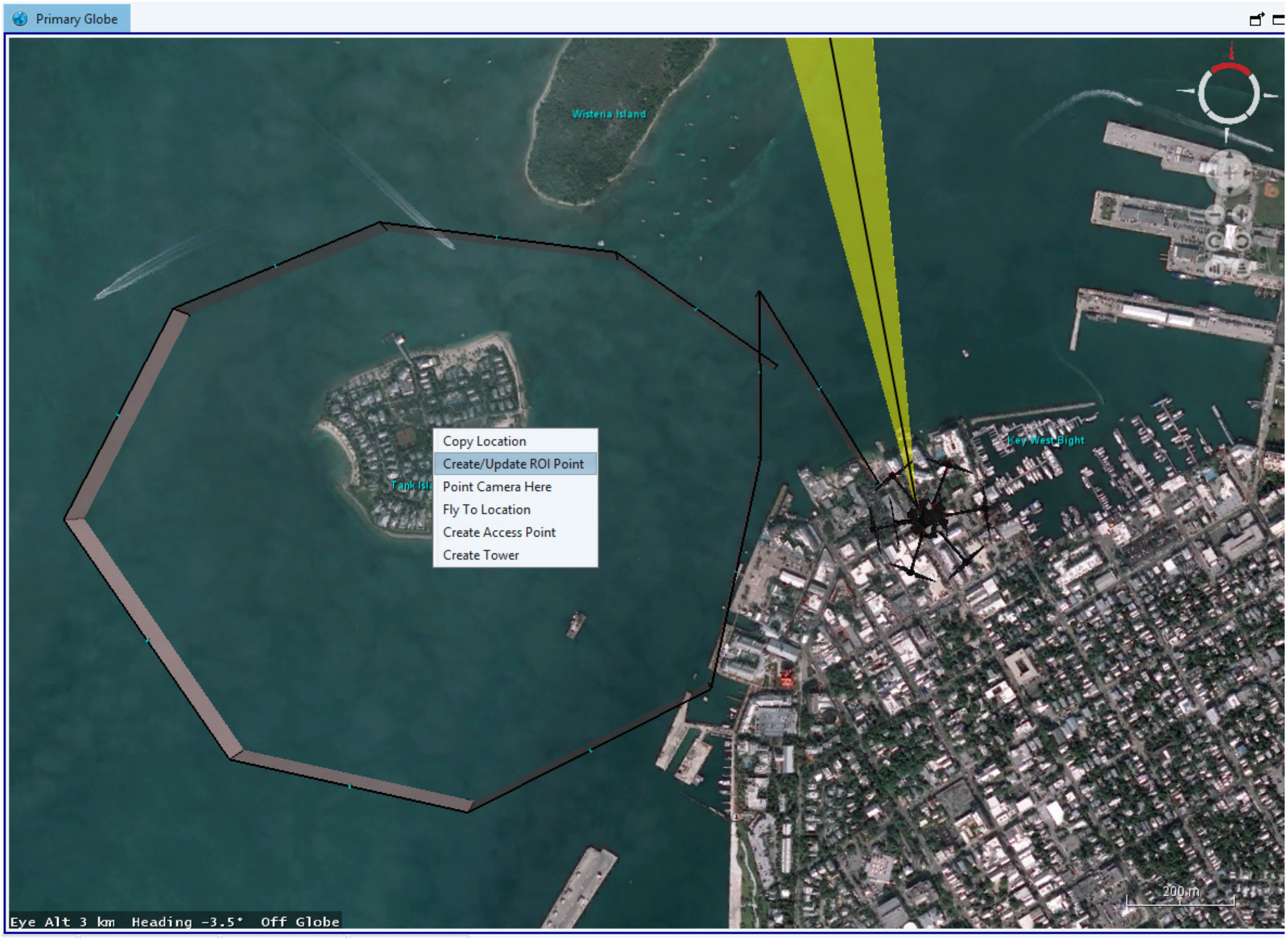


Figure 48 – Creating a Region of Interest (ROI) location point. The copter will point to this location during the flight.

As shown in Figure 48, the create ROI point is available by right clicking on the map at the location of the desired location. The action will prompt the user for a target altitude as shown in Figure 49 and then create a yellow circle marker on the ground and a 3D yellow sphere at the current target altitude shown in

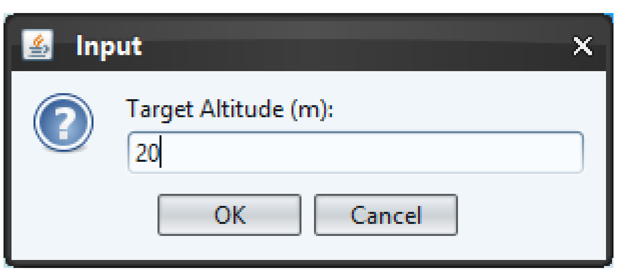


Figure 49 - Specifying the altitude of the ROI location

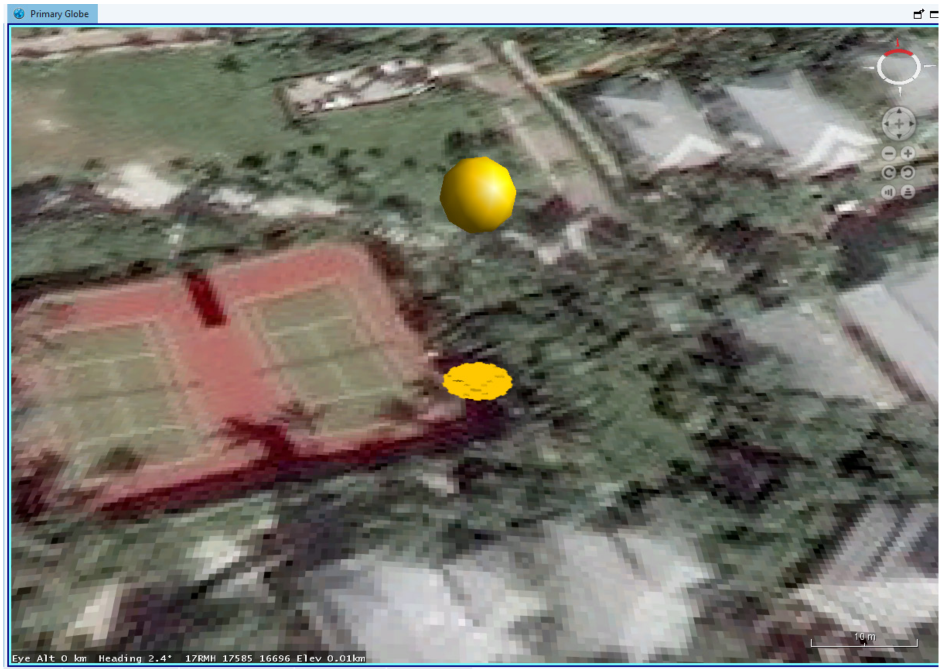


Figure 50 – Visualization of ROI Target Location

Once an ROI target is specified, a "DO_SET_ROI" command will automatically be inserted into the mission upon the next update of the mission as shown in Figure 51, which will command the copter to continuously point to the ROI location.

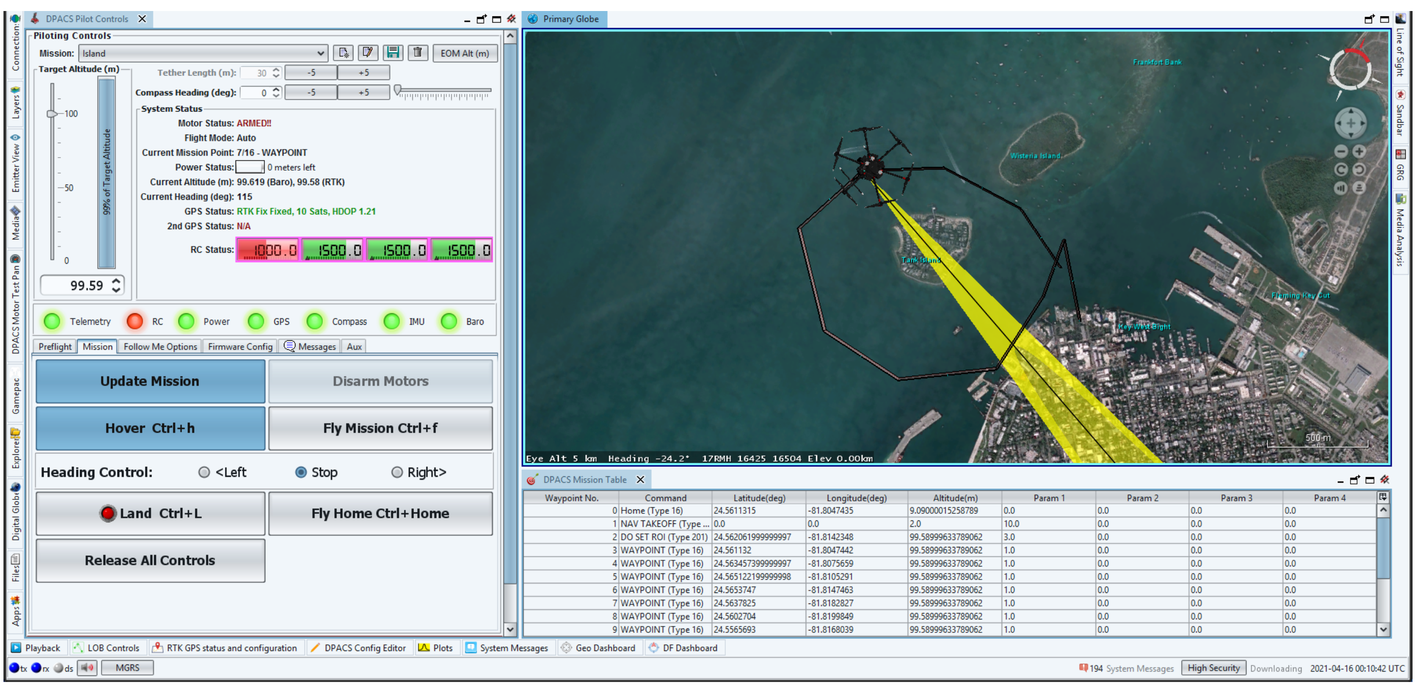


Figure 51 – Example of a mission with an ROI location created by clicking on the "Update Mission" button.

Point Camera Here

To immediately point the drone or camera to a given location, right click on the map at the desired location and select the "Point Camera Here" menu option shown in Figure 52.

Figure 52 – Globe popup menu to immediately point the camera/drone to a location.

This action will bring up the altitude input dialog shown in Figure 53.

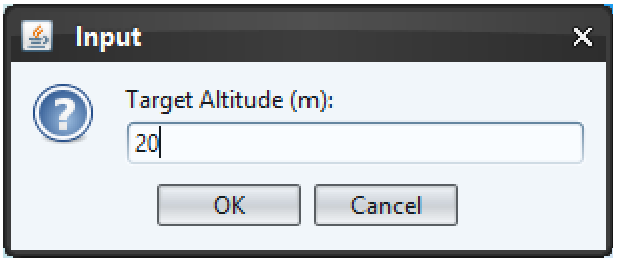


Figure 53 - Specifying the altitude of the camera target location

Clicking OK, will create a square marker on the ground shown in Figure 54 and immediately command the drone to point to the location and pitch the camera to the correct angle to point on the target altitude.

Figure 54 – Representation of the current camera target location.

Fly To Location

Every mission can be interrupted so that the drone can be tasked to fly to a given location on the map. This capability is useful when a target shows up that needs to be immediately investigated for instance. Any time during the mission, just right click on the globe at the desired target location and select "Fly To Location", as shown in Figure 55, to immediately task the drone to fly to that location at the current altitude.

Figure 55 – Initiating a "Fly To Location" mission

This action will also drop a point yellow point and display range rings to make it easy to see how far away the drone is from the target as shown in Figure 56.

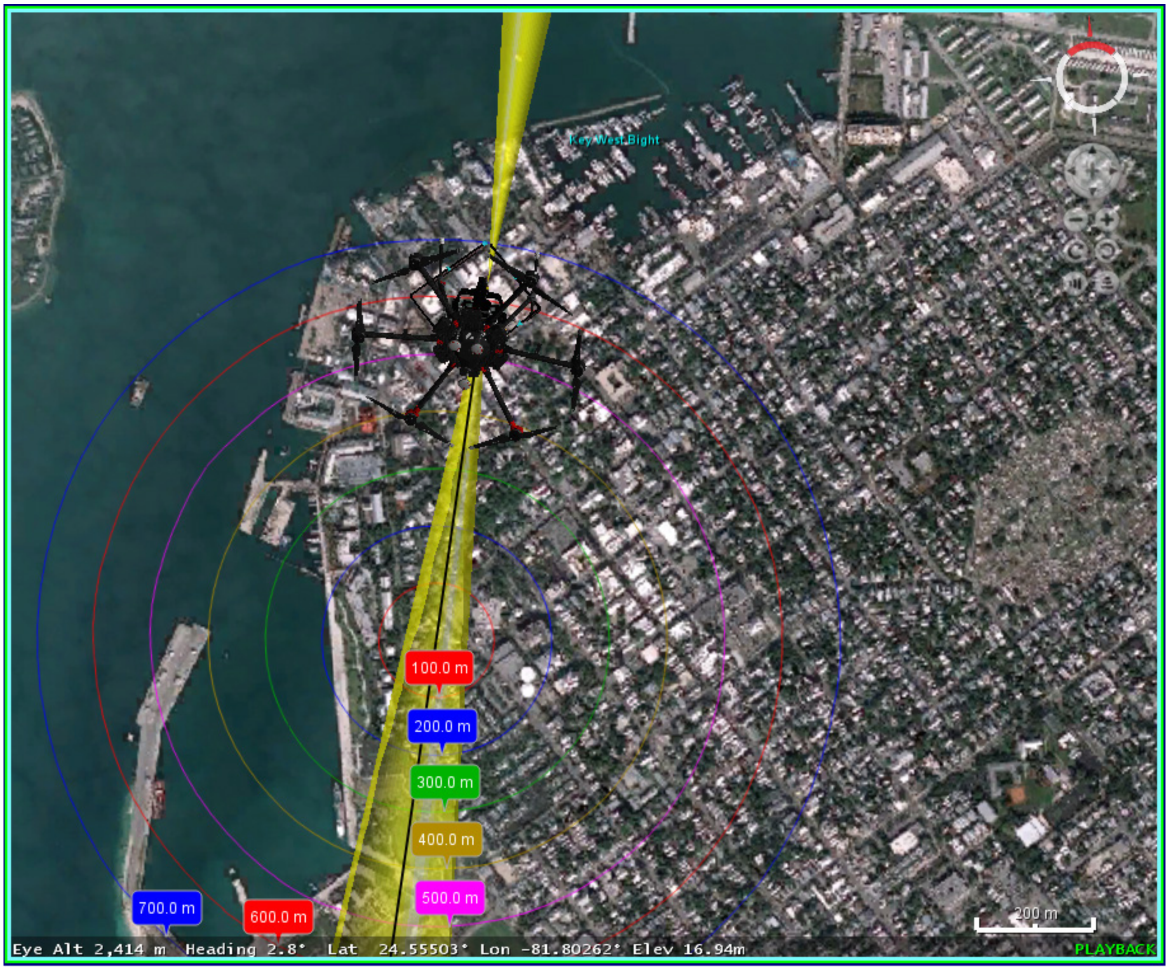


Figure 56 – Target location and range rings for Fly To mission

Auxiliary Flight Mode Access

There are times where the pilot needs to be able to switch to other flight modes for testing purposes or to perform auto tuning. Access to the flight modes is available in the "Aux" panel as shown in Figure 57. Be sure to raise the throttle midway before selecting Stabilize, Loiter or Altitude Hold. CAUTION: ONLY EXPERIENCED PILOTS SHOULD USE THIS PANEL.

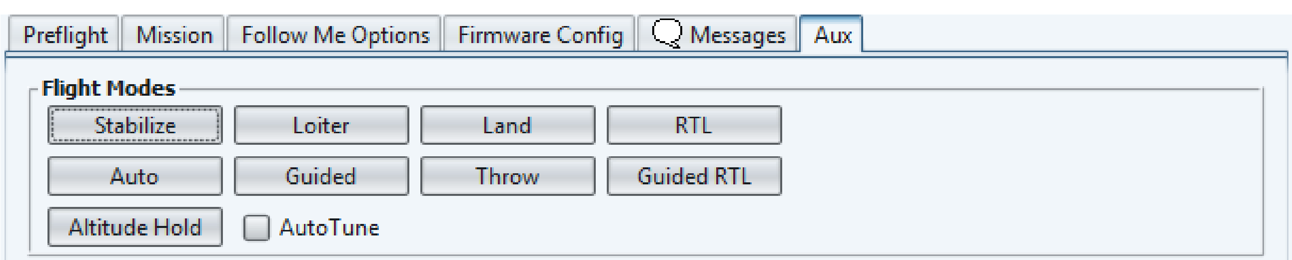


Figure 57 – Flight modes accessible in the auxiliary flight mode panel

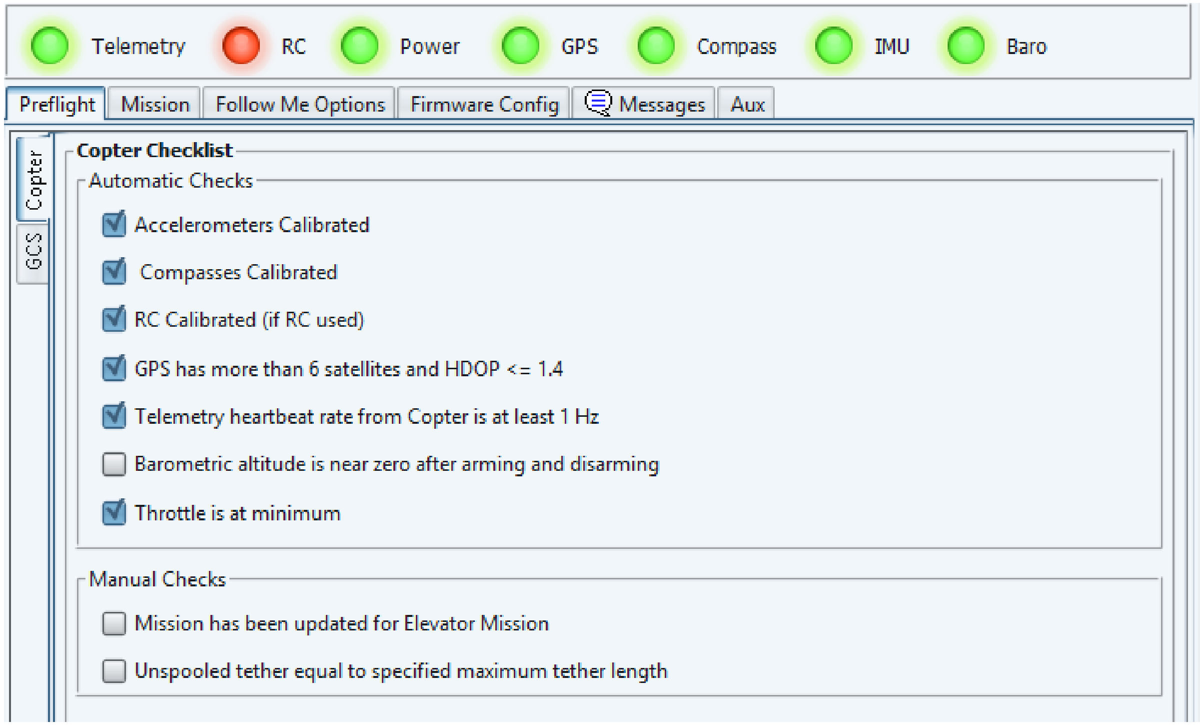


Figure 58- Drone preflight checklist

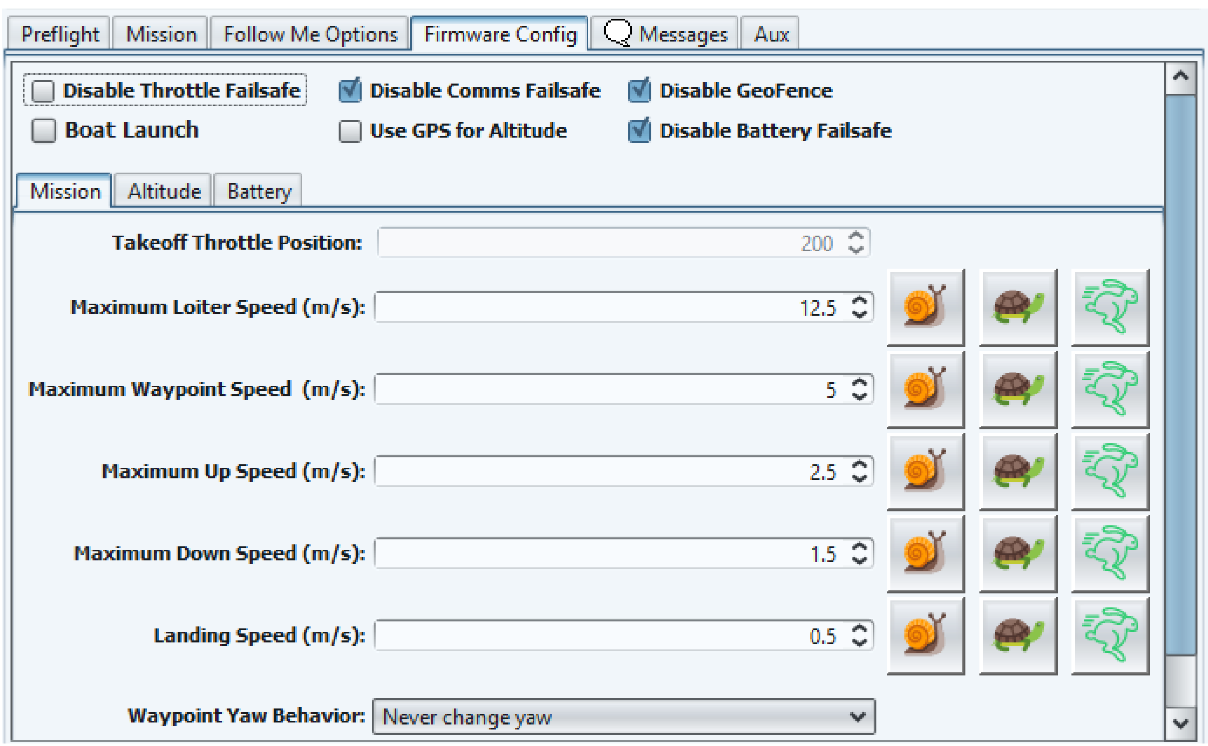


Figure 59 – Commonly used waypoint-related firmware configuration parameters

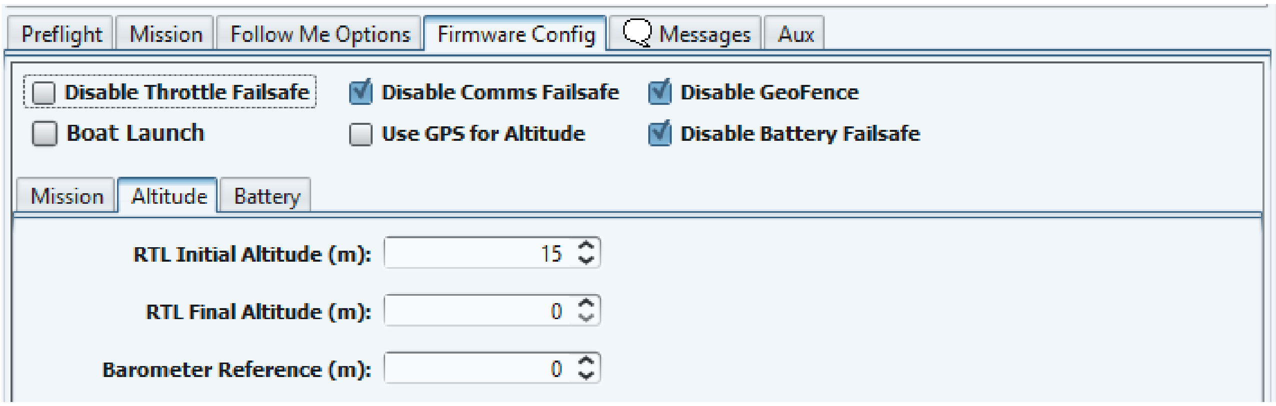


Figure 60 – Commonly used altitude-related firmware configuration parameters

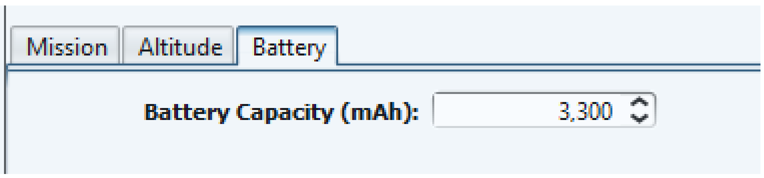


Figure 61 – Commonly used battery-related firmware configuration parameters

DPACS Preferences

The global DPACS preferences can be accessed by clicking on the Edit Preferences button in the DPACS ribbon bar shown in Figure 62.

