Janus Review

A guide to navigating the waters of the USV Industry



2025

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FOREWARD

Dear Valued Clients, Partners, and Industry Colleagues,

In a field flooded with hype and half-formed solutions, The Janus Review was built to do one thing: offer clear, unfiltered insight into the unmanned surface vessel (USV) landscape, from the perspective of those who operate in it.

What began last year as a focused, limited-run publication for a tight circle of industry insiders has quickly evolved thanks to a response that was louder, and broader, than expected. The market demanded that we bring this year's edition to a wider audience, with deeper analysis and expanded contributions. Now in its second year and expanding beyond its original circle, The Janus Review remains committed to the same mission: giving operators, decision-makers, and stakeholders the honest, field-driven information they need.

This year's edition reflects that growth. In addition to our platform evaluations and capability assessments, we've included op-eds and articles from respected voices in maritime autonomy, experts who eat, breathe, and sleep this field. They bring fresh perspectives and critical insight into the trends, tensions, and opportunities shaping the space right now.

In 2025, we've also expanded our evaluation criteria, tracked year-over-year changes, and taken a closer look at launch/recovery methods, software integration, and mission flexibility. We've also called out where meaningful progress has been made, and where the industry still has ground to cover.

At Janus Marine and Defense, we're still guided by the same principle: operators first. We use these systems, we know what matters in the field, and we evaluate through that lens, mission-focused, results-oriented, and unfiltered.

Thank you for reading The Janus Review. If this helps you and your team navigate the USV space with more clarity and confidence, then it's done its job. When you're ready to move beyond the marketing slides and surface-level specs, give us a call. We don't just talk autonomy, we operate in it.

Respectfully,

Jack Dougherty, CEO & Michael Diehl, COO

Janus Marine and Defense LLC

ACKNOWLEDGEMENTS

The editorial team at *The Janus Review* would like to express our deepest appreciation to the individuals and organizations who generously contributed their time, insight, and expertise to this edition. Your willingness to share your work and perspectives plays a critical role in shaping a more informed and connected global maritime autonomy community.

The ideas and opinions presented within this publication are those of the respective contributors and may not necessarily reflect the views of the *Janus Review* editorial team. They are shared in the spirit of fostering dialogue, provoking thought, and encouraging meaningful conversation across our field.

We extend a special thank you to the following contributors:

- Chance Maritime Technologies – www.chancemaritime.com
- Robosys Automation – www.robosysautomation.com
- Ocean Power Technologies (OPT) – www.oceanpowertechnologies.com
- Mahi Autonomy – www.mahi.be
- Autonomous Maritime Services (AMS) – www.autonomousmaritimeservices.com
- The USV Group – www.theusvgroup.com

Each of your contributions strengthens the purpose of The Janus Review: to serve as a curated space for candid discourse, lessons learned, and forward-looking ideas in the uncrewed systems space. We are proud to feature your work and look forward to continued collaboration as the domain continues to evolve.

Lastly we would like to extend a special thanks to Ben Pennington and his team at Polaris Media (https://polarismediapr.com/) for all their help in promoting Janus, the Quarterdeck and now the 2025 Janus Review. Thank you for your partnership and for helping to make this edition possible.

We are already looking forward to seeing what next years edition will hold!

Respectfully,

Jack Dougherty, CEO & Michael Diehl, COO

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WHY READ THIS REVIEW?

The Janus Review was born out of equal parts necessity and curiosity. In an industry filled with glossy brochures and tech demos that rarely see saltwater, we wanted to cut through the noise, to offer something practical, field-aware, and unvarnished. We're operators, builders, testers, and troubleshooters. We work on these platforms, we deploy them, and we see firsthand what works and what doesn't. That perspective shapes every word in this document.

At its core, The Janus Review and this accompanying Supplemental USV Products Document aim to educate, inform, and connect. We've built this report to help demystify the unmanned surface vessel (USV) landscape:

- To give newcomers an honest look at the state of the tech.
- To give experts a reference that actually reflects real-world use.
- And to give everyone a central, unbiased source of insight into who's building what, why it matters, and where it's all headed.

Let's be honest, this isn't the easiest drone domain. Autonomy at sea is hard. Signal loss, unpredictable weather, hostile environments, regulatory gray zones, it's a brutal proving ground. That's why we love it. It's why we built this review. And it's why we update it each year.

What's Inside?

This year's review includes:

- Size class breakdowns and autonomy level guides
- Trends and technological updates that define the current landscape
- Product listings from dozens of USV manufacturers
- Commentary from field operators and autonomy experts
- And, new this year, a standalone USV Products Supplemental Document with detailed, structured entries for each platform

What We Learned from Last Year

The first Janus Review taught us a lot. Feedback from industry peers was clear and honest:

- It was a great reference, for people already familiar with the field.
- It could be more approachable for newcomers.
- It read a little too much like a government report.
- And most importantly: it needed more **product-level detail**.

We listened. This year's version keeps the analysis sharp, but adds more visual structure, more platform-level information, and more accessible language where possible. We also split out the product deep-dives into a companion guide, so readers can navigate the content more intuitively, whether they're skimming or doing a deep-dive.

We hope this year's edition brings clarity, sparks discussion, and maybe even changes a few minds. Whether you're building, funding, regulating, or operating USVs, we hope you find this review as useful as we did putting it together.

Let's get into it.

DISCLAIMERS

Source Limitation: This review is compiled from publicly accessible information found online and presented at trade shows. It does not include any proprietary or confidential data held by Janus Marine and Defense LLC or any other entities within the USV industry.

Accuracy and Completeness: While every effort has been made to ensure the accuracy and completeness of the information in this review, we cannot guarantee that it fully reflects all available details. The provided information is on an "as is" basis, and the conclusions represent the author's interpretations based on the data reviewed.

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Temporal Relevance: The findings and conclusions of this review are relevant as of its publication date. Due to the dynamic nature of the USV and defense industries, some information may become outdated or less applicable over time.

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ANNUAL SUMMARY

HERE'S WHAT WE DISCOVERED

Autonomy Hype vs. Reality: Autonomy is still the headline feature but dig deeper and most systems are just semi-autonomous. Truly adaptive, perception-based USVs that require little to no human intervention are rare. Why? The tech is hard. It's a robot reliant on its sensors, and its autonomy's decision-making ability to operate on a moving corrosive medium to perform its designed mission without breaking itself.

ITAR Walls Are High: Many advanced platforms, especially those in defense space, are ITAR-restricted. That's a major blocker for international sales, integration, and collaboration.

Logistics Are Still a Pain: Launching in rough seas is tough. Multiple USV deployments from shore or sea are slow and gear-heavy, often requiring cranes, ramps, or chase boats. And that doesn't even include the storage required for large scale operations. Scaling up operations adds real logistics strain most overlook.

No Clear Standards in Sight: Interfaces and autonomy stacks are still vendor specific. Government interface standards are slow to react to industry demands, slowing down innovation. The first company with an open, developer-ready API, and makes it accessible to everyone will lead the field. Public, usable standards are key to ecosystem growth.

Swarming is Hot Right Now, but it's mostly in labs: Swarm and distributed USV control are trending, but most efforts are stuck in testing. Robust multi-vessel mission planning, communications and control infrastructures that supports true autonomous swarming just aren't there yet.

Specialization Still Wins: USVs work best when they're built for a clear mission. Try to make one boat do everything, and it won't do anything particularly well. Boats are tools, and good boats are purpose-built.

Hitting on interfacing standards again, let the folks building the platform decide how their vessels and their payloads are controlled. The USV builder knows what the boat is for, give them the flexibility to implement autonomy their way for their customers.

Hull Builders Can Deliver, With the Right Mindset: Boatbuilders can make great USVs, but only if they break from manned design habits. USVs must be optimized for payload, endurance, sensor layout, and shock isolation, not human comfort.

Autonomy Isn't Plug-and-Play: There's still no true bolt-on autonomy system. Builders need deep partnerships with autonomy providers or full vertical integration to succeed. Even modular autonomy requires vessel-specific tuning and expert validation. You can't just slap a brain on a hull and call it good.

Why Tech is Still Lagging: Demand remains low. Most USVs are built in very small numbers. With limited customer pull and little pressure to scale, R&D investment stays conservative. Until the orders pick up, the tech curve will stay slow.

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USV SIZE CLASS BREAKDOWN

WHY IT MATTERS AND WHAT IT MEANS

Size matters, especially when it comes to Unmanned Surface Vessels (USVs). While autonomy levels often steal the spotlight, size-based classification plays a crucial role in defining how these vessels operate, what they can carry, and where they thrive. A 40-foot reconnaissance USV navigating coastal waters has vastly different challenges than a 300-foot autonomous mothership patrolling the open ocean. That's why size classification isn't just about dimensions, it's about mission adaptability, transportability, and survivability in unpredictable environments.

The U.S. Navy's Family of Unmanned Surface Vehicles (FoUSV) breaks USVs into four main size categories: Small (SUSV), Medium (MUSV), Large (LUSV), and Extra-Large (XLUSV). Each class is designed with specific missions in mind, from shallow-water mine countermeasures to long-range reconnaissance and high-endurance payload delivery. Other nations, including China and European allies, follow similar size-based classification systems, though their priorities and approaches may differ.

Want to know which USV class is built for what? Here's a quick guide to the essentials:

Size Class	*Vessel Length (ft)*	*Vessel Length (m)*	*Beam (ft)*	*Beam (m)*	*Optimal Operational Sea-State*	*Available Gross Weight (tons)*	*Common USV Applications*
SUSV	5-40	1.5-12.2	2-12	0.6-3.7	0-4	0-10	Coastal surveillance, shallow-water surveys, mine countermeasures, bathymetric mapping.
MUSV	41-200	12.5-61.0	13-50	4.0-15.2	3-8	15-200	Long-range ISR, reconnaissance, hydrographic surveys, and hazardous area missions.
LUSV	201-300	61.3-91.4	50-75	15.2-22.9	7-9	200-300	High-endurance payload delivery, ISR, and advanced autonomous operations in open-ocean conditions.
XLUSV	>300	>91.4	>75	>22.9	7+	300-400	Conceptual vessels for logistics support, combat roles, and mothership operations, not yet widely deployed.

While these categories provide a useful framework, the real world isn't always so neatly defined. Technological advancements are blurring the lines, with smaller USVs taking on missions once reserved for larger ones, and modular payloads reshaping what a single platform can do. Add in evolving autonomy, regulatory hurdles, and global variations, and you've got a classification system that, while necessary, is constantly adapting.

CLASSIFYING USVS BY SIZE

THERE IS A LOT MORE TO CONSIDER

Trying to classify Unmanned Surface Vessels (USVs) by size is like organizing a garage full of power tools some look similar but pack wildly different and unique uses. Thanks to rapid advancements in autonomy and modularity, size alone doesn't tell the full story anymore. Small USVs can now punch above their weight, taking on missions once reserved for larger vessels. Some platforms can swap out modular payloads on the fly, changing their capabilities faster than a pit crew at a Formula 1 race. Meanwhile, sea-state survivability varies widely, even among vessels of the same class, making rigid classifications unreliable. Add in the rise of USV swarms, where a fleet of small vessels functions as one cohesive unit, and things get even more complicated. And let's not forget the evolving regulatory landscape, which still struggles to keep up with these fast-moving technologies. Bottom line? USV classification needs to be as flexible as the vessels themselves, because in this industry, one size definitely does not fit all.

USV Size Classes

GENERAL RULES OF THUMB

While USV classifications can be fluid, here are some quick and practical rules to help make sense of the size categories:

Small USVs (SUSVs): Think "road transportable." These nimble vessels can be hauled on trailers or deployed from small ships, making them highly mobile. They're built for short-range missions (<1000nm) and can operate anywhere from a few hours to about a month without human intervention. Perfect for coastal surveillance, mine countermeasures, and shallow-water surveys.



CARIBBEAN SEA (Sept. 10, 2013) A Hammerhead unmanned, remote controlled vehicle from the Canadian navy auxiliary oil replenishment ship HMCS Preserver (AOR 510) makes a close pass by the guided-missile frigate USS Rentz (FFG 46) during a live-fire exercise during the annual UNITAS multinational maritime exercise. (U.S. Navy photo by Lt. Cmdr. Corey Barker)

Naval Drones. "Hammerhead USV-T." Naval Drones, September 10 2025, http://www.navaldrones.com/Hammerhead.html. Accessed February 2nd, 2025.

