Chapter Outline

Unmanned Aerial Vehicle (UAV) Assembly, Debugging and Flight Tests

Chapter 1 Introduction

1.1 Concepts and Applications

1.2 History and Trends

1.3 Components and Architecture

1.4 Coordinate Systems and Control Principles

1.5 Assembly and Debugging

1.6 RflySim Toolchain

1.7 Learning Path and Experiments

1.8 Exercises and Discussion

5 Units in This Section

1.5.1 Component Connections and Prototype Components
Textbook: Sec. 1.3.1

1.5.2 Quadcopter Assembly Steps and Wiring
Textbook: Secs. 1.3.1–1.3.2

1.5.3 Debugging and Experiments: Ground Validation
Textbook: Sec. 1.3.3

1.5.4 Debugging and Experiments: First Flight and Review
Textbook: Sec. 1.3.3

1.5.5 Fixed-Wing Assembly and Debugging
Textbook: Secs. 1.3.1–1.3.3

1.5.1 Component Connections and Prototype Components: Scope and Examples

General Assembly and Debugging: UAV Examples

Identify Components	Mechanics and Wiring	Configure and Validate	Staged First Flight	Postflight Review
Models and Interfaces	Mounts and Connections	References and Responses	Fit Propellers with Power Off	Inspect and Record

- **Book scope:** Unmanned vehicles of many types and embodied intelligent systems such as robots.
- **Shared methods:** Structural and power integration, measurement calibration, control configuration, and staged validation.
- **Examples here:** Full X500 V2 quadcopter workflow, with UltraStick 25e fixed-wing differences.
- **Platform adaptation:** Mechanisms, actuators, parameters, and test conditions vary with vehicle type.

Assembly and debugging methods transfer across vehicles; structure and loads determine the implementation.

1.5.1 Component Connections and Prototype Components: Component Locations

Component Locations on the X500 V2



Platform plate and fittings: see Unit 1.5.2

Figure: X500 V2 with Propellers Installed

- **Frame and propulsion:** Each arm has a motor, an electronic speed controller (ESC), and a propeller; two propellers of each rotation direction.
- **Autopilot location:** The autopilot (flight controller) sits at the top-plate center, facing the nose; a raised mount supports the Global Navigation Satellite System (GNSS) module.
- **Lower structure and communications:** Twin rails carry the battery tray and platform plate. Landing gear supports the airframe; the receiver and telemetry radio mount on the body.

In the X layout, the nose lies between the front arms; the flight controller is centered on the top plate and faces forward.

1.5.1 Component Connections and Prototype Components: Assembly Layers

Connecting Arms, Center Plates, and Supports



Four Propellers: Fit After Ground Validation

Figure: X500 V2 Parts, Including Propellers

- **Center assembly:** Seat all four arms in the lower-plate slots; check internal wiring before closing and securing the plates. Mount peripherals on the top plate or brackets.
- **Internal power:** Insulate the power distribution board (PDB) from the lower plate; connect the power module (PM) between the battery and PDB.
- **Lower connections:** Lower-plate brackets connect to the twin rails; battery-tray sliders and platform-plate brackets carry their respective plates.

Check internal wiring before closing the plates to avoid pinched wires and repeated disassembly.

1.5.1 Component Connections and Prototype Components: Assembly Checklist

Teaching Prototype: Components and Quantities

Assembly Group	Qty	Components and Preassembled State
Frame	1 set	Upper/lower plates, twin rails, trays, landing gear, and fasteners
Propulsion Arms	4	One preinstalled motor and ESC per arm
Power and Control	1 each	PDB; PM02D power module; Pixhawk 6X controller and baseboard
Onboard Devices	1 each	GNSS, receiver, telemetry radio, microSD card
Propellers to Fit	4	Two clockwise and two counterclockwise propellers, with fittings

- **Installation and spares:** Four propellers are for the aircraft; store spares separately. Keep all propellers off during ground tests.
- **Ground equipment:** Also prepare a battery, transmitter, ground telemetry radio, and charger. A camera and companion computer are optional.

1.5.1 Component Connections and Prototype Components: Propulsion Matching

Matching the Battery, ESCs, Motors, and Propellers



Figure: Propulsion Battery

- **Example combination:** 4S battery, 2216 KV920 motors, 20A ESCs, and 1045 propellers. Check voltage, load, and interface compatibility across the whole set when replacing parts.
- **Battery markings:** 4S means four cells in series. A conventional lithium polymer (LiPo) battery is rated at 14.8V nominal and 16.8V fully charged; 5000mAh is an example capacity.
- **Discharge capability:** Capacity (Ah) × C rating gives the rated discharge current, e.g., 5Ah×20C=100A. Actual capability also depends on cells, temperature rise, and wiring.
- **Connectors and charging:** XT60 is the main power connector; the balance connector exposes each cell voltage. Use a balance charger compatible with LiPo, 4S, and the battery's permitted charge current.

Battery cell count sets the voltage range; motors, ESCs, propellers, and wiring jointly constrain the propulsion combination.

1.5.1 Component Connections and Prototype Components: Propulsion Specifications

Reading Motor, ESC, and Propeller Specifications

- **Motor 2216:** Stator diameter 22 mm, height 16 mm. A larger stator generally provides more torque and adds weight.
- **Motor KV920:** About 920 r/min per volt at no load; voltage × KV approximates no-load speed.
- **ESC 20A:** About 20 A continuous current capacity; it must exceed the motor's full-throttle current with the propeller fitted, with margin.
- **Propeller 1045:** Diameter 10 inches, pitch 4.5 inches. Pitch is the theoretical distance advanced in one revolution.
- **Quick estimate:** 4S nominal 14.8 V × 920 r/(min·V) ≈ 13,600 r/min at no load. Fitting a 1045 propeller reduces speed and increases current.
- **Matching rule:** A larger propeller or higher voltage increases current; allow margin in the ESC, battery, and wiring.

Voltage and KV set the speed scale; larger propellers raise load, and ESC current capacity must cover the propeller load.

1.5.1 Component Connections and Prototype Components: Hardware Power Architecture

Propulsion Power, Component Power, and Control Signals

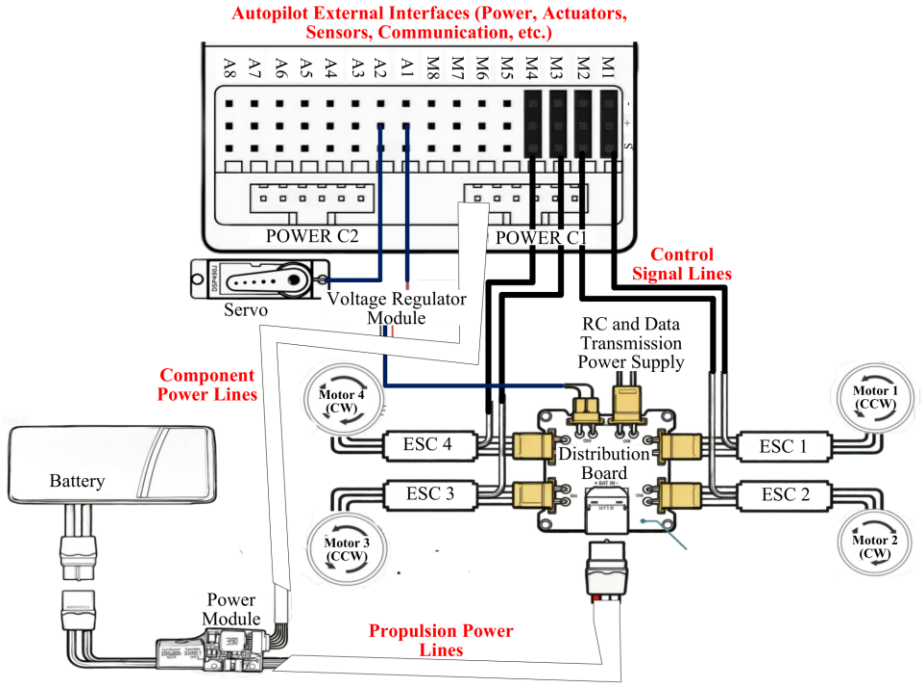


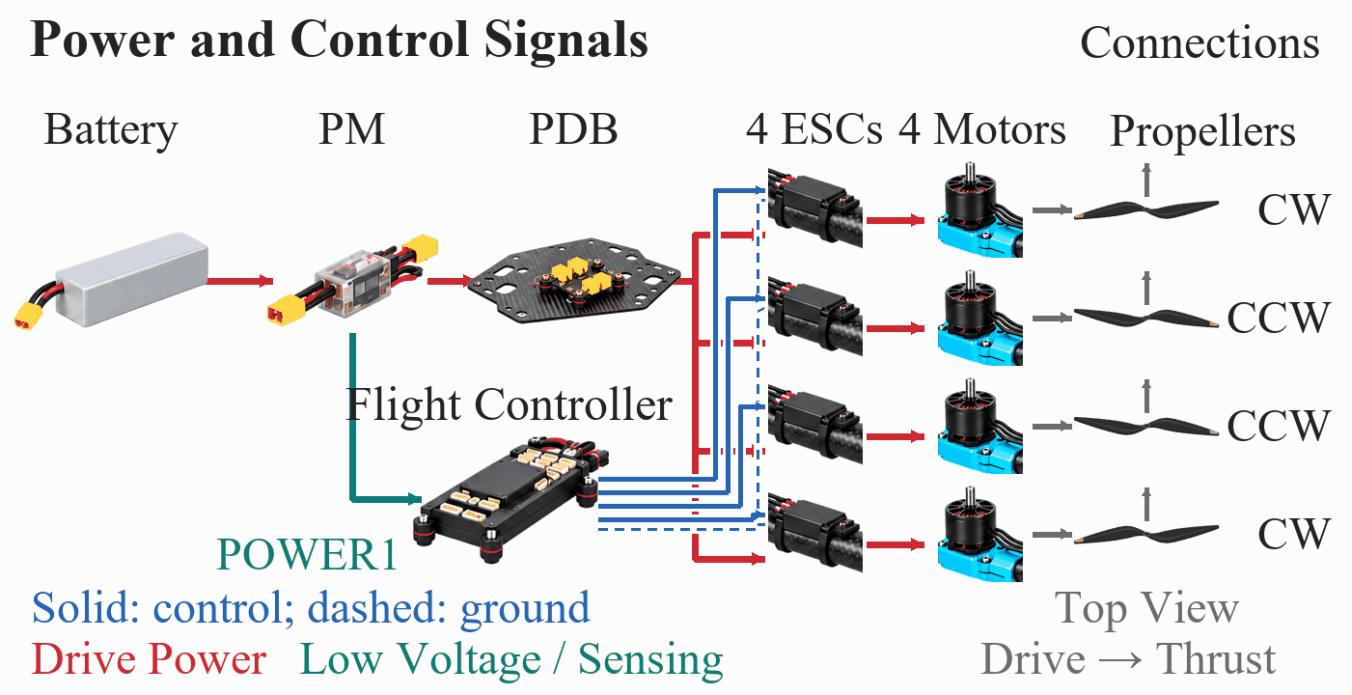
Fig. 1.15 Hardware Power Connections

- **Propulsion power:** Battery→PM→PDB→ESC→motor. High current requires suitable wire gauge, reliable connectors, and cooling.
- **Component power:** POWER C1 is illustrative here; a buck converter powers the servos. This 6X example uses POWER1.
- **Control signals:** The autopilot sends PWM commands via M1–M4 to the ESCs; sensors communicate over I²C, serial ports, SPI, and CAN.
- **Reading the figure:** M and A headers denote main (MAIN) and auxiliary (AUX) outputs. Motor numbers in this figure are illustrative.

The three line types carry propulsion power, regulated power, and commands; check wiring by line type.

1.5.1 Component Connections and Prototype Components: Power and Signal Paths

How Power and Signals Traverse the Aircraft



Power and Thrust: CW = Clockwise; CCW = Counterclockwise

- **Propulsion power:** Battery power passes through the PM and PDB to the ESCs. Each ESC drives a motor, whose propeller generates thrust.
- **Component power (low voltage):** The PM02D six-wire cable connects to POWER1, powering the 6X and carrying digital measurements.
- **Control signals and measurements:** PWM wires carry motor commands; attitude, positioning, and power measurements feed back to the flight controller.

Propulsion power, flight-controller power, and control signals take different paths; measurements inform state assessment.

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1.5.2 Quadcopter Assembly Steps and Wiring: Assembly Preview

From Separate Components to the X500 V2



Figure: X500 V2 Assembly and Completed Aircraft

- **1. Frame:** Fit rails, brackets and landing gear. Position arms, finish internal wiring, then close and secure the plates.
- **2. Equipment:** Center the flight controller on the top plate, facing forward. Secure positioning and communication devices; strap the battery along the rails.
- **3. Validation:** With propellers removed, verify motor numbers, rotation and control responses. After checks pass, disconnect power and fit the propellers.

Complete the frame, wiring, and equipment mounting, validate with propellers removed, then disconnect power before fitting them.

1.5.2 Quadcopter Assembly Steps and Wiring: Preparation

Tools, Fasteners, and Preassembled Units

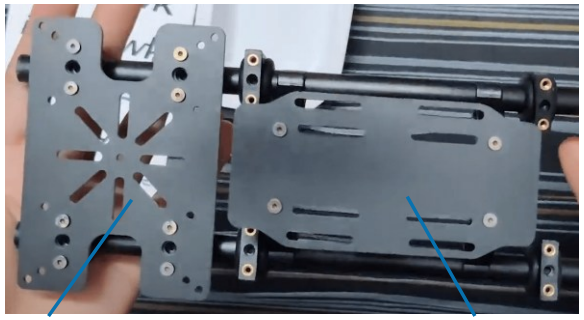
- **Match tools:** Use hex keys that fit the screw heads and a small wrench to hold nuts. Also prepare a multimeter, straps, and cable fasteners for initial electrical checks and routing.

- **Sort fasteners:** M3×14 means 3 mm nominal diameter and 14 mm length. Separate sizes and lengths and match them to the mounting holes; overlong screws can contact plates or wiring.
- **Inspect preassembled units:** Check each arm's motor and ESC mounts, connectors, and insulation. With power off, gently turn the motor bell; it must not rub or interfere with leads.

- **Prepare wiring:** This PDB and ESC set uses matching connectors. Do not dismantle sound assemblies; soldering procedures for loose-component frames do not apply directly.

