DIY Hexacopter

Assembly and Basic Configuration

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Acknowledgements

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Introduction

These instructions provide the details necessary to build a DIY hexacopter drone with a connected Raspberry Pi companion computer. This UAV is suitable for several experiments, including autonomy, multi-drone coordination, and various other machine learning applications. After completing these instructions, additional applications can be developed and deployed on a ground station or on the companion computer. Note that this is outside the scope of these instructions and is not discussed further.

The diagram below shows the major components of the UAV and their communication channels. Items shaded in black are not discussed in this document.

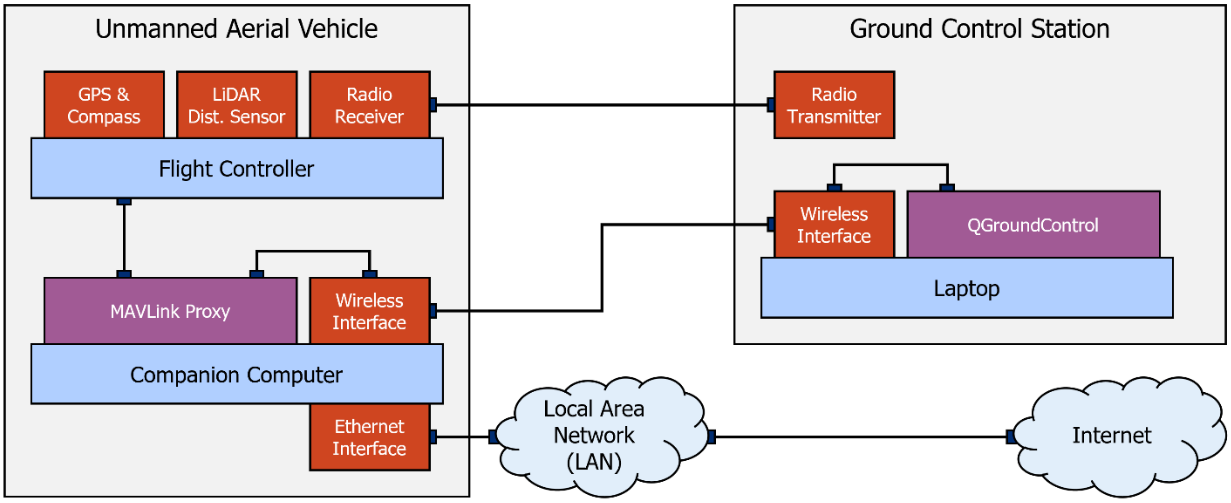

Figure 1 *A diagram showing the major components of the UAV and connected Ground Station*

Inventory

This section contains a complete inventory of the parts needed to assemble the UAV to the specifications in this document. **The total cost of all the components in this list is $1,507.89**.

UAV Frame

The frame of the UAV is a JMT Saker675 hexacopter kit. It is a large platform that can carry a payload of 1.5 kilograms. Its frame supports numerous attachments which makes for a highly versatile platform suitable for a wide range of experiments.

JMT Saker675 675mm Folding Hexacopter (eBay) [1]	**$ 572.55**
16 AWG Stranded Tinned Copper Wire (Amazon)	**$ 28.88**

- ☐ 6x 1. Bag of Motor Components
- ☐ 1x 1.A. Motor
- ☐ 3x 1.B. Male-End Connector
- ☐ 3x 1.C. Female-End Connector
- ☐ 4x 1.D. Long Bolt
- ☐ 4x 1.E. Short Bolt
- ☐ 6x 2. Bag of Motor Housing Components
- ☐ 1x 2.A. Motor Wire Housing
- ☐ 1x 2.B. Motor Mounting Plate
- ☐ 4x 2.C. Long Bolt
- ☐ 4x 2.D. Short Bolt
- ☐ 4x 2.E. Nut
- ☐ 6x 3. Bag of Locking Hinge Components
- ☐ 1x 3.A. Locking Hinge
- ☐ 1x 3.B. Long Bolt
- ☐ 9x 3.C. Short Bolt
- ☐ 1x 3.D. Lock Nut
- ☐ 1x 4. Bag of Frame Plates
- ☐ 1x 4.A. Large Bottom Frame Plate
- ☐ 1x 4.B. Large Top Frame Plate
- ☐ 1x 4.C. Small Bottom Frame Plate
- ☐ 1x 4.D. Small Upper Frame Plate
- ☐ 1x 5. Bag of Drone Frame Components
- ☐ 4x 5.A. Long Spacer
- ☐ 4x 5.B. Short Spacer
- ☐ 4x 5.C. Spacer Bolt

[1] If purchasing from this link, be sure to select the "Pix PNP Kit" option

☐	20x	5.D. Bolt
☐	4x	5.E. Nut
☐	1x	6. Bag of Power Distribution Board Components
☐	1x	6.A. Power Distribution Board
☐	1x	6.B. Flight Controller Mounting Plate
☐	1x	6.C. Flight Controller Power Cable
☐	4x	6.D. Vibration Dampening Spacer
☐	2x	6.E. Double-Sided Adhesive
☐	1x	7. Bag of Landing Skid Mounting Components
☐	2x	7.A. Landing Skid Mounting Block
☐	8x	7.B. Long Bolt
☐	1x	7.C. Medium Bolt
☐	9x	7.D. Short Bolt
☐	10x	7.E. Lock Nut
☐	1x	8. Bag of Landing Skid Components
☐	1x	8.A. Bag of Landing Skid Hardware #1
☐	2x	8.A.1. Tee Connector
☐	2x	8.A.2. Long Bolt
☐	4x	8.A.3. Short Bolt
☐	6x	8.A.4. Nut
☐	1x	8.B. Bag of Landing Skid Hardware #2
☐	2x	8.B.1. Long Bolt
☐	8x	8.B.2. Short Bolt
☐	2x	8.B.3. Nut
☐	2x	8.C. Wide Landing Skid Tube
☐	2x	8.D. Narrow Landing Skid Tube
☐	4x	8.E. Landing Skid Pad
☐	2x	8.F. Landing Skid Mounting Plate
☐	3x	9. Bag of Propellers
☐	1x	9.A. Clockwise Propeller
☐	1x	9.B. Counter-Clockwise Propeller
☐	6x	10. Electronic Speed Controller
☐	6x	11. Arm Tube
☐	1x	12. XT60 to Bare Wire Cable
☐	6x	13. Three-Pin ESC Extension Cable
☐	1x	14. 16-Guage Tinned Copper Wire
☐	1x	15. Large Double-Sided Adhesive

Flight Controller

The flight controller contains the hardware and software necessary to fly the UAV. It controls the motors and processes signals from attached sensors. Additionally, it is capable of executing missions autonomously when coupled with ground control software.

PX4 Flight Controller Pixhawk 2.4.8 32 Bit Flight Control Board (Amazon) [2] **$ 159.99**

- ☐ 1x 16. Pixhawk Flight Controller
- ☐ 1x 17. Bag of Flight Controller Components
- ☐ 1x 17.A. Buzzer
- ☐ 1x 17.B. Arming Switch
- ☐ 1x 17.C. Six Pin Connector
- ☐ 1x 17.D. Three Pin Connector
- ☐ 1x 17.E. MicroSD Card Adapter
- ☐ 1x 18. Bag of I2C Splitter Components
- ☐ 1x 18.A. Four Pin Connector
- ☐ 1x 18.B. I2C Splitter

Companion Computer

The companion computer is a powerful addition to the UAV, and provides the flight controller with advanced offboard computing capabilities. It is capable of exchanging data with the flight controller and a ground station.

GeeekPi Raspberry Pi 4 8GB Starter Kit - 128GB Edition (Amazon) [3] **$ 134.99**

- ☐ 1x 19. Raspberry Pi 4
- ☐ 1x 20. Bag of Fan Components
- ☐ 1x 20.A. Fan
- ☐ 4x 20.B. Spacer Bolts
- ☐ 1x 20.C. Double-Sided Adhesive
- ☐ 2x 21. HDMI to Mini-HDMI Cable
- ☐ 1x 22. Power Cable
- ☐ 1x 23. MicroSD Card Reader
- ☐ 1x 24. MicroSD Card
- ☐ 1x 25. Case with Vented Case Cover
- ☐ 1x 26. Solid Case Cover
- ☐ 4x 27. Fan Screws

[2] Only required if not included with the JMT Saker675 Hexacopter Kit. Not included in the total cost at the beginning of this chapter.

[3] The components in this list and the assembly instructions in this document show the LABIST Raspberry Pi 4B kit, which is no longer available. The link above should provide a suitable replacement; but this has not been verified.

Batteries and Chargers

The UAV has several power requirements. The motors are powered with a lithium polymer battery, while the flight controller and companion computer are powered by a separate USB battery pack. This is to guarantee stable voltage to the latter components and maximize flight time.

Zeee 14.8V 4S Lipo Battery 50C 3300mAh Soft Case Battery with XT60 Plug (Amazon)	**$ 68.99**
HOTA D6 Pro Lipo Charger (Amazon)	**$ 113.08**
Tyrone 18500 Rechargeable Batteries with Charger (Amazon)	**$ 26.77**
Zeee Fireproof Explosionproof Large Capacity Battery Storage Guard Pouch (Amazon)	**$ 14.99**
VR Battery Pack– High Speed 10,000mAh VR Power Bank (Amazon)	**$ 39.99**

- [ ] 2x 28. Lithium Polymer (LiPo) Battery
- [ ] 1x 29. LiPo Battery Charger
- [ ] 1x 29.A. LiPo Battery Charger Power Cable
- [ ] 4x 30. 18500 Battery
- [ ] 1x 31. 18500 Battery Charger
- [ ] 1x 32. Fireproof Battery Bag

Transmitter / Receiver

The transmitter/receiver combination is necessary to manually fly the UAV. With it, an operator can arm the UAV, change flight modes, and fly it in all six directions.

FrSky Taranis X-Lite Pro 2.4GHz 24CH Radio (Amazon)	**$ 228.00**
FrSky Taranis Receiver X8R 8 Channel 2.4ghz (Amazon)	**$ 38.99**

- [ ] 1x 33. Transmitter Case
- [ ] 1x 34. Transmitter
- [ ] 2x 35. Throttle Caps
- [ ] 1x 36. Micro USB Cable
- [ ] 2x 37. Transmitter Endcaps
- [ ] 1x 38. Bag of Parts
- [ ] 1x 38.A. Screwdriver
- [ ] 2x 38.B. Switch Caps
- [ ] 1x 38.C. Heat Shrink Tubing
- [ ] 1x 38.D. Throttle Adjustment Bolt
- [ ] 1x 39. Radio Receiver

GPS & Compass Module

Although the JMT Saker675 kit comes with a GPS module, this is a low-cost upgrade that ensures more accurate and stable measurements. Note that Pixhawk and Ardupilot flight controllers have different connections for their GPS modules; the former uses a six-pin connection while the latter uses a five-pin connection. Ensure that the GPS module has a connection that matches the flight controller, or it will cause permanent damage to its circuitry.

Radiolink M10N GPS SE100 Module (Amazon) **$ 39.99**

- [ ] 1x 40. GPS Module
- [ ] 1x 41. Bag of GPS Components
- [ ] 1x 41.A. Ardupilot Five Pin Adapter
- [ ] 1x 41.B. Extension Bar Top Mounting Plate
- [ ] 1x 41.C. Extension Bar Bottom Mounting Plate
- [ ] 1x 41.D. Extension Bar
- [ ] 1x 41.E. Double Sided Adhesive

LiDAR Module (Optional)

The LiDAR module provides a height estimate on the flight controller, which facilitates landing and hovering modes.

TFmini-s Micro Lidar Module (Amazon) **$ 42.99**

- [ ] 1x 42. LiDAR Module
- [ ] 1x 42.A. 4-Pin Serial Cable (Female 1.25mm connector)
- [ ] 1x 42.B. 4-Pin Serial Cable (Male Dupont connectors)

Miscellaneous Hardware

This hardware is used to extend the frame and remediate minor flaws in the original kit's design.

M4x70mm Bolts (Amazon)	**$ 9.89**
M4x100mm Bolts (Amazon)	**$ 13.79**
M4 Flat Washers (Amazon)	**$ 5.16**
M4 x 0.7mm Nylon Insert Hex Locknuts (Amazon)	**$ 6.49**
M3 Hex Socket Head Cap Screws Bolts Washers Nuts Kit (Amazon)	**$ 9.99**
M2.5x25mm Bolts (Amazon)	**$ 9.09**
M2.5 x 0.45mm Nylon Insert Hex Locknuts (Amazon)	**$ 6.99**
M2.5 Screws Nuts Washers Set (Amazon)	**$ 9.99**

- [ ] 1x 43. M4 70mm Bolt [4]
- [ ] 4x 44. M4 100mm Bolt
- [ ] 10x 45. M4 Flat Washer
- [ ] 5x 46. M4 Lock Nut
- [ ] 16x 47. M3 Lock Washer
- [ ] 16x 48. M3 Flat Washer
- [ ] 2x 49. M2.5 12mm Bolt
- [ ] 8x 50. M2.5 25mm Bolt
- [ ] 14x 51. M2.5 Flat Washer
- [ ] 6x 52. M2.5 Lock Nut
- [ ] 2x 53. M2.5 Nut

Miscellaneous Wires, Connectors, and Cables

During the assembly, additional wire and connectors are necessary to complete the platform.

9 PCS 1.25mm to Dupont 2.54mm Pitch Adapter Cables Wire (Amazon)	**2x @ $ 8.99 each**
Heat Shrink Tubing Kit (Amazon)	**$6.59**
USB-A to Micro USB 2.0 Cable, 480Mbps (Amazon)	**$ 4.88**
USB-A to USB-C Cable, Fast Charging (Amazon)	**$ 9.99**
10pcs USB Cap Port Cover Anti Dust Protector, Silicone (Amazon)	**$ 8.99**

- [ ] 2x 54. Bag of Pre-Made Cables
- [ ] 55. Heat Shrink Tubing
- [ ] 1x 56. USB A to Micro USB Data Cable
- [ ] 1x 57. USB A to USB C Data Cable
- [ ] 2x 58. USB Dust Protector

[4] An M4x65 bolt is a better fit, but more difficult to find.

Miscellaneous Materials

Zip Ties Assorted Sizes (Amazon)	**$ 3.99**
Reusable Fastening Tape Cable Ties 3/4 Inch Double Side Hook Roll (Amazon)	**$ 18.99**
ScotchBlue Original Multi-Surface Painter's Tape, 0.94 Inches x 60 Yards (Amazon)	**$4.88**

- [ ] 59. Small Zip Ties
- [ ] 1x 60. Hook and Pile Tape
- [ ] 1x 61. Painter's Tape

Test Flight Materials

Not explicitly referenced, in order to create a safe test environment that minimizes risk to people and equipment, certain materials will be needed. First, two weights that exceed 1.5 kilograms each (in total, double the maximum payload of the UAV) are needed, along with strong string or small rope. These materials will be used to tether the UAV to the ground, physically limiting its flight area.

3D Printed Components

By adding on to the original frame, the UAV can be outfitted with additional sensors and components. This is for improved quality of life, better component management, and flexibility for future experiments. Instructions for 3D printing these components are not included in this document. The minimum build plate dimensions for the 3D printer must be 22 cm x 15 cm.

https://github.com/JH-UAS-Capstone/Capstone (GitHub)

- [ ] 1x 62. Extension Frame Plate A
- [ ] 1x 63. Extension Frame Plate B
- [ ] 1x 64. Extension Frame Plate C
- [ ] 1x 65. Extension Frame Plate C w/ LiDAR Attachment Point
- [ ] 1x 66. 7.5mm Spacer

Software

Multiple applications are necessary to configure various components on the UAV. These should be downloaded and installed on a laptop computer that will be used throughout these instructions.

QGroundControl – Ground Control Station Software
Raspberry Pi Imager

Tools

Commonly available tools are required to assemble the UAV and its components, including needle-nosed pliers, wire strippers, adjustable pliers, and flat-tipped and cross-tipped screwdrivers. Additionally, 1.5mm, 2mm, 2.5mm, and 3mm hex wrenches are required. Finally, a complete soldering kit is required, including a soldering iron, electrical solder, flux, and so forth.

Arm Assembly

The first step is to assemble the six arms that connect the motors to the body of the drone. Before starting, see an overview of the hexacopter assembly [1] and a detailed guide on how to solder electronic components [2].

Materials List

The item numbers of the components here match the numbers in the inventory section near the beginning of this document. Return all unused components to their original bags, as they may be needed in later steps.

☐	6x	1.A. Motor
☐	18x	1.B. Male-End Connector
☐	24x	1.E. Short Bolt
☐	6x	2.A. Motor Wire Housing
☐	6x	2.B. Motor Mounting Plate
☐	24x	2.C. Long Bolt
☐	24x	2.D. Short Bolt
☐	48x	2.E. Nut
☐	6x	3.A. Locking Hinge
☐	6x	3.B. Long Bolt
☐	6x	3.D. Lock Nut
☐	6x	10. Electronic Speed Controller
☐	6x	11. Arm Tube
☐		14. 16-Guage Tinned Copper Wire
☐		55. Heat Shrink Tubing
☐		59. Small Zip Ties

Instructions

Modify the Motors

The motor is assembled by cutting the wires attached to the motor to the appropriate length, stripping a section of sheathing off each wire, and soldering male-end connectors on to the wire.

1. Cut the three motor wires so that there is 4½ inches of excess, as shown in **Figure 2**.
2. Strip approximately 3/8 inches of sheathing off of each wire [5], and twist the strands of wire together, as shown in **Figure 3**.
3. For each of the three wires:
    a. Apply flux paste to the exposed wire.
    b. Slide heat shrink tubing onto the wire.
    c. Center the wire in the male-end connector so that the end of the wire contacts the bottom of the connector as shown in **Figure 4**, then solder them together as shown in **Figure 5**.
    d. Slide heat shrink tubing over the wire and secure it with a heat gun as shown in **Figure 6**.

Repeat these steps for all six arms. The completed motor assembly is shown in **Figure 7**.

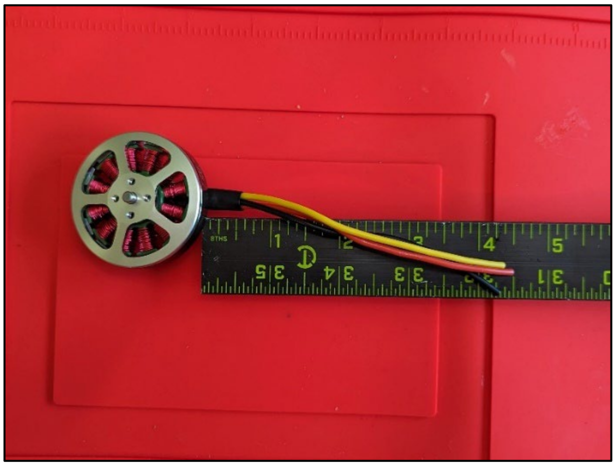

Figure 2 *Motor with wires cut to approximately 4½ inches*

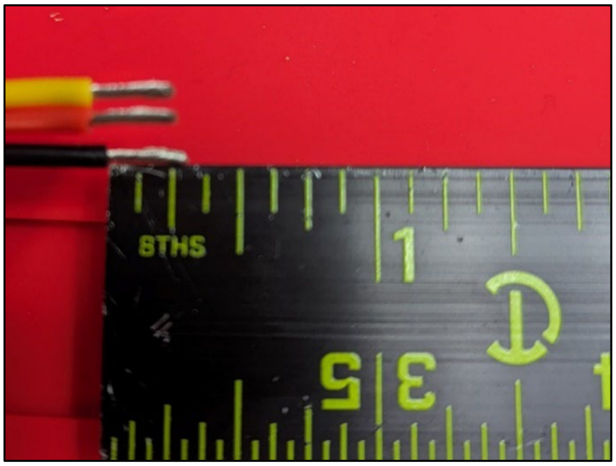

Figure 3 *Ends of stripped motor wires*

[5] Stranded wire can easily break; a good technique is to rotate the wire cutters around while applying light pressure to cut the sheathing. Then, remove the wire cutters and use your fingers to gently remove the cut portion of sheathing.

Figure 4 *Motor wire centered in the male-end connector*

Figure 5 *Motor wire soldered to the male-end connector*

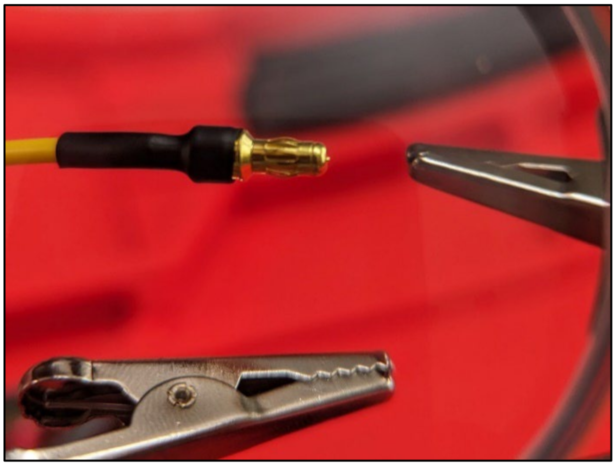

Figure 6 *Heat shrink tubing applied to connector*

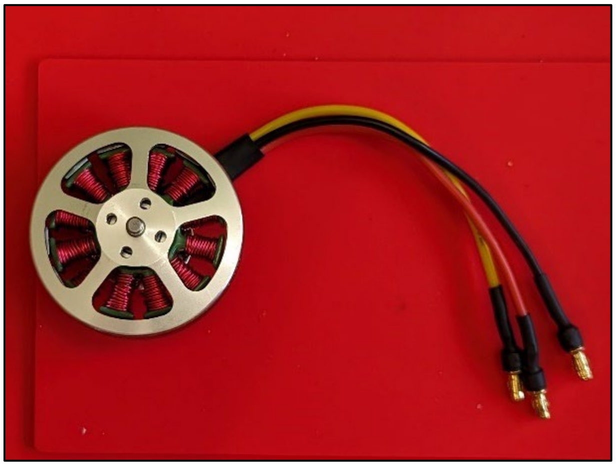

Figure 7 *The completed motor assembly*

Modify the Electronic Speed Controllers

Assembling the Electronic Speed Controller (ESC) is straightforward and involves extending the length of the wires so that it can be connected to components on the drone body.

1. Cut one piece each of red and black 16-gauge wire [6] to approximately 18 inches.
2. Strip approximately ¾ inches of sheathing from the end of the red and black wire pair attached to the ESC.
3. Strip approximately ¾ inches of sheathing from one end of the lengths of additional wire.
4. For each of the two wires on the ESC:
   a. Apply flux paste to the exposed end of the ESC wire and additional length of wire.
   b. Solder the wires together; one technique is shown in **Figure 8** and **Figure 9**.
   c. Slide approximately 1½ inches of heat shrink tubing over the exposed wire and secure in place with a heat gun.

Repeat these steps for all six arms. The completed ESC assembly is shown in **Figure 10**.

Figure 8 *Additional wire twisted around the ESC wire*

Figure 9 *ESC wire and extension soldered together*

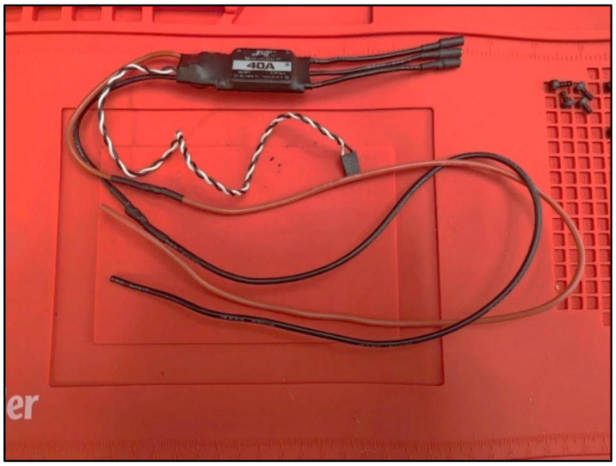

Figure 10 *The completed ESC assembly*

[6] These wires will be cut to their final length in later steps of the assembly process.

Assemble the Motor Arms

This step involves mounting the motor and ESC assemblies to the drone arm. Be patient; it can be challenging to get all of the wires positioned so that they fit in the housing. Each arm has a unique configuration, defined in **Table 1**.

Arm Label	Arm Position	Wire Housing Color	Motor Spin Direction
M1	Mid Right	Black	Clockwise
M2	Mid Left	Black	Counterclockwise
M3	Front Left	Red	Clockwise
M4	Back Right	Black	Counterclockwise
M5	Front Right	Red	Counterclockwise
M6	Back Left	Black	Clockwise

***Table 1** Arm Configurations*

The arm labels in **Table 1** reference the original instructions provided with the JMT Saker675 Hexacopter Kit, shown in **Figure 11**. In order to make the motor spin clockwise or counterclockwise, the motor wires need to be connected to the ESC in a particular order. The connections to spin the motor clockwise are listed in **Table 2** and those to spin the motor counterclockwise are listed in **Table 3**.

ESC Wire	Motor Wire
A	Red
B	Yellow
C	Black

***Table 2** Clockwise Spin Connections*

ESC Wire	Motor Wire
A	Black
B	Yellow
C	Red

***Table 3** Counterclockwise Spin Connections*

Pay attention to these configurations, as it is very difficult to correct them later in the assembly process.

1. Clean out the pilot holes on each side of the arm tube with a round file.
2. Connect the arm tube to the motor wire housing [7], noting the orientation shown in **Figure 12** [8].
3. Route the red, black, and braided black/white wires from the ESC through the wiring housing and the arm tube as shown in **Figure 13** [9]; take note of the orientation of the ESC and its wire groups.
4. Zip-tie the ESC to the motor wire housing to prevent it from disconnecting during flight.
5. Attach the motor to the mounting plate using four short bolts (1.E) with a 2.5mm hex wrench, ensuring that the wires are pointed towards one of the short sides of the mounting plate, as shown in **Figure 14**.
6. Route the red, yellow, and black wires on the motor through the opening on the motor wire housing closest to the arm tube. The wires should be routed from bottom to top as shown in

---

[7] You may need to use pliers or a small flathead screwdriver to open the jaws of the motor wiring housing so that they fit around the arm tube.

[8] There are holes that go through each side of the arm tube. The correct hole is approximately $^5/_8$ inches from the end; the incorrect hole is approximately $^3/_8$ inches from the end.

[9] Note that in this figure, the bottom of the motor wire housing is facing up; the indentations to secure the nuts are visible.

Figure 15 [10] [11]. Note the orientation of the motor, motor wires, and ESC wires.

7. Connect the motor to the ESC [12] [13] as described in **Table 2** and **Table 3**. The wires need to be routed between the heads of the bolts that attach the motor to the motor mounting plate, as shown in **Figure 16**.
8. The motor mounting plate should sit flush with the top of the motor wire housing. Hold the plate in position and gently pull on each of the wires to ensure that the bolt heads are not clamping them to the bottom of the housing. If positioned correctly, the wires should slide freely back and forth inside the housing.
9. Attach the motor mounting plate to the motor wire housing using the four long bolts (2.C) with a 2mm hex wrench and secure each bolt with a nut (2.E).
10. Secure the wiring housing to the arm tube by inserting the four short bolts (2.D) with a 2mm hex wrench. Secure the bolts [14] with a nut (2.E) [15]; they match the indentations on the motor wiring housing.
11. Ensure that none of the wiring touches the silver moving component of the motor by securing them to the wiring housing with a zip tie, as shown in **Figure 17**.

Repeat these steps for all six arms. The completed arm assembly is shown in **Figure 18**.

