Free-Roving Subsea Cable Inspection Drone

A Technical Feasibility Study

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November 12, 2025

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Problem - Subsea Cable Inspection

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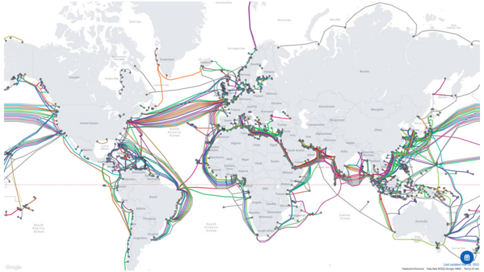
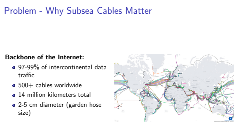
Problem - Why Subsea Cables Matter

Backbone of the Internet:

- 97-99% of intercontinental data traffic
- 500+ cables worldwide
- 14 million kilometers total
- 2-5 cm diameter (garden hose size)





Before we dive into our design and feasibility assessment, let's give some context to the problem we're tackling: Subsea cables. Your internet connection, whether that be for online banking or video calls, 97-99% of that data goes through a dense network of over 500+ undersea cables, spanning a total of 14 million kilometers over the seafloor making it THE largest and possibly greatest man-made infrastructure ever. This is the backbone of the internet, and when they fail, the consequences are severe. Despite the significance of these cables, these cables are no thicker than your average garden-hose around 2-5 cm in diameter, with hair-thin strands of optical fiber embedded within, designed to remain undisturbed across the seabed.

Problem - Current Limitations

Cable Faults:

- 200 faults/year
- Shallow waters most vulnerable
- Shetland Islands 2022: 23,000 people offline

Traditional: Tethered ROVs

- \+ Unlimited power
- \+ Real-time comms
- – Limited range
- – Tether entanglement
- – High operational cost

Solution: Free-roving Autonomous Underwater Vehicle

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In shallow waters however, these subsea cables are susceptible to a wider range of disturbances, largely from human activities such as anchoring, or snagged by nets, resulting in roughly 200 faults a year. In October 2022, both cables serving the Shetland Islands were damaged. For days, 23,000 people had no internet, could not use card payments, could not access online banking. Businesses lost thousands. Emergency services were disrupted. These are not rare events, they require constant monitoring and effective maintenance. When a fault occurs, an army of ships strategically placed around the world would identify and repair the location of the fault, which usually involves the usage of a tethered drone to inspect the damaged cable. Despite the effectiveness of tethered communications and unlimited power, this comes at the cost of a limited range of motion and risks of entanglement, as well as higher maintenance costs for dedicated vessels. Therefore we propose the use of an untethered AUV

Requirements and Operating Environment

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"A free-roving (no umbilical cable) submarine inspection drone is required for undersea cables: operating down to 250 m depth. It should have an endurance of 2 hours continuously powered operation, carrying video and ultrasound imaging equipment drawing a 30 W electrical load, and have suitable propulsion to travel up to 4 m/s peak speed with 1 m/s cruise. Total mass is to be < 25 kg, to allow easy handling on board the mothership."

Key Specifications:

- Depth: 250m (25 bar pressure)
- Endurance: 2 hours continuous
- Speed: 1 m/s cruise, 4 m/s peak
- Payload: 30W (imaging + ultrasound + lighting)
- Mass: < 25 kg total

Operating Challenges:

- Pressure: $P = \rho g h \approx 25$ bar
- Temperature: 4°C seawater
- No GPS/RF underwater
- Saltwater corrosion
- Turbid water (limited visibility)

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We are required to design an untethered cable inspection drone operating at 250m depth with a top speed of 4m/s and 1m/s cruise, allowing an operation time of around 2 hours, while keeping the total weight below 25kg. The pressure at this depth is approximately 25 bar, calculated using P = rho g h, where rho is seawater density (1027 kg/m cubed).The temperature is approximately 4 degrees Celsius. We should account for the high signal attenuation underwater, as well as materials' resistance to corrosion. Sensors must work in turbid water with near-zero visibility.

Problem Definition

Communications and Navigation
Assess feasibility of underwater wireless communication methods for control and data transfer.

- Attenuation in seawater
- Navigation and mapping

Hydrodynamics
Analyze underwater drag forces to estimate thrust needed for efficient movement.

- Degrees of freedom and stability control
- Drag and resistive forces

Power Budget Analysis
Identify energy storage limits to define mission duration and vehicle size within constraints.

- 2 hours continuous operation
- Support 30W load as well as communications and mechanical systems

Mechanical and Structural Design
Develop the mechanical system ensuring all components fit within the 25kg weight limit.