1.5.2 Quadcopter Assembly Steps and Wiring: Lower Supports

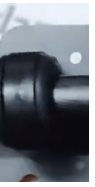
Brackets, Rails, and the Battery Tray



Platform Plate



Overview



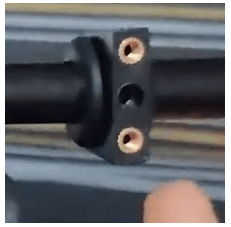


Rubber Ring



Platform Bracket

Tray Slider



Lower Bracket ×4

Figure: Two Trays and Three Fitting Types

- **1. Preassemble trays:** Seat rubber rings in bracket grooves. Use M2.5×6 countersunk screws to join the battery tray to its sliders and the platform plate to its brackets.
- **2. Thread onto rails:** Fit the 4 lower-plate brackets onto both rails, then the two tray assemblies. Apply the battery tray's nonslip pad.
- **3. Check positioning:** Locate and secure each fitting; rails must be parallel, trays level, and rubber rings seated without folded edges.

Lower-plate brackets, platform-plate brackets, and battery-tray sliders connect different parts; position each after threading onto the rails.

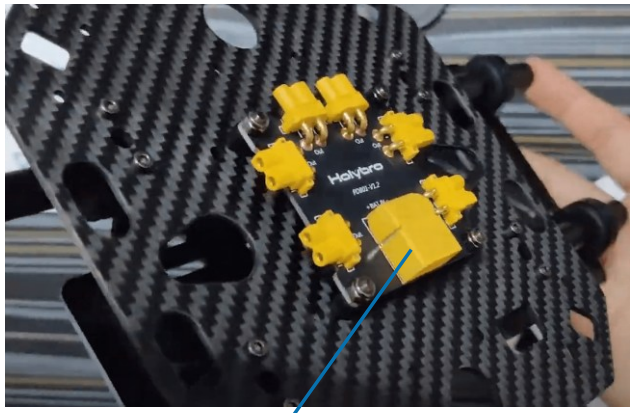
1.5.2 Quadcopter Assembly Steps and Wiring: Lower Plate and PDB

PDB Mounting and Wiring Clearance

PDB and Lower Plate



Lower Brackets and Rails



Check Connector Mounting and Access Clearance

Figure: Lower Plate and PDB Connector Detail

- **1. Insulate and mount:** Fit M3×14 screws and nylon standoffs in the 4 lower-plate holes. Align and secure the PDB, leaving clearance above the carbon plate.
- **2. Connect rails:** Use the supplied screws to join the lower plate to the 4 brackets. Keep both rails parallel and plate positions aligned.
- **3. Check the main connector:** Check XT60 mounting and insertion/removal clearance. Cables must not press on plate edges; fittings must not touch exposed conductors.

Insulating standoffs separate the PDB from the carbon plate; reserve connector and wiring space for later connections.

1.5.2 Quadcopter Assembly Steps and Wiring: Landing Gear

Landing-Gear Connections and Support Checks

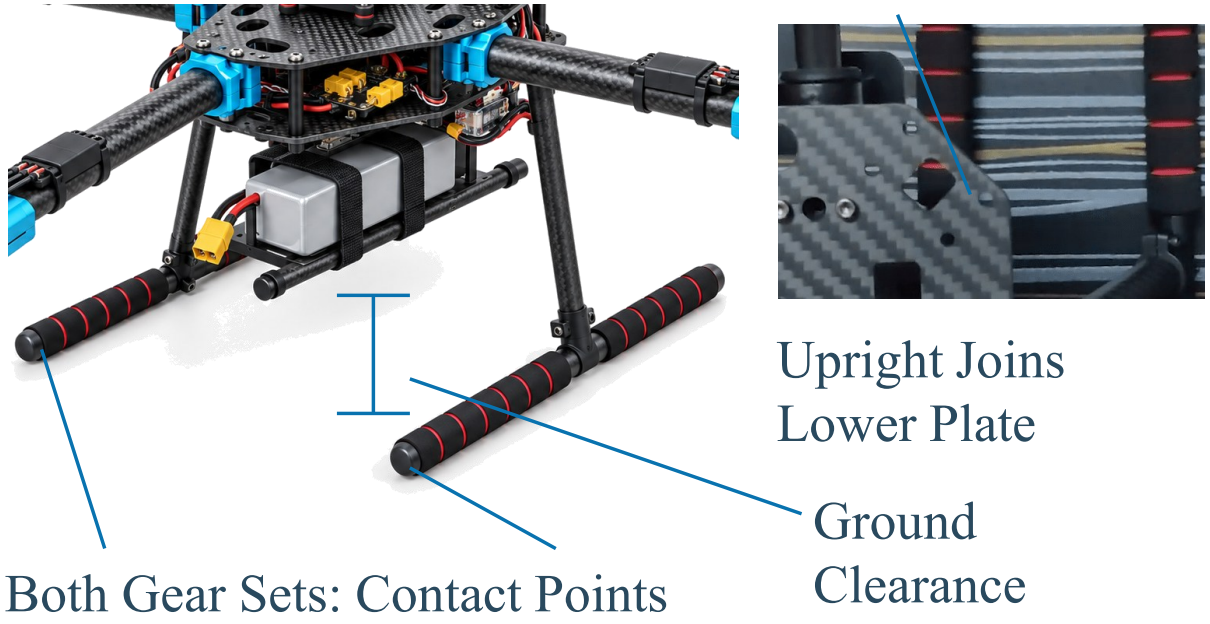


Figure: Side Supports and Lower-Plate Joint

- **1. Connect struts:** Loosen the preinstalled screws in the crossbar joints. Insert uprights to the specified position; check equal heights and orientation on both sides.
- **2. Secure to the lower plate:** Tighten joints until the uprights cannot slip or rotate, then mount the landing gear with the supplied M3×8 screws.
- **3. Check support:** On a flat table, the frame must stand without rocking. Check symmetry and ground clearance beneath the battery tray and payload area.

Landing gear supports the aircraft through the lower plate; symmetry and ground clearance jointly determine the support condition.

1.5.2 Quadcopter Assembly Steps and Wiring: Initial Arm Positioning

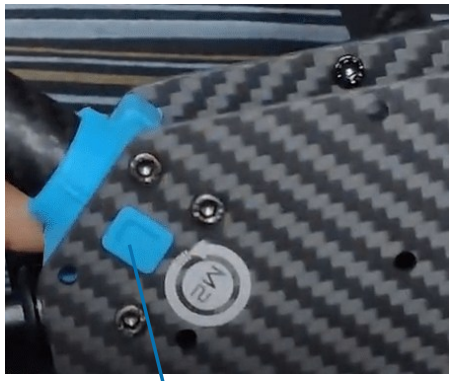
Four Arms and Preassembled Propulsion Units

Arms on Lower Plate (Schematic)



Top Open; Tightening Pending

Closed-Plate Joint



Rectangular Root Boss

Slot Hidden by Boss

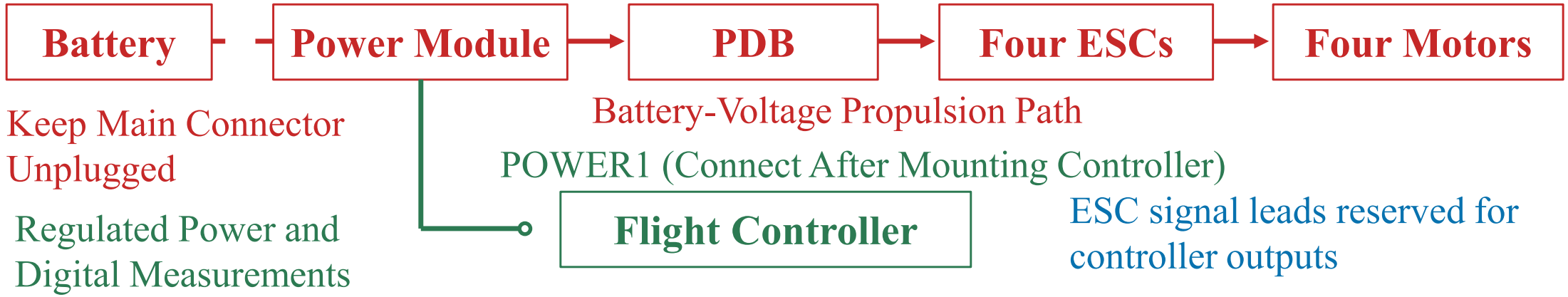
Figure: Initial Arm Fit and Actual Joint Detail

- **1. Match arm positions:** Place the four preassembled arms using the nose reference and kit markings, with propellers removed. Seat the rectangular root bosses in the lower-plate slots.
- **2. Position provisionally:** Seat all four arms with mating surfaces flush. Leave hole-alignment adjustment until the top plate is fitted; do not fully tighten.
- **3. Inspect propulsion units:** Retain preinstalled motors and ESCs. Check ESC security and lead condition; with power off, turn each bell and check for rubbing.

Seat all four arms in their locating slots first, leaving adjustment for internal wiring and top-plate hole alignment.

1.5.2 Quadcopter Assembly Steps and Wiring: Power Wiring with Power Off

Connecting the Battery, PM, PDB, and ESCs



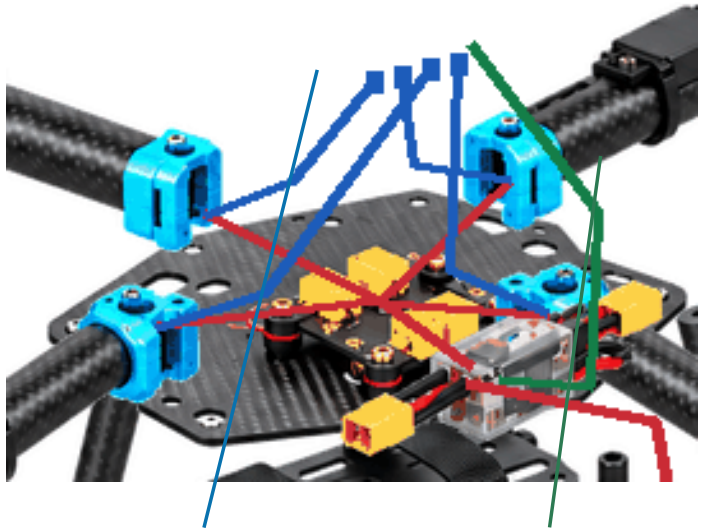
- **Main power path:** Disconnect the battery, USB, and other supplies; check polarity. Connect PM output to the PDB XT60 and the four ESCs to its XT30 branches; leave the battery connector unplugged.
- **Low-voltage branch:** Route the PM02D six-wire cable toward POWER1 for regulated power and digital measurements.

The main power path feeds the PDB; reserve the low-voltage branch for the flight controller, keeping the battery disconnected while wiring.

1.5.2 Quadcopter Assembly Steps and Wiring: Closing and Securing Plates

Check Wiring Before Closing the Top Plate

Before Closing: Reserved Leads



4 ESC Signals

PM 6-Wire Cable

Arm-Root Clamping Surface



Photo: Plates Already Closed

Keep Wiring off Clamping Faces

Figure: Reserved Leads and Arm-Root Clamps

- **1. Reserve leads:** Recheck PDB insulation. Bring out four ESC signal leads and the POWER1 cable, keeping them clear of screw holes and clamping surfaces.
- **2. Close and tighten:** Align all four arms with both plates, then progressively tighten 16 sets of M3×38 screws and flanged locknuts as instructed.
- **3. Inspect assembly:** Arms must not slip or rotate, plates must not warp, and wires must not be pinched. Keep connectors and reserved leads accessible.

Keep internal wiring clear of clamping surfaces; align all four arms with both plates before final tightening.

1.5.2 Quadcopter Assembly Steps and Wiring: Flight-Controller Installation

6X Position, Orientation, and Mounting



Figure: 6X Orientation Mark and Nose Direction

- **1. Position and orientation:** Center the 6X on the top plate near the center of gravity, top side up, with its arrow pointing between the front arms (X layout). Leave connector access.
- **2. Secure and isolate:** Clean the mounting surface and use adhesive pads as specified by the manufacturer. Prevent sliding and leave slack in the wiring.
- **3. Connect with power off:** Connect the reserved six-wire cable to POWER1. Check the baseboard label and plug engagement; keep tension off the port.

Controller orientation must match the nose reference; secure mounting and slack wiring reduce external disturbances.

1.5.2 Quadcopter Assembly Steps and Wiring: Positioning-Module Installation

GNSS Mount, Compass, and GPS1 Connection

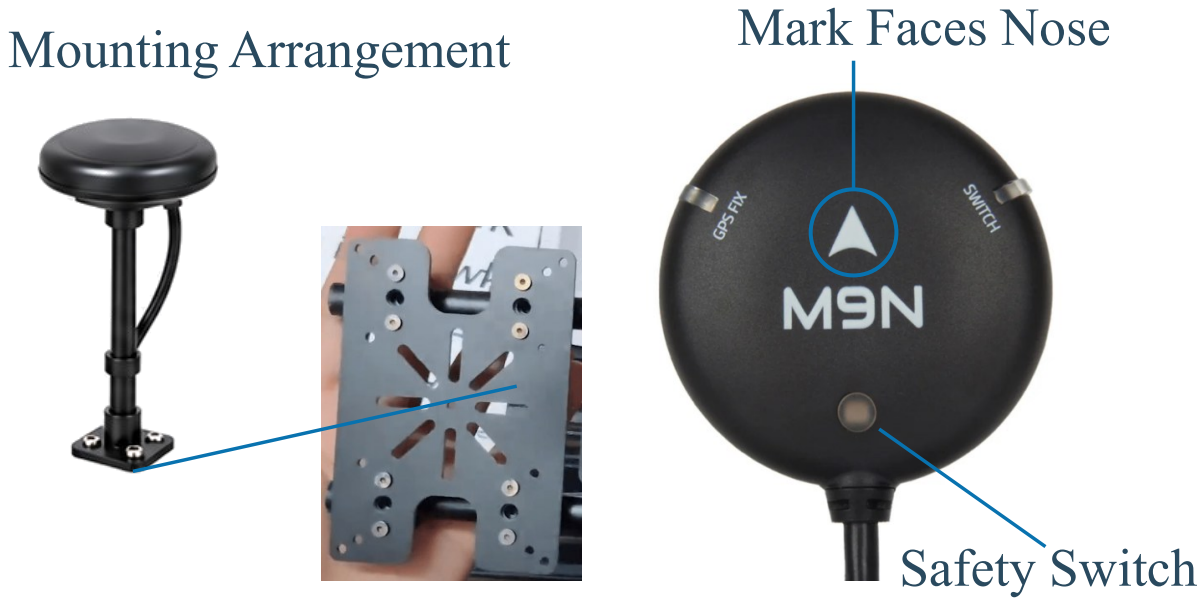


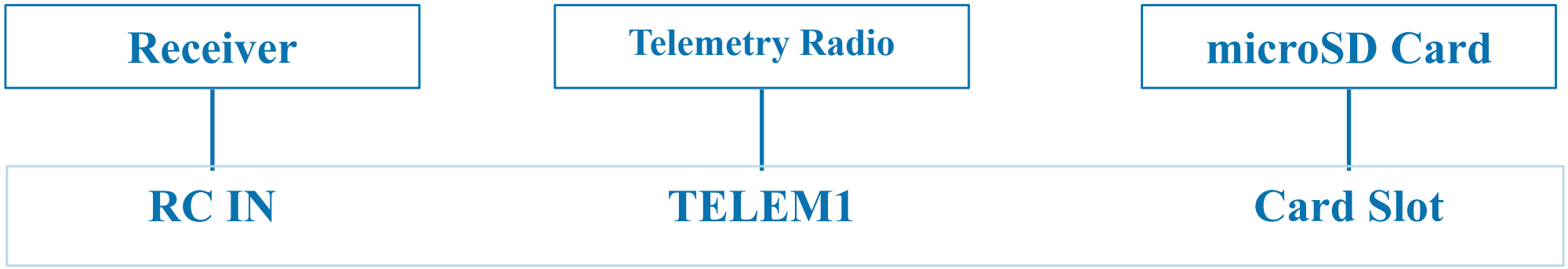
Figure: GNSS Mount and Forward Orientation

- **1. Secure the mount:** Attach the bracket to the specified platform-plate holes. Point the antenna upward and orientation mark forward; secure the base.
- **2. Check surroundings:** The module includes a magnetic heading compass. Keep it away from the PM, ESCs, and power wiring; leave the sky above the antenna unobstructed.
- **3. Wire with power off:** Connect this serial GNSS module to GPS1 with the matching cable. Secure the cable without port tension; keep the switch accessible and LEDs visible.

