



Triton Robotics 2026 MATE ROV Technical Documentation

Company: Triton Robotics, Ranger Team #0353A
Organization: Triton Robotics (Community Team), Seattle, Washington, USA



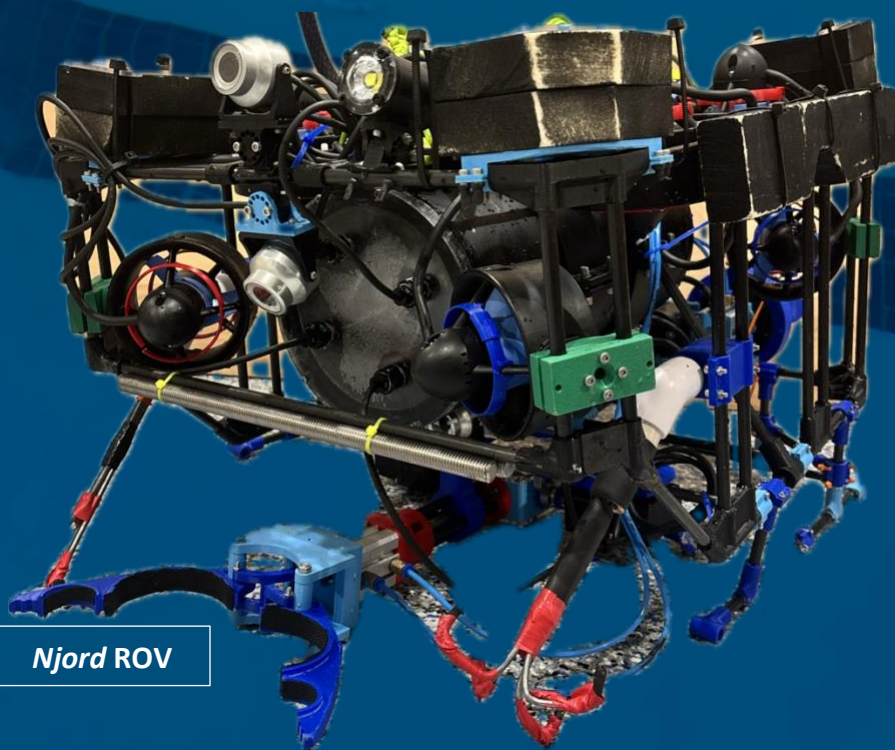
Team Triton 2026

2026 Team — all 11th grade:

Listed from left to right in photo:

- Griffin Fisher — Chief Mission Specialist and Pilot
- Tenzin Larkin — Co-Founder / CEO, Chief Engineer
- Miles Lipson — Chief Safety Officer, Lead Pilot
- Thomas Gust — Co-Founder / CEO, Software Lead
- Emi Enoki — Chief Marketing Officer, Electrical
- Simon Hajduk — Chief Float Engineer, Software
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Njord ROV



Skadi Float

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Abstract

Triton Robotics is a fully independent community team from Seattle, Washington, competing in its fourth MATE season and third RANGER season. For the 2026 competition season, Triton presents **Njord**, an eight-thruster remotely operated vehicle, and **Skadi**, a precision buoyancy float, that are designed for reliable performance in harsh-environment mission scenarios, including under-ice operation, low-light visibility, denser EGADS water, and flume-tank current.

Njord was rebuilt from the ground up around three design priorities: **cross-mission utility and marketability, serviceability and reliability, and growing our capabilities as a company**. Its carbon-fiber rod frame, adjustable ballast and buoyancy system, six-degree-of-freedom propulsion, four-camera vision system, and swappable front and rear manipulators allow the vehicle to complete both precision manipulation and survey-oriented tasks with minimal poolside reconfiguration. The vehicle's modular architecture supports rapid repair, tool changes, and re-trimming during testing and product demonstrations.

A major focus of this year's development was **TritonSuite**, a custom Python control stack. TritonSuite replaces the off-the-shelf control software used in previous seasons and enables onboard 50Hz control, depth and attitude hold, reverse-drive operation, four-stream video, live telemetry, and pool-deck software updates. Together, Njord's mechanical, electrical, and software systems were designed to improve operator control, reduce downtime, and increase mission-task consistency.

1. Company Overview + Mission Statement

Triton Robotics is committed to designing adaptable equipment that is robust and mission ready. We are a fully independent community team based in Seattle, Washington, USA. This is our fourth year competing in MATE and our third in RANGER class. All seven members are 11th-grade students; six are returning from the 2025 program and one, Emi Enoki, joined this year as Chief

Marketing Officer and as part of the electrical team. The roster and roles, along with our mentors, are on the title page.

Mission Statement: Helping the environment through engineering. We iterate and learn to build adaptable, serviceable, and reliable systems while growing our capabilities as engineers.

Independence: Last year we became an independent team due to rules changes prohibiting robotic and athletic team participation at our school. That was challenging but fostered our sense of independence and growth. This year we made a deliberate choice to operate as independently as possible to grow our project-management and team-leadership skills. Every decision about priorities, scope, budget, and schedule was made by the team members themselves, with our mentors giving us the space to try, fail, and learn. This led us into complex choices. We knew a ground-up rebuild of both vehicles including software, while navigating our junior year, in a fully self-managed structure, would test us. It did. Project management proved to be our biggest non-technical challenge, but it forced us to adopt better documentation and more resilient organizational structures.

Cross-training: Due to our seven schedules rarely aligning, we built in redundancy on purpose: when someone learns something, they teach it. Examples include Tenzin teaching Miles CAD so he could contribute to mechanical design; Thomas and Simon writing Skadi's onboard software together so they both fully understand it; Theo and Griffin welcoming Emi into the fabrications and electrical work. When a team member is away for a game or preparing for an exam, their workload needs to be transferable to others. This works because communication and tools utilized by the team: including GitHub, for code and version control, shared Google Docs and Google Calendar for planning, a group text for daily coordination, keeps momentum from depending on any single person. That redundancy is how we finished the rebuild on time for the regional competition and are able to bring it to the MATE World Championships.

2. Mission Discussion

The 2026 MATE ROV Competition is built around the United Nations Decade of Ocean Science for Sustainable Development (2021–2030) and the Decade of Action for Cryospheric Sciences (2025–2034). The four 2026 mission tasks each translate a real-world ocean problem into a Request for Proposals. We designed Njord and Skadi to serve those four missions:

- **Task 1 — Seabed 2030: A Kaleidoscope of Corals in Cold Water.** Inspired by the Marine Institute of Memorial University’s discovery of a densely populated soft coral garden at the Funk Island Deep marine refuge off Newfoundland. The pressing need is mapping and protecting cold-water coral ecosystems on continental slopes and seamounts worldwide.
- **Task 2 — SmartAtlantic Alliance: Better Information, Better Decisions.** The SmartAtlantic Alliance, run by the Marine Institute and COVE in Halifax, supports operational efficiency and safety in the marine environment through real-time data from ocean buoys and the Holyrood Subsea Observatory in Conception Bay. The need is deploying and maintaining the instrumentation that feeds storm forecasting, shipping decisions, invasive species tracking, and iceberg monitoring for offshore industry.
- **Task 3 — Wind-Powered Offshore Oil Platform: Scalable Solutions for Global Energy Needs.** Modeled on real installations like Hywind Tampen, the world’s first floating wind farm

built to supply power to offshore oil platforms. The real-world need is integrating renewable generation with existing offshore infrastructure to diversify energy portfolios, improve energy security, and reduce the environmental footprint of offshore operations.

- **Task 4 — MATE Floats Under the Ice.** Inspired by the NSF-funded GO-BGC project, which is deploying 500 profiling floats with chemical and biological sensors to monitor circulation, chemistry, and ocean health globally. The real-world need is extending profiling-float coverage into ice-covered waters — a long-standing gap in the Global Ocean Observing System — where conventional surface-communicating floats cannot operate.

3. Development Schedule + Project Management

We organized the 2026 build around four phases (Table 1): previous year analysis, general systems development, system-specific development, and testing. Across the season, the team logged approximately 2,120 student-hours.

Resources, procedures, and protocols: project management runs on a small set of tools chosen to be easy to access and use across seven student schedules. We use **GitHub** for both TritonOS and TritonPilot and project boards for non-code tasks. **Google Docs** holds design documents, mission notes, the safety checklists, and the JSEAs. **Google Calendar** manages the meeting and pool-test schedule. **Group texts** are used for daily coordination and last-minute updates. Finance and

Table 1. Four-phase 2026 development schedule.

	Phase 1 (Aug–Sep)	Phase 2 (Oct–Dec)	Phase 3 (Jan–Mar)	Phase 4 (Mar–Apr)
Focus	Brainstorming + 2025 after-action review	Develop core systems	MATE RFP + mission-specific designs	Full system testing
Meetings	1–2× / week	2–3× / week	3–5× / week	5–7× / week
Pool tests	—	A few	~1 / week	2–5 / week

accountability are managed through the **quarterly Investment Committee** led by Jackie Borges, where we present budgets, defend assumptions, and answer challenges before funds are released to the Triton bank account.

4. Engineering Design Rationale

4.1 Design goals

Njord, the ROV, was rebuilt around three design priorities.

1. **Cross-mission utility and marketability:** the vehicle is re-configurable across the 2026 mission task categories and designed for the kinds of harsh-environment work researchers and offshore operators perform: modular tooling, field-updatable software, and a pilot-friendly interface so a novice can operate Njord within minutes.
2. **Serviceability and reliability:** every subsystem is repairable poolside, and every fastener uses a tools that are standard on the pool deck; components are chosen to survive the season without single-use failures, accepting some cost in ROV mass to avoid losing operational time when things go wrong.
3. **Growing our capabilities as a company:** we expanded what we could do as a team, building software, manipulators, frame, custom PCBs; where commercial parts were proven and reliable, we purchased. This principle drove every build-vs-buy decision (§14).

Skadi, the float, has two primary design goals:

1. **Precision:** Skadi must be able to follow any depth profile precisely, to a tight tolerance.
2. **Ease of use:** Skadi must be deployable by one person and run autonomously without an operator in the loop, as the mission scenario has the ROV crew occupied elsewhere.

4.2 The 2026 MATE RFP

The 2026 RFP pushed Njord towards becoming a reliable survey-and-manipulation platform for harsh operating conditions. For the ROV, the most important constraints are current, waves, low-light

visibility, video-based scoring, and fast recovery from problems during the product demonstration. MATE specifies that the ROV will operate in the wave and flume tanks at the World Championship, while the float will operate in the ice tank (*Ref: 1*).