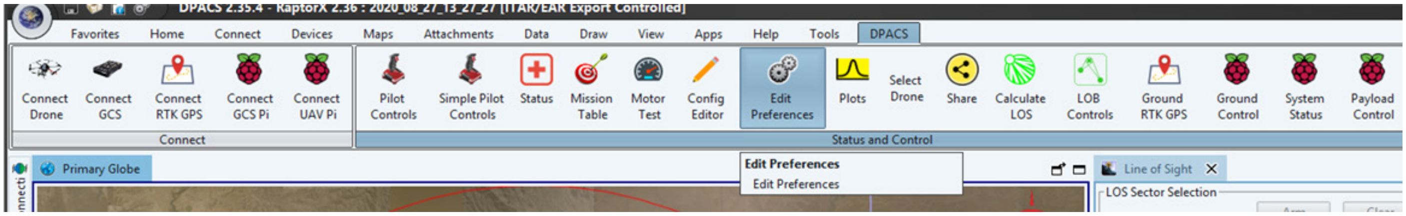


Figure 62- Accessing the DPACS global preferences

The preferences are grouped into GUI, Mission, Battery, Communications and Pilot Controls.

GUI Preferences

These preferences are related to the user experience and exposed GUI capabilities. "Use Voice Feedback" enables text2speech audio messages. "Enable Desktop Notifications" turns on desktop messages that are outside the GUI for cases where the operator might be using other applications and may not see an important message shown within the DPACS GUI. Deselecting "Enable Hotkeys" will turn off all DPACS shortcuts in case they conflict with another desktop application or windows manager.

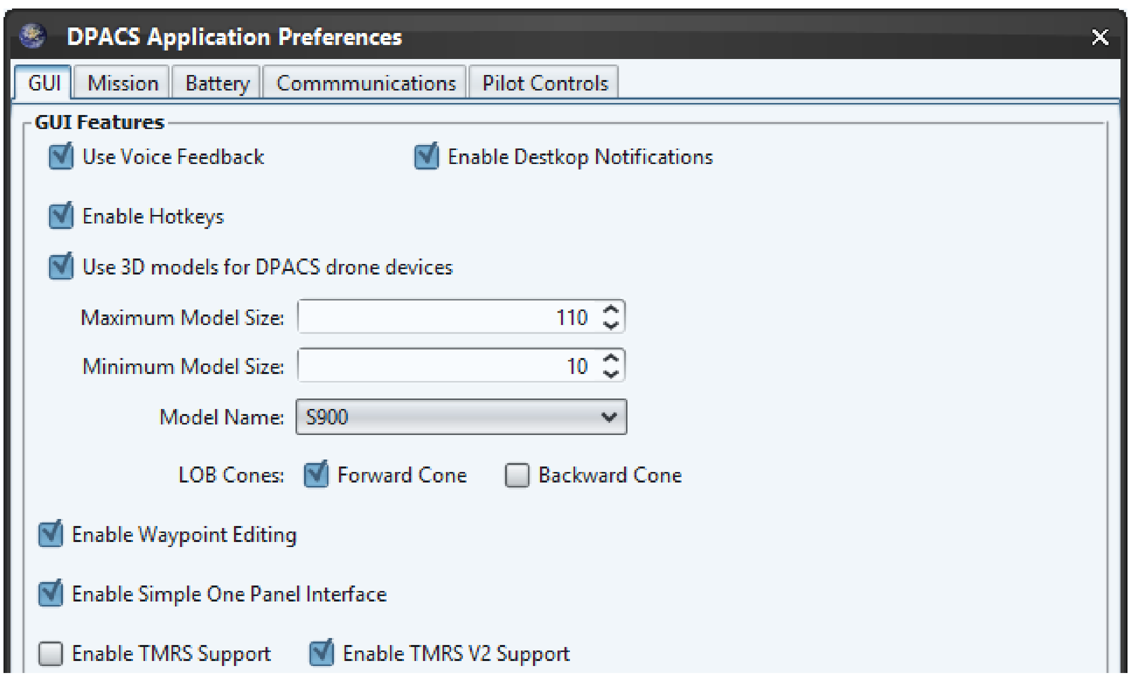


Figure 63 – DPACS GUI Preferences

DPACS can render the device with a 3D model or a 2D icon. The "Use 3D models for DPACS drone devices" checkbox will enable the 3D model feature. The minimum and maximum size of the model can be specified as well as the 3D model as shown in the Figure 63.

The 3D LOB cones can be displayed to the front and rear of the drone to provide a quick assessment of the direction the drone is facing and a rough estimate of the line of sight of the drone for the given altitude.

The “Enable Waypoint Editing”, “Enable Simple One Panel Interface”, “Enable TMRS Support”, “Enable TMRS V2 Support” will display the panels for these features upon saving and restarting RaptorX.

Mission Preferences

Mission preferences shown in Figure 64 correspond to flying behavior. Hover Height is the height off the ground that the copter will hover at when the “Launch” or “Hover” buttons are pressed. It should be high enough for the drone to safely hover, but low enough to prevent significant damage to the copter if something mechanically goes wrong during the initial takeoff. When taking off a moving vehicle or boat, we recommended that this value be high enough for the aircraft to clear any obstructions between it and the rear of its launch platforms.

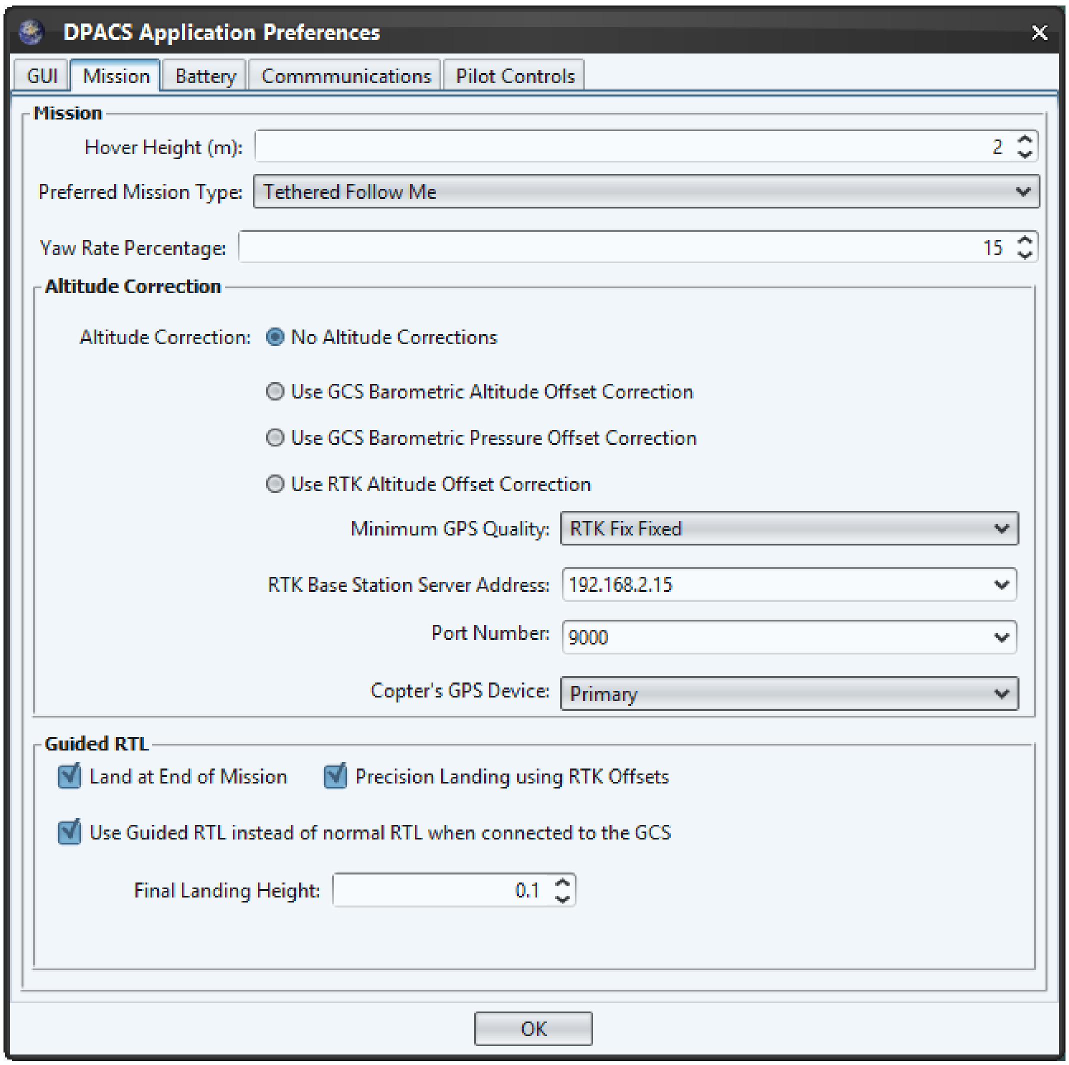


Figure 64 – Mission Preferences

The Preferred Mission Type applies to the selected mission shown in the Pilot panel.

The Yaw Rate Percentage will control the angular speed (i.e. how fast it rotates) when the heading control or yaw control buttons are pushed in the pilot and simple pilot controls panels. The rate will is doubled when the “>>” or “<<” buttons are pushed in the simple pilot controls panel.

The options in the “Altitude Correction” panel are used to correct the altitude for long running flights. If RTK is available, we recommend not to use any of these options, but rather to enable the “Use GPS for Altitude” option located in the Firmware Config panel.

The options in the “Guided RTL” alter the behavior of RTL when a GCS is used typically during a follow-me mode mission. Guided RTL behaves like RTL except that the final destination can be continuously moving. The copter will rise to the RTL altitude then fly to near the original offset location relative to the GCS. Then it will lower to an altitude based on the high and low landing altitude while adjusting the copter position to match the target offset. When the altitude is within the “Final Landing Altitude”, the land command is issued to land in place and turn off the motors.

Battery Preferences

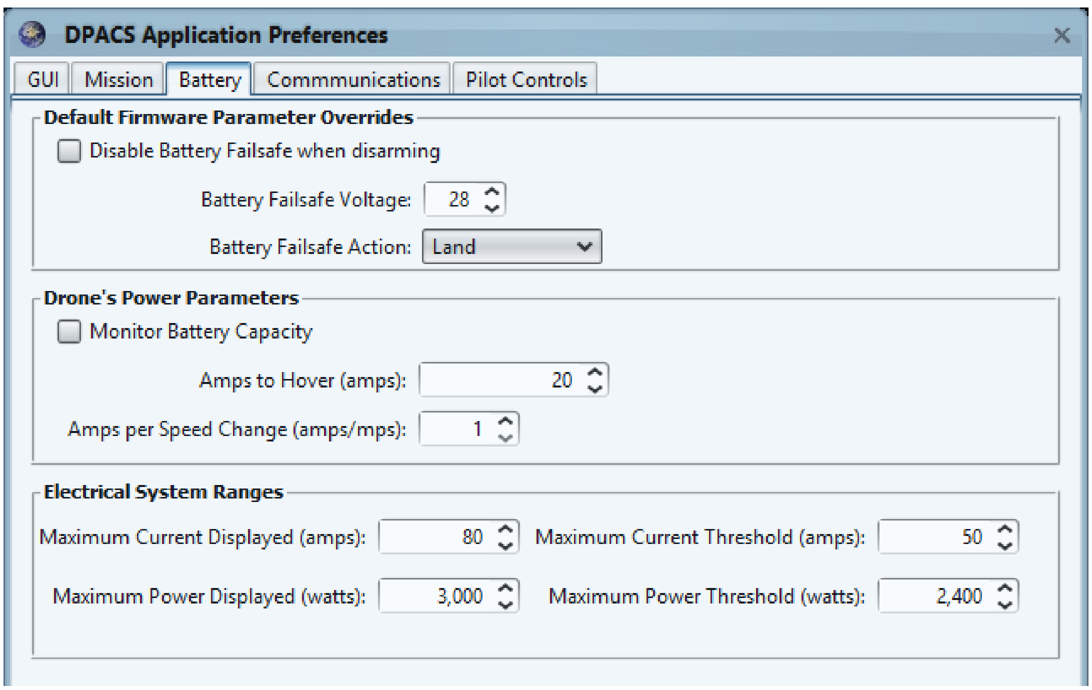


Figure 65 – Battery Preferences

Communications Preferences

Communication preferences can be accessed in the Communication tab of the DPACS Application Preferences shown in Figure 66. The RTK messaging allows the operator to choose the smaller MSM 4 RTK messages if the telemetry link is too slow to support the more detailed MSM 7 messages. The status alerts options allow the user to increase or reduce notifications of alerts based on selected severity level. These can help reduce to audio and visual noise from alert messages.

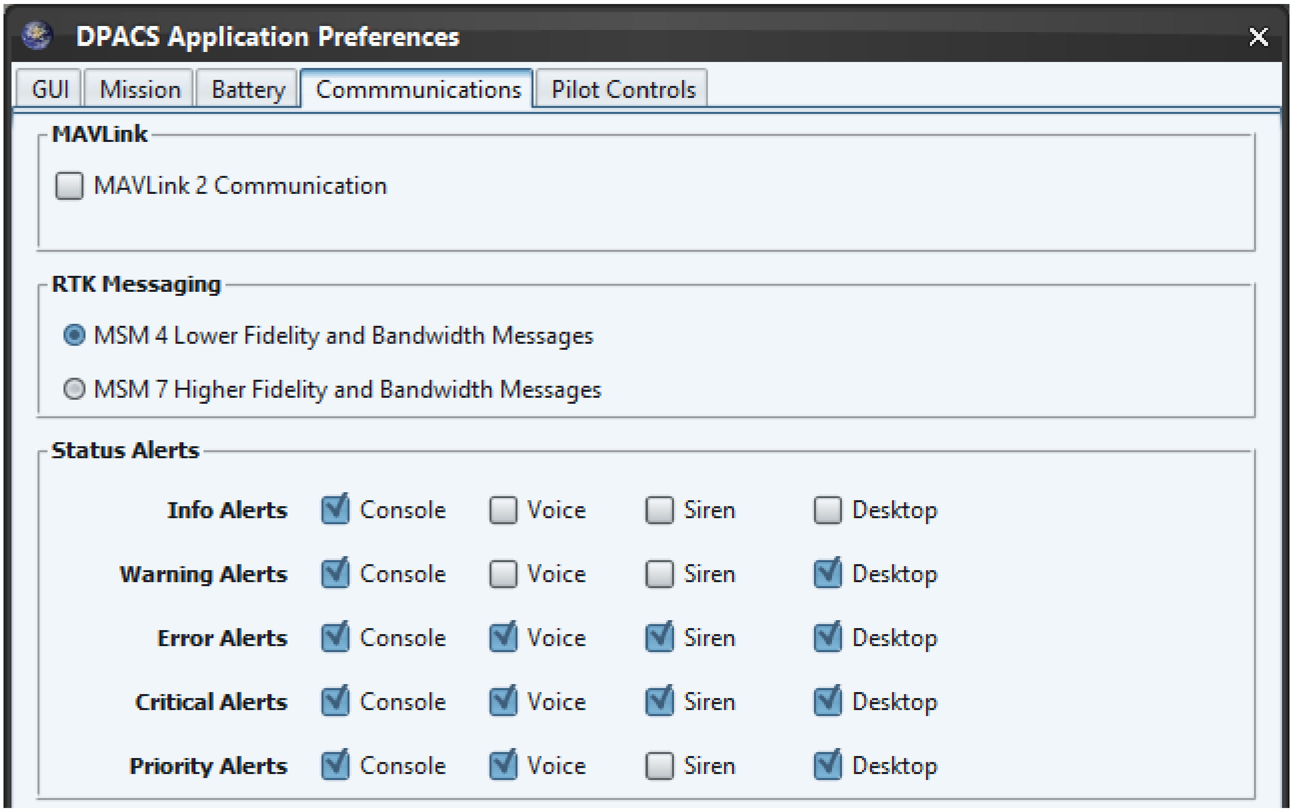


Figure 66 – RTK messaging and Status Alerts panel

Pilot Control Preferences

Parameters that influence the control over the drone are found in the “Pilot Control” tab of the DPACS Application Preferences shown in Figure 67.

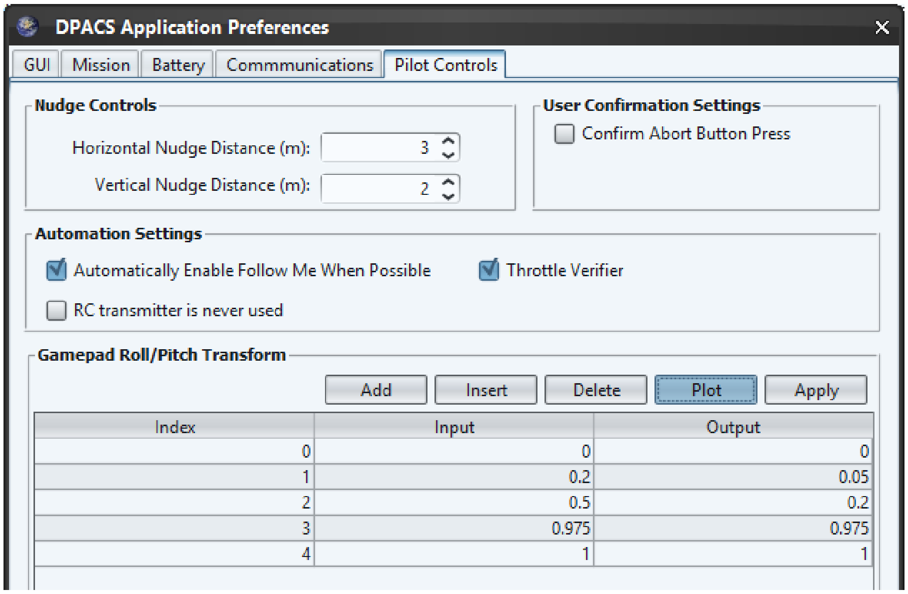


Figure 67 – Pilot Controls preferences

Nudge Controls

The “Horizontal Nudge Distance” in the “Nudge Controls” panel are used to control how many meters the copter is moved horizontally when the nudge arrow buttons are clicked in the Simple Pilot Panel or when Ctrl+Arrow keys are pressed. The “Vertical Nudge Distance” control how far the copter ascends or descends with Ctrl+U or Ctrl+D respectively.

User Confirmation Settings

Enabling the “Confirm Abort Button Press” checkbox will prompt the user before turning off the motors of the drone to prevent an accidental crash. But, issuing the Ctrl+Q keyboard shortcut will still act immediately.

Automation Settings

These are settings that influence automatic behaviors.

Selecting the “Automatically Enable Follow Me when Possible” checkbox will switch to follow-me mode automatically if a GCS connection is made.

If an RF RC is never used, select the “RC transmitter is never used” checkbox to bypass the RC detection logic and force DPACS to always override the RC controls.

Enabling the “Throttle Verifier” will automatically raise the throttle to 50% if no RC is being used and the flight mode is changed to any non-automatic mode like stabilize, loiter and altitude hold where having a low throttle can be catastrophic. In addition, if the RC is being used, the flight mode will automatically be changed to guided after increasing the throttle to 50% to prevent a crash. It is recommended that stabilize not be used in practice or assigned to the RC since the crash can happen quicker than the aforementioned mitigation steps can take effect when the throttle is at a minimum when the flight mode is switched to stabilize.

Note: DPACS will always raise the throttle to midway if a non-automatic flight mode is selected while the drone is flying.

Gamepad Roll/Pitch Transform

The gamepad controllers like the XBox controller can be sensitive in pitch and roll given the short throw of the sticks. The response can be customized by altering the spline knot locations for the roll & pitch output response curve. Currently, the user is required to edit the numbers directly in the table in the “Gamepad Roll/Pitch Transform” panel and then iteratively clicking the “Plot” button to view the response curve shown in Figure 68.[5] Once the user is satisfied with the response curve, he can click the “Apply” button to immediately change the response behavior of the gamepad.