Positioning-module installation must account for orientation and magnetic surroundings; match wiring to the actual module and port.

1.5.2 Quadcopter Assembly Steps and Wiring: Communications and Storage

Installing Radio Control, Telemetry, and Storage



- **Radio control:** The receiver sends stick and switch commands to RC IN over SBUS, carrying multiple channels on one signal wire.
- **Telemetry:** SiK radios work as a pair. The onboard unit connects to TELEM1 for two-way status and parameter exchange with the ground station.
- **Storage:** A microSD card stores flight logs. Inspect it with power off and insert it into the 6X slot if not already installed.

1.5.2 Quadcopter Assembly Steps and Wiring: Physical Ports and Logical Motors

Mapping MAIN/AUX Ports to Motor Numbers

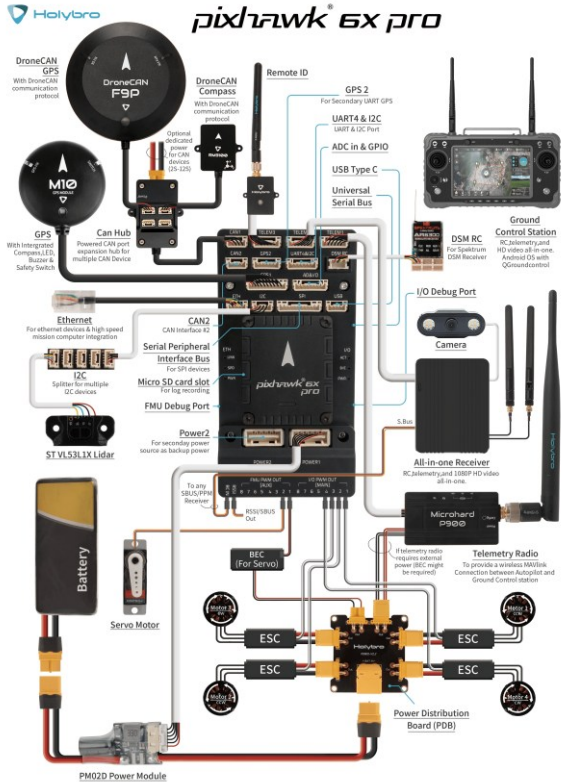
6X Board Label	PX4 Output Group	Example Connection
FMU PWM OUT	AUX	Signal and ground for four ESCs on AUX1–4
I/O PWM OUT	MAIN	Unused here; role follows assigned functions

- **Signal and ground:** FMU is the main processor and I/O the coprocessor. Connect each ESC signal and GND according to the baseboard pinout.
- **Logical mapping:** Motor 1–4 are motor functions. Assign them using geometry and wiring, then check each output with propellers removed.
- **Separate power rail:** The output-header "+" row powers loads such as servos; POWER1/2 does not power it. ESC propulsion power comes from the PDB; servos need a suitable separate supply.

Physical ports and logical motors have separate names; function mapping connects wiring to the actual motors.

1.5.2 Quadcopter Assembly Steps and Wiring: Official Wiring Extension

Pixhawk 6X Pro Extended Wiring Example



- **Model scope:** This diagram surveys optional 6X Pro peripherals. Our prototype uses a standard 6X baseboard; verify pins and wiring against the actual board.
- **Power and outputs:** POWER connects to a PM; the PDB powers the ESCs. PWM carries control signals; servos require a suitable power supply.
- **Optional extensions:** Select positioning, telemetry, radio control, and mission-computing devices for the task. Installing every device shown is not required.

PX4 Docs: Wiring, Assembly and Baseboard Pinout

https://docs.px4.io/main/en/flight_controller/pixhawk6x_pro

Figure: Official 6X Pro Wiring Diagram (Holybro / PX4)

Official diagrams relate controller ports to peripherals; use the actual baseboard and pin definitions for each connection.

1.5.2 Quadcopter Assembly Steps and Wiring: Battery and Aircraft Layout

Battery Mounting, Center of Gravity, and Final Wiring Check

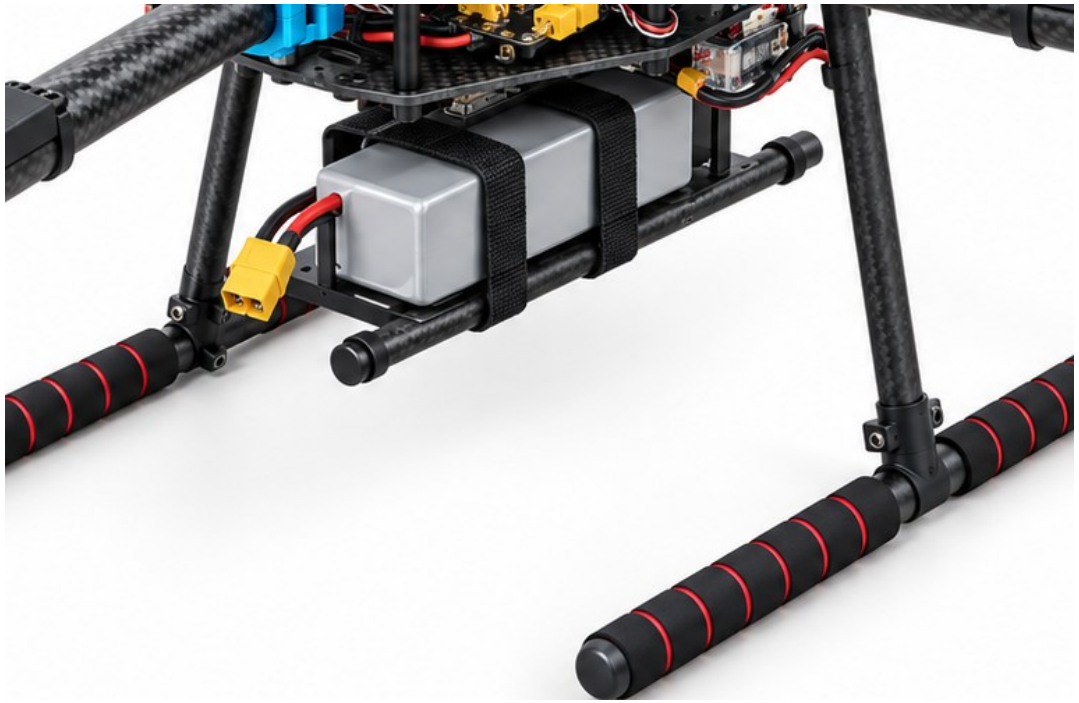


Figure: Battery, Straps, and Tray

- **1. Adjust position:** Support the aircraft securely, then adjust fore-aft position along the rails. Check the equipment layout for lateral imbalance.
- **2. Secure fully:** Seat the battery on the nonslip pad and lock both straps and the tray. A gentle push must not move it; keep the main connector unplugged.
- **3. Final wiring check:** Keep wiring, antennas, and brackets clear of propeller disks. With power off, turn the motor bells and check for rubbing.

Battery position shifts the aircraft center of gravity; two straps and a locked tray jointly prevent movement.

1.5.2 Quadcopter Assembly Steps and Wiring: Initial Checks Before Power-On

Power-Off Checks and Conditions for First Power-On

- **No power or propellers:** Disconnect the battery, USB, and other supplies. Confirm all four motors have no propellers; discharge input capacitors as instructed before resistance tests.
- **Structure and connections:** Gently move arms, landing gear, and battery to check for looseness (assembly strength check). Recheck PDB insulation, connector latches, and polarity; remove exposed conductors, metal debris, and trapped wires.
- **Obvious-short check:** Measure across the main input with the multimeter's resistance or continuity range. Investigate sustained low resistance branch by branch; a brief beep may reflect capacitor charging.
- **Proceed to power-on:** Explain and resolve abnormal readings, record structural and wiring checks, and account for tools and unused fasteners before controlled power-on.

Power-off checks assess structure, polarity, and obvious shorts; interpret each measurement using the circuit.

1.5.2 Quadcopter Assembly Steps and Wiring: First Power-On Without Propellers

First Power-On and Device-State Observation

- **Prepare:** Place the aircraft on a stable insulating table. Confirm propellers are removed and the vehicle is disarmed. Keep the planned power-disconnection point accessible; keep hands and tools clear of motors.
- **Connect main power:** Leave USB unplugged and connect the checked 4S supply. Alternatively, first use a current-limited DC supply at a 4S voltage; the limit constrains short-circuit current but must allow startup.
- **Observe startup:** Interpret controller and peripheral indicators using the actual hardware and firmware instructions. Record normal startup, supply stability, or repeated restarts.
- **Stop on abnormalities:** For unusual odor, smoke, abnormal heating, or repeated restarts, stop and disconnect power as planned. Identify the cause before trying again.

First power-on with propellers removed checks startup and supply; propulsion behavior under load still requires later validation.

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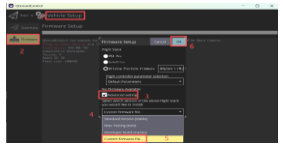
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Textbook: Sec. 1.3.3

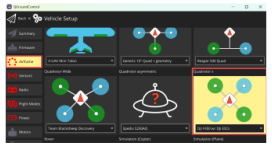
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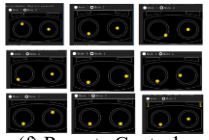
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1.5.3 Debugging and Experiments: Ground Validation—Debugging and Flight Steps

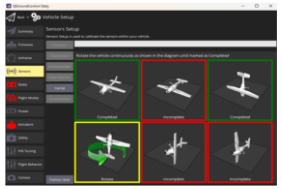
Two Sequences from Firmware Flashing to Flight Tests

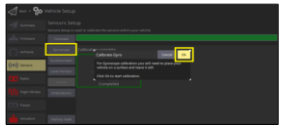

(a) QGC Firmware Flashing


(b) Airframe Setup

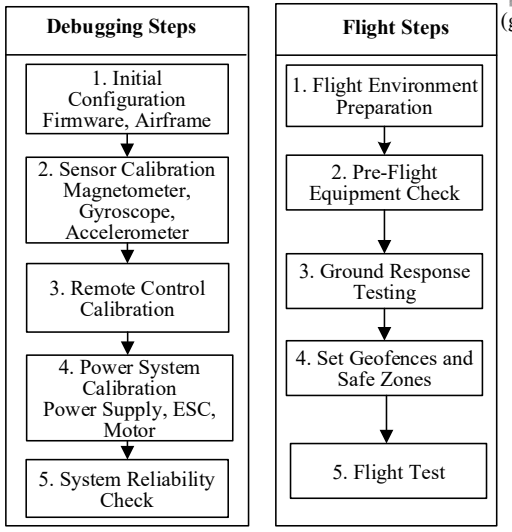

(f) Remote Control Calibration

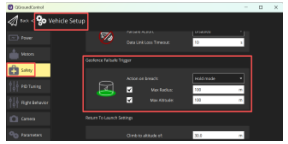

(g) Pre-Flight Full Vehicle Inspection

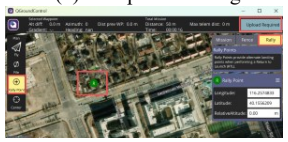

(c) Magnetic Compass Calibration


(d) Gyroscope Calibration


(e) Accelerometer Calibration




(h) Set up Geofencing


(i) Set Safe Return Point


(j) Real-Vehicle Flight Test

Fig. 1.16 Debugging and Flight Steps

- **Debugging:** Firmware and airframe → sensor calibration → radio-control calibration → propulsion calibration → reliability checks.
- **Flight testing:** Prepare the environment → preflight inspection → ground response tests → geofence and safe return point → flight.
- **Geofence:** An example cylindrical fence limits radius and height around the firmware home position; a breach triggers warning, hold, return, or landing.
- **Correspondence:** This unit expands the left sequence; first-flight pages expand the right.

Ground debugging aligns configuration with hardware; set the geofence and return point before staged flight tests.