- Buoyancy system
- Structural integrity

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We characterise the requirements into 4 sections, Communication and control, hydrondynamics, power and mechanical design, each addressing different aspects of the design to be considered. Communication and control addresses the difficulty of untethered communications, as well as navigating in the undersea environment. Hydrodynamics characterises the operating environment, addressing movement and agility of the drone. Power defines the endurance of the operations, and finally mechanical design ensures structural integrity.

Existing Commercial Solutions

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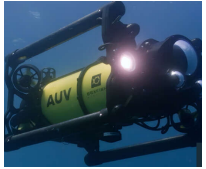
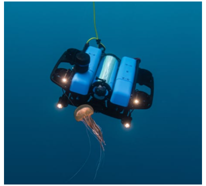
Model	Type	Mass	Depth	Speed	Endurance	Cost
Our Target	AUV	<25 kg	250m	4 m/s peak	2 hrs	$9-10K
Iver3 (L3Harris)	AUV	27-39 kg	100m	1.3 m/s	8-14 hrs	$75-120K
ecoSUB m-Power+	AUV	17 kg	500m	1.5 m/s	8-10 hrs	£35-50K
Boxfish AUV	AUV	25 kg	300-600m	2 m/s	10 hrs	$80-150K
BlueROV2	ROV	10-11 kg	100-300m	1 m/s	3-5 hrs	$3-3.5K

Iver3: Single thruster + fins

ecoSUB: 500m rated, alkaline

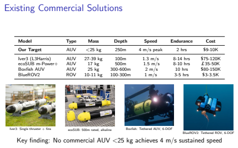


Boxfish: Tethered AUV, 6-DOF



BlueROV2: Tethered ROV, 6-DOF

Key finding: No commercial AUV <25 kg achieves 4 m/s sustained speed



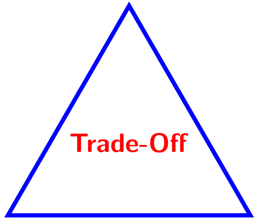
Many commercial solutions exist but vary in capability. Simple untethered designs such as the Iver3 and ecoSUB use fully autonomous operation with single thruster designs plus fins for pitch/yaw control, but can be limited in depth and agility. More advanced designs offer better mobility such as the Boxfish using 8 vectored thrusters for full 6-DOF control, allowing hovering and other fine movements. BlueROV2 demonstrates the capabilities of a tethered ROV with an optional autonomous mode, offering lighter design as well as live feedback as an example of a semi-tethered design. We find that few commercial AUVs achieve 4 m/s sustained speed - most operate at 1.5-2.5 m/s due to power limitations, however it is reasonable to believe our target specifications despite ambitious is achievable with careful trade-off management.

Design Approach and System Architecture

Design Approach and System Architecture

Trade-offs

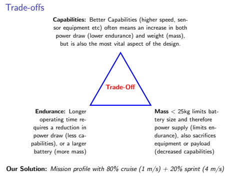
Capabilities: Better Capabilities (higher speed, sensor equipment etc) often means an increase in both power draw (lower endurance) and weight (mass), but is also the most vital aspect of the design.



Endurance: Longer operating time requires a reduction in power draw (less capabilities), or a larger battery (more mass)

Mass < 25kg limits battery size and therefore power supply (limits endurance), also sacrifices equipment or payload (decreased capabilities)

Our Solution: *Mission profile with 80% cruise (1 m/s) + 20% sprint (4 m/s)*



The design is constrained by three competing requirements forming a trade-off triangle. Capabilities - speed, sensors, and mission functionality - drive both power consumption and weight. Better capabilities mean higher speed requiring more thrust power, and more sensor equipment adding weight.

Endurance requires either reducing power draw or installing larger batteries. Reducing power limits capabilities. Larger batteries add weight, conflicting with the mass constraint.

Mass under 25 kilograms limits battery capacity to 4 to 5 kilograms maximum. This restricts available energy, which directly limits either endurance or capabilities.

The solution is a mission profile approach: 80 percent time at 1 meter per second cruise speed, 20 percent time at 4 meters per second peak speed. Average power is much lower, which satisfies all three constraints simultaneously.

