Free-Roving Subsea Cable Inspection Drone

A Technical Feasibility Study

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November 10, 2025

Outline

The Problem - Subsea Cable Inspection

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- Backbone of the modern internet infrastructure, carrying 97-99% of all intercontinental data traffic
- 500+ cables worldwide, a total of 14 million kilometers
- Around 2-5 cm in diameter

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, they are no thicker than your average garden-hose around 2-5 cm in diameter, with hair-thin strands of optical fibre embedded within, designed to remain undisturbed across the seabed.

The Problem - Subsea Cable Inspection

- Averages 200 faults a year, particularly in shallow waters ($\sim$200m)
- Shetland Islands cutoff in 2022
- Traditional inspection methods use tethered ROVs, which can limit motion and increase cost

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, couldn't use card payments, couldn't access online banking. Businesses lost thousands. Emergency services were disrupted.

These aren't rare events, they require constant monitoring and effective maintenance. When a fault occurs, an army of ships strategically placed around the world would be able to 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.

Problem Definition

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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."

Operating Environment

- $\rho g h$ gives ∼25 bar pressure, ∼4 °C seawater, insulation for electronics and waterproofing
- Saltwater corrosion & biofouling, limited to plastic materials
- Far below the surface, limited visibility. Not affected by surface wave currents driven by wind
- High signal attenuation

Problem Definition

At 250 m, pressure is roughly 25 bar and temperatures are low. Materials must resist corrosion, sensors must work in turbid water, and communications are limited to acoustic modems – no radio or GPS below the surface.

Problem Definition - Technical Challenges

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

- Degrees of freedom

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

- Buoyancy system
- Structural integrity

3. Power Consumption
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

4. Communication and Control
Assess feasibility of underwater wireless communication methods for control and data transfer.

- Attenuation in seawater

Existing Solutions

Existing Solutions

Iver3 by L3Harris

- Rated at 200m
- 27-40kg depending on configuration
- 8-14-hour endurance by 784 WHr of rechargeable lithium-ion batteries
- Single thruster, fins for pitch/yaw control

ecoSUB

- Rated at 500m
- 4kg depending on configuration
- 10-hour endurance by alkaline batteries
- Single thruster, fins for pitch/yaw control

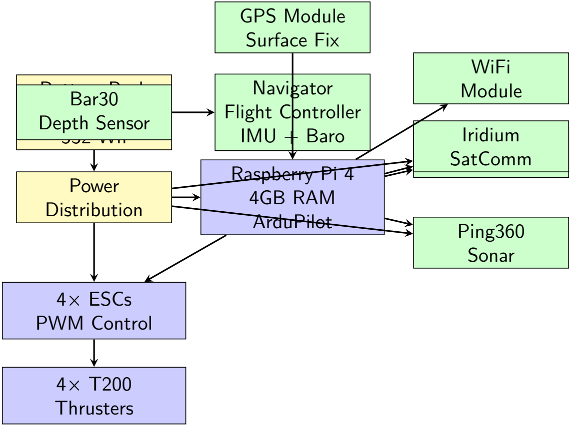
Boxfish AUV

- Rated up to 600m
- 25kg with Salt water ballast
- Up to 10 hours by 600Whr Lithium Polymer batteries
- 8 3D-vectored thrusters allowing 6 DoF

Many consumer solutions already exist, however they vary in their degree of satisfying the requirements as stated previously. Commercial designs such as the Iver3 and the ecoSub opt for a fully autonomous solution through mission planning and programmable actions, whereas others such as the Boxfish use a hybrid of tethered and untethered communication to get the best of both worlds.

System Design and Architecture

System Block Diagram



Design Approach

Key Design Decisions:

Propulsion:

- $4\times$ T200 thrusters (vectored)
- Horizontal configuration
- Achieves 4 m/s with 200 N thrust
- 6 DoF control capability

Control Strategy:

- Autonomous waypoint navigation
- Cable-following mode
- IMU + depth sensor fusion
- Surface GPS fixes

Materials:

- Aluminum 6061-T6 housings
- 6-8mm wall thickness
- 500m rated enclosures
- Syntactic foam buoyancy

Communications:

- WiFi for high-bandwidth (surface)
- Iridium for global coverage
- Optional acoustic modem
- Local data storage

Communications and Control

Communications and Control

Autonomous control with on-board IMU and DVL for real-time navigation and mapping