Medium USVs (MUSVs): Bigger and better-equipped, MUSVs can handle rougher seas and tackle longer, more complex missions than their smaller counterparts. Their added size also means a higher sensor height, making them ideal for surveillance and reconnaissance where line-of-sight matters.



The unmanned surface vessels Ranger (foreground) and Nomad (the former Riley Claire) under way in the Pacific in July 2021.

Walsh, Edward J. "Navy to Launch MUSV Prototype This Year." *Proceedings*, April 2022, https://www.usni.org/magazines/proceedings/2022/april/navy-launch-musv-prototype-year. Accessed February 2nd, 2025.

Large USVs (LUSVs): These are true ocean-going workhorses, too big for easy removal from the water for most shipyards, they stay in the water except for maintenance and repairs. Designed for payload delivery, ISR, extended open-ocean ops and anything else under the sun. While largely still conceptual, they're envisioned to bring serious endurance and capability to the table.



Austal concept of Large Unmanned Surface Vessel (LUSV) showing an optionally-manned bridge, VLS cells and engine funnels amidships. Note that there is plenty of free deck space with a tethered UAS aft of the ship. The LUSV is meant to be the U.S. Navy's adjunct missile magazine.

Naval News Staff. "Second Vendor Clears U.S. Navy LUSV Milestone." Naval News, 10 Jan. 2024, https://www.navalnews.com/event-news/sna-2024/2024/01/second-vendor-clears-u-s-navy-lusv-milestone/. Accessed February 2nd, 2025.

Extra-Large USVs (XLUSVs): Right now, autonomous ships of this size exist mostly on paper, but they represent the future of unmanned fleet operations. Designed for logistics, combat support, and mothership roles, these behemoths could redefine naval strategy and cargo logistics with their extreme endurance and massive payload capacity. However, sending a high-value logistics asset into the open ocean without a crew comes with serious risks. Because of this, the likely first step toward full autonomy will be manned-autonomous hybrid cargo ships, where automation handles most operations while a small onboard crew ensures security and maintenance.



The world's first self-propelled, fully electric autonomous cargo ship MV Yara Birkeland docks at Langkaia quay in Oslo, Norway. PHOTO: EPA-EFE

"First Electric Autonomous Cargo Ship Launched in Norway." *The Straits Times*, 19 Nov. 2021, https://www.straitstimes.com/world/europe/first-electric-autonomous-cargo-ship-launched-in-norway. Accessed February 2nd, 2025.

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LEVELS OF MARINE AUTONOMY

HOW AUTONOMOUS IS IT?

As Unmanned Surface Vessels (USVs) take on bigger roles in defense, commercial shipping, and scientific exploration, defining how autonomous they really are is crucial. After all, there's a big difference between a remotely piloted vessel and one that makes its own decisions on the high seas. That's where autonomy scales come in, they help categorize how much human oversight a USV needs and how independently it can operate.

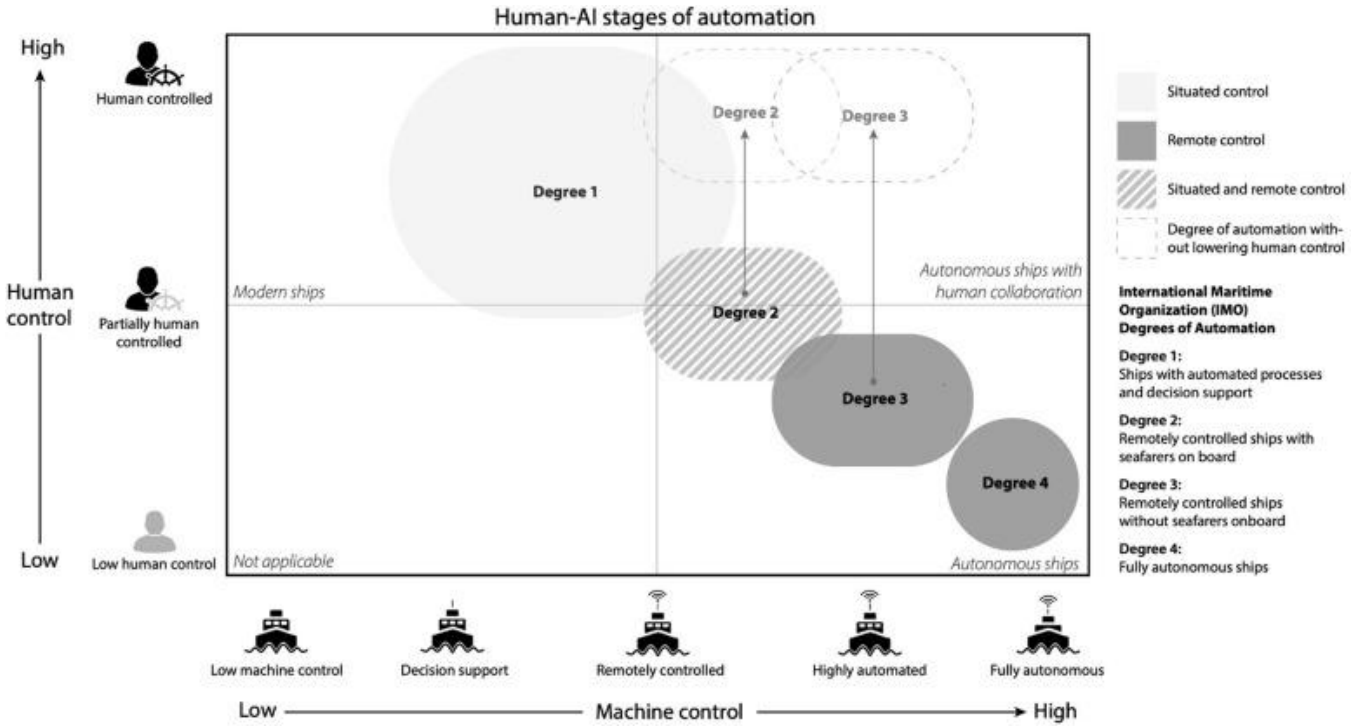


Diagram illustrating the framework for human supervision and control in autonomous shipping, highlighting the interaction between human operators and AI systems.

Porathe, T., & Rødseth, Ø. J. (2022). A systematic review of human-AI interaction in autonomous ship operations: The need for human-centered design. *Safety Science*, 152, 105792. https://doi.org/10.1016/j.ssci.2022.105792.

Different organizations have tackled this challenge, each with its own framework, but all very similar to the general structure illustrated above. Today, the most common scales are:

- **The U.S. Department of Defense (DoD)** focuses on autonomy levels for military operations.
- **The International Maritime Organization (IMO)** aims for a global standard in maritime automation.

While these scales help with mission planning, regulatory compliance, and operational safety, they aren't perfect. They often struggle to capture advanced capabilities like adaptive decision-making, multi-sensor fusion, and collaborative USV swarms. But as maritime autonomy evolves, so will these frameworks.

U.S. DoD Autonomy Scale

MILITARY-FOCUSED & MISSION-DRIVEN

When it comes to Unmanned Surface Vessels (USVs), the U.S. Department of Defense (DoD) classifies autonomy based on how much human involvement is needed for mission success. While this structured approach is useful for military planning, it sometimes falls short in capturing real-world complexity, like how reliable an AI-driven decision is in combat or how well an autonomous system adapts to dynamic conditions.

Unlike civilian frameworks, the DoD doesn't adhere to a single, universally accepted autonomy scale. Instead, it has developed several classification models to assess Unmanned Systems (UxS) across different domains. One of the most notable is the Autonomy Levels for Unmanned Systems (ALFUS) Framework, created by the National Institute of Standards and Technology (NIST) in collaboration with federal agencies. ALFUS provides a structured way to define and measure autonomy across mission complexity, environmental challenges, and human independence.

Although different DoD documents may use slightly varying terms, they generally align on these core autonomy levels:

Level	***Definition***
Remote Control	Fully dependent on human operators, either via direct line-of-sight or remote control.
Supervised Autonomy	The USV can operate autonomously, but human operators monitor and intervene as needed.
Semi-Autonomous	Executes specific tasks (e.g., waypoint navigation) on its own, but operators define mission parameters and step in for complex situations.
Fully Autonomous	No human intervention is required, makes decisions, plans missions, and avoids obstacles dynamically.

IMO MASS Framework

A GLOBAL STANDARD FOR MARITIME AUTONOMY

The International Maritime Organization (IMO) created the MASS (Maritime Autonomous Surface Ship) framework to align with global regulations. While it's great for international standardization, it lacks technical depth when it comes to things like AI-driven situational awareness, real-time decision-making, or multi-vessel coordination.

Degree	*Autonomy level*	*Seafarers onboard*	*Remotely controlled*	*Real-time connectivity required*
1	Ships with automated processes and decision support	Yes	No	Not necessarily, depending on the extent of automation and decision support systems.
2	Remotely controlled ship with seafarers on board	Yes	Yes	Yes, to facilitate communication between onboard personnel and remote operators.
3	Remotely controlled ships without seafarers on board	No	Yes	Yes, for continuous communication and control of the vessel from a remote location.
4	Fully autonomous ships	No	No	Not necessarily, vessel itself operates independently without the need for direct human intervention.

International Maritime Organization (IMO). "Autonomous Shipping." International Maritime Organization, https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx. Accessed February 9th, 2025.

Orca AI. "Guide to Maritime Autonomous Shipping Terms." *Orca AI*, https://www.orca-ai.io/blog/guide-to-maritime-autonomous-shipping-terms/. Accessed February 9th, 2025.

DEFINING AUTONOMY

IT'S NOT ALWAYS CLEAR-CUT

If only autonomy levels were as simple as ticking a few checkboxes, but reality isn't that neat. The lines between these levels are often blurry, because real-world conditions don't always fit into a rigid scale. A USV might be fully autonomous in calm waters but require human intervention in a congested harbor. Some systems can make their own decisions but still rely on operators for mission approvals or high-risk scenarios. Even within the same classification, autonomy can vary based on sensor quality, AI sophistication, environmental adaptability, and mission complexity.

To add to the challenge, different organizations define autonomy in different ways. The U.S. military emphasizes human control and operational risks, while the U.K. focuses on regulatory oversight, and the IMO tries to create a universal standard for international waters. As technology evolves, these frameworks will need to adapt, because the future of autonomy isn't just about whether a USV is remote-controlled or independent, but how well it can think, react, and operate in a rapidly changing world.

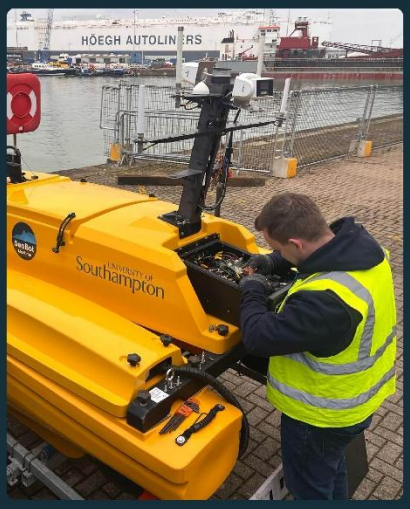


U.S. Coast Guard fast response cutter sails alongside a MARTAC T-38 Devil Ray unmanned surface vessel. (Photo: U.S. Fifth Fleet / SPC James Webster)

Suffern, Brennan. "Collision Regulations Need to be Updated for USVs." Proceedings, February 2024. https://www.usni.org/magazines/proceedings/2024/february/collision-regulations-need-be-updated-usvs.







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EVOLVING TRENDS

NEW MOVEMENT IN USV TECHNOLOGY & OPERATIONS

The Unmanned Surface Vessel (USV) industry is at a pivotal moment. What was once an experimental field dominated by research prototypes and defense contracts is now evolving into a mature, multi-industry technology sector. From offshore energy and environmental monitoring to defense, logistics, and security, USVs are becoming more capable, accessible, and widely deployed.