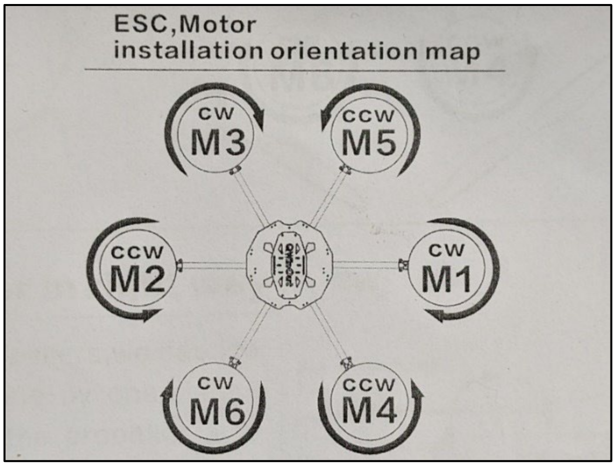

Figure 11 *ESC, Motor Installation Orientation Map*

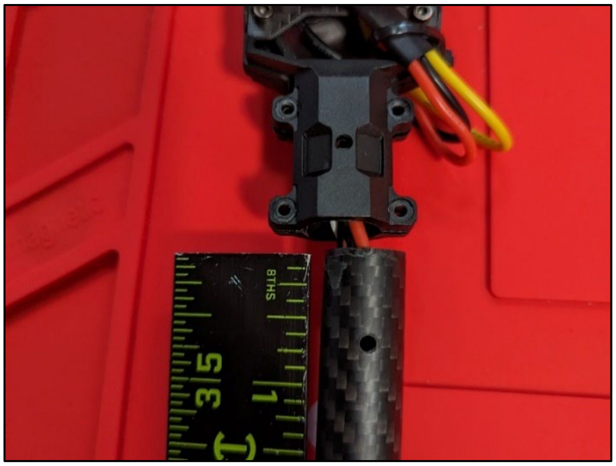

Figure 12 *The correct orientation of the arm tube*

[10] Note that in this figure, the top of the motor wire housing is facing up; the indentations to secure the nuts are not visible.

[11] Optionally, route the motor wires on three of the arms (two black and one red) from the opposite side to give the drone a symmetrical appearance.

[12] The connections depend on the motor spin direction, described in **Table 2** and **Table 3**.

[13] It is helpful to label each arm with the motor's direction or arm label to prevent confusion in further steps.

[14] Ensure that all four bolts are threaded into the nut before tightening all the way. Do not over-tighten the bolts or you risk damaging the wiring housing. The jaws of the wiring housing may not close all the way around the arm tube.

[15] You can press the nuts into the matching cutouts on the wiring housing with a pair of adjustable pliers to secure them into place before inserting the bolts.

Figure 13 *ESC wires fed through the housing and arm*

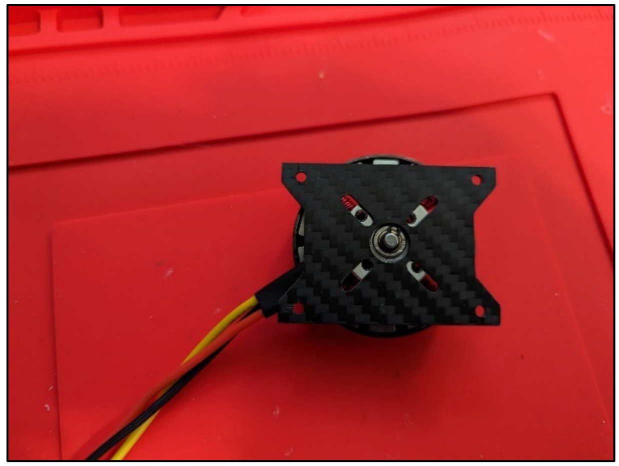

Figure 14 *Motor attached to motor mounting plate*

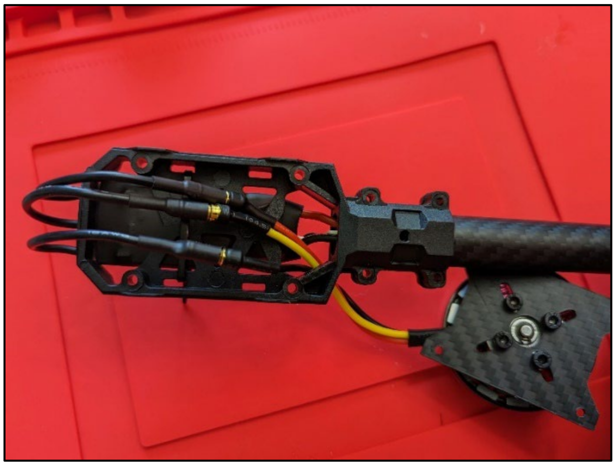

Figure 15 *Motor wires connected in the housing*

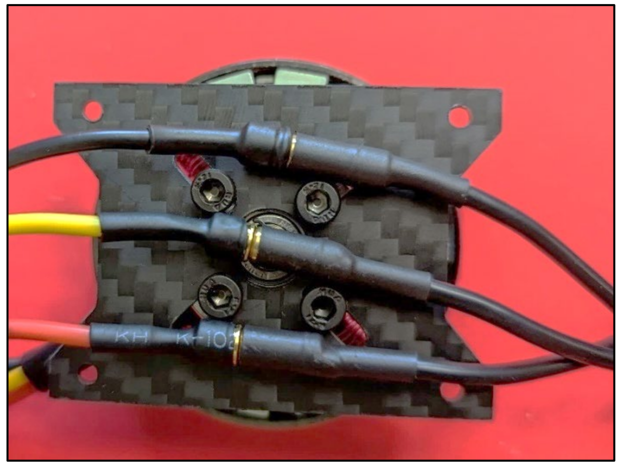

Figure 16 *Example routing of wires around bolt heads*

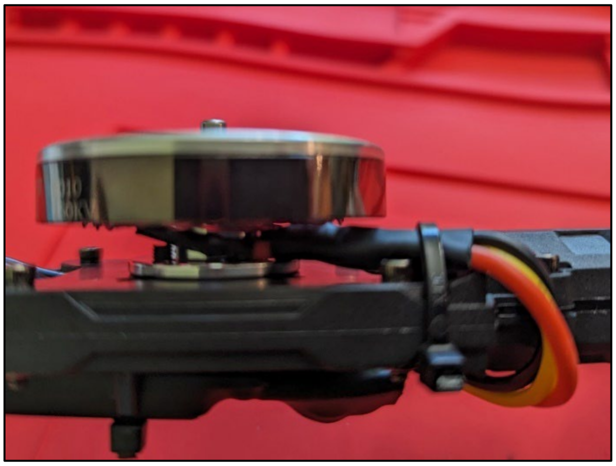

Figure 17 *Motor wiring zip-tied to the housing*

Figure 18 *The completed arm assembly*

Attach the Locking Hinges

The hexacopter arms are designed to fold down using a locking hinge mechanism.

WARNING: The locking mechanism can pinch or cut the loose black and white braided ESC wires, requiring complete disassembly and repair. Be careful when changing the arm position!

1. Separate the two parts of the locking hinge assembly by unscrewing the bolt from the brass-colored barrel nut using a 1.5mm hex wrench, as shown in **Figure 19**.
2. Thread the red, black, and braided white and black ESC wires through the small part [16] of the locking hinge as shown in **Figure 20**.
3. Insert the long bolt (3.B) through the small part of the locking hinge and secure it with the lock nut (3.D) [17] [18] using a 1.5mm or 2mm hex wrench (depending on the variation of the hinge provided in the kit), taking note of the orientation in **Figure 21**.
4. Reassemble the locking hinge by lining up the large holes in both parts [19], inserting the barrel nut, and re-threading the bolt. Note the position of the ESC wires shown in **Figure 22** and the orientation of the components shown in **Figure 24**.
5. Zip-tie the wires together to minimize the risk of the hinge mechanism damaging the ESC cable, as shown in **Figure 23** [20].

Test the locking mechanism by pulling back on the red handles and moving the arm until it locks into to up and down positions [21] as shown in **Figure 24** and **Figure 25**, respectively.

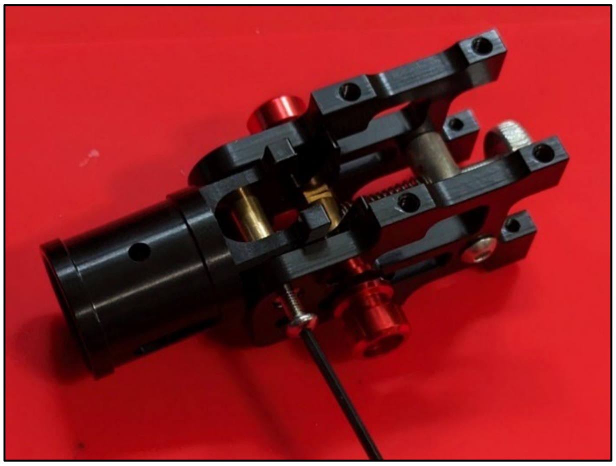

Figure 19 *Screw to remove from the locking hinge*

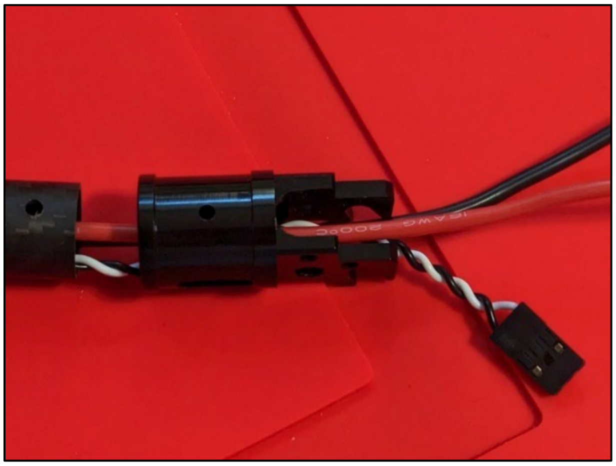

Figure 20 *ESC wires routed through the locking hinge*

[16] It is easiest to push the black and white braided wire through first, then follow with the red and black wires. Take note of the square arm tube stop inside the hinge piece; use a pair of needle-nosed pliers to gently pull the braided wires through.

[17] The lock nut is small enough that you can hold it with a pair of pliers while threading the bolt into it.

[18] The gasket inside the lock nut should face away from the locking hinge assembly.

[19] It may be necessary to pull back slightly on the red handles to align the holes properly. Make sure to avoid pressing on the silver disc in the back of the hinge assembly with your hand, or the mechanism will not move.

[20] Note the damage to the white wire in the bottom middle of this image, resulting from being pinched while the arm was down.

[21] If the mechanism does not lock in place, it is likely that you have installed the arm side of the hinge upside down. The motor should be facing up, and the hooks pointing down.

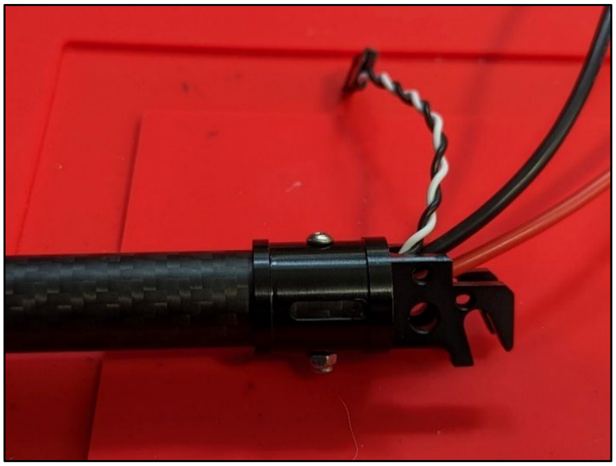

Figure 21 *Small hinge piece secured to the arm tube*

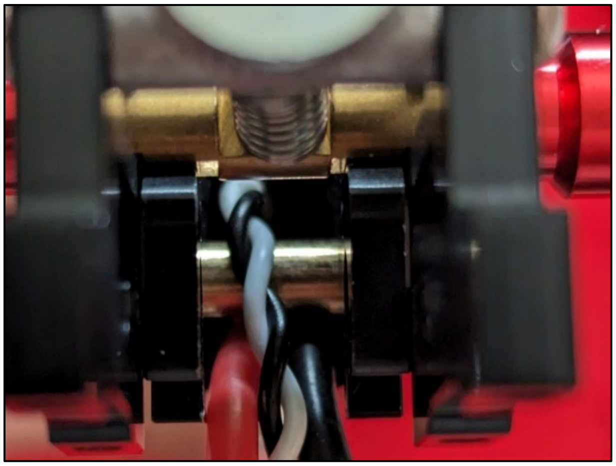

Figure 22 *ESC wires routed around the barrel nut*

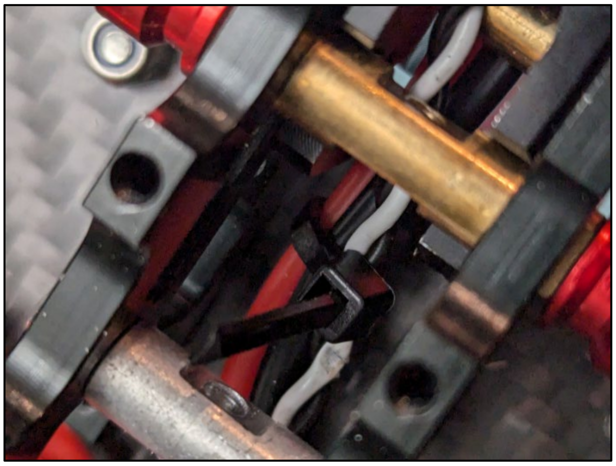

Figure 23 *ESC wire bundle secured with a zip tie*

Figure 24 *Hinge locked in the "up" position*

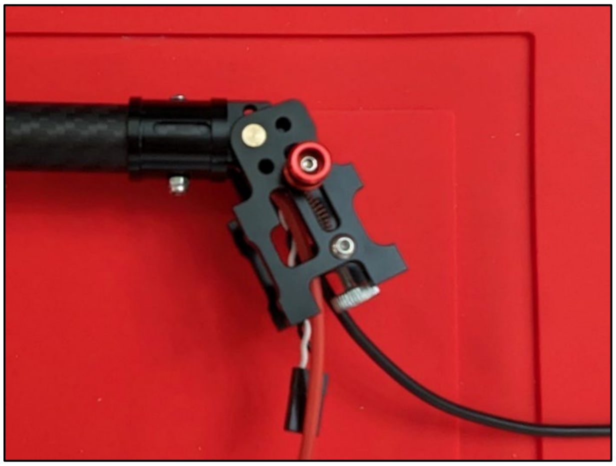

Figure 25 *Hinge locked in the "down" position*

Conclusion

At the end of this chapter, you should have six drone arms with motors, ESCs, and locking hinges attached. Optionally, each arm is labeled with its motor rotation direction or label according to the instructions provided with the kit, as shown in **Figure 26**. In the next chapter, you will assemble the body of the drone and connect the arms to it.

Figure 26 *The six completed arms with motors, ESCs, and locking hinges*

Landing Skids and Power Distribution

The power distribution board (PDB) provides power to the drone and its components. The arms completed in the previous chapter and landing skids will also be attached. Before starting, review references [1] and [2].

Materials List

The item numbers of the components here match the numbers in the inventory section near the beginning of this document. Return all unused components to their original bags, as they may be needed in later steps.

- [ ] 24x 3.C. Short Bolt
- [ ] 1x 4.A. Large Bottom Frame Plate
- [ ] 4x 5.C. Spacer Bolt
- [ ] 20x 5.D. Bolt
- [ ] 4x 5.E. Nut
- [ ] 1x 6.A. Power Distribution Board
- [ ] 2x 7.A. Landing Skid Mounting Block
- [ ] 8x 7.B. Long Bolt
- [ ] 1x 7.C. Medium Bolt
- [ ] 9x 7.D. Short Bolt
- [ ] 10x 7.E. Lock Nut
- [ ] 2x 8.A.1. Tee Connector
- [ ] 2x 8.A.2. Long Bolt
- [ ] 4x 8.A.3. Short Bolt
- [ ] 6x 8.A.4. Nut
- [ ] 2x 8.B.1. Long Bolt
- [ ] 8x 8.B.2. Short Bolt
- [ ] 2x 8.B.3. Nut
- [ ] 2x 8.C. Wide Landing Skid Tube
- [ ] 2x 8.D. Narrow Landing Skid Tube
- [ ] 4x 8.E. Landing Skid Pad
- [ ] 2x 8.F. Landing Skid Mounting Plate
- [ ] 1x 12. XT60 to Bare Wire Cable
- [ ] 1x 28. Lithium Polymer (LiPo) Battery
- [ ] 1x 29. LiPo Battery Charger
- [ ] 1x 29.A. LiPo Battery Charger Power Cable
- [ ] 6x Arm Assembly

Instructions

Assemble the Landing Skids

Installing the landing skids before the other components elevates the large bottom plate off the ground and provides a level working surface for attaching and soldering the PDB components.

1. Clean out the pilot holes on the wide landing skid tubes with a small round file.
2. For each of the two landing skids…
   a. Attach the landing skid mounting plate to the landing skid mounting block using four short bolts (7.D) [22] as shown in **Figure 27** and **Figure 28**.
   b. Attach a wide landing skid tube to the mounting plate using a long bolt (8.B.1) and nut (8.B.3) [23] as shown in **Figure 29**.
   c. Slide a narrow landing skid tube into the tee-shaped landing skid connector and center it [24]. Slide a long bolt (8.A.2) through the hole and loosely [25] secure it with a nut (8.A.4) as shown in **Figure 30**.
   d. Slide landing skid pads on each side of the exposed narrow arm tube as shown in **Figure 31**.
   e. Slide the wide landing skid tube into the tee connector [26]. Tighten the long bolt (8.A.2) and secure the connector with two short bolts (8.A.3) and nuts (8.A.4) as shown in **Figure 32**.

The completed landing skid assembly is shown in **Figure 33**.

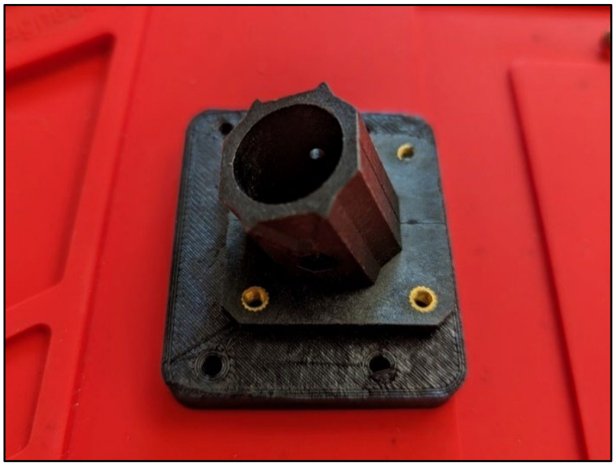

***Figure 27** Mounting plate on mounting block*

***Figure 28** Mounting plate secured with four bolts*

[22] Enlarge the holes slightly with a small round file if necessary.

[23] There are circular and hexagonal indentations that match up to the bolt and nut sides of the mounting plate.

[24] Use a landing skid pad on each side of the narrow arm tube to gauge where the center point is.

[25] If you tighten the bolt all the way, you will not be able to get the wide landing skid tube to slide into the connector.

[26] Align the landing skid in the connector plate by laying the skids and edge of the connector plate flat on a table.

Figure 29 *Landing skid tube secured to mounting plate*

Figure 30 *Tee connector on narrow landing skid tube*

Figure 31 *Landing skid pad on narrow landing skid tube*

Figure 32 *Landing skid secured to wide landing skid tube*

Figure 33 *Completed landing skid*

Solder the XT60 Connector

The XT60 connector transfers power from the lithium polymer battery through the power distribution board to the electronic speed controllers.

1. Apply a bead of solder to the VCC and GND pads on the PDB.
2. Solder the power cable to the power distribution board. The red wire should touch the VCC contact, and the black wire should touch the GND contact, as shown in **Figure 34**.

The completed power distribution board assembly is shown in **Figure 35**.

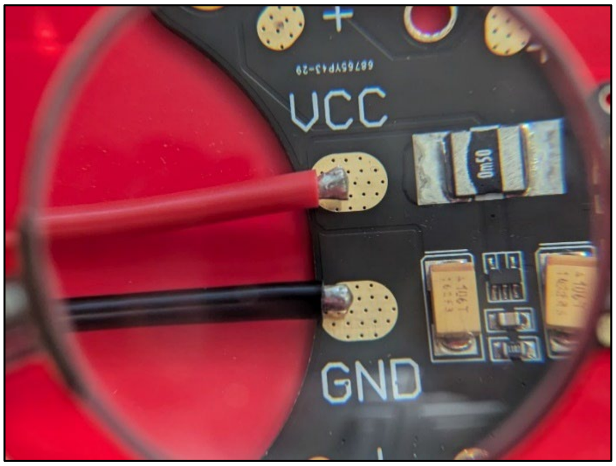

__Figure 34__ Power cable position

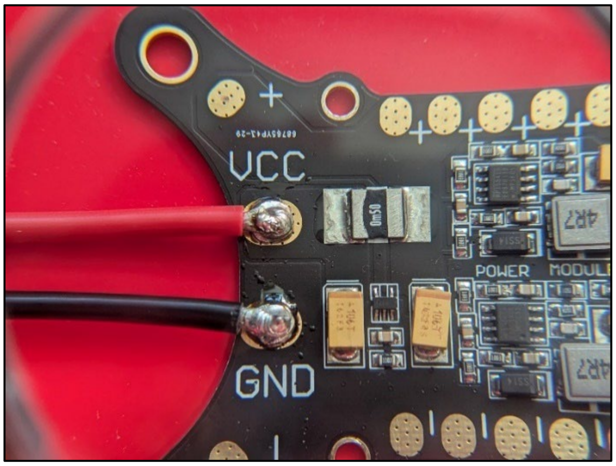

__Figure 35__ Power cable soldered to PDB

Assemble the Bottom Frame

The power distribution board is centrally mounted on the large bottom frame plate and provides primary power to the motors, as well as secondary power to the flight controller.

1. Attach the six arms [27] that were assembled previously using four short bolts (3.C) each and a 2mm hex wrench as shown in **Figure 36**.
2. Attach the two landing skids to the large bottom plate with four long bolts (7.B) and lock nuts (7.E) each as shown in **Figure 37**.
3. Secure the power distribution board to the large bottom plate by threading four bolts (5.D) into the spacer bolts using a 2mm hex wrench as shown in **Figure 38**.
4. Insert the spacer bolts into the corresponding holes on the bottom plate and threading a nut (5.E) to each one [28] as shown in **Figure 39**.

[27] The red arms are oriented towards the front of the drone; the VCC and GND contacts are oriented towards the back.

[28] Be careful with the spacer bolt, as it is plastic. Use a 5½ mm socket wrench to help secure the nut; do not over-tighten.

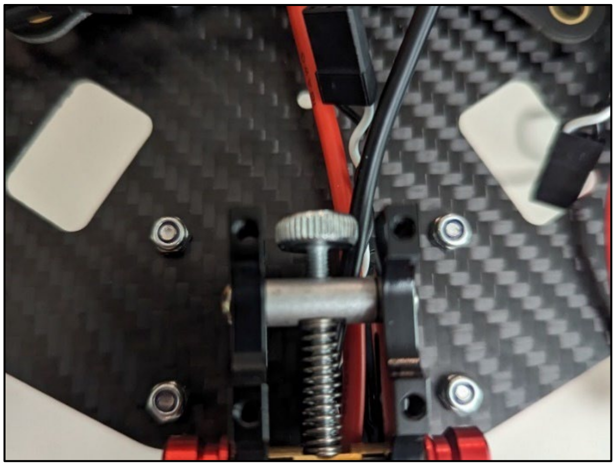

Figure 36 *Arm attached to the bottom plate*

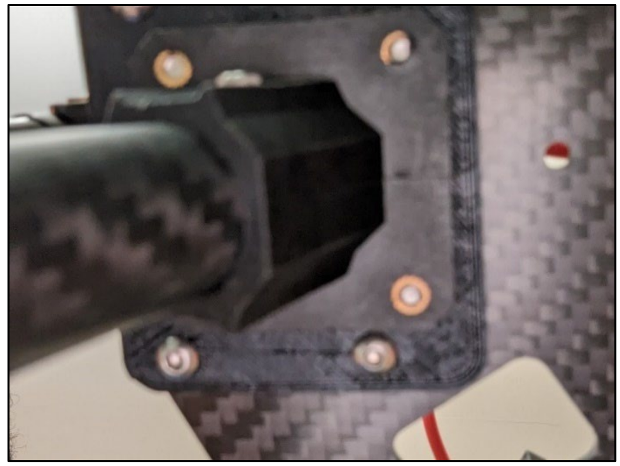

Figure 37 *Landing skid attached to the bottom plate*

Figure 38 *Spacer bolt secured to power distribution board*

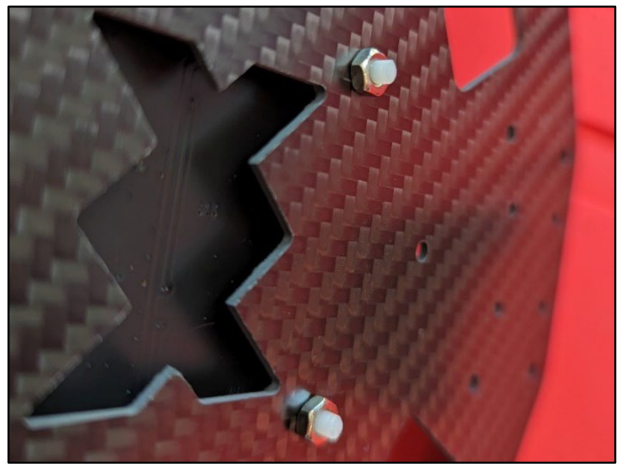

Figure 39 *Spacer bolt secured to bottom plate with nut*

Solder the Electronic Speed Controller Wires

Now that the PDB is resting on a stable platform, attach the ESCs to the PDB.

1. Apply a small amount of solder to each of the 12 pads on the PDB as shown in **Figure 40**.
2. Flux and apply solder to the exposed ends of each wire as shown in **Figure 41**. Ensure that the red and black wires for each ESC occupy pads that are directly opposite each other.
3. Solder each ESC's red and black wires to their corresponding pads [29] as shown in **Figure 42** and **Figure 43**.

The completed power distribution board, with excess cable secured, is shown in **Figure 44**.

[29] Perform a dry run before soldering any wires, as you will not get another chance to correct mistakes after they are all attached. Ensure that the wires can route the way that you want them to go and then trim any excess wire away. Pay close attention that each ESC's red and black wires are in the same position on the positive and negative sides of the PDB.