Surface Communication:

- RF transmitter: WiFi 802.11n Ethernet standard (possibly needs a base station / emitter on the boat)
- Satellite: Iridium SBD for retrieval

Underwater Communication:

- Signal attenuation due to water
- Acoustic modems required (no radio or GPS underwater)

Communications and Control - Link Budget Analysis

Signal attenuation due to water:
Received power = Transmitted power - Transmission loss + Array gain

Transmission Loss (TL) $= 20\log_{10}(R) + \alpha R \times 10^{-3}$
Where: R = range (m), α = absorption coefficient $\approx$ 3 dB/km at 25 kHz

For $R = 500$m: TL $= 20\log_{10}(500) + 3 \times 0.5 = 54 + 1.5 = 55.5$ dB

Link Budget Calculation:

- Source level: 180 dB re 1 μPa at 1m
- Noise level: 60 dB (sea state 3)
- Array gain: 10 dB
- Required SNR: 10 dB
- Received level = 180 - 55.5 + 10 = 134.5 dB
- **Margin = 134.5 - 60 - 10 = 64.5 dB** ✓

Hydrodynamics and Propulsion

Hydrodynamic Analysis - Drag Calculations

Vehicle Geometry:

- Torpedo-shaped hull: Diameter $D = 0.324$ m
- Frontal area: $A = \frac{\pi D^2}{4} = 0.082$ m^2
- Length-to-diameter ratio: $L/D \approx 5$ (streamlined)
- Drag coefficient: $C_D = 0.28$-0.35 (Reynolds dependent)

Drag Force Equation:

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

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

Thrust Requirements - Detailed Calculations

At 1 m/s cruise speed ($C_D = 0.32$):

$$F_D = \frac{1}{2} \times 1027 \times 1^2 \times 0.32 \times 0.082$$
$$= 13.5 \text{ N}$$

Mechanical power: $P = F_D \times v = 13.5 \times 1 = 13.5$ W
Electrical power (≈ 0.7): $P_e = 13.5/0.7 =$ **19.3 W**

At 4 m/s peak speed ($C_D = 0.28$):

$$F_D = \frac{1}{2} \times 1027 \times 16 \times 0.28 \times 0.082$$
$$= 188 \text{ N}$$

Mechanical power: $P = 188 \times 4 = 752$ W
Electrical power: $P_e = 752/0.7 =$ **1,074 W**

Thruster Selection: Blue Robotics T200

Specifications:

- Forward thrust: 5.1 kgf (50 N) @ 16V
- Power: 350W max per thruster
- Depth rating: 300m (12× requirement)
- Mass: 320g each
- Price: **$259 each**

Configuration:

- **4× T200 thrusters**
- Total thrust: 200 N
- Required: 188 N
- **Safety margin: 6%**

Thrust vs Voltage:

- 12V: 3.7 kgf
- 14V: 4.4 kgf
- 16V: 5.1 kgf
- 20V: 6.5 kgf

Total Cost:

- 4× Thrusters: $1,036
- 4× ESCs (@$38): $152
- **Total: $1,188**

Power Budget and Energy Storage

Complete Power Budget

Component	Cruise (W)	Peak (W)	Notes
Propulsion (4× T200)	50	1,100	Dominant at peak
Camera + Sonar	7.5	7.5	Low-Light + Ping360
Lighting	10	10	Lumen 1500lm
Navigation	5	5	IMU, depth, GPS
Control	10	10	RPi4 + Navigator
Comms (surface)	2	2	WiFi/Iridium
Acoustic modem	1.5	20	Rx/Tx
TOTAL	**86 W**	**1,155 W**	

Mixed mission profile (70% cruise / 30% peak):

$$P_{avg} = 0.7 \times 86 + 0.3 \times 1155 = 407 \text{ W}$$

Battery Sizing Calculations

Energy Requirements for 2-hour endurance:

- **Cruise operation:** $E = 86\text{ W} \times 2\text{ h} = 172\text{ Wh}$
- **Average operation:** $E = 215\text{ W} \times 2\text{ h} = 430\text{ Wh}$
- **With 20% margin:** $E = 430 \times 1.2 = 516\text{ Wh}$