While many core USV technologies, such as waypoint navigation, remote control, and propulsion, are well understood and widely implemented, the next phase of growth hinges on solving new challenges, integrating smarter autonomy, and improving operational efficiency.

Key trends are shaping the next generation of USVs, from breakthroughs in multi-vessel mission planning to the rise of passive perception, high-bandwidth connectivity, and cybersecurity concerns. As the industry moves forward, these trends will define how USVs are built, how they operate, and how they fit into the broader maritime ecosystem.

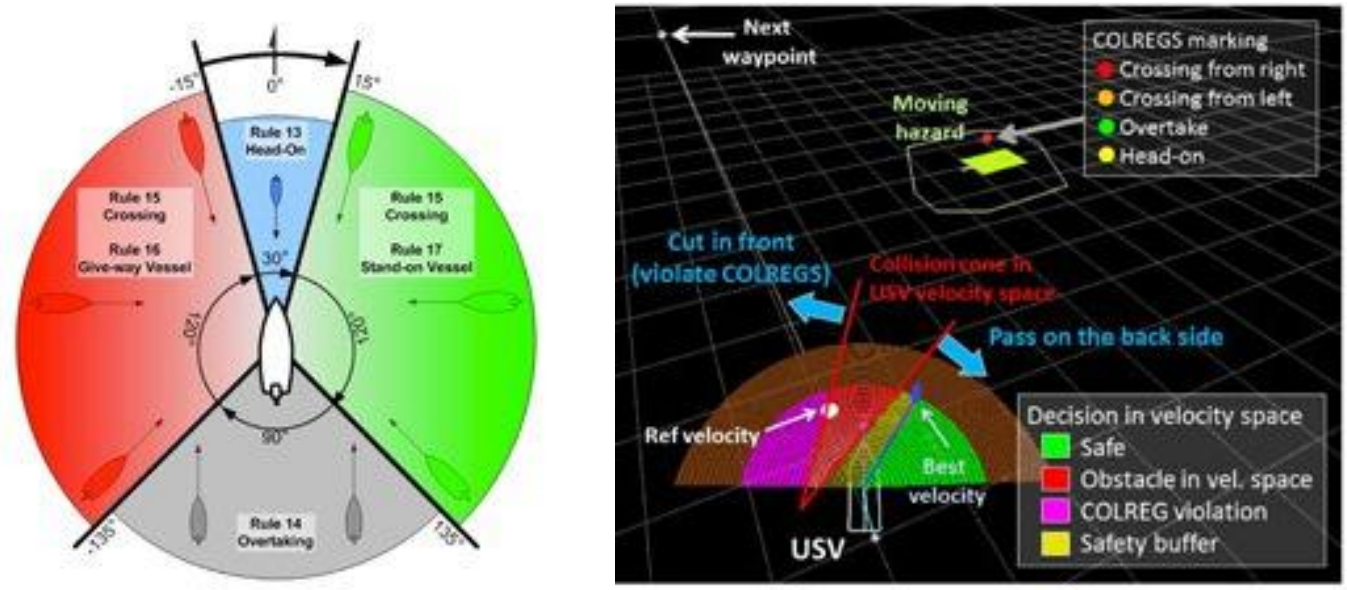
LESS FOCUS ON COLREGS

MORE ON BASIC COLLISION AVOIDANCE

For years, there has been a strong push for Unmanned Surface Vessels (USVs) to fully comply with the International Regulations for Preventing Collisions at Sea (COLREGS). After all, Rule #1 of maritime navigation is simple: Don't hit anything (at least, not anything you don't want to). But in practice, strict adherence to COLREGS has become less of a defining factor in USV development, especially for smaller, slower vessels operating outside heavily regulated waterways.

The reality is that COLREGS was designed to prevent collisions between manned vessels, where human decision-making, communication, and judgment play a major role. Most small crewed vessels in regions outside the US and UK don't fully adhere to COLREGS as it is, so the emphasis on making USVs strictly follow these rules is diminishing.

Moreover, many USVs are small, slow-moving, and lightweight, meaning that even in the event of a collision, the risks of significant damage, harm to personnel, or blockage of critical channels are significantly lower than with larger crewed vessels. Instead of focusing on full COLREGS compliance, there is a growing industry preference for generalized collision avoidance behaviors that keep USVs safe in dynamic environments without the complexity of full regulatory adherence.



Graphical representation of the rules used for boat navigation relative to other vessels. On the right is one example of those rules in use.

Suffern, Brennan. "Collision Regulations Need to be Updated for USVs." *Proceedings*, February 2024. https://www.usni.org/magazines/proceedings/2024/february/collision-regulations-need-be-updated-usvs

Technical Complexity

From an autonomy perspective, true COLREGS compliance is incredibly difficult to implement. Effective COLREGS Collision avoidance requires:

- Perception systems that can accurately identify and track obstacles, determining their course, speed, and distance both at short and long range.
- CPA (Closest Point of Approach) and TPA (Time to Point of Approach) calculations to predict potential conflicts.
- Maneuvering decisions that comply with right-of-way rules while also considering environmental conditions, traffic density, and mission priorities.

This is a complex problem, and many in the industry realize that perfect COLREGS adherence is not always necessary, especially in lower-risk environments.

COLREGS Still Matters

Despite this shift, COLREGS is far from irrelevant, especially for USVs operating in major shipping channels or conducting survey work in high-traffic areas. In these cases, regulatory compliance remains a requirement, but the industry is recognizing that rigid, one-size-fits-all COLREGS compliance is impractical for many USV applications.

Today, several autonomy providers offer collision avoidance solutions, with about half of them using CPA/TPA-based autonomy behaviors to predict and prevent collisions. However, as the market evolves, we can expect to see a shift toward more adaptive, perception-driven avoidance systems that prioritize real-time safety over rigid compliance with maritime regulations until technology can catch up.

PASSIVE SENSING

THE RISE OF COMPUTER VISION

For years, Unmanned Surface Vessels (USVs) have relied heavily on active sensors like radar and AIS (Automatic Identification System) for situational awareness. However, passive perception, driven by computer vision (CV), is rapidly becoming a game-changer in the industry.

While CV-based autonomy has long been a staple in the automotive and aerospace sectors, its adoption in the maritime world has lagged due to limited datasets, high costs of data collection, and the expense of labeling that data into usable datasets. That gap is closing quickly. Just a few years ago, there were almost no commercially available computer vision-based perception systems for USVs, today, multiple solutions exist, and in the next 2-3 years, this is expected to be at a maturity level good enough for the maritime industry.

But, Why Is It Needed?

Better Close-Quarters Navigation in Littoral Environments

- Commercial USVs operating near harbors, coastlines, or congested waterways need highly accurate, short-range perception to avoid small, unmarked obstacles that radar often misses.
- CV-based systems provide real-time detection of small objects, floating debris, or even low-profile craft that may not show up on radar.

Stealth & Low-Emissions Navigation for Defense Applications

- Active sensors like radar and AIS broadcast a vessel's presence, making it easily detectable.
- Passive perception allows defense-focused USVs to navigate safely without emitting RF signals, reducing their electronic signature and making them more survivable in contested environments.

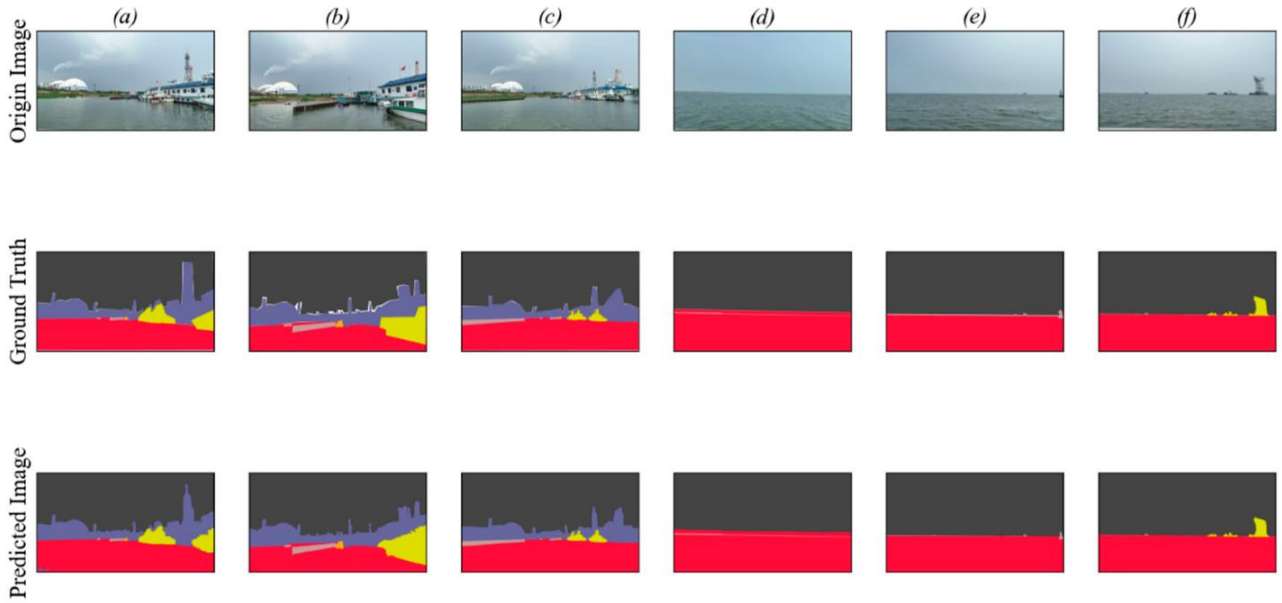
What are the Challenges?

Unlike cars or airplanes, USVs operate in highly unstructured, constantly changing environments. Some of the biggest hurdles include:

- **Data Scarcity:** Unlike road-based autonomy, which benefits from vast image datasets, maritime datasets are expensive and difficult to collect.
- **Labeling Costs:** Even when data is collected, annotating maritime imagery (e.g., identifying and labeling ships, waves, buoys, weather conditions) is time-consuming and costly.
- **Extreme Environmental Variability:** Glare from the sun, changing light conditions, heavy rain, and wave motion add significant complexity to CV algorithms.
- **Representative Data:** Just because you have data, and have trained a model does not mean the

model is optimized to reliably enough detect objects to use it for Navigational purposes. Model optimization requires representative data. Meaning, a large portion of training data needs to come from the specific camera and operational environment for the USV.

Technology Is Rapidly Evolving



Demonstration of a cooperative unmanned surface vehicle (USV) CV system designed for enhancing visual perception capabilities using semantic segmentation.

Cheng, C., Liu, D., Du, J.-H., & Li, Y.-Z. (2023). Research on Visual Perception for Coordinated Air–Sea through a Cooperative USV-UAV System. *Journal of Marine Science and Engineering*, 11(10), 1978. https://doi.org/10.3390/jmse11101978.

Despite these challenges, major advancements in AI, edge computing, and sensor fusion are accelerating CV adoption in maritime autonomy. New USV perception and navigational aid systems that didn't exist two years ago are now entering the market. As the industry continues investing in maritime datasets and AI training models, passive perception is on track to become a widely deployed, standard capability in the next few years.

USVs Are Becoming More Attainable

For years, Unmanned Surface Vessels (USVs) were seen as high-cost, specialized platforms primarily used by defense organizations and large commercial operators. But that's starting to change. Prices are dropping, competition is increasing, and USVs are becoming more accessible to a wider range of industries. While we're still in the early stages of mass adoption, the industry is shifting toward more productized, cost-effective, and user-friendly solutions than ever before.

Affordability & Market Growth

As more companies enter the USV space, economies of scale and improved manufacturing efficiencies are gradually driving down costs. Instead of each vessel being a custom-built, one-off prototype, we're seeing more standardized models that balance capability, cost, and ease of use.

This shift is especially critical for commercial applications, where cost has historically been a major barrier. Surveying, offshore inspection, and environmental monitoring are prime examples of industries that are starting to see USVs at price points that make sense for routine operations, rather than just as cutting-edge experiments.

Complexity Vs Practicality

The growing competition in the USV market is forcing manufacturers to rethink both how USVs are built and how they function in the field. A key trend is the optimization of both production processes and system complexity:

- Simpler, more modular designs reduce manufacturing and maintenance costs.
- User-friendly control interfaces that make USVs easier to operate, even for those without deep maritime or robotics expertise.
- Smarter autonomy features that require less operator intervention, making USVs more practical for smaller organizations with limited technical staff.