1.5.3 Debugging and Experiments: Ground Validation—Connection and Setup Entry

Ground-Station Connection and Propeller-Off Debugging Preview

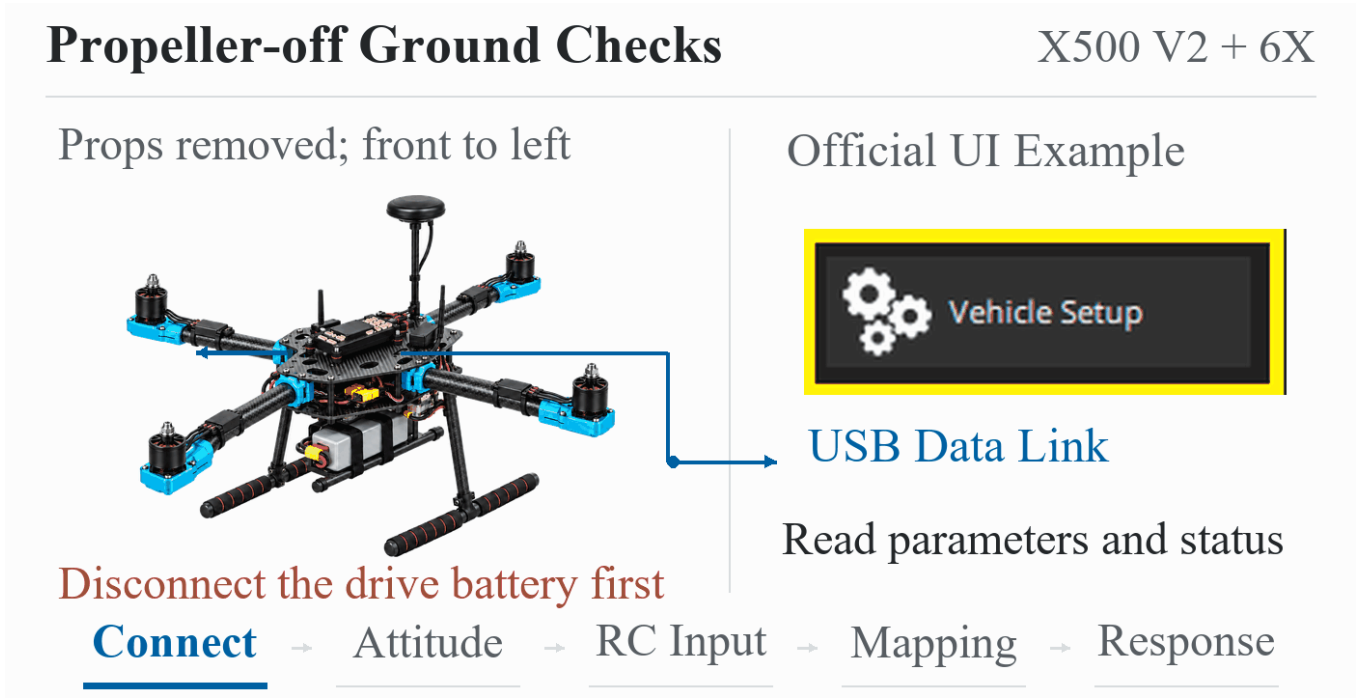


Figure: Ground Validation with Propellers Removed

- **Ground station:** Remove all propellers; disconnect the propulsion battery. Connect a USB data cable directly to the 6X; open QGroundControl (QGC).
- **Setup entry:** After detection and parameter loading, enter Vehicle Setup. Check attitude and radio-control inputs first.
- **Motor validation:** Secure the aircraft. Following the procedure, power the ESCs; briefly run each motor separately, propellers removed. Record responses.

The ground station relates physical motion to controller state; observe responses after configuration.

1.5.3 Debugging and Experiments: Ground Validation—Hardware and Software Combination

Record the Actual Hardware, Firmware, and Ground Station

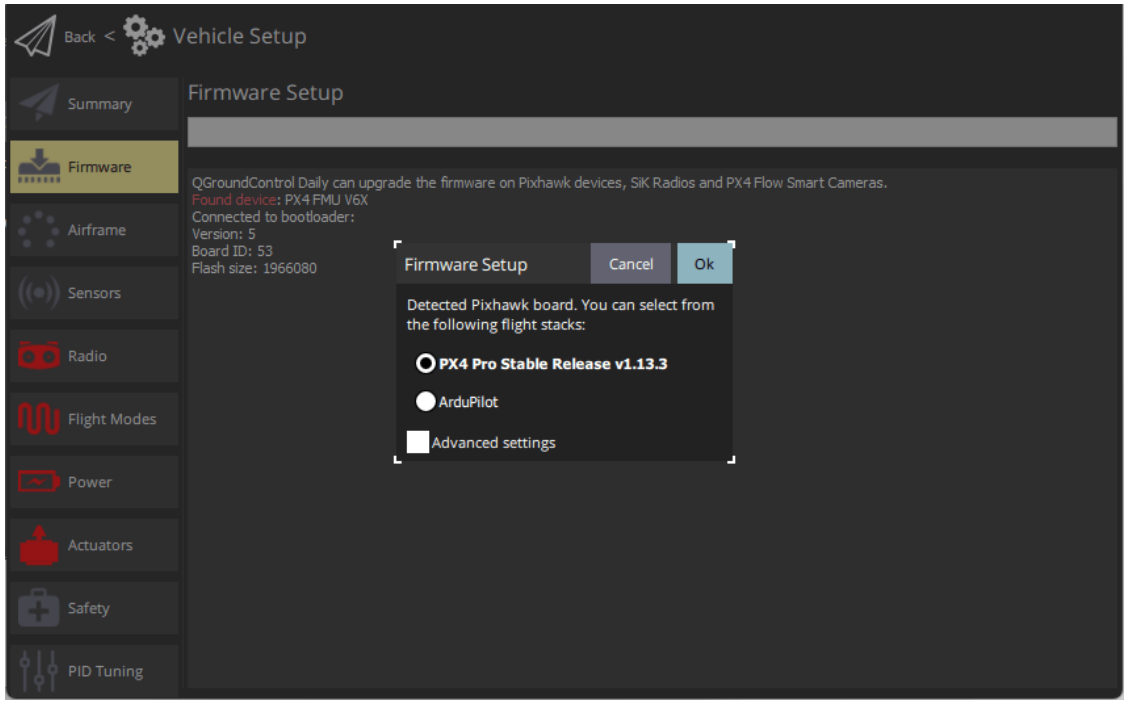


Figure: QGC Firmware Setup for the 6X and PX4

- **Teaching setup:** 6X baseboards and revisions may differ in interfaces and supported power modules. This example uses the standard baseboard with PM02D.
- **Actual record:** Record controller, baseboard, PM, and peripheral revisions, actual PX4 and QGC versions, and configuration date.
- **Firmware flashing:** Disconnect the battery and save parameters. Enter QGC's Firmware page before connecting USB; identify the board, select the PX4 version, and recheck configuration afterward.

Hardware revision and firmware jointly determine configuration methods; the actual combination is the basis for review.

1.5.3 Debugging and Experiments: Ground Validation—Airframe Preset and Motor Geometry

Select an X-Quadcopter Preset and Check Nose and Motor Positions

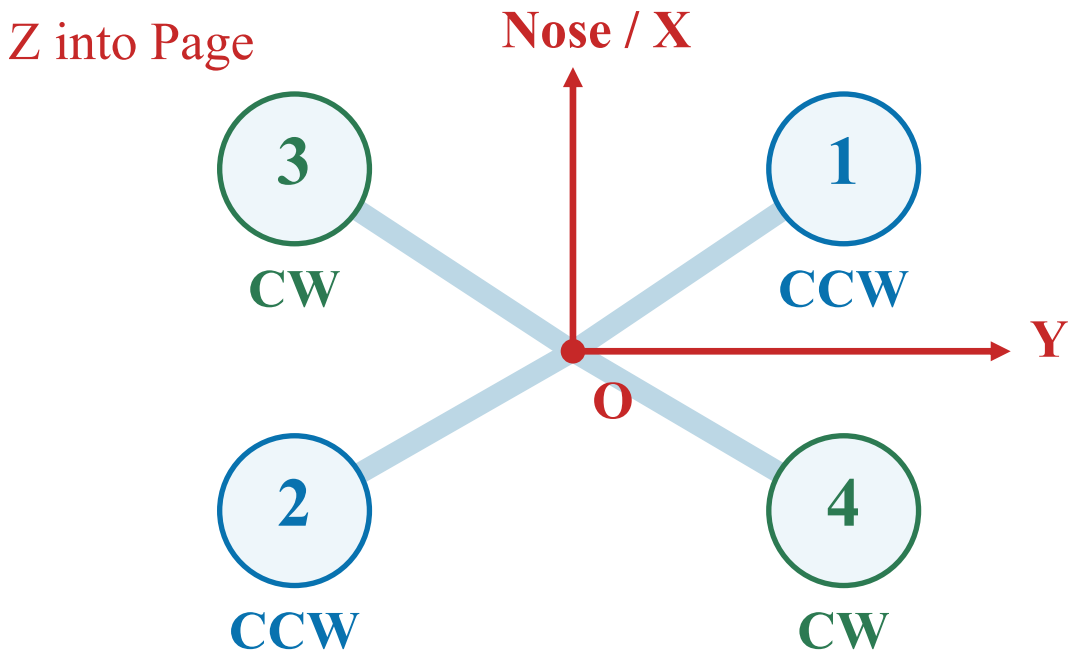


Figure: Top-View Axes and Motor Numbers

- **Airframe selection:** Choose the X500 V2 preset supported by the installed firmware. Check the four motors' X layout and actual nose direction.
- **Geometry reference:** Body X points forward, Y right, and Z down. Opposite motors rotate alike and adjacent motors oppositely, balancing reaction torques.
- **Number mapping:** Check each logical motor number, physical location, and rotation before matching output ports. A preset does not replace physical validation.

The airframe preset defines motor geometry; match every output mapping to the actual motor location.

1.5.3 Debugging and Experiments: Ground Validation—Orientation and Stationary Calibration

Flight-Controller Orientation and Gyroscope Bias

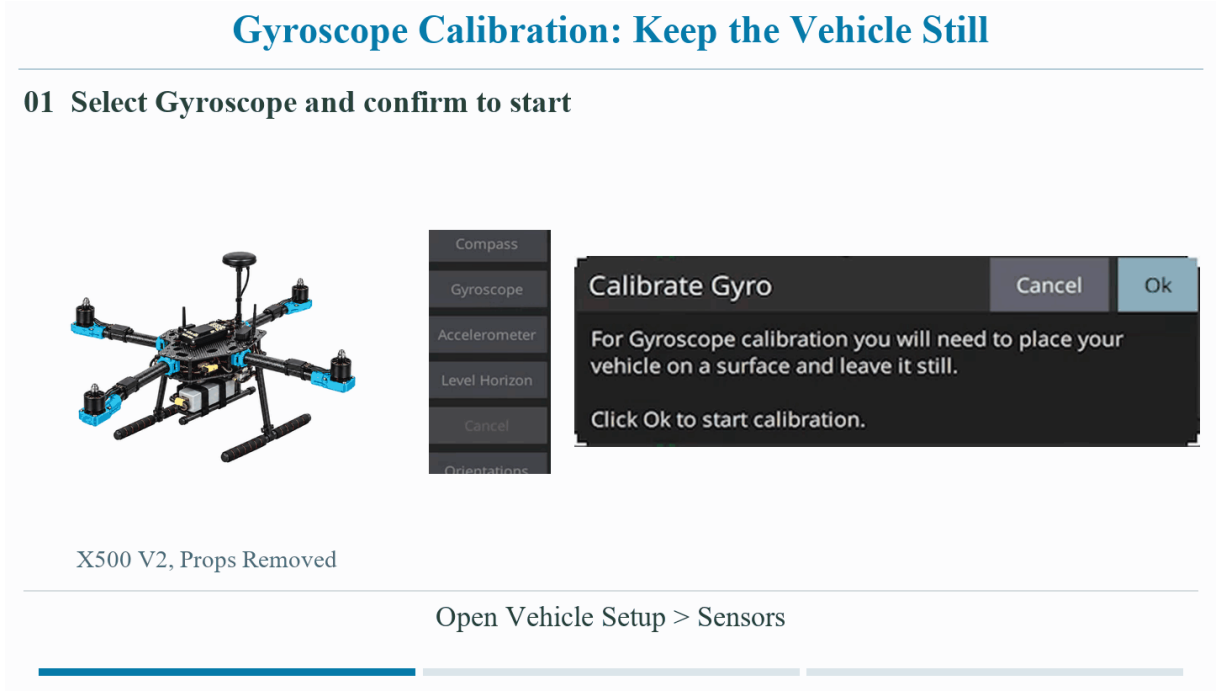


Figure: Stationary Gyroscope Calibration Steps

- **Mounting orientation:** Check the 6X direction mark against the nose and configure its actual orientation relative to the body.
- **Stationary calibration:** Bias is the offset of the gyroscope's mean reading at rest. Stabilize the aircraft and keep motors stopped before calibration.
- **Attitude check:** Once sensors are ready, pitch up and roll the body; the display must represent the motion. For wrong directions check orientation first; for drift check disturbances first.

Correct orientation relates measurements to body motion; stationary calibration establishes the zero-rotation reference.