System Design Directions

- Autonomous/programmable solution to remove the need for high-quality real-time data transmission which limits untethered ROVs
  - Enables self-contained operation with onboard power, navigation, and data handling
  - Supports scalable inspection missions without reliance on surface tethers
- 4-thruster design gives a good balance between maneuverability, stability, and power efficiency
  - Sufficient for precise hovering and pitch/yaw stability
  - Redundancy for safe recovery in case of partial thruster failure
  - Efficient low-speed maneuvering for inspection tasks
- Hull design to be cylindrical (pill) shaped to minimise volume as well as simplify hydrodynamic calculations.
  - Streamlined shape reduces drag forces at higher speeds
  - Simplifies internal component layout and waterproofing
  - Proven design in existing AUVs for balance of speed and stability

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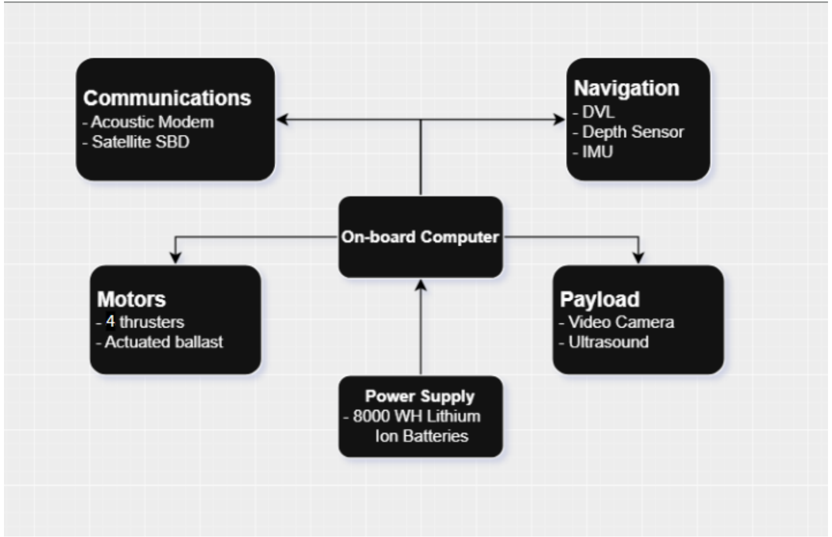
Our design uses an autonomous approach instead of untethered ROV operation, as untethered ROVs require continuous high-bandwidth communication for real-time control, which is impractical with limited battery life and processing power (more on this later). Autonomous operation enables self-contained missions with onboard power, navigation, and data storage, and removes the need for human operators to constantly monitor the mission.

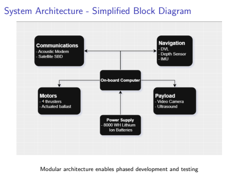
The 4-thruster configuration provides a good balance between maneuverability and power draw. This enables precise hovering at fixed positions for detailed cable inspection, and lateral motion without changing heading. The configuration is efficient for low-speed maneuvering typical of inspection tasks.

The cylindrical pill-shaped hull minimizes drag and simplifies hydrodynamics, and is a staple in underwater ROV design.

System Architecture - Simplified Block Diagram



Modular architecture enables phased development and testing



This simplified system architecture shows the five main subsystems. POWER provides 803 Wh from three 18Ah lithium-ion batteries at 14.8V. CONTROL uses the Navigator flight controller with dual IMUs plus Raspberry Pi 4 running ArduSub for mission control, along with depth sensor, compass, and surface GPS. PROPULSION consists of four T200 thrusters controlled by ESCs. PAYLOAD includes camera and ultrasound totaling 30W. COMMUNICATIONS uses WiFi for high-bandwidth surface data transfer and Iridium satellite for position reporting. This modular design allows independent testing and phased development.

Communications and Navigation

Communications and Navigation

Underwater Communication Challenges

Underwater Communication:

- High signal attenuation limits the usage of radio frequency signals - effective range only a few metres
- Optical communication limited by turbidity and scattering - short range, line-of-sight only
- Acoustic communication is the only viable option for long-range underwater comms, but inherently slow, high latency, and affected by multipath

Result: Minimise communication underwater — store data onboard, transfer at surface

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Result: Minimise communication underwater — store data onboard, transfer at surface

Before diving into our design decisions, it's important to understand why underwater communication and navigation are inherently difficult problems.

First, radio waves — which power all our terrestrial wireless communication — are heavily absorbed by seawater. Even at low frequencies, the signal strength drops to unusable levels within just a few meters.

Optical communication, like lasers or LEDs, can achieve higher data rates, but only in clear water and over short, line-of-sight distances — typically less than 100 meters.

That leaves acoustics as the only practical long-range option. Acoustic modems can reach several kilometers, but at a steep cost: data rates of only a few kilobits per second, high latency, and unit prices easily exceeding twelve thousand dollars. For our small, autonomous inspection drone, these trade-offs simply aren't efficient.

As a result, our design minimizes underwater communication by storing all sensor data onboard during the mission and transferring it to the surface once the vehicle resurfaces. This approach maximizes data throughput while avoiding the complexities of underwater communication.