This industry movement mirrors what happened in the drone industry, what once required specialized pilots and extensive training is now becoming increasingly plug-and-play.

What's Next?

Despite these improvements, USVs are not yet at the level of affordability and accessibility seen in aerial drones or autonomous land vehicles. Many still require specialized training, infrastructure, and support that limit widespread adoption. However, as manufacturing scales up and technology matures, we can expect to see:

- More off-the-shelf USV solutions for specific industries.
- Lower entry costs for organizations looking to integrate USVs into their operations.
- A continued push for streamlined intuitive user experiences that reduce operational barriers.

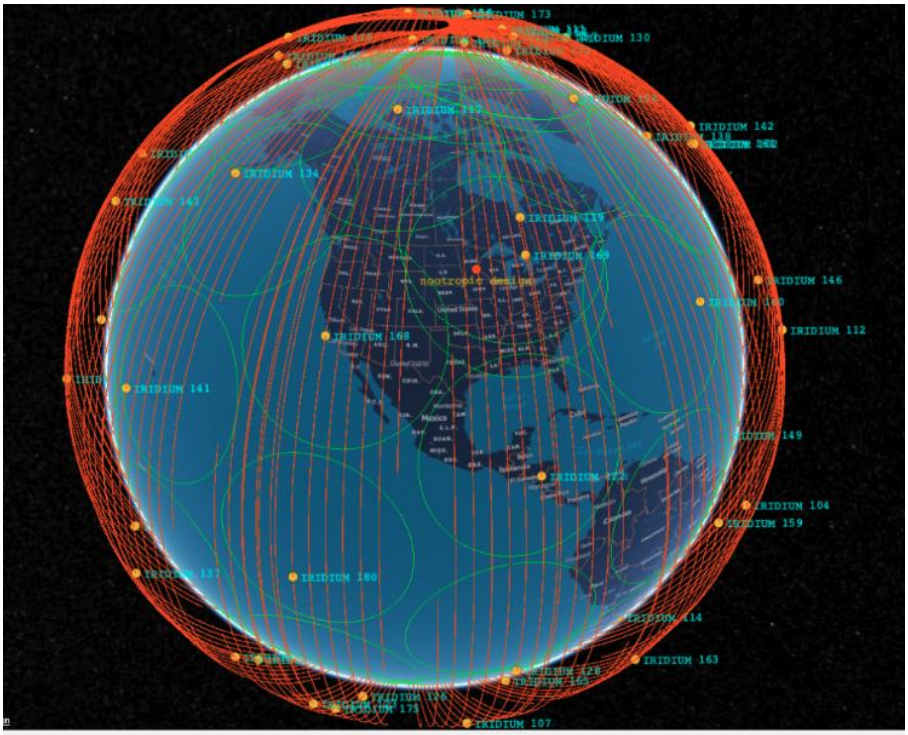
BLOS Comms & Cloud-Based C2

IMPROVED SATILITE DATA THROUGHPUT IS CHANGING THINGS

One of the biggest barriers to Beyond-Line-of-Sight (BLOS) USV operations has always been limited communication bandwidth. Traditionally, USVs operating outside of direct radio range relied on low-bandwidth satellite links, which restricted real-time control, status updates, and data transmission. Enter Starlink.

The arrival of high-bandwidth, low-latency satellite internet, led by Starlink and similar providers, is a game changer for USV operations. For the first time, USVs can maintain continuous, high-speed connectivity across the globe, unlocking new capabilities for both commercial and defense applications.

Before Starlink and next-generation satellite networks, USV operators had to work within strict data limitations. The constraints forced onboard autonomy systems to handle nearly all decision-making, as real-time operator intervention was impractical over limited satellite links. Now, cloud-based command and control (C2) is becoming a reality, allowing USVs to operate more like modern IoT devices.



Iridium constellation provides full coverage

Starlink's advertised global coverage appears comprehensive, but real-world suitability, especially for lone worker safety in remote or maritime environments, depends heavily on regional availability, uplink speed, and coverage stability.

Hakansson, Henrik. "Why Starlink Coverage Isn't Suitable for Lone Worker Safety." *LinkedIn Articles*, January 8, 2024. https://www.linkedin.com/pulse/why-starlink-coverage-isnt-suitable-lone-worker-safety-hakansson

This shift in reliable High data throughput BLOS Communications enables:

- Consistent remote software updates, Just like a smartphone or Tesla, USVs can receive firmware upgrades, security patches, and new autonomy behaviors over-the-air.
- Higher-fidelity real-time monitoring, Operators can now receive detailed system diagnostics, live sensor feeds, and mission status updates from anywhere in the world.
- Improved remote operation, With latency and bandwidth constraints reduced, operators can make more granular adjustments to USV missions, rather than relying entirely on pre-programmed autonomy.

Until recently, USVs were primarily limited to coastal, line-of-sight (LOS) operations due to the bandwidth limitations of traditional satellite communications. Now, with high-throughput satellite connectivity, USVs can be deployed globally with the same level of control and data access as LOS operations.

This is particularly impactful for:

- Long-range survey and environmental monitoring missions, USVs can now transmit full-resolution sonar, camera, and environmental data in real time from remote locations.

- Maritime security and defense applications, Continuous, high-bandwidth links allow for real-time intelligence gathering, threat assessments, and remote tactical adjustments without reliance on human crews.
- Offshore energy and industrial IoT, USVs can now seamlessly integrate into cloud-based asset management platforms, improving efficiency for offshore wind, oil, and gas operations.

What's Next?

As satellite communications continue to evolve, expect to see an even deeper integration between USVs and cloud-based services. Future advancements may include:

- AI-assisted mission control, where real-time analytics in the cloud can optimize USV behaviors dynamically.
- Multi-vehicle coordination, where fleets of USVs share real-time data and adjust their missions collaboratively.

PERSONNEL & TRAINING DEMANDS

THE GROWING NEED FOR PEOPLE & KNOWLEDGE

As USV adoption grows, so does the demand for skilled personnel to operate, maintain, and support these increasingly complex systems. However, finding and training the right teams remains a major challenge. Unlike traditional crewed vessels, USVs require a diverse mix of technical and maritime expertise, and assembling well-rounded operational teams isn't always easy.

Building the Right USV Ops Team

JACKS OF ALL TRADES REQUIRED

Successfully operating and maintaining a USV goes far beyond just having a someone click waypoints on a digital nautical chart. Depending on vessel size and mission a functional USV support team ideally includes:

- **Network Technicians**, To manage remote communications, BLOS connectivity, and cybersecurity.
- **Software Engineers**, To troubleshoot, update, and optimize autonomy and control software.
- **Vessel Mechanics**, To ensure propulsion systems, steering, and mechanical components remain operational.
- **Electrical Technicians**, To handle power systems, sensors, and onboard electronics.
- **Vessel Captains/Coxswains**, To provide traditional maritime expertise and ensure safe operations.

Each of these roles requires specialized skills, and while some cross-training is possible, forming a fully

functional USV operations team remains a complex staffing challenge, especially as the industry scales.

Do USVs Reduce Personnel Needs?

NOT EXACTLY

A common assumption is that increased automation leads to reduced personnel demands, but that's not always the case. While USVs remove the need for a physical crew on board, they often increase the level of expertise required to operate and maintain them remotely.

Instead of replacing jobs, USVs are shifting workforce demands from traditional vessel operations to more technology-focused roles. This means that skilled technicians, engineers, and operators with maritime knowledge are now in high demand, yet they remain difficult to find.

The Growing Need for Training

Most USV manufacturers have historically relied on their own test teams to support customer operations, deploying the same internal personnel who built and tested the platforms. However, as USVs become more productized and widely adopted, this model is becoming unsustainable. Manufacturers now need to scale their training efforts to enable customers to operate USVs independently.



The rating symbol for the newly established Navy Robotics Warfare Specialist (RW) rating, announced in NAVADMIN 036/24, comprises an airplane propeller and lightning bolt crossed over a treaded wheel, all layered over a single wave.

Source: Anderson, Zachary. "Robotics Warfare Specialist Rating Symbol." *DVIDS*, February 22, 2024. https://www.dvidshub.net/graphic/29264/robotics-warfare-specialist-rating-symbol.

There's a major opportunity here for USV manufacturers to:

- Develop robust training programs that allow customers to onboard their own personnel.
- Provide comprehensive manuals and online training courses to improve user experience.
- Offer on-site or simulator-based training programs to accelerate skill-building for operators.

Standardized Training & Certifications

Looking ahead, standardized USV training and certification programs will likely become essential for large-scale adoption. In the next 3-5 years, we can expect to see:

- **Industry-recognized certifications** for USV operators, much like traditional maritime licenses (e.g.,

6-passenger, 25-ton, 100-ton vessel licenses).

- USV-specific certifications developed alongside regulatory bodies such as the U.S. government or classification societies.
- **Training programs from leading USV companies**, setting the standard for operator education in the U.S.

This is already beginning to take shape in the UK, where structured USV training programs are emerging. The companies that establish comprehensive training ecosystems early will not only differentiate themselves but also create new revenue opportunities in USV operator certification.

Multi-USV Mission Planning

THE NEXT BIG CHALLENGE

Operating a single Unmanned Surface Vessel (USV) is relatively straightforward. Many of the fundamental technologies, waypoint navigation, precise speed control, and course-holding, are solved sciences that have been refined over years of autonomous marine development. But as demand for multi-USV operations increases, the industry faces an entirely new set of challenges.



U.S. Navy unmanned surface vehicles operating in swarm maneuvers on the James River in August 2014

Gettinger, Dan. "What You Need to Know About Drone Swarms." *Center for the Study of the Drone at Bard College*, November 3, 2014. https://dronecenter.bard.edu/what-you-need-to-know-about-drone-swarms/.

Beyond Formation Control

TRUE COLLABORATIVE AUTONOMY

Controlling multiple USVs simultaneously isn't just about keeping vessels in formation or assigning them individual routes. True multi-USV mission planning requires vessels to work together dynamically, adapting to mission progress, failures, and environmental changes in real time.

This is particularly critical for survey, security, and coordinated fleet operations, where collaborative autonomy is necessary to ensure the mission is completed efficiently.

Example: Multi-USV Survey Operations

Imagine a fleet of four USVs conducting a survey of a large area. If one vessel drifts off course and fails to cover its assigned track, the system must:

1. **Recognize the gap** in coverage and determine the most efficient way to fill it.
2. **Assign another USV to compensate**, adjusting its mission plan dynamically.
3. **Recalculate paths in real-time**, ensuring minimal disruption to the overall mission.

Similarly, if a USV experiences a mechanical failure and must return to base, the remaining vessels must redistribute the workload to ensure the mission is still completed efficiently. This level of adaptive mission coordination remains a major unsolved challenge in the industry.

Why Is Multi-USV Control Hard?

While single-vessel autonomy is well understood, multi-USV coordination requires significant advancements in:

- **Real-time mission progress tracking**, The system must continuously monitor where each USV is, what task it has completed, and what remains unfinished.
- **Collaborative decision-making**, USVs must autonomously reallocate tasks based on mission status, rather than waiting for a human operator to adjust their plans.
- **Communication & Data Sharing**, Each USV needs to understand the progress of the others without overwhelming bandwidth constraints or relying on constant operator oversight.
- **AI-Based Task Optimization**, The system must evaluate the most efficient way to complete the mission in the event of deviations or failures.

Where The Industry Stands Today

Right now, few solutions exist for truly adaptive multi-USV mission planning. Many current approaches still rely heavily on predefined mission scripts, where each vessel follows an assigned role without the ability to adjust dynamically.

However, several companies are actively developing next-generation autonomy that integrates:

- Swarm intelligence models inspired by nature (such as flocks of birds or schools of fish).
- AI-driven task redistribution to ensure mission continuity in the event of system failures.
- Enhanced data-sharing protocols that allow for low-latency mission updates across multiple USVs.

What's Next?

