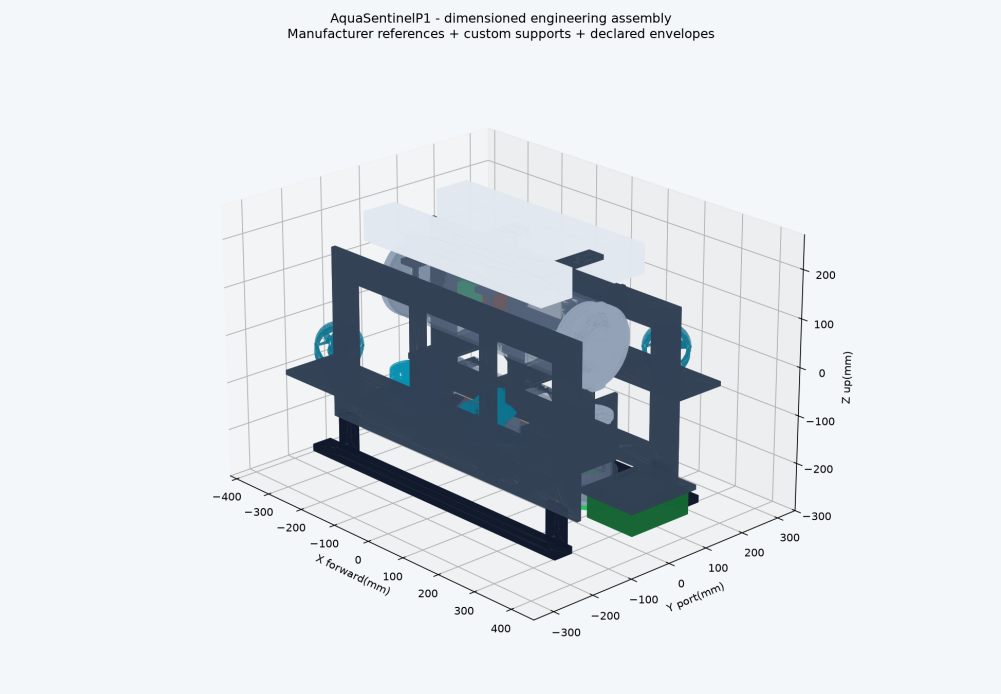
P1 Prototype Build Guide

Mechanical assembly, interface control and commissioning

A dimensional digital package for a six-thruster, five-axis survey prototype. Purchased pressure interfaces and manufacturer component models form the hardware basis. Physical acceptance remains pending.



Revision	Canonical identity	Physical release
P1	98aa0b7dd9d069b5b48e...	PENDING / not authorized

Generated from 57 BOM lines and 50 logical harness routes. No supplier quote, pressure test, trained species model or hardware acceptance result is fabricated.

Read the package in this order

1. Review the configuration and generated assembly/drawing manifest.
2. Confirm component identities, interface holds and the full BOM.
3. Assemble non-pressure structure, purchased pressure assemblies and protected wiring.
4. Run the supplied offline verification, then qualify a separate physical adapter.
5. Record actual inspection, bench, controlled-water and site acceptance evidence.

Assembly	Tube / placement	Main interface
Electronics	BR-106281-500 L500 / OD163.9 / ID150	Center [0, 0, 80] mm Axis [1, 0, 0]
Battery	BR-106279-300 L300 / OD112 / ID103	Center [0, 0, -120] mm Axis [1, 0, 0]
Downward optics	BR-106278-150 L150 / OD86.5 / ID79	Center [245, 0, -150] mm Axis [0, 0, 1]

Configuration authority

All project positions are in a right-handed body frame: x forward, y port, z up. Manufacturer drawings control bought-part mating surfaces. Compare the CAD manifest/configuration hash before relying on a printed value. The full configuration hash is:

```
98aa0b7dd9d069b5b48ee1c71b5be3b48fbb30c453cc2caad32cbe1120a5727d
```

Captured digital geometry checks

Digital geometry: 12 passed, 0 failed; 3 interface/physical checks remain on hold. Configuration identity matches this guide.

Reference-geometry note: T200.STEP: vendor reference compound fails global BRep validity; source reference retained without attempted re-certification.

Captured offline software verification

Unit tests: 65 passed of 65, 0 failures, 0 errors; captured integration scenarios: 5. Configuration identity matches this guide. These are offline software results, not accepted physical tests.