Communications Systems

Multi-Mode Communication Strategy:

Mode	Product	Specifications	Cost
Surface WiFi	**802.11n module** (Raspberry Pi built-in)	2.4/5 GHz, 150 Mbps 50-100m range in air	**$50**
Satellite	**RockBLOCK 9603N**	Iridium Short Burst Data 340 byte messages Global coverage (open ocean) GPS position reporting	**$260**

Operational Modes:

- **At surface:** WiFi for high-bandwidth video/data + GPS fix
- **Open ocean:** RockBLOCK for GPS position reporting every 10 min

When the AUV surfaces, it uses the Raspberry Pi 4's built-in WiFi with a marine-grade antenna to transfer data at around 150 megabits per second. This allows a complete upload of all mission data such as recorded video — roughly 7–8 gigabytes — in just a few minutes. Surfacing every 30 minutes lets us offload data incrementally when the vehicle is in the 50-100 meter range, reducing onboard storage requirements and ensuring data safety even if the vehicle is lost.

For open-ocean or long-range missions, we include a RockBLOCK 9603N Iridium module. It provides global satellite coverage and transmits compact status messages — GPS coordinates, depth, and system health — every 10 minutes. This ensures vehicle recoverability and global operational capability.

Excluding acoustic and optical modems dramatically reduces costs, as acoustic systems cost over 12,000 dollars, have very low bandwidth (under 20 kbps), and are impractical for transferring gigabytes of data.

Navigation Scoping Calculations

- MEMS IMUs measure angular rate and acceleration; position is estimated by integrating these signals.
- **Integration:** $\theta(t) = \int \omega \, dt$ (orientation); $x(t) = \iint a \, dt^2$ (position)
- Each integration amplifies sensor noise and bias:
- Without correction, small biases lead to large accumulated position errors over time.

Drift Mitigation Strategies:

1. **Zero-velocity updates:** Detect stationary periods and reset velocity estimates.
2. **Sensor fusion:** Combine IMU with magnetometer and depth sensor for heading and vertical stabilization, or DVL to constrain horizontal drift.
3. **Cable-relative navigation:** Use sonar or visual tracking to constrain lateral drift.
4. **Surface GPS fix:** Acquire GPS position during surfacing to reset accumulated horizontal error.

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Speaker Notes:

When designing a free-roving underwater vehicle, one of the biggest challenges is maintaining a reliable sense of position and orientation without GPS. One of the most cost-effective solutions is to rely on an Inertial Measurement Unit, or IMU, which combines gyroscopes and accelerometers to track motion. However, IMU-based navigation underwater is an integration problem: we integrate angular rate for orientation and acceleration twice for position. This process inherently accumulates error—random noise grows as the square root of time, and bias causes linear drift. Over long missions, these effects can lead to significant position uncertainty if left uncorrected.

Our mitigation strategy combines multiple complementary techniques: zero-velocity detection to reset errors during stationary periods, sensor fusion to stabilize heading and depth, cable-relative tracking using sonar or vision to maintain lateral alignment, and periodic GPS updates during surfacing to reset accumulated horizontal drift.

Together, these methods ensure reliable navigation for cable inspection, with accuracy sufficient for operational needs without requiring costly DVL systems.

Navigation System Component Options

Core Navigation Stack:

Component	Specification	Performance	Cost
Flight Controller	Navigator (dual IMU) Pixhawk 6C	$2.8^\circ/\mathrm{s}/\sqrt{\mathrm{Hz}}$ gyro noise Similar performance	\$220 \$300
Depth Sensor	Bar30 (MS5837) Keller PA-7LD	2mm resolution, ±2m accuracy ±0.3m accuracy, stable	\$90 \$200-500
Surface GPS	u-blox NEO-M8N RTK GPS	2.5m accuracy <0.1m accuracy	\$35 \$300-600
Computer	Raspberry Pi 4	Quad-core ARM, 4GB RAM	\$75
DVL (Optional)	Nortek DVL1000 Teledyne Pathfinder	0.2 cm/s, ¡1m over 2 hrs Similar, proven	\$20,000 \$18-28K

Baseline Cost: \$420 (Navigator + Bar30 + u-blox + RPi4)

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Our navigation system is built around the Blue Robotics Navigator, which integrates dual IMUs and magnetometers for reliable attitude and heading estimation, and connects directly to our Raspberry Pi. At 220 dollars, it costs less than the Pixhawk 6C with a similar performance, and is fully supported by ArduSub. Sensor fusion uses the Bar30 pressure sensor, offering 2 mm resolution and 2 m accuracy, ideal for maintaining a 2–5 m altitude during cable inspection.

At the surface, a u-blox NEO-M8N GPS resets accumulated IMU drift with 2.5 m accuracy, which is sufficient for our 30-minute surface intervals—no need for costly RTK GPS.

We also considered a DVL like the Nortek DVL1000 for sub-meter accuracy, but at a 15–25k dollar price and +1.2 kg weight, it's unnecessary for cable-following missions.