- **Current and waves:** the flume tank current and wave-tank conditions drove the eight-thruster layout, 30° horizontal thruster angle, depth and attitude hold, and adjustable vertical thruster rails. These choices prioritize controlled station keeping and predictable movement near mission props over maximum agility in one direction. MATE also notes that venues may include unexpected currents from pool systems.
- **Low-light and video-dependent tasks:** the manual says pools will not be intentionally darkened, but low-light conditions may still occur from task setup, surface ice, or waves. This drove four low-light HD cameras, dedicated lighting, and camera placements for forward driving, rear operation, and close manipulator work.
- **Fast task changes and recovery:** each product demonstration includes 5 minutes for setup, 15 minutes for tasks, and 5 minutes for demobilization. As the clock does not stop for payload changes, buoyancy adjustments, or troubleshooting, we treated serviceability as an operating constraint. Njord's swappable tooling, accessible frame, adjustable trim, and poolside software workflow are designed to reduce downtime.
- **Ice tank and EGADS:** EGADS-specific design choices are addressed in Skadi's float §13.

4.3 Design Evolution

The 2026 mission environment pushed three subsystems further than the rest.

1. We specifically designed our new **camera system** to provide situational awareness, the potential for stereo vision position-keeping assist, as well as low light capabilities. To ensure performance, we focused on improved compression, faster tether throughput, and enhanced processing to enable multiple active

camera streams. This also required a larger enclosure, which could fit both additional boards, as well as higher thermal dissipation from the enhanced compute load.

2. Our **grippers and arm system** were built from scratch to support the mission task list (coral sampling, sub-observatory connection, eDNA placement, panel rotation). This required fine manipulations including angular positioning—resulting in a multi-axis arm, and multi-revolution rotation—resulting in our rear gripper.
3. We created an all-new **suite of software** this year including an original **flight control system**. We recognized that we needed both enhanced control capabilities as well as video streaming and processing capabilities that were not available otherwise. Our new **software** allows new modes of ROV operation including advanced depth holds and directional holds that allow for controlled movement in waves and current. Ambidextrous mode allows full use of both the front and back of the ROV. Mission-specific analysis applets (crab CV, eDNA tabulation, iceberg photogrammetry) provide fast data processing. While these were the largest customizations we made, everything, including our thrust and frame geometries, our tether, and our surface control boxes, are new this year.

5. Innovation + Problem Solving + Systems Approach

5.1 Innovation

The 2026 program has three major innovations that improved capability while lowering long-term cost and risk.

TritonSuite (custom software stack): at our 2025 after-action review, we identified our software controls as the highest leverage opportunity. Using BlueOS and ArduSub at previous competitions had left the ROV vulnerable to control system dropouts and unreliable multi-camera streaming. We also wanted to be able to customize flight modes and create intuitive advanced arm controls. Building

TritonOS (our ROV system) and **TritonPilot** (our topside system) unlocked features that off-the-shelf software could not support, including ambidextrous drive, advanced depth and directional holds, mixed hold and drive modes to help adjust for currents and waves, and advanced multi-camera awareness and automated control systems. In addition, our new custom **TritonFloat** software allows for better float-surface communications as well as precise depth profiles. **TritonAnalysis** provides custom mission-specific analysis applets (see §9 for full discussion and architecture).

Differential gearbox arm: a long manipulator with a heavy servo at the tip imposes a weight-balance problem for the vehicle. Our design places servos at the arm base, driving an aluminum 1:1 differential gearbox at the wrist through multiple 8mm GoBilda hex shafts. The result is a full vertical-plus-rotation 2-Degrees of Freedom (DOF) reach with moving mass concentrated near the frame, removing the need for tip-counterweight or extra buoyancy compensation that a servo-at-the-tip design would have required. Machined aluminum was chosen after ABS prototypes flexed under load (see §16).

Float cascaded buoyancy controller with internal pressure sensing: instead of assuming an open-loop pump model, Skadi uses an internal pressure sensor (BMP388) inside the hull, alongside the external pressure sensor (Blue Robotics BAR02) to estimate the syringe's dV/V state from the two readings using a cascaded controller (see §13).

5.2 Problem solving

Brainstorming sessions in Phase 1 drew on our 2025 after-action review and the 2026 RFP to generate candidate features and subsystems. We prioritized each candidate by plotting it on paper with two axes: **potential impact** (improvement to performance or reliability) and **difficulty** (team energy commitment) with **chance of success** drawn as a differential circle around the point (a larger circle for higher confidence; smaller circle for higher risk). Each candidate was then checked against the question of whether viable alternatives were already available before committing. High-impact, manageable-difficulty, and high-confidence

candidates with no readily available commercial alternative became build candidates; **TritonSuite**, the multi-axis arm, and the cascaded float controller all cleared this bar. Reused components (thrusters, ESCs, Navigator board) cleared a different bar: low difficulty, high reliability, and no significant value in re-engineering.

Measured data anchored every evaluation. Three trade studies anchor this year's decisions: the carbon fiber rod test (§5), the tether wire comparison (§9), and the buoyancy engine matrix (§13). Two physical prototyping tracks ran in parallel: **scale prototypes** for the frame and multi-axis arm (1:2 mock-ups built with available stock to test integration before machining), and **bench prototypes** for all three buoyancy engine candidates (solenoid valve, servo-actuated syringe, and peristaltic-plus-syringe) before committing to a single design for Skadi.

5.3 Systems approach

Integration was a consideration from the start, not something to clean up at the end. The tightest vehicle constraint this year was power: eight thrusters, 3 arm motors/servos, four cameras, the LX200 Ethernet board, and the Pi all live downstream of one 25A tether fuse. That constraint propagated outward to the tether wire choice (§9), the low-power LX200 chipset (§7), and choosing pneumatic over servo grippers (no electrical draw while holding load). The mission-task × tool mapping (§12) shows the result: every 2026 RFP task can be completed with two or fewer existing tools.

6. Vehicle Structure

6.1 Materials Selection

Carbon fiber rod selection: we tested nine rod configurations across three manufacturers, three cross-sections (hollow circular, solid square, solid circular), and four sizes (one square at 6mm; circular at 6mm, 8mm, and 10mm). Loading went up to 176N using adjustable dumbbell weights: blunt impact via 5cm weight drops at the center of a 0.35m span, and sharp impact via a chisel and hammer. The 6mm square failed under blunt

impact at 107N; the 6mm circular at 137N. The 8mm circular survived 176N with roughly 0.5cm deflection and only minor damage; the 10mm circular survived 176N with under 0.1mm deflection. We chose **8mm circular**: it passed every test with 64% of the original volume and 80% of the cross-sectional area of 10mm, balancing a marginal increase in deflection in exchange for substantial drag reduction.

Other materials: we use ABS for printed parts in regular water contact because it is water-resistant and compatible with solvent welding for repairs. PLA is used only for internal, non-structural components this year. We use stainless steel for every bolt, nut, and washer: M2 where space is constrained (slew-bearing assembly), M3 for general mounting, M4 for heavy-duty mounting, and M6 for the gripper-head swap interface. We used aluminum machining for the multi-axis arm's differential gearbox after the ABS prototype flexed (§16), and for one face of the main electronics enclosure end plate (§7).

6.2 Frame

Njord's frame (see Figure 1, next page) is built with carbon fiber rods connected by 3D-printed ABS joints, with stainless steel hardware throughout. Vehicle dimensions are **0.76m (L) × 0.48m (W) × 0.41m (H)**, mass **16.8 kg**, weight **165N**. This year we moved up to **8 thrusters and a 6-inch Blue Robotics aluminum enclosure**. At 16.8kg, Njord lands in the 15.01–20 kg weight bracket (+5 points) rather than the under-15 kg bracket (+10 points). We accepted this 5-point trade-off because the larger platform enabled three capabilities we judged to be worth the difference:

- **Pitch authority:** eight thrusters add controllable forward-back pitch on top of the three axes translation and roll and yaw a six-thruster layout provides. Pitch authority is critical, however, as it sets the nose in attitude of the vehicle to any task, which affects the visualization of the task, as well as how the manipulators can reach objects. Pitch allows us to orient the grippers along any approach angle to a mission target and hold station against

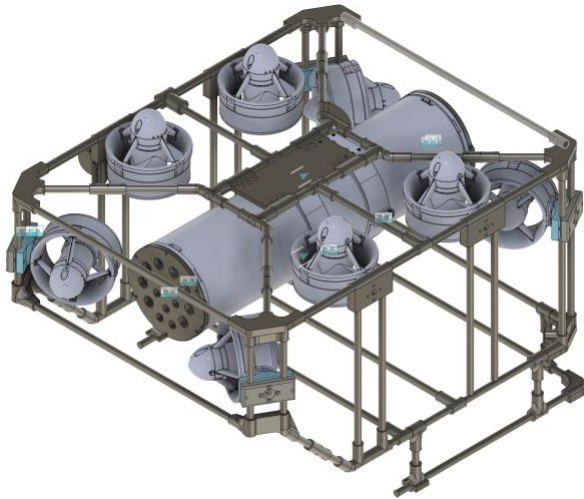


Figure 1: Njord frame design: 8 thrusters enable 6 DOF movement. Cutout in front allows multi-axis arm to get closer to objects and still move. Thrusters and ballast can be repositioned for rapid thrust – center of mass rebalancing. The external frame design provides protection to all interior components. Image by T. Larkin.

wave action and tether disturbance, creating a precise pose near coral or a sub-observatory panel.

- **Thermal headroom** for higher-bandwidth electronics: aluminum thermal conductivity and increased surface area (§7.3).
- **Interior volume** for the camera compression hardware: The 6-inch tube accommodates the DWE-USB7PCH camera hub (§7.3), alongside the Pi, Navigator, and LX200-V50 (components that would not have fit cleanly in a smaller container).

The frame architecture follows three guiding principles:

Impact resilience: the external frame contacts obstacles before they come into contact with any internal system. ABS corner pieces act as bumpers, sized to absorb impact; they are the frame's only known source of failure experienced in practice (see §16).

Serviceability: every rod can be removed from its joints and easily replaced. A full frame rebuild is possible poolside in under an hour. However,

across roughly 30 pool tests, we have not broken any rods.

Thruster placement: the eight T200 thrusters mount inside the frame envelope: four vertically and four horizontally, each one at 30° corner angles to the front (see §10). Each vertical thruster pair rides on adjustable up-and-down rails so we can rebalance the center of mass when we swap mission tooling.

7. Electrical System

7.1 Power

Njord runs from a **12VDC main supply at 25A** through the tether. The eight T200 thrusters are the dominant load: each is rated 17A, and together they constitute the bulk of the electrical budget.

TritonOS software caps PWM output to keep each motor to approximately 6A maximum, thereby keeping system current under the 25 A main fuse rating (we have not blown a fuse during testing). Our full load amps was measured to be **24.4A**, so our main ATO blade fuse was sized at **25A**. Note that this is partially based on how our software limits current draw. The logic and motor feeds are physically separate within the tether, but this split occurs after the main fuse. Motor and servo power flows through a dedicated 10AWG conductor and dedicated 24AWG conductors supply the logic bus. Logic power is stepped down to 5V at the ROV by **Blue Robotics 12 to 5VDC converters** feeding the Pi and Navigator.

