

Underwater Refuelling-in-Motion: A USV-Towed Submerged Docking Station for AUV Recharge and Rapid Data Offload

UDT 2026

¹Thomas J.J. Meyer, COO, Unplugged, Kristiansand, Norway, tjmm@unplugged.no

²Felipe Lima, Subsea Consultant Aker BP, Stavanger, Norway

³Per Norval Boge, Principal Technology Engineer, DeepOcean, Bergen, Norway

⁴Helge Sverre Eide, COO, Subsea USB, Sandnes, Norway

⁵Geir Gyland, R&D Manager, Unplugged, Kristiansand, Norway

⁶Lars Gunnar Hodnefjell, R&D Manager, Blue Logic, Sandnes, Norway

Aerial refuelling revolutionized air combat by allowing fighter jets to extend range, payload, and mission persistence — effectively turning the sky into an agile, distributed logistics network. This paper introduces a subsea analogue of aerial refuelling: an Uncrewed Surface Vehicle (USV) towed charging station that allows autonomous underwater vehicles (AUVs) to dock, recharge, and offload data while remaining underwater and in motion.

1 Introduction

AUVs (Autonomous Underwater Vehicles) and UUVs (Unmanned Underwater Vehicle) are increasingly central to naval and offshore operations, yet their operational tempo remains constrained by surface recovery, battery replacement, and data offload requirements. Each turnaround demands a manned vessel, favourable weather, and in some cases several hours of deck manual deck handling —conditions seldom available in harsh or contested environments.

In practice, traditional AUV launch, and recovery (LARS) operations are restricted to Sea State 3–4, reducing operational availability to roughly 60% of the year in North Atlantic waters [1] —an unacceptable limitation for sustained or defence missions. Compounding this, crewed support vessels typically cost US \$60 000–250 000 per day, and each recovery cycle demands several hours of work by a four- to six-person deck crew [2-3].

While fixed resident seabed charging stations alleviate AUVs endurance constraints, they are static, detectable, and logistically intensive to install [3], making them unsuitable for mobile or covert operations.

This paper introduces a third approach: a towed, submerged docking station operated behind a surface vessel or Uncrewed Surface Vehicle (USV). The system relocates docking, recharging, AUV mission replanning, and data transfer entirely underwater—an analogue to aerial refuelling—allowing autonomous vehicles to extend endurance, maintain stealth, and operate continuously without the need of surfacing (Fig. 1).



Fig. 1. USV-Towed Submerged Docking Station for AUV Recharge and Rapid Data Offload

Demonstrated in the ACCESS AUV project, a towed docking module deployed behind a vessel achieved 2 Gb/s full-duplex contactless data transfer and 500 W inductive power delivery while being towed at 4 knots.

During coastal trials in Åsenfjorden, Trondheim Fjord (55 m depth), the system demonstrated reliable docking, alignment, and high-speed data and power transfer. A three-stage sensor fusion architecture—combining ultra-short baseline (USBL) positioning, forward-looking sonar, and optical tracking—guided the approach and capture sequence. The results confirms that uncrewed surface vessels (USVs) can function as mobile underwater refuelling platforms and communication hubs, extending AUV endurance and enabling persistent, networked undersea operations.

2 System Architecture

2.1 Overall System Design

The system comprises two primary components: a modified AUV equipped with an integrated wireless docking interface (Fig. 2 and 3) engineered by Blue Logic/Unplugged, and a hydrodynamically stabilised towhead (Fig. 4 and 5) deployed 10–50 m below the surface and connected to a surface vessel or uncrewed surface vehicle via a tensioned umbilical. This configuration positions the docking station below the wave zone, allowing safe, stable operations even in rough sea state while the host platform remains underway.

The towhead incorporates hydrodynamic control surfaces based on EIVA ScanFish technology, real-time positioning sensors, and an alignment funnel that guides the approaching AUV into the docking interface. Once docked, a mechanical latching mechanism secures the connection, and inductive coupling establishes both power transfer and data communication channels simultaneously. The design enables the AUV to dock while maintaining a straight-line trajectory at predetermined depth, requiring no modifications to the AUV control system.