Altogether, the baseline navigation stack — Navigator (220), Bar30 (90), GPS (35), and Raspberry Pi 4 (75) — costs 420 dollars total.

Hydrodynamics Analysis

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Hydrodynamic Drag

Vehicle Geometry (Torpedo Hull):

- Diameter: $D = 0.3$ m, Length: $L = 1.2$ m
- Frontal area: $A = \frac{\pi D^2}{4} = 0.0707$ m^2
- Drag coefficient: $C_D = 0.28$–0.32 [MDPI CFD]

Drag Force Equation:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Where $\rho = 1027$ kg/m^3 (seawater)

- **At 1 m/s cruise** $C_D = 0.32$: $F_D = 11.6$ N
- **At 4 m/s peak** $C_D = 0.28$: $F_D = 162$ N

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Hydrodynamic drag is the fundamental constraint on our design. The drag equation shows that drag force scales with velocity squared.

We chose a torpedo-shaped geometry for the vessel: 1.2 meters long, 0.3 meters diameter. This length-to-diameter ratio of 4 to 1 optimizes streamlining. Frontal area is 0.071 square meters.

Drag coefficient C-D varies from 0.28 to 0.32 with speed. At low speeds, flow separation and turbulence increases C-D to 0.32. At high speeds, Reynolds number increases, boundary layer becomes thinner, and C-D drops to 0.28. These values are validated against real CFD studies on AUVs

At 1 meter per second, drag is 11.6 newtons. At 4 meters per second, drag is 162 newtons - a 14-fold increase for 4-times speed increase. This quadratic relationship creates a core challenge: high speed requires overcoming dramatically higher drag forces.

Power Requirements and Thruster Efficiency

Mechanical power: $P_{mech} = F_D \times v$
Electrical power: $P_{elec} = \frac{P_{mech}}{\eta}$ (thruster efficiency $\eta \approx 0.55$ at high load[T200])

Speed	F_D (N)	P_{mech} (W)	η	P_{elec} (W)	Notes
1 m/s cruise	11.6	11.6	0.30[T200]	39	Low efficiency
4 m/s peak	162	648	0.55[T200]	1,178	High efficiency

4 m/s requires 1.2 kW propulsion power (30× cruise power)

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Power scales with velocity cubed because power equals force times velocity. Thruster efficiency varies with load. At 1 meter per second, mechanical power required is 11.6 watts, but thruster efficiency at light load is only 30 percent, which gives us a minimum electrical power requirement of 39W

At 4 meters per second, mechanical power required is 648 watts - much higher than at cruise speed. At heavy load, thruster efficiency increases to 55 percent, so electrical power is 1,178 watts.

The critical number: 1,178 watts propulsion at peak versus 39 watts at cruise. This is 30 times more power for 4 times speed, which is helped by efficiency gains with higher speed

However this cubic scaling makes sustained high-speed underwater operation challenging. The constraint is battery energy, where a larger battery weighs much heavier

Thruster Selection

Model	Thrust (N)	Power (W)	Depth (m)	Mass (kg)	Cost ($)	Thrust/Cost
T200	**51.5 fwd**	**390 max**	**300**	**0.427**	**230**	**0.22**
SeaBotix BTD150	28	80	150	0.5	800	0.035
Maxon MT30	49	180	6000	0.45	2,500	0.020
T500	158	1000+	300	1.1	690	0.23

4× T200 Configuration:

- Total thrust: **206 N**
- Required: 162 N
- Propulsion cost: $920
- ESCs (4× 30A): $160

Justification:

- 6-20× lower cost than alternatives
- Adequate thrust
- 300m depth rating (vs 250m spec)
- Proven reliability

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Four thruster configurations were evaluated: SeaBotix, Maxon, and Bluerobotics T200 and T500 thrusters. SeaBotix has good efficiency but insufficient thrust: 28 newtons versus 51.5 newtons for T200. Maxon has 6000 meter depth rating and costs much more - unnecessary for 250 meter requirement. T500 provides 158 newtons thrust but weighs much 1.1 kilograms.

T200 offers best thrust-to-cost ratio at 0.22 newtons per dollar. Four T200 thrusters provide 206 newtons total thrust for 162 newtons required - 27 percent safety margin. This margin accommodates deviation in drag coefficient calculations.

We also need 4 Electronic Speed Controllers. We need one for each of the four thrusters. This is the small electronic board that takes the command from our flight controller to control the motor's speed and direction.