Over the course of the next 5 years, expect to see:

- More sophisticated mission planning software that allows USVs to operate truly collaboratively.
- Advancements in AI-driven autonomy, reducing reliance on human intervention for multi-asset coordination.
- Breakthroughs in real-time data fusion, enabling fleets of USVs to share situational awareness seamlessly

CYBERSECURITY & DATA PROTECTION

As USVs become more connected, leveraging BLOS communication, cloud-based command and control, and AI-driven autonomy, they are also becoming more vulnerable to cyber threats, data breaches, and electronic warfare tactics.

The maritime industry has traditionally lagged behind aerospace and defense in implementing robust cybersecurity measures, but as USVs take on critical missions in commercial, government, and military operations, securing them from cyber threats is becoming an urgent priority.

Growing Cybersecurity Risks

While traditional crewed vessels face cybersecurity risks mainly in navigation systems (GPS spoofing) and shipboard networks, USVs depend entirely on digital communications and software-driven autonomy. This creates additional attack vectors, such as:

- **GPS Spoofing & Jamming**, Malicious actors can manipulate positioning data to mislead an autonomous vessel, sending it off course or into restricted areas.
- **Remote Hacking of USV Control Systems**, Cloud-based C2 systems and remote-control interfaces create vulnerabilities that could allow hackers to take control of a USV, disrupt missions, or even repurpose the vessel.
- **Data Interception & Exploitation**, USVs generate and transmit vast amounts of data, including sensor feeds and mission telemetry. Without proper encryption, this data could be intercepted and exploited by competitors, criminals, or hostile nations.
- **Malware & Software Integrity Attacks**, Since USVs rely on autonomous decision-making algorithms, an attacker could inject malicious software updates that alter mission parameters or disable safety features.

Physical & Digital Protections

To counter these threats, USV manufacturers, operators, and cybersecurity firms are now focusing on:

- **End-to-End Encryption**, Encrypting all communication channels, including satellite links, telemetry, and mission control data, to prevent unauthorized access.
- **Multi-Layered Authentication & Access Controls**, Implementing role-based access, two-factor authentication (2FA), and encrypted command channels to prevent unauthorized remote operation.
- **Anomaly Detection**, Using machine learning models to detect suspicious behavior, such as unexpected course deviations, unauthorized command inputs, or abnormal data transmissions.
- **Redundant Navigation & Control Systems**, Integrating alternative navigation methods (e.g., visual SLAM, celestial navigation, or inertial systems) to ensure a USV can continue operating safely if GPS signals are compromised.
- **Tamper-Resistant Hardware**, Strengthening onboard systems with secure boot sequences, physical security layers, and encrypted storage, ensuring USVs cannot be easily hijacked or reverse-engineered.

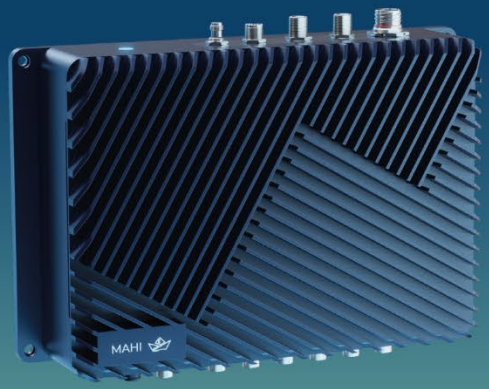
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- **Navigation Autonomy** including Radar-Camera-AIS fusion, station keeping, and precise path-following



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NAVIGATING CYBER SECURITY CHALLENGES IN UNCREWED SURFACE VESSELS

By: Bertold Van Den Bergh - MAHI, 2025/02/26

Uncrewed Surface Vessels (USVs) face two significant cybersecurity threats: interference with their connectivity systems and direct breaches of their internal networks. While jamming and spoofing attacks on connectivity systems such as radio and GPS disrupt operations, a more significant concern is the impact of an attacker gaining access to the USV's system, thereby turning an asset into a hostile threat.

A successful breach could allow unauthorized control of a vessel, potentially redirecting it, disabling it, or holding it for ransom. Given the increasing deployment of USVs in military and commercial applications, securing their internal systems is critical. This article examines the vulnerabilities of currently deployed USVs and explores measures to mitigate these risks.

EXPANDING SYSTEMS BROADEN THE ATTACK SURFACE

A USV comprises several interconnected modules, often sourced from different vendors, illustrated in Figure 1. While system architecture varies between manufacturers, the core structure remains similar.

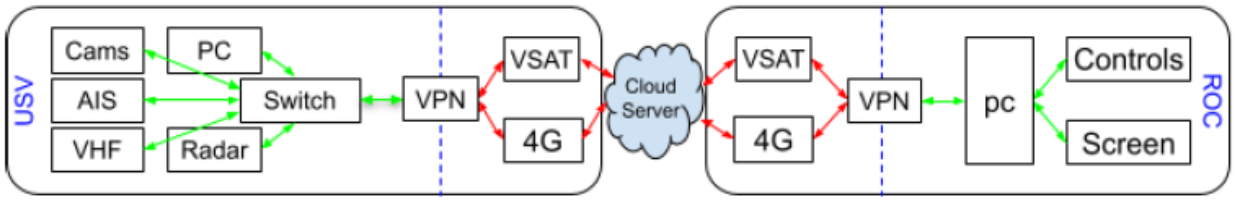


Figure 1: USV and ROC architecture, showing trusted network in green and untrusted network in red. The blue dashed lines indicate the security boundary ('moat').

USVs are progressively integrating more sensors and payloads. This ongoing expansion increases complexity and broadens the attack surface as each new component introduces potential vulnerabilities.

'CASTLE-AND-MOAT' CYBERSECURITY MODEL

Traditionally, USVs employ a 'castle-and-moat' cybersecurity model: a trusted internal network, 'the castle', and a set of firewalls and VPNs, 'the moat'. The assumption is that the moat prevents unauthorized access to the internal network. However, once a single device behind the 'moat', in the castle is compromised—such as a sensor, communication module, or even the VPN router itself—an attacker can move freely within the network and gain total system control.

There are three categories of breaches that can be distinguished:

1. Physically tampering with a USV. This is difficult as it requires direct access to the often well-protected vessels.
2. Inserting backdoored components. Malicious actors access the supply chain of USV components to install hidden backdoors in them. If undetected during quality checks, these corrupted devices allow exploitation once integrated into the USV system. While this approach requires complex orchestration, it is already more common than the former.

3. Remotely exploiting a vulnerability in the component. This is the most powerful approach as the breach happens anonymously over the internet and can be applied at scale.

IDENTIFYING AND ADDRESSING REAL-WORLD VULNERABILITIES

Security risks in maritime devices are real, as illustrated by the examples in the table below. At MAHI, cybersecurity is a top priority. We audit every external device before integration to identify and mitigate potential vulnerabilities. In doing so, we have uncovered vulnerabilities in many widely used maritime devices (Table 1). We continuously report these issues to the vendors and contribute to the Unites States government ran Common Vulnerabilities and Exposures (CVE) program to improve overall security posture1.

Table 1: Examples of identified vulnerabilities and risks in maritime devices

Maritime device	Discovered vulnerability	Risk in 'Castle-and-moat'
Radar	*Hackers can take control wirelessly, even with wireless functions turned off.*	*Breaching the moat via the radar leads to full USV control.*
4G modem	*Remote root access via cloud management function, allowing takeover from anywhere on the internet even in the presence of a firewall.*	*Compromising the modem and included router exposes all internal networks and systems leading to full USV control.*

ZERO-TRUST MODEL AS THE MITIGATION STRATEGY

Based on our experience, we cannot blindly trust the external equipment to be secured. The 'castle-and-moat' model is thus unsustainable. As systems get more complex and more components are added, so does the risk of integrating an insecure component.

The advised mitigation strategy is to adopt 'zero-trust' cybersecurity[2][3], built on the following principles:

- No device or user is inherently trustworthy, even if integrated into the network. They must securely authenticate against any resource the device needs to function.
- Isolate the network into segments so that a breach in one area, such as a camera, doesn't automatically expose the entire system, such as navigation and payload systems.
- Active monitoring to detect suspicious activity as compromised devices behave abnormally

The MAHI Sense and other well-designed systems natively adopt the 'zero-trust' architecture including micro-segmentation.

CONCLUSION

In today's contested maritime environment, USVs must be equipped to handle a wide variety of sophisticated cyber threats and navigational hazards. The widely used Castle-and-moat model is insufficient for this. Secure-by-design principles are essential, such as the Zero-trust model which MAHI is pioneering for USVs. Through these efforts, USVs can remain both technologically advanced and secure. Ready to navigate challenging waters without compromising on safety or mission objectives.

Contact your autonomy supplier and ask how they go about cybersecurity implementation.

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[1] United States Department of Homeland Security - Cybersecurity and Infrastructure Security Agency, CVE Program https://www.cve.org/

[2] National Institute of Standards and Technology, Zero-Trust Architecture, SP.800-207, August 2020 https://nvlpubs.nist.gov/nistpubs/specialpublications/NIST.SP.800-207.pdf

[3] Google, Beyond Corp Zero Trust Enterprise Security https://cloud.google.com/beyondcorp?hl=en

THIS INDUSTRY IS ROUGH

HERE'S WHY

The Unmanned Surface Vessel (USV) industry is an exciting and fast-evolving field, but let's be honest, it's no walk in the park. Designing, building, and operating robotic boats is hard enough, and turning that into a successful business? Even harder. From recruiting the right talent to dealing with regulatory red tape, let's dive into why making waves in the USV market is tougher than it looks.

Finding the Right People

USVs aren't just boats, they're sophisticated robotic platforms that require expertise across multiple disciplines. Designing one is like merging the worlds of shipbuilding, robotics, software engineering, and field operations into a single, cohesive system. That means assembling a team with a wide range of skill sets.

Naval Architects & Marine Engineers ensure the vessel is structurally sound, hydrodynamic, and built to endure the relentless ocean environment. Unlike traditional boats, USVs must be designed to function without human crews, which introduces unique stability and maintenance challenges.

Software Engineers & AI Developers provide the brainpower behind autonomy. These specialists develop navigation, obstacle avoidance, and mission execution software, ensuring USVs can make decisions in real-time without human intervention.

Networking & Communications Specialists enable secure and reliable long-distance control. Whether through satellite links, radio, or encrypted data streams, keeping USVs connected in remote locations is a critical challenge.

Payload Integration Experts handle the primary reason most USVs exist: carrying and operating mission-critical sensors. Whether it's sonar for underwater mapping, radar for surface tracking, or cameras for inspection, these engineers ensure payloads function effectively in harsh marine environments.

Mechanical & Electrical Engineers design power systems, engines, batteries, and energy management solutions, balancing efficiency, reliability, and endurance for long missions at sea.

Fabricators & Marine Electricians build and assemble everything, from composite hulls to intricate electrical systems. Marine environments are unforgiving, and every component must withstand corrosion, vibration, and impact.

Field Technicians & Operators deploy, maintain, and troubleshoot USVs in real-world conditions. The best designs in the world mean nothing if there's no one who can repair or operate them efficiently in the field.

All of these disciplines must work together seamlessly. A USV isn't just a floating platform, it's a fully autonomous robotic system, and failure at any level can compromise its entire mission. If a survey mission is delayed, data collection costs

skyrocket. If a security patrol system malfunctions, the consequences could be severe. Designing, building, and maintaining these systems requires a multi-disciplinary team that can integrate complex technologies into a single, reliable package.

The Hiring Challenge

Finding the right talent for the USV industry isn't just difficult, it's one of the biggest roadblocks to innovation and growth. Unlike industries with deep talent pools, like automotive or aerospace, USVs sit at the intersection of multiple fields, making recruitment a constant challenge.

A Split Talent Pool – Most engineers and technicians come from either the maritime world or the robotics world, but rarely both. Finding professionals who understand both shipbuilding and autonomy is rare, forcing companies to either cross-train employees or assemble highly interdisciplinary teams.

High Demand, Low Supply – Many of these skill sets overlap with high-demand fields like aerospace, defense, and artificial intelligence, meaning companies must compete with major tech firms for top talent. Offering competitive salaries, benefits, and career growth opportunities is essential, but expensive.