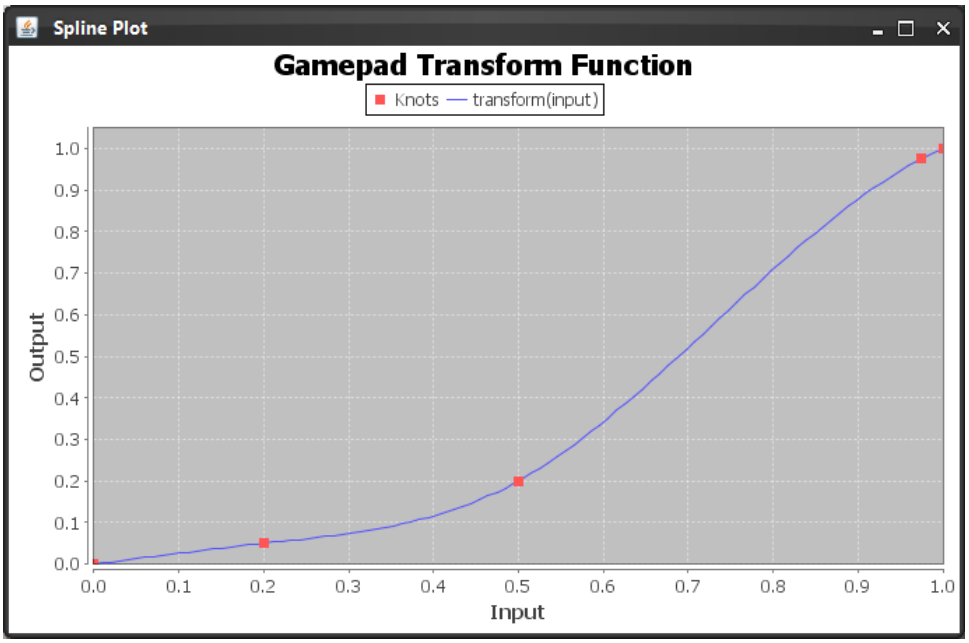


Figure 68- Display of output response spline based on user input spline knots.

[5] In a future release, the knots of the spline curve will be allowed to be dragged to a new position interactively.

Working with the RTK GPS

DPACS supports the use of the high precision (2 cm) RTK GPS. DPACS supports the M8P RTK GPSes such as the DroTek XL M8P, Proficnc Here2+ and the Reach M8T RTK GPS, as well as, the F9P RTK GPSes such as the DroTek Sirius F9P and XL F9P and the ArduSimple simpleRTK2B.

The drone's RTK GPS requires measurements from a second base RTK GPS positioned on the ground. This base RTK GPS needs to be connected to DPACS so that it can bundle the RTCM3 messages from the base RTK into MAVLink messages to send over telemetry to the drone. This connection can be a direct USB connection to the RTK GPS or a TCP/IP or UDP connection to an intermediary networked device such as a Raspberry Pi connected via USB to the RTK GPS.

Click on the "Connect RTK GPS" button in the DPACS "Connect" ribbon bar shown in Figure 69 to connect to the base RTK GPS using the appropriate protocol and connection settings.

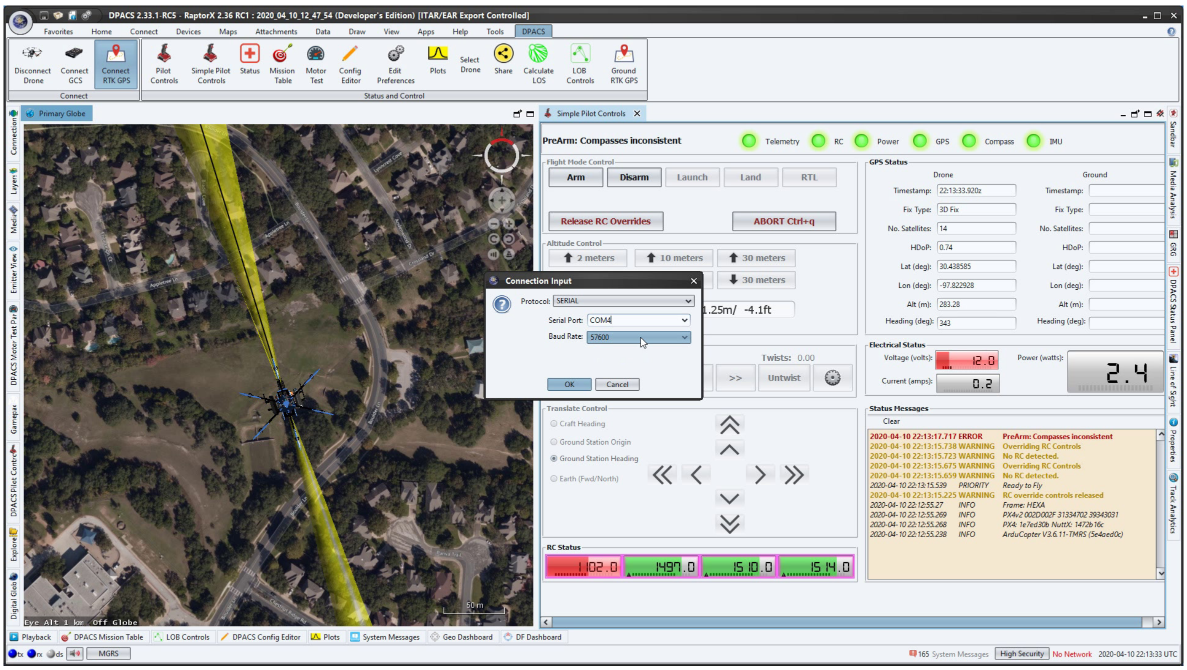


Figure 69 - Connecting DPACS to the RTK GPS

Click on the "Ground RTK GPS" button in the DPACS "Status and Control" ribbon bar to display the view shown in Figure 70. If the GPS is configured correctly already, the position and satellite power bars will be displayed as shown.

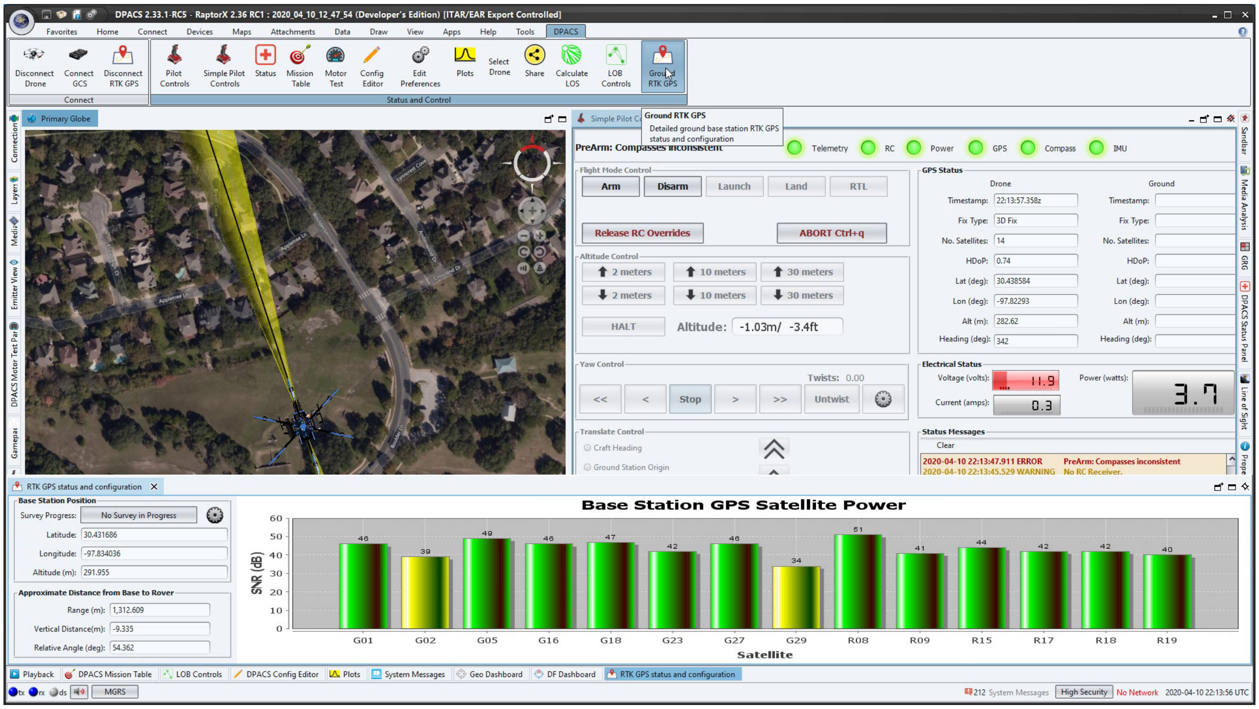


Figure 70 – The RTK GPS status and configuration panel displayed after the "Ground RTK GPS" button is clicked.

To configure the base RTK GPS and to specify the base position strategy, click on the gear icon shown in Figure 71.

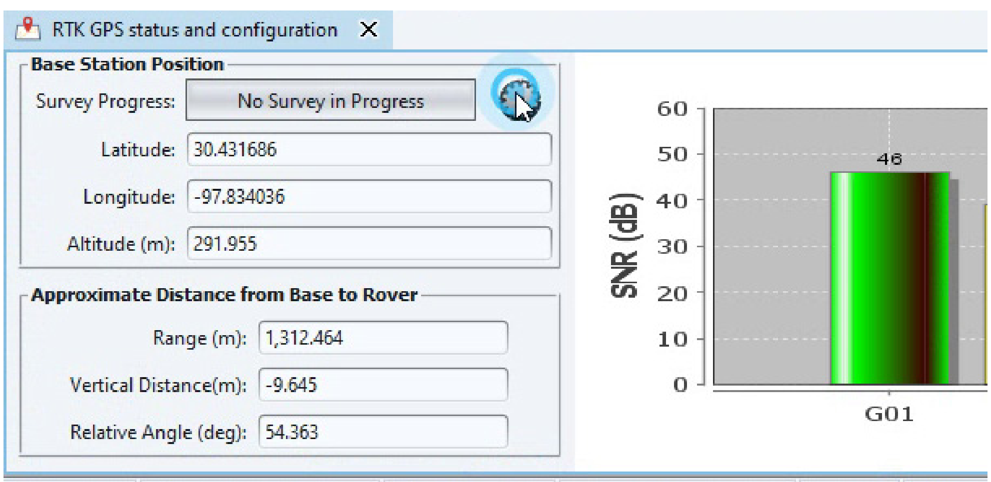


Figure 71 – Button to access the dialog to automatically configure the base RTK GPS and to choose the approach to specify the base station position.

For the M8P and F9P GPS, DPACS can automatically configure it to send the correct messages by checking the "Automatically configure the base GPS setting for RTK" as shown in Figure 72.

The base station position can be specified manually, obtained through a survey, or provided by the base station GPS dynamically when in moving baseline mode.

Survey Mode

Typically, the survey is used unless the position is known already. The target accuracy and minimum collection time in seconds can be specified for the survey. The target accuracy only affects the absolute position of the drone. The relative accuracy from the drone to the base station will always be within 2 cm once an RTK Fixed Fix is obtained. The tighter the accuracy for the base, the longer it will take to obtain it. Two meters is a good compromise and should take a couple of minutes to obtain. One meter may take 10 minutes or so to achieve with the M8P.

The Reach RTK currently has to be setup manually using the ReachView web interface documented on the website here: https://docs.emlid.com/reach/common/reachview/base-mode

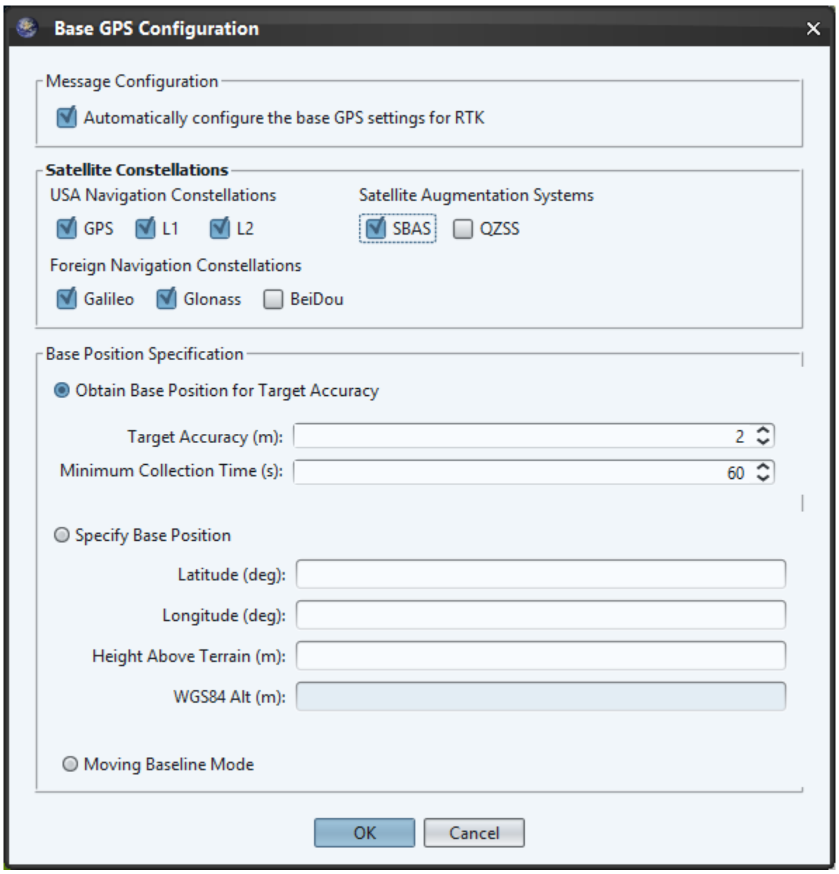


Figure 72 – The dialog used to automatically configure the base RTK GPS for the correct messaging and satellite constellations, as well as choose the approach to specify the base station position.

Once the OK button is clicked, the M8P RTK GPS will be configured and a survey will be started to obtain the target accuracy. The progress bar should display the target accuracy and the current accuracy as shown in Figure 73, as well as the current position and the approximate distance between the drone and the base station GPS.

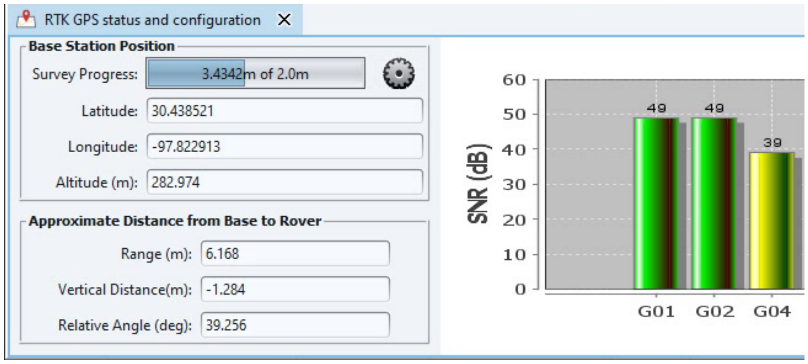


Figure 73 – Progress bar and position data shown during an active survey

Once the survey is finished, the message "Survey Finished with Accuracy of x.x" will be displayed in the progress bar as shown in Figure 74[6].

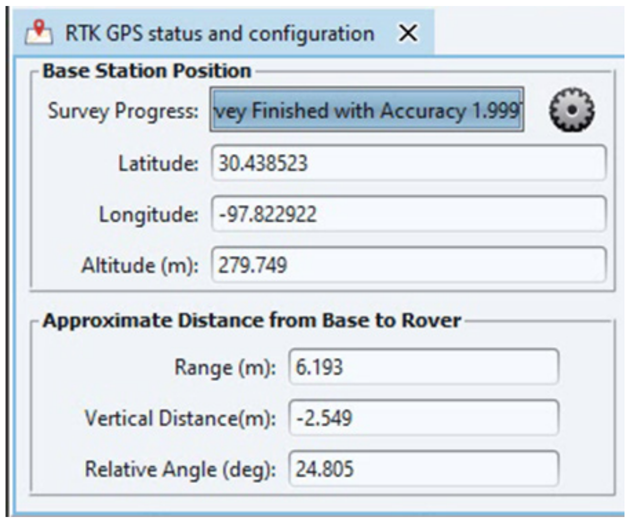


Figure 74 - Progress bar and position data shown when the survey is finished.

As soon as the survey is finished, a RTCM 1005 position message is forwarded from the base RTK to the drone's GPS over MAVLink. As soon as the drone's GPS receives this message, the status of the fix should change to RTK Fix Float as shown in Figure 75. A RTK Fix Float is an intermediate RTK solution and has no guarantee of accuracy. Over time, the accuracy will be better as the solution converges.

[6] It appears that the F9P firmware will stop the survey if it detects that the solution is not getting better such as when testing indoors.

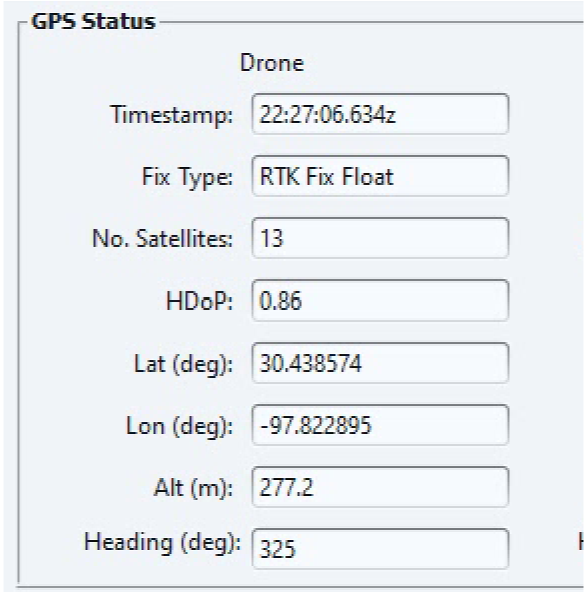


Figure 75 – GPS Status panel showing the initial RTK Fix Float status when observations are received from the base station RTK GPS.

The Reach and the M8P RTK GPSes can take a few minutes to achieve a full RTK Fixed Fix solution state. The F9P should achieve a RTK Fixed Fix in less than 20 seconds. This GPS state is guaranteed to have a less than 2 cm accuracy in position. The GPS state shown in Figure 76 indicates a RTK Fixed Fix solution with guaranteed accuracy. If a Reach GPS is being used or if the M8P patch has been applied to the firmware being used in the drone, the actual computed RTK offset between the drone and the base station GPSes will be shown in the RTK Computed Offset from Base.

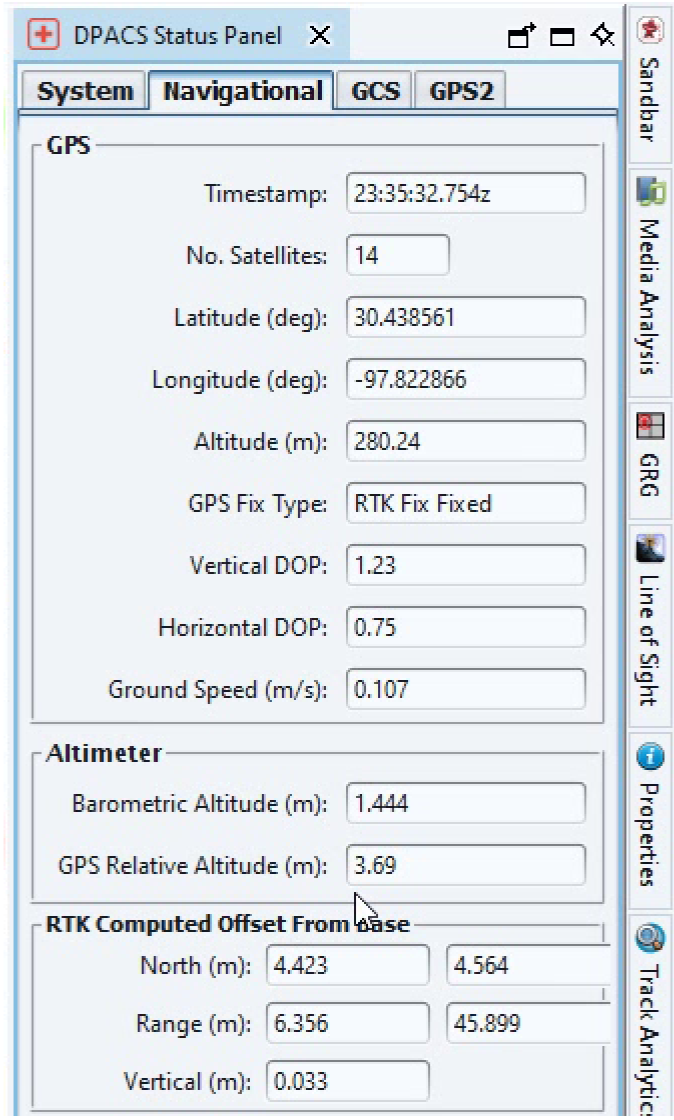


Figure 76 – GPS Panel showing a RTK Fix Fixed status once the drone's GPS gets convergence to a 2 cm fix. The actual offset solution is shown in the RTK Computed Offset from Base panel if the customized Ardupilot firmware is being used.

The GPS status for the RTK Fixed Fix solution is shown in Figure 77. Once this solution state is achieved, wait another 30 seconds to ensure that the state is not transient.

If the RTK Fixed Fix state does not appear after 5 minutes, make sure that the drone or the base station is not too close any buildings or trees and that the satellite SNR for the base GPS is at least 40 dB for more than 8 satellites. The new multi-band F9P is less sensitive to blockages and should achieve an RTK Fixed Fix solution in less than 20 seconds.