Power Budget Analysis

System Power Budget

Subsystem	Cruise (W)	Peak (W)	Notes
Propulsion (4× T200)	39	1,178	Dominant at peak
Payload (camera, lighting and sonar)	30	30	Low-light USB
Navigation sensors	5	5	IMU, depth, GPS
Control (RPi4+Nav)	10	10	ArduSub firmware
Comms (WiFi/Iridium)	2	2	Surface only
TOTAL	**86 W**	**1,225 W**	

$$P_{avg} = 314 \text{ W (Accounting for mission profile)}$$

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Navigation sensors	5	5	IMU, depth, GPS
Control (RPi4+Nav)	10	10	ArduSub firmware
Comms (WiFi/Iridium)	2	2	Surface only
TOTAL	86 W	1,225 W	

P_{avg} = 314 W (Accounting for mission profile)

The 30 watt payload specification is a combined budget for all payload components: camera at 2.5 watts, sonar at 2 to 5 watts, and lighting at around 20 watts adjustable.

Propulsion dominates total power at peak speed, with 1,178 watts for propulsion alone. This gives us a total power of around 1.2kW

Fortunately our mixed mission profile gives a much lower average power of 314 watts. This determines battery capacity requirements.

Battery Sizing

Energy Requirements:

$$E = P_{avg} \times t = 314\text{ W} \times 2\text{ h} = 628\text{ Wh required}$$

Option	Voltage	Capacity	Energy	Mass	Cost
Blue Robotics 3×18Ah	**14.8V**	**18Ah**	**803 Wh**	**4.05 kg**	**$1,275**
Blue Robotics 2×18Ah	14.8V	18Ah	532 Wh	2.7 kg	$800
Samsung 35E (4S6P)	14.8V	21Ah	311 Wh	1.5 kg	$310-590
SubCtech PowerPack	14-50V	Custom	650-3400 Wh	Varies	$3-10K+

Selected: 3× Blue Robotics 18Ah

- Energy: 803 Wh
- Endurance: 2.6 hrs @ 314W
- Proven platform (BlueROV2)

Justification:

- 2× config: only 532 Wh (insufficient)
- Samsung 35E: DIY, higher risk
- SubCtech: 2.5-8× cost, overkill

The minimum energy requirement is 314 watts times 2 hours which equals 628 watt-hours minimum.

Four battery options were evaluated. Two Blue Robotics 18Ah batteries provide only 532 watt-hours, insufficient for 628 watt-hour requirement. Custom Samsung 35E pack provides 311 watt-hours at lower cost, but requires self-assembly and custom pressure housing. SubCtech PowerPack offers professional-grade performance with 6000 meter depth rating but costs 2.5 to 8 times more.

Three Blue Robotics 18Ah batteries provide 803 watt-hours - 28 percent margin over requirement. This enables 2.6 hour missions at 314 watts average power. This configuration is proven in the existing BlueROV2 platform with integrated battery management system.

Mechanical and Structural Analysis

Mechanical and Structural Analysis

Material Selection and Component Specifications

Pressure Housing Comparison:

Material	Yield (MPa)	Density	Cost/kg	250m Rating
Al 6061-T6	276	2,700 kg/m³	$7	Excellent
Ti Grade 5	880	4,430 kg/m³	$30	Overkill (6000m+)
Acrylic	70	1,180 kg/m³	$4	Insufficient

Selected: Blue Robotics 3" Aluminum Enclosures

- ID: 74.7mm, Thickness: 6.35mm
- Depth: 500m (2× safety)
- Hard anodized

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Three materials were compared for the pressure housing. Aluminum has yield strength of 276 megapascals and density of 2,700 kilograms per cubic meter. Titanium has 880 megapascals yield strength but costs 30 dollars per kilogram versus 7 dollars for aluminum. This is unnecessary for 250 meter depth. Acrylic has only 70 megapascals yield strength, insufficient for 250 meter external pressure.

Blue Robotics 3 inch aluminum enclosures were selected. Internal diameter is 74.7 millimeters, rated to 500 meters depth - twice the required safety margin. Hard anodizing provides corrosion resistance.

Pressure Vessel Design - Theory

Basic Thin-Walled Cylinder Theory

For external pressure P on cylinder with radius R and wall thickness t:

$$\text{Hoop stress: } \sigma_\theta = \frac{P \cdot R}{t}$$

Apply Safety Criteria

Stress must not exceed allowable stress S (with weld efficiency E):

$$\sigma_\theta \leq S \cdot E$$

$$\frac{P \cdot R}{t} \leq S \cdot E \quad \Rightarrow \quad t \geq \frac{P \cdot R}{S \cdot E}$$

ASME Section VIII Refinements[ASME]

- Add biaxial stress correction: denominator becomes $(S \cdot E - 0.6P)$
- Add corrosion allowance: $+C_A$ term

$$\boxed{t = \frac{P \cdot R}{S \cdot E - 0.6P} + C_A}$$

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Pressure vessel design starts from thin-walled cylinder theory. Hoop stress equals P R over t. This stress must not exceed allowable stress S times weld efficiency E.