Geographic Limitations – USV development and testing usually require proximity to water, yet much of the best software and engineering talent is concentrated in landlocked tech hubs. Recruiting and relocating employees to coastal locations where shipbuilding infrastructure exists can be a tough sell.

No Established Industry Pipeline – Unlike aerospace or automotive, where educational programs and internships feed into established career paths, USV companies must often build their own workforce pipelines from scratch. This requires internal training programs, mentorship, and partnerships with universities or technical schools to develop future talent.

Unpredictable Work Environments – Unlike factory-based engineering roles, USV development requires engineers to account for the unpredictability of the ocean. Designing for a dynamic, corrosive, and constantly changing environment is an entirely different challenge from working on land-based robotic systems.

The bottom line? Hiring for USVs isn't just about filling positions, it's about finding specialists who can bridge multiple disciplines and thrive in an industry that lacks the structure and predictability of more mature fields. Without the right people, even the best USV concepts will struggle to get off the ground.

Low Demand, Low Volume

USVs aren't mass-produced like cars or consumer drones, and that creates a cascade of challenges. The industry is still relatively young, and while interest is growing, the demand remains low compared to more established sectors. Unlike the automotive or aerospace industries, where economies of scale drive down costs, USVs are typically built in small batches or even as one-off custom builds. This lack of mass production has significant consequence.

High Costs Per Unit – Without large production runs, materials, components, and labor remain expensive, making each USV a costly investment for customers.

Limited Supplier Interest – With low order volumes, suppliers of critical components like marine-rated sensors, propulsion systems, and high-performance batteries don't prioritize the USV market, leading to longer lead times and higher prices.

Slow Technological Maturity – Since fewer USVs are in the field, real-world testing and iterative improvements take longer, delaying advancements in performance and reliability.

Uncertain Return on Investment – Many potential customers, particularly in the commercial sector, hesitate to invest in USVs due to their high price points and the lack of proven long-term cost savings.

Unlike industries with predictable consumer demand, USVs often cater to niche markets such as defense, offshore surveying, and research. This makes it difficult for manufacturers to justify large-scale production lines, keeping costs high and innovation slow. The lack of a robust secondhand market also means that buyers must make a long-term commitment when purchasing a USV, further slowing adoption.

Additionally, companies looking to break into the market face significant challenges in funding and scaling operations. Developing a new USV requires heavy upfront investment in R&D, testing, and certification, costs that must be recouped over a small number of sales. Unlike automotive startups that can enter the market with well-established supply chains and contract manufacturers, USV companies often have to build their own infrastructure from the ground up, further increasing costs.

Ultimately, the low-volume nature of the industry creates a cycle: high costs limit demand, limited demand discourages investment, and slow investment stifles technological progress. Until USVs become more widespread and production volumes increase, these challenges will continue to shape the industry's growth.

TECHNICAL CHALLENGES

Unmanned Surface Vehicles (USVs) operate in one of the most challenging environments on the planet, the open ocean. Unlike their land-based counterparts, USVs must perform reliably for long durations without human intervention, often in corrosive, high-motion, and communication-limited conditions. Every onboard system, from propulsion to perception, must be engineered for resilience, efficiency, and mission-specific performance.

To thrive in this environment, USVs need more than autonomy; they require intelligent design across mechanical, electrical, and software systems. Each mission demands a careful balance of endurance, situational awareness, energy management, and real-time decision-making. Meeting these challenges isn't just a matter of good design, it takes cross-disciplinary innovation, relentless iteration, and deep domain expertise in both robotics and maritime operations.

Power & Energy Management

USVs must complete long-duration missions without the ability to refuel or recharge. Each propulsion choice, combustion, hybrid, or electric, presents tradeoffs. Combustion engines require scheduled maintenance and fuel logistics; hybrids introduce complexity in source switching; and electric platforms face limitations due to battery capacity and sparse offshore recharging infrastructure.

Energy harvesting systems such as solar panels, rigid sails, or wave energy converters provide supplemental power but introduce design and reliability challenges. These systems often generate inconsistent output and increase mechanical complexity, which directly affects reliability and maintainability. Efficient onboard power management and careful energy budgeting are critical to mission success.

Hull & Propulsion Design

The physical design of the vessel heavily influences mission suitability. Planing hulls are favored for speed and interdiction missions, while displacement hulls offer better stability and endurance for survey or monitoring roles. Selecting and optimizing propulsion systems, whether propellers, waterjets, or azimuth thrusters, requires balancing efficiency, noise, redundancy, and durability.

All propulsion components must be ruggedized to handle continuous exposure to saltwater, biofouling, and impact from debris, with minimal maintenance.

Autonomy & Navigation

USVs must process environmental data in real time to navigate, avoid obstacles, and respond to dynamic threats, all without human input. This includes path planning, collision avoidance, and behavior adaptation under variable sea states, currents, and winds.

Unlike ground vehicles, USVs operate at the interface of air and water, where conditions can change rapidly. Furthermore, they must interpret and comply with maritime rules (COLREGs), often while contending with manned vessels that may not. Designing robust autonomy systems capable of reacting predictively and safely is a core challenge in USV development.

Command & Control (C2)

Reliable command and control is critical for both remote operation and autonomous oversight. Bandwidth limitations, signal latency, and cybersecurity threats hinder real-time communication, especially in open-ocean or contested environments.

Effective systems require secure, low-latency communication pipelines, intuitive user interfaces, and scalable APIs. Coordinating fleets of USVs introduces additional complexity in task allocation, collaboration, and telemetry routing. User experience plays a critical role in enabling mission planners to manage autonomous behaviors efficiently and safely.

Sensors & The Environment

USVs depend on sensor arrays, cameras, radar, sonar, LIDAR, to perceive the maritime environment. Marine conditions degrade sensor performance: fog, rain, salt buildup, and rough seas obscure vision, distort signals, and reduce data fidelity. Biofouling introduces further long-term degradation.

Sensor fusion and environmental compensation algorithms are necessary to produce consistent situational awareness. Ensuring the performance and longevity of these sensors is among the most persistent technical challenges in USV design.

Data Processing At The Edge

High-performance edge computing is essential for real-time autonomy. USVs generate massive sensor datasets that must be processed locally due to bandwidth constraints. Running computer vision, object detection, and sensor fusion workloads onboard, while conserving power and managing heat, requires hardware that balances compute density and efficiency.

Systems often employ processors like NVIDIA Jetson or Intel Movidius to perform onboard AI inferencing. However, power constraints, cost, and physical space limit compute capability, especially for small USVs or those on long-endurance missions.

Computer Vision & AI

Computer vision is foundational for obstacle detection, object classification, and mission planning. However, training effective AI models for maritime environments is difficult due to limited labeled datasets. Annotating maritime objects such as buoys, vessels, and hazards requires domain expertise and is resource intensive.

Real-time perception at sea is also more complex than on land. Estimating object range and velocity from a moving platform in a fluid medium requires constant sensor fusion and computational effort. AI systems must operate reliably in noisy, low-contrast environments and make safe decisions even with incomplete or ambiguous data.

Maintainability & Reliability

Without a crew aboard, USVs must be self-sufficient. Saltwater corrosion, mechanical wear, and environmental exposure degrade components quickly. Failures during missions can require complex and costly recovery operations.

Designing for durability includes selecting corrosion-resistant materials, implementing redundant systems, and enabling predictive maintenance through health monitoring. Modular design for rapid part replacement also improves maintainability across varying mission profiles.

DEMOCRATIZING AUTONOMY

RENTABLE REMOTE OPERATIONS CENTERS ENHANCE GLOBAL OPERATIONS

By: **Jack R. Dougherty, MSM**

Co-Founder/Uncrewed Systems Principal - Janus Marine and Defense LLC.

The maritime industry's shift toward uncrewed surface vessels (USVs) is reshaping how survey operations are conducted. From offshore wind farms to subsea cable inspections, the adoption of USVs has delivered measurable gains in safety, efficiency, and sustainability. Autonomous Industry leaders like Fugro, Ocean Infinity and Sulmara have been at the forefront of this transition, leveraging purpose-built Remote Operations Centers (ROCs) to remotely manage their autonomous fleets. But for small and mid-sized survey companies, the same level of technological integration has remained out of reach. The infrastructure required to operate a fleet of USVs, particularly the ROC, is prohibitively expensive and complex.



That gap is now addressable. A new model of rentable ROCs is emerging, offering smaller players access to high-grade operational command centers without the massive upfront investment. This isn't just a cost-cutting measure. It's a critical enabler of competition, innovation, and operational parity in a sector that has long favored the well-capitalized.

Economic Access to Autonomy

Building a dedicated ROC is a heavy lift. Beyond the bricks and mortar, companies must invest in secure communications systems, satellite links, operational software, redundancy protocols, and cybersecurity compliance. That kind of infrastructure is feasible for global operators, but it's a non-starter for most regional survey firms or startups.

A rentable ROC changes that equation. For a fraction of the cost, smaller firms can access secure, professionally staffed ROCs outfitted with the latest technology. This allows them to run USV missions with the same level of command and control as those with significantly larger revenue streams. It means a three-person startup in Aberdeen can manage a North Sea hydrographic survey with the same situational awareness, data fidelity, and responsiveness as a multinational survey corporation.

The advantages aren't just technical. With remote capabilities handled by a third-party ROC, survey firms can focus on what they do best, data interpretation, project design, client service, rather than building out complex operational infrastructure.

Scalable Operations and Flexible Deployment

One of the biggest strengths of the rentable ROC model is scalability. Survey demands fluctuate, by season, by contract volume, or by client need. A rentable ROC lets companies scale operations up or down without carrying the fixed overhead of a permanent command center.

Whether you're running a week-long geophysical survey or a multi-month environmental baseline study, you only pay for what you use. This allows smaller survey companies to bid on larger, more complex projects, knowing they have the backend support to execute without compromise.

Strategic Support for Larger Players

While rentable ROCs clearly level the field for smaller companies, they also provide important strategic benefits to large survey operators. A distributed network of rentable ROCs around the globe enables these firms to maintain their high standard of command and control while improving regional accessibility.

Take, for example, a leading global survey provider operating a fleet of USVs from a central ROC in Glasgow. That center might efficiently control vessels operating in both the North Sea and, via satellite link, as far afield as the Arabian Gulf. But regional clients in the Gulf Cooperation Council (GCC) might not be keen on flying halfway across the world to observe operations or conduct a site visit.

A rentable ROC located in, say, Abu Dhabi or Doha offers the solution. It provides the same technical capability but with geographic proximity, enabling clients to engage more directly with ongoing operations. This is particularly valuable in regions where in-person oversight is expected or culturally preferred. It strengthens client relationships and builds trust, all while maintaining the operational consistency of a larger networked command system.

In this way, rentable ROCs don't just support new entrants; they enhance the agility of major firms by enabling regional extensions of their global control networks.

Enhancing Compliance, Security, and Client Trust

The remote operation of autonomous vessels involves not only technical complexity but also regulatory and cybersecurity burdens. A shared ROC model consolidates those responsibilities. Facilities are built to meet international cybersecurity standards and regional data sovereignty laws, which can be difficult and expensive for individual firms to address alone.

This is a win-win. Operators benefit from robust, standardized compliance infrastructure, and clients gain confidence knowing their data is handled in secure and legally compliant environments.

The Innovation Engine: Experimentation Without Infrastructure Risk

Rentable ROCs also serve as incubators for innovation. Startups and research organizations can test new USV platforms, mission profiles, or AI navigation systems without the need for a full operational buildout. This makes the ROC not just a utility, but a sandbox, an environment for experimentation that supports faster iteration and development of the next generation of autonomous marine technology.

Even defense organizations can benefit, using rentable ROCs to host multi-vendor trials or simulate hybrid fleet operations before making large-scale procurement decisions.

Manned-Unmanned Teaming & Future-Proofing Operations

The next frontier in maritime autonomy is not just fully unmanned operations, but seamless teaming between manned and unmanned systems. Rentable ROCs provide an integrated hub where operators can manage hybrid fleets, coordinate with crewed ships, and respond to dynamic mission needs in real-time.

Whether for offshore energy surveys, marine research, or defense applications, these hubs become central to mission coordination, tying together human expertise and machine efficiency into a cohesive operational unit.