1.5.3 Debugging and Experiments: Ground Validation—Acceleration and Level Reference

Six-Side Accelerometer Calibration and Level Reference

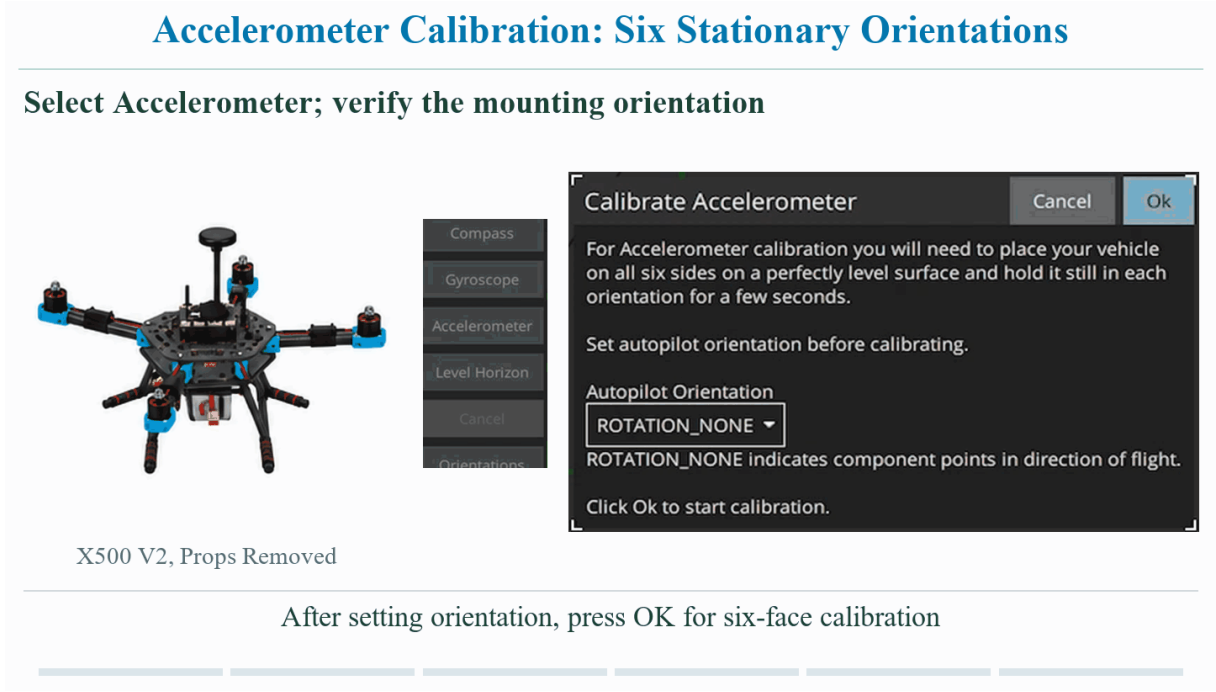


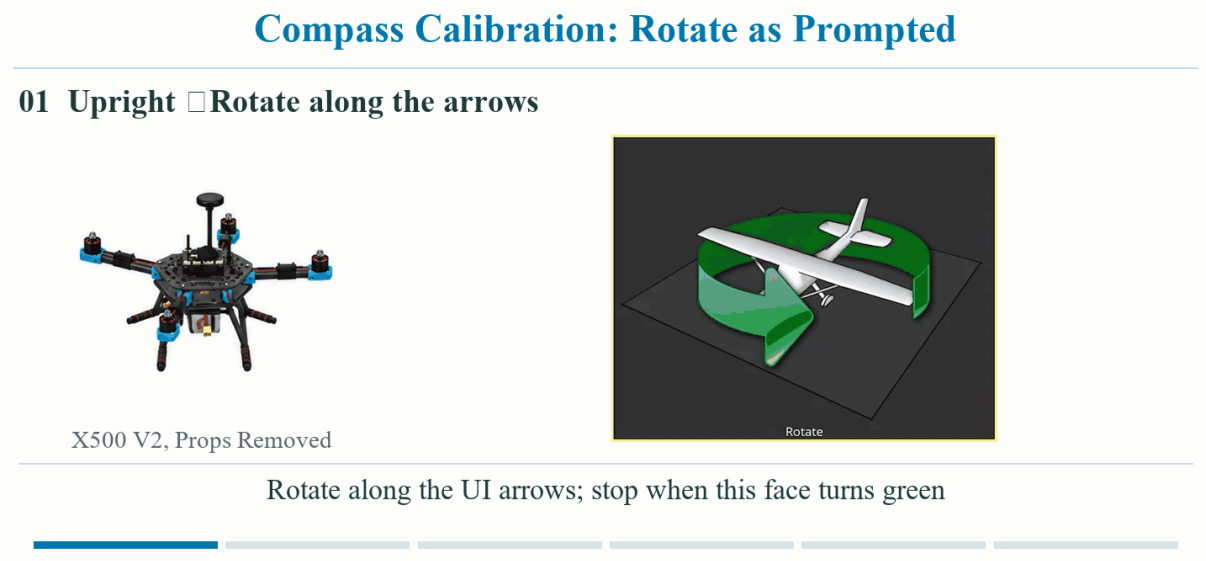
Figure: Six-Side Sampling and Level Calibration

- **Six-side calibration:** After setting orientation, sample six stationary attitudes to correct acceleration offsets and scale factors.
- **Level calibration:** Use reliable level support and a body reference to correct small mounting offsets. This does not replace orientation configuration.
- **Check results:** Change pitch and roll separately, then level the aircraft. The display must represent the actual attitude and return to the level reference.

Six-side calibration establishes acceleration references; level calibration corrects small mounting offsets.

1.5.3 Debugging and Experiments: Ground Validation—Heading and Positioning

Compass Calibration and Satellite-Positioning Status



Fly View → GPS Icon → Fix / Quality

Figure: Compass Calibration and GPS Status

- **Heading calibration:** Stay clear of steel structures and strong magnetic interference. Remove propellers, stop motors, rotate the aircraft as guided, and check heading.
- **Position fix:** Open the GPS icon to inspect the fix. Horizontal dilution of precision (HDOP) reflects satellite geometry and is dimensionless.
- **Estimator status:** Open readiness status at the upper left for position-related checks. Verify the current mode; assess heading and position separately.

Compass and satellite positioning supply different information; check heading and position separately.

1.5.3 Debugging and Experiments: Ground Validation—Radio-Control Inputs

Radio Binding, Channels, and Endpoint Calibration

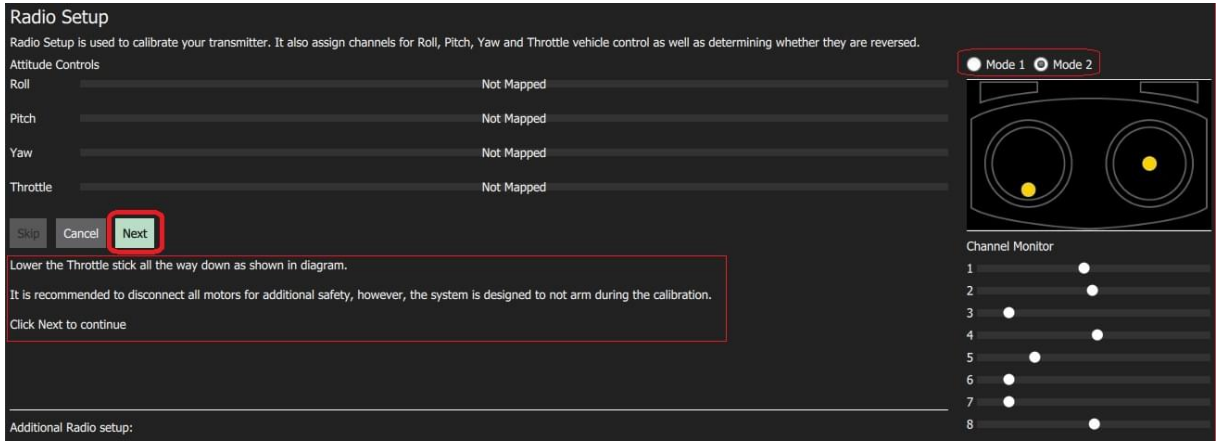


Figure: Radio-Channel Calibration Interface Example

- **Bind and connect:** Bind the SBUS receiver using the radio manufacturer's instructions, connect it to RC IN, and first confirm an active link.
- **Channel travel:** Check roll, pitch, yaw, and throttle direction, center, and endpoints individually. Confirm minimum throttle separately.
- **Switch mapping:** Observe each switch position as a channel value. Record positions before assigning modes and arming; do not assume fixed channel numbers across radios.

Radio calibration maps stick travel to correct inputs; switch functions require separate assignment.

1.5.3 Debugging and Experiments: Ground Validation—Modes and Input Meaning

Flight Modes and Response to Centered Sticks

Mode	Roll, Pitch, Throttle	Centered-Stick Response	Valid Estimates
Stabilized	Tilt angles; total thrust	Returns level; altitude/drift need control	Valid attitude
Altitude	Tilt angles; climb/descent rate	Centered throttle holds altitude; horizontal drift possible	Valid attitude and altitude
Position	Horizontal accel./velocity; climb/descent rate	Brakes, then holds position and altitude	Valid attitude, altitude, and position

- **Check switches:** Confirm the actual QGC mode at every position: Stabilized, Altitude, or Position. The yaw stick commands turning rate.

Flight mode changes stick meaning; response to centered sticks depends on control targets and valid estimates.

1.5.3 Debugging and Experiments: Ground Validation—Actuator Output Mapping

Assign Motor Functions to Ports and Match Output Protocols

Motor Function	Physical Port	Protocol
Motor 1	FMU1/AUX1	PWM
Motor 2	FMU2/AUX2	PWM
Motor 3	FMU3/AUX3	PWM
Motor 4	FMU4/AUX4	PWM

- **Output assignment:** AUX comes directly from the main FMU processor with lower latency; PX4 recommends AUX for motors. Validate every mapping in the table.
- **PWM:** A 1000–2000 µs pulse width represents minimum to maximum command. Channels in one timer group must share protocol and rate.
- **DShot:** Sends digital throttle values without endpoint calibration. Requires compatible ESCs and FMU channels; still check rotation direction.

Logical motors map to physical ports; hardware and ESC support jointly constrain the protocol.

1.5.3 Debugging and Experiments: Ground Validation—Individual Propeller-Off Motor Tests

Motor Tests: Number, Position, and Rotation

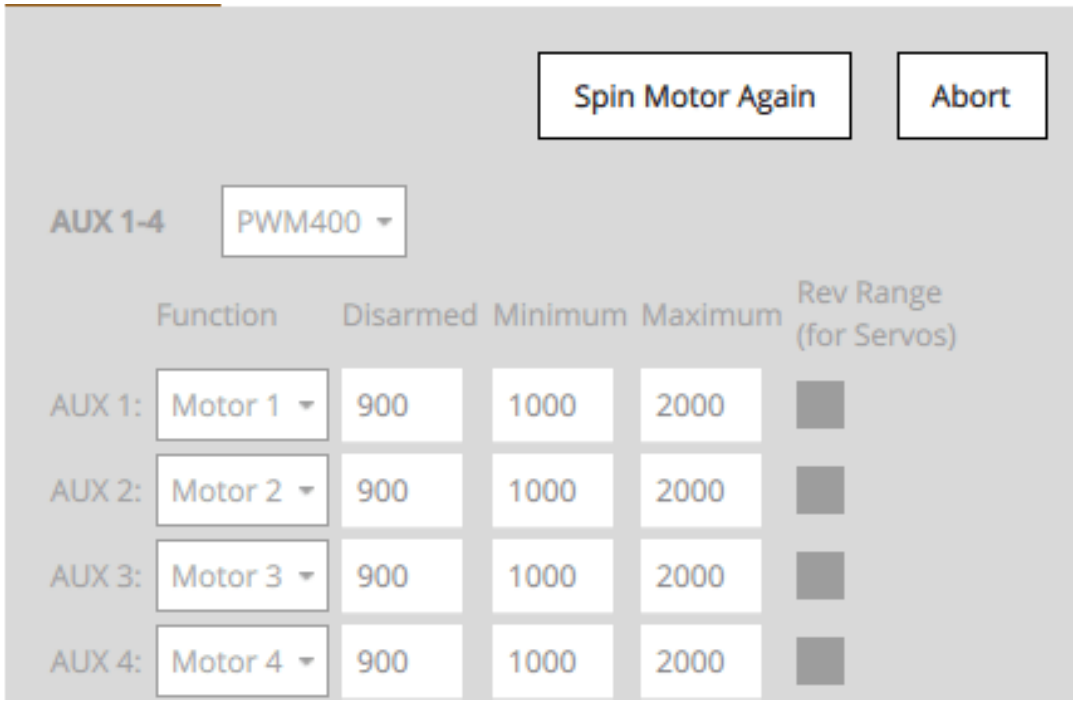


Figure: Motor Identification on the QGC Actuators Page

- **Prepare without propellers:** Remove all propellers, steady the aircraft, clear rotating areas, then power the ESCs. Run one motor briefly at low speed.
- **Check from above:** Use the nose as forward. Compare logical number and top-view rotation, recording physical location and start/stop response.
- **Return on faults:** Startup must be smooth and stopping effective. Stop on wrong position or rotation; disconnect battery and USB before reconnecting wires.

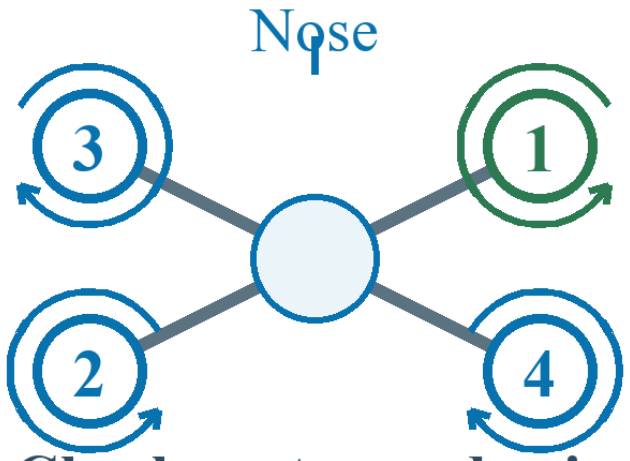
Test one motor at a time; actual position, rotation, and start/stop behavior must match configuration.

1.5.3 Debugging and Experiments: Ground Validation—Individual Propeller-Off Motor Tests

Abnormal Motor Tests: Check Position, Then Rotation

Motor jog: position / spin

Top view



Check motor and spin

Stop → power off → correct → retest

- **Wrong position:** Command 1; motor 2 turns. Disconnect power; check mapping and connectors.
- **Wrong rotation:** Command 3; it turns backward. Disconnect power; reverse per ESC instructions.
- **Retest:** With propellers off, run briefly at low speed. Check position, top-view rotation and stopping.

Motor Faults (Top View; Propellers Off)

Stop and disconnect power for wrong position or rotation; correct the fault, then retest briefly at low speed without propellers.

1.5.3 Debugging and Experiments: Ground Validation—Digital Power Measurements

Digital Power-Module Detection and Battery Readings



Figure: PM02D Digital Power Module

- **Digital detection:** Check PM02D revision, wiring, and firmware detection. Investigate chip-specific firmware drivers only if detection fails.
- **Check readings:** Set cell count, capacity, and thresholds from battery data. Compare voltage with a meter and observe current changes during brief propeller-off motor tests.
- **Separate faults:** For missing readings, check connections and drivers. If voltage and current are reasonable but charge estimates are abnormal, check battery configuration.

Establish trustworthy digital power measurements before using battery settings to estimate remaining charge.