2.2 AUV Modifications

The AUV platform was modified with a custom nosecone housing the secondary-side inductive interfaces for both power and data transfer. An integrated battery management system coordinates charging operations and monitors cell voltages, temperatures, and state of charge

throughout the docking cycle. In addition, a forward-facing LED arrays provide visual references for camera-based final approach guidance. The nosecone also incorporates the mechanical latching interface designed to mate with the towhead docking structure (Fig. 3).

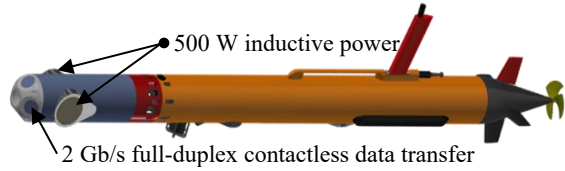


Fig. 2. Modified AUV equipped with an integrated wireless docking interface composed of two inductive coils of 250 W each, delivering 500 W, two set of Tx and Rx gigabit antennas delivering 1 Gbps each

The mechanical latch interface employs actuated fingers that secure the AUV nose upon contact, absorbing minor impact and providing a controlled friction grip without damaging the vehicle. Once engaged, the latch maintains a stable connection throughout towing and charging while allowing limited axial displacement to accommodate motion dynamics. Lateral and angular movement are constrained within defined tolerances, and roll-axis misalignment was found to be particularly critical—if uncontrolled, it can lead to wedging or uneven load distribution between the coupled systems.

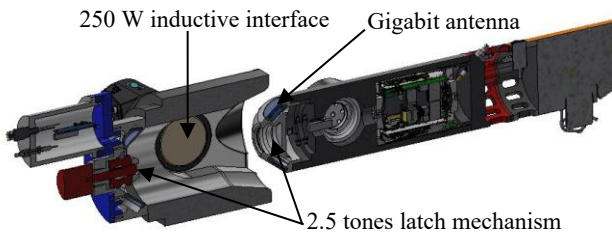


Fig. 3. Cross section of the latching mechanism and AUV nosecone

2.3 Towhead Docking Station

The towhead docking station (Fig. 4 and 5) forms the mobile subsea charging and data transfer interface towed behind a surface vessel or uncrewed surface vehicle (USV). It functions as both the mechanical and electrical connection between the host and the AUV, combining active hydrodynamic control, precision guidance, and a universal coupling system that allows any AUV with a standardised nose interface to dock, recharge, and exchange data while maintaining steady trajectory and depth.

Hydrodynamic wings and actively controlled fins provide depth regulation and station-keeping, compensating for tether dynamics and current variations to maintain stable alignment during towing (Fig. 4).

Integrated sonar, camera, and acoustic positioning sensors feed real-time data to the control loop, allowing the towhead—rather than the AUV—to perform final alignment corrections as docking commences. During the final approach, an alignment funnel guides the AUV into the capture zone, progressively constraining lateral deviation as axial closure proceeds; its tapered geometry transitions from a wide acceptance envelope to a precisely

aligned latching interface.

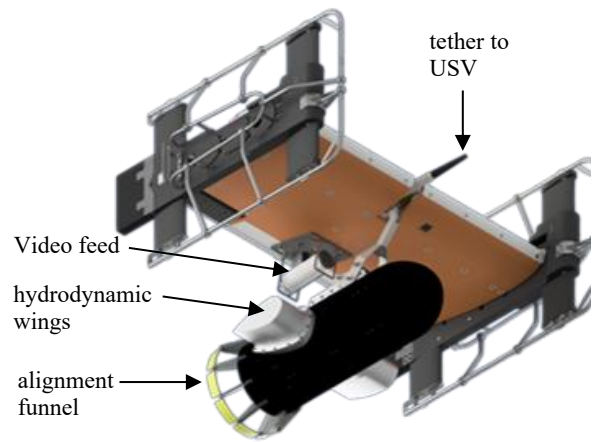


Fig. 4. The towhead structure houses sensors (i) acoustic transponders (ii) primary-side power and data interfaces positioned to mate with corresponding secondary interfaces on the AUV nosecone and (iii) hydrodynamic wings and control fins