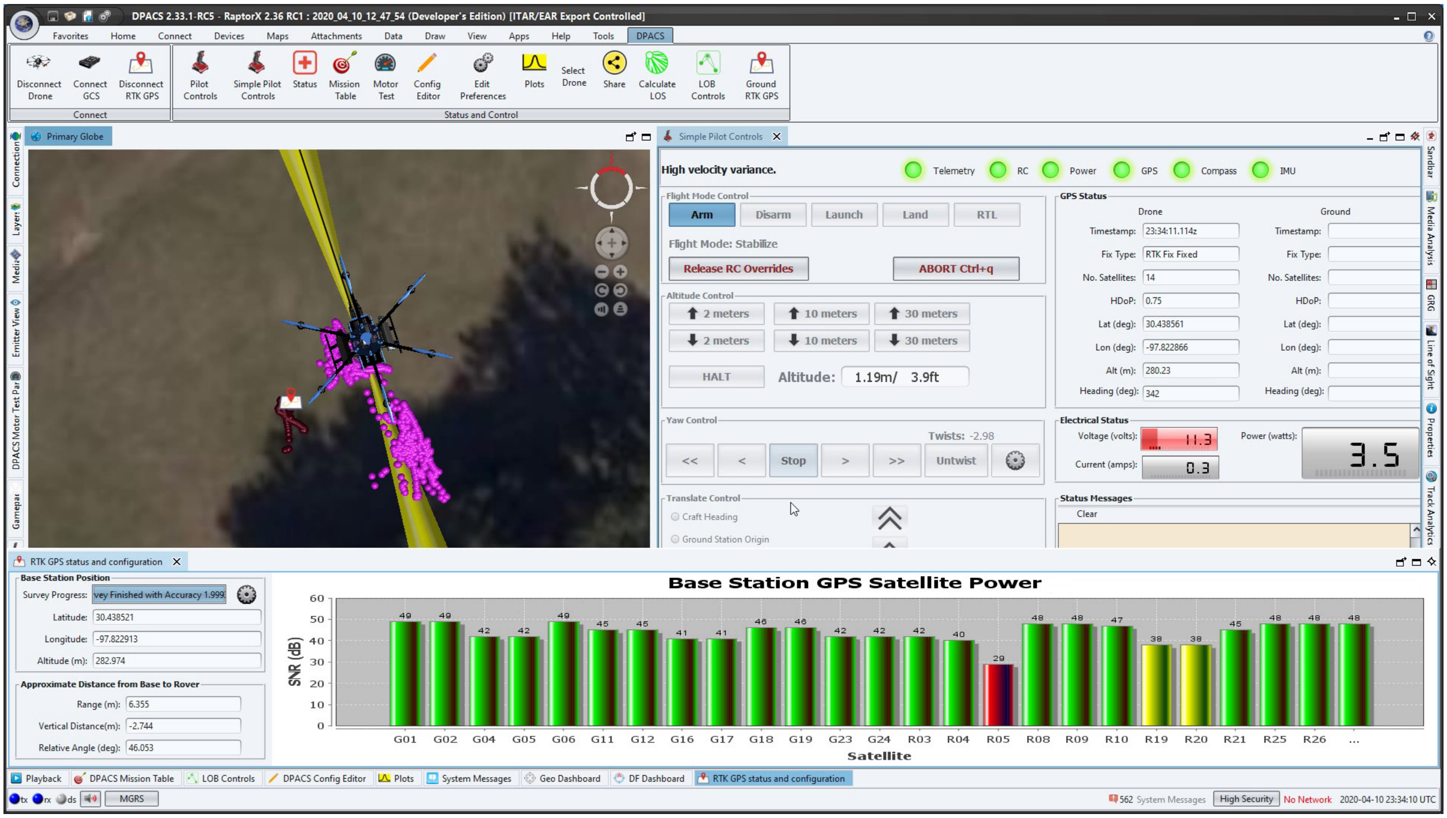


Figure 77 – GPS and Simple Pilot Controls view with the RTK Fix Fixed Solution

The RTK observation type can be changed as well using the DPACS preferences shown in Figure 78. The reduced precision MSM4 message type is selected by default to keep the telemetry from getting bogged down RTK GPS solution rate is too low for the moving base mode

high precision MSM 7 message type is selected by default, but if the, the MSM 5 message type can be used instead.

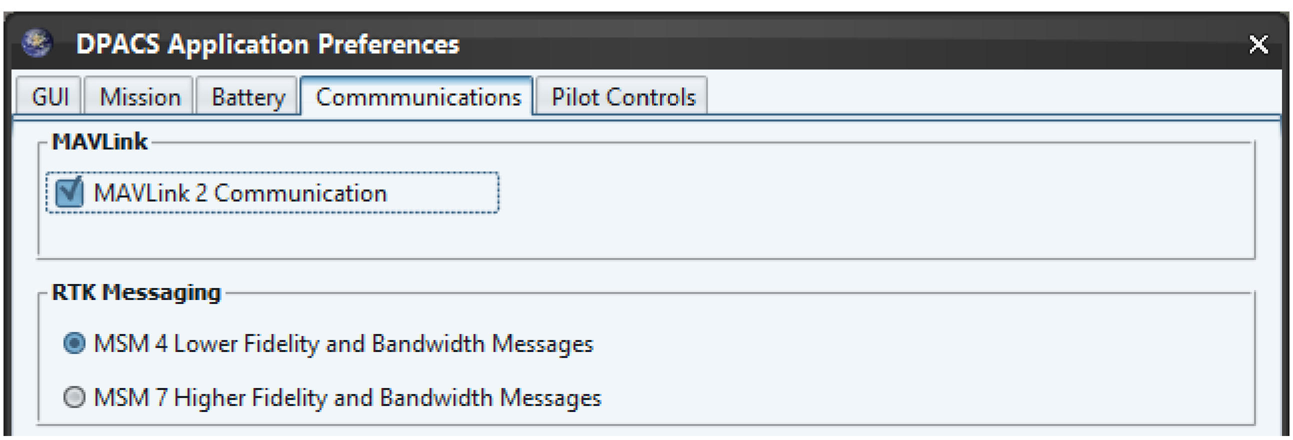


Figure 78 – DPACS preference to choose RTK messaging types.

Moving Baseline Mode

For cases where the base station is moving and precision landing and altitude control is desired, the moving baseline mode is required. The F9P RTK GPS is required for this mode since it supports a higher rate of moving baseline solutions and is much more robust than the M8P.

Currently, this mode requires a 460,800 baud rate throughout the system including the GPS to Pixhawk connection, the telemetry and the DPACS to the local RTK GPS. A modified version of the ArduCopter 4.0 software is also required as well to provide the RTK solution back to the GCS for precision landing and to relax the 5 Hz solution rate check since 5 Hz is not achieved many times with the moving baseline mode and is not required for navigation.

If the F9P was being used in a static baseline situation via the survey option for instance and has received the 1005 RTCM base position message, it will not automatically switch to moving baseline mode when it received the related PVT messages. The drone will need to be power cycled to get it out of the static baseline mode[7].

Once a successful moving baseline RTK Fixed Fix solution is achieved on the drone, the "Use GPS for Altitude" option should be enabled in the Firmware Config panel shown in Figure 79. The drone will require a restart when this option is selected. The "Precision Landing using RTK Offsets" and "Use Guided RTL instead of normal RTL when connected to the GCS" option in the DPACS Mission preferences should also be selected as shown in Figure 80.

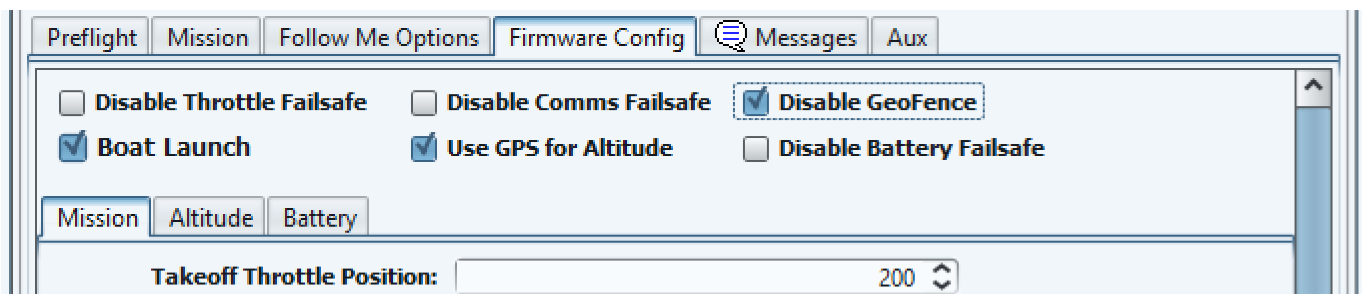


Figure 79 - Firmware recommended for moving baseline mode

[7] The power cycling may not be required in the future if a work-around is found to force the GPS out of the static baseline mode.

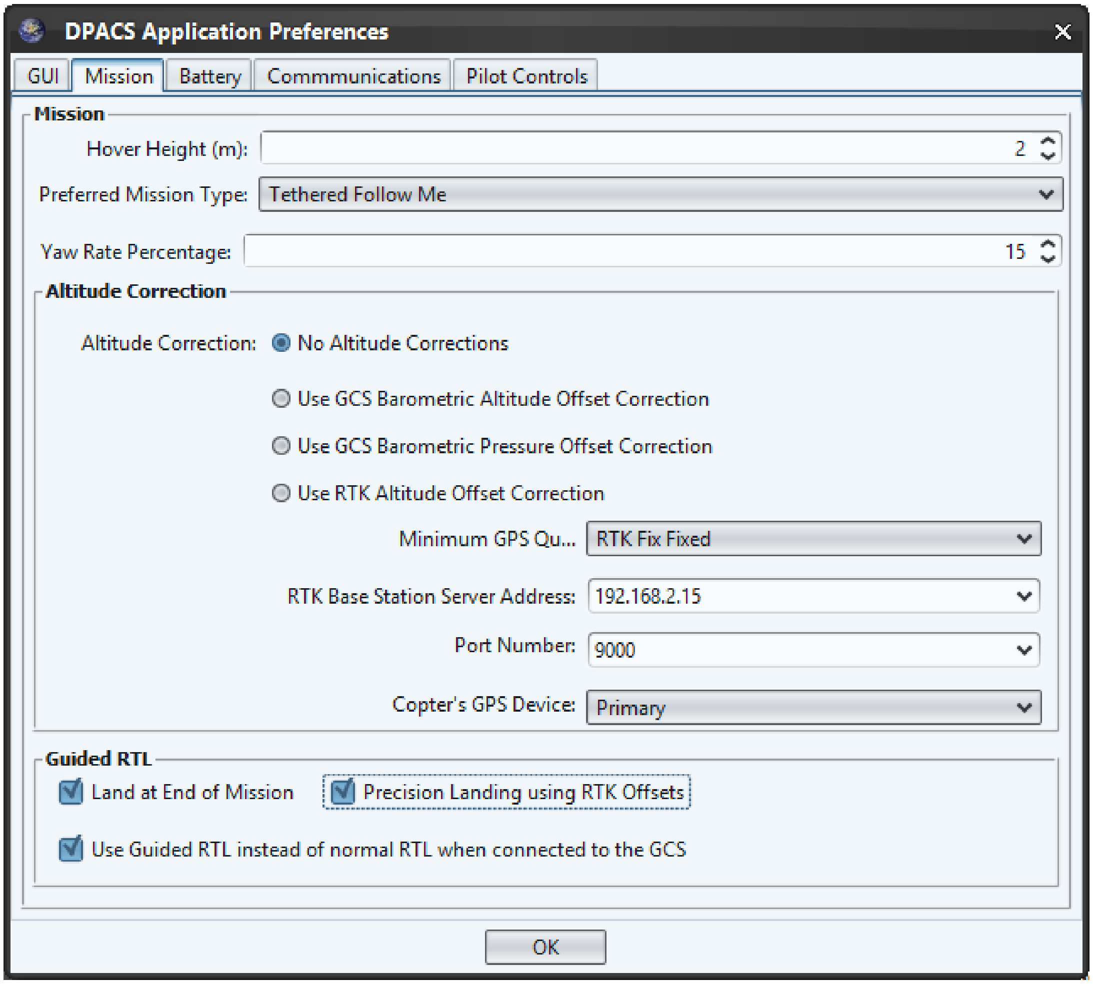


Figure 80 - Recommended Guided RTL settings for moving baseline operations

Compass Calibration

The compasses can be calibrated from within DPACS by right clicking on the device on the map or in the explorer tree and selecting "Calibrate Compass" as shown in Figure 81.

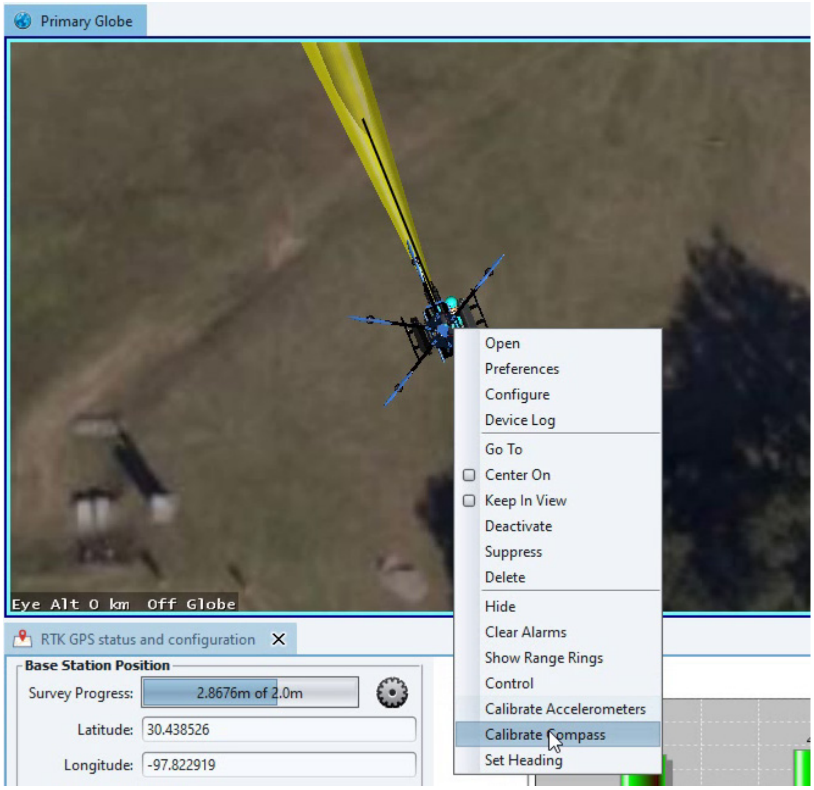


Figure 81 – Right click device menu selection to calibrate the accelerometers

Click the start compass button in the Compass Calibration dialog shown in Figure 82 and perform the compass dance: face the drone north and rotate the drone end over end towards north then yaw the drone 90 degrees and rotate the drone end over end towards north again. Continue to repeat the rotations until the calibration process is finished. Then click the "Reboot" button to restart the flight controller.

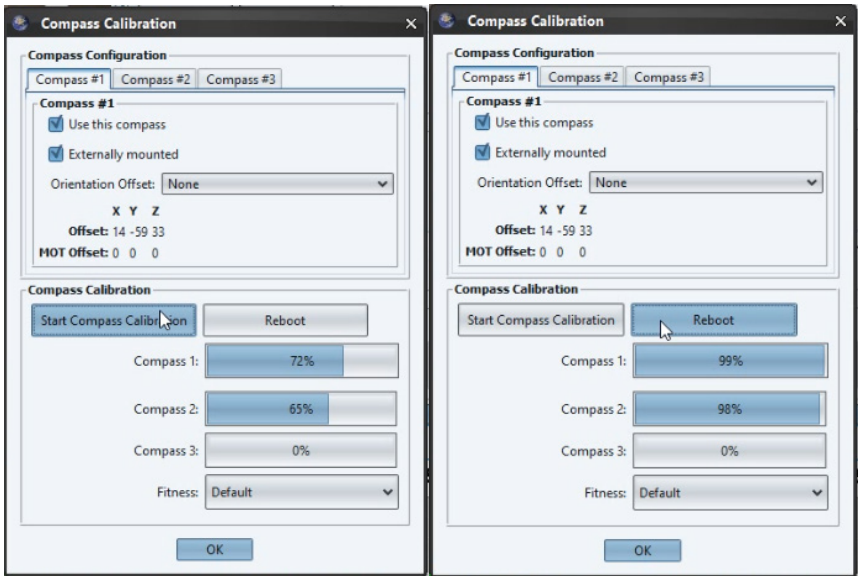


Figure 82 – Compass calibration dialogs during execution and when finished.

Accelerometer Calibration

To calibrate the drone's accelerometers, right click on the device on the map or in the Explorer tree to show the menu in Figure 81 and select the "Calibrate Accelerometers" menu item to bring up the calibrate accelerometer dialog shown in Figure 84.

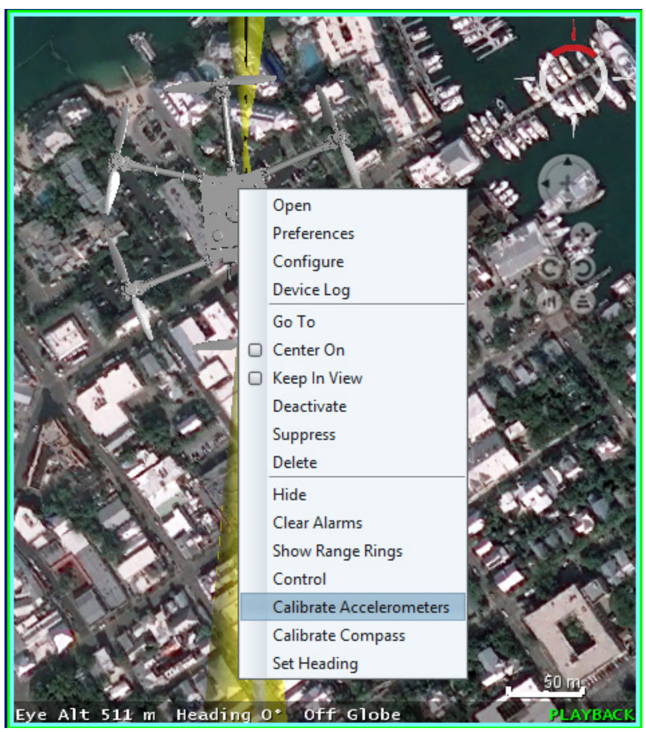


Figure 83 – Right click device menu selection to calibrate the accelerometers

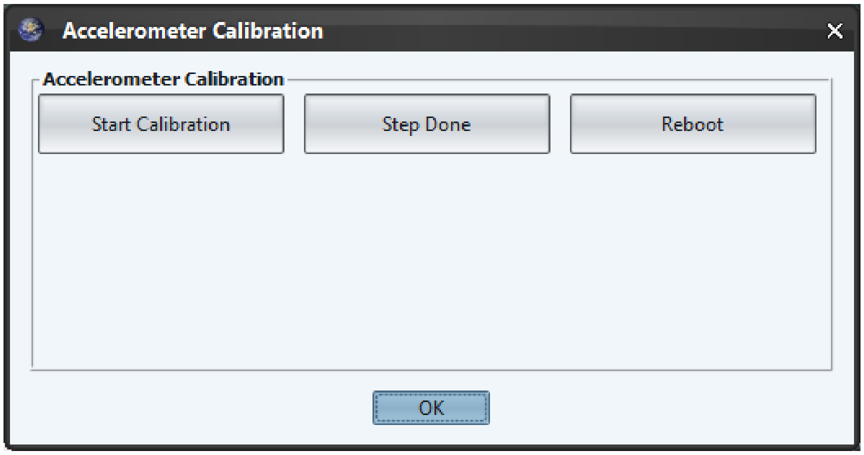


Figure 84 – Accelerometer calibration dialog

Click the "Start Calibration" button and follow the directions displayed in the dialog shown in Figure 85 and spoken over the computer's speaker. Click the "Reboot" button when the calibration process is completed.

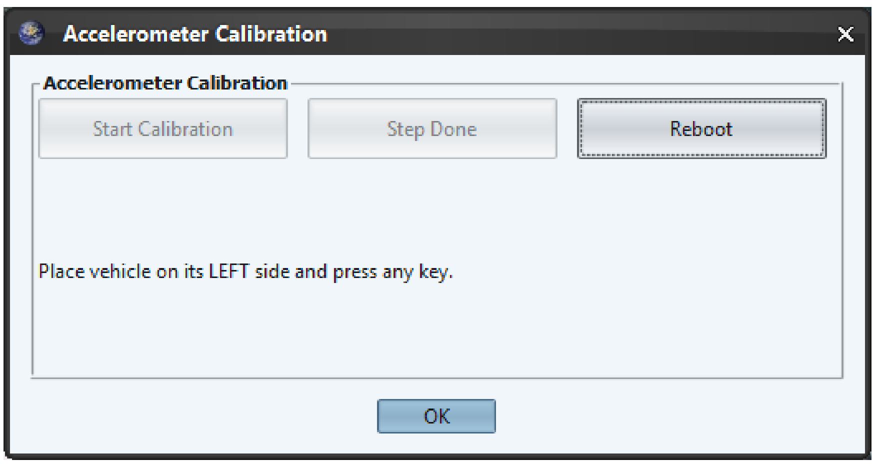


Figure 85 – Accelerometer calibration dialog state during execution

Motor Testing, Relay and Servo Controls Panel

The Motor Testing panel is useful for diagnosing wiring problems, motor and ESC issues, as well as, propeller orientation errors. To test each motor, just click on the checkbox and move the slider to 10% or so of the total throttle value and then click on the "Test All Selected Motors". All of the checked motors will spin for the duration specified or until the "Stop Motors" button is clicked. See this page for a description of the motor orders and spin direction for the different frame configurations: https://ardupilot.org/copter/docs/connect-escs-and-motors.html

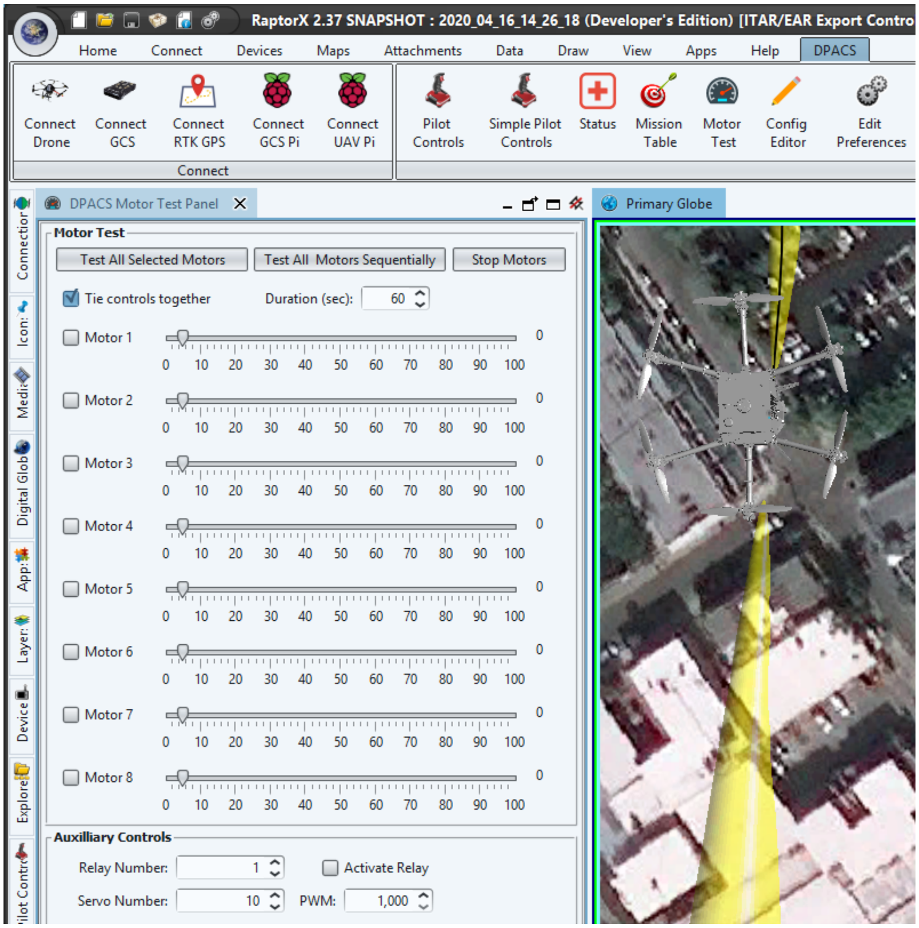


Figure 86 - Panel to individually test motors, relays and auxiliary servos

To test the relay just change the relay number to 0 or 1 and click "Activate Relay". The relays are on Aux Pins 5 & 6 as shown in Figure 87.