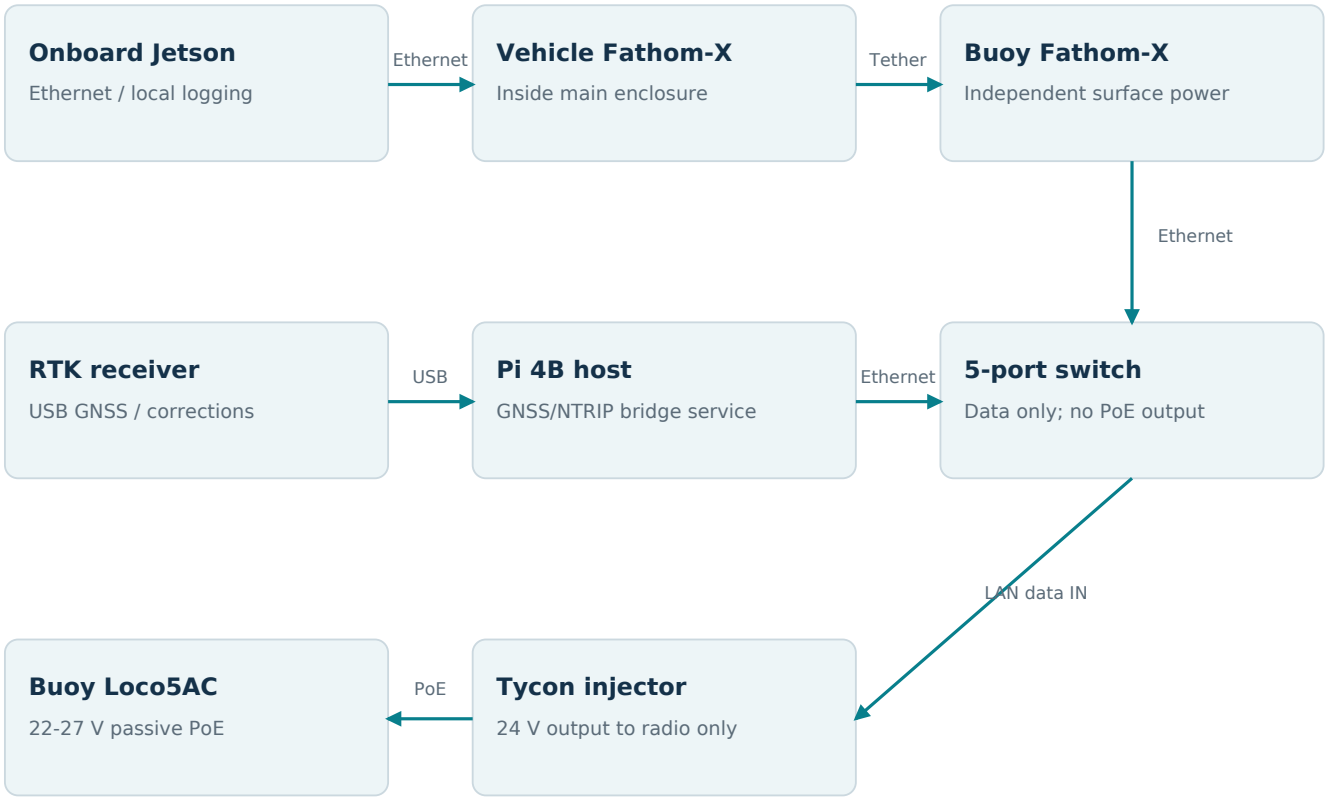
Implementation boundary

The included runtime performs dry-run allocation, fault handling, survey simulation, replay and optional artifact-verified inference. Receive-only MAVLink telemetry and a serial GNSS-to-JSON buoy bridge are implemented with offline wire fixtures. It does not open a physical motor-control interface. The physical control adapter, calibrated sensors, independent protection and actual species-validation dataset are acceptance work.

The historical ten-volume engineering lineage is documented separately. Its old release-path and inherited-source issues are not made valid by generating this P1 package.

Power and data architecture

Logical topology for implementation review. The physical protection circuit, pinouts and hardware adapter require their own accepted electrical release.



Data links are bidirectional; wireless radio settings and the shore link budget require acceptance.

Vehicle power path

Source	Independent protection	Protected loads
Factory 4S6P battery	Adjacent DC fuse; measured-current/latching disconnect; reviewed reset and kill path	Six ESC branches, filtered Jetson supply, FC module, lights, camera and normally-off laser supply

Surface power path

A separate fused battery powers the buoy. The Pi needs its matched 5 V supply, the switch and Fathom-X use their rated inputs, and the radio uses the dedicated 24 V passive PoE injector. Do not backfeed that powered injector output into the Pi, switch or Fathom-X. Include every branch and converter loss in the measured buoy load budget.

Local fabrication and product inspection

Local polymer and metal printing are available. The manufacturing package maps the existing CAD to actual part quantities and full-size files. Printing a replacement material is an engineering change: baseline HDPE and wrought 6061-T6 properties are not established by a similar-looking printed part.

Workshop deliverable	Scope
12 flat profile designs / 25 pieces	Individual zero-origin millimetre STL, STEP/DXF authority, material and orientation records
Ancillary custom parts	Separate exact-geometry exports and open interface details; do not substitute printer infill for buoyancy foam
Piece traveler and inspection records	Actual dimensions, material, process and inspection fields remain blank until manufactured
Offline full-product view	Extract the package and open viewer/index.html; assembled, internal, exploded and separate surface-relay modes

Pressure tubes, caps, windows, seals, penetrators and thrusters remain purchased components. Manufacturer CAD is reference geometry, not authorization to print a rated pressure part. Secondary end taps, joints, laser attachment, cable bends and load/trim acceptance remain explicit work in the manufacturing plan.

Corrected commissioning power allowance

The initial allocation surrogate is limited to 30 A propulsion with 12 A house reserve. The earlier 6 A house allowance did not cover simultaneous maximum electronics and lights. This corrected 42 A planning total is an assumption to test; the 48 A measured software abort is not independent hardware protection.

Electronics selection and release sequence

Read prototype/electrical/ for supply and protection candidates, a circuit/port proposal and remaining rating/packaging work. Confirm ordered options and actual dimensions before committing protection-module hardware or drilling custom supports. Complete the independent inhibit circuit and accepted fault tests before operating motors in water.

AquaSentinel P1 assembly and commissioning

Revision P1. Purpose: turn the digital design into an inspected bench assembly and then a qualified controlled-water prototype. The canonical configuration is `prototype/config/prototype.json`; generated CAD, component identities and the most recent validation report must agree with that file before purchasing or cutting parts. Current digital status is DESIGN REVIEW. No physical assembly, pressure test, motor test or field acceptance is represented as completed.

1. Open the package and establish the build identity

1. Record a build serial number, configuration revision, configuration SHA-256, drawing/CAD manifest SHA-256, builder, reviewer and intended operating site.
2. Open the complete assembly and exploded view. Verify the six thrusters, three pressure enclosures, downward clear window, optical scale, guards, skids, electronics tray, foam and separate surface relay.
3. Read `Hardware_Design_Review.md`, `Interface_Control.md`, `prototype/bom/components.csv` and `prototype/bom/harness.csv`. The CSV files contain the item and logical connection schedules. Neither a quote-required BOM row nor a modeled envelope is an accepted physical interface.
4. Print or save the manufacturer instructions for each purchased revision. The pressure boundary uses purchased tubes, flanges, endcaps, seals and pressure-rated cable interfaces. A simplified project envelope cannot be used to machine a replacement pressure component.
5. Resolve the engineering holds: hardware cutoff/protection schematic, regulator and fuse selection, full cable bend routes, laser mounting/power option, surface bridge host/switch and the final buoy electrical load budget. Do not erase a hold merely because a model was exported.

2. Receive and inspect components

Check part number, revision, quantity, serial number, supplier drawing, visible damage, connector variant and certificates supplied with the actual item. Record dimensions where a tolerance or interface controls fit. The pressure-enclosure inventory includes:

- 6-inch locking aluminum electronics tube, 500 mm long, with the specified front and rear ported caps and two matching flanges.
- 4-inch locking aluminum battery tube, 300 mm long, with one ported cap and one blank cap, plus two matching flanges.
- 3-inch locking aluminum optical tube, 150 mm long, with an aluminum upper cap, a clear acrylic lower cap and two matching flanges.
- The factory BR-100842 cylindrical 4S6P battery, its matched charger, the selected UWI laser option, actual camera/USB boards and all cable assemblies.

Inspect sealing faces and supplied elastomers using the manufacturer's acceptance criteria. Quarantine scratched, contaminated, damaged, mismatched or unidentified pressure components. Count unused M10/M14 holes against the actual port schedule, including service fittings; each unused hole must receive the matching face-sealed plug.

3. Fabricate the external structure

Use the individual project part files and their current drawings to cut the HDPE side plates, rails, skids, guards, non-pressure trays and brackets. Confirm material and thickness from the manifest. Machine only the defined non-pressure parts. Remove burrs, inspect every finished edge, and measure locating holes and slots against the drawing.

Dry-assemble the frame on a flat fixture. Check squareness, symmetry and clear access to enclosure service ends. Install the skids and guards without loading the pressure tubes. Use the specified corrosion-compatible fasteners, washers, isolation and locking features. Select final tightening instructions for the actual fastener/HDPE joint; the project does not assign a generic torque to all frame bolts.

Record an as-built deviation if a hole, material or geometry differs. Rebuild and recheck the digital assembly when a deviation changes clearance or equipment location.