A winch system and topside control unit complete the towhead assembly. The control unit enables both manual and automated operation, with switching capabilities allowing human intervention when necessary. Remote access capabilities permitted shore-based monitoring and configuration adjustments during sea trials.



Fig. 5. The towhead structure under swimming pool tests

3 Technical insight

3.1 Positioning the AUV on approach

Docking guidance employs a three-stage sensor fusion approach (Fig. 6)

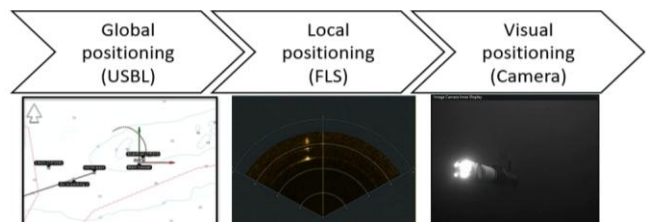


Fig. 6. Sensor transition on approach to docking

An ultra-short baseline (USBL) acoustic system provides coarse range and bearing during initial approach. As distance between the AUV and docking station narrows, a forward-looking sonar refines relative positioning and detects the towhead. Then a camera, located on the towhead tracks the LED markers on the AUV nosecone (Fig. 8) as a feedback loop.

The control algorithm dynamically selects the optimal sensor for each range regime while continuously cross-checking against secondary sensors for fault detection.

Bidirectional sensor transitions enable recovery from signal loss or occlusion, ensuring robust performance in variable conditions. Testing confirmed that local USBL nodes were redundant once global positioning and sonar integration achieved sufficient accuracy.

The guidance system conceptually coordinates vessel speed, tow-cable layback, and towhead control surfaces to maintain a stable intercept geometry for docking. In the current demonstration, however, these integrations were not yet implemented. The Åsenfjorden trials were conducted with experienced vessel operators using manual control from the bridge, without automated coupling to the vessel's speed or navigation systems. This operational mode does not affect the underlying control-system architecture.

Once the AUV enters the alignment funnel, passive mechanical guidance constrains the trajectory, reducing control demand during the final docking phase.

3.2 Wireless charging when docked

The power transfer system employs near-field electromagnetic induction across a nominal 1 cm gap, delivering a combined 500 W through two independent 250 W channels. This pinless design eliminates galvanic contacts, ensuring immunity to biofouling, contamination, and wear common to wet-mate connectors (Fig. 7).

Efficient coupling is maintained across operational displacements, withstanding ± 4 mm axial, ± 7.5 mm lateral, and $\pm 5^\circ$ angular offsets without significant degradation. The system's design depth rating exceeds 1000 m.



Fig. 7. Wireless charging configuration

3.3 Gigabit data offload/upload

The communication interface supports 1 Gigabit Ethernet per transmit/receive channel, and the inductive link can host up to four antennas integrated into the AUV nose section. This configuration enables an aggregate full-

duplex throughput of 2 Gb/s across the same inductive medium (Fig. 8). At this data rate, a 100 GB mission dataset can be offloaded in under seven minutes, allowing rapid turnaround while the vehicle remains submerged.

The interface is hardware-transparent, supporting standard TCP/IP traffic—mission data, video streams, etc—without modification to existing AUV network architectures.

Link establishment occurs in <0.1 second, allowing docking and data exchange without sensor downtime, thereby maintaining situational awareness and reducing turnaround time for time-critical missions.