Figure 87 - Relay outputs for PIxhawk

Only relay 0 is enabled by default. To enable the second relay, just ensure that the Ardupilot configuration parameters are set to:

1. BRD_PWM_COUNT = 4
2. RELAY_PIN=54
3. RELAY_PIN2=55

See this document for more details: http://copter.ardupilot.com/wiki/common-relay/

When the relay is activated, the signal pin will output 3.3 volts

To test the servos, enter a servo number in the range of 9-12 and change the PWM to a higher value like 1500. A servo connected to the corresponding pins should move halfway. Servo 9 corresponds to Aux output of 1 and servo 12 is the Aux output of 12. More info can be found here:

http://copter.ardupilot.com/wiki/common-servo/

Gimbal Control

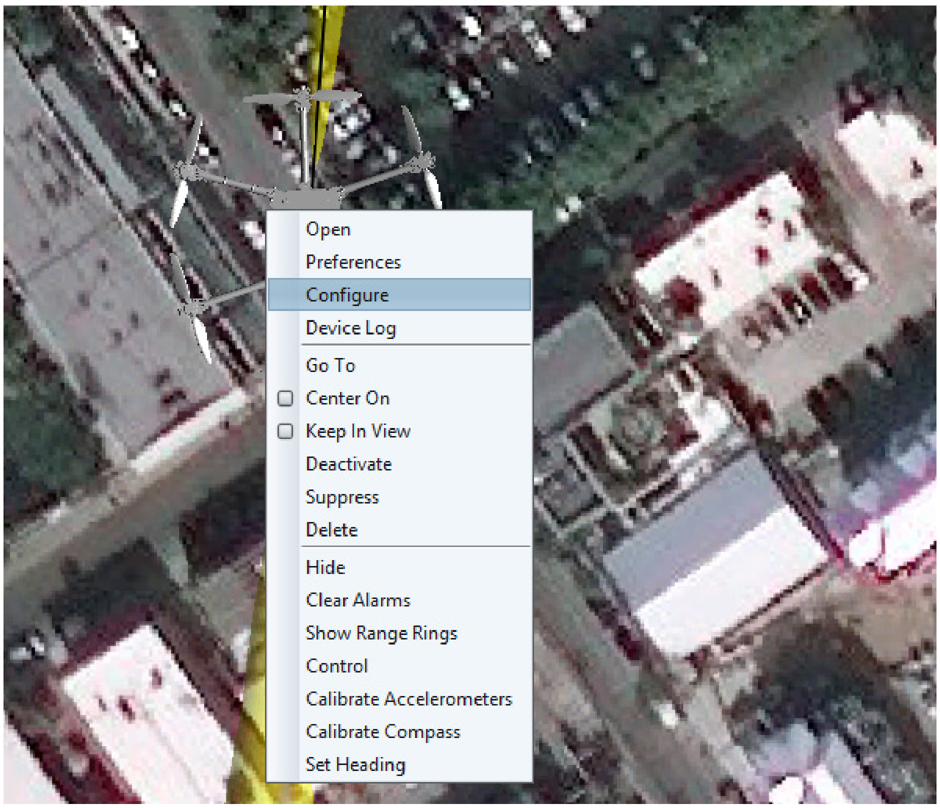


Figure 88 – Right click menu item selected to configure the drone device

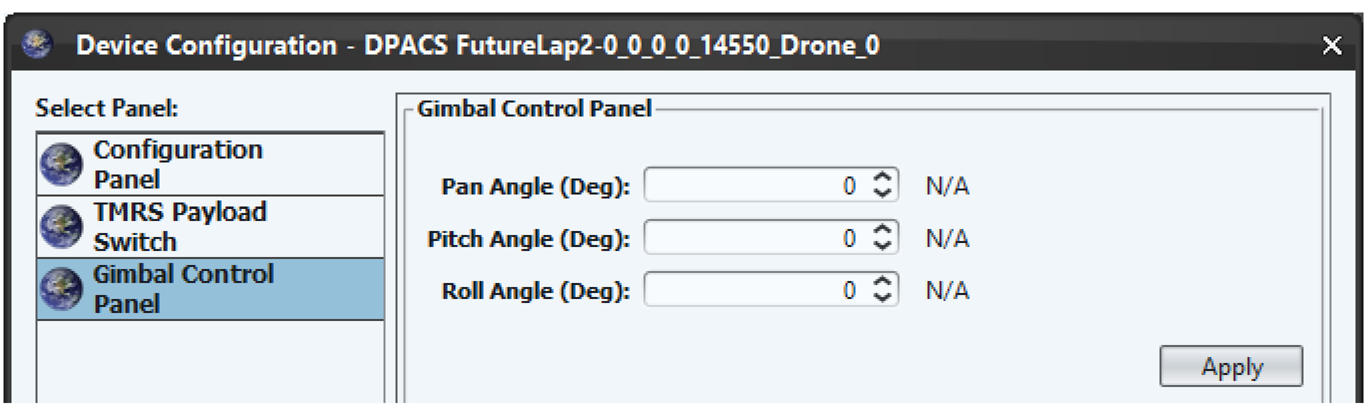


Figure 89 – Test interface for gimbal controls

Telemetry Data Plot

An initial capability to plot telemetry data is available now that can be accessed from the “Plots” ribbon bar button shown in Figure 90.

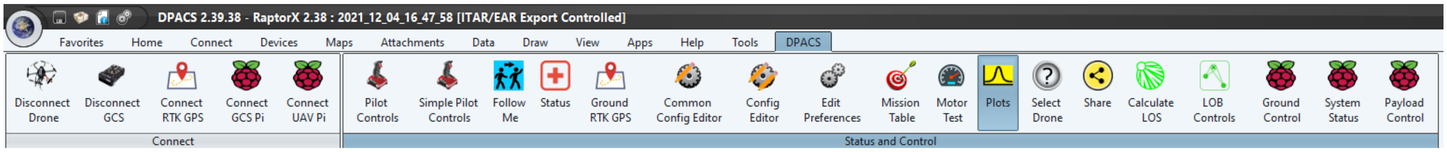


Figure 90 – Plots Ribbon Bar button

Once a drone is connected to DPACS and initialized, the “Populate” button shown in Figure 91. (This button may be removed in the future.)

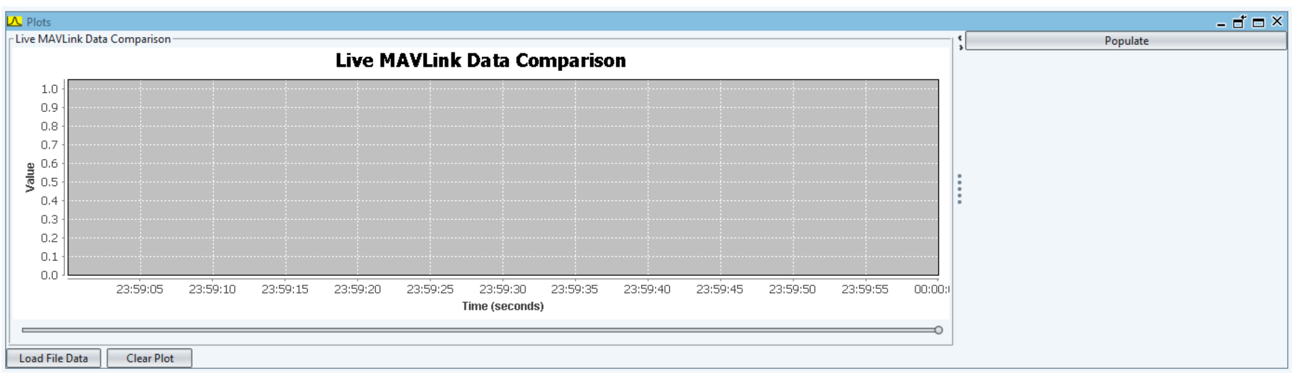


Figure 91 – Telemetry Plot before being initialized

Once the available variables are displayed, any combination of variables can be selected to see the live data being displayed. If the data was loaded from a file, all the data from the file will be shown with a one-minute scrolling window. For example, the live yaw, roll and pitch data can be plotted simply by selected the parameters in the variable tree as shown in Figure 92.

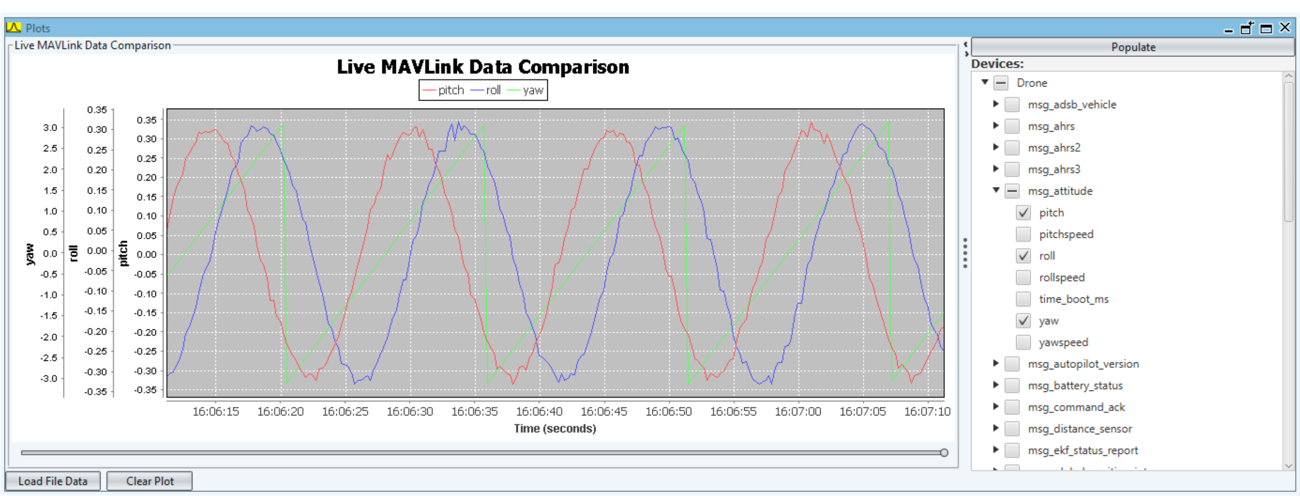


Figure 92 - Plot display of live yaw, roll and pitch data

Emergency SOPs

UAS begins to fly away while performing missions

1. First try Ctrl+L or click the "Land" button
2. If UAS is not responding to the land command perhaps due to loss of telemetry, use the RC to takeover:
    a. If the RC is already on, ensure that the throttle is at mid-position and then toggle the mode to "Loiter". Lower the throttle to bring the UAS to the ground.
    b. If the RC is not already on, first increase the throttle to mid-position and then turn on the RC. The UAS will switch modes to whatever mode is currently selected on the RC. Then ask the GCS GUI operator to "Release All Controls" to hand over all controls to the RC.
3. If GPS has lost lock, Ctrl+L. The autopilot should use a non-GPS version of Land. If the UAS is not coming down in a controlled fashion, move the RC throttle to the mid-position and turn on the RC, switch to Stabilize and fly the UAS to safety.
4. As a last resort, click the "Abort" button or type Ctrl+q to immediately shutdown power to the UAS. This command will cause the UAS to freefall with no power to the propellers and the UAS and payload will likely get damaged by the crash landing.

Telemetry Fails while UAS is flying

If the communications between the laptop and the UAS completely fails while the UAS is flying its mission (it is stuck loitering in the air if GCS failsafe was disabled or failed for some reason), perform one of the following steps:

- If the RC was already on, toggle to land. Make sure the throttle is raised halfway in case you need to switch to Loiter to take over if something goes wrong.
- If the RC is not on already, raise the throttle halfway, toggle the RC to Land mode and turn on the RC. The UAS should start descending in Land mode. If not, toggle the RC switch to Loiter and then back to Land. Since the RC was turned off, the GCS overrode the Roll, Pitch and Yaw commands to prevent
- Enabling GCS fail safe will also prevent this situation from happening. The UAS will RTL when the flight controller does not receive a heartbeat for 5 seconds and there are GCS RC overrides active. Be sure to set the RTL altitude to much less than the expected deployed tether length.

Taking Back Control with RC

There are a couple scenarios where the UAS may switch out of the AUTO flight mode to Land, RTL or Loiter. If there is a temporary failure such as a short pause in telemetry communications that triggers a failsafe such as the GCS failsafe, the mode may switch to RTL or Land depending on how the failsafe is configured. The RC pilot may turn on the RC or explicitly switch the flight mode to Altitude Hold or Loiter to handle a situation. In both cases, the interrupted mission can be resumed by issuing the Ctrl+r command when the RaptorX screen selected on the desktop.

Failsafe (FS) Parameters

Note: Failsafes can be turned off, on, or thresholds changed within DPACS using the Configuration Editor or the Firmware Parameters panel. They consist of a parameter type, a trigger threshold, and an action. The most used parameters are shown below, but a complete description can be found here: https://ardupilot.org/copter/docs/failsafe-landing-page.html .

Table 1 – Summary of Important Failsafe Parameters

Failsafe Name and Related Parameters	**Type**	**Threshold**	**Action**	**Description**
Low Battery Voltage BATT_LOW_VOLT BATT_CRT_VOLT BATT_FS_VOLTSRC BATT_FS_LOW_ACT BATT_FS_CRT_ACT BATT_LOW_TIMER FS_OPTIONS	Voltage	Low Voltage	None, Land or RTL	If the vehicle battery voltage drops below a specified voltage for 10 seconds (or time specified in BATT_LOW_TIMER) or the estimated remaining capacity has dropped below a configurable threshold.
GCS FS_GCS_ENBLE FS_OPTIONS	Heartbeat	5 second outage	None, Land or RTL	A threshold defined as the absence of a “heart-beat” for x seconds that triggers an action like Land or RTL. The heart-beat is a message sent from the ground to the aircraft
EKF FS_EKF_THRESH FS_EKF_ACTION	Measurement Variances of compass, position or velocity	Upper bounds on variance for 1 second	None or Land	Values within the Extended Kalman Filters (EKF) that if high, will trigger an action that prevents UAS arming or landing. Examples are vibration and positioning
RC FS_THR_ENABLE FS_THR_VALUE FS_OPTIONS	Throttle PWM	Throttle PWM falls below FS_THR_VALUE for more than .5 seconds	None, RTL or Land	The system monitors the RC’s channel 3’s PWM value, (throttle). A typical threshold is 900. When the RC IS ON, channel 3 is higher than 900. The trigger is a value at or below the RC low throttle PWM.

Geofence FENCE_ENABLE FENCE_ALT_MAX FENCE_RADIUS FENCE_ACTION FENCE_TYPE	Position	Outside of Geofence	Report Only, RTL, Land, Land, Brake	This is a defined boundary ("fence") that constrains the aircraft from exiting an area. GPS coordinates define the boundary. The trigger prevents the aircraft from crossing the virtual "fence". The UAS must have GPS sensing turned on.

TMRS Status Panels

Tethered Multirotor System (TMRS) has servers running on a Raspberry Pi in the reel and on the drone that are used for enhanced control and monitoring of the reel, power, and communications systems. All communications with the server are achieved with MAVLink v2 messages that are defined with an XML file that are described in

For a TMRS or other system that supports the same messaging, the TMRS control and status panels can be enabled by selecting the “Enable TMRS V2 Support” in the DPACS preferences panel shown in Figure 93, saving the settings and restarting DPACS.

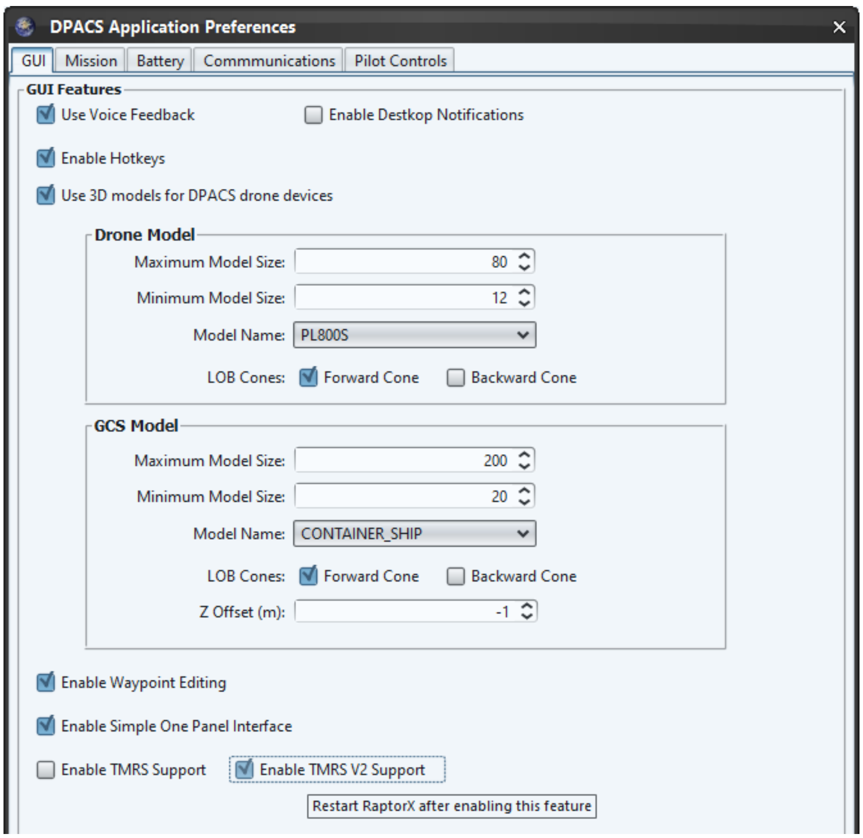


Figure 93 – Enabling TMRS V2 Support

After restarting DPACS, the TMRS connection buttons and panel buttons with Raspberry Pi icons will show up in the Ribbon Bar shown Figure 94.

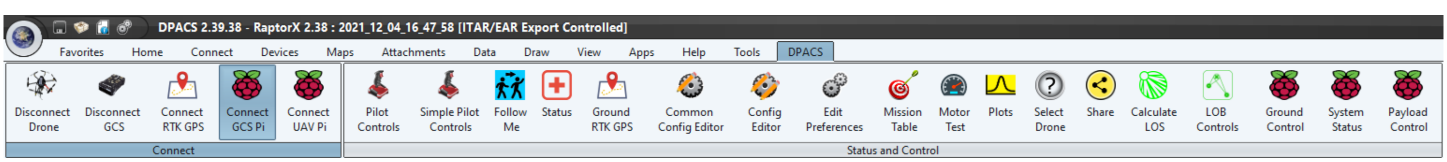


Figure 94 – DPACS ribbon bar with the TMRS related connection and panel buttons displayed

Click on the Connect GCS Pi button and Connect UAV Pi buttons to connect to the TMRS servers. The IP addresses will default to the correct addresses agreed up for the TMRS as shown in Figure 95 and Figure 96.

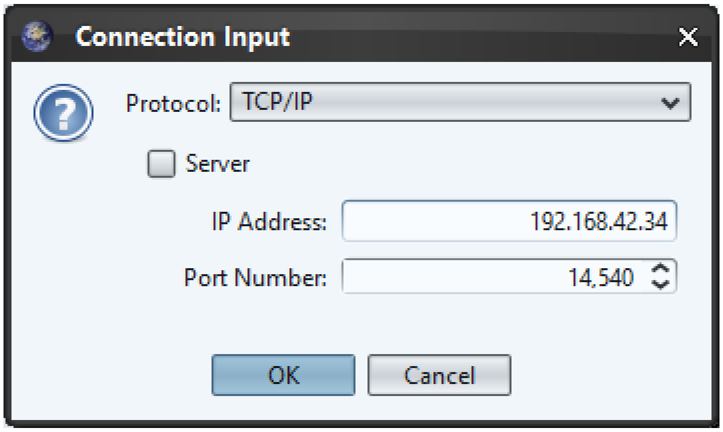


Figure 95 – Connection dialog with default IP address of the Raspberry Pi housed in the TMRS reel box

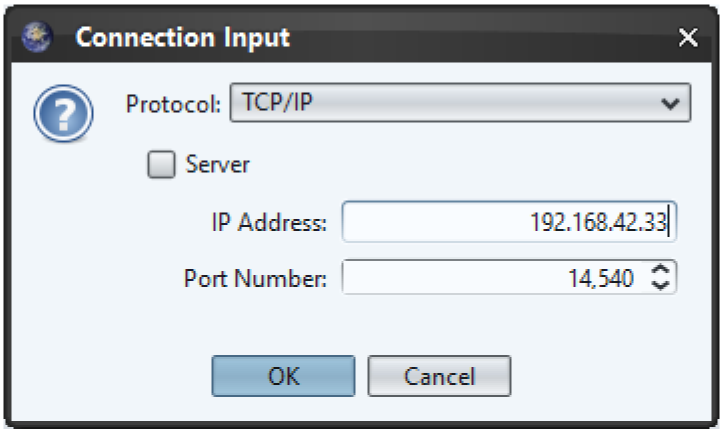


Figure 96 - Connection dialog with default IP address of the Raspberry Pi housed in the TMRS drone

Once connected to the two servers the three status panels shown in Figure 97, Figure 98 Figure 99 will populate with the current status information and allow enable the controls.