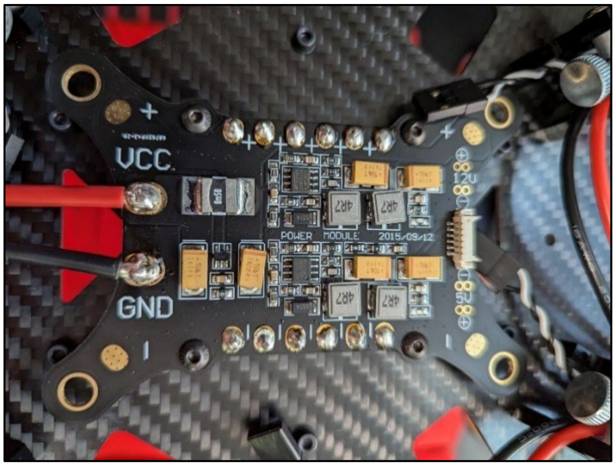

__Figure 40__ Solder applied to PDB contacts

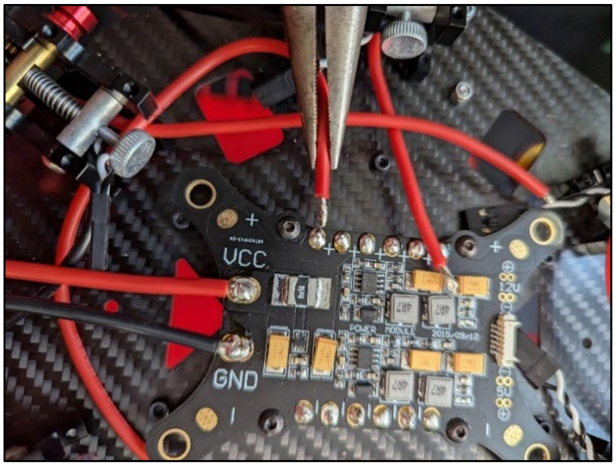

__Figure 41__ Exposed wire with flux and solder applied

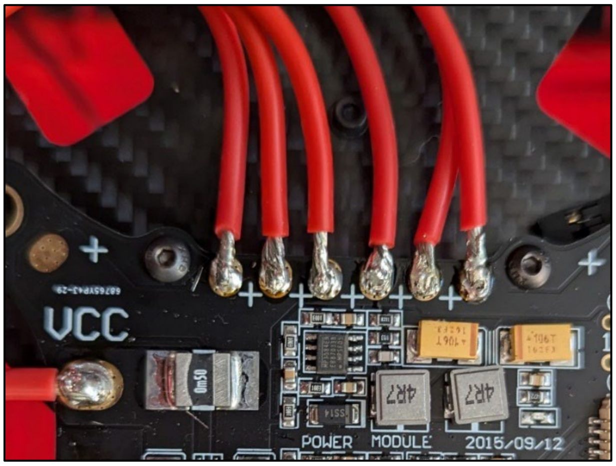

__Figure 42__ Red wires soldered to the PDB

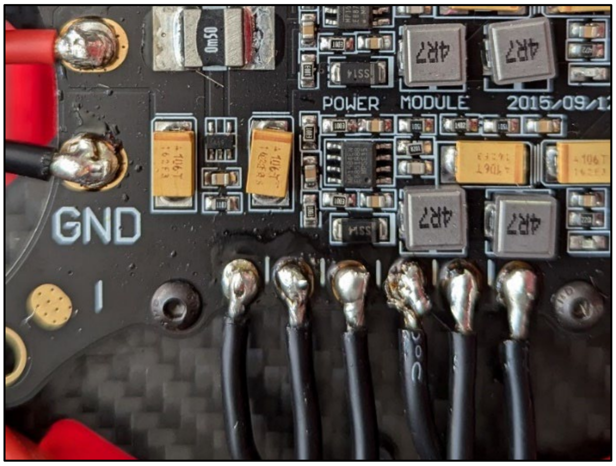

__Figure 43__ Black wires soldered to the PDB

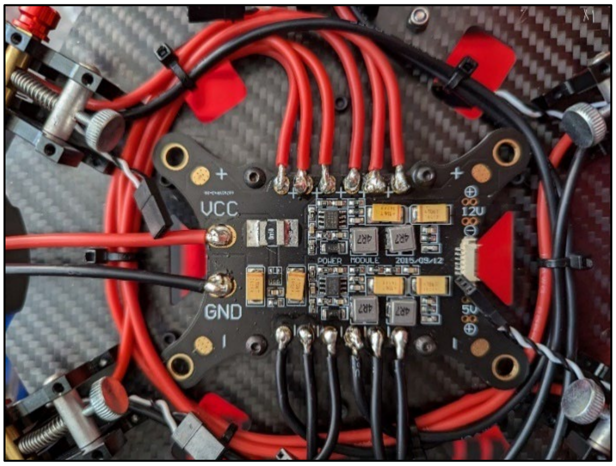

__Figure 44__ Excess wire secured neatly with zip ties

Test the Power Distribution Board

Charge a LiPo battery according to the instructions in **Appendix C. Charging a Lithium Polymer Battery** (a full charge is not required, nor advised). Plug in a charged LiPo battery to the XT60 connector. If successful, each ESC should emit a sound once every second and the motors should twitch slightly. Check that the motors move in the correct direction (clockwise or counterclockwise).

Make sure to return the LiPo battery to a storage voltage once the test is complete.

Conclusion

At the end of this chapter, you should have something that now resembles a drone with arms and power distribution, as shown in **Figure 45**.

Figure 45 *The UAV frame with arms, landing skids, and power distribution components attached*

Lower Frame Components

Assembling the lower body involves installing points of attachment for components under the UAV, as well as the mounting plate for the flight controller. At the end of this chapter, the drone will be ready to attach and configure the flight controller.

Materials List

The item numbers of the components here match the numbers in the inventory section near the beginning of this document. Return all unused components to their original bags, as they may be needed in later steps.

- ☐ 1x 6.B. Flight Controller Mounting Plate
- ☐ 1x 6.C. Flight Controller Power Cable
- ☐ 4x 6.D. Vibration Dampening Spacer
- ☐ 6x 13. Three-Pin ESC Extension Cable
- ☐ 1x 43. M4 70mm Bolt
- ☐ 4x 44. M4 100mm Bolt
- ☐ 10x 45. M4 Flat Washer
- ☐ 5x 46. M4 Lock Nut
- ☐ 6x 50. M2.5 25mm Bolt
- ☐ 12x 51. M2.5 Flat Washer
- ☐ 6x 52. M2.5 Lock Nut
- ☐ 1x 62. Extension Frame Plate A
- ☐ 1x 63. Extension Frame Plate B
- ☐ 1x 64. Extension Frame Plate C **or**
- ☐ 1x 65. Extension Frame Plate C w/ LiDAR Attachment Point
- ☐ 1x 66. 7.5mm Spacer

Instructions

Attach the Bottom Extension Frame

The bottom extension frame secures the companion computer and batteries to the body of the UAV. If you intend to install the LiDAR described in **Distance Sensor (LiDAR)** on **page 65**, use the version of plate C that has the attachment point. If you change your mind later, the plates can be switched out relatively easily. Note that each plate has a letter engraved on it, which should be facing up towards the frame of the UAV.

1. Super glue five M4 washers in the larger indents [30] on the top of extension frame plate A as shown in **Figure 46**.

[30] Once extension plate A is attached to the UAV frame, there will not be room to easily install the M4 washers.

2. Thread a M2.5 washer on two M2.5x25mm bolts and thread them through the center holes on the large bottom frame plate. One hole is in-line with the XT60 connector wires, and the other is opposite it, near the center of the short side of the PDB.
3. Starting with the two middle holes, then the outer four, secure extension frame plate A [31] to the two bolts with M2.5 washers and M2.5 lock nuts as shown in **Figure 48**. Do not tighten the nuts past the nylon gasket until all six are threaded on [32].
4. Once all the bolts are correctly aligned, tighten (but do not over-tighten) the six M2.5 lock nuts using a pair of adjustable pliers. The result of this step is shown in.
5. Thread the 7.5mm spacer [33] on the M4x70mm bolt, then thread the bolt up through the hole at the rear of the extension frame plate B into the corresponding hole on extension plate A as shown in **Figure 49**.
6. Thread four M4x100mm bolts through the remaining holes in extension frame plates C, B, and A as shown in **Figure 50**.
7. Secure the M4 bolts with five M4 lock nuts loosely as shown in **Figure 51**; once all five are threaded on to the bolts, tighten the lock nuts.

The completed bottom extension frame is shown in **Figure 52**.

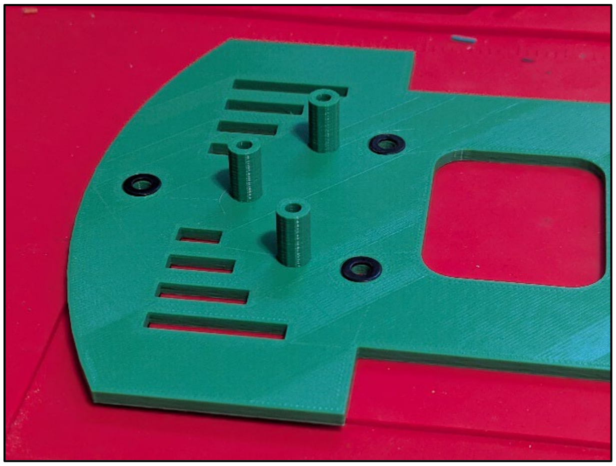

Figure 46 *Plate A with washers installed*

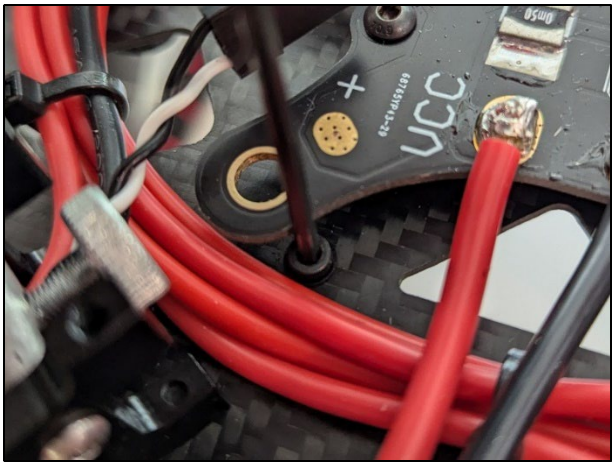

Figure 47 *Inserting the M2.5 bolt near the PDB's wing*

[31] The text on each plate should be facing up, towards the existing UAV frame.

[32] Tightening the nuts all the way before all six bolts are threaded through the extension plate will make it difficult to align the remaining four bolts.

[33] Do not include the spacer if using a M4x65 bolt.

Figure 48 *Attaching Plate A to the UAV frame*

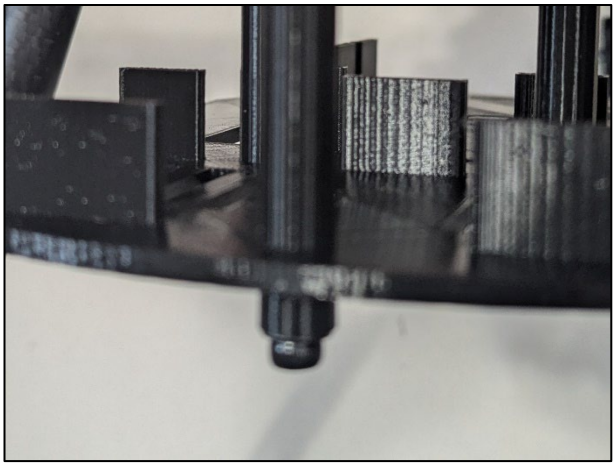

Figure 49 *Attaching spacer and Plate B*

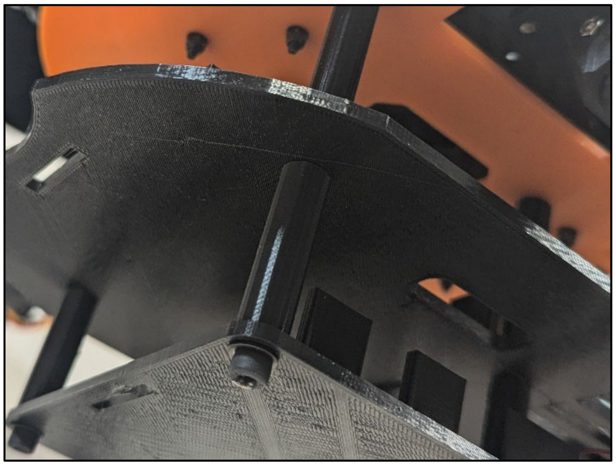

Figure 50 *M4 bolts supporting bottom extension frame*

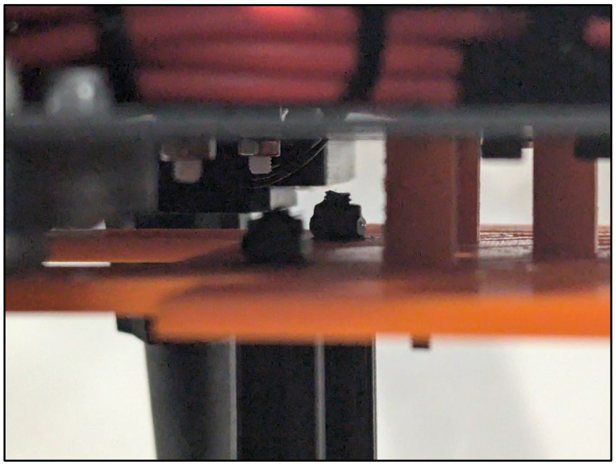

Figure 51 *M4 lock nuts securing extension frame plates*

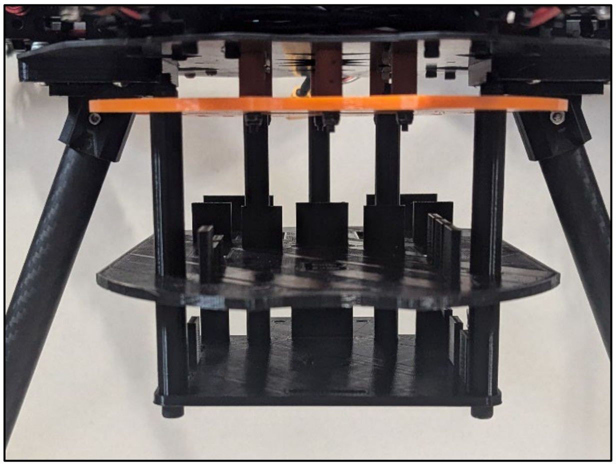

Figure 52 *The completed bottom extension frame*

Attach the Flight Controller Mounting Plate

The flight controller is mounted to a vibration-dampening plate above the power distribution board.

1. Attach four vibration-dampening spacers to the mounting plate as shown in **Figure 53**.
2. Install the flight controller power cable as shown in **Figure 54**.
3. Attached the flight controller mounting plate to the power distribution board by attaching the spacers to the holes in the wings [34] as shown in **Figure 55**.
4. Attach an ESC extension cable to each black and white braided wire pair, ensuring that the colors match, as shown in **Figure 56**.

The completed assembly is shown in **Figure 57**.

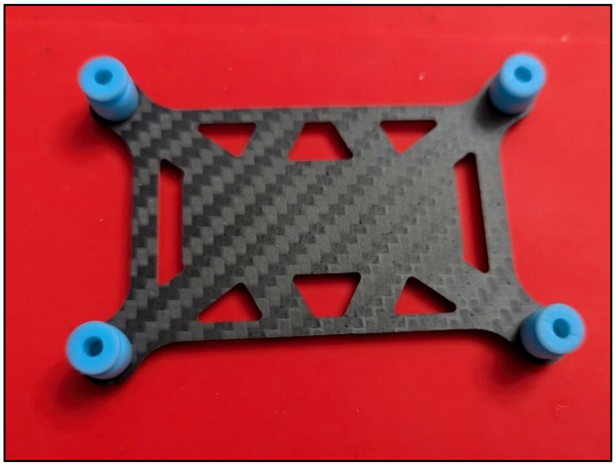

Figure 53 *Spacers attached to mounting plate*

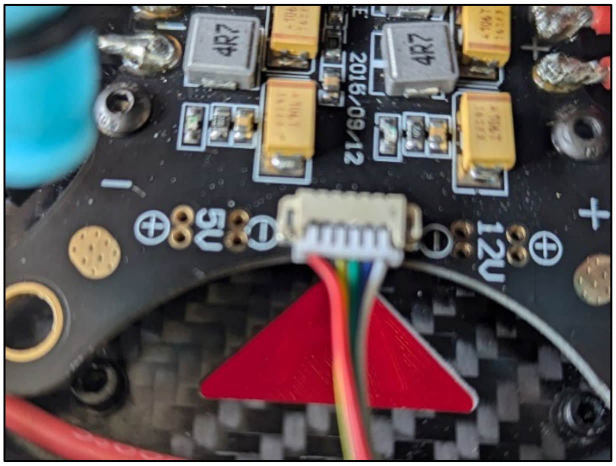

Figure 54 *Attaching flight controller power cable to PDB*

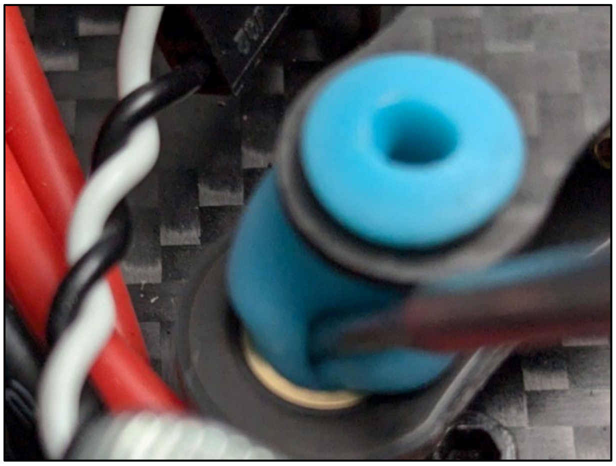

Figure 55 *Attaching mounting plate to PDB*

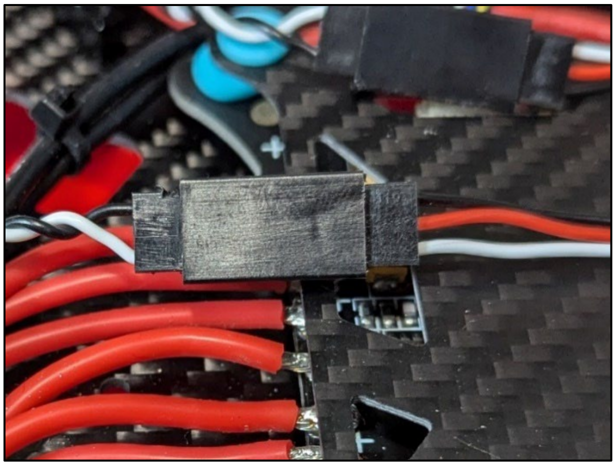

Figure 56 *Extension cable attached to ESC*

[34] The spacers can be pushed into the holes on the PDB using a flat-tipped screwdriver. Ensure that the spacer is pushed in evenly, all the way around so that it doesn't come loose later.

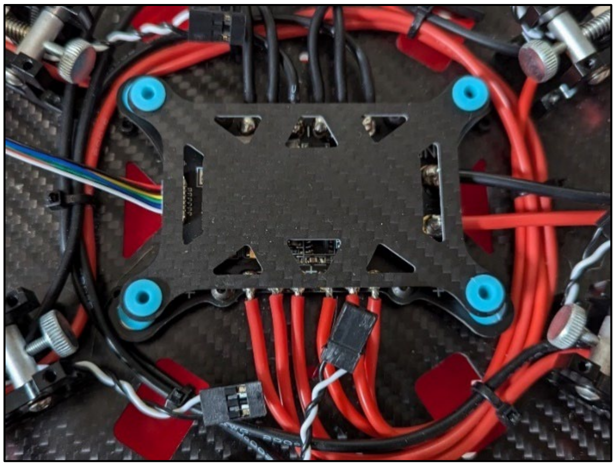

Figure 57 *Completed flight controller mounting plate*

Conclusion

At the end of this relatively short chapter, you have completed the bottom half of the drone, as shown in **Figure 58** [35]. In the next chapter, you will attach and configure the flight controller.

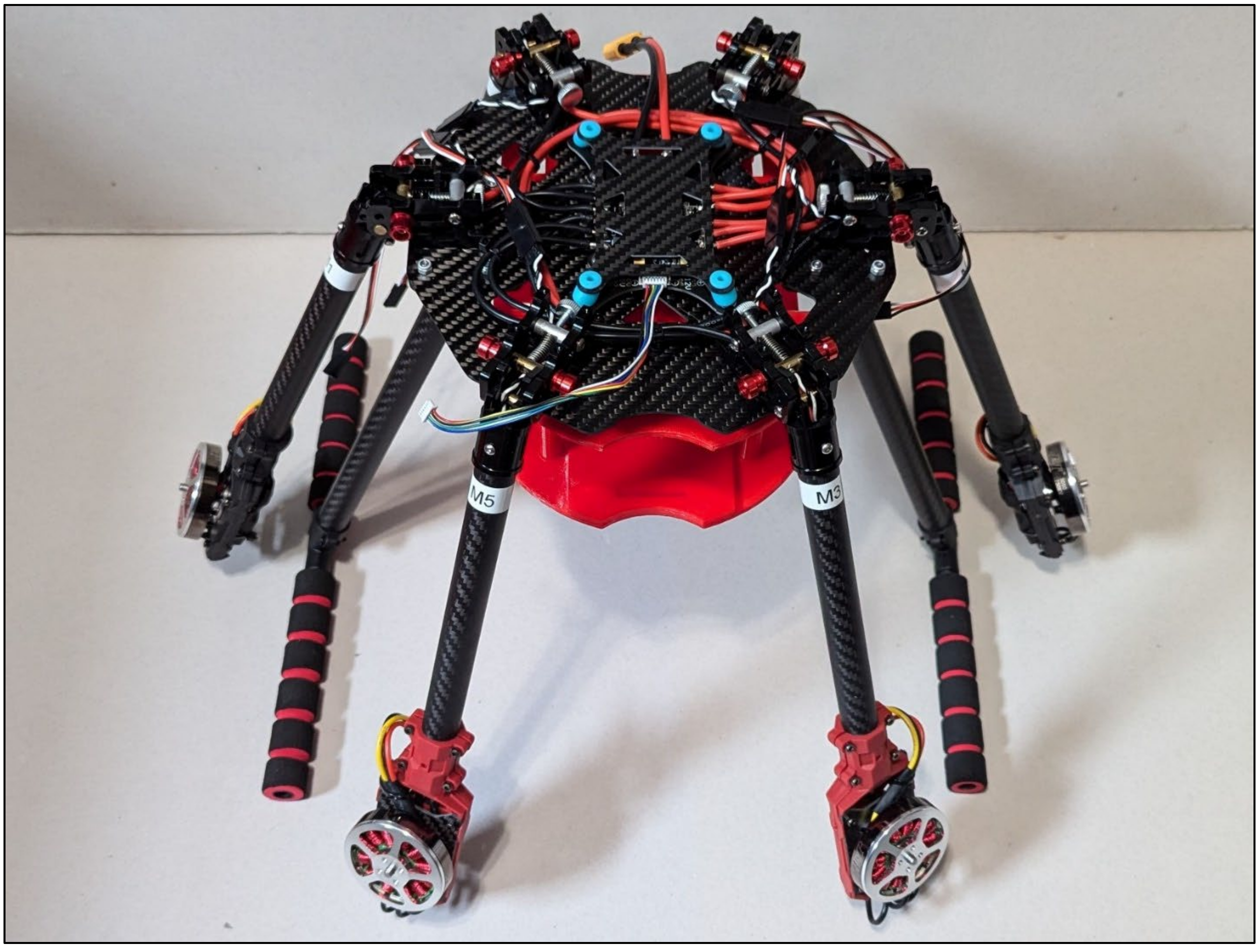

Figure 58 *The UAV with completed bottom attachment points and flight controller mounting plate*

[35] Note that the blue and green labels with the motor direction on each arm are missing from this picture. They were replaced with white labels showing the arm's alphanumeric designation, as identified in **Table 1**.

Flight Controller and Primary Sensors

The goal of this chapter is to set up the UAV to execute a basic test flight. This will bring us to a "90%" solution, which will be further improved in later chapters.

Materials List

The item numbers of the components here match the numbers in the inventory section near the beginning of this document. Return all unused components to their original bags, as they may be needed in later steps.

- [ ] 16x 1.D. Long Bolt
- [ ] 24x 3.C. Short Bolt
- [ ] 1x 4.B. Large Top Frame Plate
- [ ] 3x 9.A. Clockwise Propeller
- [ ] 3x 9.B. Counter-Clockwise Propeller
- [ ] 1x 15. Large Double-Sided Adhesive
- [ ] 1x 16. Pixhawk Flight Controller
- [ ] 1x 17.A. Buzzer
- [ ] 1x 28. Lithium Polymer (LiPo) Battery
- [ ] 2x 30. 18500 Battery
- [ ] 1x 34. Transmitter
- [ ] 2x 35. Throttle Caps
- [ ] 1x 38.D. Throttle Adjustment Bolt
- [ ] 1x 39. Radio Receiver
- [ ] 1x 40. GPS Module
- [ ] 12x 47. M3 Lock Washer
- [ ] 12x 48. M3 Flat Washer
- [ ] 1x 56. USB A to Micro USB Data Cable
- [ ] 1x 58. USB Dust Protector
- [ ] 60. Hook and Pile Tape

Instructions

Attach Sensors to the Flight Controller

The flight controller is a piece of hardware that manages the UAV's sensors and provides instructions to the motors. The flight controller used here is a Pixhawk 2.4.8; the two terms are used interchangeably throughout this document.

1. Attach the GPS module by inserting the six-pin cable into the **GPS** socket and the two-pin cable into the **I2C** socket on the flight controller.
2. Attach a three-pin cable to the receiver's **SBUS** port as shown in **Figure 59**. Note that the red wire is positive, and the black wire is negative.
3. Attach the other end of the three-wire cable to the **RCIN** pins [36] on the flight controller, noting that the top pin is negative, and the middle pin is negative as shown in **Figure 60**.
4. Install the buzzer by inserting the connector into the **BUZZER** socket on the flight controller.
5. Attach all six ESC cables to the **MAIN OUT** pins. M1 should be at position one, M2 at position two, and so forth as shown in **Figure 61**. The black wire should be facing up [37].
6. Attach the USB cable to the MicroUSB port on the side of the flight controller. This will stay attached to the flight controller for easy access when needed.
7. Attach the flight controller power cable to the flight controller.
8. Attach the flight controller to the flight controller mounting plate using double-sided adhesive.

The flight controller with attached sensors is shown in **Figure 62**.

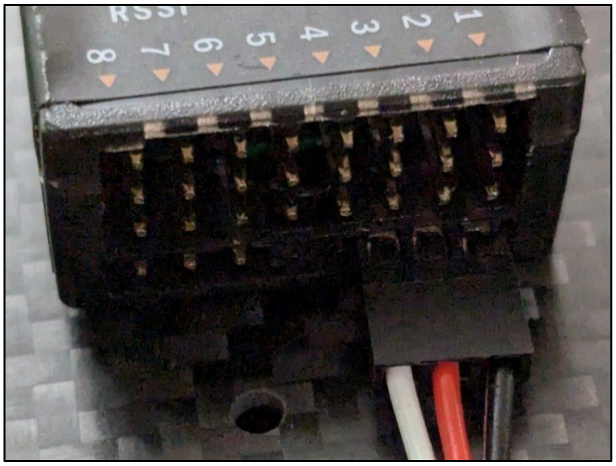

Figure 59 *Cable connected to receiver's SBUS pins*

Figure 60 *Receiver cable attached to RCIN pins*

[36] Some online guides say specifically to use the SBUS pins; however, this method was unsuccessful at the time of writing.

[37] Optionally, secure the ESC wires to the power wires with zip ties. This will prevent movement and help organize the cables.

Figure 61 *ESC cables attached to the flight controller*

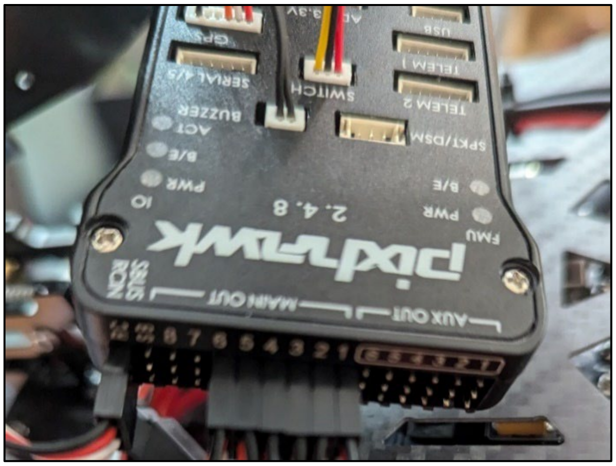

Figure 62 *Flight controller with attached sensors*

Attach the Top Frame Plate

The top frame plate protects the internal wiring and provides a platform for the sensors to mount to.

1. Install the top plate using the remaining short bolts (3.C) as shown in **Figure 63**.
2. Using painter's tape [38], temporarily attach the various sensors [39].
3. Using a piece of hook and pile tape, secure the LiPo battery to the bottom extension frame. Make sure there is enough excess that the battery cannot come loose during flight.

An example of the temporary sensor placement is shown in **Figure 64**.

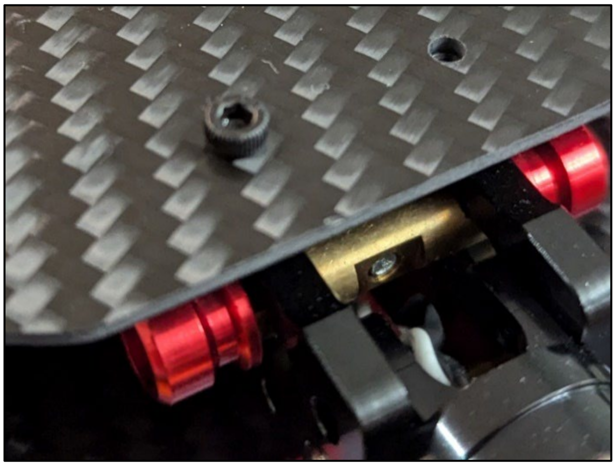

Figure 63 *Bolt placement on large top plate*

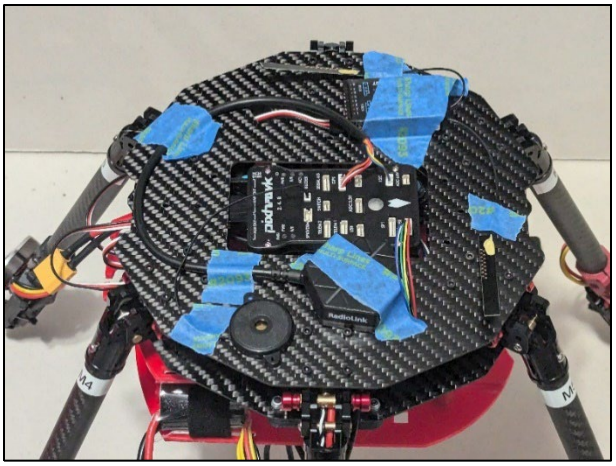

Figure 64 *Temporarily placed sensors*

[38] High quality painter's tape is idea for this because it will not leave behind residue when removed later.