4. Install enclosure supports and removable trays

Use the manufacturer clamp geometries and supplied support interfaces. Confirm that each tube is supported without point loading, clamp interference or inaccessible locking cords. The optical pod must remain vertical with the clear lower endcap unobstructed.

Check the following from the canonical configuration rather than old dashboard dimensions:

- Electronics tube center and orientation; board and tray placement.
- Battery tube center, service-end orientation and complete power-cable route.
- Optical pod center, camera optical center and the outer window reference.
- Laser envelope, optical baseline and mounting adjustment reserve.

Slide each tray through its real insertion path with representative connectors installed. Verify standoff clearances, fan inlet/exhaust recirculation space, service tools, terminal covers and cable bend radii. Board envelopes alone are insufficient. Restrain the battery and the removable electronics against shock without crushing the pack or blocking pressure service access.

5. Install the six propulsion channels

Label physical thrusters T1 through T6 according to their positions in the canonical configuration. Four horizontal channels are vectored; the two midship vertical channels provide heave and roll authority. The package has no independently actuated pitch axis.

Use the manufacturer brackets and mounting holes. Verify screw engagement, CW/CCW identity, cable exit direction, guard clearances and the absence of pinch/snaring points. Select fastener length and tightening from the current manufacturer instructions. Physical channels and directions must be verified later; a geometric T-number is not an ArduSub output-channel number.

Keep motor power disconnected while inspecting the installed rotors and routing. Any powered rotation check must use the manufacturer's approved operating conditions and the reviewed commissioning fixture; the digital guide does not authorize dry running.

6. Build the protected electrical assembly

Follow the reviewed wiring schematic and `harness.csv`. The schedule describes logical signals and routes; manufacturer connector drawings provide pin numbers and orientation.

1. Install the covered fuse and selected normally-open disconnect close to the battery output. Complete the independent current-detection and latching inhibit circuit before propulsion energization. The 48 A total-pack operating constraint is not a hardware current limiter.

2. Route the factory underwater positive and negative power cables to the main enclosure. Demonstrate the entire cable centerline, endcap exit bends, strain relief and removal path. Obtain a longer approved assembly if the factory length does not satisfy those constraints.
3. Install covered distribution, separately protected ESC branches and protected house branches. Verify conductor sizes, connector ratings, protective-device time/current coordination and heat dissipation for the actual installation.
4. Connect the FC power module on its low-current branch. Do not pass the whole vehicle load through the stock PM07 XT60/12 AWG harness; its published continuous limit is lower than the proposed vehicle operating ceiling.
5. Install the filtered Jetson supply, camera supply and the selected laser regulator. Verify polarity, output voltage and startup behavior on a current-limited bench supply before connecting electronics. The Jetson carrier jack is not a 5 V input; the selected laser 3 V option is not a raw battery input.
6. Connect each PWM signal and its signal return. Prevent accidental backfeeding between power-module, USB and external 5 V sources. Verify shields and logic-level compatibility from the actual manufacturers' pinouts.
7. Release the H50 measured-current acquisition and H51 cross-enclosure hard-inhibit interfaces, including isolation, port assignments and revised gland/plug quantities. Fit electronics and battery leak sensing, a hard inhibit independent of the companion computer, and separate status reporting. A fault-clear signal must not cause automatic rearming.

Record continuity, polarity, insulation where applicable, no-load voltages and terminal pull checks before enabling loads. Then use reviewed fixtures to characterize startup, load steps, current, cutoff response, fault latching and temperature. Preserve raw traces and instrument identities.

7. Assemble the optical and scale system

The IMX477 board, lens and B0278 USB adapter remain dry inside the optical pod. The CSI ribbon is short and internal. A round shielded USB cable crosses the pressure interfaces using cable-matched penetrators; a flat CSI ribbon is not sealed by an ordinary round-cable gland.

Mount and lock the lens without contact with the clear window. Reserve cable and connector space, protect the acrylic surface and verify that trays or screws cannot obstruct the field. Keep the exact camera and lens identity with all calibration data.

Install the UWI scale using its confirmed supplier mounting pattern and the project bracket. Confirm the ordered direct-power option before connecting it. The published external envelope is modeled; this does not prove the mounting hole pattern or beam alignment. The lasers are Class 3R: use the supplier's alignment/handling procedure and normally-off hardware enable.

Verify both spots are visible in the submerged camera image at the required survey plane. Measure the actual beam separation and parallelism underwater; a nominal 100 mm body or drawing dimension is not a calibration certificate. Validate focus, distortion correction and plane eligibility at each selected resolution and lens setting. Record rejected frames as rejected rather than inventing scale or biomass.

8. Close pressure assemblies using manufacturer procedures

Use the current manufacturer enclosure assembly guide, WetLink assembly guide and vacuum service guide for the purchased revisions.

For every enclosure, record the exact tube, flange, cap, seal, penetrator and service-device identities. Use the manufacturer-prescribed cleaning, compatible lubricant, orientation, fastener lengths, tightening sequence, torque values and cable assembly instructions for those exact parts.

Do not apply one universal torque to cap screws, cable glands and different-size fittings. Do not drill, re-tap or modify a pressure part using the frame drawing. Use the supplied locking features and verify that every unused port is sealed with its intended plug.

Execute the approved vacuum/pressure qualification plan with calibrated instruments and appropriate fixtures. Target pressure, hold time, allowable change, instrumentation and acceptance authority must be entered before the test. This guide does not assign a new pressure rating to the assembled vehicle or mark an unperformed test as passed.

9. Run the supplied offline software verification

Use Python 3.10 or newer; the host system's `python3` may be older. The source tree runs without installation. These commands do not control physical actuators:

```
python3 prototype/software/run.py inspect --config prototype/config/prototype.json
python3 prototype/software/verify.py
python3 prototype/software/run.py simulate --config prototype/config/prototype.json --seconds 20 --log
/tmp/aquasentinel-bench-simulation.jsonl
python3 prototype/software/run.py simulate --config prototype/config/prototype.json --seconds 12 --fault leak
--fault-at 5 --log /tmp/aquasentinel-leak-simulation.jsonl
python3 prototype/software/run.py replay prototype/software/examples/observations.jsonl --output
/tmp/aquasentinel-replay.jsonl
```

Use new output filenames; the tools refuse destructive replay/inference overwrites. Inspect the generated software `verification.json` for actual test results, configuration/source hashes and explicit limits. Its synthetic logs are software evidence only.

10. Commission the separate physical control interface

ArduSub 4.7.2 on Pixhawk 6C is the selected integration target as verified from the official firmware server. Record the actual firmware file hash, board revision and parameters. Confirm the proper Bar02 external MS5837 driver and compare sensor values with reference measurements.

The supplied Python runtime ends at a dry-run output sink. A separately reviewed hardware adapter, sensor acquisition path and autopilot handoff are required before actual control. The physical integration must preserve the coordinate conversion, latching faults, independent kill/current protection, watchdog and explicit restart rules in `Interface_Control.md`.