1.5.3 Debugging and Experiments: Ground Validation—Protection and Return Conditions

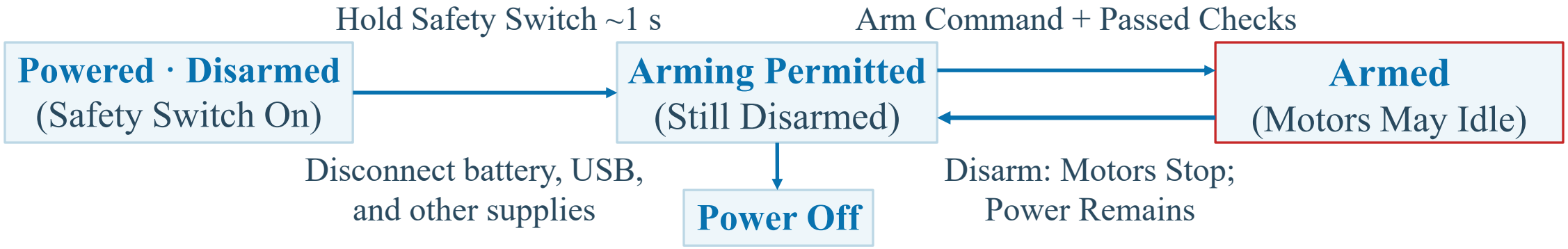
Link Loss, Low Battery, and Return Conditions

- **Radio-control loss:** The receiver must let PX4 detect lost or invalid signals. Holding the last valid channel values may conceal link loss.
- **Telemetry loss:** A SiK interruption is ground-station link loss. Check its delay, applicable modes, and failsafe action separately from radio control.
- **Low-battery protection:** Set warning, return, or landing using battery estimates and protection levels. Reserve energy for returning and landing.
- **Return and validation:** Check the return target, position estimate, altitude and its reference, obstacles, and remaining energy. Validate in simulation or by an appropriate propeller-off method.

Failsafes require correct detection and executable actions; returning also depends on position and remaining energy.

1.5.3 Debugging and Experiments: Ground Validation—Safety Permission and Arming

Safety Switch, Arming, and Mode Changes



- **Safety switch:** When enabled, permits arming; releasing the safety lock does not arm motors.
- **Arming state:** After command acceptance and passed checks, motors may rotate. Disarming does not cut power.
- **Mode change:** Changes targets and required estimates. Use the mode actually accepted by the controller.
- **Arming rejected:** Read failed checks. Inspect power, sensors, radio control and mode prerequisites; repair and recheck.

Safety permission, arming, and flight mode have distinct roles; verify state before the corresponding operation.

1.5.3 Debugging and Experiments: Ground Validation—Records and First-Flight Readiness

Ground-Test Records and Conditions for First Flight

- **Record:** Date____ Configuration/firmware____ Test____. Retain version records after wiring or parameter changes.
- **Logs and readiness:** Save log files and time intervals. Proceed to first-flight preparation only after a readable trial log and successful fault retests.

Example Record: Brief Propeller-Off Test of Motor 1 (Fill Blanks During Experiment)

Expected	Physical position____; top-view rotation____; must stop on command.
Observed	Actual motor position____; rotation____; startup/stopping behavior____.
Judgment	Matches / differs from expected____; abnormality and related path____.
Retest	Correction with power off____; repeat test result____; log/record ID____.

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Chapter 1 Introduction

1.1 Concepts and Applications

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1.4 Coordinate Systems and Control Principles

1.5 Assembly and Debugging

1.6 RflySim Toolchain

1.7 Learning Path and Experiments

1.8 Exercises and Discussion

5 Units in This Section

1.5.1 Component Connections and Prototype Components
Textbook: Sec. 1.3.1

1.5.2 Quadcopter Assembly Steps and Wiring
Textbook: Secs. 1.3.1–1.3.2

1.5.3 Debugging and Experiments: Ground Validation
Textbook: Sec. 1.3.3

1.5.4 Debugging and Experiments: First Flight and Review
Textbook: Sec. 1.3.3

1.5.5 Fixed-Wing Assembly and Debugging
Textbook: Secs. 1.3.1–1.3.3

1.5.4 Debugging and Experiments: First Flight and Review—Flight-Sequence Preview

Preview Takeoff, Hover, Movement, and Landing

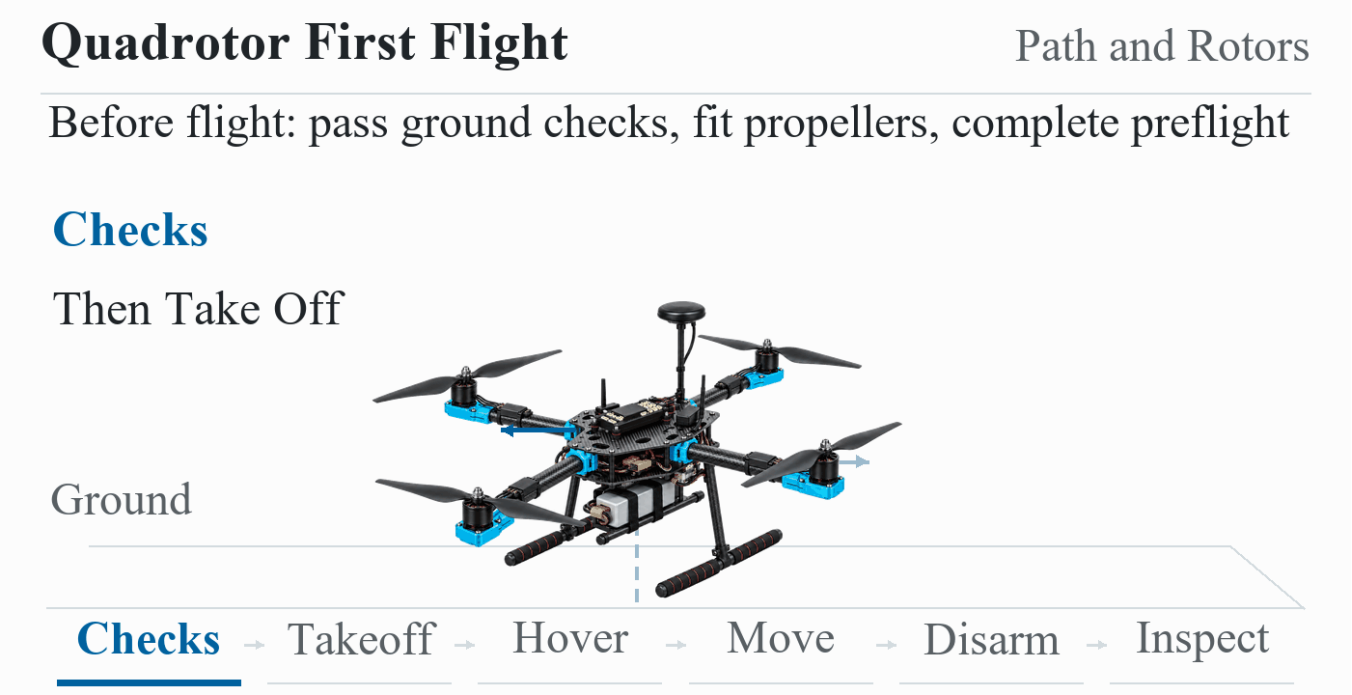


Figure: Quadcopter First-Flight Sequence

- **Prepare for takeoff:** Complete ground validation, propeller installation, and preflight checks, with experienced personnel guiding on site.
- **Validate in stages:** Take off and hover briefly; if normal, add small movements and turns. Reserve enough energy to land.
- **Finish under control:** Land as planned. Stop expanding tests on abnormalities and land promptly if controllable. Disarm, confirm stopped motors, disconnect power, then inspect.

Add first-flight maneuvers in stages; observations at each stage determine whether to continue or land.

1.5.4 Debugging and Experiments: First Flight and Review—Propellers and Site Preparation

Propeller Installation and Site Preparation



Figure: Fitting Propellers After Propeller-Off Validation

- **Fit with power off:** After ground validation, disconnect the battery, USB, and other supplies. Match propellers to motor rotation and check installation orientation.
- **Check mounting:** Lock hubs and retainers as the kit specifies. Check looseness, damage, and propeller-disk clearance; color alone is insufficient.
- **Prepare the site:** Open space and wind must suit the prototype and operator. Define a landing area and keep people outside the rotor operating area.

After ground validation, disconnect power before fitting propellers; check propeller type, rotation, mounting, and site together.

1.5.4 Debugging and Experiments: First Flight and Review—Preflight State and Control Readiness

Check Aircraft, Links, Protection Settings, and Site Conditions

- **Aircraft and battery:** Recheck propellers, fasteners, center of gravity, and wiring. Secure the battery and confirm charge and health suit the task.
- **Controls and links:** Confirm radio control works and throttle is at the required starting position. Establish takeoff mode, mode changes, and motor-stop procedures.
- **Positioning and protection:** Check required estimates, return point and altitude, geofence limits, and failsafe actions. Resolve failed preflight checks.
- **Site readiness:** Assign operator and observer roles, stop conditions, and landing area. Confirm usable logging and a flight area clear of people.

Preflight checks establish aircraft state, control method, and site conditions for this specific flight.

1.5.4 Debugging and Experiments: First Flight and Review—Initial Liftoff and Hover

First Takeoff and Brief Hover Observation



Figure: Quadcopter Flight Configuration

- **Observe takeoff:** With experienced guidance, hover briefly after liftoff. Watch attitude, yaw, vibration, and power warnings.
- **Mode criteria:** Position mode should brake and hold position. Stabilized or Altitude mode may drift in wind; interpret observations by mode.
- **Handle abnormalities:** Stop adding maneuvers and land promptly while controllable. Investigate after landing; do not change parameters in flight.

A brief hover reveals behavior under real load; judge abnormalities in the context of the current mode.

1.5.4 Debugging and Experiments: First Flight and Review—Small Inputs and Recovery

Validate Small Control Inputs and Responses



Figure: Quadcopter Flight Configuration

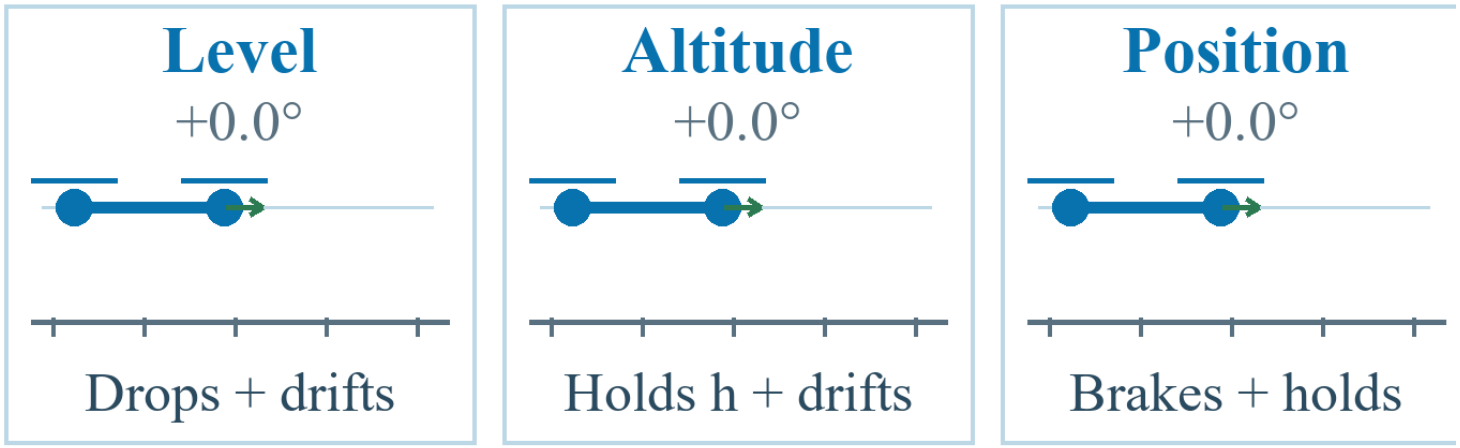
- **Test individually:** After normal hover, add small roll, pitch, yaw, and climb/descent inputs, testing one at a time.
- **Direction and recovery:** Use the nose as reference. Observe return to level, altitude hold, or braking and position hold according to the current mode.
- **Continue only if stable:** Finish one stable test before the next. End on sustained oscillation, reversed response, or warnings; keep the first flight to basic control.

Validate one small command at a time; increase maneuvers only after direction and recovery match expectations.

1.5.4 Debugging and Experiments: First Flight and Review—Small Inputs and Recovery

Centered Sticks: Level Attitude, Altitude Hold, and Position Hold

Release: level / height / hold



- **Stabilized:** Returns level; may lose altitude and drift.
- **Altitude:** Returns level and holds altitude; may still drift.
- **Position:** Tilts back to brake, then leans into the wind to hold.

Three-Mode Responses (Teaching Model)

Recovery criteria depend on mode: level attitude, altitude hold, then braking and position hold add successive functions.

1.5.4 Debugging and Experiments: First Flight and Review—Landing and Power-Down

Landing, Disarming, Motor Stop, and Power-Off

- **Prepare descent:** Return to the planned landing area, control horizontal motion, and descend smoothly according to the current mode.
- **Confirm touchdown:** Check stable ground contact. Disarm by the validated method; verify actual state if automatic disarming is enabled.
- **Approach after stopping:** Confirm all four motors have fully stopped. Minimum throttle or ground contact alone does not mean disarmed.
- **End power:** After normal shutdown, end logging and wait for writes as specified for this aircraft. Disconnect all supplies, then turn off the transmitter.

Confirm stable touchdown, disarming, and stopped motors before approaching and disconnecting power.

1.5.4 Debugging and Experiments: First Flight and Review—Postflight Review and Fault Location

Postflight Structure, Power, and Log Review

- **Structure:** With power off, inspect propellers, arms, fasteners, controller mounting, and wiring. Record looseness, rubbing, or movement.
- **Power:** Check battery condition and abnormal heating in motors, ESCs, and connectors; compare with in-flight voltage and current.
- **Logs:** At the abnormal time, inspect mode, inputs, attitude targets and responses, vibration, and power. Do not assign a cause from one curve alone.
- **Correct and retest:** Return faults to assembly, measurement, configuration, or control. Change only related items each time, then repeat the relevant propeller-off validation.

Align physical observations and logs in time; correct the cause, then validate before flying again.