[39] This is just to confirm that the UAV can be calibrated; the sensors will be permanently attached later.

Configure the Transmitter

The transmitter must be configured and paired with the receiver before it can be used.

1. Charge, and then install a pair of 18500 batteries into the handles of the transmitter.
2. Follow the instructions in reference [3] to configure and adjust the throttle control stick.
3. Attach the flight controller's USB cable to a power source (a laptop is sufficient).
4. Follow the instructions in reference [4] to bind the transmitter to the receiver.
5. Follow the instructions in [5], starting at 5:42 and ending at 6:18, to enable the switches on the transmitter.
6. Optionally, change the model's name by following the instruction in [5], starting at 10:29.

Configure the Flight Controller

WARNING: Do not install the propellers on the UAV for this section!

The Pixhawk is managed using the ground control station. These instructions use QGroundControl, recommended by the PX4 developer community. Before starting, ensure that you have access to a level and plumb surface, large enough for the landing skids to rest on, as shown in **Figure 65**.

1. Attach the microUSB cable to the flight controller and connect it to a laptop with QGroundControl installed. Open QGroundContol.
2. Follow the instructions in reference [6] to configure the flight controller with QGroundControl. Note the following additions and changes from that reference:
   a. **Firmware:** At the time of writing, the current stable version of the PX4 firmware is 1.15 [40] [41]. Attempt to download the **Stable Release.** If you encounter problems, repeat this section using the **Dev Release.** This step is shown in **Figure 66**.
   b. **Airframe:** Select "hexarotor x" (**not** "hexarotor +") as shown in **Figure 67**.
   c. **Sensors:** Calibrate the sensors outside for the best results.
   d. **Radio:** Don't forget to calibrate the switches that were configured in the previous section in addition to the control sticks.
   e. **Flight Modes:** The recommended pre-configured flight modes are Position, Return, and Mission [7]; all flight modes can be found in reference [8]. Additionally, configure a kill switch.
   f. **Power:** Use the data sheet that comes with your battery to configure the full and empty voltages. If using the battery from these instructions, the correct values are:

Number of Cells (in Series)	4	A 4S battery has four cells
Empty Voltage (per cell)	3.800	Will read "empty" at storage voltage
Full Voltage (per cell)	4.200	The full voltage of a LiPo battery

   g. **Motors:** In 1.15(dev), "Motors" has been replaced with "Actuators". Using the guided setup

[40] At the time of writing, the Pixhawk 1.15 stable firmware caused pre-flight errors that could not be overcome, so these instructions are using the 1.15(master) build, which has not been flight tested. Always attempt to use the (stable) version first, then the (beta) version, before resorting to the (master).

[41] At the time of writing, the Pixhawk 1.15(master) build does not save parameters. It is necessary to downgrade the firmware to 1.15(stable), write parameters, then upgrade to firmware 1.15(master) to fly the UAV without various position estimation errors.

by pressing the **Identify & Assign Motors** button in the upper right corner of **Figure 68**. Map each motor to its position on the UAV. Ensure that the propellers are spinning in the right direction, indicated by the arrows on each motor position. If one is not, disassemble the housing, connect the correct wire pairs, then re-assemble the housing according to **Assemble the Motor Arms** on **page 18**.

h. **Parameters:** An example is shown in **Figure 69**. Also configure the following parameters:

`COM_CPU_MAX`	-1	Disables CPU load check
`COM_RAM_MAX`	-1	Disables available RAM check [42]
`COM_POWER_COUNT`	0	Disables redundant power source check

Disconnect all power sources from the flight controller, then re-connect the flight controller to the laptop. Verify that the UAV's status is "Ready to Fly", shown in **Figure 70**.

Figure 65 Level and plumb surfaces for calibration

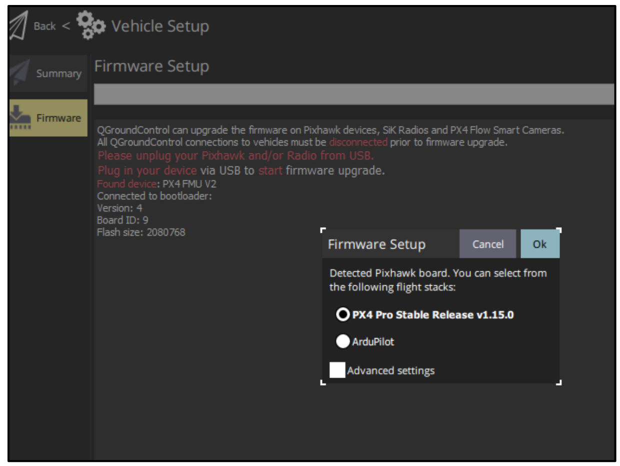

Figure 66 The Firmware Setup dialog box

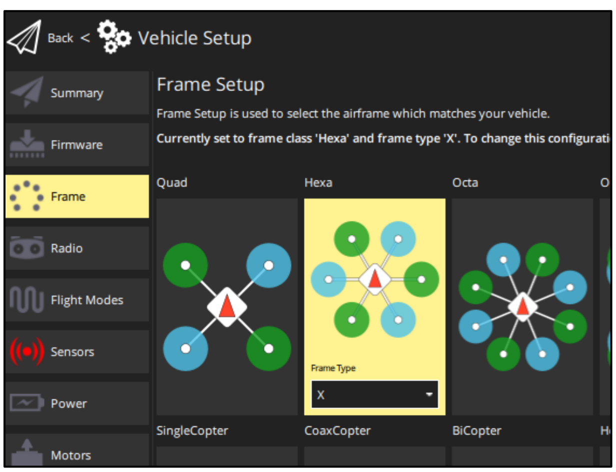

Figure 67 The correct frame type

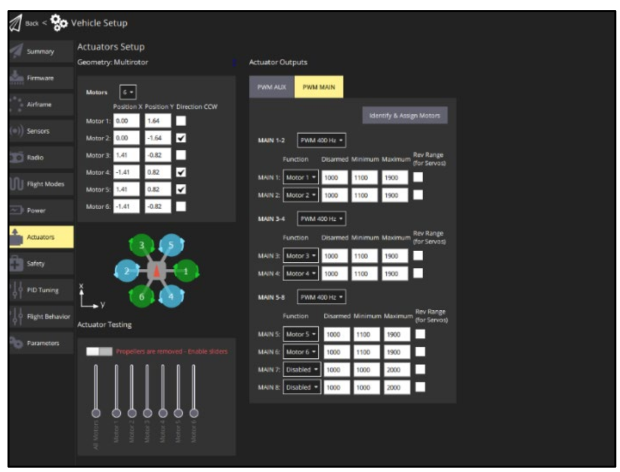

Figure 68 The Actuators page in 1.15(master) firmware

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[42] This parameter is not present on the 1.15(stable) version of the PX4 firmware and can be ignored.

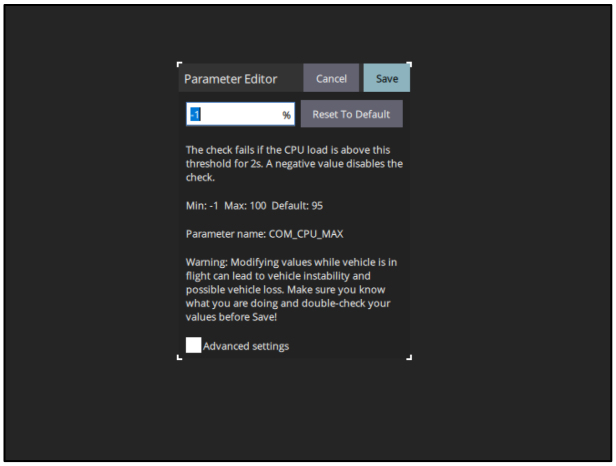


Figure 69 *Updating the COM_CPU_MAX parameter*

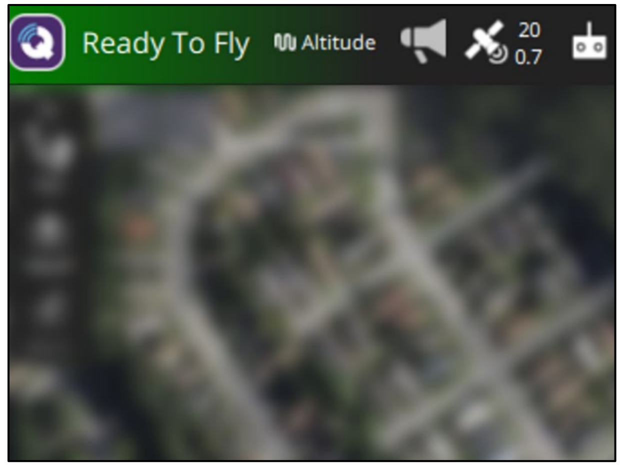


Figure 70 *"Ready to Fly" with no pre-flight alerts*

Validate Transmitter Controls

WARNING: Do not install the propellers on the UAV for this section!

Disconnect the flight controller from the laptop. Verify that the transmitter can perform the following functions:

1. Arm the UAV with the configured switch [43].
2. Engage the throttle, ensuring that all six motors spin.
3. Engage the kill switch and ensure that all six motors stop spinning.
4. Disengage the arming switch.

When finished, disconnect the UAV from all power sources. Ensure that the LiPo battery is returned to a storage voltage.

Install the Propeller Blades

Take note of the correct propeller blades for each motor as shown in **Figure 71**.
Secure each propeller to a motor using two long bolts (1.D), a flat washer (48), and a lock washer (47) [44] as shown in **Figure 72**.

[43] You should hear one long, continuous tone indicating that it is armed. If there is a pre-flight error, you will hear three alternating tones instead.

[44] The lock washer should be installed between the flat washer and the head of the bolt.

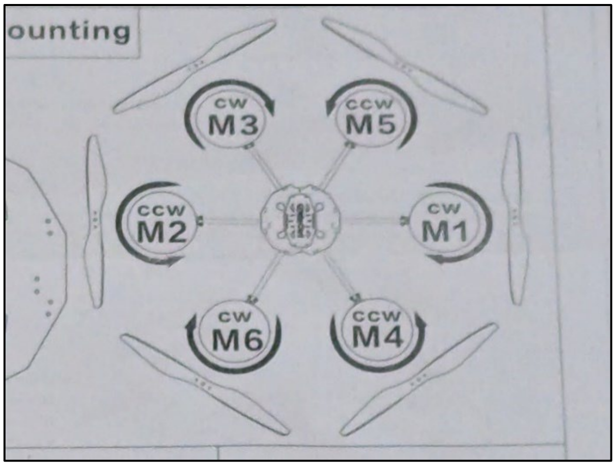


Figure 71 *Correct propeller orientation*

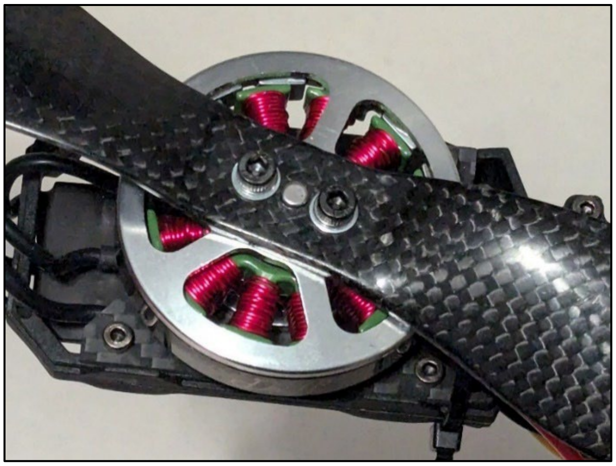


Figure 72 *Propeller installed on a motor*

Conclusion

In this chapter, you have completed a baseline UAV platform which is ready for a test flight, as shown in **Figure 73**. In the next chapter, you will fly the UAV for the first time.

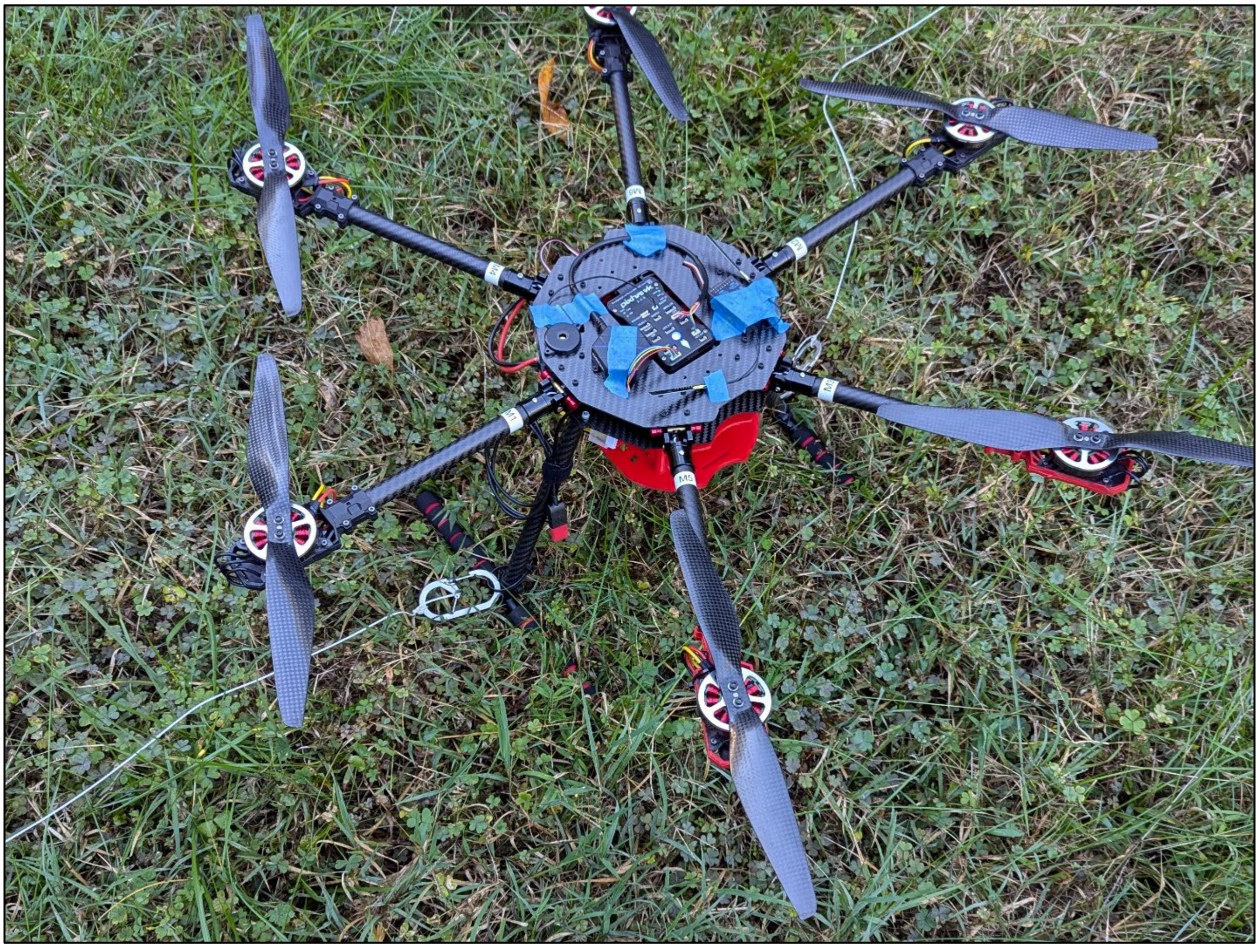


Figure 73 *The flight-ready UAV with flight controller, sensors, and propellers*

Test Flight

The test flight will verify that the UAV was assembled and configured correctly. It should be done in a large, open space during conditions of good visibility and no wind. During the test, the UAV will be tethered to the ground to minimize the risk of injury or damage.

Materials List

Gather the materials outlined in **Test Flight Materials** on **page 13**. Additionally, ensure that all participants are wearing head, eye, and hand protection.

Instructions

Prepare the Test Environment

Set up a test environment using the steps below as a rough guide.

1. Cut two strings approximately 20 feet long, and secure a carabiner to one end of each.
2. Tie each string to a weight that exceeds the UAV's maximum load (1.5kg or 3.3 lbs) as shown in **Figure 74**. Place each weight a few feet from the UAV's takeoff location.
3. Secure a large zip tie to each of the UAV's landing skids, ensuring that it cannot come off when moved in any direction.
4. Secure the carabiner to the zip tie as shown in **Figure 75**. The UAV should now be tethered to the ground.
5. Lay the excess string away from the weights in a straight line as shown in **Figure 76**, ensuring they do not tangle as the UAV takes off.

When prepared correctly, the test environment should look something like **Figure 77**.

Figure 74 *String and weight exceeding the UAV's carry capacity*

Figure 75 *Carabiner secured to UAV's landing skid*

Figure 76 *Excess string lying flat and tangle-free*

Figure 77 *Prepared test flight environment*

Execute Test Flight

WARNING: The first test flight is a particularly dangerous activity. Take all proper safety precautions before flying.

After completing the relevant steps in **Appendix B. Pre-Flight Checklist** on **page 76**, perform the following actions:

1. Arm the UAV.
2. Gently engage the throttle until the motors start to spin. Do not take off yet.
3. Engage the kill switch, ensuring that the motors stop as expected.
4. Disengage the kill switch.
5. Engage the throttle until the UAV takes off. Adjust the throttle so that the UAV hovers a few feet in the air.
6. Move the UAV in all four horizontal directions (forwards, backwards, left, and right).
7. Turn the UAV by moving the throttle stick left/right.
8. Gently reduce the throttle so that the UAV lands.
9. Disarm the UAV.

Once the test flight is complete, make sure that the LiPo battery is returned to a storage voltage. Troubleshoot any issues encountered during the test flight before proceeding on to adding the additional components in the next chapters.

Conclusion

In this short but very critical chapter, we have confirmed that the baseline UAV has been assembled correctly. An image of a successful test flight is shown in **Figure 78**.

Figure 78 *Test flight with UAV tethered safely to the ground, allowed to hover a few feet in the air*

Companion Computer

The PX4 documentation [9] refers to an attached computer as the “companion computer”. In this documentation, the companion computer is a Raspberry Pi 4. These terms may be used interchangeably throughout this document. It is an optional component that greatly extends the functionality of the UAV. It can be used to provide a wireless link to the ground control station, and process data from, and send commands to, the flight controller.

Materials List

- ☐ 1x 17.C. Six Pin Connector
- ☐ 1x 19. Raspberry Pi 4
- ☐ 1x 20.A. Fan
- ☐ 1x 21. HDMI to Mini-HDMI Cable (Optional)
- ☐ 1x 22. Power Cable
- ☐ 1x 23. MicroSD Card Reader
- ☐ 1x 24. MicroSD Card
- ☐ 1x 25. Case with Vented Case Cover
- ☐ 4x 27. Fan Screws
- ☐ 1x 54. Bag of Pre-Made Cables
- ☐ 1x 55. Heat Shrink Tubing
- ☐ 1x 57. USB A to USB C Data Cable
- ☐ 1x 58. USB Dust Protector
- ☐ 60. Hook and Pile Tape

Instructions

Install the Operating System

Review reference [10], then perform the following steps:

1. Insert the MicroSD card into the USB MicroSD card reader, and then the reader into the laptop.
2. Download, install, and run the Raspberry Pi Imager application.
3. Under **Raspberry Pi Device**, select **Raspberry Pi 4** as shown in **Figure 79**.
4. Under **Operating System**, select **Raspberry Pi OS (64-bit)** as shown in **Figure 80**.
5. Under **Storage**, choose the USB reader attached to the laptop, as shown in **Figure 81**.
6. Verify the configuration matches the selections in **Figure 82**; select **Next**, then **Edit Settings**.
7. Under the **General** tab, configure a hostname, username, password, wireless LAN, and locale settings like the example shown in **Figure 83**.
8. In **Services**, enable SSH and select **Use Password Authentication** as shown in **Figure 84**.
9. Navigate through the remaining dialog boxes as shown in **Figure 85** and **Figure 86**.

10. The application will write, then verify, the OS files to the MicroSD card as shown in **Figure 87** [45].

Once the OS has been written and you see the prompt in **Figure 88**, close the Imager application and remove the MicroSD card from the USB reader.

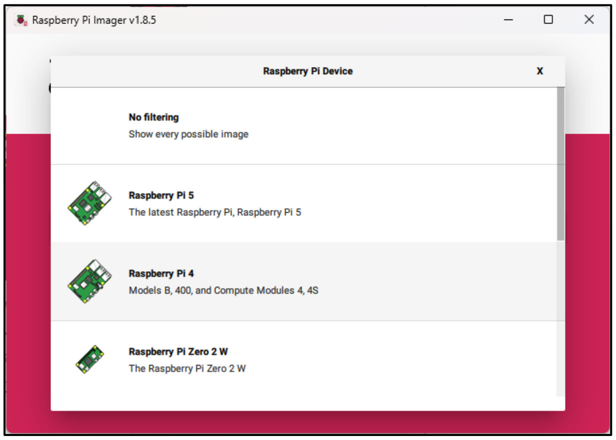


Figure 79 *Selecting the Device*

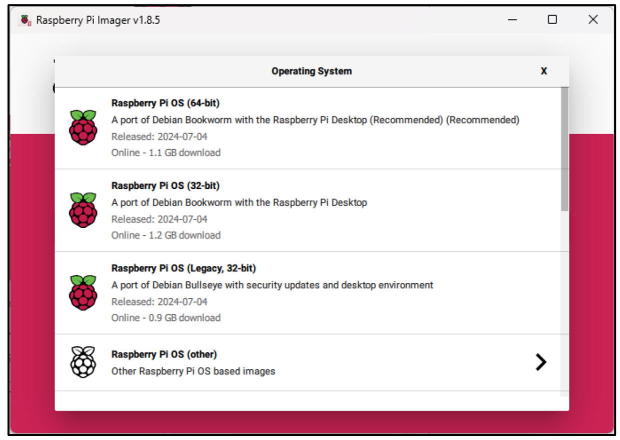


Figure 80 *Selecting the Operating System*

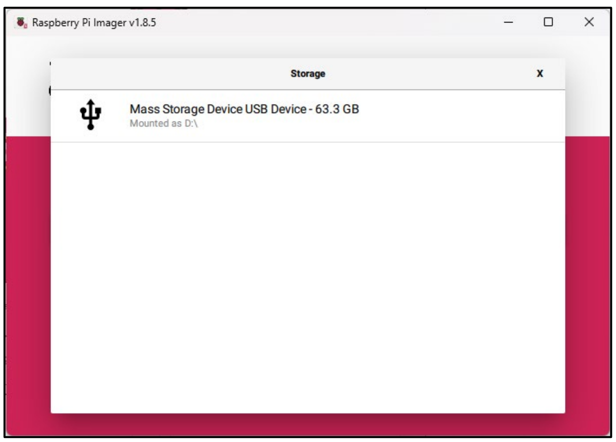


Figure 81 *Selecting the MicroSD Card*

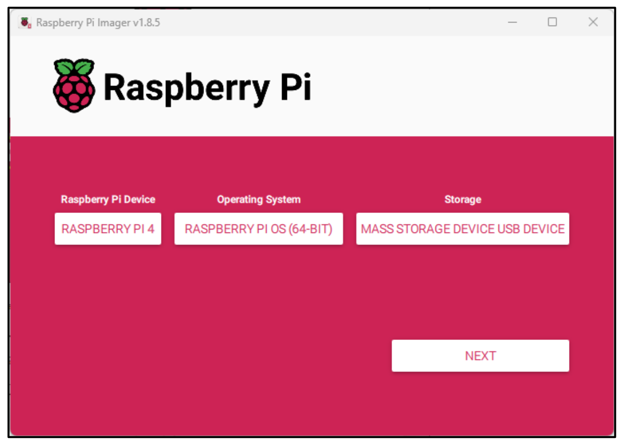


Figure 82 *Confirmation*

[45] Ignore warning about formatting the drive from Windows after the last step.