We decided to split the tether power after transient and low voltage issues were found during high maneuvering. The issues caused brown outting of the Pi, causing disconnection, and what was determined to likely be transient motor voltage interference that also affected Pi functioning. We believe both have affected previous product demonstrations and that these changes will eliminate that issue. Splitting the buses fixed the loss of connection issues across testing during the 2026 season. The Njord electrical systems integration diagram (SID) is shown in Figure 2.

7.3 Electronics and Control System

Our flight control system is based on a **Raspberry Pi 4B** paired with the Navigator board. The Navigator communicates directly with the ESCs, servos, and sensors without requiring ArduSub, which lets us build TritonOS on the same hardware (\$9) that we relied upon in 2025. That freed us to focus our limited engineering time on software instead of building a custom flight controller this year.

The enclosure is a **Blue Robotics Series 150 mm (6inch) aluminum tube (BR-106281-300, Ref: 3)**: 6061-T6 anodized aluminum, 150mm ID, 163.9mm OD, 300mm length, 800m depth rating. This year, we upgraded from the 100mm (4inch) acrylic for two reasons: aluminum thermal conductivity (237 W/m·K) is roughly 1000× that of acrylic (0.2 W/m·K),

Ref: 7), and the 150mm diameter tube has roughly 60% more total surface area than 100mm diameter tube when end caps are considered. Combined, these solved the CPU overheating challenges we encountered late in 2025. The end plates are mixed-material: **aluminum** on the cable-pass side and **laser-cut layered acrylic** on the other, glued with acrylic adhesive. **WetLink penetrators** seal the smaller wires; **epoxied passthroughs** seal the power conductor and ethernet bundle.

7.4 Communications

We are using a **LX200-V50 ethernet compression module**, which uses a more advanced chipset with multi-line duplexing and gives us **5–7× higher measured bandwidth** than our previous module across our 1080p H.264 test load. This allows four

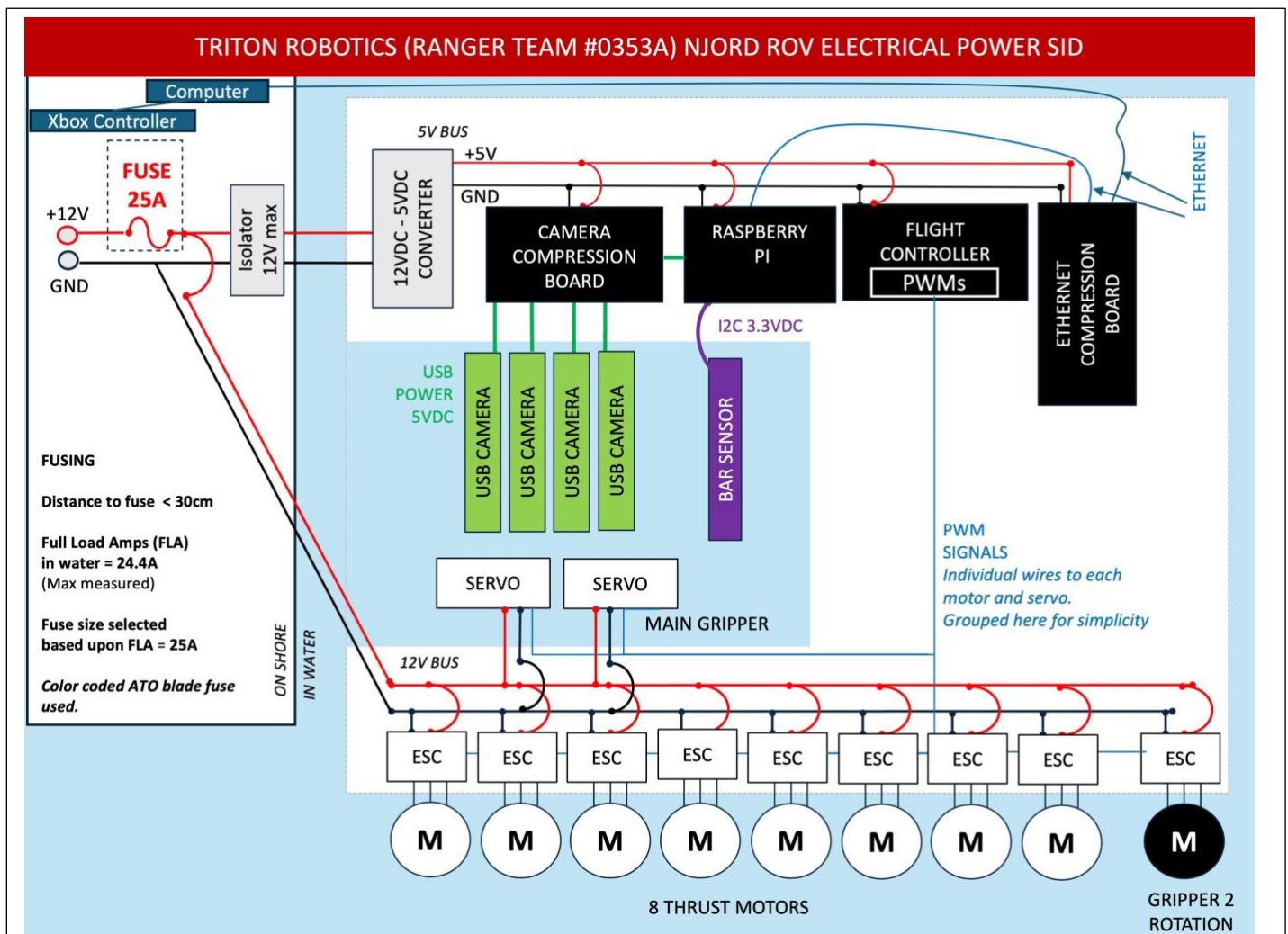


Figure 2: Njord ROV Electrical power system integration diagram (SID), showing full load amps test.

Image by T.Larkin

simultaneous 1080p H.264 streams to be run. The **DWE-USB7PCH 7-port camera hub** sits between the cameras and the Pi, providing hardware-accelerated H.264 encoding off-chip and resolving a multi-camera streaming failure documented in §16.

7.5 Tether

The tether is an **18m** VideoRay neutral tether for ethernet plus **Ancor 10AWG marine wire** for power. Our tether also carries the four **2.5mm ID / 4mm OD pneumatic lines** and the separate **24AWG logic wires** that solved the 2025 brownout challenges (§7). Strain relief occurs both in frame loop at the ROV, and a friction knot on a carabiner at the surface. Pool-lane buoys give near-neutral tether buoyancy.

Power conductor selection. We tested four configurations for mass, resistance, voltage drop at 25A, power delivery, and flexibility (full results in Table 2). We selected 10AWG as the balance point between limited power loss, weight, and good flexibility and cost. For 10AWG, the Ancor data sheet (*Ref: 4*) gives 0.98Ω per 305 m: 0.1176Ω over 18 m each direction, 2.94V drop at 25A on 14V, giving **~80% power delivery**, our design floor.

7.6 Tether Management Protocol

Theo Lipson (COO/CFO) is the dedicated tether person at every pool test with Griffin Fisher (CMS) acting as a backup. The protocol, adapted from industry standards (*Ref: 5*) is reviewed during pre-launch.

1. Pre-launch inspection: full 18m for nicks/kinks/crashes; strain reliefs at ROV frame loop and surface carabiner; pneumatic and power conductors unstressed at both terminations.
2. Verify Njord PRV tightness (double-check before launch).
3. Pay out one coil at a time as the ROV descends. No pulls, no excess slack, no tension.
4. During operations, the tether person is silent except for required callouts: tether paid out at 1, 2, 3, 5, and 10m; ROV surfaced; ROV at pool deck side.
5. Manage slack continuously. Watch for tether crossing the body or threading obstacles.
6. Retrieve hand-over-hand at the ROV's ascent pace. No yanking; no winching. Coil in figure-eight back to staging to prevent twist memory.

7.7 Workmanship

Every circuit is labeled at both ends. Connections are terminal-blocked or soldered with heat-shrink. There are no jumper pins in final wiring. The topside control box is **IP-30 sealed** with finger and tool protection for all internal connections (ELEC-022R). There are no sharps, untrimmed zip ties, nor glass faceplates on monitors. Strain relief is present at every penetration point on both ends of the tether: a loop attached to the frame at the ROV end and a friction knot on a carabiner at the topside end. Enclosures are transparent or openable per the 2026 inspection requirement.

Table 2. Tether power conductor trade study. Single 10AWG lines were selected. Flex (higher is better) was measured as inverse of the radius of a 180-degree turn in of a 1-meter wire attached to a 2.3N weight and held with a coat hanger. Cost is from our local supplier (West Marine). Colors indicate judgements.

Configuration	Mass / 18m	R (ohms) / 18m	V drop @ 25A	Delivered Power	Flex (inv. radius)	Cost
Single 12AWG	1.66kg	0.184 Ω	4.60V	~67%	0.15/cm	\$1.44/m
Single 10AWG ✓	2.32kg	0.126 Ω	2.94V	~80%	0.12/cm	\$2.30/m
Single 8AWG	4.62kg	0.074 Ω	1.85V	~87%	0.05/cm	\$3.44/m
Dual 12AWG	3.32kg	0.092 Ω	2.30V	~84%	0.15/cm	\$2.88/m

8. Pneumatics

Njord runs four pneumatic lines from our surface control box to the ROV to use pneumatic power for our gripper actuation. Figure 3 shows the fluid power SID for layout and details.

Pneumatics over servos: we found that pneumatic actuation is faster than a comparable servo at our load, and a pneumatic actuator holds clamping force without continuous electrical draw. The trade-off is active maintenance: lines are inspected for fluid intrusion before each pool test.