A Strategic Investment for an Autonomous Future

Ultimately, the rise of rentable ROCs isn't just about efficiency or economics, it's about ensuring the entire industry can move forward. Autonomy can't reach its potential if only a handful of companies can afford to participate. By making high-end operational infrastructure accessible, rentable ROCs unlock new capacity, new business models, and new innovations.

For policymakers and investors, supporting the development of a global network of ROCs is a strategic move. It ensures local capability, enhances national resilience, and promotes an open, competitive market where the best ideas can win, regardless of who had the most capital to start with.

Rentable ROCs aren't just a cost-saving alternative, they're a catalyst for growth, access, and global capability in maritime autonomy. By making high-end operations infrastructure accessible, they lower the barrier to entry and accelerate broader USV integration across the commercial sector. The faster the industry embraces this model, the sooner uncrewed systems can become a standard part of maritime operations.

A REVIEW OF SOME OF THE ISSUES HINDERING THE APPLICATIONS OF AUTONOMOUS SYSTEMS ON UNSCREWED OR REDUCED CREWED VESSELS.

By Keith Henderson, Director: Robosys Automation Ltd. Jan 30, 2025

Propulsion Control Protocols

The increasing use of proprietary engine control systems without providing access by third parties is restricting adoption of situation awareness autonomous navigation systems capable of collision avoidance solutions.

While the general trend of an increase in propulsion engines controlled electronically is to be welcomed, a number of manufacturers are regrettably opting for proprietary control systems that exclude their use by third party autonomous systems. Control of such systems on crewed vessels is monopolised by forcing the use of hardware exclusively from the engine manufacturer.

Where a solution for unmanned vessels is not available, it leaves the boatbuilder with the only alternative of changing the originally specified engine brand for a company with a more tolerant policy! Depending on the vessel type and duties, changing from, for example, a large outboard to a sterndrive or inboard propulsion system may reduce operational flexibility from a performance or maintenance aspect. Some companies such as Volvo Penta provide open access to their own proprietary control system with an interface gateway. Fortunately, in contrast to recreational market engines, all inboard engines for commercial applications offer full control through an industry standard IMO protocol option.

Although this particularly affects USV applications, the increasing availability of navigational aids with situation awareness, collision avoidance and route planning, contribute towards safer boating, crewed or uncrewed. Not all but the majority of marine accidents involve the man in the loop and any automatic warning systems should reduce the number of accidents, especially collisions or the severity thereof. It is to the industry's advantage to recognise these facts; in a similar way, the commercial aircraft industry has reduced if not almost eliminated the number of mid-air collisions since the introduction of the TCAS[1] automated collision avoidance system.

Marine Information Communications

Broadcast information systems such as AIS are a valuable aid to situation awareness for vessels using this useful tool. Early versions of AIS were introduced over 20 years ago, but despite its development, there are still many inadequacies due to a number of shortcomings. Particularly smaller vessels and recreational craft have no obligation in most areas to provide position and track information to other vessels. AIS is switched off in certain circumstances such as to avoid informing possible criminals or pirates of the vessel's position, commercial fishing boats do the same to avoid informing competitors of their location.

VTS (Vessel Traffic System) and Pilot Service messages are transmitted over voice VHF yet this information if transmitted digitally could be an additional stream of valuable data. VDES (VHF Data Exchange System)[2] sometimes referred to as AIS 2.0, introduces two-way communications using VHF for short distances and a global facility by satellite. Test programmes are already running, facilitating message exchanges with greater bandwidth sent as a digital signal which is less prone to misunderstandings and information being lost in translation. The ability of vessels to digitally "talk to each other" is expected to be an important safety contributor. Automatic two-way communication between aircraft is a major component in aviation's TCAS collision avoidance system. Progress is being made with ILAS (International Association of

Marine Aids to Navigation and Lighthouse Authorities) working groups looking to standardise digital messaging for information broadcasting.

Equipment Redundancy

The introduction and increasing use of electronic navigational aids on board vessels, while reducing accidents and increasing safety, encourages greater dependency on them. So long as these aids function correctly all is good but when they fail, first of all, is the failure noticed and secondly, what is the substitute? Present systems seem to rely on human intervention which is possible assuming there is some human-qualified person(s) on board but on an uncrewed vessel. Unmanned systems not only are required to control the vessel as if or even better than with humans onboard but is the system controlling that all functions are working correctly?

As AI continues to develop, the opportunities for it to monitor existing systems seem to offer great opportunities. But even when a fault is noticed, is there a standby system ready to take over? In the aero industry, triple redundant systems are used as the consequences of failure can be great. How is the USV industry looking at this safety aspect; are at least dual redundancy systems able to take over at short notice and reduce if not prevent a disastrous situation from developing? While some companies such as Robosys have been delivering double redundant systems on USVs for more than a decade, will legislation be the motivator to encourage redundant systems to be more often on offer?

Loss of Communications (LOC)

LOC, whether as a result of technical failure or interference by accident or design is a vulnerability of USV operation. Using dual methods such as 4/5G and RF offers some protection against this occurrence, adding a satellite system is not always an option due to budget considerations. A sound policy is to consider LOC not “if”, but “when” and prepare accordingly. Automatic return to the nearest base, is an ideal move but hold position may be a possibility depending on the vessel size and position. ….. stopping and loitering in a channel is not in anyone’s interest. If the vessel is fitted with a route planning capability and collision avoidance, heading to its nearest base would be a good solution.



Examples of two different pre-programmed actions if Loss of Communications occurs. (Images courtesy of Robosys Automation)

References

TCAS[1]: Airborne Collision Avoidance System (ACAS) | Federal Aviation Administration

VDES[2]: VDES - VHF Data Exchange System - IALA AISM





ADVANCED MARITIME AUTONOMY

- DECISION AIDED **VOYAGER AI** AUTONOMY SOFTWARE
- FOR 3-340 METRES NEW BUILD + RETROFIT CRAFT
- REMOTE OPERATIONS HARDWARE
- INDUSTRY AGNOSTIC SYSTEMS
- DEGREE 4 AUTONOMY
- COLREGS COMPLIANT

RoboSys
Autonomous marine solutions

www.robosysautomation.com

sales@robosysautomation.com

USV SOFTWARE FEATURES

Not all USVs are created equally. Some are simple remote-controlled workhorses, while others push the boundaries of artificial intelligence, operating for weeks at sea without human intervention. Whether they're used for oceanographic research, surveillance, or offshore inspections, these vessels are redefining how maritime operations are conducted.

At the core of every USV is a combination of human-machine interfaces, autonomous control systems, and sensor-driven awareness, all working together to ensure safe and efficient operation. But not every USV has the same level of capability. Some require direct human oversight, while others make independent decisions based on real-time environmental data.

Understanding the latest advancements in USV technology helps operators, engineers, and decision-makers identify the features that best match their mission needs. Key capability areas include:

Operator Interface
How humans interact with and control USVs, from touchscreen dashboards to automated alerts.

Perception Sensing
How USVs see and interpret their surroundings using radar, cameras, and sonar.

Command & Control (C2)
The systems that handle navigation, mission execution, and decision-making.

Advanced Autonomy
The complex algorithms that allow USVs to plan, adapt, and operate with minimal human input.

From basic remote-controlled vessels to highly autonomous platforms capable of multi-ship coordination, USVs continue to evolve. Some features are now standard, while others are still emerging or experimental. The following sections outline these capabilities, providing insight into where the technology stands today and what to look for in a modern USV.

Adoption Level Key:
Tables in this section classify each feature based on its adoption level in the industry:

Common
Widely implemented across commercial and defense USVs. Considered an industry standard.

Rare
Experimental or only available in high-end systems or is a niche requirement. May see broader adoption soon.

Uncommon
Found in some USVs but not yet standard. Often it depends on mission requirements.

Need
A capability that would be valuable but is not yet widely available. Often an area of active development.

Operator Interface

A USV's operator interface is the bridge between human oversight and machine autonomy. Whether controlling the vessel remotely or simply monitoring its performance, operators rely on intuitive dashboards, interactive displays, and real-time data feeds to make informed decisions. The table below outlines key features that enhance usability, mission planning, and situational awareness.

ID	Feature	Description	Adoption Level
OI-01	Nautical Chart Integration	Import certified nautical charts for enhanced situational awareness.	Common
OI-02	Satellite Map Integration	Import satellite overlays for enhanced situational awareness.	Common
OI-03	Unit Customization	Chart display can be configured in yards/nautical miles or meters/km.	Common
OI-04	Heuristic Chart Markings	Operators can draw and place icons on charts for mission planning and knowledge transfer.	Uncommon
OI-05	AIS Contact Overlay	Displays real-time AIS contacts on the navigation chart.	Common
OI-06	Radar Contact Overlay	Displays radar-detected objects as overlays on the chart.	Common
OI-07	EO/IR Sensor Overlay	Displays Electro-Optical/Infrared (EO/IR) sensor data over the navigation chart.	Rare
OI-08	Sonar Contact Overlay	Displays sonar-detected obstacles on the chart.	Need
OI-09	LiDAR Contact Overlay	Displays LiDAR-detected objects on the chart for 3D situational awareness.	Rare
OI-10	Commanded Course Display	Shows the commanded course heading on the chart.	Common
OI-11	Actual Course Display	Displays the actual course heading in real-time.	Common
OI-12	ETA Markings on Course Line	Shows minute-based estimated time of completion of mission along the course heading.	Common
OI-13	Historical Path Visualization	Provides a display of past navigation paths.	Common
OI-14	Obstacle Avoidance Visualization	Displays planned autonomy-driven obstacle avoidance routes.	Uncommon
OI-15	Survey Mission Coverage	Displays survey coverage area on the chart for mission tracking.	Rare
OI-16	Multi-Mission Plan Overlay	Allows multiple mission plans to be visualized simultaneously on the chart.	Uncommon
OI-17	Customizable UI Layouts	The ability to rearrange interface elements to suit operator preferences.	Need
OI-18	Multi-Screen & Multi-Device Support	Interface works across multiple screens, tablets, or phones.	Uncommon
OI-19	Gesture-Based Controls	Enables touchscreen gestures for quick interaction.	Need
OI-20	Operator Fatigue Monitoring	Detects signs of operator inactivity as a warning against reduced attention.	Need
OI-21	Standard Operations Checklists	Provides quickly accessible digital checklists for common operations to reduce user error.	Rare
OI-22	Emergency Stop Button	Emergency stop can be activated within two button presses or less.	Common

OI-23	Communication Interface Management	Can control and configure communication interfaces.	Common
OI-24	Live Perception Feeds	Operators can view real-time perception feeds (radar, EO/IR, sonar).	Common
OI-25	Alerts & Warnings	Notifications, Alerts, and Warnings flagging vehicle and mission performance anomaly and/or potential failures.	Common
OI-26	Automated Maintenance Scheduling Tracking	Automated Tracking of maintenance schedule, and logging for preventative and corrective maintenance and corrective actions taken.	Need
OI-27	Automated Data Offload	User can download pre-parsed Data logs in their preferred format from historical missions.	Common
OI-28	Predictive Fuel Monitoring	Monitors Fuel/Battery quantity and expenditure rate and simulates fuel remaining at the end of the mission based on mission parameters and vessel operating efficiency.	Rare

Command and Control (C2)

Command and Control (C2) systems dictate how a USV is piloted, whether through direct operator input, pre-planned mission logic, or fully autonomous behaviors. These systems integrate navigation, communication, and mission execution to ensure seamless operation. The table below highlights the essential features that enable reliable and responsive USV control.