Verify each motor-channel/direction mapping individually in the reviewed fixture. Confirm that the correct channel responds and all others remain neutral, then verify surge, sway, yaw, heave and roll combinations at limited load. A configuration label or successful software rank calculation does not replace this test.

Inject link loss, stale/future timestamps, low supply, leak inputs, current threshold and kill-loop faults. Confirm physical output removal, retained fault identity and explicit disarm-reset-rearm sequencing. Preserve measurements with a named reviewer. Do not infer physical motor neutralization from a zero in a dry-run JSON record.

11. Commission the independent surface relay

Install the separate fused buoy battery, matched 5 V Pi supply, Raspberry Pi 4B GNSS/NTRIP host, BR-100457 Ethernet switch, RTK receiver/antenna, Fathom-X endpoint and Tycon 24 V passive PoE injector in the selected 5 L box. Connect the injector data-only LAN input to the switch and its powered output only to the Loco5AC radio. Include the box's published 7890 g empty mass in the buoy displacement/freeboard and stability checks; a large enough deck does not prove floating stability. Verify all power input ranges and include their measured draw in buoy runtime calculations.

Record the GNSS correction source, antenna reference, FIX/FLOAT/invalid status, timestamps and latency. Prove that buoy-position messages reach the intended logger. They represent the surface receiver location.

They must not be silently used as the camera's underwater coordinates. Inspect the tether strain relief, service length, bend path and snag response with the actual floating assembly.

12. Qualify in controlled water

After the preceding gates are accepted, measure the assembled dry mass, displacement, water density, CG/CB, trim and recovery behavior. Adjust only through documented changes to ballast, foam or equipment placement. The frame is flooded; its open voids are not sealed displacement. Rebuild the digital configuration if those changes alter clearance or extrinsics.

Depth references must remain explicit. For the current camera extrinsic z=-195 mm and outer-window z=-241.9 mm, a level body origin at 1.4 m depth in 2.0 m water gives optical-center altitude 0.405 m and window clearance 0.3581 m. These are different quantities. The nominal 0.6 m survey altitude is a camera-plane requirement; choose body depth from the measured geometry and bathymetry.

Use staged tests to establish pressure integrity, current/temperature behavior, guarded propulsion, operator recovery, drift and tether response. Then validate optical scale and counting against independent ground truth. Site operations require a separately accepted geofence, weather/current limits, recovery method, operator roles, biosecurity procedure and test authority.

13. Commissioning record template

Field	Entry
Build serial / operator / reviewer	To be completed
Configuration / CAD / firmware hashes	To be completed
Purchased component revisions and serials	To be completed
Fixture / instrument IDs and calibration dates	To be completed
Procedure revision and pre-approved acceptance limits	To be completed
Measurements and raw-file locations	To be completed
Anomalies / corrective actions / retest identity	To be completed
Result / reviewer / date	PENDING - no test result recorded

Gate	Required evidence	Current physical status
G01 Mechanical and service fit	As-built inspection, CAD comparison and cable bend routes	PENDING
G02 Pressure boundary	Manufacturer assembly inspection plus approved qualification record	PENDING
G03 Electrical protection	Reviewed schematic, device/fuse coordination and measured fault tests	PENDING
G04 Thermal endurance	Closed-enclosure logs at applicable ambient/water conditions	PENDING
G05 Motor map and interlocks	Witnessed channel/direction, kill, current, leak and watchdog tests	PENDING
G06 Buoy and communications	Measured independent power budget, link and timestamp tests	PENDING
G07 Hydrostatics and recovery	Measured mass, displacement, trim and recovery record	PENDING
G08 Optical calibration and AI	Immersed calibration, plane validation and held-out species evidence	PENDING
G09 Controlled-water acceptance	Accepted integrated functional trial and anomaly closure	PENDING
G10 Lagoon operation	Site-specific approval, personnel, recovery and biosecurity records	PENDING

AquaSentinel P1 interface control

Revision P1. This document binds the mechanical configuration, logical electrical harness, offline runtime and future physical adapter. Status: engineering review. It defines contracts and review tests; it does not assert that a physical interface has been built or accepted.

1. Authority and change control

`prototype/config/prototype.json` is the canonical project geometry and configuration. Its hash must match the CAD manifest and the configuration identity recorded by software verification. Supplier drawings control purchased-part interfaces. `components.csv` controls procurement identities and holds; `harness.csv` controls logical routes. Update affected documents and regenerate derived data when a position, component, cable, frame transform or operating limit changes.

Manufacturer reference geometry, simplified component envelopes and project-made frame geometry have different evidence scopes. An envelope does not release a supplier's hidden mounting geometry or a project pressure vessel.

2. Frames and units

Interface	Contract
Canonical mechanical frame	Right-handed body frame: x forward, y port, z up; positions in mm
Physical allocation	Force in N, torque in N m; convert mm positions to m before cross products
Software control geometry	Six unique thruster positions and unit direction vectors from canonical configuration
Depth	Positive downward, with the body-origin reference explicitly identified
Camera altitude	Distance from the calibrated optical center to the measured plane; report the plane normal and uncertainty
Window clearance	Independent geometric clearance of the outer window, not the optical-center altitude
ArduPilot body convention	FRD: x forward, y right, z down; convert explicitly from project FLU
Geographic coordinates	Specify geodetic datum, receiver/antenna reference, time basis and FIX/FLOAT/invalid quality

For level rigid-body FLU-to-FRD conversion, the vector transform is diag(1,-1,-1). Apply the proper rotation to positions, force, torque and orientation; do not copy a yaw sign or quaternion without checking conventions. A body yaw angle and a geodetic heading require their own documented reference.

The current optical center is [245,0,-195] mm and outer window reference z=-241.9 mm. Read actual values from configuration rather than copying these into software constants. For general attitude, rotate the extrinsic into the world/measurement frame before projecting onto the plane normal. A tilted camera must not use the level shortcut unconditionally.

3. Thruster allocation and firmware channel map

T1-T4 are the four horizontal vectored channels; T5-T6 are midship vertical channels. Positive commanded thrust points along each declared unit direction. The software builds columns [force; position cross force] from that geometry and confirms rank five. Pitch is not an independently actuated degree of freedom.

T1-T6 are geometric IDs. Their firmware output numbers, CW/CCW hardware identity, direction signs, neutral value, command endpoints and arming behavior form a separate commissioned map. The existing software does not upload or invent that map. Verify one channel at a time with the approved physical fixture and then verify combined-axis behavior. Record the accepted map, firmware hash and parameter file with the build serial.

The Basic ESC uses a servo PWM interface. Obtain current exact endpoints, neutral/deadband and electrical signal requirements from the manufacturer. Any future physical adapter must produce neutral and revoke enable on invalid/stale input and every latched abort. It must not bypass the autopilot's own arming and watchdog logic.