Customization through testing: we also customized our pressure (**35 PSI** regulated down below the MATE supply in our topside box), line sizes (2.5mm ID vs 4mm ID) and actuator bore strokes (20mm for the multi-axis arm and 25mm for the rear gripper) and sizes (25mm) to tailor our grip strength and closing speeds to prevent injuries and protect delicate mission targets like coral. This was done through a comparison study that compared grip

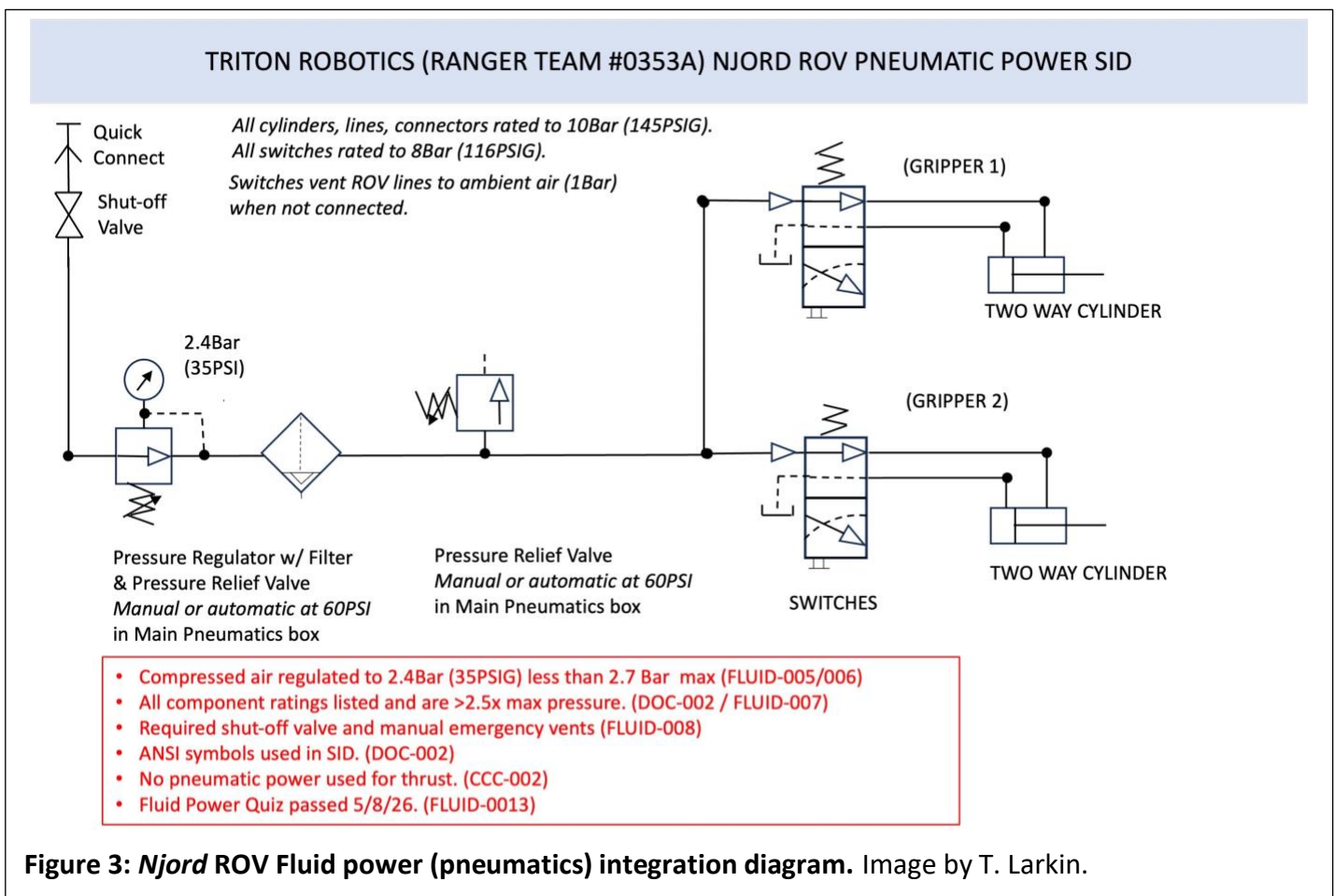
strengths for combinations of 20mm, 25mm, and 36mm bores with 4mm OI and 6mm OD tubing (18m) and pressures from 30PSI to 40PSI, using a tomato for damage testing. The combination of 4mm tubing and 20mm / 25mm bores provided the best tradeoff between strength and damage potential. Emergency and manual depressurization can vent all four lines in under 5 seconds.

9. Control System (Software)

We developed all new software this year including our flight control software, as this was identified as our most impactful potential improvement. The new suite of software, **TritonSuite**, includes:

TritonOS (onboard ROV) and **TritonPilot** (surface ROV flight control) combined for ROV control.

TritonFloat is the float onboard and surface control and data display, and **TritonAnalysis** includes mission-specific applets, all in Python. All repositories are public on GitHub: github.com/ThomasGust/.



9.1 Architecture

For the ROV, the flight control software is split into two substructures. **TritonPilot** runs on the surface laptop and handles the PyQt6 GUI, controller input, telemetry display, recording, and hand off of data to mission applets, while **TritonOS** runs on the Raspberry Pi 4B + Navigator stack inside the ROV and handles arming, failsafes, thrust mixing, depth and attitude hold, PWM output, sensor publishing, and GStreamer video streaming. The data flow between them is shown in Figure 4. Real-time control runs onboard. **TritonPilot** publishes pilot intent at ~30 Hz and **TritonOS** runs a closed control loop at 50Hz that makes decisions on safety-critical areas, including arming, neutral-gate, stale-pilot failsafe, and output clamping. If communication degrades, the ROV disarms safely on its own; the GUI does not need to be alive for the vehicle to fail safely.

9.2 Mission-driven capabilities

We mapped each 2026 RFP task to the software capability required, recorded those in `rov_config.py`, and tested them through the staged protocol (§9.3).

- **Precision manipulation** for coral sampling and eDNA placement: depth hold (PID with filtered BAR02 depth, deadband, integral clamp, stale-sensor gate) and attitude hold (pitch/roll from the Navigator IMU, magnetometer-health-gated yaw).
- **Ambidextrous operation** for the rear gripper's panel-rotation task: reverse-drive mode that remaps reference frame and camera-pane layout so the pilot operates from either end without re-learning the controls.
- **Mission data collection:** **TritonAnalysis** applets for crab CV (PyTorch), eDNA tabulation, iceberg photogrammetry (RealityScan), and underwater color correction.

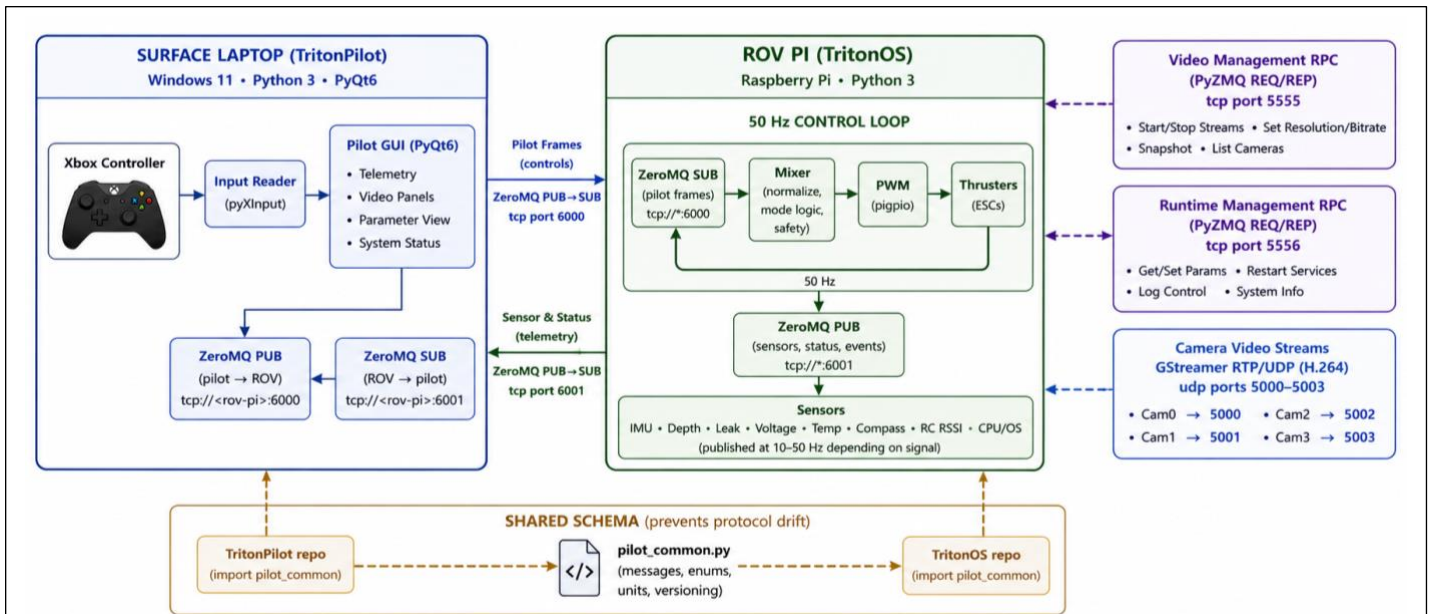


Figure 4: TritonOS and TritonPilot flight control software data flow. Surface laptop (TritonPilot) runs a PyQt6 GUI and reads the Xbox controller. Pilot frames publish over ZeroMQ port 6000 to TritonOS on the ROV Pi, which runs the 50Hz control loop through mixer → PWM → thrusters. Sensors publish back on port 6001. Video management RPC runs on 5555, runtime management RPC on 5556, and GStreamer RTP/UDP camera video streams on ports 5000–5003. The shared schema (`pilot_common.py`) exists in both repositories to prevent drift. Image by T. Larkin.

- **Multi-camera visibility** for efficient piloting in difficult conditions: four hardware-accelerated 1080p/30 H.264 streams at 8 Mbps, GOP 15. See Figure 5 for the multicamera view in TritonPilot.
- **Pool-deck reliability:** onboard 50Hz control independent of GUI timing, graceful process restart on optional-import failure. Over the air (OTA) updates via git pull allow changes without opening the ROV.

9.3 Development process and version control

Both control repositories live on GitHub with a modular package structure (sensors, control, video, motion, AHRS, tools in TritonOS; analysis, GUI, video, input in TritonPilot). The shared `pilot_common.py` schema must be kept in sync between repos and is verified by a schema-roundtrip test in each. **Branching strategy:** Feature branches then lead into a development branch, which is merged into main on a green test basis. OTA updates automatically pull the main track.

Testing is performed in stages. **Unit tests** in both repositories cover protocol serialization, mixer math, hold-controller math, config persistence, channel mapping, and management RPC behavior.

Bench tests run **TritonOS** in dry-run mode with a mock hardware sink, verifying channel identity and PWM behavior with the ROV out of water. **Pool tests** measure closed-loop control, camera reliability, telemetry, and operator performance.

9.4 Advantages

Njord includes many **customizable features**. The 50Hz control loop runs on the ROV Pi regardless of GUI timing, with graceful process restart. The depth and attitude-hold check detects freshness and reverts to manual mode if data goes stale, rather than acting on it. **Ambidextrous reverse-drive** means that by pressing one key, the reference frame and camera layout are reframed so the pilot operates the rear gripper as comfortably as the front arm. **Four-stream 1080p video** at 8Mbps via hardware-accelerated H.264 through the DWE hub makes the under-ice and sub-observatory work possible. **OTA updates from the pool deck:** code

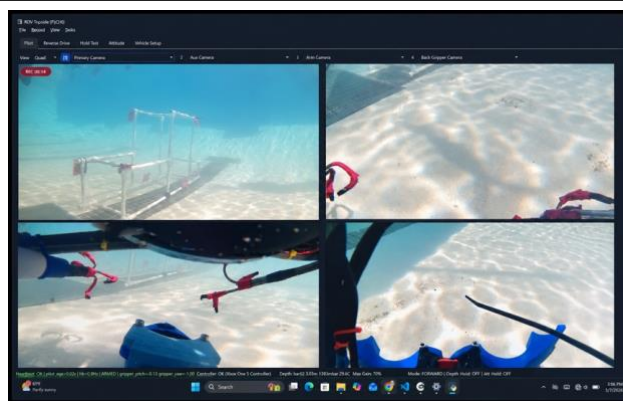


Figure 5: Pilot view using TritonPilot software. Four 1080p camera views including on arm view give awareness. Minimal loss video compression results in less lag and higher quality images. Image by T. Gust.

pushed to GitHub deploys to the ROV via git pull without requiring the enclosure be opened. **Pool-deck tuning:** a hardware dry-run mode with mock sink enables safe bench testing, run-time gain scaling adjusts control gains without code edits, and surface-pressure and flat-attitude references plus live config tuning are accessible from the GUI via a management/calibration remote procedure call (RPC).