Rearranging gives minimum thickness t greater than or equal to P R over S E. This is the basic thin-wall formula.

ASME Section VIII adds two refinements. First, the 0.6P biaxial stress correction in the denominator accounts for both circumferential and longitudinal stresses acting simultaneously. Second, corrosion allowance C-A is added for long-term durability in marine environments.

The final formula gives us the standard formula for pressure vessel design under external pressure.

Pressure Vessel Design - ASME Calculation

Operating Conditions:

- Pressure: $P = \rho g h \approx 2.52$ MPa (25.2 bar)
- With safety factor 3x, design pressure: $P_d = 7.56$ MPa

ASME Section VIII Formula (External Pressure):[ASME]

$$t = \frac{P \cdot R}{S \cdot E - 0.6P} + C_A = 6.3mm$$

Where:

- $P = 7.56$ MPa
- $R = 50$ mm (for 3" tube)
- $S = 92$ MPa (Al 6061-T6: σ_{yield}/safety factor of $3 = 276/3$)
- $E = 1.0$ (seamless)
- $C_A = 2$ mm (corrosion)

Blue Robotics 3" tubes has thickness of 6.35 mm **(Feasible)**

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Blue Robotics 3" tubes has thickness of 6.35 mm (Feasible)

Operating pressure at 250 meters is rho g h equals 2.52 megapascals. With safety factor of 3, design pressure is 7.56 megapascals.

Applying ASME Section VIII formula (standard for design UAV vessels), calculation gives us 6.3 millimeters minimum thickness, using a safety factor of 3 for the opreating pressure and yield stress.

Blue Robotics 3 inch tubes have 6.35 millimeter wall thickness - just nice for our calculated requirement. This validates the pressure housing design.

Mass and Cost Budgets

Mass and Cost Budgets

Mass & Cost Summary

Subsystem	Mass (kg)	Cost ($)	Key Components
Propulsion	1.88	1,080	4× T200 + ESCs
Power	4.55	1,755	3× 18Ah batteries + housing
Control & Navigation	0.62	765	RPi4 + Navigator + Bar30 + GPS
Payload	0.96	3,370	Ping360 ($2,750) + camera + light
Communications	0.12	310	WiFi + Iridium
Structure	5.50	1,917	Frame, foam, fairings, penetrators
Total	**15.67 kg**	**$9,197**	

- **Mass:** 15.67 kg total, providing a 37% margin under the 25 kg limit.
- **Cost:** $9,197 total build cost
- **Key Drivers:** Power/Structure are largest mass contributors; Payload (Ping360) is the largest cost.

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(Mass Details) The mass budget shows the AUV will weigh approximately 15.7 kg, well under the 25 kg limit with 37 percent margin. The largest contributors are the structure and power system . This substantial margin allows for future additions like the acoustic modem (approximately 1.5 kg) without exceeding the weight limit.

(Cost Details) The estimated build cost of 10k dollars represents 15-20 percent of comparable commercial AUV systems (50-150K range). Optional additions like the EvoLogics acoustic modem (12K) or Nortek DVL (20K) would increase total cost but are not required for basic cable inspection missions. The design prioritizes core components to minimize cost while maintaining technical performance.

Conclusions

Requirements Verification

Requirement	Specification	Achieved	Status
Mass constraint	<25 kg	15.7 kg	Met
Endurance	2 hours	2.6 hrs (mixed)	Met
Cruise speed	1 m/s	1 m/s	Met
Peak speed	4 m/s	4 m/s	Met
Payload power	30W	30W (all)	Met
Overall Feasibility			**Viable**

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Payload power	30W	30W (all)	Met
Overall Feasibility			Viable

All requirements have been met. Mass is 15.7 kilograms, much less than the 25 kilogram limit. Endurance is 2.6 hours with 80/20 mission profile, exceeding 2 hour requirement. Cruise speed of 1 meter per second is achievable with 40W propulsion. Peak speed of 4 meters per second is achievable with 1.2kW watts propulsion and 206N total thrust. Payload power is 30 watts total for camera, sonar, and lighting.

The mixed mission profile reduces average power to 314 watts, making the design feasible.