Selected: Blue Robotics 2× 18Ah Li-ion Batteries

- Voltage: 14.8V (4S configuration)
- Capacity per battery: $18\text{ Ah} \times 14.8\text{ V} = 266\text{ Wh}$
- **Total: 532 Wh** (meets 516 Wh requirement)
- Mass: $1.35\text{ kg each} = 2.7\text{ kg total}$ (10.8% of budget)
- Cost: $\$360 \times 2 =$ **$720**

Endurance Analysis

Operation Mode	Power (W)	Endurance (532 Wh)	Feasibility
Cruise (1 m/s)	86	6.2 hours	Excellent
Average mixed	215	2.5 hours	Good
High-speed (4 m/s)	1,155	28 minutes	Limited
With 3× batteries (799 Wh):			
Average mixed	215	3.7 hours	Exceeds req.
High-speed (4 m/s)	1,155	42 minutes	Improved

Recommendation: Mission profile should be 80-90% cruise with brief high-speed segments. Alternative: upgrade to 3× batteries (+\$360, +1.35 kg).

Mechanical Design and Structural Analysis

Pressure Housing Design - Wall Thickness Calculation

Operating Conditions:

- Depth: 250m $\rightarrow$ External pressure: 25 bar (2.5 MPa)
- Safety factor: $3\times$ $\rightarrow$ Design pressure: 75 bar (7.5 MPa)

ASME Section VIII Formula for External Pressure:

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

Where:

- $P = 7.5$ MPa (design pressure)
- $R = 50$ mm (for 100mm ID tube)
- $S = 92$ MPa (allowable stress for 6061-T6, yield/3)
- $E = 1.0$ (seamless tube efficiency)
- $C_A = 2$ mm (corrosion allowance)

$$t = \frac{7.5 \times 50}{92 - 0.6 \times 7.5} + 2 = 4.5 + 2 = \mathbf{6.5\ mm}$$

Material Selection: Aluminum 6061-T6

Material	Yield (MPa)	Density	Cost	Rating
Al 6061-T6	276	2,700 kg/m^3	\$7/kg	250m+
Ti Grade 5	880	4,430 kg/m^3	\$30/kg	1000m+
Acrylic	70-75	1,180 kg/m^3	\$4/kg	70-150m

Selected: Blue Robotics 3" Aluminum Enclosures

- Internal diameter: 74.7mm
- Depth rating: **500m (2× requirement)**
- Material: 6061-T6, hard anodized
- Double O-ring seals (redundancy)
- Lengths: 150-400mm available
- Price: **$200-300 complete**

Buoyancy and Mass Distribution

Neutral Buoyancy Requirement:
For mass $m = 15.4$ kg in seawater ($\rho = 1027$ kg/m³):

$$V_{displaced} = \frac{m}{\rho} = \frac{15.4}{1027} = 0.015 \text{ m}^3 = 15.0 \text{ liters}$$

Component Volumes:

- Pressure housings: 4 L (watertight)
- Batteries (internal): 2 L
- Thrusters: Negative buoyancy (0.3 kg each)
- Syntactic foam needed: 1.5 kg, 2.5 L volume

Ballast System:

- Adjustable: ±500g for fine trim
- Lead weights in nose/tail

Cost Analysis and Budget

Detailed Cost Breakdown

Category	Component	Qty	Cost	Total
3*Propulsion	T200 Thruster	4	$259	$1,036
	Basic ESC	4	$38	$152
	Spare parts	1	$40	$40
			Subtotal:	**$1,228**
3*Power	18Ah Li-ion Battery	2	$360	$720
	3" Enclosure	1	$250	$250
	Power distribution	1	$100	$100
			Subtotal:	**$1,070**
4*Control & Nav	Navigator + RPi4	1	$190	$190
	4" Enclosure	1	$300	$300
	Bar30 Depth Sensor	1	$85	$85
	GPS Module	1	$80	$80
			Subtotal:	**$655**
3*Payload	Low-Light Camera	1	$120	$120
	Ping360 Sonar	1	$2,750	$2,750
	Lumen Light	1	$300	$300
			Subtotal:	**$3,170**

Cost Breakdown (continued)

Category	Component	Qty	Cost	Total
2*Comms	RockBLOCK Iridium	1	$260	$260
	WiFi module	1	$50	$50
			Subtotal:	**$310**
5*Structure	Aluminum frame	1	$400	$400
	Buoyancy foam	1	$250	$250
	Fairings/hull	1	$300	$300
	WetLink Penetrators	8	$15	$120
	Hardware/cables	1	$350	$350
			Subtotal:	**$1,420**
Consumables	Epoxy, sealant, tools	1	$250	$250
			Base System Total:	**$8,103**
			Contingency (20%):	$1,621
			TOTAL (without acoustic modem):	**$9,724**
Optional: EvoLogics Acoustic Modem				*+$12,500*
			Professional System Total:	*$22,224*