9.4.1 Mission-specific analysis applets

TritonAnalysis ships purpose-built tools for the 2026 mission tasks (example shown in Figure 6): a fine-tuned classifier for crab species ID, an eDNA placement tabulation tool, an iceberg photogrammetry pipeline, and underwater color correction. Each data analysis task launches as a

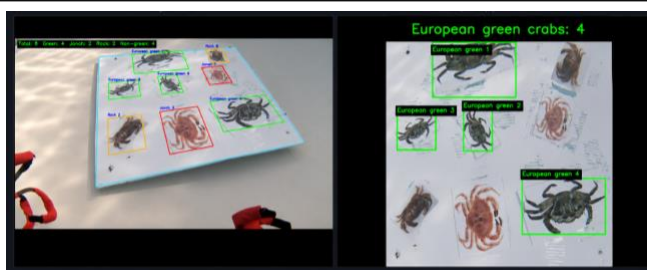


Figure 6: One of the TritonAnalysis applets. The applet shows both the original video feed and the analyzed image. Presentation of the raw data and identification is useful in creating user confidence in the results. Image by T. Gust

standalone applet. For mission purposes a mission specialist does this so the pilot can continue the run.

9.5 Limitations

Run-time config persistence: configuration changes are saved, but most require a process restart to apply. **Topside platform specificity:** the video receiver runs in Windows 11 and MacOS topside environments; Linux is not yet supported. **Quirks:** some receiver behavior requires a USB rebinding to recover a stalled camera. **Network trust model:** management and video RPC are designed for a controlled tether network, not for untrusted public networks. **Pool-measured metrics pending:** depth hold RMS error, video latency, and failsafe response times are still being collected before Worlds.

9.6 Open-source foundations

TritonSuite is built around proven open-source libraries: **PyQt6** (GUI), **ZeroMQ/pyzmq** (messaging), **pygame/SDL** (controller input), **GStreamer** (video pipeline), **OpenCV** (analysis) and **NumPy** (data processing). Our custom code builds on their proven capabilities to meet mission specifications.

10. Propulsion

Propulsion is tailored for three 2026 ROV mission demands: transit between mission stations, stability against flume-tank current during Task 2 instrumentation deployment, precise low-velocity hover for Task 1 coral sampling and Task 3 sub-observatory and micropile alignment. (Task 4 MATE Floats Under the Ice is a float-only task addressed by Skadi.)

Njord uses **eight Blue Robotics T200 thrusters** (four vertical and four horizontal at **30° corner angles**) for full 6-DOF motion (three translation + three rotation). All eight units are reused from last year (two were spares); we verified each against the 2026 mission load requirements before the season opened. T200s are rated 17A each. **TritonOS caps PWM** in software so sustained system current stays under the 25A fuse rating, leaving thermal headroom for transient peaks during maneuvers (details in §7 and §9).

We choose **30° rather than 45° angles** for our motors. This choice trades agility for forward-back authority. A 45° corner gives equal lateral and longitudinal thrust; a 30° corner biases thrust toward longitudinal, better for transit between mission stations and for holding station against flume-tank current. We accepted lateral-translation as the trade-off as most 2026 RFP tasks are reached by re-pointing the bow rather than crab-walking.

Placement and serviceability: thrusters mount inside the frame envelope so the external frame makes contact with obstacles first. Adapted UWROV IP-20 motor guards shroud each propeller. The vertical thruster pairs ride on adjustable up-and-down rails so we can re-balance the center of mass when we swap mission tooling.

Maximum thrust and thrust-to-weight ratio: at our 25A limited supply, maximum thrust is obtained with 4 motors running at approximately 6A and 12V due to compute power needs and tether voltage losses down from the MATE 14.4V supply. The four vertical thrusters together produce 74.7N (7.62kgf) of combined thrust (*Ref: 2*). The four horizontal thrusters at 30° corner angles produce 64.7N (6.60kgf) of forward-back thrust and 37.4N (3.81kgf) of lateral thrust at the same current limit. Against the vehicle's 165N weight, these give thrust-to-weight ratios of **0.45 vertical**, **0.39 forward-back**, and **0.23 lateral**. The T/W ratios are well below 1 by design: Njord is engineered for **near-neutral buoyancy** (§12), so the vertical thrusters only need to overcome the small 1–5N net negative buoyancy plus disturbances, not lift the vehicle's full weight. The 30° angle biases thrust toward forward-back authority, which station-keeping against flume current and transit between mission stations require more often than lateral crab-walking.

11. Buoyancy and Ballast

Njord targets **1–2N of net negative buoyancy**, with up to 5 N accepted across the operating envelope. The vehicle can be **ballasted** using multiple ballast and buoyancy attachment points, so the operating envelope is maintained across all conditions. The

vertical thrusters carry the resulting small continuous load to hold depth. At 12V, one T200 produces 1–5N at well under 1A, a tiny fraction of the 25A power budget and well within thermal headroom.

Tuning stability: the envelope absorbs day-to-day variation in temperature, salinity, and trapped microbubbles rather than requiring re-trim. For an ROV, the buoyancy goal is *minimal thrust budget at pose*, rather than zero drift, and TritonOS's depth-hold controller (§9.4) adjusts for the variance.

Buoyancy and ballast are **separated and spread as far apart as possible**. Positive buoyancy comes from custom polyurethane foam shaped to fit holder parts at the top of the frame; ballast is concentrated at the corners and along the bottom midline. The center of buoyancy and the center of mass form a vertical dipole, and **the restoring**

torque on any pitch or roll disturbance scales with the length of the dipole arm (Ref: 6). Maximizing the vertical separation between the two centers maximizes the corrective torque per degree of tilt, important for precise pose in flume current, against wave action, and against tether tugs during station-keeping. Corner ballast pieces are movable across the multiple attachment points so we can shift ballast on the fly as we change loads.

12. Payload and Tools

Njord's tooling is matched directly to the 2026 ROV tasks: a multi-axis arm with swappable pneumatic grippers for fine-manipulation tasks (Task 1 coral sampling, Task 2 eDNA placement, Task 3 sub-observatory connection); a continuously rotating rear gripper for the Task 3 panel-rotation task; and passive tent-stake tools for the broad-area collection tasks (Task 1 coral collection, Task 3 oil-platform port removal) where active grip control adds no benefit. Software-based tools (crab CV, iceberg photogrammetry, lighting; see §10) cover the ROV tasks where the limiting factor is identification, measurement, or visibility rather than physical manipulation.

12.1 Multi-axis arm

The multi-axis arm (Figure 7) is Njord's primary precision manipulator, providing 2 DOF vertical translation and continuous rotation, for the 2026 RFP's fine-manipulation tasks: coral sampling, eDNA placement, and sub-observatory connection.

Two DOF motion: vertical translation + rotation.

Rather than place a heavy servo at the end of a lever arm, we employ a differential gearbox. The driving servos (two Blue Trail Engineering SRV-30 units) live at the arm base, transferring torque outboard through **8mm GoBilda hex shafts** (hex over round for positive torque engagement that does not slip under load). Force is summed at the wrist by a **1:1 differential gearbox machined from aluminum**. When ABS-printed prototype flexed under load (§16.2), machined aluminum was chosen for rigidity.

Anti-rotation camera mechanism. The arm needed to rotate while preserving a stable visual frame for

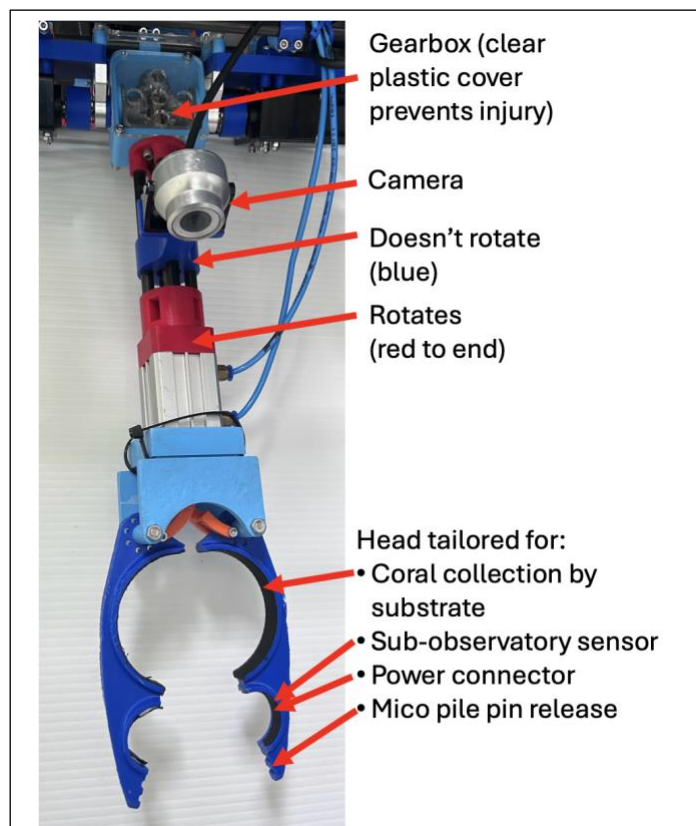


Figure 7: Multi-axis arm: differential gearbox allows vertical angle and rotation control. Camera allows for visibility and sits on non-rotating base. Head rotates and is tailored for specific tasks in MATE RFP. Photo / image by T. Larkin.

the pilot. We solved this by designing a rotating internal shaft through the gearbox, supported by a down-shaft ball bearing near the pneumatic actuator, so the camera view remains usable during subsea observatory and coral-sampling tasks. The mechanism isolates the camera mount from arm rotation while preserving the vertical-translation DOF. This approach required multiple iterations before the assembly worked without play or flex; the final solution doubles as stiffening for the arm's vertical axis.

Gripper actuators: the actuators are pneumatic cylinders, **20mm or 25mm bore** depending on mission load. At 35PSI, the 20mm provides **75N** holding force and the 25mm gives **117N**. Pressure was calibrated incrementally against fruit (tomatoes) until the cylinder reliably gripped without damaging the target. Heads swap via four **M6 screws** in under two minutes poolside.