Fig. 8. Front view of the modified AUV showing the wireless gigabit antennas

4 Operational Demonstration

4.1 Test Environment

Sea trials (Fig. 9) were conducted in Åsenfjorden, Trondheim Fjord (Norway), at an average depth of 55 m. The site provided realistic subsea conditions—moderate currents, sloping seabed, and low vessel traffic—ideal for controlled docking experiments. The available depth allowed the AUV to maintain bottom lock, improving navigation accuracy while keeping the towhead safely submerged below the wave zone.

To minimise collision risk and prevent turbulence interference in shallow water, the vessel and towhead passed the AUV laterally, not directly overhead. The vessel then reduced speed and increased tether layback, allowing the towhead to trail behind the AUV at matching speed and depth. This side-overtake strategy provided stable relative geometry during docking manoeuvres.



Fig. 9. AUV and towhead docking station tested in Åsenfjorden, Trondheim Fjord (Norway). Extended-duration tests performed on wet deck showed that the inductive couplers supported reliable charging, mission preparation, and high-speed data transfer eliminating the need for temporary deck cables and simplifying pre-deployment workflow

The complete integrated system was then operated from the surface vessel (Fig. 10) with the towhead deployed at controlled standoff distances via an instrumented tether.

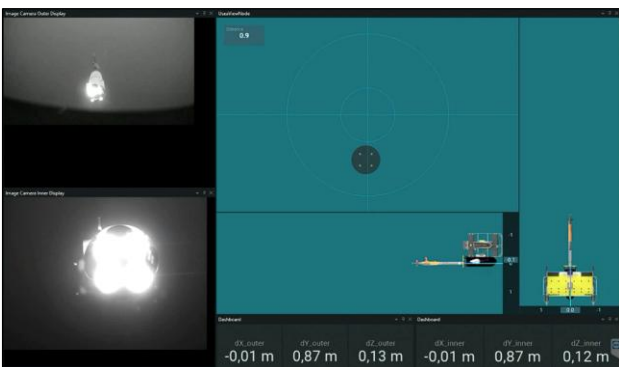


Fig. 10. Graphical user interface displaying the AUV's position relative to the towhead, complemented by a live visual feed of the vehicle.

4.2 Results and Performance

The docking sequence was repeatedly and successfully demonstrated, validating both the mechanical and control architecture. A large portion of the testing was designed to validate the sensors and their suitability for the control algorithms to succeed with automated docking. The test sequences included multiple approach/abort iterations to prove USBL, Sonar, Camera data as input to the docking method. The alignment funnel achieved reliable capture even with moderate trajectory variation, and mechanical latching was tested as part of the final trials.

Power transfer remained stable throughout all docked periods. The battery management system confirmed normal charging profiles equivalent to bench testing. The inductive communication interface-maintained gigabit full-duplex throughput with negligible packet loss.

Stability testing between the AUV and towhead at 7, 13, 20, and 30 m depths in Sea State 3–4 showed minimal dynamic variation, validating the hydrodynamic design across the intended depth envelope. The results confirmed that the towhead-maintained alignment, coupling integrity, and data continuity under representative operational conditions.

5 Lessons learned

5.1 System Design Insight

Towhead design optimisation proved critical to overall docking reliability. The mechanical structure must tolerate AUV misalignment—particularly around the roll axis—to prevent wedging or uneven contact during capture. Material selection for contact surfaces strongly influences friction and docking smoothness, making surface finish and coating properties key design parameters.

The latching mechanism demanded precise actuator sizing to deliver sufficient retention force without unnecessary complexity. Once correctly dimensioned, the interface operated reliably throughout testing, though initial estimates required recalibration based on measured docking loads observed in sea trials.

In addition, vehicle-specific design work is required for each AUV class. The geometry of the docking head and its interface to the AUV must be adapted to the mass distribution, structural layout, and hydrodynamic characteristics of the combined AUV–towhead assembly. Coupling loads, weight distribution, and alignment forces must be analysed for each vehicle type to ensure safe and repeatable capture.