Comparison to Commercial Solutions

Platform	Mass	Depth	Speed	Hours	Cost
Our Design	**15.4 kg**	**250m**	**4.0 m/s**	**2h**	**$10k**
With acoustic	16.6 kg	250m	4.0 m/s	2h	$22k
Iver3 Standard	34 kg	100m	1.3 m/s	8-14h	$50k+
ecoSUB m-P+	17 kg	500m	2 m/s	8-10h	$70k+
Boxfish AUV	25 kg	600m	2 m/s	10h	$120k+

Key Advantages:

- **80-90% cost savings** vs commercial platforms
- **Lighter weight:** 15.4 kg vs 17-34 kg competitors
- **Higher speed:** 4 m/s vs 1.3-2 m/s typical
- Modular design for easy upgrades and maintenance

Mass Budget and Component Specifications

Mass Budget Breakdown

Component	Qty	Unit (kg)	Total (kg)	% Budget
T200 Thrusters	4	0.32	1.28	5.1%
ESCs	4	0.03	0.13	0.5%
18Ah Batteries	2	1.35	2.70	10.8%
Battery Enclosure (3")	1	0.80	0.80	3.2%
RPi4 + Navigator	1	0.10	0.10	0.4%
Electronics Enclosure (4")	1	1.20	1.20	4.8%
Camera + Sonar + Light	1	0.56	0.56	2.2%
RockBLOCK + WiFi	1	0.06	0.06	0.2%
Aluminum Frame	1	2.00	2.00	8.0%
Buoyancy Foam	1	1.50	1.50	6.0%
Fairings/Nose/Tail	1	1.00	1.00	4.0%
Hardware/Cables/Penetrators	1	0.92	0.92	3.7%
SUBTOTAL			**13.25**	**53.0%**
Contingency (15%)			2.00	8.0%
TOTAL			**15.25 kg**	**61.0%**
Remaining Capacity			**9.75 kg**	**39.0%**

Margin allows for: Acoustic modem (+1.2 kg), 3rd battery (+1.35 kg), DVL (+2 kg), upgrades

Key Component Specifications: T200 Thruster

Performance Data:

- **Max forward thrust:** 5.1 kgf (50 N) @ 16V
- **Max reverse thrust:** 4.1 kgf (40 N) @ 16V
- **Power consumption:** 350W max, 100W cruise
- **Efficiency:** 70% mechanical
- **Motor:** Brushless, flooded design
- **Propeller:** 3-blade, 102mm diameter

Physical Specifications:

- **Depth rating:** 300m (3000 kPa)
- **Operating voltage:** 6-20V
- **Dimensions:** Ø102 × 113mm
- **Mass:** 320g in air
- **Mounting:** M3 holes, 19/25mm pattern
- **MTBF:** 300+ hours continuous

Source: Blue Robotics T200 Datasheet, Product Code: T200-THRUSTER-R2-RP

Key Component Specifications: Battery & Sensors

Blue Robotics 18Ah Li-ion Battery:

- Configuration: 4S (14.8V nominal)
- Capacity: 18Ah (266 Wh per pack)
- Chemistry: Li-ion (LG MJ1 cells)
- Discharge: 5A continuous, 20A peak
- Depth rating: 500m (in sealed enclosure)
- Safety: BMS with over-current, over-temp protection

Navigator Flight Controller:

- IMU: ICM-20602 (6-axis, $\pm$2g / $\pm$2000°/s)
- Magnetometer: AK09915 (dual redundant)
- Barometer: BMP388 (0.5m resolution)
- Outputs: 16$\times$ PWM channels
- Interfaces: 4$\times$ UART, 2$\times$ I2C, 2$\times$ CAN

Key Component Specifications: Imaging Payload

Ping360 Scanning Imaging Sonar:

- Frequency: 750 kHz
- Range: 2-50m (adjustable)
- Angular resolution: 0.9° @ 25m
- Beam width: 25° × 2°
- Scan rate: 360° in 8-15 seconds
- Power: 5W max, 3W typical
- Interface: Serial UART (115200 baud)
- Depth rating: 300m