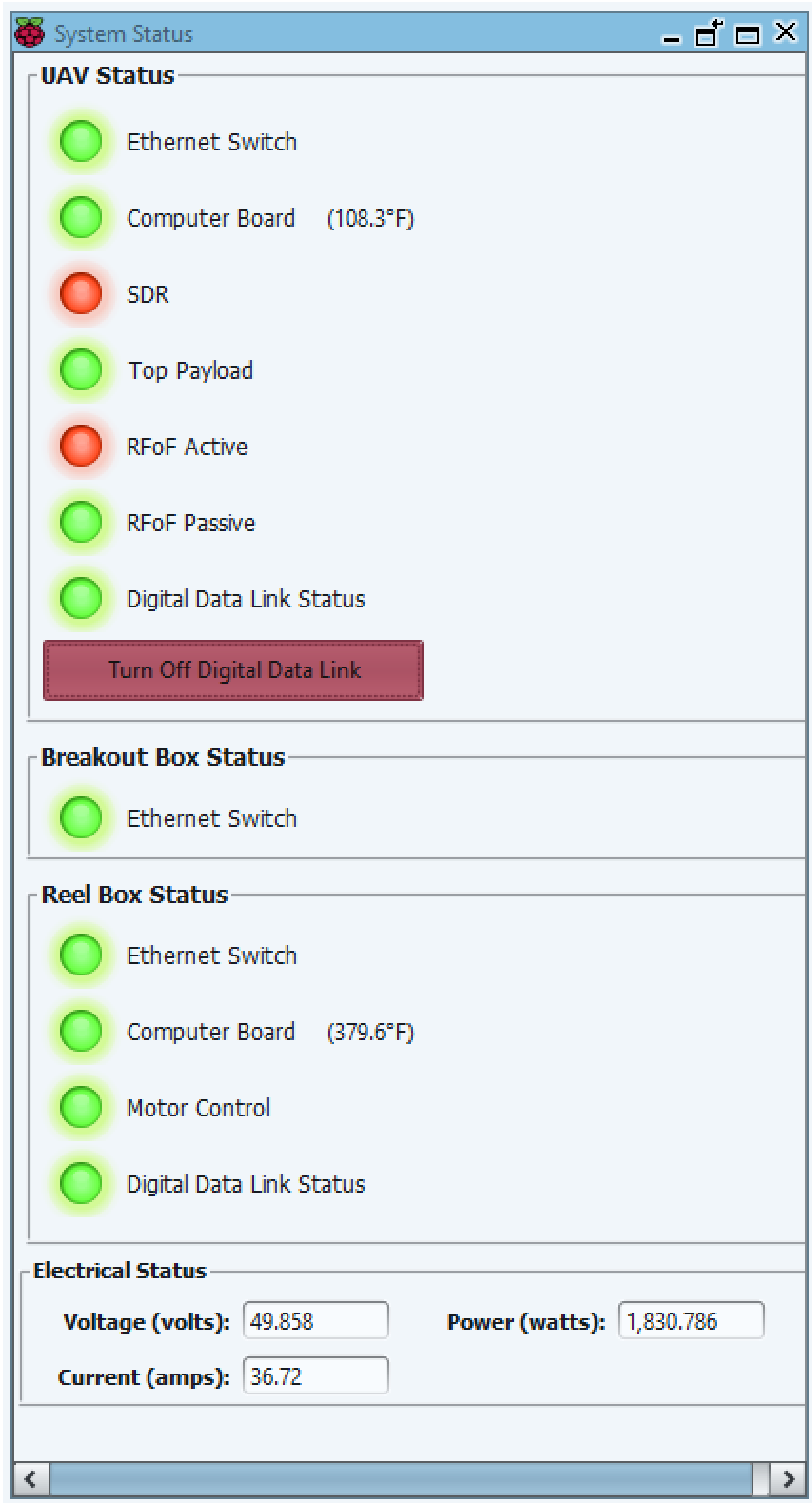


Figure 97 – TMRS V2 System Status Panel

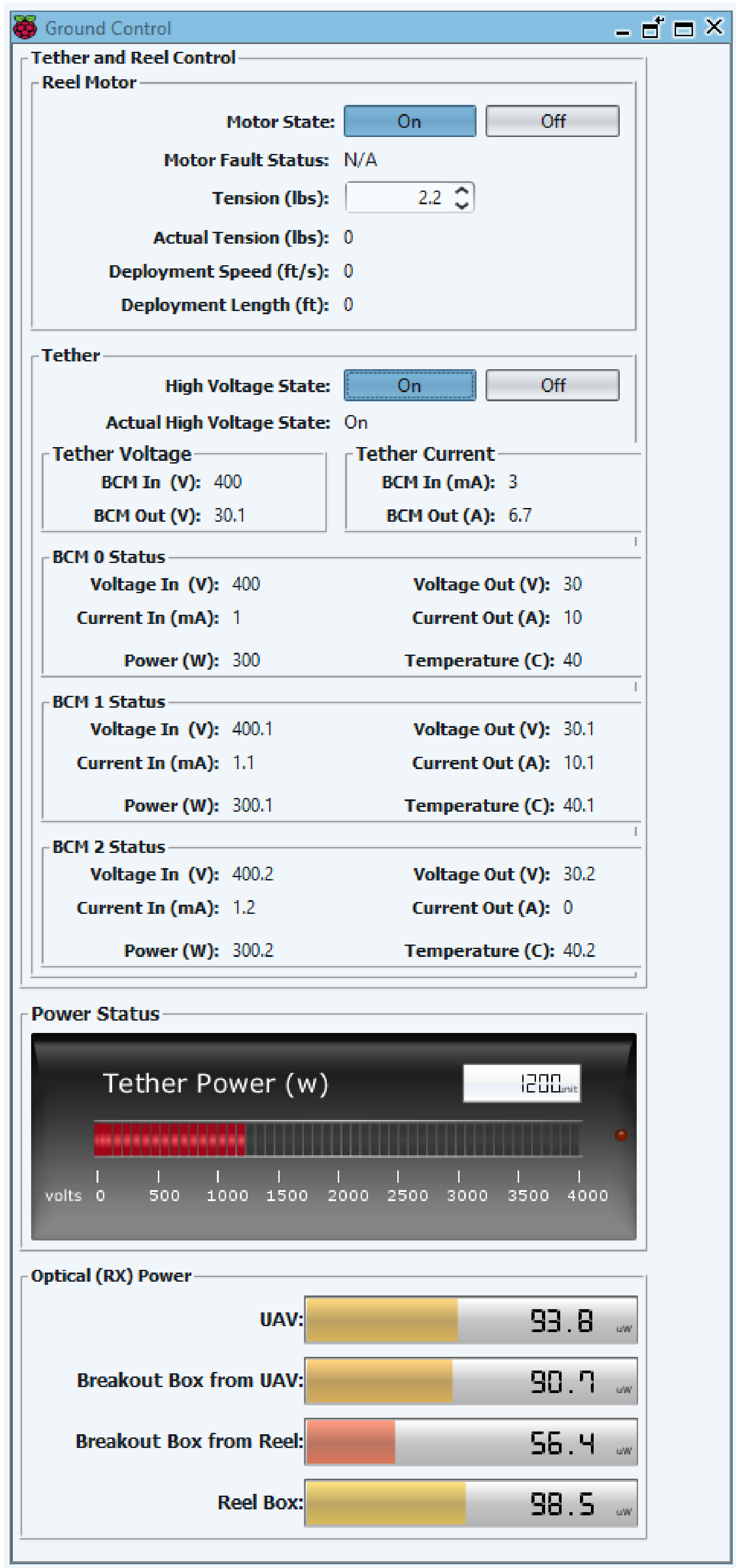


Figure 98 – TMRS V2 Ground Control and Power Status Panel

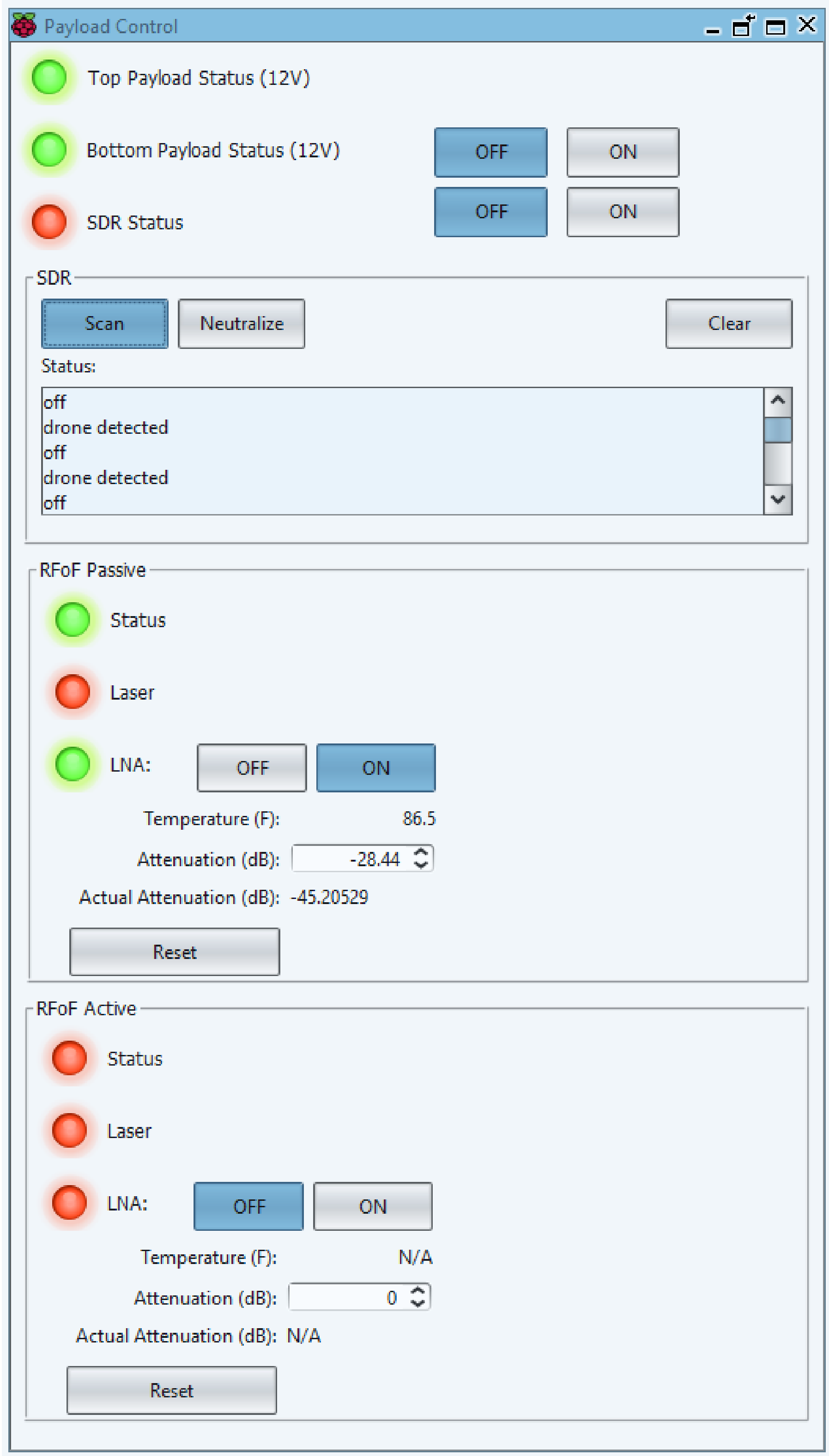


Figure 99 – TMRS V2 Payload Control Panel

Appendix A – Troubleshooting Connection Issues

If DPACS fails to connect, make sure the green light is solid (not flashing) on the USB telemetry radio to ensure that you have a link. Your computer may also need the FTDI and Pixhawk drivers installed. Go to these sites to download the drivers for your computer:

1. http://www.ftdichip.com/Drivers/VCP.htm
2. Pixhawk Drivers are here: https://pixhawk.org/firmware/downloads
3. Also, if this is the first time you've used a particular Windows 8 computer, you may have to go through this process to install the unsigned driver especially when connecting with a USB cable:
    a. https://pixhawk.org/users/drivers_win
    b. http://www.makeuseof.com/tag/how-can-i-install-hardware-with-unsigned-drivers-in-windows-8/

Appendix B - Replaying Data from a Previous Flight

DPACS can replay received MAVLink data from a previous flight. This replay capability is useful for diagnosing problems noticed during flight or creating screen recordings for presentations of the flight for instance.

DPACS automatically stores all the raw MAVLink messages that are received in a binary file stored in dpacs directory located in the user's home directory. On Windows, the directory would be located in %HOMEPATH%\dpacs and on Unix, the directory would be located in $HOME/dpacs. The *.mavlog files contain only the raw MAVLink messages and the *.tlog files have the raw MAVLink messages with the timestamp corresponding to the receive time inserted between each record that is compatible with MissionPlanner's requirements.

To display the data in DPACS, create a File connection to one of the tlog files. The File connection is located on the "Connect" ribbon bar shown in Figure 100.

Figure 100 - File Connection

After clicking on the File Connection button, select the .tlog file and enable the options shown in Figure 101. Specify at least 255 bytes per cycle and 100ms cycle duration. These settings appear to realistically replay the data.

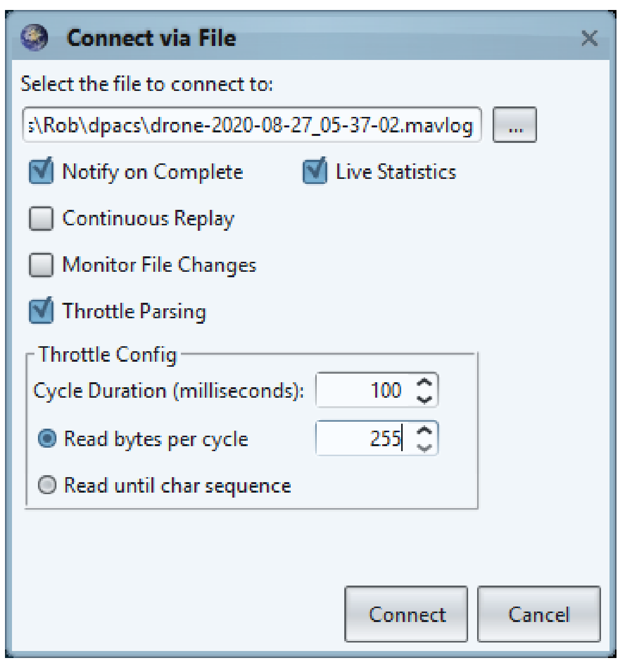


Figure 101 – Creating a File Connection

Once the data starts streaming, you will see a normal DPACS session displayed as shown in Figure 102. The only difference will be that the drone controls are ignored since there is no real device or simulator to communicate with.

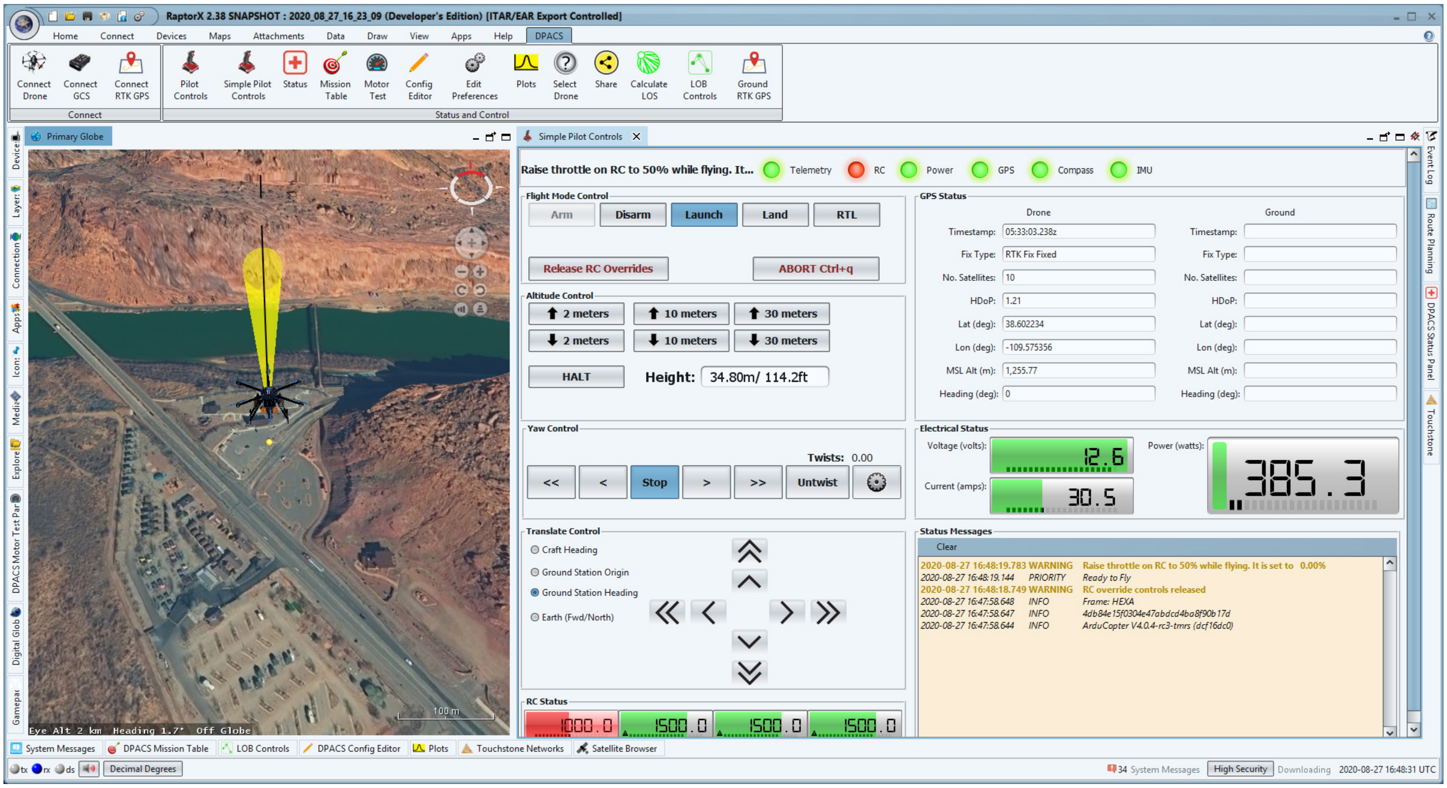


Figure 102 - Mission being replayed from a file

Once the file is completely read, you will see the notification dialog shown in Figure 103.

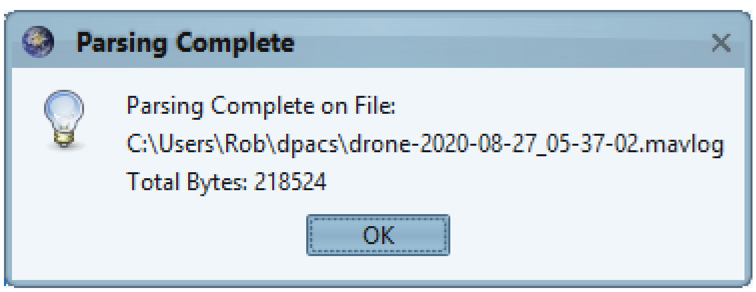


Figure 103 – Notification the file parsing has is completed

Once all data is read from the file, a subset of the data can be replayed using the RaptorX Playback feature that can be accessed in the Home/Bottom ribbon bar shown in Figure 104.

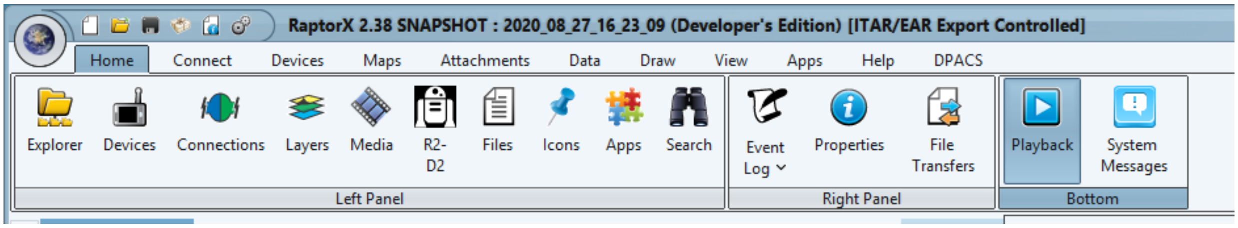


Figure 104 – Button to display Playback timeline

The Playback timeline panel will display at the bottom of the RaptorX GUI. Click on the gear icon shown highlighted below to associate the DPACS device with the timeline as shown in Figure 105.

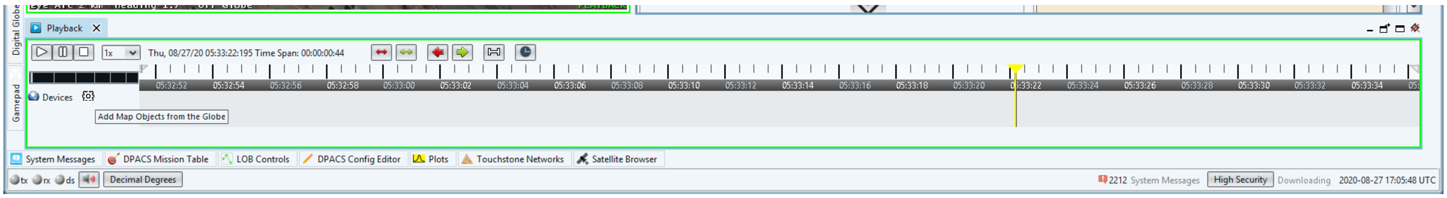


Figure 105- Playback timeline with gear button highlighted to select devices

Select the DPACS device as shown in Figure 106. Once a device is selected, it will show up in the timeline as shown in Figure 107.