Finally, since the AUV nose section often houses forward-looking sonar (FLS) or other mission sensors, a redesigned nose cone that integrates FLS alongside the docking interface would offer advantages for certain platforms, reducing the need to compromise sensor placement while enabling compatibility with a towed docking system.

5.2 Sensor and Control System Findings

Initial design assumptions suggested that docking would require high-precision navigation inputs from the AUV, such as INS-aided USBL, to maintain a stable relative position during approach. Field testing showed that this level of sensor integration was unnecessary. The system achieved stable approach and capture using the available sensor suite, without additional navigation coupling between platforms. Likewise, local acoustic-positioning systems proved redundant when combined with global USBL and forward-looking sonar, enabling later prototype iterations to remove several sensors without affecting tracking performance.

Control-algorithm tuning nonetheless required substantial refinement to ensure coordinated motion

between the vessel, towhead, and AUV. Early attempts to combine towhead autopilot behaviour with vessel navigation inputs exposed several timing and interface issues, prompting updates to filtering, control logic, and synchronisation.

Visual-based alignment introduced a separate set of challenges. Light pollution emerged as a major issue for image-recognition algorithms: forward-facing lights on the AUV illuminated suspended sediment (Fig. 11), generating false targets that degraded detection reliability. Introducing distinctive lighting patterns and colours on the towhead (Fig. 12) improved discrimination between true markers and background reflections, enabling more consistent visual tracking in turbid water conditions.

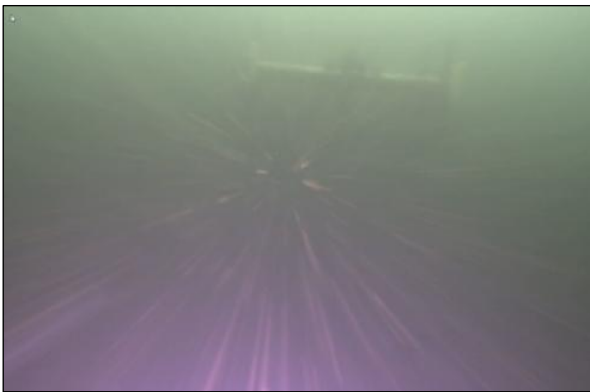


Fig. 11. Forward-facing lights illuminate sediment particles

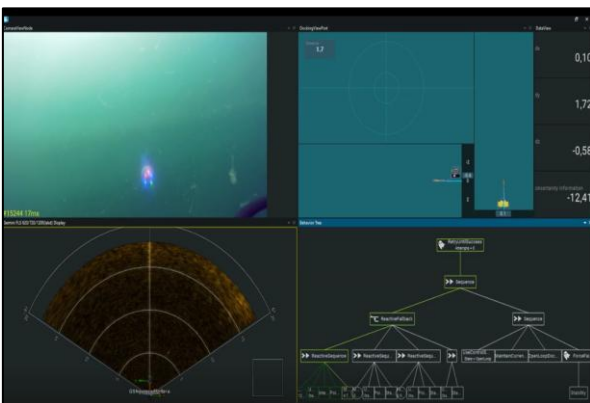


Fig. 12. Test conditions for camera multi-coloured LED.

Together, this three-layer sensing approach—global acoustic positioning, local sonar refinement, and final visual alignment—provided a robust and redundant framework for guiding the AUV from long-range intercept to precise docking.

5.3 Thermal and Power System Observations

Heat production in inductive power transfer elements required more active thermal management. Initial thermal analysis identified potential temperature concerns, leading to the implementation of extended cooling ribs on inductive coupling assemblies. These modifications successfully maintained operating temperatures within acceptable ranges during sustained power transfer operations.