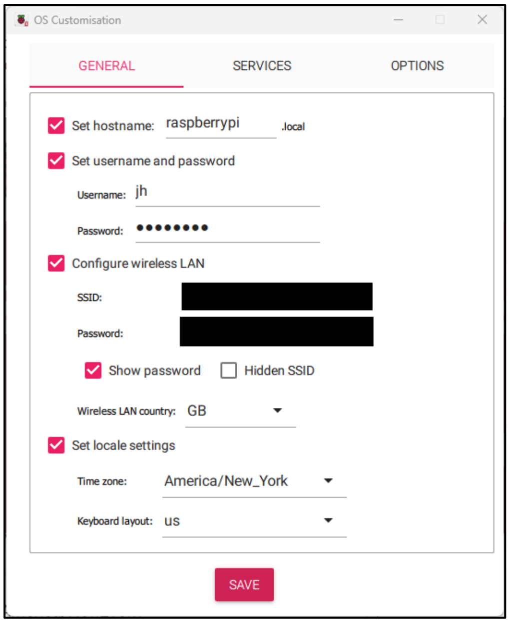


Figure 83 General Settings

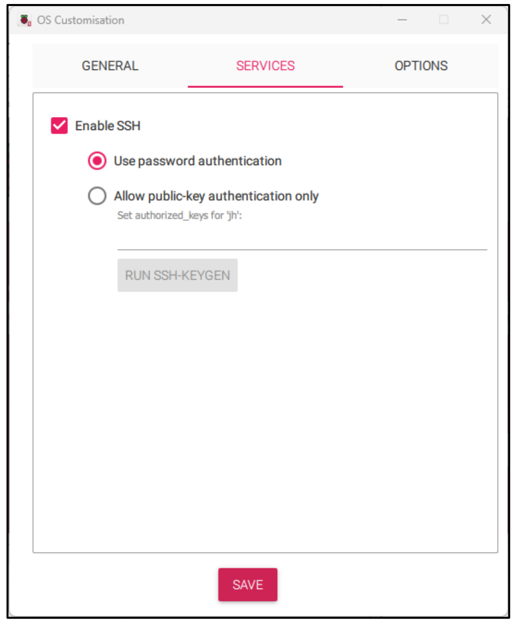


Figure 84 Services Settings

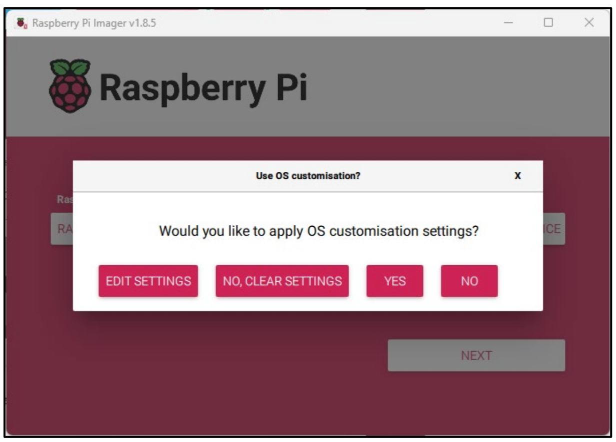


Figure 85 Confirmation

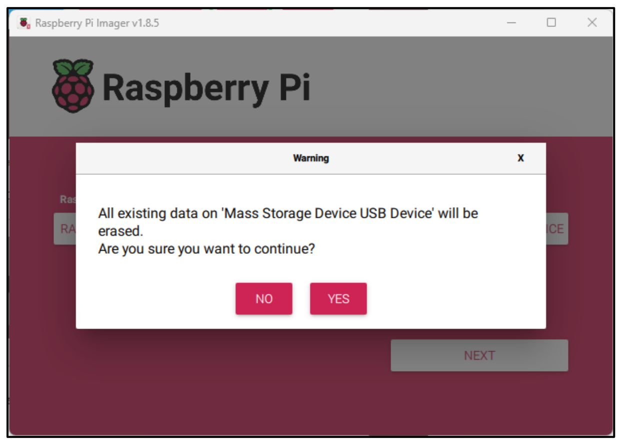


Figure 86 Overwrite Confirmation

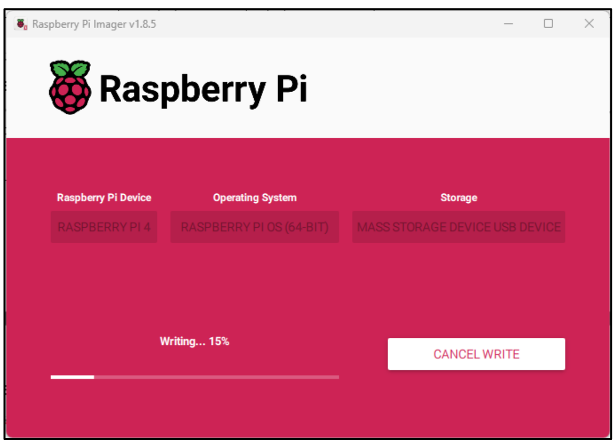


Figure 87 Writing the OS Data to the MicroSD Card

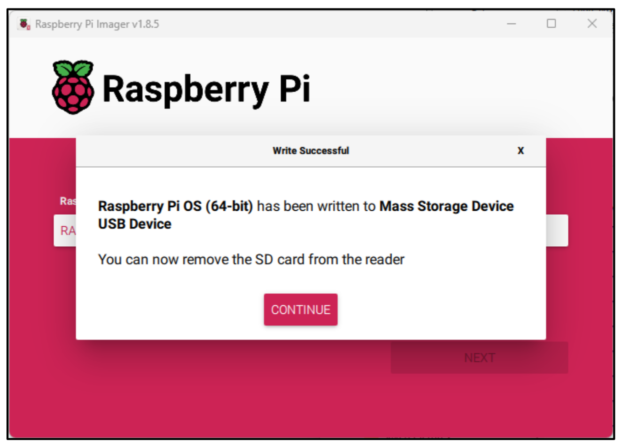


Figure 88 Prompt indicating that the OS is installed

Assemble the Companion Computer

1. Install the Raspberry Pi in the lower half of the case with the provided screws as shown in **Figure 89**.
2. Install the fan on top of the Raspberry Pi with four screws as shown in **Figure 90**.
3. Connect the power wire to General Purpose Input/Output (GPIO) pin 1 and the ground to GPIO pin 6 as shown in **Figure 91**.
4. Install the vented top cover on the case.
5. Optionally, connect a monitor using the provided mini-HDMI cable and connect a mouse and keyboard via the USB ports.
6. Optionally, attach the Raspberry Pi to a connected router with an Ethernet cable.
7. Install the MicroSD card into the appropriate slot, and connect the provided USB-C power cable.
8. Plug in the power cable to an AC outlet and turn on the power switch.
9. If monitor, keyboard, and mouse are not attached, connect to the Raspberry Pi via SSH.
10. Access the Raspberry Pi's terminal, and update the installed packages with these commands:

```
sudo apt update
sudo apt upgrade -y
```

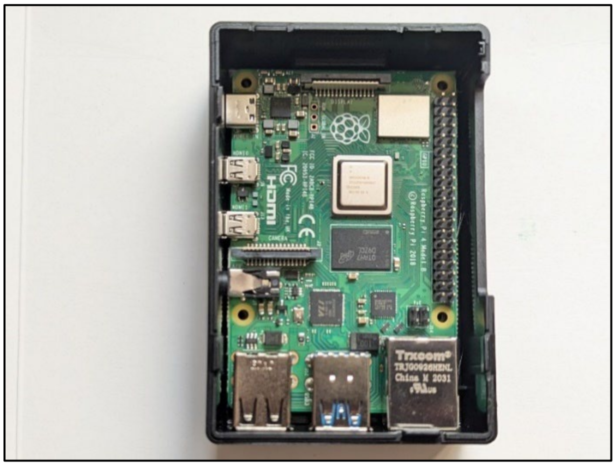


Figure 89 *Raspberry Pi installed in case*

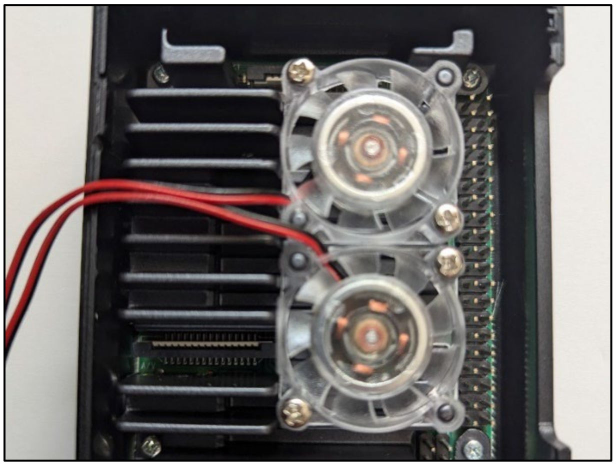


Figure 90 *Fan installed on top of Raspberry Pi*

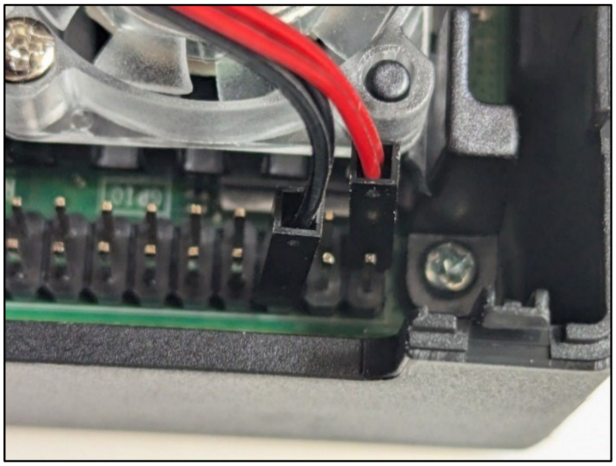


Figure 91 *Fan jumper wires connected to GPIO pins*

Make and Connect the Serial Cable

The appropriate connector that comes in the bag of pre-assembled connector wires is too short to reach from the flight controller to the companion computer when it is installed on the UAV, so it must be extended. When completed, the serial cable will match the layout shown in **Table 4**. Note that any color can be selected for the jumper wires, but black is highly recommended for the ground, as this is a standard convention.

Flight Controller		Function	Companion Computer	
Position	Color		GPIO Pin	Color (Example)
1				
2	Black	RX ⇔ TX	10	Blue
3	Black	TX ⇔ RX	8	Green
4				
5				
6	Black	Ground	9	Black

Table 4 *Flight Controller to Companion Computer Serial Cable Configuration*

To create the serial cable, review references [11] and [12], then perform the following steps:

1. Cut one end from the six-pin connector that came with the Raspberry Pi as shown in **Figure 92**.
2. With the red wire to the left and progressing to the right, cut off wires 1, 4, and 5 as shown in **Figure 93**.
3. Set aside a six-pin connector from the bag of pre-assembled connector wires. **This is for troubleshooting later; do not cannibalize this connector to make the serial cable!**
4. Select a four-pin connector from the bag of pre-assembled connector wires. Cut them as close to the connector plug as possible, leaving individual wires with their Dupont connectors intact as shown in **Figure 94**. Discard the red wire, as this color is reserved for power cables and will not be used.

5. Carefully cut away the insulation from the wires with a utility knife as shown in **Figure 95** [46].
6. Select three pieces of shrink wrap tubing from the box of connectors and cables and slide them on the ends of the individual wires as shown in **Figure 96** [47].
7. Solder each jumper wire to the modified six-pin cable and apply heat to the heat shrink tubing as shown in **Figure 97**. Optionally, and only once you have confirmed the wire colors and their function, apply a larger piece of heat shrink tubing over all three wires. This further protects the soldered sections and makes it easier to route the cable through the body of the UAV.
8. Connect the six-pin connector to the Pixhawk's **TELEM 2** port as shown in **Figure 98**.
9. Connect the ground wire to GPIO pin 9, the Tx wire to GPIO pin 10, and the Rx wire to GPIO pin 8 as shown in **Figure 99**.

At this point in the process, it is not necessary nor advisable to route the cable through the body of the UAV or secure the companion computer to the bottom plate of the UAV. If the test is unsuccessful, the cable will likely need to be removed and/or replaced.

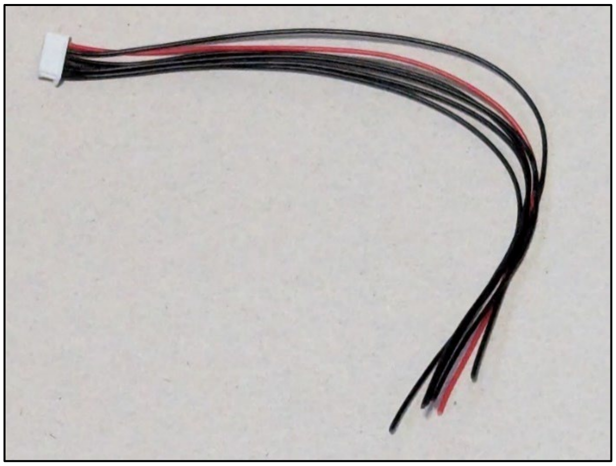


Figure 92 *Six-pin cable with one plug removed*

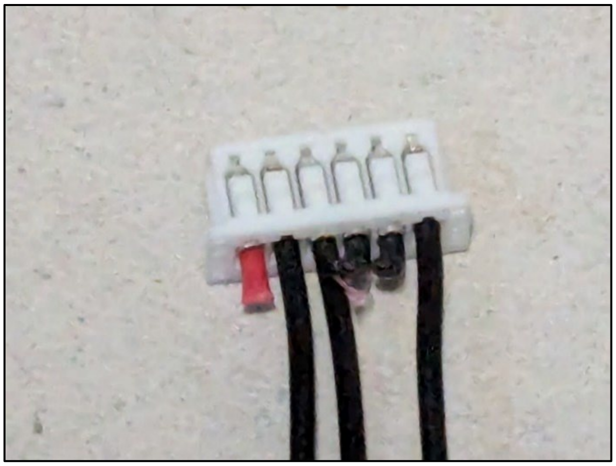


Figure 93 *Serial cable with wires 1, 4, and 5 trimmed*

[46] Note that in this figure, the cut with the utility knife was too aggressive and took off some of the stranded wire underneath. This section was cut off and re-done before soldering to ensure the full wire was present on the end.

[47] Unlike the ESC wires, this step cannot be done after the soldering is completed.

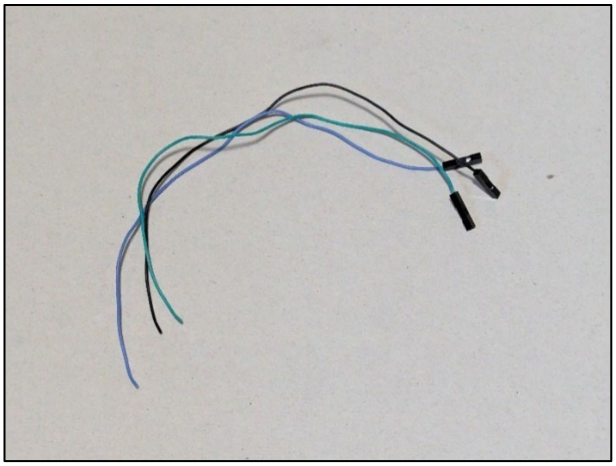


Figure 94 *Three repurposed jumper wires*

Figure 95 *Insulation removed from wire with utility knife*

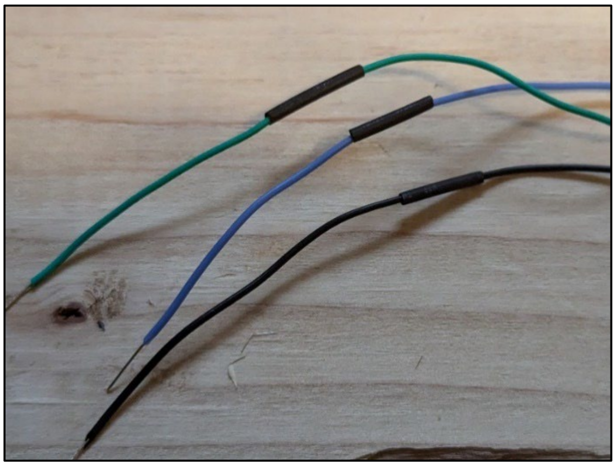


Figure 96 *Stripped jumper wires with heat shrink*

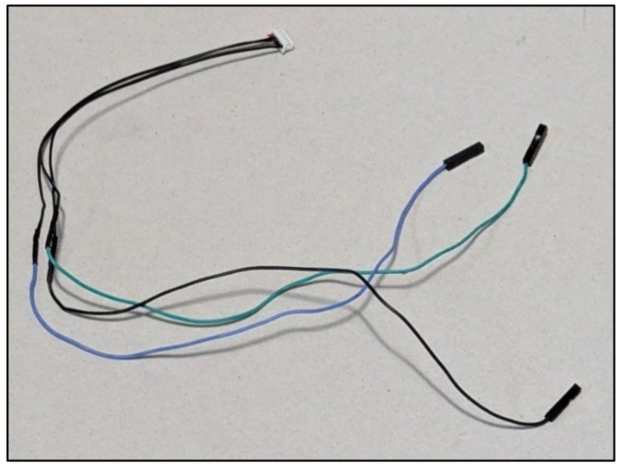


Figure 97 *Completed serial cable*

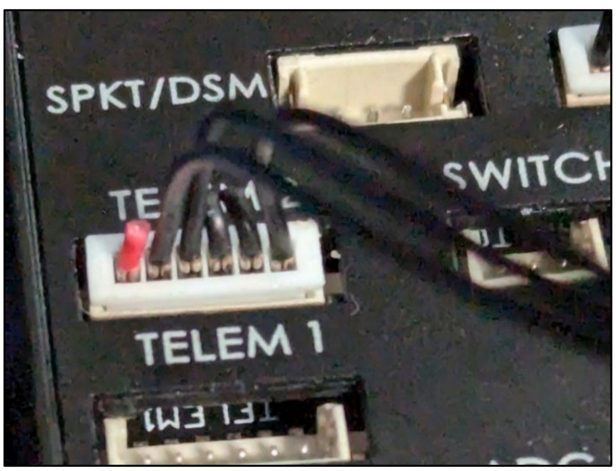


Figure 98 *Serial cable connected to TELEM 2*

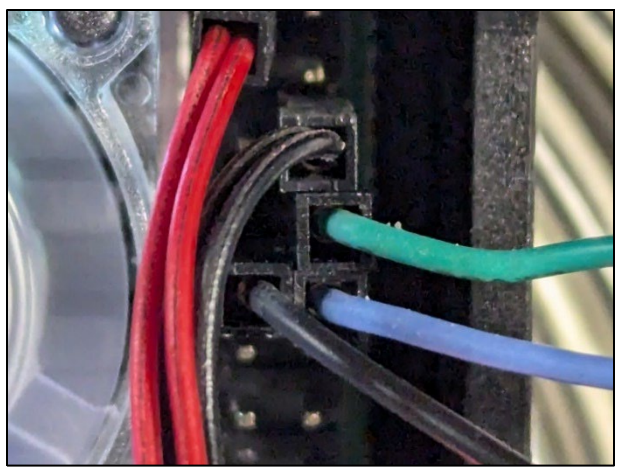


Figure 99 *Serial cable connected to GPIO pins*

Configure Companion Computer Serial Connection

By default, the Raspberry Pi will not communicate over its serial connection. Review reference [13], then perform the following steps:

1. Access the terminal on the Raspberry Pi (SSH is most convenient for this step, but it is possible to do this by connecting a mouse, keyboard, and monitor).
2. To enable the serial connection, first enter `sudo raspi-config`.
    a. Use the arrow keys to navigate to **3 Interface Options**, then **I6 Serial Port**.
    b. When asked to make a login shell accessible over serial, select **No**.
    c. When asked to make the serial port hardware enabled, select **Yes**.
    d. Ensure that the settings match those shown in **Figure 100**.
    e. When asked to reboot now, select **No**. This will be done manually later.
3. Disable Bluetooth by entering `sudo nano /boot/firmware/config.txt` to edit the configuration file.
4. Use the arrow keys to navigate to the bottom of the file.
    a. Under `[all]`, confirm that `enable_uart` is set to `1` as shown in **Figure 101**.
    b. Under `[all]`, add `dtoverlay=disable-bt` as shown in **Figure 101**.
5. Manually reboot the Raspberry Pi with `sudo reboot`.

The Raspberry Pi is now ready to send and receive data over its GPIO pins.

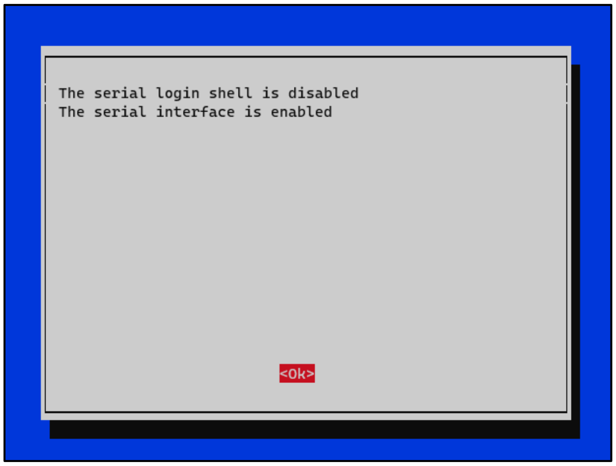


Figure 100 Confirmation of serial interface settings

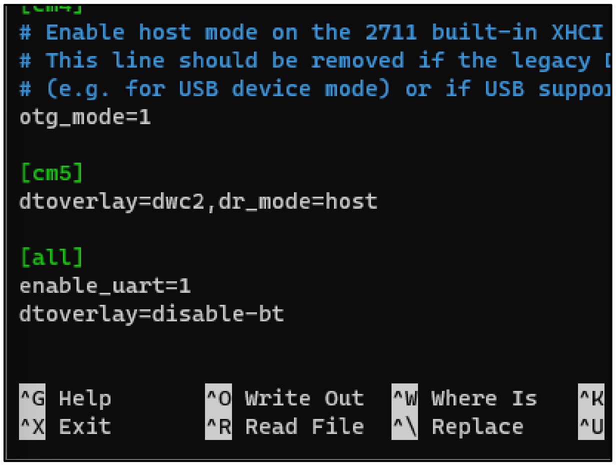


Figure 101 Configuration to enable serial connection

Configure Flight Controller Serial Connection

By default, the Pixhawk will not communicate over its TELEM 2 [48] port.

1. Connect to the flight controller with QGroundControl.
2. Navigate to the parameter configuration section, and update the following items. Note that after

[48] The TELEM 1 port meant to communicate to the ground control station via radio, while the TELEM 2 port is meant to communicate to an offboard API.

setting **MAV_1_CONFIG**, you must reboot the flight controller before **SER_TEL2_BAUD** is available.

`MAV_1_CONFIG`	`102`	Enables TELEM 2 [49]
`SER_TEL2_BAUD`	`115200`	Sets the baud rate

Leave the Pixhawk connected to the laptop, as it will need to be powered on for the test later in this chapter.

Verify Serial Connection to Flight Controller

Test the connection to the flight controller using MAVProxy, which is installed as a Python module that reads MAVLink messages.

1. Access the terminal on the Raspberry Pi, either by directly connecting a monitor, mouse, and keyboard or remotely via SSH.
2. Ensure that Python is installed by entering `python --version` and confirming that there are no errors.
3. Create a temporary virtual environment, so that we do not clutter the global Python environment or interfere with other projects.
4. Create a directory for this test. In this example, it is `~/UAV`. Enter the following commands:

```
cd ~
mkdir UAV
cd UAV
```

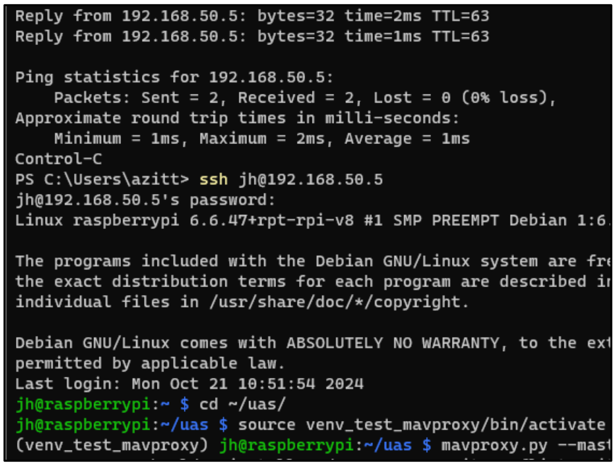
5. Once inside the directory, create and activate a virtual environment. In this example, the environment's name is `venv_test_mavproxy`. Enter the following commands:

```
python -m venv venv_test_mavproxy
source venv_test_mavproxy/bin/activate
```

6. Confirm that the virtual environment's name has been prepended to the terminal's prompt as shown at the bottom of **Figure 102**.
7. Install the required packages for MAVProxy by entering `python -m pip install PyYAML mavproxy`.
8. Remove ModemManager, since it interferes with the connection between the Raspberry Pi and Pixhawk by entering `sudo apt purge modemmanager`.
9. After powering on the Pixhawk, enter `mavproxy.py --master=/dev/ttyAMA0,115200`. Verify that the output includes a line like "link 1 OK" as shown near the middle of **Figure 103**.
10. If you instead receive a message like "link 1 down", then the connection was unsuccessful and requires additional troubleshooting. If necessary, cut wires 1, 4, and 5 from the six-pin cable that was set aside earlier chapter and replace the soldered serial cable with it. This will determine if the connection issue is with the soldered wires or with the software configuration in one of the devices.

[49] In Pixhawk 1.15(master) the integer field is replaced with a dropdown. If you see this, select "TELEM2".

Once finished with this step, press Ctrl+C to terminate MAVProxy.



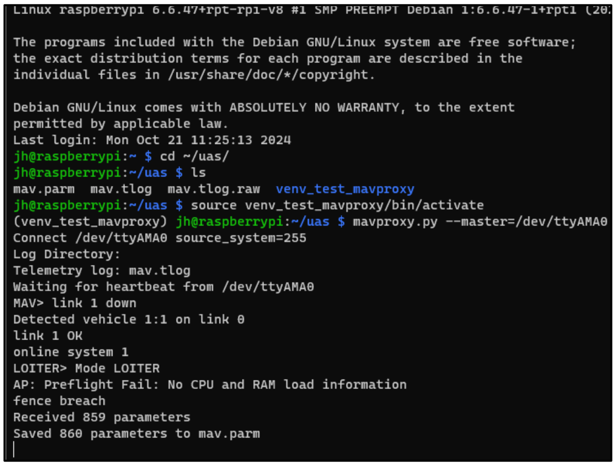
```
Reply from 192.168.50.5: bytes=32 time=2ms TTL=63
Reply from 192.168.50.5: bytes=32 time=1ms TTL=63

Ping statistics for 192.168.50.5:
    Packets: Sent = 2, Received = 2, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 2ms, Average = 1ms
Control-C
PS C:\Users\azitt> ssh jh@192.168.50.5
jh@192.168.50.5's password:
Linux raspberrypi 6.6.47+rpt-rpi-v8 #1 SMP PREEMPT Debian 1:6.

The programs included with the Debian GNU/Linux system are fre
the exact distribution terms for each program are described i
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the ext
permitted by applicable law.
Last login: Mon Oct 21 10:51:54 2024
jh@raspberrypi:~ $ cd ~/uas/
jh@raspberrypi:~/uas $ source venv_test_mavproxy/bin/activate
(venv_test_mavproxy) jh@raspberrypi:~/uas $ mavproxy.py --mast
```

Figure 102 *Activation of the Python virtual environment*



```
Linux raspberrypi 6.6.47+rpt-rpi-v8 #1 SMP PREEMPT Debian 1:6.6.47-1+rpt1 (20

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Mon Oct 21 11:25:13 2024
jh@raspberrypi:~ $ cd ~/uas/
jh@raspberrypi:~/uas $ ls
mav.parm  mav.tlog  mav.tlog.raw  venv_test_mavproxy
jh@raspberrypi:~/uas $ source venv_test_mavproxy/bin/activate
(venv_test_mavproxy) jh@raspberrypi:~/uas $ mavproxy.py --master=/dev/ttyAMA0
Connect /dev/ttyAMA0 source_system=255
Log Directory:
Telemetry log: mav.tlog
Waiting for heartbeat from /dev/ttyAMA0
MAV> link 1 down
Detected vehicle 1:1 on link 0
link 1 OK
online system 1
LOITER> Mode LOITER
AP: Preflight Fail: No CPU and RAM load information
fence breach
Received 859 parameters
Saved 860 parameters to mav.parm
```

Figure 103 *Successful connection to the flight controller*

Configure Wi-Fi Access Point

Although it is possible to communicate with the ground control station using TELEM 1, it requires a separate radio. Instead, we will connect via the companion computer's Wi-Fi adapter, using MAVProxy to pass traffic from QGroundControl through the Raspberry Pi to the Pixhawk.

After this section is complete, the companion computer will have two configured interfaces, each with a different purpose. The wired Ethernet connection will be used to connect to a Local Area Network (LAN). This is used to get updates, and as an emergency link in case the Wi-Fi access point becomes unavailable. During flight, the wireless interface will be used to create an isolated LAN for the ground control station laptop to connect to. While connected, the laptop will not be able to access the Internet, since there is no means of passing traffic through the companion computer's ethernet interface while it is disconnected. Note that **Figure 104** shows the IP addresses as they appear in this document; they will likely be different in your network.

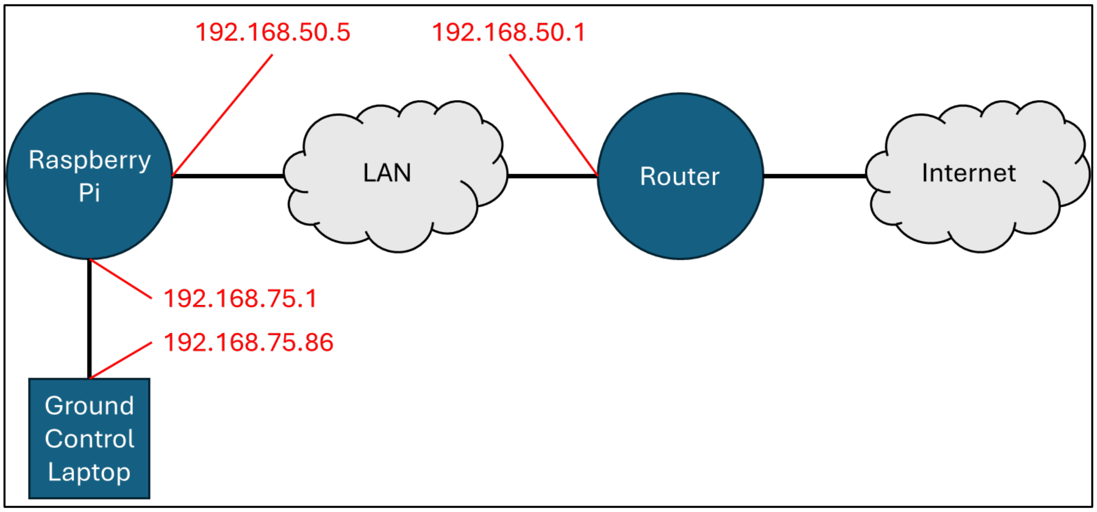


Figure 104 *A network diagram showing the companion computer's IP connections to other devices.*

1. Access the terminal on the Raspberry Pi, either by directly connecting a monitor, mouse, and keyboard or remotely via SSH. You must use the wired Ethernet connection if you choose to use SSH, as this section involves disabling the default Wi-Fi configuration.
2. Optionally, verify that the regional settings are correct [50] by entering `sudo raspi-config`, navigating to "**Localisation Options**", and then "**WLAN Country**". Select the appropriate value.
3. Verify that the onboard Wi-Fi adapter can be used as a wireless access point.
   a. Enter `iw dev` to view the available devices. Verify that you have an interface named something like `wlan0`.
   b. Enter `nmcli -f WIFI-PROPERTIES.AP device show wlan0` and verify that the value is `yes`.
   c. Enter `sudo nmcli dev wifi hotspot ifname wlan0 ssid <SSID NAME> password <PASSWD>` to create a new Wi-Fi hotspot, substituting <SSID NAME> and <PASSWD> with your own values.
4. Configure the hotspot with the following commands [51]:

```
sudo nmcli connection modify Hotspot ipv4.addresses 192.168.75.1/24
sudo nmcli connection modify Hotspot ipv4.method shared
sudo nmcli connection modify Hotspot ipv6.method ignore
sudo nmcli connection modify Hotspot 802-11-wireless.band bg 802-11-
wireless.channel 6
```

5. Restart the access point by entering `sudo nmcli connection up Hotspot`. Once this step is complete, the companion computer will lose access to the access point that it was connected to during the initial configuration.
6. Verify that you can connect to the SSID with the laptop and that it receives an IP address in the given range (192.168.75.x in this example). Verify that you can ping the internal IP address that was assigned to the Ethernet interface earlier in this chapter (192.168.50.5 in this example).
7. By default, the hotspot will not start up when the companion computer is rebooted. To enable this functionality, enter `crontab -e` in the companion computer's terminal. After selecting the text editor of your choice, add the following line:

```
@reboot sleep 60 && sudo nmcli connection up Hotspot
```

   Adding the sleep timer before the `nmcli` command is important, because it allows the companion computer to complete its startup and ensures that the interface is enabled.