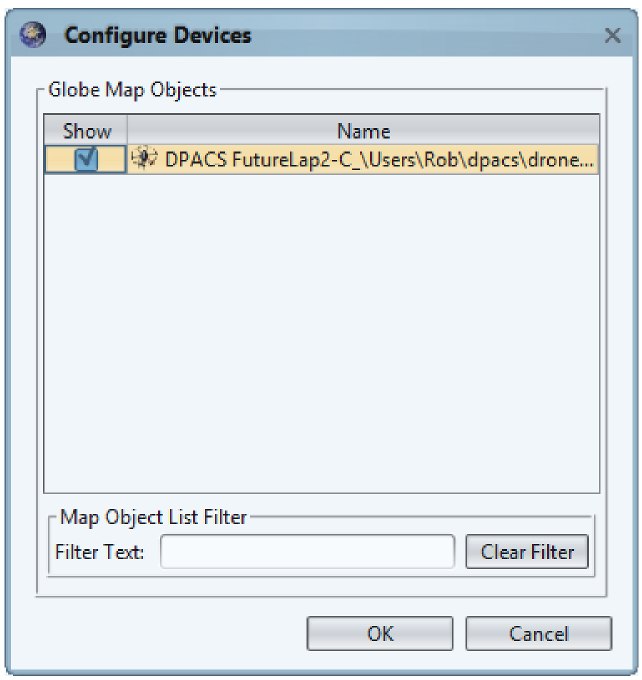


Figure 106 – Device selection for the timeline

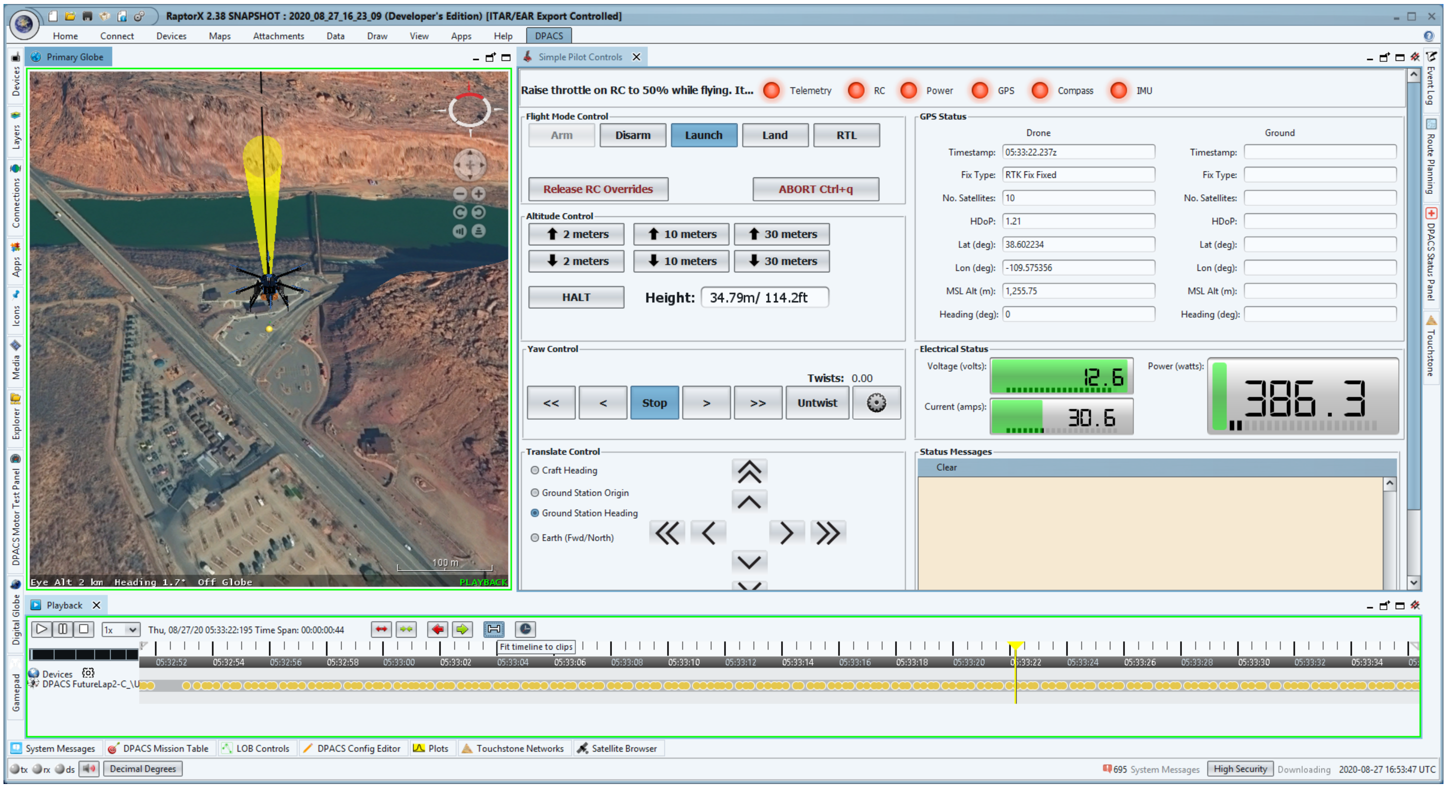


Figure 107 – Playback timeline with DPACS device selected and displayed

The DPACS tlog files can be processed by Mission Planner (MP) and APM Planner (APM) as well. For instance, MP can be used to plot the data as shown in Figure 108 or replayed as shown in Figure 109.

Figure 108 – Using Mission Planner's Graph Log capability to display data from the DPACS tlog file.

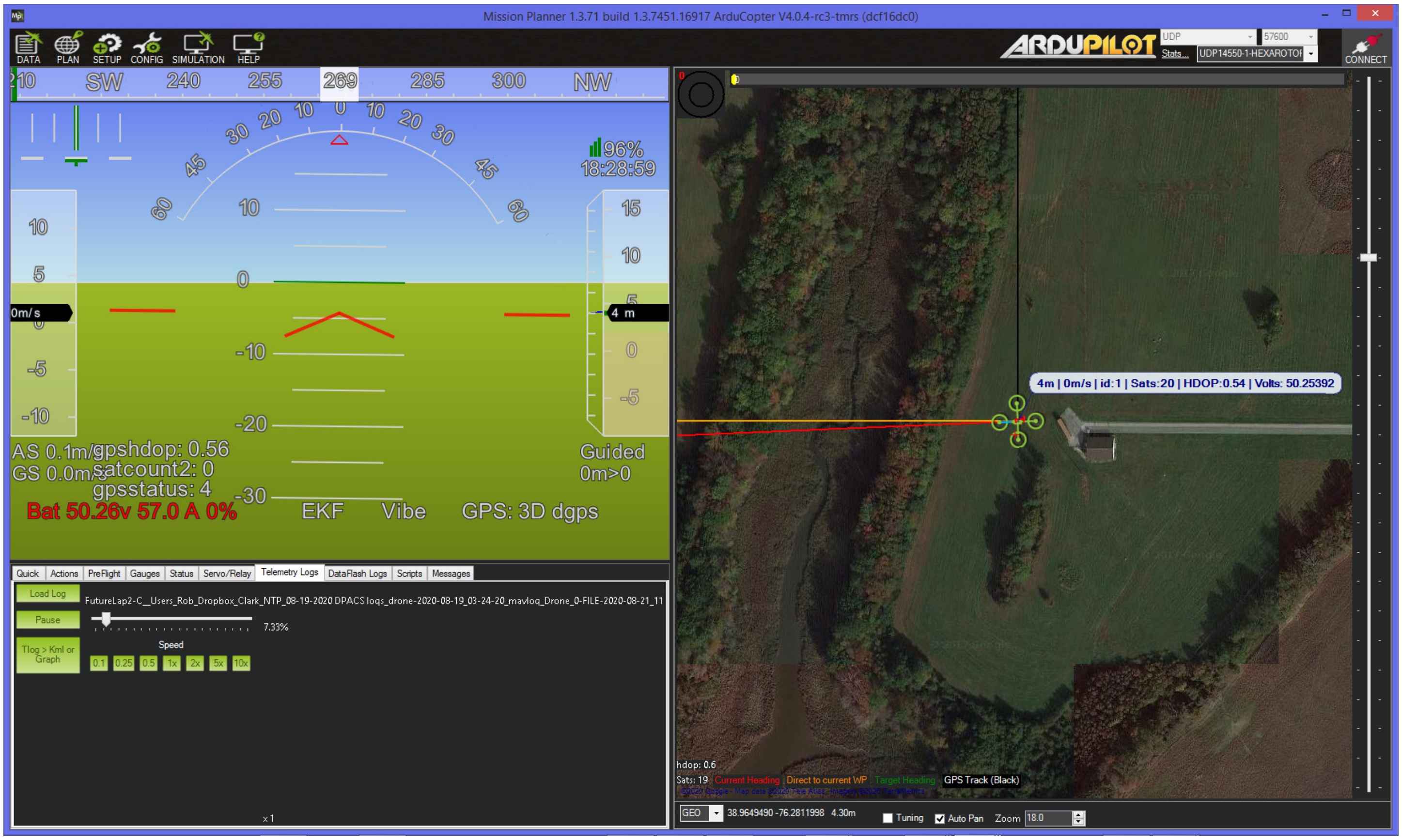


Figure 109 – Replaying the tlog data from DPACS within Mission Planner.

Appendix C - Using Sandbar with DPACS for RF Link Analysis

A benefit of RaptorX is that there are many plugins available that can interoperate. A useful plugin called Sandbar can be used to perform RF link analysis. A good use case for using Sandbar would be to determine the altitude required of your drone at a given location with a transmitter payload to achieve link with a remote receiver.

Sandbar can be used independently of DPACS, but a tighter coupling between the Sandbar device and the DPACS drone device can be obtained using the RaptorX device containment feature so that the altitude and locations are synched. Setup a typical Sandbar scenario as shown in Figure 110 with an ROI drawn around the drone operational area. Create a transmitter and a friendly receiver using the buttons on the Sandbar toolbar. Change the DPACS device to a 2D icon temporarily using the DPACS preferences and moving the device a bit if it is not connected live. Drag the transmitter device onto the DPACS icon to associate the transmitter's position and altitude with the DPACS device. Then switch the DPACS device back to using the 3D model in the preferences.

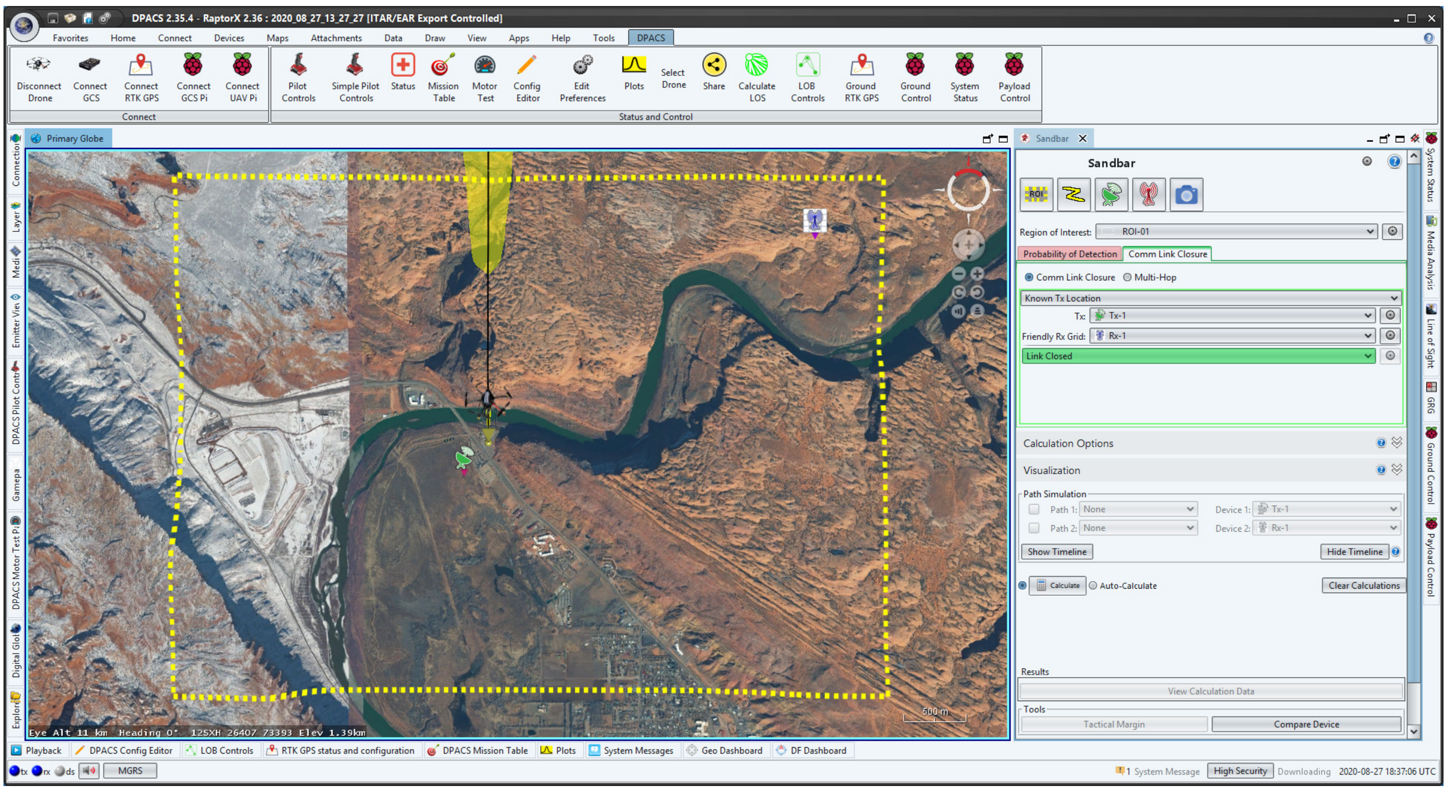


Figure 110 – Initial Sandbar setup with ROI around the drone with a transmitter and friendly receivers created.

You can verify that the Sandbar device is contained by the DPACS device by double clicking on the DPACS device on the map or the explorer tree. You should see a Sandbar icon in the list of the Contained Map Objects as shown in Figure 111

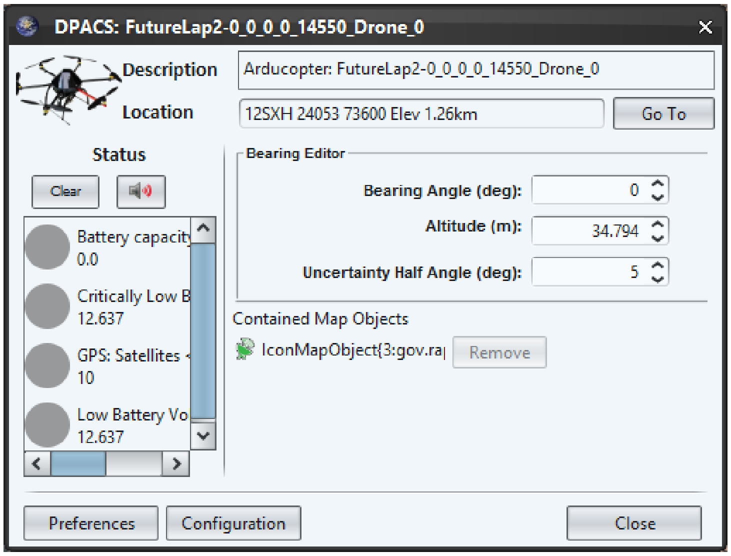


Figure 111 – DPACS properties panel with contained Sandbar transmitter device

The position and altitude of the contained Sandbar device will be synchronized with the position and altitude of the drone. To run a Sandbar calculation, the drone needs to be disconnected since changes to the position or altitude will cause Sandbar to continually recalculate the solution. (There will be a fix to this in the future.) The solution for the given altitude is shown in Figure 112.

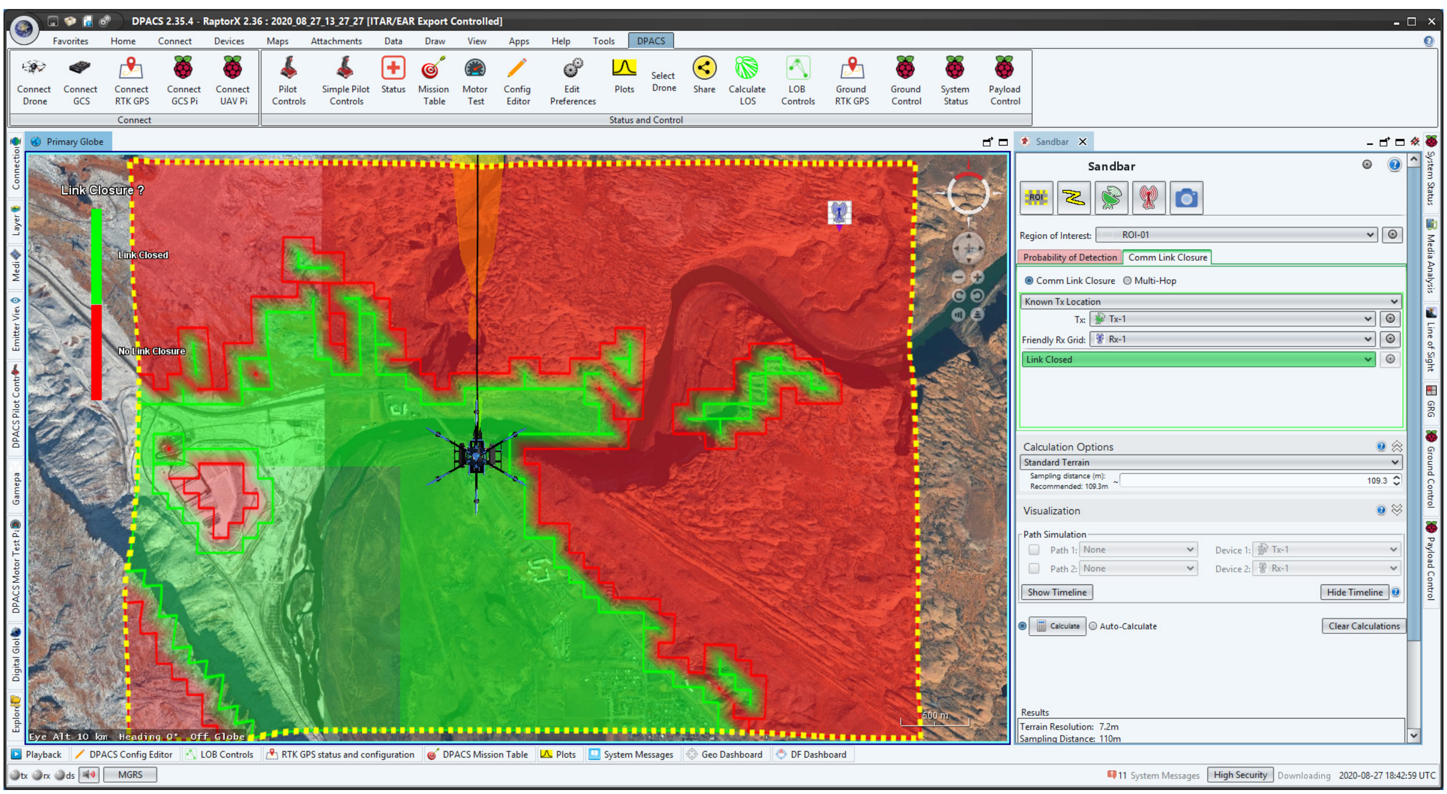


Figure 112 – RF Link solution at an altitude of 35 meters

Once the drone is disconnected, the altitude can be manually adjusted using the altitude input field shown in Figure 113.

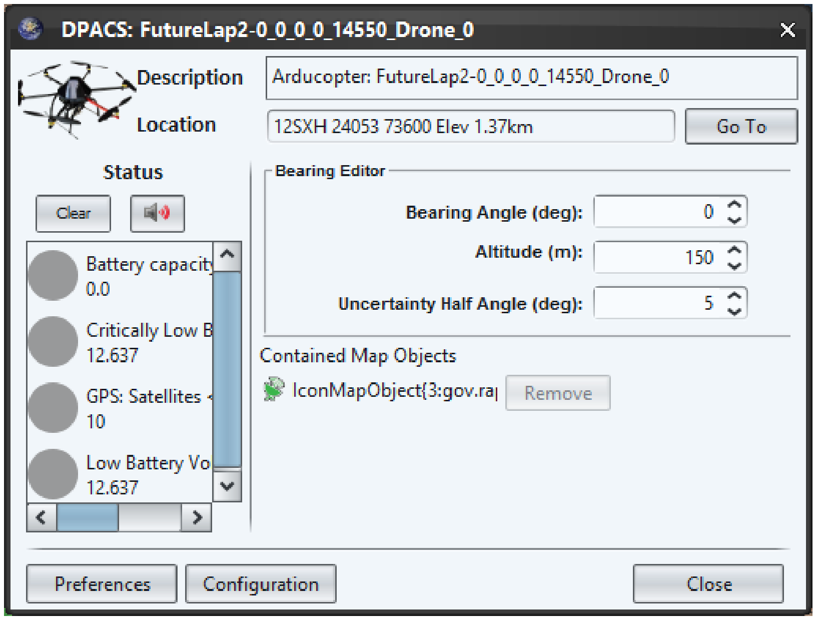


Figure 113 – Manually input altitude

The RF Link solution for a 150m altitude is shown in Figure 114. The position of the copter can be changed by dragging the copter to a new position as well.

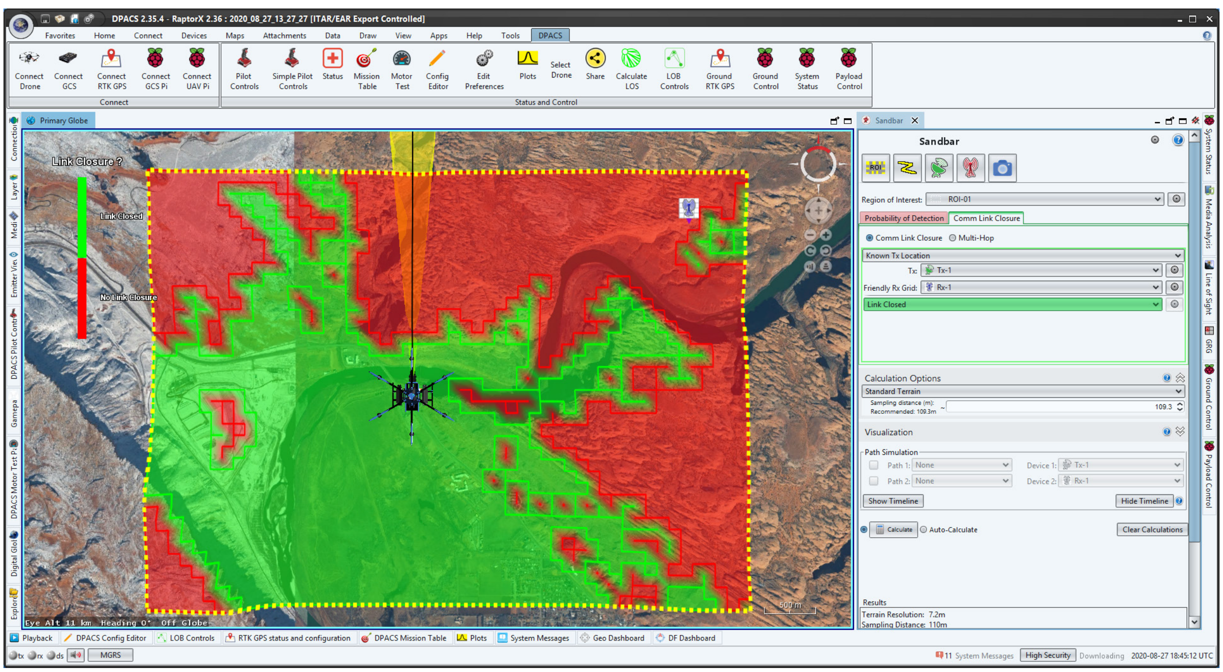


Figure 114 - RF Link solution at an altitude of 150 meters

If a more a detailed solution is desired, the sampling distance can be reduced to 30m for instance as shown in Figure 115.