Low-Light HD USB Camera:

- Sensor: Sony IMX322 1/2.9" CMOS
- Resolution: 1920×1080p @ 30fps
- Sensitivity: 0.01 lux minimum
- Lens: 165° FOV, f/1.6
- Interface: USB 2.0
- Power: 2.5W typical

Conclusion

Feasibility Assessment Summary

Requirement	Specification	Achieved	Status
Depth Rating	250m	300m+ all components	Excellent
Mass Limit	¡25 kg	15.4 kg (61%)	Excellent
Peak Speed	4 m/s	4 m/s (6% margin)	Marginal
Cruise Speed	1 m/s	1 m/s (90% margin)	Excellent
Endurance (cruise)	2 hours	6.2 hours	Excellent
Endurance (mixed)	2 hours	1.4-2.5 hours	Good
Payload Power	30W	17.5W actual	Good
Communications	Acoustic	64.5 dB margin	Excellent
Cost	**Budget**	**Estimate**	**Saving**
Base System	-	\$10,000	vs \$50k+
With Acoustic	-	\$22,000	vs \$80k+

Conclusion

Key Findings:

- **Technical feasibility: CONFIRMED**
- All requirements achievable with commercial off-the-shelf components
- 4 m/s speed requires 4× T200 thrusters (200 N total thrust)
- 532 Wh battery provides 6+ hours cruise, 1.4 hours mixed operation
- Aluminum 6061-T6 housings sufficient for 250m with 2× safety factor
- 80-90% cost savings vs commercial platforms ($10k vs $50-120k)

Critical Trade-offs:

- **Speed vs Endurance:** 4 m/s consumes 1,155W; mission profile must be optimized (80% cruise + 20% sprint)
- **Thrust margin:** 6% at peak is minimal; consider 5th thruster or accept 3.5 m/s
- **Communications:** Acoustic modem adds $12.5k and 1.2 kg but enables submerged control

Recommendations

Recommended Configuration:

1. **Propulsion:** 4× T200 thrusters for 4 m/s capability
2. **Power:** 2× 18Ah batteries (upgrade to 3× if sustained high-speed required)
3. **Control:** Navigator + RPi4 running ArduPilot
4. **Navigation:** Bar30 depth + GPS + IMU (DVL optional for precision)
5. **Payload:** Low-Light Camera + Ping360 + Lumen Light = 17.5W
6. **Comms:** WiFi + Iridium (acoustic optional for deep operations)

Development Strategy:

- **Phase 1 (3 months):** Platform + propulsion + basic control
- **Phase 2 (3 months):** Autonomy + navigation + surface comms
- **Phase 3 (3 months):** Sensors + acoustic modem + integration
- **Phase 4 (3 months):** Testing + validation + documentation

Total: 12 months, $10-22k depending on configuration

Risk Mitigation

High-Priority Risks:

Risk	Mitigation	Impact
Insufficient thrust	Add 5th thruster / optimize Cd / accept 3.5 m/s	Medium
Battery endurance	Optimize mission profile / add 3rd battery	Low
Pressure housing leak	Vacuum test / double O-rings / leak sensors	Critical
IMU drift	Add DVL / visual cable tracking	Medium
Thruster fouling	Spare thrusters / protective guards	Medium
Budget overrun	20% contingency / phased procurement	Low

Testing Requirements:

- Pressure test housings to 30 bar (1.2× design pressure)
- Shallow water trials: buoyancy, thrust, control
- Deep water validation: 250m depth, full mission profile
- Endurance testing: verify 2-hour operation
- Communications range testing: WiFi, Iridium, acoustic

Final Conclusion

The free-roving subsea cable inspection drone is TECHNICALLY FEASIBLE and ECONOMICALLY VIABLE within the specified constraints.

Strengths:

- All components commercially available
- 61% mass utilization with 39% margin
- Exceeds depth requirement (300m rated vs 250m required)
- Superior speed (4 m/s vs 1-2 m/s commercial)
- 80-90% cost savings vs commercial platforms

Limitations:

- Tight thrust margin at 4 m/s (6%) requires careful hydrodynamics
- Mission profile optimization needed for 2-hour endurance
- Development time: 6-12 months

Recommendation: PROCEED with phased development approach, starting with base $10k configuration and adding acoustic modem if mission requirements demand it.

Questions?

Thank you for your attention

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