12.2 Rear gripper

The rear gripper (Figure 8) handles tasks that require continuous rotation, most importantly the sub-observatory panel-rotation task. A **T200 motor core drives a slew bearing through a gear pair**, giving **360°+ continuous rotation**. It pairs with the TritonOS ambidextrous reverse-drive mode so the

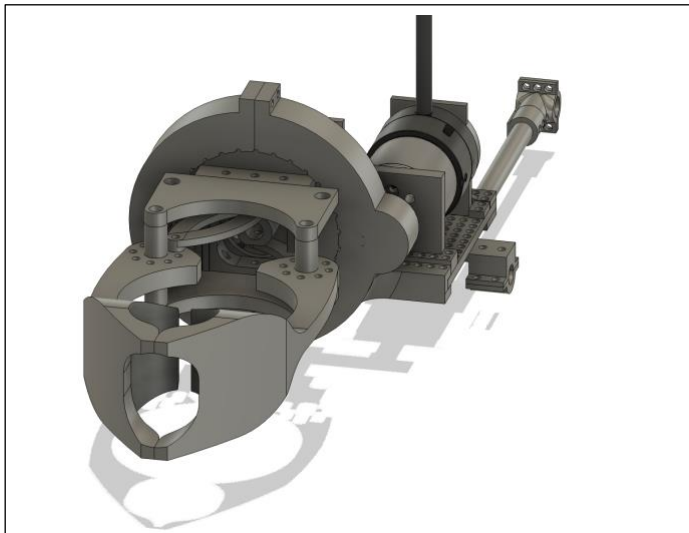


Figure 8: Rear rotating gripper model including gear shroud and customized gripper head that allows secure sub-observatory panel handle gripping. Image by T. Larkin.

pilot can operate the rear consistent with how they operate the front (§9).

12.3 Passive tools

Passive tools are hooks created from multiple tent stakes to handle coral collection and oil platform port removal. The tent stakes attach at the front of the ROV when needed and ends are covered with red heat-shrink tubing to make them more visible for safety and cover any sharp edges.

12.4 Mission-task × tool mapping

Table 3 presents a mapping between Njord's tools and the RFP mission tasks. All 2026 RFP tasks can be completed with no more than two tools, meaning tooling is never swapped mid-run. The 2026 RFP

Table 3. Mission-task coverage across Njord's tools. Every 2026 RFP task is reachable with two or fewer existing tools.

2026 RFP Task	Multi-axis arm	Rear gripper	Passive	CV crab	Photogr.	Lighting
Coral sampling	☑					
Sub-observatory connection	☑					
eDNA sensor placement	☑					
Sub-observatory panel rotation		☑				
Coral collection			☑			
Oil platform port removal			☑			
Crab ID				☑		
Iceberg measurement					☑	
Under-ice operations						☑

includes both fine-manipulation tasks (coral sampling, eDNA placement, sub-observatory connection) and continuous-rotation tasks (panel rotation), which is why Njord carries both a precision multi-axis arm and a high-torque rear gripper rather than relying on one general-purpose manipulator. Passive tent-stake tools handle the two collection tasks that don't benefit from active grip control — coral collection at the broad-area sites and oil platform port removal where the geometry is fixed. The three software-based tools (crab species CV, iceberg photogrammetry, lighting for under-ice operations) cover the four tasks where the limiting factor is identification, measurement, or visibility rather than manipulation.

12.5 Cameras

The ROV includes four DWE HD low-light cameras, placed for mission coverage:

- **Dual Forward:** two forward facing cameras provide the primary driver view as well as clear view for data analysis
- **Rear:** primary view in reverse-drive mode (§9), supporting the rear gripper's panel-rotation task.
- **Arm-mounted:** fixed orientation via the anti-rotation mechanism (§12) so arm rotation does not rotate the view.

Each camera streams 1920×1080 at 30 fps, H.264, 8 Mbps, GOP 15, with a 25ms latency target on UDP ports 5000–5003. We chose low-light cameras to support the under-ice and iceberg tasks.

12.6 Sensors

Sensors are selected for the tasks they support.

External depth: Blue Robotics BAR02, feeds the depth-hold PID. **Internal pressure:** BMP388, used by Skadi's cascaded controller (§13). **IMU/AHRS:** Navigator-board accelerometer, gyroscope, and magnetometer, fused in sensors/attitude.py for pitch/roll stabilization with magnetometer-health gating, gyro-bias compensation, and yaw correction. **Leak detection** and **power sensing** run through the Navigator ADC.

13. Skadi Float

Skadi is a vertically profiling float with a precision peristaltic-pump buoyancy engine, a custom PCB, and a cascaded controller that estimates the syringe state from paired internal and external pressure: a uniquely structured approach for student-built profiling floats. Dimensions: **0.12m max diameter × 0.33m height**, mass **2.6 kg**, weight **26N**. The hull is a shorter Blue Robotics acrylic tube with laser-cut layered acrylic end caps glued with acrylic adhesive. A digital twin copy of the entire float helps reduce integration errors (§9).

13.1 Buoyancy engine

A **Foreshine Fluid BP200 peristaltic pump** drives a **200 mL automotive syringe** to change ballast. The pump can change the float's dV/V in increments below **1/10,000**, and adjusts speed accordingly for rapid profile following. Three buoyancy engines were prototyped on the bench before committing to peristaltic and syringe design. The peristaltic design provided the best precision and waterproofing, with the main tradeoff being slower dV/V response due to the pump's limited flow rate.

13.2 Electronics and Safety

A **custom PCB built around the ESP32-S3R8** (240 MHz, built-in WiFi for OTA firmware) runs the float. **Blue Robotics BAR02** external and **BMP388** internal pressure sensors provide the two inputs for the cascaded controller. A **LoRa 915 MHz radio** handles long-range telemetry to the topside PCB and operator display. Power is a **12V NiMH pack** (10AA cells, pre-assembled for MATE compliance), with a



Figure 9: Skadi's CAD digital twin was used to make precise design choices more rapidly. Image by S. Hajduk

TRITON ROBOTICS (RANGER TEAM #0353A) SKADI FLOAT (NRD) ELECTRICAL POWER SID

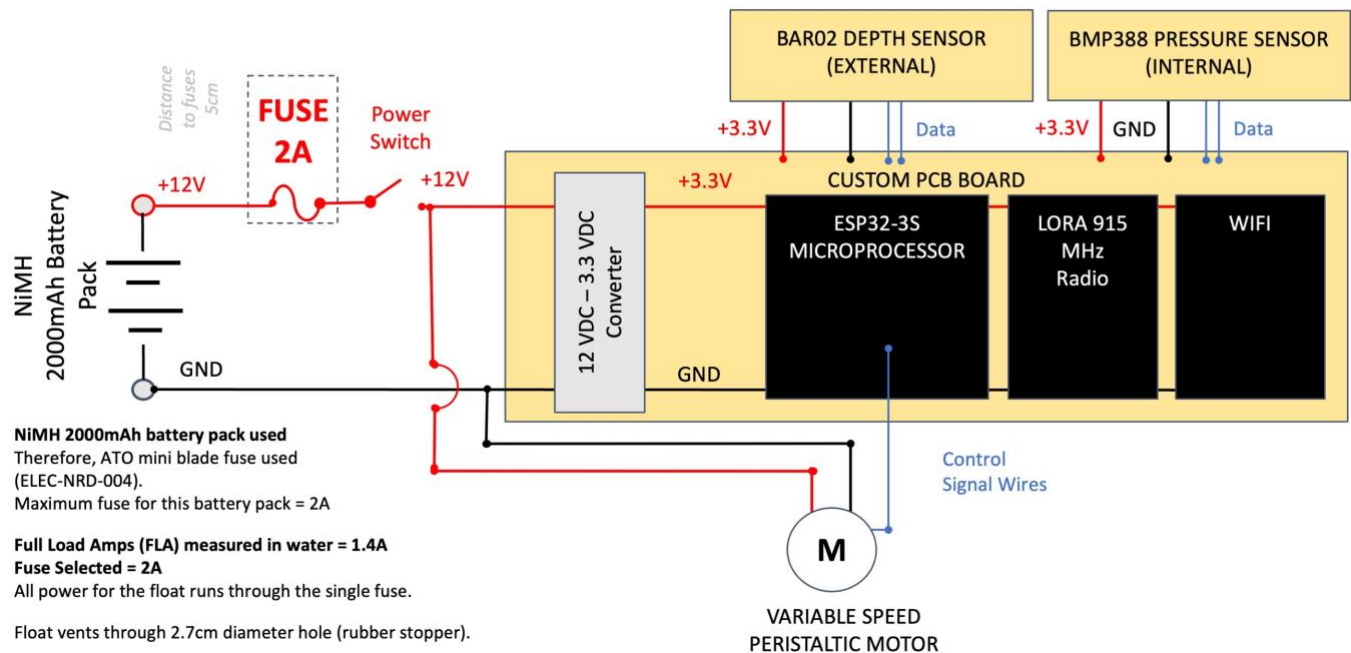


Figure 10: Skadi float electrical power system integration diagram.

2A ATO mini blade fuse within 5cm of the battery. See Figure 10 for Skadi's electrical SID. A **2.7cm rubber stopper** in the bottom end plate serves as the pressure relief valve.

13.3 Float software

TritonFloat is our on-float and topside paired software solution (Figure 11) The control problem is to track an arbitrary depth profile over time. Skadi reads both **external** pressures to know depth and **internal** pressure to estimate the syringe's dV/V state, enabling an enhanced control loop. It uses a cascaded control loop structure: the outer loop commands a desired buoyancy from depth error; the inner loop commands pump PWM to track the buoyancy command, using internal pressure as the state estimate as well as observed acceleration from depth data. This replaces a traditional plunger position sensor.

Depth hold precision is ± 5 cm, tested to 10 m in a lake. Component depth ratings (including the reused enclosure rated to 140 m) give a theoretical operating limit above 100 m.

The float reports observed depth over time and diagnostic variables to the custom topside software for display to the user. This includes depth, ballast estimate, ballast command, pump PWM (commanded and applied), target depth, and error values.

14. Build vs. Buy / New vs. Used

Every build, buy, outsource, and reuse decision for the 2026 season was tested against the demands of the mission tasks. Evaluating if a component or

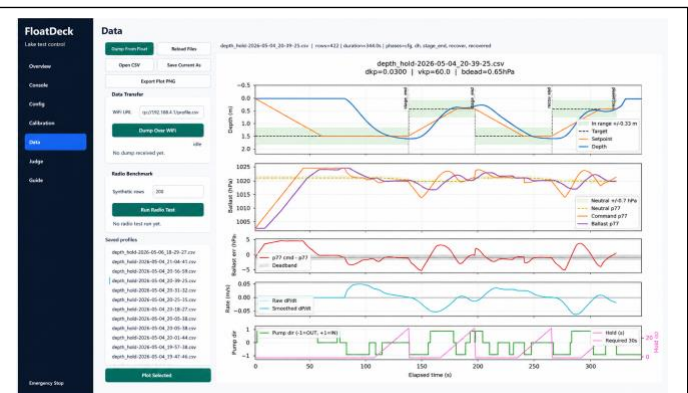


Figure 11: TritonFloat's topside software display showing both external pressure over time and internal state readings. Image by T. Gust

system enables the task scope, and what can be re-qualified against this year’s mission loads. Build-versus-buy decisions follow three criteria: **mission need**, **capability growth** (how building expands skills for future years products), and **reliability and price**. Reused components must be retested against 2026 mission loads before they carry forward. Table 4 summarizes the build, purchase, outsource, and reuse decisions across Njord and Skadi.