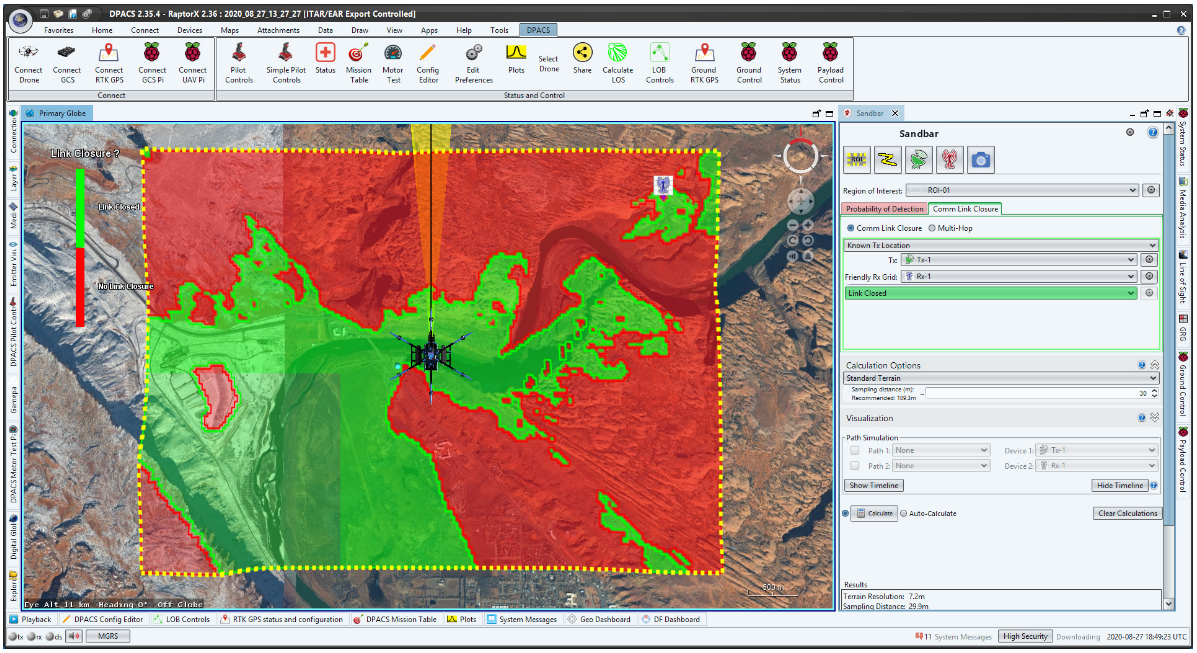


Figure 115 - RF Link solution at an altitude of 150 meters with a higher resolution solution with 30 meter spacing.

The 3D cone intersection with the terrain and its correlation with the Sandbar solution can be seen in Figure 116. Currently the cone cuts through the terrain and extends to the predicted RF horizon distance for the given altitude.

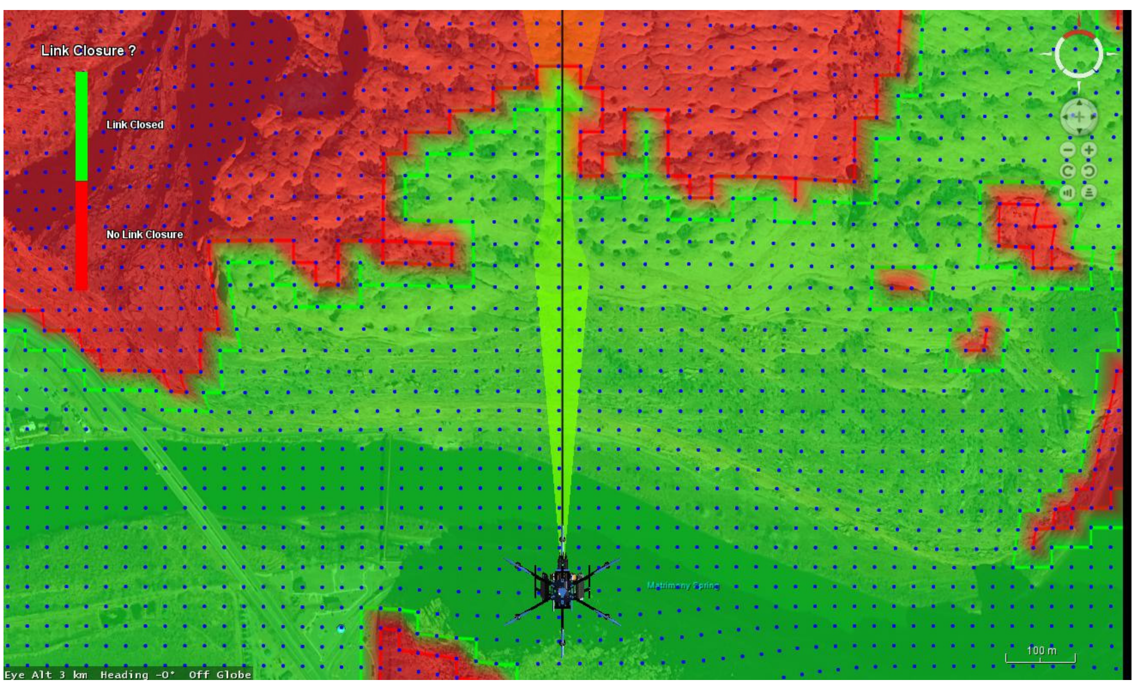


Figure 116 – 3D cone compared to the RF Link solution

Appendix D - Line of Site Estimation

DPACS integrated the NASA World Wind line of sight calculation algorithm and can be accessed in the ribbon bar shown in Figure 117. The antenna height is initialized to the current height of the drone above the ground. This capability is useful to quickly check the line of site of the drone for a given altitude.

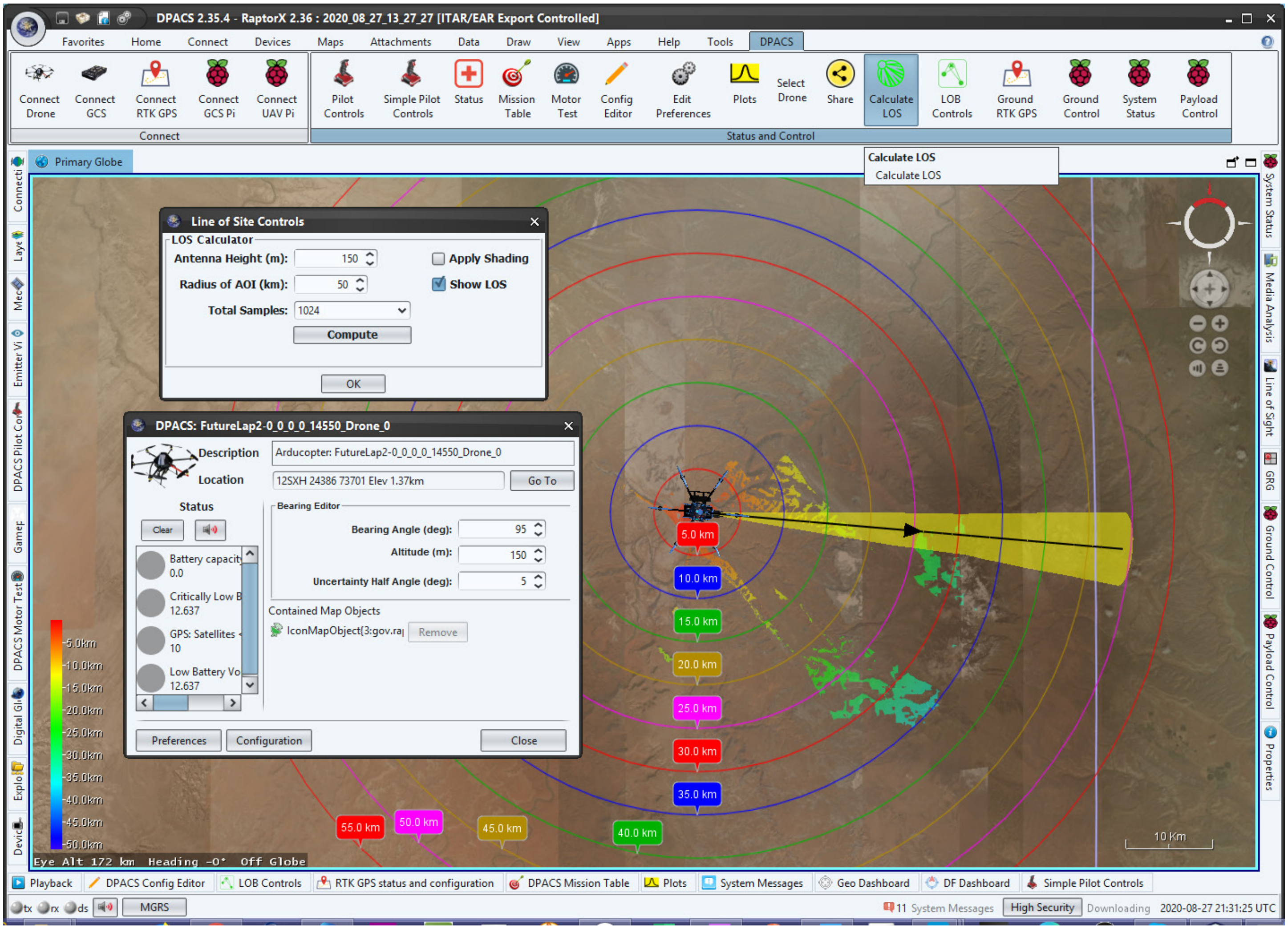


Figure 117 – Example of using the NASA World Wind Line of Sight algorithm

Appendix E – TMRS2 MAVLink Message Definitions

This appendix contains a snapshot of the TMRS2 MAVLink V2 message definitions. The most current version can be found on github here:

https://github.com/rrr6399/DPACS-Releases/tree/master/mavlink

(Contact Rob Ratcliff for access to the repository.)


```xml
<?xml version="1.0"?>
<mavlink>
  <messages>
    <!--  GCS PANEL -->
    <!-- REEL -->
    <message id="7000" name="TMRS2_REEL_STATUS">
      <description>TMRS Reel Status</description>
      <!-- <field type="float" name="reel_power" units="watts">Reel Power</field> relocated to new,
bird srcd message-->
      <field type="uint8_t" name="motor_fault_state">Motor Fault State</field>
       <!-- 0 for Bad, 1 for Normal -->
      <field type="float" name="actual_tension" units="lbs">Actual Tension</field>
      <field type="float" name="deployment_speed" units="ft/s">Deployment Speed</field>
      <field type="float" name="deployment_length" units="ft">Deployment Length</field>
    </message>
    <message id="7001" name="TMRS2_REEL_CONTROL">
      <description>TMRS Reel Control</description>
      <field type="uint8_t" name="set_reel_motor_state">Motor State (0 for off, 1 for on)</field>
      <field type="float" name="set_tension" units="lbs">Tension</field>
    </message>
    <!-- TETHER -->
    <message id="7002" name="TMRS2_TETHER_STATUS">
      <description>TMRS Tether Status</description>
      <field type="uint8_t" name="actual_high_voltage_state">Actual High Voltage State (0 for off,
1 for on)</field>
      <!-- Voltage and current metrics relocated to new, bird sourced messaged -->
    </message>
    <message id="7003" name="TMRS2_TETHER_CONTROL">
      <description>TMRS Tether Control</description>
      <field type="uint8_t" name="set_high_voltage_state">High Voltage State (0 for off, 1 for
on)</field>
    </message>
    <!-- OPTICAL POWER -->
    <message id="7004" name="TMRS2_OPTICAL_POWER_UAV">
      <description>TMRS Optical Power at UAV Switch</description>
      <field type="float" name="uav" units="watts">UAV switch optical power reading</field>
    </message>
    <message id="7005" name="TMRS2_OPTICAL_POWER_BREAKOUT_FROM_UAV">
      <description>TMRS Optical Power at breakout switch from UAV </description>
      <field type="float" name="breakout_uav" units="watts">Breakout switch optical power reading
from UAV</field>
    </message>
    <message id="7006" name="TMRS2_OPTICAL_POWER_BREAKOUT_FROM_REEL">
      <description>TMRS Optical Power at breakout switch from reel </description>
      <field type="float" name="breakout_reel" units="watts">Breakout switch optical power reading
from reel</field>
    </message>
    <message id="7007" name="TMRS2_OPTICAL_POWER_REEL">
      <description>TMRS Optical Power at Reel Switch</description>
      <field type="float" name="reel" units="watts">Reel witch optical power reading</field>
    </message>
    <!--  UAV PANEL  -->
    <!-- UAV -->
    <message id="7008" name="TMRS2_UAV_STATUS">
      <description>TMRS UAV Status</description>
```

```
      <field type="uint8_t" name="ethernet_switch_uav_status">Ethernet Switch (0 for off, 1 for
on)</field>
      <field type="uint8_t" name="uav_computer_board">Computer Board (0 for off, 1 for on)</field>
      <field type="float" name="uav_computer_board_temperature">Computer Board Temperature
(C)</field>
     <field type="uint8_t" name="digital_data_link_uav_status">Digital Data Link (0 for off, 1 for
on)</field>
    </message>
    <message id="7009" name="TMRS2_DDL_CONTROL">
      <description>TMRS UAV Control</description>
      <field type="uint8_t" name="set_digital_data_link">Digital Data Link (0 for off, 1 for
on)</field>
    </message>
    <!-- Breakout Box -->
    <message id="7010" name="TMRS2_BREAKOUT_BOX_STATUS">
      <description>TMRS Breakout Box Status</description>
      <field type="uint8_t" name="ethernet_switch_breakout_status">Ethernet Switch (0 for off, 1
for on)</field>
    </message>
    <!-- Reel Box -->
    <message id="7011" name="TMRS2_REEL_BOX_STATUS">
      <description>TMRS Reel Box Status</description>
      <field type="uint8_t" name="ethernet_switch_reel_status">Ethernet Switch (0 for off, 1 for
on)</field>
      <field type="uint8_t" name="reel_computer_board">Computer Board (0 for off, 1 for on)</field>
      <field type="float" name="reel_computer_board_temperature">Computer Board Temperature
(C)</field>
      <field type="uint8_t" name="motor_control">Motor Control (0 for off, 1 for on)</field>
      <field type="uint8_t" name="digital_data_link_reel_status">Digital Data Link (0 for off, 1
for on)</field>
    </message>
    <!-- Motor Currents -->
    <message id="7012" name="TMRS2_MOTOR_CURRENTS_STATUS">
      <description>TMRS Motor Currents</description>
      <field type="float[6]" name="motor_currents" units="amps">Motor Currents</field>
    </message>
    <!-- BATTERY -->
    <message id="7013" name="TMRS2_UAV_BATTERY_STATUS">
      <description>TMRS UAV Battery Status </description>
      <field type="float" name="battery_voltage" units="volts">Battery Voltage</field>
      <field type="float" name="battery_percentage" units="">Battery Percentage</field>
      <field type="float" name="battery_life" units="mah">Battery Life</field>
    </message>
    <message id="7014" name="TMRS2_BATTERY_CONTROL">
      <description>TMRS Battery Control</description>
      <field type="float" name="set_system_battery" units="amp hour">Battery on System</field>
    </message>
    <!-- Error -->
    <message id="7016" name="TMRS2_ERROR">
      <description>TMRS Error</description>
      <field type="char[90]" name="error_data">Error data</field>
    </message>
    <!-- PAYLOAD PANEL -->
    <!-- SDR Payload-->
    <message id="7017" name="TMRS2_PAYLOAD_SDR_STATUS">
      <description>TMRS Software Defined Radio Status Log</description>
      <field type="char[64]" name="sdr_data">SDR Status Log</field>
      <field type="uint8_t" name="sdr_status">SDR Status (0 for off, 1 for on)</field>
    </message>
    <message id="7018" name="TMRS2_PAYLOAD_SDR_CONTROL">
      <description>TMRS Software Defined Radio Control</description>
      <field type="uint8_t" name="set_selector">SDR Selector: Scan or Neutralize (0 for Scan, 1 for
Neutralize)</field>
      <field type="uint8_t" name="set_sdr_status">Turn SDR Payload 12V on or off (0 for off, 1 for
on)</field>
    </message>
    <!-- Top Payload-->
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    <message id="7019" name="TMRS2_PAYLOAD_TOP_STATUS">
      <description>TMRS Top Payload Status</description>
      <field type="uint8_t" name="top_payload_status">Status of Top Payload 12V (0 for off, 1 for
on)</field>
    </message>
    <message id="7020" name="TMRS2_PAYLOAD_TOP_CONTROL">
      <description>TMRS Top Payload Control</description>
      <field type="uint8_t" name="set_top_payload">Turn Top Payload 12V on or off (0 for off, 1 for
on)</field>
    </message>
    <!-- Bottom Payload-->
    <message id="7021" name="TMRS2_PAYLOAD_BOTTOM_STATUS">
      <description>TMRS Bottom Payload Status</description>
      <field type="uint8_t" name="bottom_payload_status">Status of Bottom Payload 12V (0 for off, 1
for on)</field>
    </message>
    <message id="7022" name="TMRS2_PAYLOAD_BOTTOM_CONTROL">
      <description>TMRS Bottom Payload Controll</description>
      <field type="uint8_t" name="set_bottom_payload">Turn Bottom Payload 12V on or off (0 for off,
1 for on)</field>
    </message>
    <!-- RFOF Payload-->
    <message id="7023" name="TMRS2_PAYLOAD_PASSIVE_RFOF_STATUS">
      <description>TMRS Passive RFOF Status</description>
      <field type="uint8_t" name="rfof_lna_status">Status of RFoF LNA (0 for off, 1 for on)</field>
      <field type="uint8_t" name="rfof_laser_status">Status of RFoF Laser (0 for off, 1 for
on)</field>
      <field type="float" name="rfof_attenuation_status">Attenuation (db) of RFoF Module</field>
      <field type="float" name="rfof_temperature_status">Temperature (C) of RFoF Module</field>
      <field type="uint8_t" name="rfof_health_status">Status of RFoF (0 for off, 1 for on)</field>
    </message>
    <message id="7024" name="TMRS2_PAYLOAD_PASSIVE_RFOF_CONTROL">
      <description>TMRS Passive RFOF Payload Controll</description>
      <field type="uint8_t" name="set_rfof_lna">Set RFoF LNA(0 for off, 1 for on)</field>
      <field type="float" name="set_rfof_attenuation">Set RFoF Attenuation (0dB to 31.5dB in 0.5db
steps)</field>
      <field type="uint8_t" name="reset_rfof">Reset RFoF Payload (0 to not reset, 1 to
reset)</field>
    </message>
    <message id="7025" name="TMRS2_PAYLOAD_ACTIVE_RFOF_STATUS">
      <description>TMRS Active RFOF Status</description>
      <field type="uint8_t" name="rfof_lna_status">Status of RFoF LNA (0 for off, 1 for on)</field>
      <field type="uint8_t" name="rfof_laser_status">Status of RFoF Laser (0 for off, 1 for
on)</field>
      <field type="float" name="rfof_attenuation_status">Attenuation (db) of RFoF Module</field>
      <field type="float" name="rfof_temperature_status">Temperature (C) of RFoF Module</field>
      <field type="uint8_t" name="rfof_health_status">Status of RFoF (0 for off, 1 for on)</field>
    </message>
    <message id="7026" name="TMRS2_PAYLOAD_ACTIVE_RFOF_CONTROL">
      <description>TMRS Active RFOF Payload Controll</description>
      <field type="uint8_t" name="set_rfof_lna">Set RFoF LNA(0 for off, 1 for on)</field>
      <field type="float" name="set_rfof_attenuation">Set RFoF Attenuation (0dB to 31.5dB in 0.5db
steps)</field>
      <field type="uint8_t" name="reset_rfof">Reset RFoF Payload (0 to not reset, 1 to
reset)</field>
    </message>
    <message id="7027" name="TMRS2_BCM_STATUS">
      <description>BCM powersupply status</description>
      <field type="float" name="bcm0_voltage_in" units="volts">BCM0 Voltage In</field>
      <field type="float" name="bcm1_voltage_in" units="volts">BCM1 Voltage In</field>
      <field type="float" name="bcm2_voltage_in" units="volts">BCM2 Voltage In</field>
      <field type="float" name="bcm0_voltage_out" units="volts">BCM0 Voltage Out</field>
      <field type="float" name="bcm1_voltage_out" units="volts">BCM1 Voltage Out</field>
      <field type="float" name="bcm2_voltage_out" units="volts">BCM2 Voltage Out</field>
      <field type="float" name="bcm0_current_in" units="milliamps">BCM0 Current In</field>
      <field type="float" name="bcm1_current_in" units="milliamps">BCM1 Current In</field>
      <field type="float" name="bcm2_current_in" units="milliamps">BCM2 Current In</field>
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      <field type="float" name="bcm0_current_out" units="amps">BCM0 Current Out</field>
      <field type="float" name="bcm1_current_out" units="amps">BCM1 Current Out</field>
      <field type="float" name="bcm2_current_out" units="amps">BCM2 Current Out</field>
      <field type="float" name="bcm0_power_out" units="watts">BCM0 Power Out</field>
      <field type="float" name="bcm1_power_out" units="watts">BCM1 Power Out</field>
      <field type="float" name="bcm2_power_out" units="watts">BCM2 Power Out</field>
      <field type="float" name="bcm0_temp" units="degC">BCM0 Temp</field>
      <field type="float" name="bcm1_temp" units="degC">BCM1 Temp</field>
      <field type="float" name="bcm2_temp" units="degC">BCM2 Temp</field>
      <field type="float" name="tether_voltage" units="volts">Tether Voltage</field>
      <field type="float" name="tether_current" units="milliamps">Tether Current</field>
      <field type="float" name="tether_power" units="watts">Tether Power</field>
    </message>
  </messages>
</mavlink>
```