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1.5.4 Debugging and Experiments: First Flight and Review
Textbook: Sec. 1.3.3

1.5.5 Fixed-Wing Assembly and Debugging
Textbook: Secs. 1.3.1–1.3.3

1.5.5 Fixed-Wing Assembly and Debugging: Aircraft and Control Surfaces

UltraStick 25e Aircraft and Components

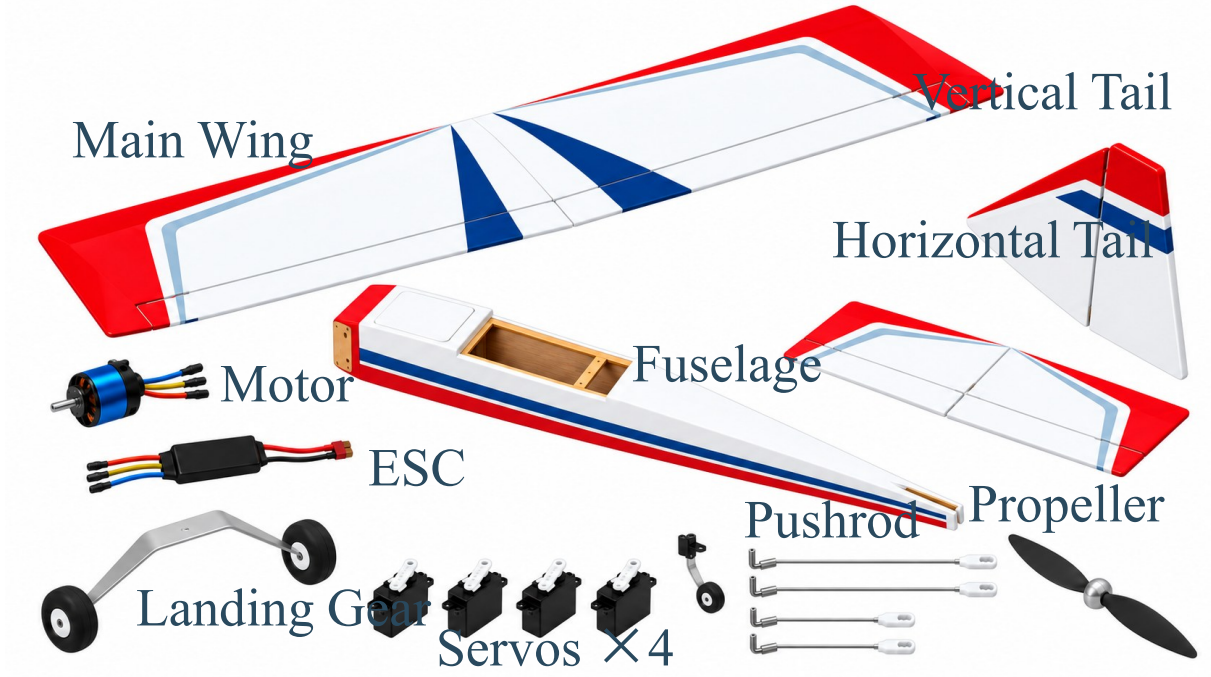


Figure: UltraStick 25e Components

- **Aircraft layout:** High wing, single tractor motor, and conventional tail. Landing gear supports the body and provides propeller ground clearance.
- **Four surface channels:** One servo for each aileron, elevator, and rudder; pushrods transmit roll, pitch, and yaw commands.
- **Teaching modifications:** The controller, GNSS, telemetry, and airspeed sensor are course additions. Consider center of gravity, wiring, and movement clearance in their layout.

A fixed-wing aircraft uses tractor propulsion and changes attitude with ailerons and tail control surfaces.

1.5.5 Fixed-Wing Assembly and Debugging: Assembly Preview

Building the Aircraft from Wing, Tail, and Landing Gear

Ultra Stick 25e Assembly



Assemble and check without the propeller; verify before fitting it

Figure: Fixed-Wing Assembly and Completed Aircraft

- **Supports, wing, and tail:** With power off and no propeller, mount propulsion and landing gear; prefit the tail. Fit the main wing, align, then secure.
- **Linkage transmission:** Servo arms and pushrods connect to control horns. Confirm supply and center positions before setting lengths and locking.
- **Validation and propeller:** Check center of gravity, clearances, and wiring. Validate surfaces and propulsion without a propeller; after passing, disconnect power and fit it.

Complete wing/tail alignment, linkage checks, and propeller-off validation, then disconnect power before fitting the propeller.

1.5.5 Fixed-Wing Assembly and Debugging: Main Wing and Landing Gear

Wing Location, Landing-Gear Fastening, and Lead Checks

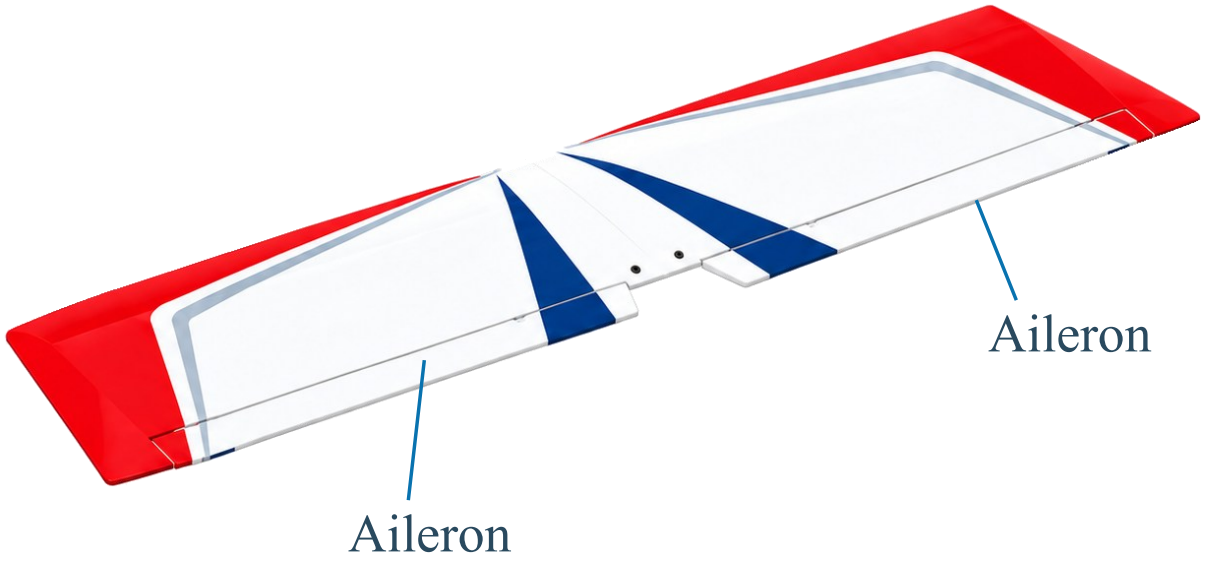


Figure: Main Wing and Ailerons

- **Wing connection:** Connect aileron leads first and seat the locating pins. Secure with the manufacturer's two bolts and washers; mating faces must sit flush without trapped wires.
- **Landing gear:** Use three screws in the specified hole orientation. Check fuselage support and free wheel rotation.
- **After assembly:** Align wing and tail before final tightening. Leave lead slack, clear of surfaces and linkages; recheck responses after removal and refitting.

Wing location and fastening jointly secure the connection; recheck aileron leads whenever the wing is refitted.

1.5.5 Fixed-Wing Assembly and Debugging: Tail and Linkages

Tail, Servo Arms, and Pushrods

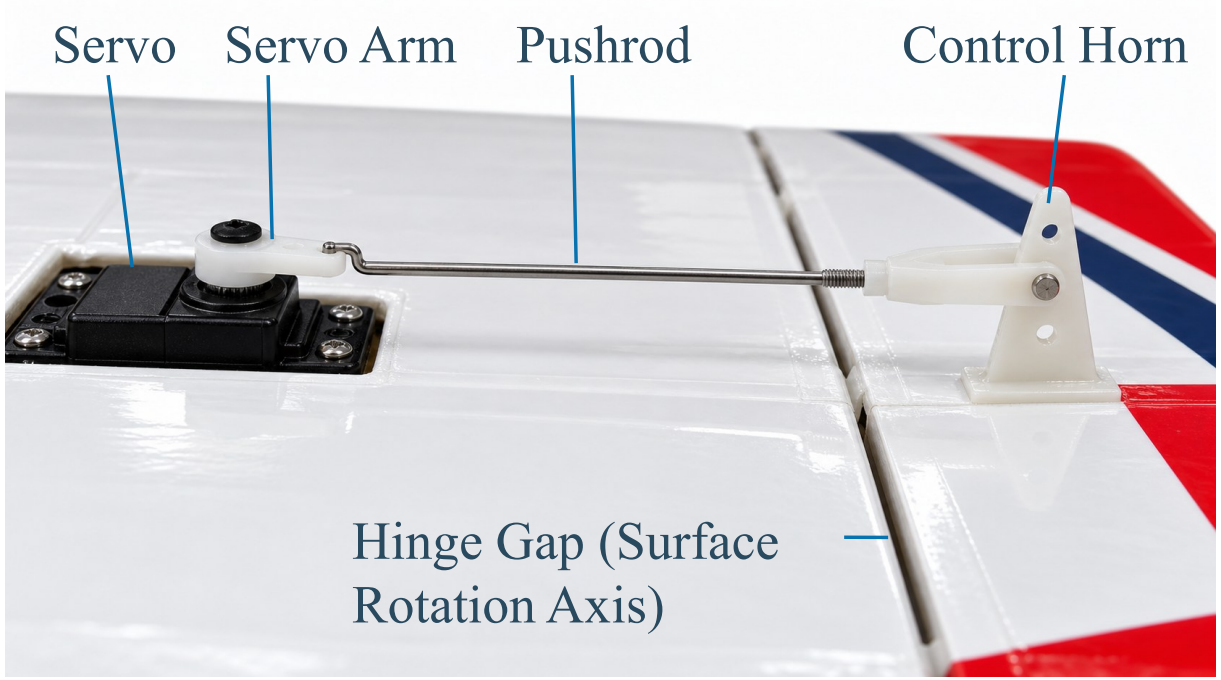


Figure: Servo Arm, Pushrod, and Control Horn

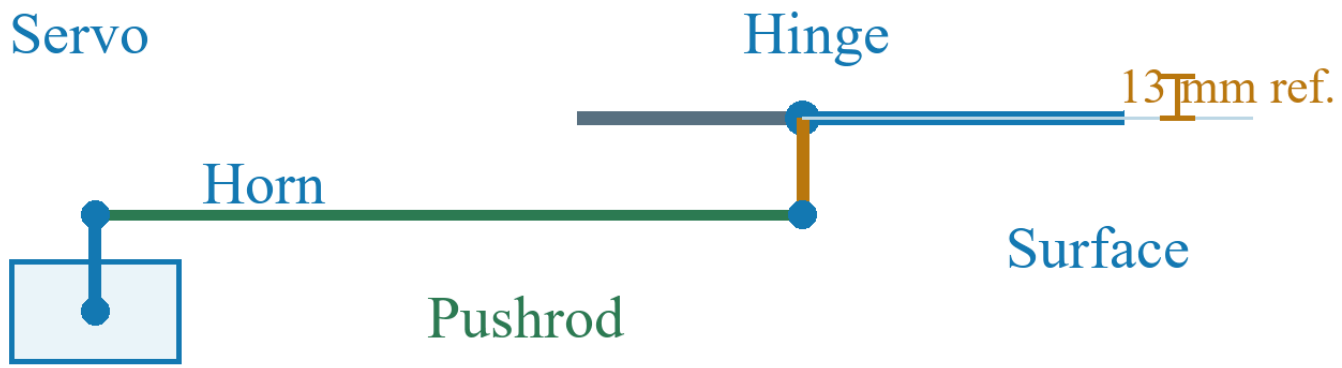
- **Tail and transmission:** Fit the tail using the manufacturer's threaded rods, washers, and locknuts. Servo arms act through pushrods and horns to rotate surfaces about hinges.
- **Center and rod length:** With propeller removed and propulsion isolated, verify supply and outputs, command center, then disconnect power to adjust arms and rods.
- **Security and travel:** Check hinges and linkages. Repower without a propeller and check centering and both endpoints, with no binding, hard stops, or excessive play.

Servo center and pushrod length jointly set surface neutral; smooth full travel is necessary for accurate force transmission.

1.5.5 Fixed-Wing Assembly and Debugging: Tail and Linkages

How Center, Pushrod Length, and Surface Travel Relate

Servo linkage travel



Model neutral 1500 µs: edge 0

- **Center:** This model uses 1500 µs. Verify the actual center, then disconnect power to adjust rod length.
- **Travel:** A 13 mm trailing-edge displacement to one side is illustrative.
- **Limit:** Stop if the pushrod bends or vibrates; reduce travel.

Four-Bar Travel (Teaching Model)

Align center first, adjust rod length with power off, and stop travel before a mechanical limit.

1.5.5 Fixed-Wing Assembly and Debugging: Controller Retrofit and Airframe Type

Fixed-Wing Controller and Airframe Setup



Figure: UltraStick 25e Equipment-Bay Retrofit

- **Retrofit mounting:** Secure the 6X near the center of gravity in the bay, arrow forward. Keep positioning/communication devices clear of propulsion interference and wiring clear of linkages.
- **Type and geometry:** Select a conventional-tail fixed wing; configure one propulsion motor and four surfaces: left/right ailerons, elevator, and rudder.
- **Shared validation:** If no dedicated preset exists, start with generic standard fixed-wing settings. Repeat shared checks and verify this aircraft's inputs, outputs, and measurements.

Fixed-wing type, mounting orientation, and surface geometry must describe the same physical aircraft.

1.5.5 Fixed-Wing Assembly and Debugging: Servo Power and Output Mapping

Servo Power and Output Functions

Function	Load	6X Output
Motor 1	ESC throttle	FMU/AUX1
Servo 1	Left aileron	I/O/MAIN1
Servo 2	Right aileron	I/O/MAIN2
Servo 3	Elevator	I/O/MAIN3
Servo 4	Rudder	I/O/MAIN4

- **Supply branch:** The PM supplies only the controller through POWER1. A battery eliminator circuit (BEC) steps voltage down separately for the MAIN-header “+” rail.
- **Ground and capacity:** Connect BEC negative to servo and signal grounds. Rated current must cover four servos' simultaneous peak demand; do not parallel two BEC positive outputs.
- **Output check:** This teaching arrangement uses PWM, commonly 50 Hz for servos. Verify each output without a propeller and inspect supply during simultaneous servo movement.

Servo power and control signals follow separate paths; output mapping relates logical functions to actual devices.

1.5.5 Fixed-Wing Assembly and Debugging: Center of Gravity and Travel References

Center of Gravity, Neutral, and Surface Travel

Surface	Low Rates	Direction
Aileron	13 mm / side	Up and down
Elevator	19 mm / side	Up and down
Rudder	51 mm / side	Left and right



Top View: Nose Up; Measure CG Aft of Leading Edge

- **Manufacturer's center of gravity:** 63.5 mm aft of the wing-root leading edge. Too far aft risks pitch instability; too far forward makes raising the nose harder.
- **Manufacturer's low rates:** The manual's smaller surface deflections suit the first flight. At the widest part, measure trailing-edge displacement from neutral to each endpoint.
- **Physical check:** Set mechanical neutral before measuring both endpoints. Move and lock the battery to adjust balance. After propeller-off validation passes, disconnect power, fit the propeller, and recheck the complete flight configuration.