Specific examples of build / buy / reuse include:

- **Build: TritonSuite.** Highest capability-growth decision of the season; the full rationale and feature set are in §5.1 and §9.
- **Buy: BR aluminum enclosure.** The 800m depth rating is ~160× our 5m competition depth. Aluminum thermal conductivity (~237 W/m·K) is ~1000× acrylic (~0.2 W/m·K, *Ref: 7*); the 6-inch outer diameter has roughly 60% more total surface area than 100mm including end caps.

Together, these addressed the 2025 CPU overheating problem.

- **Reuse: thrusters, ESCs, Navigator, sensors.** All re-qualified against 2026 mission load at the start of the season, which allowed us to spend that engineering time on TritonSuite.

15. Safety

Our safety rationale is shaped by the 2026 task environments: pneumatic grip-force calibration to protect Task 1 coral and other sensitive biological targets; pressure-vessel and electrical practices sized for the ROV venue conditions (wave tank and flume tank); cold-environment and float-deployment safety practices for Skadi at the NRC ice tank; and venue-specific hazard controls documented in the separately submitted JSEA. The rationale covers personnel, equipment, and operational safety.

Table 4: Build versus buy versus reuse.

Category	Components	Rationale	2026 mission fit
Built	TritonSuite; custom frame; both grippers; arm differential gearbox; Skadi custom PCB + topside PCB	Highest learning opportunity of the season; building unlocked features unavailable in commercial alternatives	Software architecture, arm geometry, float controller all designed against 2026 RFP tasks
Purchased	T200 thrusters; Pi 4B + Navigator; DWE cameras + DWE-USB7PCH hub; LX200-V50; BR aluminum enclosure; BR ESCs; 12→5V converters; BAR02; ESP32-S3R8; SRV-30 servos; BP200 pump	Commercial parts where reliability or precision exceeded what we could build at our scale	Re-verified against 2026 mission load (bandwidth, depth, current, thrust)
Outsourced	Aluminum differential gearbox; machined hex shafts and gears	We lacked in-house machining at the precision required	Gearbox rigidity directly addresses our previous ABS force analysis (§16)
Reused	9 T200 + 2 spares; BR ESCs; Pi + Navigator; Skadi enclosure; IMU and pressure sensors	Like 2025, our reasoning has not changed; each item re-qualified against 2026 mission load	Thrust verified against new 30° corner curves; enclosure against new depth; sensors against new applets

15.1 Personnel safety

All team members wear PPE (safety goggles minimum) during operations. **Miles Lipson, Chief Safety Officer**, is American Red Cross certified in Lifeguarding, CPR, and First Aid. A stocked first aid kit is on deck at every pool test. The safety officer has overall safety authority and may halt all operations or countermand specific orders at any time. We have completed approximately 30 pool tests with zero safety incidents this year.

15.2 Equipment safety

Electrical safety: The ROV uses a **25A ATO main fuse**, ATO color-coded per the 2026 table; **Anderson Powerpole** connectors (red+black attached) are within 30 cm of the fuse; strain relief at every tether penetration; Skadi's **2A ATO mini blade fuse** is within 5cm of the 12V NiMH battery (confirmed with MATE).

Pneumatic safety: **two-stage pressure regulation**: the MATE-supplied compressor delivers at 40PSI (the FLUID-006 maximum), and a Triton-installed downstream regulator drops to **35PSI operating** before the pneumatics box, providing redundant pressure control independent of the upstream regulator. This is done to ensure safety for personnel as well as coral and other sensitive items (Figure 12). **Emergency depressurization vents all four lines in under 5 seconds**, meeting ELEC-020R; topside kill switches cut both electrical and



Figure 12: Testing Triton's grippers for safety by limiting pneumatic pressure and bore size based on testing on tomatoes. Photo by M. Lipson

pneumatic power. Skadi has a **2.7cm rubber stopper PRV** that vents the entire float on abnormal internal pressure. IP-20 motor guards shroud all eight T200 propellers.

15.3 Operational safety

Operations follow a discrete **Safety Checklist** (Appendix A.1) covering eight phases: unload, setup, power-up, launch, in-water operation, retrieval, power-down, and on-deck work. A complete **JSEA** documenting hazards, controls, and responsible persons for deck and dive operations across all three Worlds tanks (wave, flume, and ice) is submitted separately per the 2026 MATE requirement. It covers slip/fall, lifting, electrical, pneumatic, cold-environment, and venue-specific hazards and names a Designated Safety Lead per session with no other operational duties. **Call-and-response protocols** are used at every state transition ('Ready for power on' / 'Clear' / 'Power on'). Roles during operation are strictly assigned: only the navigator instructs the pilot; the tether person is silent except for required call-outs (§7.6); the safety officer observes and may halt.

15.4 Workmanship

Workmanship, which includes labeled wiring, **sealed IP-30 control box**, strain relief at every penetration, no sharps, no glass faceplates on monitors, trimmed zip ties, transparent or openable enclosures, is detailed in §7.5 and follows the 2026 MATE Expected Work Practices Tech Bulletin (Ref: 8). The 2026 onsite workmanship inspection is a new MATE process change, and we built toward it by adopting all required practices throughout the build season rather than retrofitting at the end.

16. Critical analysis and testing

Our process is driven by testing: every component passes a staged protocol before competition, and every failure is treated as data to find the root cause, change the design, and verify the fix. The methodology and four representative cases follow.

16.1 Testing methodology

Every component and subsystem moves through a three-stage protocol: **lab** → **shallow water** → **deep**

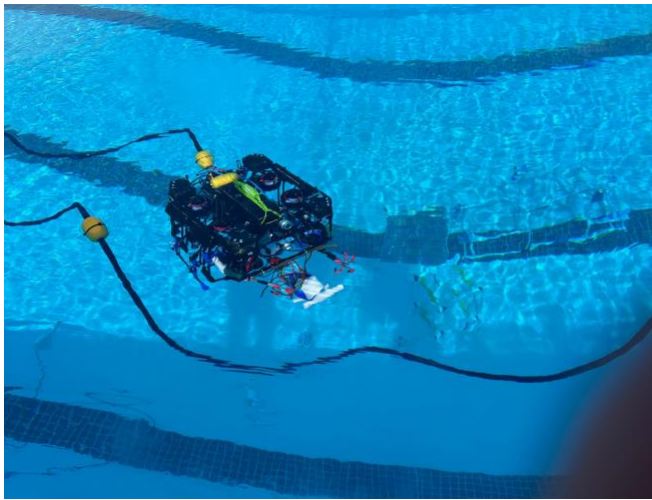


Figure 13: Njord during a deep-water pool test at the Overlake Pool facility. Photo by G. Fisher

pool (3.5 m+). Any failure returns the work to the lab; nothing advances to the next stage until it passes the current one cleanly. This year we have completed approximately **30 deep water pool tests** (Figure 13).

Beyond the deep water pools, we tested in open water to reach conditions a pool cannot reproduce. We pressure-tested Skadi in Lake Washington, profiling to depths deeper than our available pools (10m) to verify the hull and buoyancy engine under real hydrostatic load. We ran Njord in the Puget Sound for saltwater exposure and to test maneuverability and station-keeping against natural currents and wave action similar to the conditions Njord will face in the flume and wave tanks at the World Championships and in real-world operations.

16.2 Four critical-analysis stories

Each story below covers four things: what failed, how we found the root cause, what we changed, and how we verified the fix.

1. **ABS frame joints:** during Phase 2 stress testing, ABS 3D-printed frame joints failed at the corner pieces. We loaded the frame to failure in a controlled lab test and identified the corner geometry as the weak point. Corner pieces were redesigned for impact resilience, increased wall thickness, and adjusted print orientation. Since the redesign, the new corner

pieces have survived all ~30 deep-water pool tests this season without a single joint failure.

2. **ABS differential gearbox:** the first-generation ABS-printed differential gearbox casing flexed visibly under load during arm operation. Bench testing with a torque-measuring fixture confirmed flex consistent with ABS modulus at our gear ratio. We rebuilt the gearbox casing in **machined aluminum**, outsourced because our in-house precision was insufficient. The aluminum gearbox has held under mission loads across every pool test since the swap, and lab testing can no longer reproduce the failure.
3. **Skadi container flooding:** a Skadi prototype flooded during in-water testing; we suspected a seal failure. Post-flood inspection traced the leak to the end-cap interface. We tightened the **waterproofing protocol:** dry-fit verification before glue, layered acrylic end caps with full perimeter coverage, pressure check at simulated depth before each test. Skadi has remained leak-free across at least a dozen subsequent in-water tests, including lake testing to 10m.
4. **Multi-camera streaming:** with four 1080p streams active, the camera pipeline dropped frames and occasionally hung the topside receiver. Stream-by-stream and codec-by-codec testing isolated CPU encoding overhead on the Pi as the bottleneck. We added the **DWE-USB7PCH** camera hub with hardware-accelerated H.264 encoding off-chip and tuned GStreamer pipeline parameters. The four 1080p 30fps streams have run reliably across roughly 20 pool tests with all streams active.

17. Accounting

We opened the season with a \$5,600 USD operating budget for the program through Regionals; the actual total spend through Regionals came in at \$5,217 USD. See Appendix A2 for full budget tables.

17.1 Budget process

We built a yearly budget by category and received the funds in quarterly tranches, each presented and

justified to an Investment Committee headed by Jackie Borges before release into the Triton bank account. By category, actual spend through Regionals was approximately: cameras \$1,280; manipulators \$1,082; ROV electronics and enclosure \$840; Skadi float \$615; competition fees \$450; team operations and contingency \$418; frame and structure \$280; tether \$163; workshop \$89; propulsion \$0 (fully reused). Manipulators ran over-estimate because of repeated servo failures in saltwater testing, and the float PCB cost more to develop than planned; both overages were absorbed by the team operations and contingency allowance. Full detail is in Appendix A2.

17.2 Income and in-kind support

Cash funding came from six family sponsor groups (Fisher, Enoki, Gust, Hajduk, Kavalam-Seelig-Lipson, and Larkin-Spoonemore). In-kind contributions included discounted commercial parts from Blue Trail Engineering, Blue Robotics, and Fisheries Supply; a donated performance tether from VideoRay; donated team shirts from the Fisher family; the Gracz-O'Donnell family's extended laser-cutter loan; donated workshop space from the Larkin-Spoonemore family; and pool access from Chris Suver, Overlake Pool, and Jennifer Cast and Liffy Franklin. Donated items are accounted for at fair market value in Appendix A2, except pool access and workshop space, for which no defensible market rate exists (see Appendix A2 notes).