Verify Wi-Fi Connection to Ground Control Station

In this step we will connect to the flight controller through the Raspberry Pi's Wi-Fi interface.

1. Ensure that the flight controller is disconnected from the laptop's USB and Ethernet ports, and receiving power from another source [52].

[50] This step is only necessary if you intend to run the Wi-Fi adapter on the 5 Ghz band, which is only available in certain regions. 2.4 Ghz is preferred because it has a longer wavelength, and therefore, longer range.

[51] To enable 802.11ac (5 Ghz) instead of 802.11w (2.4 Ghz), replace the fourth command with "`sudo nmcli connection modify Hotspot 802-11-wireless.band a 802-11-wireless.channel 36`".

[52] The flight controller can be powered using one of the Raspberry Pi's USB ports.

2. Identify the IP address of the laptop. On Windows, this is done by opening a command prompt and entering ipconfig as shown in **Figure 105**.
3. Start MAVProxy, adding an additional argument to enable MAVLink message forwarding: mavproxy.py --master=/dev/ttyAMA0,115200 --out <IP_ADDRESS_OF_LAPTOP>:14550.
4. Open QGroundControl and verify that it is connected to the flight controller. For this test, it does not matter if the UAV passes its pre-flight checks.
5. Further verify that there is two-way communication by waiting for MAVProxy to output a message like Got COMMAND_ACK: RUN_PREARM_CHECKS: ACCEPTED as shown at the bottom of **Figure 106**. This means that QGroundControl is periodically requesting that the flight controller run a pre-arm check.

Once finished with this step, press Ctrl+C to terminate MAVProxy.

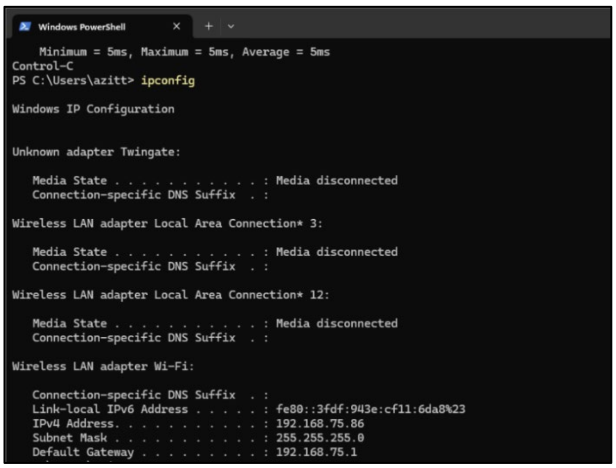


Figure 105 Identifying the laptop's IP address

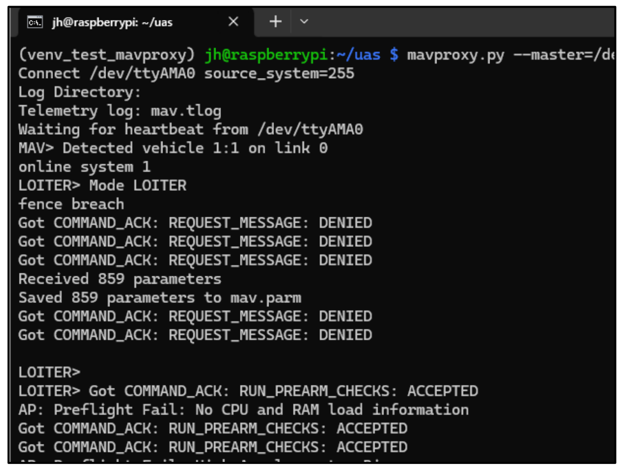


Figure 106 MAVProxy receiving preflight check request

Install the Secondary Battery

To improve flight time and provide the most stable current possible to both the flight controller and companion computer, install a secondary battery dedicated to those components. Additionally, now that we have verified the connections, we can secure the companion computer in place.

1. Charge the secondary battery with a USB-C cable attached to the battery's port labeled "IN".
2. Route the serial cable through the body of the UAV as shown in **Figure 107**
3. Secure the companion computer and secondary battery with a piece of hook and pile tape as shown in **Figure 108** and **Figure 109**. Ensure that there is plenty of overlap between the ends of the hook and pile tape to minimize the risk of the component coming loose or falling off the frame during flight.
4. Verify that the secondary battery powers both the flight controller and companion computer by attaching the USB-A ends of both cables to the two USB-A ports on the secondary battery as shown in **Figure 110**. Note that the companion computer should use the "OUT:5V/3A" port (on the right in the figure), and the flight controller should use the "OUT:5V/2.4A" port (on the left in the figure).

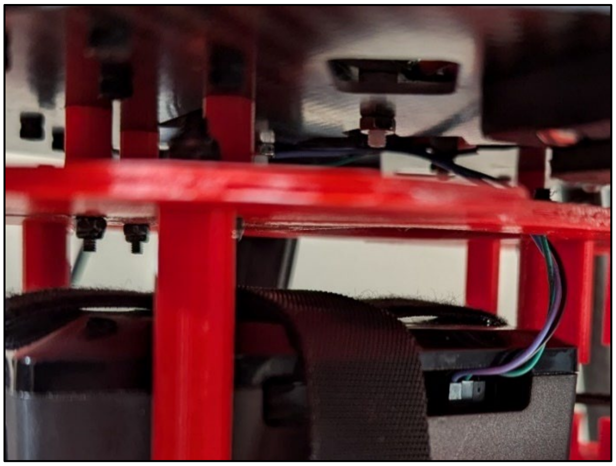


Figure 107 *Serial cable routed through UAV body*

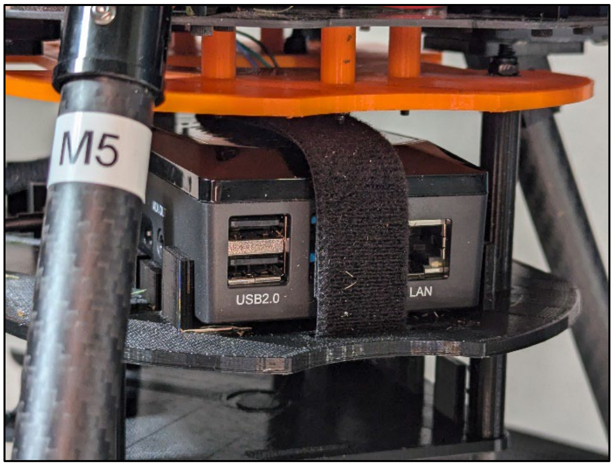


Figure 108 *Companion computer secured to the frame*

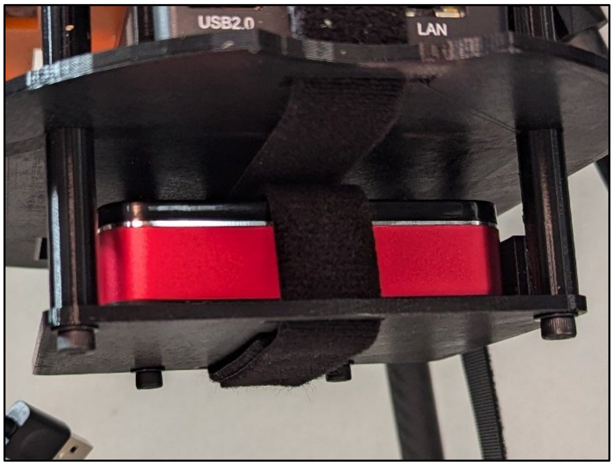


Figure 109 *Secondary battery secured to the frame*

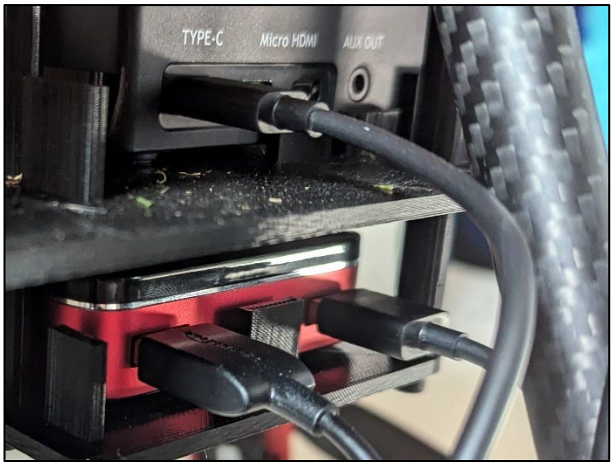


Figure 110 *Secondary battery powering components*

Conclusion

In this chapter, we have installed and configured the companion computer as shown in **Figure 111**. It is accessible via Wi-Fi, but also has a backup Ethernet connection. With the UAV hosting its own access point, the ground control station laptop can connect to it, and through it access the companion computer's terminal and communicate with the flight controller. This enables autonomous flight and real time telemetry monitoring while the UAV is executing a mission.

Figure 111 *The assembled UAV with attached companion computer*

Autonomous Mission Test Flight

This test flight will verify that the UAV can execute a mission using only the ground control software.

Materials List

Gather the materials outlined in **Test Flight Materials** on **page 13**. Additionally, ensure that all participants are wearing head, eye, and hand protection.

Instructions

Execute Autonomous Test Flight

WARNING: This test flight is a particularly dangerous activity because the UAV will execute instructions provided to it by QGroundControl. Take all proper safety precautions before flying, and be prepared to manually engage the kill switch if the UAV behaves unexpectedly.

Prepare the test environment in the same manner as **Test Flight: Prepare the Test Environment** on **page 44**. After completing the steps in **Appendix B. Pre-Flight Checklist** on **page 76**, perform the following actions:

1. Power on the flight controller and companion computer by connecting them to the secondary battery. Connect the motors to the LiPo battery.
2. Prepare the transmitter, and verify that it can kill the UAV's motors by:
   a. Engaging the arming switch
   b. Engaging the throttle until the propellers spin, but not enough that the UAV takes off.
   c. Engaging the kill switch
   d. Disengage the throttle, kill switch, and arming switch on the transmitter, but leave it powered on and readily accessible.
3. Wait for the companion computer's access point to be enabled, then connect to it with the ground control station laptop.
4. Determine the IP address of the ground control station laptop and the companion computer. On Windows, this is done by opening the command prompt and entering `ipconfig`. The companion computer's IP address is listed as the "Default Gateway", and the ground control station laptop's is listed as "IPv4 Address" in the appropriate interface's section.
5. Connect to the companion computer via SSH by entering `ssh <user>@<gateway_ip>`.
6. Once you have access to the companion computer's terminal, activate the Python virtual environment and start MAVProxy as shown in **Figure 112** using the appropriate commands in the **Verify Wi-Fi Connection to Ground Control Station** section on **page 57**.
7. Start QGroundControl, and wait for it to connect to the flight controller.
8. Create a simple autonomous mission:
   a. Click the "Plan" button as shown in **Figure 113**.
   b. In the "Mission Start" box in the upper right corner, set the Initial Waypoint at **less than half of the length of the tethers** as shown in **Figure 114**. In this example, the tethers were 20

feet long, so the value was set to 7 feet.

c. Click the “Takeoff” button as shown in **Figure 115** to add that command to the mission. Ensure that the height matches the number set in the previous step, as shown in **Figure 116**.
d. Click the “Return” button as shown in **Figure 117** to add that command to the mission.
e. Send the mission to the flight controller by clicking the “Upload” button on the right side of the top toolbar, as shown in **Figure 118**.
f. Verify that MAVProxy prints a line reading `Got MISSION_ACK: TYPE_MISSION: Accepted`.

9. Once QGroundControl reports that the UAV is ready to fly, drag the slider that appears at the top of the QGroundControl window to the right to start the mission, shown in **Figure 119**. The UAV should take off, fly to the correct height, then immediately land.
10. Once the test is complete, press `Ctrl+C` in the companion computer’s terminal to stop the MAVProxy application. Next, shut down the companion computer safely by entering `sudo shutdown now`. The SSH session will immediately disconnect.
11. Wait around 30 seconds before disconnecting the companion computer from the battery, to ensure that it has finished the shutdown sequence since you cannot see the terminal’s output.
12. Disconnect the flight controller and motors from their power sources.

Once the test flight is complete, make sure that the LiPo battery is returned to a storage voltage. Troubleshoot any issues encountered during the test flight before proceeding on to adding the additional components in the next chapters.

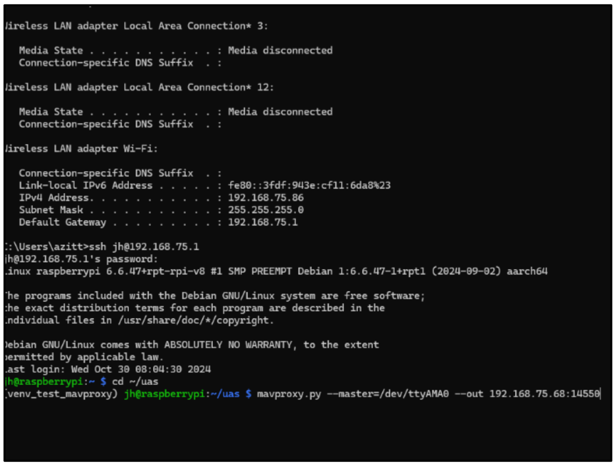


Figure 112 Connecting to companion computer via SSH

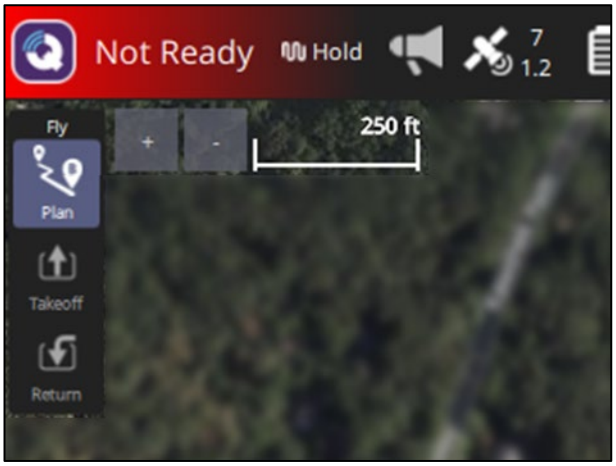


Figure 113 The Plan button in QGroundControl

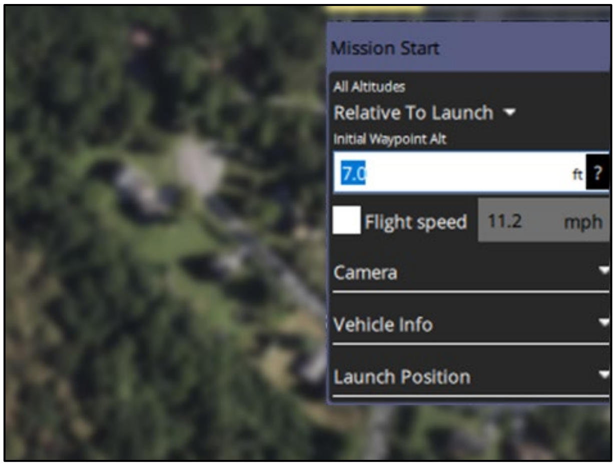


Figure 114 *Setting the default height*

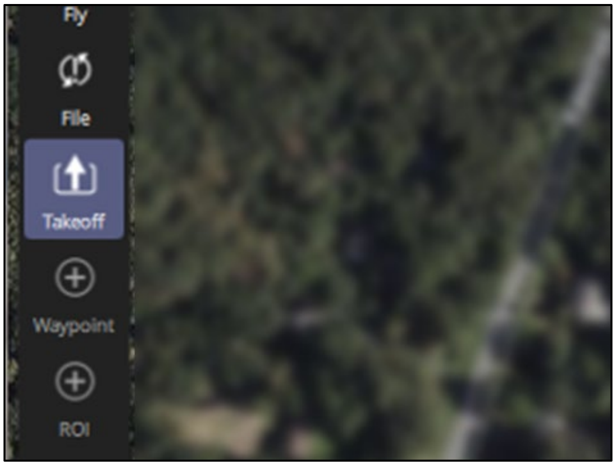


Figure 115 *The Takeoff button in QGroundControl*

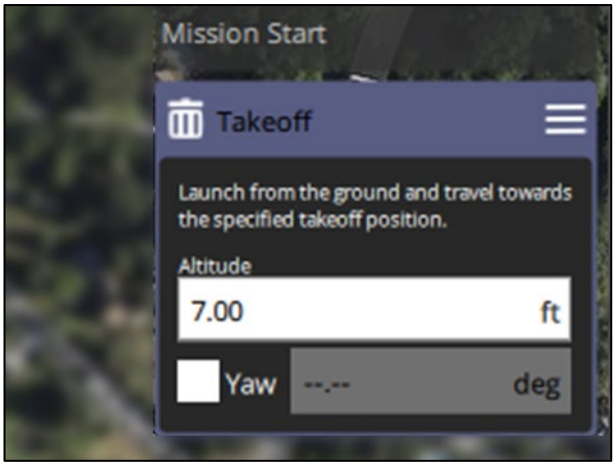


Figure 116 *Configuring the Takeoff instruction*

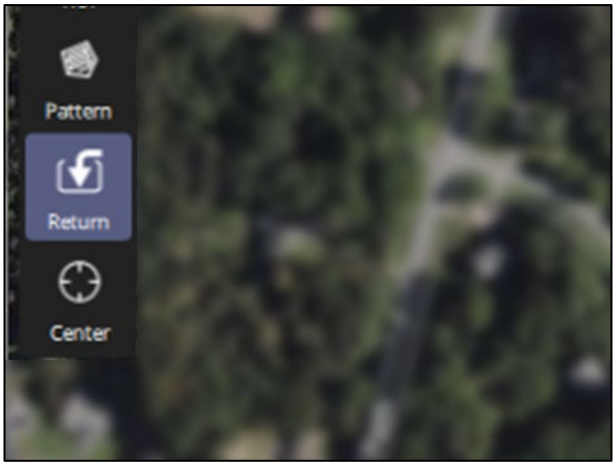


Figure 117 *The Return button in QGroundControl*

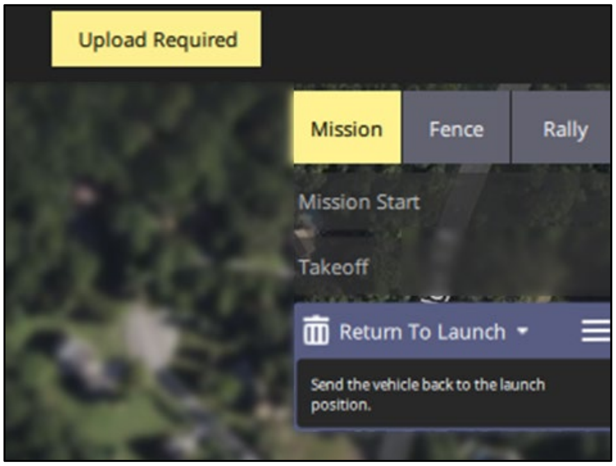


Figure 118 *The Upload button (top) in QGroundControl*

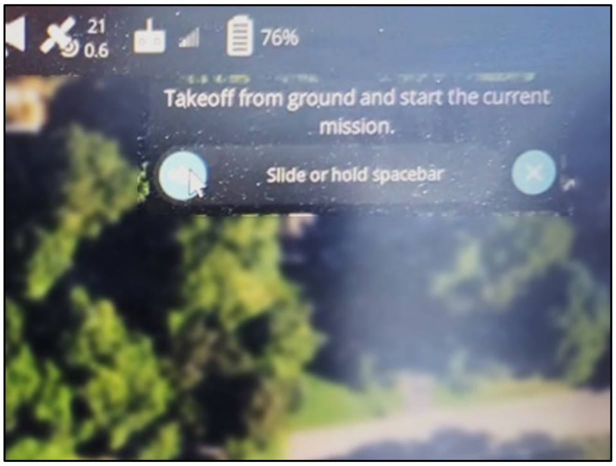


Figure 119 *Mission Start in QGroundControl*

Conclusion

In this chapter, we confirmed that the UAV can receive and execute missions without transmitter input from the pilot. An image of a successful test flight is shown in **Figure 120**.

Figure 120 *Test flight with UAV tethered safely to the ground, executing takeoff mission from QGroundControl*

Distance Sensor (LiDAR)

Asdf

Materials List

The item numbers of the components here match the numbers in the inventory section near the beginning of this document. Return all unused components to their original bags, as they may be needed in later steps.

- [ ] 1x 42. LiDAR Module
- [ ] 1x 42.A. 4-Pin Serial Cable (Female 1.25mm connector) **(if soldering)**
- [ ] 1x 42.B. 4-Pin Serial Cable (Male Dupont connectors) **(if not soldering)**
- [ ] 2x 49. M2.5 12mm Bolt
- [ ] 2x 51. M2.5 Flat Washer
- [ ] 2x 53. M2.5 Nut
- [ ] 1x 54. Bag of Pre-Made Cables
- [ ] 55. Heat Shrink Tubing **(if soldering)**
- [ ] 1x 65. Extension Frame Plate C w/ LiDAR Attachment Point **(if not already installed)**

Instructions

Make and Connect the Serial Cable

The appropriate connector that comes with the sensor is both too short and does not have the required connector to fit a serial port on the flight controller, so it must be modified. When completed, the serial cable will match the layout shown in **Table 5**. Note that **the power (red) and ground (black) wires switch to different positions** between the flight controller and LiDAR connectors. These instructions follow the wiring diagram in reference [14], which is also shown in **Figure 121**.

Flight Controller		Function	LiDAR Sensor	
Position	**Color (Example)**		**Position**	**Color**
1	Red	Power	2	Red
2	White	RX ⇔ TX	3	White
3	Blue	TX ⇔ RX	4	Green
4				
5				
6	Black	Ground	1	Black

Table 5 Flight Controller to LiDAR Serial Cable Configuration (note position change in black ground wire)

To make the modified serial cable, perform the following steps:

1. Remove a six-pin connector from the bag of pre-made cables. Cut or pull off wires 4 and 5

(green and yellow, in this example) as shown in **Figure 122**.

2. **Option 1:** Solder the wire. This method creates a stronger connection, but is more prone to failure (if the soldering is done incorrectly) and creates a slightly shorter cable.
   a. Using the cable with the 1.25mm connector, identify the connectors on each end. The connector that attaches to the distance sensor is shown in **Figure 123**, and the connector that needs to be removed is shown in **Figure 124**. Additionally, remove the Dupont connectors from the ends of the wires attached to the six-pin connector.
   b. With a sharp utility knife, strip the insulation away from the end of each wire as shown in **Figure 125**. Be sure not to cut into the wire itself.
   c. Slide heat shrink tubing over the wires as shown in **Figure 126**. In this example, each wire is individually covered, then all the wires are bundled with a larger piece.
   d. Apply flux and solder to each exposed end individually, then solder them together. After a few seconds, attempt to pull the wires apart to ensure that the connection is strong.
   e. Use a heat gun to secure the heat shrink tubing over the exposed section of wire as shown in **Figure 127**.
   f. The finished cable using this method is shown in **Figure 128**.
3. **Option 2:** Connect the wires via Dupont connectors. This method is less secure, but the cable is a few inches longer and eliminates the need to solder.
   a. Attach the male and female Dupont connectors together, as shown in **Figure 129**.
   b. Optionally, secure the connection with electrical tape to prevent the wires from coming loose during flight.

The finished cable attached to the distance sensor is shown in **Figure 130**.