4. Power and inhibition

The factory 4S6P battery is nominal 14.8 V, maximum 16.8 V and manufacturer-rated 60 A continuous. The current project operating budget is 48 A total pack, with a 30 A estimated propulsion allowance and 12 A house reserve. These are initial design constraints; acceptance requires measured loads and independent cutoff protection.

The dry-run allocator currently bounds a surrogate estimate using a 32 A full-command coefficient and the sum of absolute normalized commands. Real thrust/current is nonlinear. The measured pack-current input above 48 A latches a software fault, but software is not the physical overcurrent protector.

The hardware inhibit contract is energize-to-enable with a reviewed fault-latching disconnect. Local kill, leak, excessive current and loss of its own control power must inhibit propulsion independently of the Jetson application. Reset is deliberate and does not rearm. Define protection threshold/timing/tolerances, fuse coordination, current-sensor calibration, disconnect ratings, suppression and failure response in the electrical release.

H37 records the internal companion/autopilot connection. H50 measured-current acquisition and H51 cross-enclosure hard inhibition remain electrical release holds; choose the sensor placement, isolated acquisition, cable and physical pressure ports, then revise the plug and penetrator counts. Their names in a CSV are not accepted circuits.

House and propulsion branches must be separately protected. The buoy power domain is independent. Do not connect or parallel the FC, USB and auxiliary 5 V sources without an approved power-path design. Connector pin numbers and polarity come from actual component drawings; color or a CSV route name is not a pinout.

5. Companion computer and autopilot link

The initial physical integration target is Pixhawk 6C with ArduSub 4.7.2. Pin the downloaded binary hash and accepted configuration rather than tracking an unqualified moving 'latest' image.

A future companion link must document transport, voltage levels, baud/network settings, message IDs, ownership, heartbeat timestamps and loss-of-link handoff. For a UART path, use a correctly leveled approved adapter and verified TX/RX/GND mapping; do not connect RS-232 voltages to a logic UART or join two supply outputs. Explicit runtime commands can now open a receive-only MAVLink UDP listener or a GNSS serial input and publish typed surface-fix JSON. The runtime has no motor-command encoder, arming sender or PWM channel. Offline wire fixtures test reception; real sensor calibration and end-to-end commissioning remain required.

Arming requires fresh healthy sensor data, no latched fault, valid timestamps and explicit user/operator action. Every abort first neutralizes the dry-run output and preserves a fault set. Clearing a sensor does not resume a mission: disarm, explicit fault reset with fresh healthy inputs, rearm and restart are separate steps. Reproduce this state contract in the physical adapter and independently test actual actuator removal.

6. Sensor and telemetry contract

The software input contract includes monotonic controller time, sensor sample time, battery state, measured pack current, depth and leak/power-fault flags. Document units, validity flags and sensor identity. Reject NaN/Infinity, backward time, stale or future samples and invalid commands. Initial maximum heartbeat age is 0.5 s; the initial normalized command bound is 0.35. Canonical configuration and accepted integration measurements may tighten these values through change control.

The Bar02 interface uses the manufacturer's supply/logic/harness and the MS5837 external driver on compatible firmware. Confirm I2C address and bus voltage from the actual sensor revision. Log atmospheric zero, water-density assumption, reference depth and calibration identity. I2C has no inherent physical acknowledgement that a pressure measurement is accurate; driver discovery alone is not acceptance.

Controller logs are JSONL with run UUID, schema version, monotonic sequence, state, fault set, timestamp, synthetic-input flags and normalized dry-run outputs. Synthetic pose records remain distinct from physical telemetry. Preserve raw files and hashes; an append-only log must not turn a truncated or incompatible previous run into a valid continuation.

7. Camera and USB boundary

B0240 IMX477 and B0278 CSI-to-USB electronics sit inside the dry optical pod. The short CSI ribbon remains internal. The boundary to the Jetson is shielded round USB2 cable through correctly matched pressure penetrators, carrying VBUS, differential data and ground with the required shield termination. Preserve pair geometry, verify the actual board connector pinout, prevent host-power backfeed and validate UVC enumeration under motor electrical noise.

Record camera ID, sensor, lens, focus lock, frame width/height, crop, binning and distortion/undistortion settings. A resolution change invalidates calibration unless the transformation is explicitly modeled and verified. A driver-ready flag is separate from a metrology-ready flag.

8. Laser scale and planar metrology

The UWI-SLS-26-10 baseline is nominal 100 mm; record the calibrated underwater value and uncertainty. The selected purchase request is the supplier's 3 V DC direct option with 700 mA reference total current. Confirm the ordered interface and pinout before wiring. Its laser-enable path is normally off and disabled on an abort. Use the supplier's Class 3R handling and alignment instructions.

Accepted measurements require two unambiguous in-frame laser centroids, the matching camera identity and resolution, distortion correction, calibrated baseline, explicit common-plane verification and stated baseline/centroid/endpoint uncertainties. Initial plane eligibility is within five degrees of frontoparallel in the software policy. That policy is not an achieved length-accuracy certificate.

The nominal 130 mm forward offset from the camera center to the scale's current beam line means both dots must be verified within the **immersed** field of view at the chosen altitude. Use actual optical geometry, not air FOV or body center spacing alone. Missing or off-plane dots, truncated objects, ambiguous centroids and unverified distortion are rejected; the pipeline must not substitute a nominal altitude-derived scale silently.

The length relation is pixel length times calibrated baseline divided by dot separation. Random uncertainty propagation excludes unmodeled systematic flat-port/lens/plane biases, which require physical calibration. No species wet-mass regression or harvest threshold is assumed by the prototype runtime.

9. Detection, tracking and species model boundary

The supplied observation replay includes synthetic test data. Optional ONNX inference requires a local SHA-256-pinned artifact and manifest with model identity, ordered class labels, training-dataset identity, evaluation-report identity, input geometry and supported output layout. No trained species weights are included. Do not rename a generic detector class as a sea-cucumber model or infer accuracy from a runtime's ability to load an artifact.

Replay deduplicates recent frame IDs, associates observations with gated one-to-one tracking and counts confirmed track events. This is not a census of the farm: occlusion, association failure and track expiry can split or swap IDs. Report tracking policy and uncertainty separately from raw detection counts.

World association is permitted only with explicit verified world points and a positioning-calibration identity. Otherwise the tracker remains in the camera's pixel frame. Surface RTK coordinates cannot be silently assigned to organisms or the vehicle.

10. Surface communications and position identity

The main enclosure Fathom-X endpoint carries Ethernet over the selected twisted pair to the independently powered buoy endpoint. Inspect cable OD/glands, strain relief, bend path and snag response. Link status, latency, packet loss and timestamp integrity are acceptance measurements.

The selected buoy host is Raspberry Pi 4B, reading the RTK receiver over its verified USB interface. Its Ethernet connection, the Fathom-X endpoint and the Tycon injector LAN side use three distinct BR-100457 switch ports. The selected injector converts the independent battery bus to 24 V passive PoE for the Loco5AC radio only; never connect its powered output to the Pi, switch or Fathom-X. The radio requires 22-27 V DC and the selected injector/polarity must match that range under load. A UART GNSS port cannot be connected directly to Ethernet by naming the link in a drawing. The surface electrical budget must include that host, switch, RTK receiver, Fathom-X, radio and regulator losses.