6 Summary or Operational Advantages and conclusion

The towed docking station architecture provides several key operational advantages:

- **Extended endurance:** Enables AUVs to remain submerged for prolonged periods, increasing time on station and reducing visual signature exposure.
- **Extended operational window:** Enables AUVs to remain submerged during poor weather conditions. Eliminating the dependency of weather for recovery to deck.
- **Rapid data exploitation:** Transfers 100 GB in under seven minutes, providing near-real-time intelligence and faster mission retasking.
- **Unlimited refuelling cycles:** The contactless power interface eliminates mechanical wear, contamination, and maintenance downtime.
- **Mobile and unpredictable logistics:** Towed platforms move with surface task groups and cannot be pre-targeted or easily detected like fixed seabed installations.
- **Reduced vulnerability:** In-motion underwater refuelling removes the need for surface recovery—eliminating exposure during the most vulnerable mission phase.
- **Platform-agnostic integration:** Requires no modification to AUV control systems, ensuring interoperability across multiple vehicle classes.
- **Electronic signature on surface:** No need for the AUV to broadcast messages or data while on surface back to support vessel.
- **In-motion stabilized Station:** The towhead's hydrodynamic wings and active fins stabilise its depth and attitude while in motion, providing a predictable path for the AUV to dock into rather than requiring complex manoeuvres/controls.
- **Multi-vehicle swarm support:** Standardising the AUV nose interface would allow one towed station to service several vehicles within the same mission.

For defence applications, this technology enables a new generation of autonomous, networked undersea missions, including persistent ISR, mine countermeasures, and covert logistics.

7 Further work

The next phase of development shall focus on key areas identified as critical for scaling the technology toward operational deployment.

First, autonomous docking precision and reliability remain central to mission success. Continued refinement of control algorithms—particularly in dynamic sea states—will enhance repeatability and robustness. The introduction of machine learning-based trajectory optimisation and fault detection is expected to further reduce human intervention and improve docking success rates under variable conditions.

In terms of system capability, power and data capacity are the principal enablers for larger, more capable autonomous systems. While the demonstrated system delivered 500 W and 2 Gb/s throughput, R&D efforts are

already advancing toward 2.5 kW conformal inductive coils with curved geometries for improved coupling efficiency, and 10 Gb/s subsea wireless data transfer to support next-generation sensor payloads and real-time situational awareness.

Finally, future developments should explore multi-vehicle servicing concepts, where a single towhead could support several AUVs in sequence or concurrently, and the standardisation of docking interfaces to enable a common logistics architecture across multiple vehicle classes and mission types. These advancements will collectively move the system from a prototype capability to a deployable, fleet-ready infrastructure for persistent undersea autonomy.

8 Acknowledgements

The authors gratefully acknowledge the support of the Research Council of Norway through the ACCESS AUV project, which enabled the development and demonstration of the towed submerged docking concept.

Special thanks are extended to project partners USEA Ocean Data, Blue Logic, NTNU, SINTEF, and NORCE for their contributions in system design, simulation, testing, and field validation.

9 References

- [1] Marek Szczotka, AUV launch & recovery handling simulation on a rough sea, *Ocean Engineering*, Volume 246, 2022, ISSN 0029-8018.
- [2] S. Li, Y. Sun, W. Yang, B. Wang, C. Ma, and Z. Tian, "Research on the Average Daily Operating Cost of Oceanographic Research Vessels of Both China and the United States and Its Application Analysis," *Advances in Economics and Management Research*, vol. 6, pp. 47–56, 2023.
- [3] T. J. J. Meyer, H. Mubasier, K. T. Humborstad, H. S. Eide, A. Vasilijevic, and J. C. Torvestad, "Enabling Resident AUV and ROV Subsea Operations: The Role of Wireless Inductive Charging and Docking Stations," *Offshore Technology Conference, Houston, USA, 2025*, OTC-35570-MS. doi:10.4043/35570-MS.

10 Speaker Biographies

Dr. Thomas J.J. Meyer is Chief Operating Officer at Unplugged AS in Norway, where he leads the development of wireless subsea power and communication systems for defence and autonomous operations. He holds a Licence in chemistry a PhD in Physics and an Executive MBA.