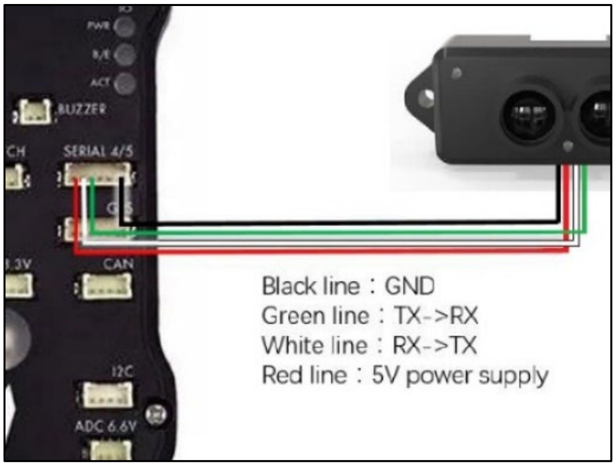


Figure 121 *TFmini wiring diagram from Ardupilot*

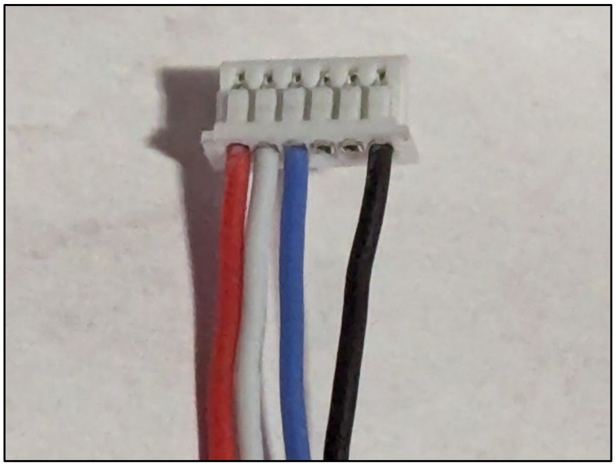


Figure 122 *Six pin cable with unnecessary wires removed*

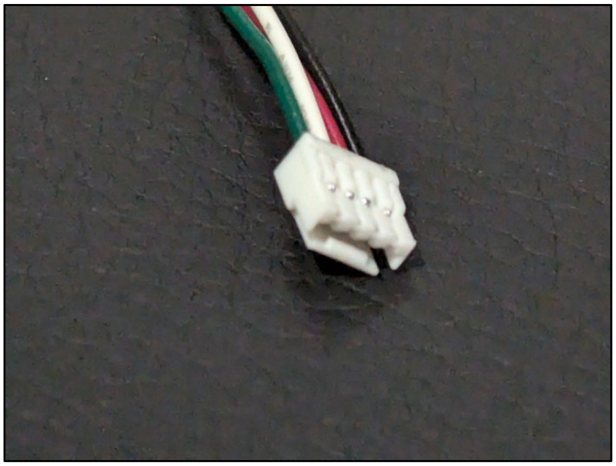


Figure 123 *Connector for the distance sensor*

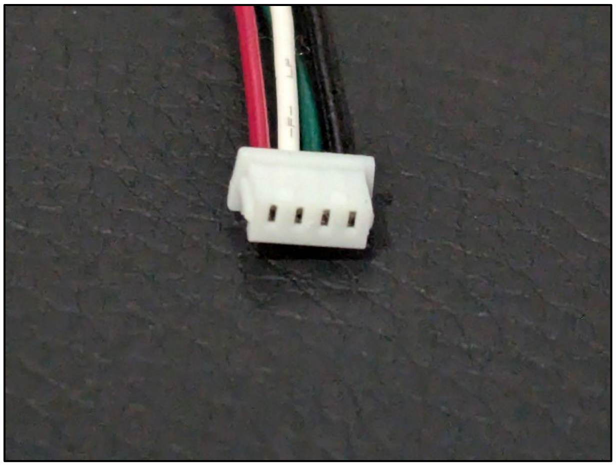


Figure 124 *Connector to be removed*

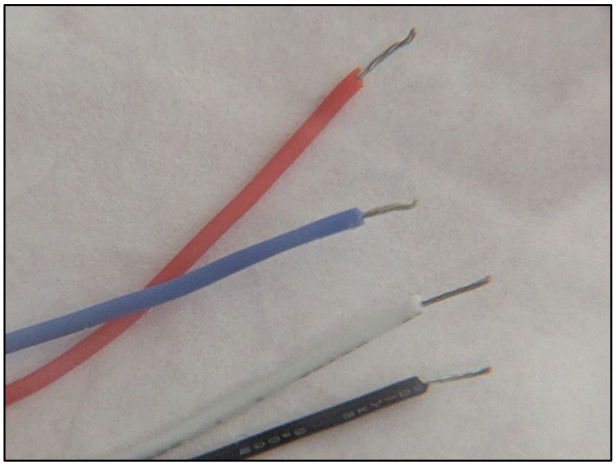


Figure 125 *Insulation cut away from wires*

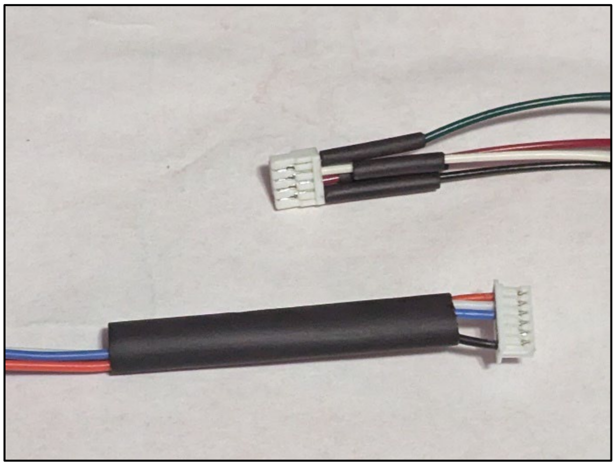


Figure 126 *Heat shrink applied to wires*

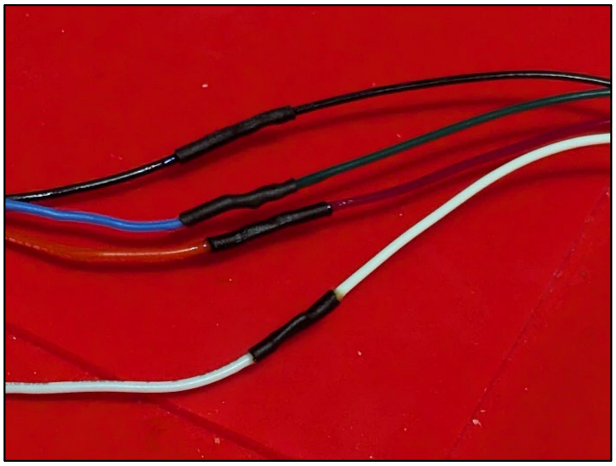


Figure 127 *Heat shrink tubing applied to individual wires*

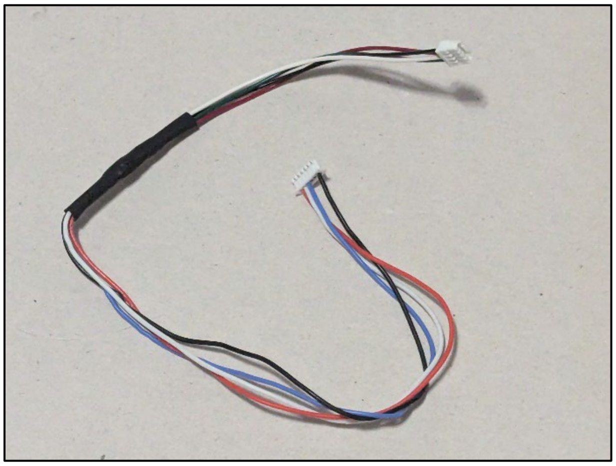


Figure 128 *Heat shrink tubing applied to all wires*

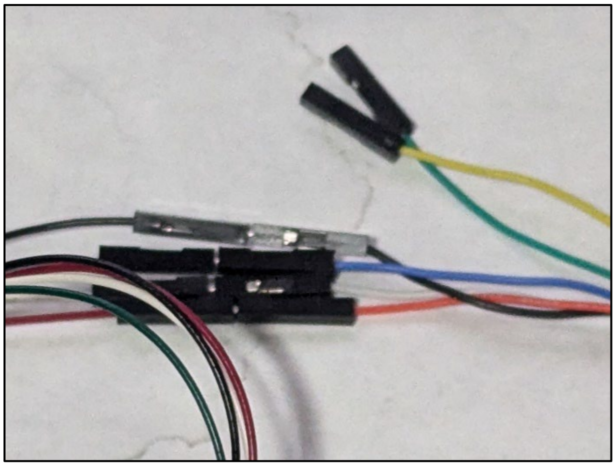


Figure 129 *Wires attached with Dupont connectors*

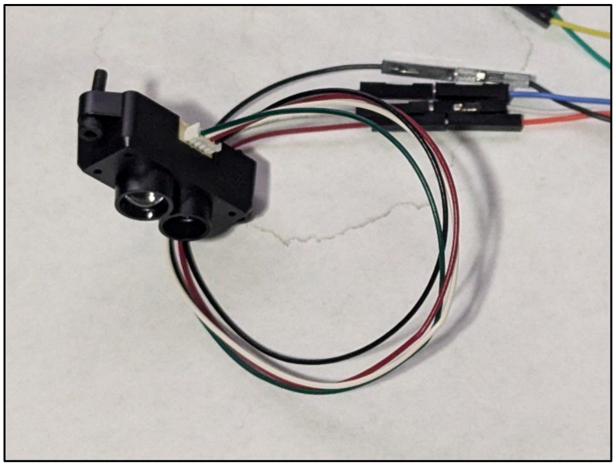


Figure 130 *Wires attached to distance sensor*

Attach the Distance Sensor

Before completing the following steps, if you chose not to install the version of Extension Plate C that has the LiDAR mounting points, disassemble and install the correct version of plate C on the bottom extension frame as described in **Attach the Bottom Extension Frame** on **page 31**. You will not need to remove plate A from the frame of the UAV.

1. Thread two M2.5x12 bolts through the holes on the distance sensor as shown in **Figure 131**. They may be angled slightly inwards; this will not affect installation.
2. Secure the distance sensor to the mounting point on the bottom extension frame using two flat washers and nuts. The distance sensor should be pointing down as shown in **Figure 132**.
3. Route the distance sensor cable through the hole in plate C, then through the frame, and connect it to the **SER 4/5** port on the flight controller as shown in **Figure 133**.

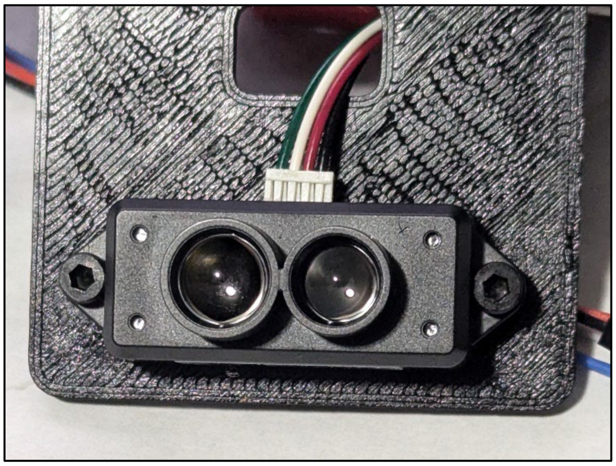


Figure 131 *Distance sensor mounted with two bolts*

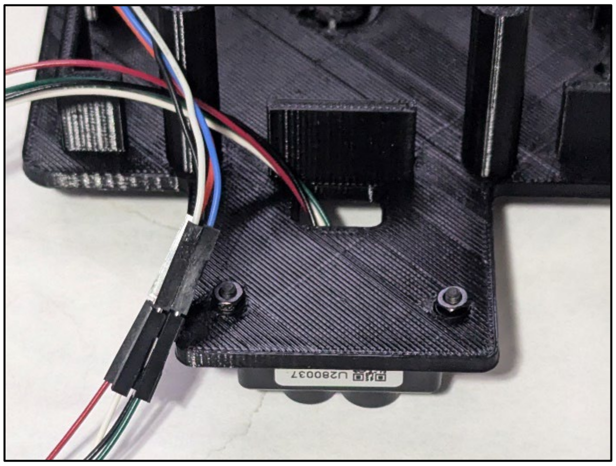


Figure 132 *Correct orientation of the distance sensor*

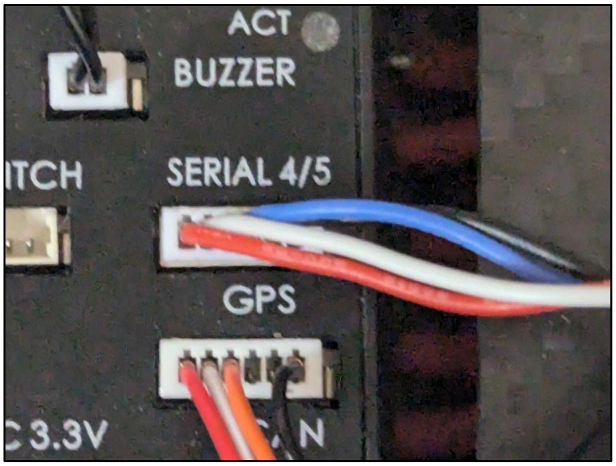


Figure 133 *Correct orientation of the distance sensor*

Configure Flight Controller

The steps in this section are derived from references [15] and [16].

1. Connect to the flight controller from the ground control station laptop, and open QGroundControl.
2. Verify that the `tfmini` driver is enabled.
   a. Navigate to the Vehicle Setup page, then select the Parameters tab.
   b. In the search box, type `SENS_TFMINI_CFG`. If you do not see an entry for this parameter (i.e. a blank page), complete the steps in **Appendix D. Loading Custom Firmware** on **page 81**.
3. Set the value of `SENS_TFMINI_CFG` to `104`, indicating that it will be attached to **SER 4/5.**

Test LiDAR Readings

Testing the LiDAR is straightforward using the MAVLink inspector in QGroundControl.

1. In QGroundControl, navigate to the **Select Tool** dialog box shown in **Figure 134** by clicking the icon in the upper left, then select **Analyze Tools**.
2. Select the **MAVLink Inspector** tab, and wait for a **DISTANCE_SENSOR** message to appear as shown in **Figure 135**. If one does not appear after several seconds, it indicates that there is a problem communicating with the LiDAR module. If this happens, verify the connections between the LiDAR, flight controller, and the wires themselves.
3. Move the UAV up and down, and check that the `current_distance` value changes, shown near the center of **Figure 136**.

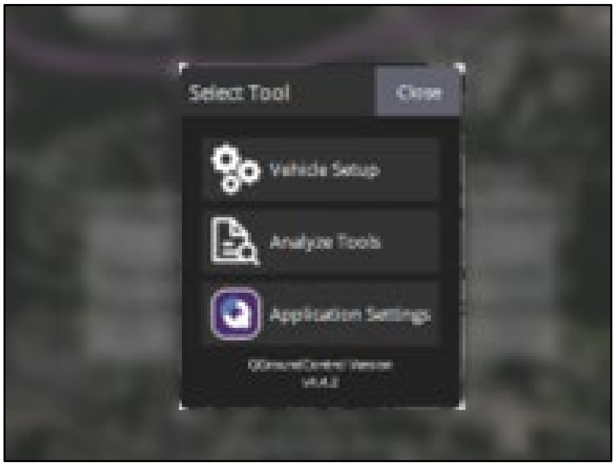


Figure 134 *Select Tool menu in QGroundControl*

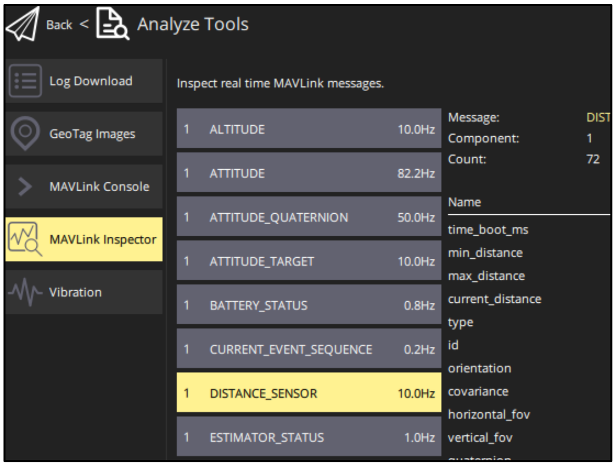


Figure 135 *MAVLink DISTANCE_SENSOR message*

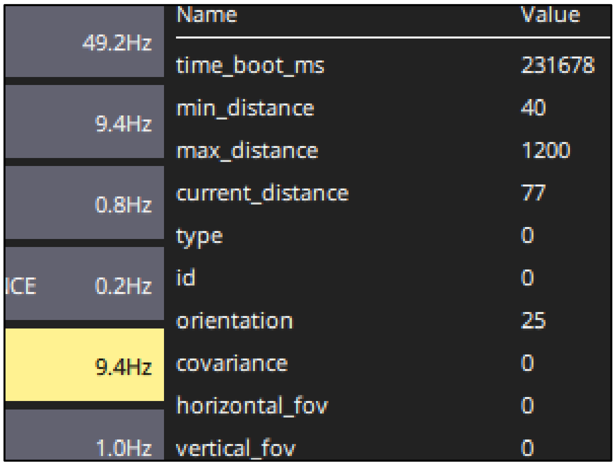


Figure 136 *DISTANCE_SENSOR values*

Conclusion

In this chapter, we installed a distance sensor on the UAV. This capability (with additional configuration) enables the UAV to perform terrain following and more accurately hover at low altitudes. The completed installation is shown in **Figure 137**.

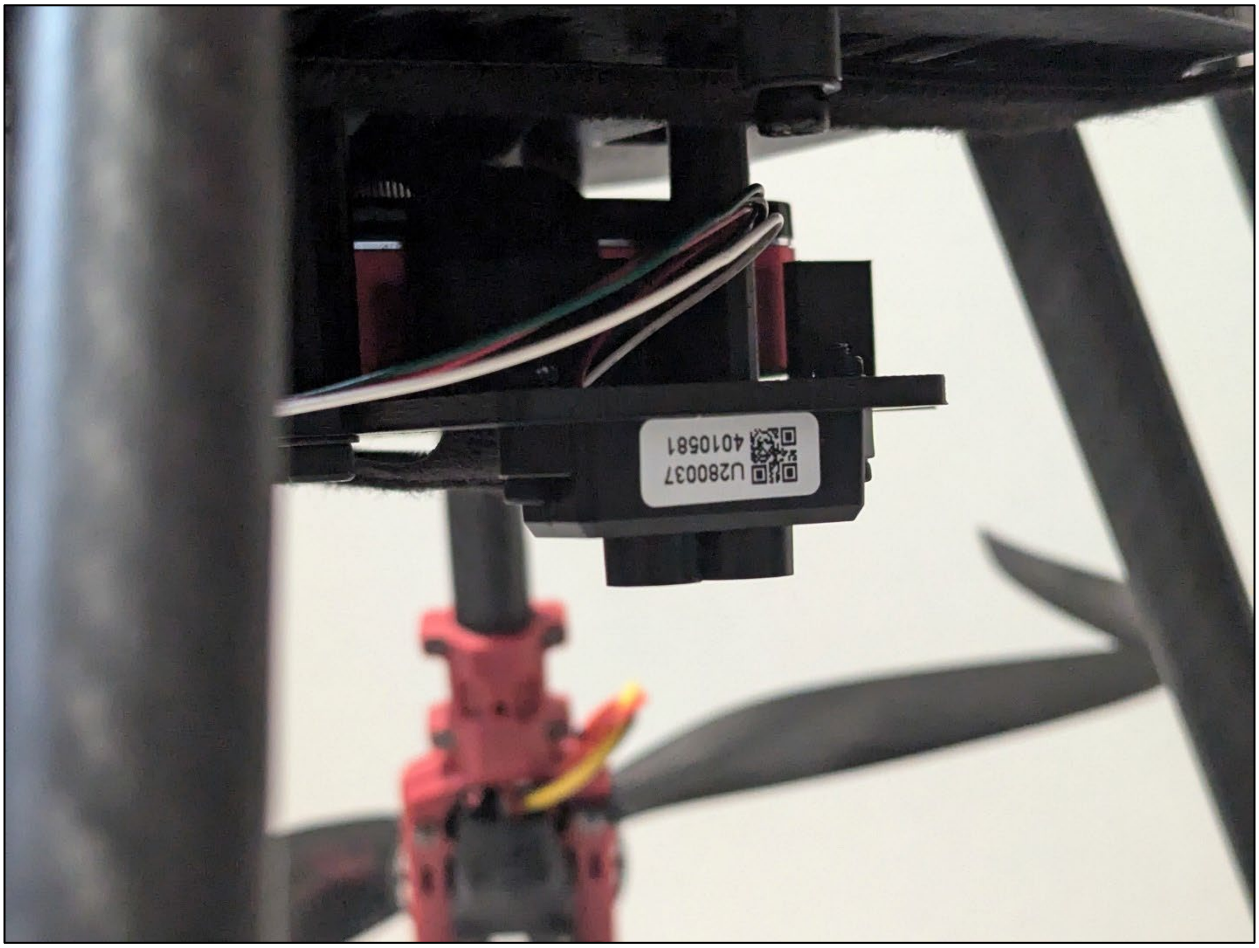


Figure 137 *Distance sensor mounted to the UAV frame*

Appendix A. Inventory Visual Reference

The number of each item corresponds to its position in the inventory list starting on **page 7**.


1


1.A

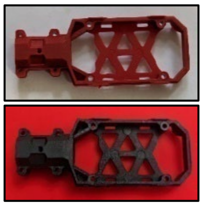

1.B


1.C

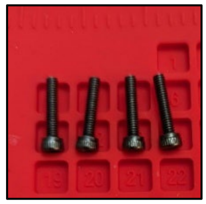

1.D


1.E


2


2.A


2.B


2.C


2.D


2.E


3


3.A

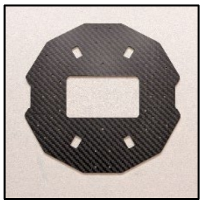

3.B


3.C


3.D


4


4.A

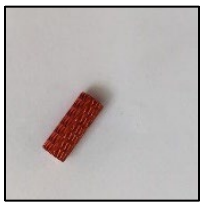

4.B

4.C

4.D


5


5.A


5.B


5.C


5.D


5.E


6


6.A


6.B


6.C

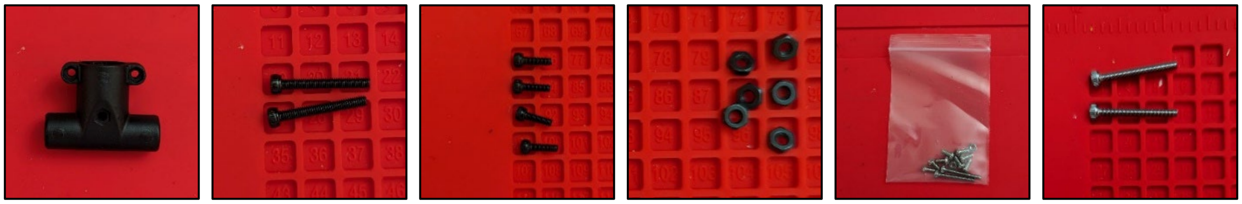

6.D

6.E


7

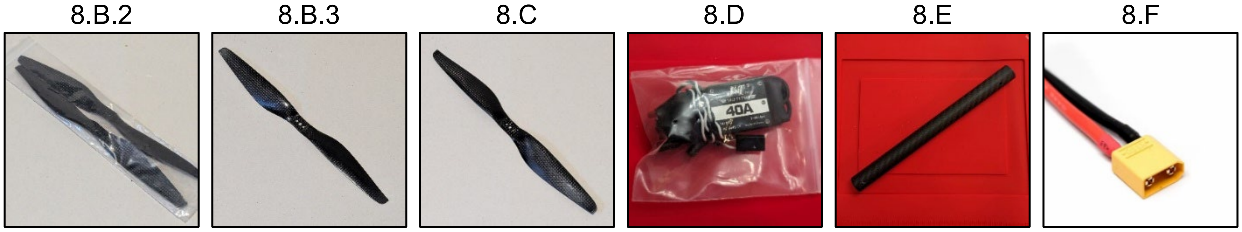

7.A

7.B 7.C 7.D 7.E 8 8.A

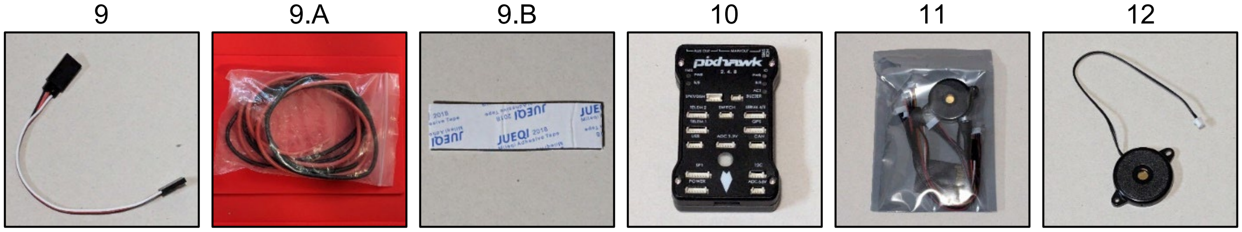


8.A.1 8.A.2 8.A.3 8.A.4 8.B 8.B.1

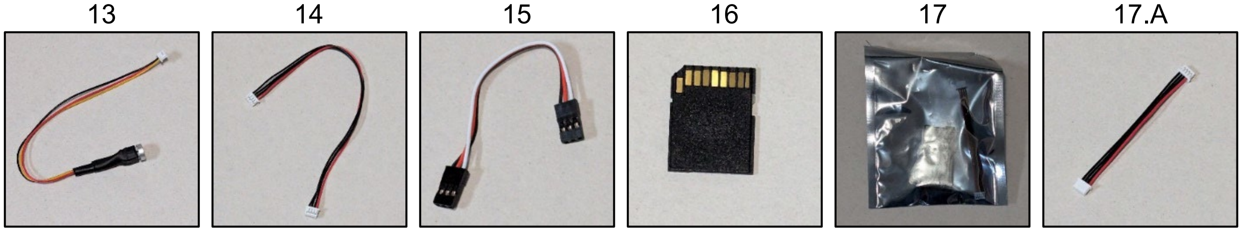
8.B.2 8.B.3 8.C 8.D 8.E 8.F



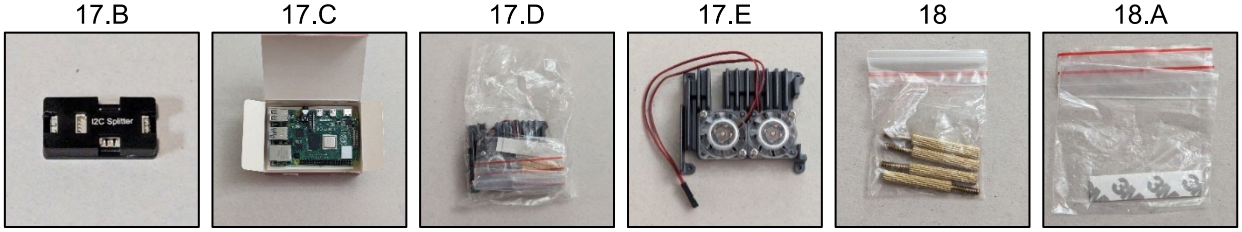
9 9.A 9.B 10 11 12



13 14 15 16 17 17.A



17.B 17.C 17.D 17.E 18 18.A

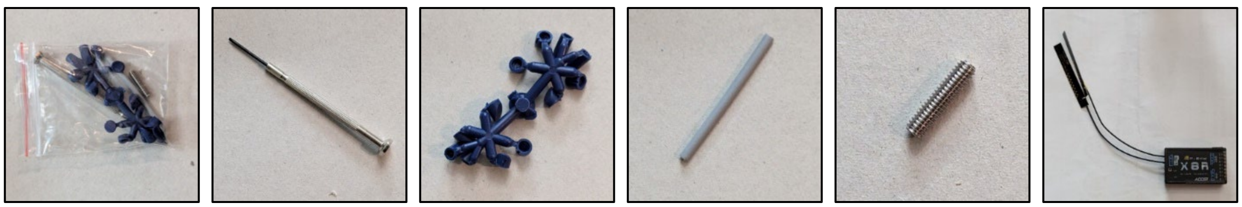


18.B 19 20 20.A 20.B 20.C

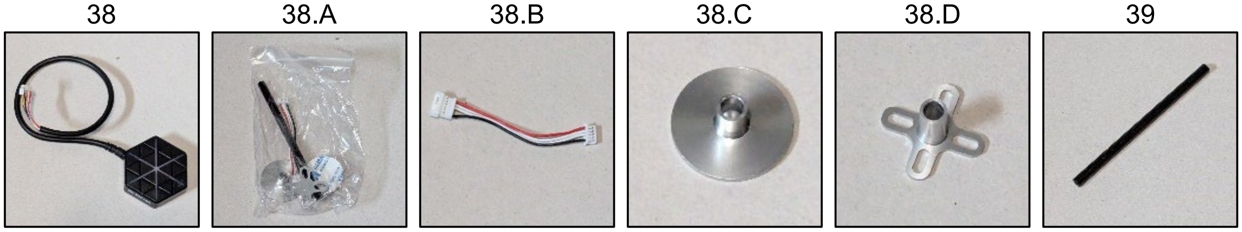
21 22 23 24 25 26

27 28 29 29.A 30 31

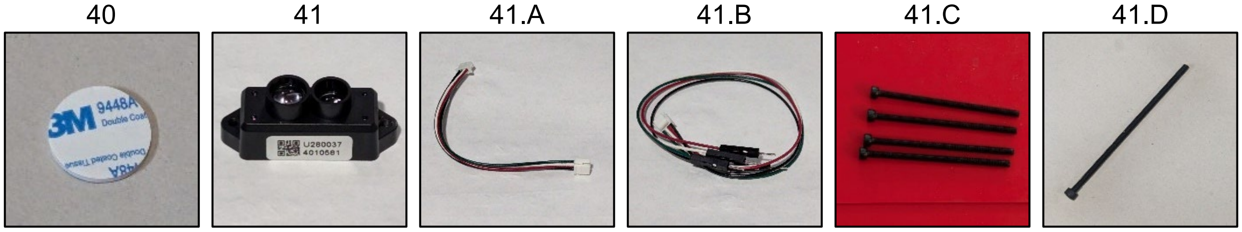
32 33 34 35 36 37



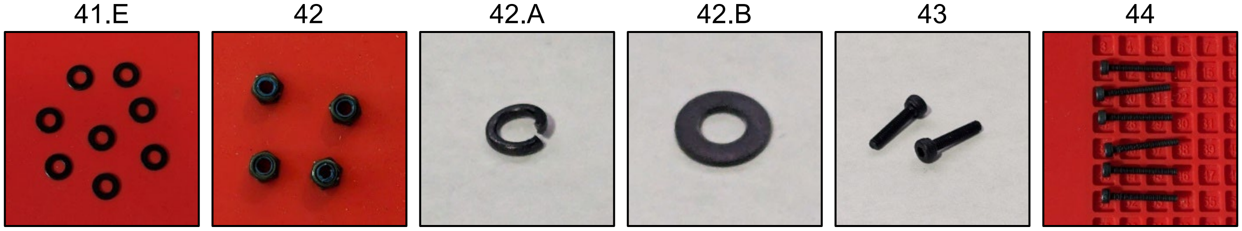
38 38.A 38.B 38.C 38.D 39



40 41 41.A 41.B 41.C 41.D



41.E 42 42.A 42.B 43 44



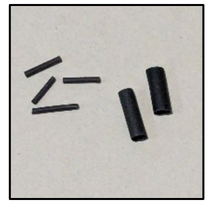
45 46 47 48 49 50


51


52

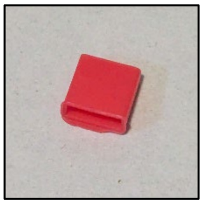

53


54

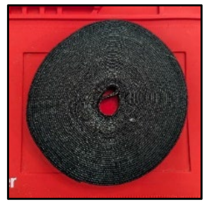

55

56

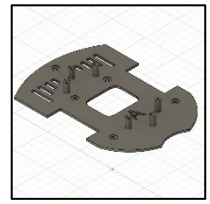

57

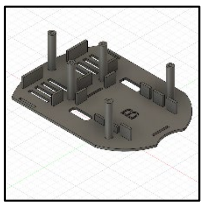

58

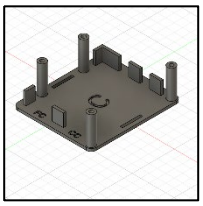

59

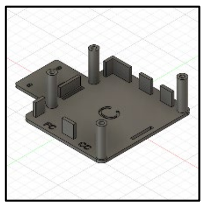

60

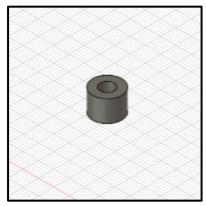

61


62


63


64


65


66

Appendix B. Pre-Flight Checklist

Perform this checklist before arming the UAV.