Each position record identifies its subject: surface antenna phase center, float/body reference, vehicle body origin or camera optical center. It carries datum, time, quality and covariance/error representation. Underwater camera position requires independently measured tether offset/bearing, another navigation observation or an accepted fusion model with uncertainty. Tether length plus vehicle heading is insufficient to identify tether bearing.

Network addressing and GNSS message identity

Use a reviewed private subnet and record the actual static addresses. For an isolated commissioning fixture, an example plan is 192.168.42.0/24: buoy host .2, onboard Jetson .3, buoy radio .4, shore radio .5 and service computer .10. Confirm that no site network or vendor-default address conflicts. The unmanaged switch and Fathom-X bridge do not acquire an application address merely because they transport the traffic. This is an example configuration, not a command that changes existing hardware.

Each GNSS record must include schema version, subject=`surface_gnss_antenna`, receiver/antenna identity, UTC measurement time, host monotonic receive time, datum, latitude/longitude, explicitly identified height reference, fix quality, correction age, uncertainty representation and transport/source identity. Mark invalid or stale data and retain sequence/drop counters. NTRIP correction source, receiver input mode, RTCM compatibility and output message rate are reviewed receiver settings. The Pi service must not emit camera/vehicle position or claim calibrated underwater covariance from a float-only observation. Credentials remain outside exported logs.

The surface GGA-to-JSONL/UDP bridge is implemented and covered by offline replay and serial-fragment tests. Receiver settings, OS/storage image and end-to-end timestamps still require integration and acceptance evidence; this package does not implement or claim an accepted NTRIP correction service.

11. Required interface evidence

ID	Interface test	Acceptance evidence	Current physical status
IC01	Configuration and frame identity	Matching configuration/CAD/software hashes and reviewed frame transformations	PENDING
IC02	Board and removable-harness fit	Measured/swept as-built clearances with actual connectors	PENDING
IC03	Power paths and disconnect	Reviewed schematic, calibrated current/voltage traces and independent fault tests	PENDING
IC04	Physical channel map	One-channel and combined-axis witnessed motor tests	PENDING
IC05	Watchdog and reset ownership	Actual output loss on stale link/fault and deliberate restart sequence	PENDING
IC06	Pressure penetrations	Cable/gland identity, plug count, installation and qualification logs	PENDING
IC07	Camera and scale	Immersed focus/distortion, baseline and common-plane validation	PENDING
IC08	Trained inference	Pinned artifact, held-out dataset and target-hardware evaluation	PENDING
IC09	Float/vehicle position identity	End-to-end timestamp/quality tests and independent offset/navigation evidence	PENDING
IC10	Site handover	Accepted controlled-water results, operator authority and operating limits	PENDING

Procurement and component schedule

57 line items. All costs require supplier quotations. Quantities are configuration-specific and include integration equipment; item notes identify interfaces that still require selection or approval.

ID / qty	Assembly / component	Part identity / review status
B01 / 6	Propulsion T200 thruster with manufacturer cable	Blue Robotics T200 / BR-100545 or BR-100228 per rotation MANUFACTURER CAD
B02 / 6	Propulsion Basic ESC bidirectional	Blue Robotics BESC30-R3 MANUFACTURER CAD
B03 / 6	Propulsion Manufacturer T200 mounting bracket	Blue Robotics T100-P-BRACKET-R1 MANUFACTURER CAD
B04 / 1	Electronics enclosure 6-inch locking aluminum tube 500 mm	Blue Robotics BR-106281-500 MANUFACTURER CAD
B05 / 2	Electronics enclosure 6-inch RAILS sealing flange with supplied seals and locking cord	Blue Robotics BR-102201 MANUFACTURER CAD
B06 / 1	Electronics enclosure 6-inch rear endcap 16 M14 and 13 M10 ports	Blue Robotics BR-102205-003 MANUFACTURER CAD
B07 / 1	Electronics enclosure 6-inch front endcap 5 M14 and 5 M10 ports	Blue Robotics BR-102205-002 MANUFACTURER CAD
B08 / 1	Battery enclosure 4-inch locking aluminum tube 300 mm	Blue Robotics BR-106279-300 MANUFACTURER CAD
B09 / 2	Battery enclosure 4-inch RAILS sealing flange with supplied seals and locking cord	Blue Robotics BR-100665 MANUFACTURER CAD
B10 / 1	Battery enclosure 4-inch endcap five M10 ports	Blue Robotics BR-102993-005 MANUFACTURER CAD
B11 / 1	Battery enclosure 4-inch blank aluminum endcap	Blue Robotics BR-102993-999 MANUFACTURER CAD
B12 / 1	Energy Factory cylindrical lithium-ion battery 4S6P 18 Ah	Blue Robotics BR-100842 MANUFACTURER CAD
B13 / 1	Energy Battery power cable pair with factory penetrators and XT90 adapter	Blue Robotics BR-100259 MANUFACTURER DRAWING
B14 / 1	Optical enclosure 3-inch locking aluminum tube 150 mm	Blue Robotics BR-106278-150 MANUFACTURER CAD
B15 / 2	Optical enclosure 3-inch RAILS flange with seals and locking cord	Blue Robotics BR-100647 MANUFACTURER CAD
B16 / 1	Optical enclosure 3-inch seven-M10 aluminum upper endcap	Blue Robotics BR-100949-007 MANUFACTURER CAD
B17 / 1	Optical enclosure 3-inch clear acrylic lower endcap	Blue Robotics BR-100949-998 MANUFACTURER CAD
B18 / 1	Optical metrology IMX477 camera board	Arducam B0240 family; confirm lens-compatible revision MANUFACTURER DIMENSIONS
B19 / 1	Optical metrology CSI-to-USB2 UVC adapter	Arducam B0278 MANUFACTURER DIMENSIONS
B20 / 1	Optical metrology 6 mm CS-mount lens compatible with IMX477	Arducam or qualified lens vendor specific lens to confirm with B0240 ENVELOPE REQUIRES CONFIRMATION
B21 / 1	Optical metrology Subsea Laser Scale 26-10 dual-green-laser assembly	Underwater International UWI-SLS-26-10 with optional 3 V DC interface SUPPLIER ENVELOPE MOUNT PATTERN HOLD
B22 / 2	Illumination Lumen subsea light	Blue Robotics Lumen current production revision MANUFACTURER CAD
B23 / 1	Compute Jetson Orin Nano Super developer kit with cooling	NVIDIA official developer kit; revision recorded on receipt MANUFACTURER DIMENSIONS