Design Conclusions

1. **Power scales as v^3:** 4 m/s requires 30× more power than 1 m/s
2. **Mission profile approach:** Mixed speed profile (80% cruise) enables 2-hour endurance
3. **Hydrodynamic optimization critical:** Low C_D (0.28-0.32) essential for achieving 4 m/s
4. **Component selection:** T200 thrusters offer best thrust-to-cost ratio (0.22 N/$)

Strengths:

- COTS components
- 37% mass margin
- 28% endurance margin
- Modular design

Constraints:

- Low-drag hull required
- IMU drift without DVL

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The fundamental constraint is that power scales with velocity cubed, so we need much higher minimum power for fast peak speeds.
The mission profile approach is essential: operating primarily at cruise speed with brief sprints enables both 4 meters per second peak capability and 2 hour endurance within 25 kilogram weight limit.
Hydrodynamic optimization is also important. Low drag coefficient of 0.28 to 0.32 is achieved through a torpedo hull shape with 4 to 1 length-to-diameter ratio. Higher drag would require more thrust, more power, heavier batteries.
Component selection focused on cost-effectiveness, specifically for the thrusters. Multiple commercial-Off-The-Shelf components from Blue Robotics ecosystem reduce integration risk and cost. These COTS components are proven in thousands of deployments, with established supply chains and documented reliability.
Strengths of our design include large mass and weight margins, where the 40 percent mass margin enables future additions like the acoustic modem at 1.5 kilograms. The 25 percent endurance margin provides operational flexibility for longer missions or unexpected delays.

However our power constraints are quite tight. The low-drag form is essential - higher drag would easily exceed available thrust and increase power requirements.

Appendix: Datasheets

Selected Component Specifications

- T200 Thruster
- Navigator Flight Controller & Bar30 Depth Sensor
- 18Ah Battery & 3" Enclosure
- Ping360 Sonar & RockBLOCK Iridium

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T200 Thruster

- Thrust: 51.5 N fwd @ 16V
- Max power: 390W
- Efficiency: 30% @ light load, 55% @ heavy load
- Depth rating: 300m
- Mass: 427g air, 239g in water
- Cost: $230

Source: bluerobotics.com/store/thrusters/t200-thruster-r2-rp/

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Navigator & Bar30

Navigator Flight Controller:

- Dual IMUs: ICM-42688-P + ICM-20602
- Dual magnetometers
- 16 PWM, 4 UART
- RPi4 direct mount, ArduSub
- Power: 10W, Cost: $220

Bar30 Depth Sensor:

- Range: 0-300m
- Resolution: 2mm
- Cost: $90

18Ah Li-ion Battery:

- Voltage: 14.8V (4S)
- Capacity: 267.6 Wh each
- $3\times$ = 803 Wh total
- Mass: 1.35 kg each
- Cost: $425 each

3” Al Enclosure:

- Wall: 6.35mm Al 6061-T6
- Depth: 500m rated
- Cost: $250

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Ping360 & RockBLOCK

Ping360 Scanning Sonar:

- Frequency: 750 kHz
- Range: 2-50m
- Resolution: 1-2° angular
- Power: 2-5W
- Depth: 300m
- Cost: $2,750

Cable detection in zero-visibility

RockBLOCK 9603N:

- Network: Iridium SBD
- Message: 340B uplink
- Coverage: Global
- Power: 0.8W avg
- Cost: $260 + $15/mo

GPS position reporting

Sources: bluerobotics.com; sparkfun.com

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- Navigator Flight Controller: https://bluerobotics.com/store/comm-control-power/control/navigator/
- Bar30 Depth Sensor: https://bluerobotics.com/store/sensors-cameras/sensors/bar30-sensor-r1/
- 18Ah Li-ion Battery: https://bluerobotics.com/store/comm-control-power/powersupplies-batteries/battery-li-4s-15-6ah/
- Ping360 Sonar: https://bluerobotics.com/store/sonars/imaging-sonars/ping360-sonar-r1-rp/
- 3" Watertight Enclosures: https://bluerobotics.com/store/watertight-enclosures/wte-vp/
- WetLink Penetrators: https://bluerobotics.com/store/cables-connectors/penetrators/wlp-vp/

Communications:

- RockBLOCK 9603N Datasheet: https://cdn.sparkfun.com/assets/4/d/2/1/1/DS_Iridium_9603_Datasheet_031720_2_.pdf

Commercial AUV Comparisons:

- BlueROV2: https://bluerobotics.com/store/rov/bluerov2/
- ecoSUB Datasheet: https://www.unmannedsystemstechnology.com/wp-content/uploads/2024/05/240305-ecoSUBm-P-datasheet.pdf
- L3Harris Iver3 Spec Sheet: https://www.l3harris.com/sites/default/files/2022-11/ims-maritime-Iver3-Spec-Sheet.pdf

Hydrodynamics & Engineering:

- MDPI - CFD Study Torpedo AUV: https://www.mdpi.com/2311-5521/6/7/252
- SCIRP - AUV Drag Coefficient Analysis: https://www.scirp.org/html/2-2320148_49513.htm
- ASME BPVC Section VIII - Pressure Vessels: https://www.asme.org/codes-standards/find-codes-standards/bpvc-viii-1-bpvc-section-viii-rules-construction-pressure-vessels-division-1