Recheck center of gravity in the complete flight configuration; measure travel using this model's specified references.

1.5.5 Fixed-Wing Assembly and Debugging: Input and Feedback Directions

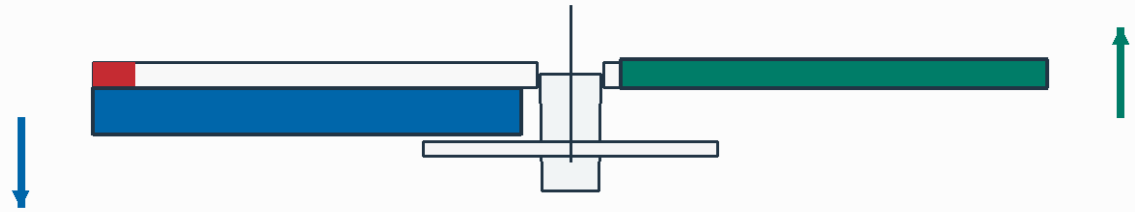
Check Manual Inputs and Automatic Correction Directions

Manual Mode: Right-roll Input



Rear view: left/right refer to the aircraft

Aircraft fixed; surfaces respond to pilot input



Left Aileron Down **Right Aileron Up**

Prop off; drive isolated; servo prearming may apply; exit actuator test

Figure: Manual Inputs and Automatic Corrections

- **Test conditions:** Remove propeller and isolate propulsion. Enable prearmed servo movement; exit actuator testing and confirm mode.
- **Manual input:** Keep the body still. Right-roll and nose-up commands must act in those directions; check opposite inputs too.
- **Stabilized correction:** Center attitude sticks, then disturb the body and check restoring action. Yaw response depends on configuration.

Manual inputs test the intended motion; automatic correction tests the restoring effect after a disturbance.

1.5.5 Fixed-Wing Assembly and Debugging: Airspeed and Pressure Checks

Airspeed Sensor and Measurement Checks

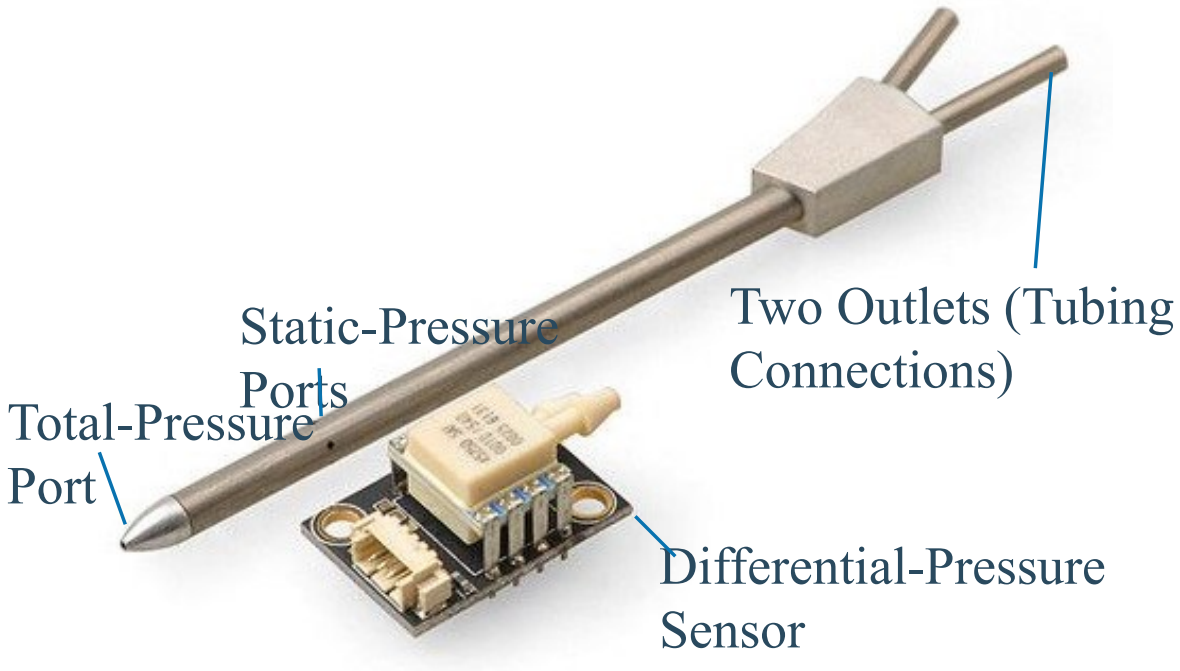


Figure: Differential-Pressure Sensor and Pitot Tube

- **Airspeed and ground speed:** Airspeed is relative to air, ground speed to ground. Wind separates them; airspeed affects lift and control effectiveness.
- **Pressure ports and tubes:** Face the total-pressure port into airflow, clear of propeller wash; sample ambient static pressure. Connect by device labels; keep tubing clear and leak-free.
- **Bias and response:** Calibrate with propeller removed and motor stopped. Shield from wind; keep ports open. Gentle airflow should give positive differential pressure and rising airspeed; both fall when airflow stops.

Airspeed requires correct pressure sampling and differential-pressure measurement; ground speed cannot replace aerodynamic-state checks.

1.5.5 Fixed-Wing Assembly and Debugging: Airspeed and Pressure Checks

Converting Differential Pressure to Airspeed

$$\Delta p = p_t - p_s = \frac{1}{2}\rho V^2$$

$$V = \sqrt{\frac{2\Delta p}{\rho}}$$

p_t / p_s: total / static pressure.
ρ: air density; V: airspeed.
Ideal low-speed incompressible flow; installation errors neglected.

- Quick calculation: For $\rho = 1.225$ kg/m³ and $\Delta p = 61$ Pa, $V = \sqrt{2 \times 61/1.225} \approx 10$ m/s.
- **Bias effect: At** 5 m/s, differential pressure is only about 15 Pa. A 3 Pa bias overestimates airspeed by about 10%, so shield from wind and zero the sensor.
- Reversed tubes: Reversed total/static tubes give negative differential pressure; reconnect by device labels and remeasure.
- Density effect: The same pressure difference means higher true airspeed at high altitude or temperature. The controller can correct using density estimated from pressure and temperature.

Airspeed comes from the square root of differential pressure; small low-speed pressures make bias and pressure-port checks essential.

1.5.5 Fixed-Wing Assembly and Debugging: Conditions for Flight

Additional Checks Before a Fixed-Wing Test Flight

- **Flight configuration:** After propeller-off validation, disconnect power and fit the matching propeller. Recheck center of gravity, wing/tail alignment, and linkages with battery and all retrofit equipment installed.
- **Controls and supply:** Review propeller-off records for manual direction, stabilized correction, neutral, and travel. Surfaces must remain controllable with the motor stopped, with normal supply during simultaneous servo movement.
- **Modes and protection:** Confirm airspeed, attitude, and links. Recheck link-loss, low-battery, and return settings for this aircraft, including return route, loiter area, and altitude.
- **Site and contingency:** Check runway, wind, obstacles, and go-around space. Agree ground-abort and airborne takeover procedures; complete common preflight checks and logging preparation.

Fixed-wing flight requires validated surfaces, balance, and airspeed, plus room for takeoff, landing, and a go-around.

1.5.5 Fixed-Wing Assembly and Debugging: Takeoff, Landing, and Flight Path

Preview Fixed-Wing Takeoff, Circuit, and Landing

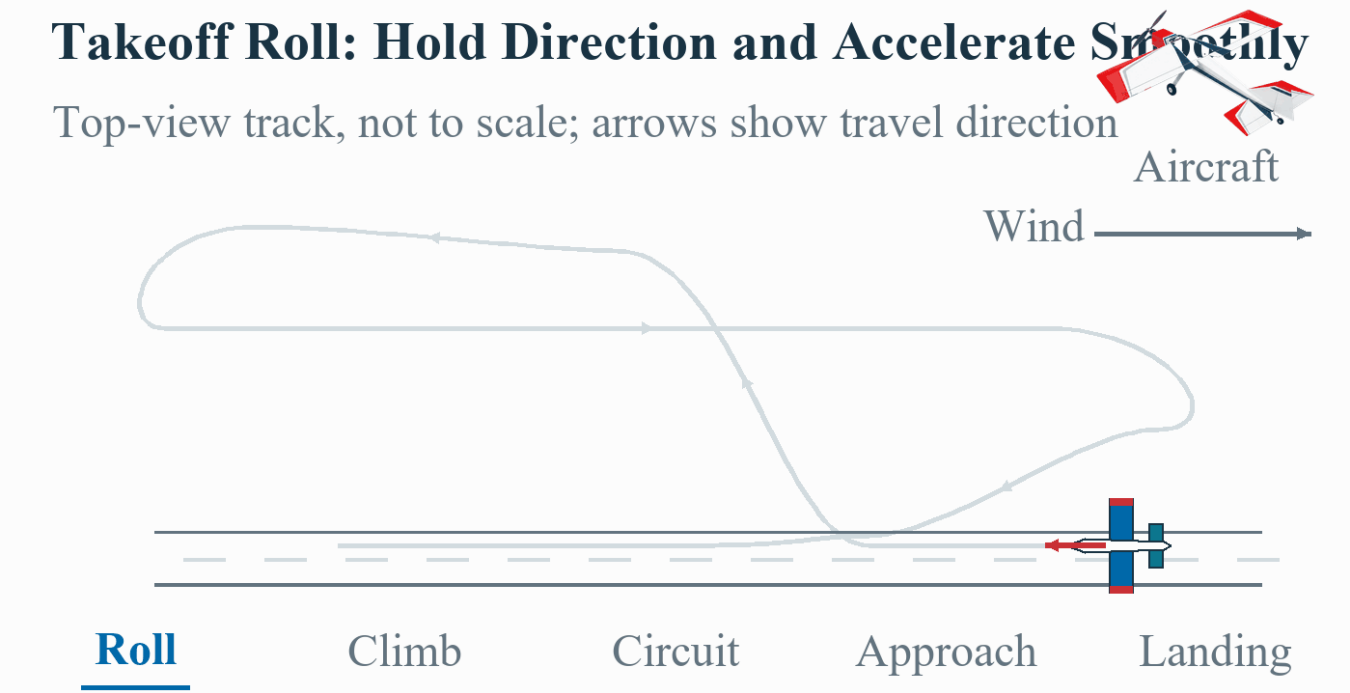


Figure: Fixed-Wing Takeoff and Landing Circuit

- **Takeoff and climb:** Roll into the wind, maintain direction, and gently raise the nose once this aircraft's liftoff conditions are met.
- **Basic circuit:** Maintain airspeed; begin straight, then use shallow-bank turns. Centering sticks in Stabilized mode still leaves forward flight.
- **Approach and landing:** Coordinate throttle and pitch through approach, flare, and touchdown. Stop the aircraft and motor, disconnect power, then inspect.

Manage airspeed throughout fixed-wing takeoff and landing; turns, approach, and go-around require space.

1.5 Assembly and Debugging

Section Resources: Assembly Documents and Official Guides

Complete Quadcopter and Fixed-Wing Assembly and Debugging from the Guides

- **Experiment documents:** [Installation directory]\RflySimAPIs\1.RflySimIntro\1.BasicExps\e10.DroneAssTutorial\
- **Quadcopter:** 1.QuadUAVAss\Readme.pdf—frame, propulsion, flight controller, communications, and QGC setup.
- **Fixed wing:** 3.FWAss\Readme.pdf—software-in-the-loop (SITL; SIL in the textbook), hardware-in-the-loop (HITL; HIL in the textbook), and real-vehicle steps.

PX4: Pixhawk 6X Wiring Quick Start

https://docs.px4.io/main/en/assembly/quick_start_pixhawk6x

PX4: Sensors, Radio Control and Actuators

https://docs.px4.io/main/en/config/

PX4: Failsafe and Geofence Settings

https://docs.px4.io/main/en/config/safety

Relating documented steps to physical responses turns a single assembly into a reproducible method.

Section Exercise: Fault Location

Diagnosing Faults: Connections, Configuration, and Responses

- **Motor location:** A brief propeller-off Motor 1 test turns a motor that differs from the selected airframe diagram. Is connector number enough? What comes first, and how do you retest?

  Reference: Check airframe position, function mapping, and wiring. Retest each motor's position and rotation with propellers removed.

- **Power:** With the battery connected, USB powers the controller; unplugging USB shuts it off. Does this prove controller damage? How do you trace the supply?

  Reference: Check battery, PM02D, and POWER1 connections and voltages. Normal USB operation does not establish controller damage.

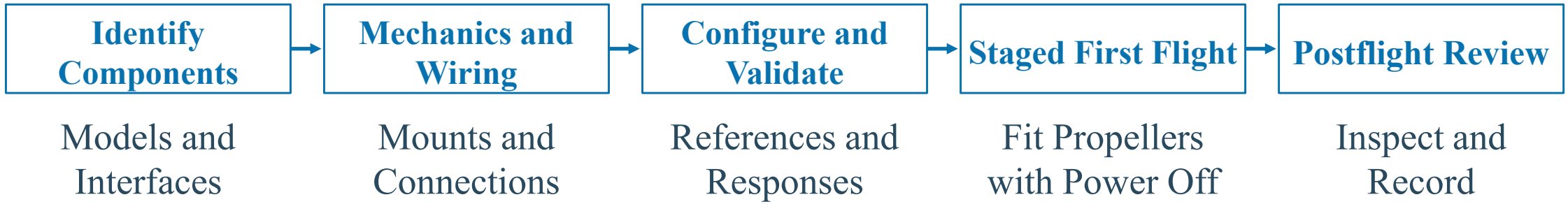
- **Surface feedback:** Manual right roll works. In Stabilized mode with sticks centered, lowering the right wing still raises its aileron. What does this show? Why is transmitter reversal alone insufficient?

  Reference: Check controller orientation, attitude estimation, and stabilization-output direction. Transmitter reversal cannot correct feedback.

Fault diagnosis should state possible causes, checking methods, and evidence from retesting after correction.

Section Summary

How Assembly and Debugging Fit Together



- **Assembly:** Establish structural connections and propulsion-power, low-voltage-power, and signal paths.
- **Configuration:** Match airframe type, mounting orientation, and output functions to the hardware.
- **Validation:** Compare inputs and responses with propellers removed; also check fixed-wing servo power, center of gravity, and airspeed.
- **Review:** After the first flight, investigate abnormalities using structure and logs, then retest after correction.

Assembly and debugging are complete when hardware, configuration, responses, and records agree.