ID / qty	Assembly / component	Part identity / review status
B24 / 1	Compute NVMe SSD 512 GB with compatible mounting hardware	qualified vendor M.2 size verified for selected carrier VENDOR DRAWING REQUIRED
B25 / 1	Control Pixhawk 6C aluminum-case controller	Holybro Pixhawk 6C MANUFACTURER DIMENSIONS
B26 / 1	Control 5.2 V Pixhawk power module on low-current branch	Holybro PM02 V3 or PM07 by harness configuration MANUFACTURER DIMENSIONS
B27 / 1	Control Bar02 10 m pressure/depth sensor	Blue Robotics Bar02 current revision MANUFACTURER CAD
B28 / 2	Safety Leak sensing elements in electronics and battery enclosures	Blue Robotics or qualified supplier sensor revision and circuit per integration drawing MANUFACTURER DRAWING
B29 / 1	Safety Hardware current monitor, latching cutoff, normally-open disconnect and suppression assembly	qualified electrical integrator PROTECTION-ASSY-REV-A to be detailed and approved ENGINEERING RELEASE HOLD
B30 / 1	Safety DC fuse and holder adjacent to battery positive	qualified protective-device vendor rating/time-current curve pending coordination SELECTION REQUIRED
B31 / 1	Power distribution Covered distribution terminals, six ESC branch fuses, regulator branch fuses and lugs	qualified electrical integrator PDB-HARNESS-REV-A ENGINEERING RELEASE HOLD
B32 / 1	Power distribution Filtered regulated Jetson supply stage	qualified DC-DC vendor 12 V >=5 A output; input includes 12-16.8 V and transient margin SELECTION REQUIRED
B33 / 1	Power distribution 5 V sensor/camera regulated supply	Pololu or qualified DC-DC vendor D24V90F5 candidate; verify load/ripple/thermal MANUFACTURER DIMENSIONS
B34 / 2	Communications Fathom-X Ethernet-over-twisted-pair boards	Blue Robotics Fathom-X MANUFACTURER CAD
B35 / 1	Communications Neutrally buoyant tether and strain-relief assembly	Blue Robotics or qualified subsea supplier 5 m service length selected; actual wet cable OD matched to gland VENDOR DRAWING REQUIRED
B36 / 1	Surface relay ZED-F9P RTK rover, antenna and approved base/NTRIP corrections	Holybro / u-blox H-RTK rover exact revision quote required VENDOR DRAWING REQUIRED
B37 / 1	Surface relay Shore/buoy radio bridge pair with approved PoE supplies	Ubiquiti or qualified radio vendor NanoStation loco5ac candidate; local radio approval required VENDOR DRAWING REQUIRED
B38 / 1	Surface relay Surface buoy protected harness, mounting hardware and deck service assembly	qualified integrator BUOY-POWER-REV-A ENGINEERING RELEASE HOLD
B39 / 3	Pressure service Pressure relief/vacuum service assemblies	Blue Robotics current manufacturer-compatible PRV with adapters and caps MANUFACTURER DRAWING
B40 / 11	Pressure interfaces M10 face-sealed unused-port plugs	Blue Robotics current plug matched to actual endcap hole type MANUFACTURER DRAWING
B41 / 21	Pressure interfaces M14 face-sealed unused-port plugs	Blue Robotics current plug matched to actual endcap hole type MANUFACTURER DRAWING
B42 / 11	Pressure interfaces Matched wet cable penetrator assemblies beyond factory power cables	Blue Robotics actual cable OD and WetLink model recorded in harness CABLE DEPENDENT SELECTION
B43 / 1	Structure Custom HDPE frame plates, rails, guarded mounts and skids	local CNC shop project drawings and part IDs in CAD manifest PROJECT PARAMETRIC CAD
B44 / 2	Structure 6-inch enclosure clamps	Blue Robotics BR-102710-006 MANUFACTURER CAD
B45 / 2	Structure 4-inch enclosure clamps	Blue Robotics BR-102710-004 MANUFACTURER CAD
B46 / 2	Structure 3-inch optical-pod clamps and mounting bracket	Blue Robotics / project CNC shop BR-102710-003 plus reviewed project interface MANUFACTURER AND PROJECT CAD

ID / qty	Assembly / component	Part identity / review status
B47 / 1	Buoyancy Qualified closed-cell subsea buoyancy foam and trim ballast	General Plastics / qualified supplier R-3312 or approved shallow-water material; final volume from measured mass MEASURED TRIM REQUIRED
B48 / 1	Assembly 316 fasteners, insulating washers, clamps, terminal covers, tie mounts and retention straps	qualified hardware vendor sizes/quantities per released fastener and cable schedule DRAWING DEPENDENT
B49 / 1	Test equipment Compatible balance charger, current-limited bench supply, current probe, insulation meter and vacuum pump	qualified suppliers equipment IDs/certification in test log TEST SETUP REQUIRED
B50 / 1	Optical power Fused regulated 3.0 V laser supply with normally-off hardware enable	qualified DC-DC integrator exact module and setpoint selected with UWI 3V option SUPPLIER INTERFACE CONFIRMATION HOLD
B51 / 1	Surface relay GNSS/NTRIP network bridge computer	Raspberry Pi Raspberry Pi 4 Model B; 2 GB or 4 GB with recorded revision MANUFACTURER BOARD DIMENSIONS
B52 / 1	Surface relay Five-port Ethernet switch	Blue Robotics BR-100457 current revision MANUFACTURER CAD
B53 / 1	Surface relay DC-to-24 V passive PoE converter/injector	Tycon Power TP-DCDC-1224G; confirm current revision MANUFACTURER DRAWING
B54 / 1	Surface relay Matched 5 V DC regulator and USB-C Pi supply harness	Pololu or approved equivalent D24V90F5 candidate plus correctly wired USB-C power cable MANUFACTURER DIMENSIONS
B55 / 1	Surface relay Five-liter manufacturer watertight box	Blue Robotics BR-102653 with supplied PRV and port plugs MANUFACTURER CAD
B56 / 1	Surface relay Independent factory buoy battery	Blue Robotics BR-100842 second pack; separate from vehicle MANUFACTURER CAD
B57 / 1	Surface relay Industrial microSD boot/logging storage and retention	qualified storage vendor 32 GB minimum; record model and endurance VENDOR DRAWING REQUIRED

Harness route index

50 logical routes; the CSV contains the complete signal, supply and verification notes. Pin numbers must come from the selected component drawings.