17.3 World Championships Costs

After advancing to the World Championships, a separate travel assessment was raised from the same six families. The Worlds travel estimate is \$16,900 USD (airfare for 9 at \$1,100, housing \$5,200, two rental SUVs at \$600, and crate/baggage \$600); MATE waived the \$450 World Championship registration fee. Total expenditures including Worlds travel are expected to be approximately \$22,117 USD.

18. Acknowledgments

MATE ROV Competition: organizers, judges, and volunteers who make the PNW Regional and World Championship possible.

Mentors: Sim Larkin (lead, workshop and safety oversight); Charles Gust (lead, educational).

Investment Committee: Jackie Borges (lead).

GitHub project management tutorial: Jude Kavalam.

Family sponsors: Fisher family (George and Ann Fisher); Enoki family; Gust family; Hajduk family; Kavalam-Seelig-Lipson family; Larkin-Spoonemore family.

Workshop space: Larkin-Spoonemore family. **Pool space and time:** Chris Suver; Overlake Pool; Jennifer Cast and Liffy Franklin. **Laser cutter loan:** Gracz-O'Donnell family.

Discounted / donated parts: Video Ray; Blue Trail Engineering; Blue Robotics; Fisheries Supply of Seattle

19. References

1. MATE 2026 RANGER Competition Manual (materovcompetition.org). Accessed May 2026.
2. Blue Robotics T200 thruster specification (bluerobotics.com). Accessed May 2026.
3. Blue Robotics aluminum enclosure BR-106281-300 specification (bluerobotics.com). Accessed May 2026.
4. Ancor 10 AWG marine wire specification (westmarine.com). Accessed May 2026.
5. Christ, R. & Wernli, R., *The ROV Manual: A User Guide for Remotely Operated Vehicles*, 2nd ed., Butterworth-Heinemann, 2013.
6. Moore, S., Bohm, H. & Jensen, V., *Underwater Robotics: Science, Design and Fabrication*, MATE Center, 2010.
7. List of thermal conductivities (wikipedia.org). Accessed May 2026.
8. MATE Expected Work Practices Tech Bulletin, 2026 (materovcompetition.org). Accessed May 2026.

A1. Safety Checklists and Supplemental Materials

Figure A1.1 presents our safety checklist used for all operations at nor near the pool deck, compressed for space here (team uses a two-page format in actual operations). Job safety and environmental analyses are submitted as a separate document along with our company safety review directly to MATE for review.

<i>Unloading:</i> ☐ Check-in with entire team/JSEAs covered ☐ Communicate with others in area ☐ Area is dry and clear ☐ Walkways and areas for staging designated ☐ Safety czar overseeing designated ☐ Safety glasses / PPE on <i>Setup (pre-power-up):</i> ☐ Unbox ROV and float ☐ Setup up computers (Xbox, ethernet, USB) ☐ Turn on computers ☐ Place compressor and pneumatics box ☐ Secure strain relief (surface control station, tether, pneumatics) ☐ Connect computers to surface control box ☐ Unroll tether (double-check strain relief) ☐ Check ROV and float for damage ☐ Check water seals on ROV and float ☐ Connect power and pneumatics <i>Power-up:</i> ☐ Verify power and pneumatics properly connected; verify emergency venting opens by doing mini test ☐ "Ready for compressor"; "Clear" before compressor on; "Compressor on" ☐ Verify MATE compressor supply at 40 PSI ☐ "Ready for pneumatics"; "Clear" before pneumatics on; "Pneumatics on" ☐ Verify downstream regulator drops to 35 PSI operating ☐ Confirm pneumatics work (arms / grippers) ☐ "Ready for power on"; "Clear" before power on "Power on" ☐ Confirm surface – ROV connection; cameras ☐ "Ready to arm"; "Clear" before arming; "Armed" ☐ Confirm motor control	<i>ROV Launch:</i> ☐ "Ready to deploy" ☐ All items in grippers ☐ Lift ROV from designated spot (use spotter) ☐ ROV out over water, down gently ☐ "Deployed" ☐ Look for unusual bubbles <i>Operating ROV:</i> ☐ Tether Manager is silent except for collisions that would damage pool, people, or ROV ☐ Only Navigator instructs Pilot ☐ Others discuss with Mission Specialist, who then confers with Navigator <i>ROV Retrieval:</i> ☐ Ensure disarmed ("Disarming"; "Disarmed") ☐ Ensure pneumatics shut-off set ☐ "Bring on deck" ☐ Tether designates handholds; spotter arrives ☐ Lift with straight back ☐ Place ROV on deck so that arms are not hitting deck ☐ "Deployed" ☐ Check for water <i>Power-off:</i> ☐ "Powering down"; "Agreed" then power off ☐ Ensure pneumatics shut-off valve closed ☐ "Emergency depressurization test"; "Clear" before depressurizing; verify all 4 lines vent within 5s <i>Working with ROV on deck:</i> ☐ Confirm disarmed ☐ Confirm pneumatics shut off ☐ If working around motors, confirm power-off ☐ Tether manager has control ☐ Ensure tools and equipment not left on ROV ☐ Ensure all wires, tape, zip ties secured ☐ Double check for water ☐ Double check water seals on ROV
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Figure A1.1: Safety checklist for on deck and in pool operations.

A2. Budget Tables

Budget and accounting notes:

- All amounts rounded to the nearest USD.
- Fair market value (FMV) assessed as cost to replace new. A 30% discount is applied to used electronics.
- All donations and discounts use FMV, but no FMV was able to be assigned for two in-kind items: pool access (85+ hours) and workshop space (500+ hours family garage with tools). We have not assigned an

FMV because these facilities have no established rental rate nor are local commercial equivalent facilities available with published rates with which to anchor an estimate.

- Note that our budget is divided into the main team budget initial funding round plus an additional funding raise after advancing to the World Championships.

Table A2.1. Available Funds (2026 Season)

Category	Item - Source	Cash (USD)	In-Kind
Cash sponsors	Operating expenses - Six family groups (Fisher, Enoki, Gust, Hajduk, Kavalam-Seelig-Lipson x 2, Larkin-Spoonemore), contributions split evenly	\$5600	
Discounts	Store discounts - Blue Trail Engineering, Blue Robotics, Fisheries Supply		\$619
Donated	Tether - Video Ray		\$216
Donated	Team shirts – Fisher family		\$470
Donated	Pool access ¹ -Overlake, Chris Suver, Liffy/Cast		n/a
Donated	Workshop and Tools ¹ – Larkin/Spoonemore (workshop), O'Donnell-Gracz (laser cutter)		n/a
Pre World Championships Total: \$6,905		\$5,600	\$1,305
Donated	World Championship registration fee waived by MATE		\$450
Cash sponsors	World Championships travel special assessment – same six families as above	\$16,900	
TOTAL (inc. World Championships): \$24,255		\$22,500	\$1,755

Footnote 1: Pool access and workshop space were not assigned an FMV – see notes at top of section A2.

Table A2.2. ROV Itemized Inventory

The fair market value for donated parts is its purchase price, new; the fair market value for reused parts is the new product price minus a 30% discount.

Budget Category	Type	Item Example(s)	Est. Value (USD)
Frame & Structure	Materials, Purchased	Carbon fiber rods (8 mm), ABS filament for printing corner parts, foam ballast	\$280
Enclosure	Purchased	BR aluminum tube (BR-106281-300), end plates, Wetlink penetrators	\$580
Propulsion + Manipulator	Reused	T200 thrusters x 9 (inc rotating gripper), BR ESCs x 9 (FMV)	\$1,701
Tether	Donated	Video Ray Performance Tether (FMV)	\$216
Tether	Purchased	Ancor 10 AWG wire, Anderson Powerpole connectors, pneumatic lines	\$163
Electronics	Reused	Pi 4B, Navigator (FMV), 5V converters	\$254
Electronics	Purchased	DWE cameras x 4, DWE-USB7PCH hub, LX200-V50	\$1,480
Electronics	Materials, Purchased	Topside box and custom wiring	\$54
Manipulators	Materials, Purchased	SRV-30 servos x 2, pneumatic cylinders (20/25 mm bore), tubing	\$1,082
Total:			\$5,810
Breakdown by Source (A2.1): Reused: \$1,955; Donated \$216; Discounts: \$619; Cash Purchase: \$3,020			

Table A2.3 World Championships Travel Estimate (June 21-28, 2026 – Seattle to St John’s)

Note: Team had no travel expenses attending regionals as this was local to our area.

Category	Description	Cost (USD)	Qty	Subtotal
Airfare	Round-trip Seattle → St. John’s, per person (7 team + 2 mentors)	\$1,100	9	\$9,900
Lodging	Shared housing for the competition week	\$5,200	1	\$5,200
Car Rental	SUV rental for transport at competition	\$600	2	\$1200
Baggage	ROV and equipment excess airplane baggage fees	\$100	6	\$600
TOTAL:				\$16,900

Table A2.4. Expenses — Budget vs Actual (July 2025 – June 2026)

Note: Team had to overspend Manipulators estimate due to repeated servo issues in salt-water testing. Float PCB also cost more to develop than expected. Team operating / contingency funding allowance was able to absorb these overages.

Budget Category	Main cost items (actual breakout)	Budgeted (USD)	Actual (USD)
Frame & Structure	Carbon fiber rods (\$112), Ballast foam (\$78), ABS filament spools (\$52), Screws and misc hardware (\$38)	\$500	\$280
Propulsion	n/a (reused)	0	0
Tether	Power wire (\$135); foam buoys (\$28) (Ethernet cable donated)	\$250	\$163
ROV Electronics inc. Container	BR aluminum tube and flanges (\$425), Ethernet Compression (\$200), Wet-link penetrators (\$135), Acrylic for laser cutter (\$80)	\$1,000	\$840
Cameras	4 DWE cameras (\$1200), DWE hub (\$80)	\$1,350	\$1,280
Manipulators	Servos (\$849), pneumatic cylinders and parts (\$112), gearbox (\$57), Misc. hardware (\$64)	\$500	\$1,082
Float	Custom PCB Board (\$473), BP200 pump (\$79); Batteries (\$44); ESP32 (\$19)	\$500	\$615
Workshop	Broken printer replacement parts (\$89)	\$0	\$89
Team Operations & Contingency Funds	Miscellaneous supplies (e.g. glue, epoxy, grease \$182), Poster and other printing (\$176), Team website (\$60)	\$1,000	\$418
Competition Fees	Regional registration	\$500	\$450
Competition Travel	Travel to regionals not applicable, local venue	n/a	n/a
Total Through Regionals:		\$5,600	\$5,217
Travel	Travel to World Championships – see Table A2.3 above (note: World Championship registration waived)	\$16,900	\$16,900
TOTAL (including World Championships):		\$22,500:	\$22,117