> **WARNING:** Do not attempt to fly the UAV in strong wind or other adverse weather conditions.

- ☐ Secure Cables, Batteries, and Sensors
  - ☐ Secure the LiPo battery with a piece of hook and pile tape, as shown in **Figure 138**.
  - ☐ Secure the companion computer with a piece of hook and pile tape, as shown in **Figure 139**.
  - ☐ Secure the secondary battery with a piece of hook and pile tape, as shown in **Figure 140**.
  - ☐ Secure excess USB cables to the UAV's landing skid with a cable tie or piece of hook and pile tape, as shown in **Figure 141**.
- ☐ Ground Station Checks (if using QGroundControl)
  - ☐ Verify that QGroundControl can connect to the flight controller.
  - ☐ Verify that QGroundControl reports "Ready to Fly" as shown in **Figure 142**.
- ☐ Transmitter Checks
  - ☐ Verify that the arming switch arms and disarms the UAV.
  - ☐ Verify that the throttle spins all six motors.
  - ☐ With the throttle engaged, verify that the kill switch immediately stops all six motors.

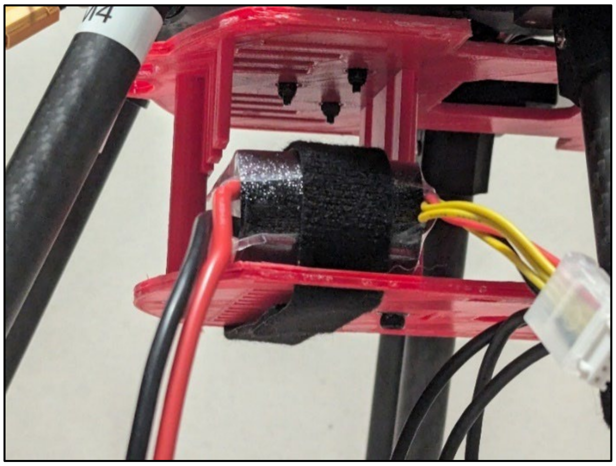


Figure 138 *LiPo battery secured*

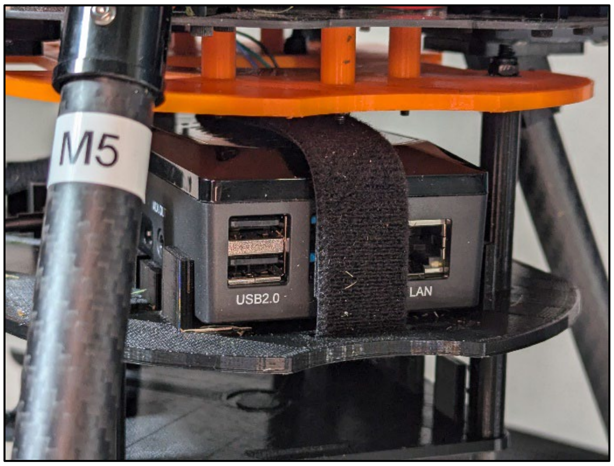


Figure 139 *Companion computer secured*

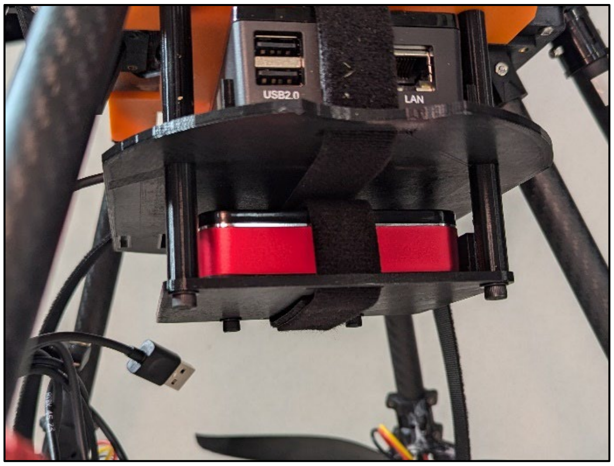


Figure 140 Secondary battery secured

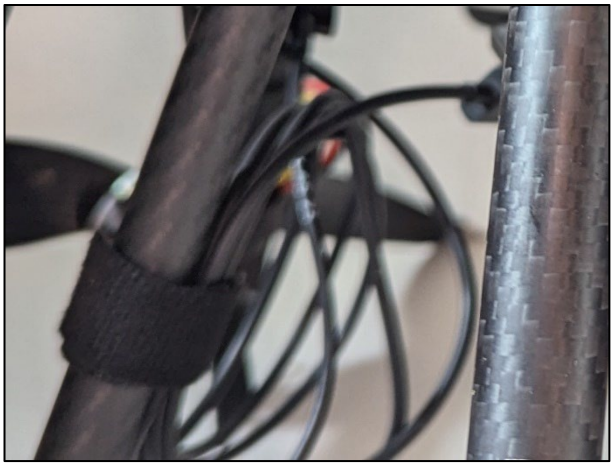


Figure 141 Excess cable secured

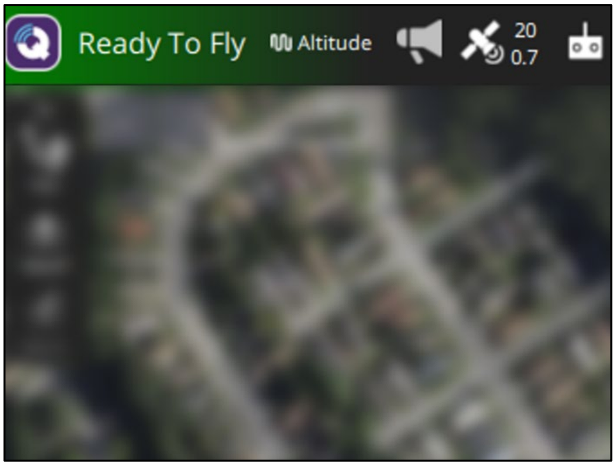


Figure 142 "Ready to Fly" indicator with no preflight errors

Appendix C. Charging a Lithium Polymer Battery

Before starting, review background information on Lithium Polymer (LiPo) batteries [17].

> **WARNING:** LiPo batteries have the potential to discharge a large amount of energy at once, which is why they are preferred for use in UAVs. However, **they have great potential to start a fire** if not properly maintained. This is especially true since these batteries will be used and abused (e.g. dropped from great heights) over time.

1. Long press the red selector wheel until the menu in **Figure 143** appears.
2. Navigate to **Task Parameters** and set the **Max. capacity** to the capacity of the battery as shown in **Figure 144**.
3. Select **System self-checking** and press the wheel to select. Wait for the diagnostic to run, as shown in **Figure 145** and **Figure 146**.
4. Press the **CH** button to go back to the main screen. Then press **CH** again to select Channel 1 as shown in **Figure 147**.
5. Plug in the battery's monitor and XT60 connections as shown in **Figure 148** and **Figure 149**.
6. Short press the selection wheel and navigate to **Charge** [53] as shown in **Figure 150**.
7. Ensure the **Battery type**, **Cell voltage,** and **Cell count** match the data sheet of the battery. If using the battery included in this documentation, the correct values are shown in **Figure 151**.
8. Select **Begin task**. The battery will begin charging and look like **Figure 152**.

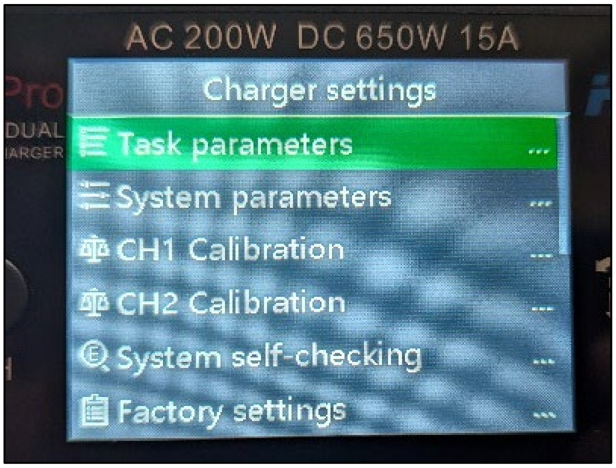


Figure 143 *Task Parameters*

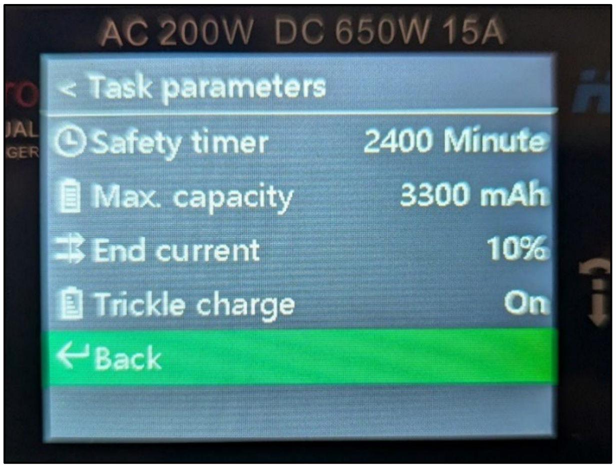


Figure 144 *Task parameters configured*

[53] Note that the associated figure is pointing to "Balance", not "Charge". It appears that by default, the charge function on the D6 Pro balance charges by default.

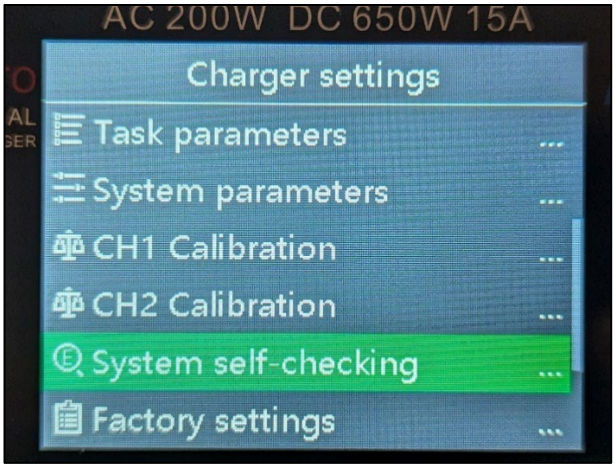


Figure 145 *System Self-Checking*

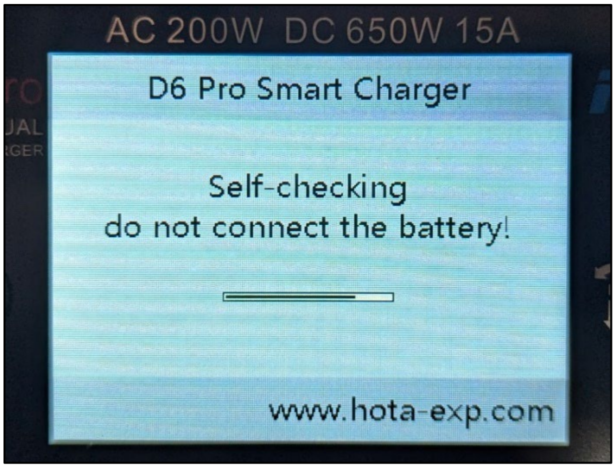


Figure 146 *Example of self-checking notification*

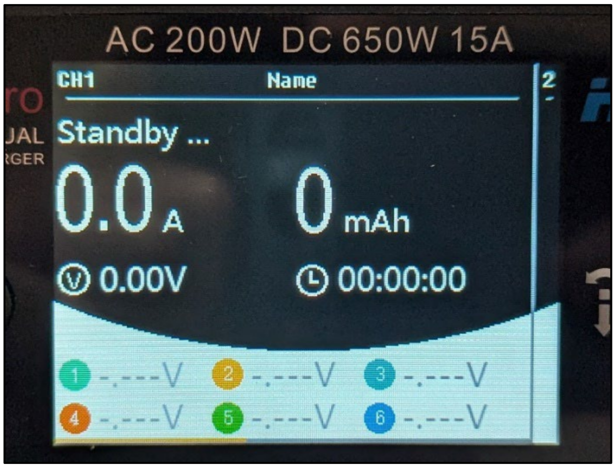


Figure 147 *Channel 1 prior to connecting battery*

Figure 148 *Balance port and XT60 cable connected*

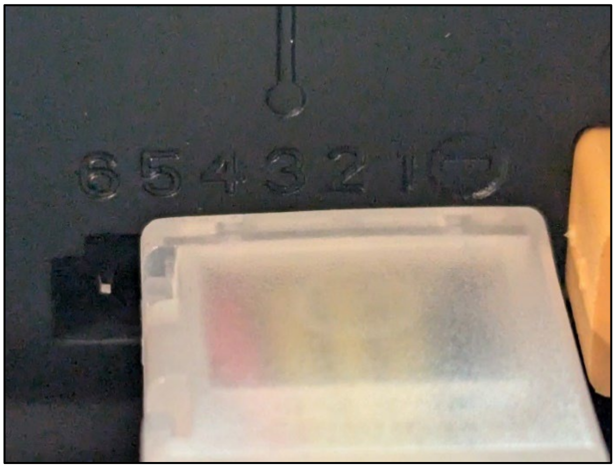


Figure 149 *Correct alignment of balance port*

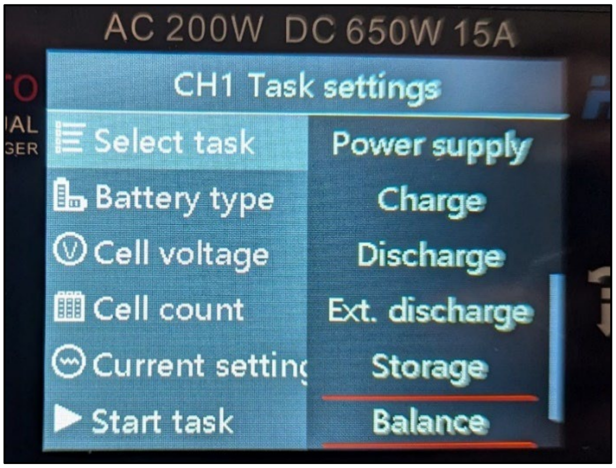


Figure 150 *Channel task settings*

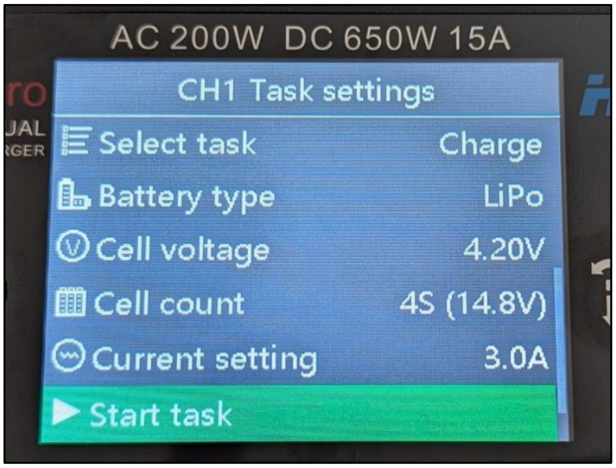


Figure 151 *Channel task settings configured*

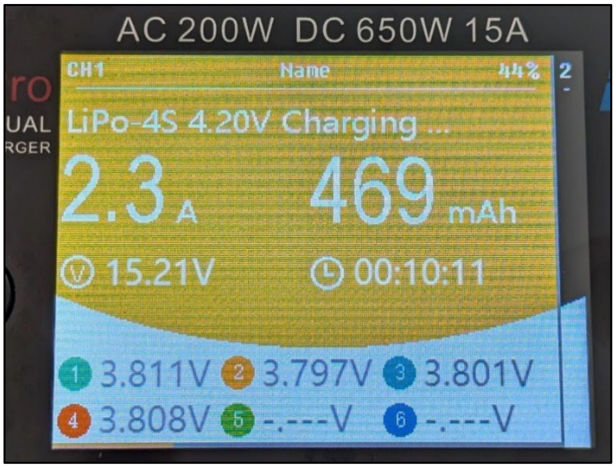


Figure 152 *Channel screen while charging*

Appendix D. Loading Custom Firmware

WARNING: It may be necessary to re-calibrate the flight controller after changing the firmware.

This section contains instructions needed to install versions of the PX4 firmware other than the defaults that come with QGroundControl, or to enable drivers that do not come turned on by default. To perform these steps, it is necessary to compile the firmware yourself.

These instructions were written using a Linux development environment inside of a virtual machine on a Windows host. In theory, these steps can also be performed using the Windows Subsystem for Linux (WSL), but there may be some slight differences. These instructions have only been tested with the fmu-v2 bootloader, which came packaged with the flight controller used in these instructions. One unfortunate limitation with this version is that the flash memory is artificially limited to 1MB. Because of this, many drivers for optional components are disabled by default.

Download Source and Select Version

The PX4 firmware is hosted on GitHub. In this section, you will download it, update its dependencies, and select the correct version of the firmware you wish to modify. These instructions are derived from references [18], [19], and [20].

1. Navigate to your working directory.
2. Ensure that `git` is installed in your development environment with the following commands:

```
sudo apt update
sudo apt install git
```

3. Download the PX4 source code and submodules with the following commands, then reboot the development machine [54]:

```
git clone https://github.com/PX4/PX4-Autopilot --recursive
bash ./PX4-Autopilot/Tools/setup/ubuntu.sh
```

4. Select the correct version of the firmware that you want to use. One way to choose is by navigating to https://github.com/PX4/PX4-Autopilot/tags and looking for the most recent stable release, as shown in **Figure 153**. In these instructions, we will use v1.15.2. Checkout the corresponding branch using the following commands:

```
make clean
make distclean
git checkout v1.15.2
make submodulesclean
```

5. Download required Python packages with the following command:

[54] The setup script is used to install the correct version of GCC, which is used to compile the firmware.

```
python3 -m pip install tk symforce
```

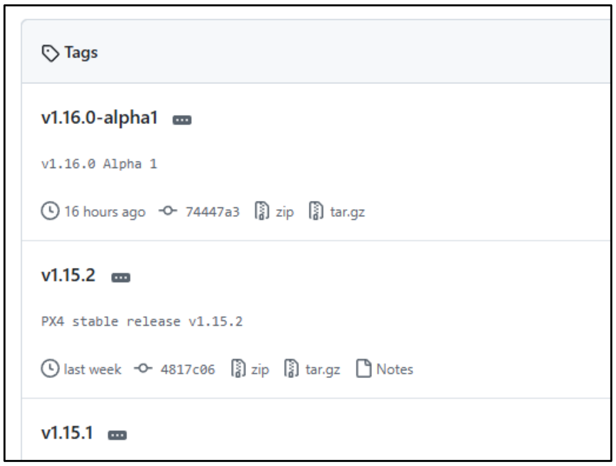


***Figure 153** Example of PX4-Autopilot Tags*

Enable Drivers and Compile Firmware

In this example, we will enable the `tfmini` driver, which is necessary for installing the LiDAR rangefinder in the **Distance Sensor (LiDAR)** chapter on **page 65**; however, any available driver can be turned on or off using this method. These instructions are derived from reference [21].

1. Navigate to the PX4-Autopilot directory from the previous section.
2. Open the board configuration GUI utility with the below command. After the compiler has finished running, you should see a window that looks like **Figure 154**.

   ```
   make px4_fmu-v2 boardguiconfig
   ```

3. Inside the configuration utility, expand `drivers`, then `Distance sensors`. Check the `tfmini` box, as shown in **Figure 155**.
4. Click the "Save" button, then exit out of the PX4 Firmware Configuration utility. Verify that there is a line in the output that reads something like "Configuration saved to <file path>/PX4-Autopilot/build/px4_fmu-v2_default/boardconfig". Make note of the location of this file.
5. Verify that the driver was enabled by entering the below command and ensuring that the line `CONFIG_DRIVERS_DISTANCE_SENSOR_TFMINI=y` is shown as in **Figure 156**.

   ```
   cat <file path to boardconfig> | grep TFMINI
   ```

6. Compile the firmware using the below command:

   ```
   make px4_fmu-v2
   ```

7. Verify that the flash memory region is not completely filled, as shown in **Figure 157**.

Make a note of the location of the binary, which is shown in the last line of the output (the file ends in `.px4`). If necessary, transfer the compiled binary to the computer that will have a direct USB connection to the flight controller.

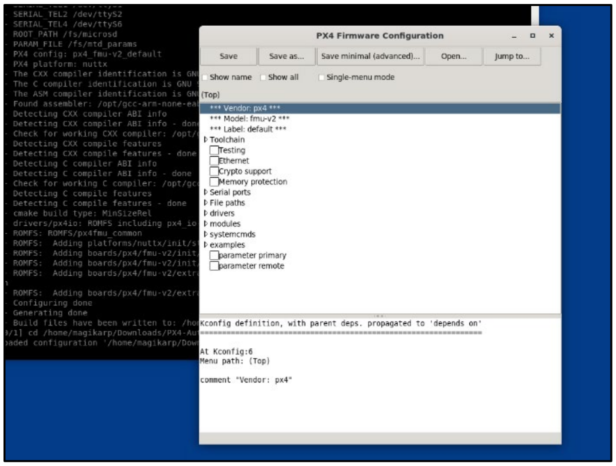


Figure 154 PX4 Firmware Configuration GUI

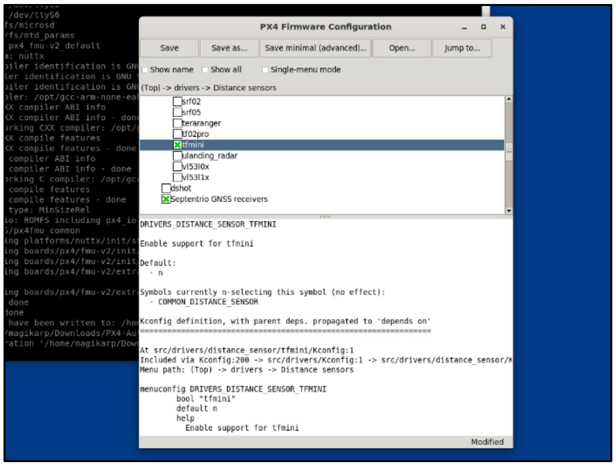


Figure 155 Checkbox enabling the tfmini driver

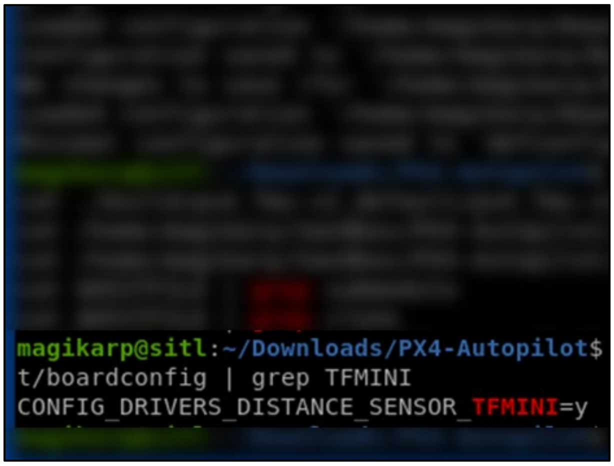


Figure 156 Verifying that the tfmini driver is enabled

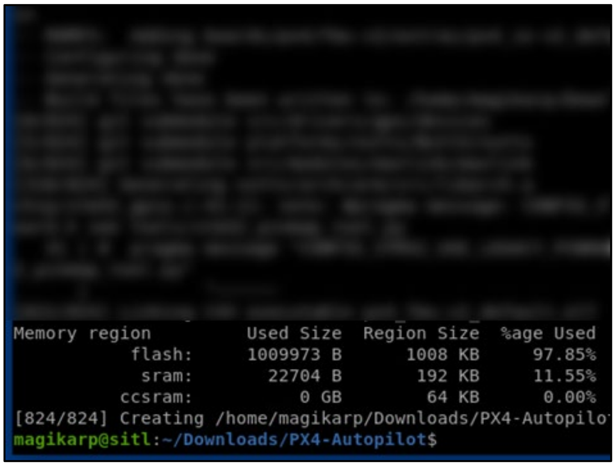


Figure 157 Verifying the flash memory region's usage

Install Firmware

In this section, the compiled firmware will be installed on the flight controller. This section assumes that you have transferred the binary (if necessary) to that machine. One transfer method is to use WinSCP to establish an SSH connection to the remote machine and copy the binary.

1. Connect the flight controller to the computer with a USB cable.
2. Open QGroundControl, and navigate to the **Vehicle Setup** page.
3. Click on the **Firmware** tab, then follow the instructions until you reach the firmware selection dialog box shown in **Figure 158**. Check the **Advanced settings** box, then in the dropdown that appears, select **Custom firmware file…**
4. Using the file dialog box, select the `px4` binary.
5. In the **Summary** tab, verify that the **Airframe: Firmware Version** value matches the expected version as shown in **Figure 159**.

In our example, we performed these steps to enable the `tfmini` driver. Verify that the required parameter now exists by navigating to the **Parameters** tab and searching for `SENS_TFMINI_CFG`.

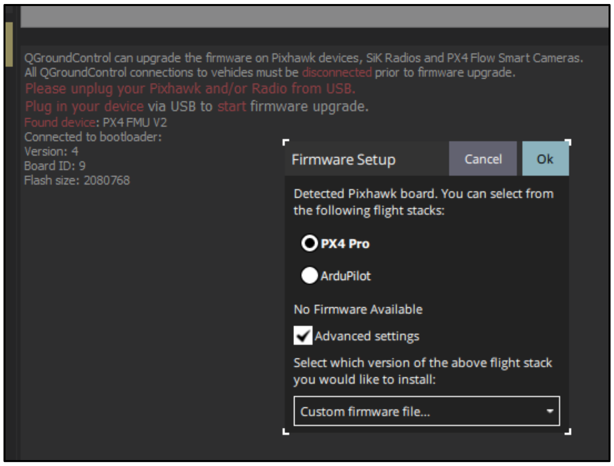


Figure 158 *Verifying that the tfmini driver is enabled*

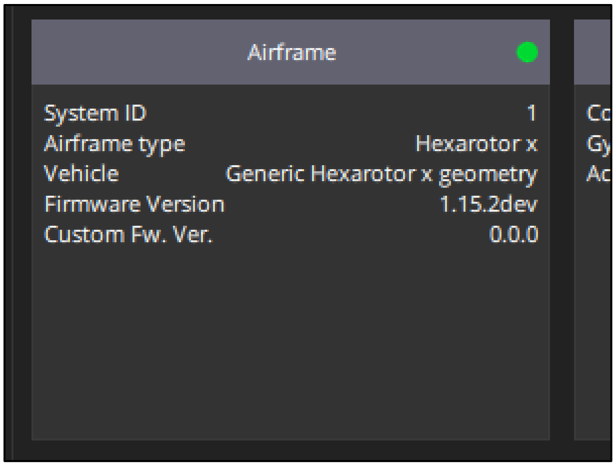


Figure 159 *Verifying firmware version*

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