Route	From / to	Signal / boundary
H01	B12 battery XT90S TO: B30 adjacent fuse / B29 cutoff	BAT+ inside battery enclosure
H02	B30/B29 battery-side protected output TO: B31 main distribution BAT+	BAT+ Battery M10-1 to main rear M10-12
H03	B12 battery negative TO: B31 main distribution BAT-	BAT- Battery M10-2 to main rear M10-13
H04	B31 fused propulsion branch 1 TO: ESC1 power input	ESC raw DC inside main enclosure
H05	B31 fused propulsion branch 2 TO: ESC2 power input	ESC raw DC inside main enclosure
H06	B31 fused propulsion branch 3 TO: ESC3 power input	ESC raw DC inside main enclosure
H07	B31 fused propulsion branch 4 TO: ESC4 power input	ESC raw DC inside main enclosure
H08	B31 fused propulsion branch 5 TO: ESC5 power input	ESC raw DC inside main enclosure
H09	B31 fused propulsion branch 6 TO: ESC6 power input	ESC raw DC inside main enclosure
H10	Pixhawk MAIN/AUX output assigned by verified frame mapping TO: ESC1 signal and ground	PWM + signal return inside main enclosure
H11	Pixhawk MAIN/AUX output assigned by verified frame mapping TO: ESC2 signal and ground	PWM + signal return inside main enclosure
H12	Pixhawk MAIN/AUX output assigned by verified frame mapping TO: ESC3 signal and ground	PWM + signal return inside main enclosure
H13	Pixhawk MAIN/AUX output assigned by verified frame mapping TO: ESC4 signal and ground	PWM + signal return inside main enclosure
H14	Pixhawk MAIN/AUX output assigned by verified frame mapping TO: ESC5 signal and ground	PWM + signal return inside main enclosure
H15	Pixhawk MAIN/AUX output assigned by verified frame mapping TO: ESC6 signal and ground	PWM + signal return inside main enclosure
H16	ESC1 three-phase output TO: T1 motor cable	U V W phases Main rear M10-1
H17	ESC2 three-phase output TO: T2 motor cable	U V W phases Main rear M10-2
H18	ESC3 three-phase output TO: T3 motor cable	U V W phases Main rear M10-3
H19	ESC4 three-phase output TO: T4 motor cable	U V W phases Main rear M10-4
H20	ESC5 three-phase output TO: T5 motor cable	U V W phases Main rear M10-5
H21	ESC6 three-phase output TO: T6 motor cable	U V W phases Main rear M10-6
H22	B31 fused house branch TO: B32 Jetson regulator	Filtered DC input Inside main enclosure
H23	B32 regulated output TO: B23 Jetson carrier DC jack	DC+ GND Inside main enclosure
H24	B31 low-current fused branch TO: B26 Pixhawk power module	DC+ GND Inside main enclosure
H25	B26 power module TO: B25 Pixhawk POWER1	Regulated 5.2 V, current/voltage sense and GND Inside main enclosure
H26	B23 Jetson USB host TO: B19 UVC adapter in optical pod	VBUS D- D+ GND and shield Main rear M10-9 to optical upper M10-1
H27	B19 UVC adapter TO: B18 IMX477 camera	MIPI CSI No pressure penetration

Route	From / to	Signal / boundary
H28	B31 fused branch via B50 regulated, normally-off output TO: B21 UWI-SLS-26-10 optional 3 V interface	3 V+ GND; control only if ordered Main front M10-1; supplier assembly gland
H30	B31 fused illumination branch 1 TO: B22 Lumen 1	DC+ GND PWM Main rear M10-7
H31	B31 fused illumination branch 2 TO: B22 Lumen 2	DC+ GND PWM Main rear M10-8
H32	B25 external I2C TO: B27 Bar02	VCC GND SCL SDA Main rear M10-11 integrated sensor bulkhead
H33	B28 electronics leak circuit TO: B29 hardware inhibit and Pixhawk fault input	Leak fault and reference Local sensor internal; cross-enclosure inhibit defined in H51
H34	B28 battery leak circuit TO: B29 battery-side disconnect	Leak fault and reference Internal battery enclosure
H35	B23 Jetson Ethernet TO: B34 onboard Fathom-X	Ethernet Internal main enclosure
H36	B34 onboard Fathom-X TO: B34 surface Fathom-X	HomePlug AV pair Main rear M10-10 to buoy box cable gland
H37	B23 Jetson companion TO: B25 Pixhawk telemetry port	Telemetry / control and signal return Internal main enclosure
H38	B36 GNSS via B51 USB host and bridge process TO: B23 logged surface-position input	NMEA/UBX/RTCM or approved serialized network records Existing tether path; no extra penetration
H39	External magnetic/manual kill device TO: B29 hard-disconnect enable	Energize-to-enable interlock Selected sealed kill interface; physical routing hold
H40	B56 separate buoy battery via B38 fuse/disconnect TO: B53 PoE converter input	DC+ GND Inside B55 box
H41	B52 switch port 3 TO: B53 LAN / data input	Ethernet data only Inside B55 box
H42	B53 powered PoE output TO: B37 buoy radio	Ethernet + 24 V passive PoE B55 matched gland to mast radio
H43	B56 buoy battery via B38 fused house branch TO: B54 Pi 5 V regulator	DC+ GND Inside B55 box
H44	B54 regulated 5 V output TO: B51 Pi 4B USB-C power	5 V VBUS/GND Inside B55 box
H45	B51 Pi 4B USB host TO: B36 RTK receiver USB	USB power + NMEA/UBX/RTCM data Inside B55 or approved receiver-cable gland
H46	B51 Pi 4B Ethernet TO: B52 switch port 2	Ethernet Inside B55 box
H47	B34 surface Fathom-X TO: B52 switch port 1	Ethernet Inside B55 box
H48	B56 protected buoy house branch TO: B52 wide-input power	DC+ GND Inside B55 box
H49	B56 protected buoy house branch TO: B34 surface Fathom-X power	DC+ GND Inside B55 box
H50	B29 independent current-monitor measurement TO: B25 acquisition or reviewed B23 adapter	Measured pack current and monitor health Internal main/battery boundary depends on selected sensor placement
H51	Electronics fault/kill supervisor TO: B29 battery-side latching disconnect	Isolated energize-to-enable hard-inhibit loop No port assignment released; reserve/reallocate actual spare ports and recount glands/plugs

Acceptance record - blank master

Complete and retain one copy per procedure execution. These fields are intentionally unfilled. A PDF check mark or source-file edit cannot substitute for raw evidence and named acceptance.

Field	Recorded value
Build serial / date / operator	
Reviewer / procedure / revision	
Configuration / firmware / CAD hashes	
Test objective and acceptance limits	
Instrument IDs / calibration dates	
Setup / fixture / ambient / water condition	
Measurements / uncertainty / raw file hash	
Anomalies and corrective action	
Retest identity	
Result / acceptance signature	PENDING - no physical result recorded

Source register and regeneration

The companion CSV and Markdown sources remain editable; regenerate after configuration, part identity or accepted interface changes. Manufacturer instructions and drawings take precedence over shortened descriptions in this guide.

Source	Purpose
prototype/config/prototype.json	Canonical geometry, operating limits and release status
prototype/bom/components.csv	Complete component identities, quantities and procurement holds
prototype/bom/harness.csv	Logical routes and required interface verification
prototype/docs/Hardware_Design_Review.md	Manufacturer facts and remaining hardware design decisions
prototype/software/README.md	Runnable software commands and physical integration boundary
prototype/software/verification.json	Captured offline test and replay results

Primary manufacturer references

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Regenerate with the project CAD Python environment:

```
python prototype/docs/build_guide.py
```