ID	Feature	Description	Adoption Level
CC-01	External Control Software Integration	Ability to accept commands from external third part control software.	Common
CC-02	Direct Vehicle Steering & Propulsion Control	Allows direct operator control of vessel steering and propulsion systems.	Common
CC-03	Speed Commanded as RPM	Enables speed control via RPM input for fine-tuned propulsion adjustments.	Common
CC-04	Speed Commanded as Speed	Enables speed control by defining absolute speed rather than RPM.	Common
CC-05	Hover at a Location	Maintains position at a defined location using dynamic thrust adjustments.	Common
CC-06	Heading Lock Hover	Maintains a locked heading in a Hover at location.	Rare
CC-07	Waypoint Navigation (Single Point)	Navigates to a single GPS waypoint using autonomy controls.	Common
CC-08	Display Time of Arrival (ToA) at Next Waypoint	Displays estimated time of arrival at the next programmed waypoint.	Uncommon
CC-09	Route Navigation (Sequence of GPS Waypoints)	Allows pre-defined routes using a sequence of GPS waypoints.	Common
CC-10	Return to Base Location	Returns to base as an executed action.	Common
CC-11	Survey Line	Executes linear survey line, which the vessel does not deviate from.	Common
CC-12	Evasion Path	Proceeds to a waypoint in a sporadic continually changing heading in a non-predictable manner.	Need

CC-13	Target Follow	follows a Target at a defined distance	Uncommon
CC-14	Real-Time Mission Task Switching	Allows dynamic switching between mission tasks without restarting a mission.	Uncommon
CC-15	Real-Time Mission Alteration	Enables real-time changes to mission parameters based on operator input.	Common
CC-16	Real-Time Mission Pause, Start, Stop, Resume	Allows missions to be paused, resumed, stopped, or restarted in real-time.	Common
CC-17	Display Estimated Time to Completion	Displays an estimated completion time based on current mission progress.	Common
CC-18	Mission Queue	Create a mission queue where tasks are executed in sequence.	Uncommon
CC-19	Criteria-Based Mission Execution	Executes missions based on defined criteria (e.g., environmental triggers, system states, remote input).	Rare
CC-20	Loop/Replay Mission	Repeats previous mission routes for iterative data collection.	Common
CC-21	Loss of Communication Action	Defines fallback behavior for loss of communication (e.g., return to base, hover, continue mission).	Common
CC-22	User-Programmable Loss of Communication Action	Allows operators to define custom loss-of-communication behaviors beyond pre-configured options.	Emerging
CC-23	Finite Control of Signal Emissions	Provides precise control over RF, heat, sound, and light emissions for mission-specific needs.	Rare
CC-24	Fire Suppression System Control	Allows remote activation and monitoring of fire suppression systems.	Rare
CC-25	Bilge System Control	Enables remote monitoring and activation of bilge systems.	Uncommon
CC-26	Electronics Coolant System Control	Allows remote monitoring and activation of coolant systems.	Uncommon
CC-27	Electrical System Control	Can control electrical system breakers remotely.	Common
CC-28	Seamless Communication Failover Protocols	Seamless switching between different communication methods (SATCOM, LTE, RF) depending on link quality.	Common
CC-29	Smart Load Shedding	Automatically disables non-essential systems when energy is low, preserving mission-critical operations.	Rare

Perception Sensing

To safely navigate and complete missions, a USV must perceive the world around it. A combination of radar, sonar, cameras, and environmental sensors enables real-time object detection, classification, and tracking. The table below details the technologies that provide USVs with the awareness they need to operate effectively.

ID	Feature	Description	Adoption Level
PS-01	LiDAR Object Detection	Uses LiDAR to detect objects in the environment for obstacle avoidance.	Rare
PS-02	Sonar Object Detection	Uses Sonar to detect objects below the water surface for obstacle avoidance.	Need
PS-03	Radar Object Detection	Uses Radar to detect objects determining range, course, and speed for obstacle avoidance.	Common
PS-04	Visual Spectrum Object Detection	Uses Visual Spectrum Cameras to detect objects within the field of view for obstacle avoidance.	Common
PS-05	Visual Spectrum Object Classification	Classifies detected objects detected the visual spectrum into categories, such as vessels, debris, etc…	Uncommon
PS-06	Visual Spectrum Object Identification	Identifies classified objects in the visual spectrum, providing information such as type of vessels, length, navigation marker type, etc…	Rare
PS-07	Visual Spectrum Distance & Bearing Determination	Determines distance and bearing to detected objects using visual spectrum cameras.	Uncommon
PS-08	Visual Spectrum Course & Speed Estimation	Estimate course and speed of detected objects via visual spectrum cameras.	Rare
PS-09	IR Spectrum Object Detection	Uses Infrared Cameras to detect objects in low-light or obscured conditions for obstacle avoidance.	Uncommon
PS-10	IR Spectrum Object Classification	Classifies detected objects detected in the infrared spectrum into categories, such as vessels, debris, etc…	Rare
PS-11	IR Spectrum Object Identification	Identifies classified objects in the infrared spectrum, providing information such as type of vessels, length, navigation marker type, etc…	Need
PS-12	IR Spectrum Distance & Bearing Determination	Determines distance and bearing to detected objects using IR cameras.	Rare
PS-13	IR Spectrum Course & Speed Estimation	Uses to estimate course and speed of detected objects via IR cameras.	Rare
PS-14	Detection of Marine Mammals	Detects marine mammals to avoid vessel strikes on marine life.	Need
PS-15	Wavefield Detection	Analyzes wavefield direction, periodicity, and height.	Rare
PS-16	Wind Direction & Speed	Detects wind direction and speed to adjust navigation and stability systems.	Common
PS-17	Classification of Relative Seas & State	Realtime classification of sea state, based on wind speed and wavefield.	Need
PS-18	Rain Detection	Detects precipitation levels to adjust perception sensors (i.e Radar).	Need
PS-19	Icing/Snow Detection	Detects ice and snow buildup on vessel surfaces and sensors.	Need
PS-20	Vessel Motion Feedback	Monitors vessel motion data for real-time feedback to the operator.	Uncommon
PS-21	Vessel Acceleration Force Feedback	Monitors acceleration forces exerted on the vessel for real-time feedback to the operator.	Need
PS-22	Fouling Detection	Detects marine fouling buildup on hull and propulsion components.	Need
PS-23	Raw Water Intake Clog Detection	Detects clogging in raw water intakes affecting cooling and filtration systems.	Need

Advanced Autonomy

Autonomy is what sets USVs apart from traditional vessels. These systems enable self-navigation, obstacle avoidance, adaptive decision-making, and even collaborative fleet operations. The following table lists the most advanced autonomy features currently being developed and deployed.

ID	Feature	Description	Adoption Level
AA-01	Automated Avoidance of Navigational Hazards Identified on Nautical Chart Data	USV autonomously adjusts course to avoid known hazards marked on nautical charts.	Common
AA-02	Obstacle Avoidance via AIS	USV detects and avoids vessels using AIS data.	Common
AA-03	Obstacle Avoidance via Radar	USV identifies and avoids obstacles using radar returns.	Common
AA-04	Obstacle Avoidance via Sonar	USV detects and avoids submerged obstacles using sonar data.	Need
AA-05	Obstacle Avoidance via LiDAR	USV detects and avoids obstacles using LiDAR.	Uncommon
AA-06	Obstacle Avoidance via Electro-Optical	USV detects and avoids objects using electro-optical cameras.	Rare
AA-07	Obstacle Avoidance via Infrared	USV detects and avoids obstacles using infrared sensors, particularly in low visibility conditions.	Rare
AA-08	Obstacle Avoidance of Marine Mammals	USV detects and avoids marine mammals to prevent collisions.	Need
AA-09	Autonomously Navigate in Compliance with COLREGS	USV follows International Regulations for Preventing Collisions at Sea (COLREGS) for safe autonomous navigation.	Rare
AA-10	Automated Path Planning Around Non-COLREGS-Compliant Vessels	USV plans alternate routes around COLREGS Non-compliant vessels.	Uncommon
AA-11	Autonomously Navigate Around User-Defined Keep-Out Zones	USV adheres to predefined operational areas, avoids breaching zone barrier(s).	Common
AA-12	Autonomously Navigate Within User-Defined Keep-In Zones	USV adheres to predefined operational areas, avoiding breaching the Keep-in Zone Barrier.	Common
AA-13	Automated Path Planning Accounting for Pre-Programmed Weather Forecast Data	USV optimizes navigation using forecasted weather data before deployment.	Rare
AA-14	Automated Path Planning Accounting for Real-Time Weather Forecast Data	USV dynamically adjusts routes based on live weather updates.	Rare
AA-15	Automated Detection of Deviation from Planned Survey Lines	USV monitors and detects deviations from Survey lines within a predefined +/- Deviation.	Rare
AA-16	Automated Re-Planning to Recover from Track Deviation	USV autonomously recalculates and corrects its planned mission when deviations occur.	Need
AA-17	Automated Path and Duty-Cycle Planning to Achieve Optimal Solar Exposure	USV adjusts navigation to maximize solar power generation.	Uncommon
AA-18	Automated Path and Duty-Cycle Planning to Optimize Wind Utilization	USV modifies its route to harness wind energy for hybrid propulsion.	Rare

AA-19	Automated Mission Planning Around Required Time of Arrival at a Desired Waypoint	USV optimizes speed to meet a defined time of arrival.	Rare
AA-20	Automated Docking of the Vessel to Piers and/or Other Vessels	USV autonomously docks with fixed structures or moving vessels.	Need
AA-21	Automated Optimization Path Planning in Relative Seas	USV modifies navigation to optimize motion in varying sea states.	Need
AA-22	Automated Refueling at Sea	USV autonomously navigates to a refueling station or vessel for fuel transfer.	Need
AA-23	Return to Base with Collision Avoidance	Returns to base while avoiding obstacles such as land, vessels, and fixed structures.	Uncommon
AA-24	Station Keeping Follow	Follows a target at a defined distance, course, and relative heading to maintain position behind the followed target.	Rare
AA-25	Deconfliction of Other Swarmed Assets	USV coordinates movements with other autonomous assets to prevent collisions.	Rare
AA-26	Swarm Survey Mission Planning (Simultaneous Planning of Multiple Assets)	USVs collaboratively plan and execute survey missions.	Rare
AA-27	Swarm Formations (Transit or Hover)	Multiple USVs maintain coordinated formations during movement or station keeping.	Rare
AA-28	Swarm Station Keeping Follow	USVs maintain relative positions in a dynamic or static environment from a followed target.	Rare
AA-29	Automated Prioritization of Data Transmissions During an Emission-Controlled State	USV prioritizes essential data transfers while limiting emissions.	Need
AA-30	Automated Adjustments to Engineering System Performance During Emission-Controlled State	USV modifies onboard system operations to reduce electronic signatures.	Need
AA-31	Recommend Alternative Run States During Degraded Propulsion/Maneuvering Performance	USV suggests alternative propulsion settings when propulsion is compromised.	Need
AA-32	Recommend Alternative Run States During Degraded Electrical System Performance	USV provides alternative power management strategies in case of electrical failures.	Need
AA-33	Adaptive Mission Prioritization	USV autonomy can prioritize mission queue based on environmental conditions or system health.	Need
AA-34	Adaptive Power Consumption Based on Mission Profile	Adjusts energy usage dynamically based on available battery/fuel and mission objectives.	Need

ITAR Regulation of COLREGs Hinders Safety and American Innovation

Michael P. Scherer
Chance Maritime Technologies
February 1, 2025

Disclaimer: The following is an opinion piece and is not legal advice. The author is not a lawyer.

The International Regulations for at-sea Collisions (COLREGS) are the "rules of the road" for maneuvering safely at sea. Compliance with COLREGS is required for all vessels by both U.S. and international law. Despite being a critical safety feature required by law, the International Traffic and Arms Regulations (ITAR) currently prevent the export of COLREGS-compliant autonomous vessel technology from the US. In this case, an "export" includes piloting a USV into international waters to conduct a survey.

A Primer on COLREGs

The International Regulations for Preventing Collisions at Sea (72 COLREGS), and the U.S. Inland Navigation Rules (33 CFR 83), together form what is colloquially called COLREGS (U.S. Coast Guard, 2023). COLREGS is the "rules-of-the-road" for safe navigation on the water. All vessels operating in U.S. and international waters are required to comply with COLREGS. Although the exact interpretation of how COLREGS applies to uncrewed vessels is still undecided (Suffern, 2024), there is broad agreement in industry that all USVs should be piloted in a manner consistent with COLREGS. Compliant autonomous maneuvering behaviors have been demonstrated, and the methodology is well published in detail (Benjamin, 2017). However, some COLREGS rules are still not broadly implemented autonomously, such as the autonomous identification of light signals (Part C of COLREGS), as it is challenging to implement in all conditions.



Figure 1: Commercial Uncrewed Ocean Drones, such as Chance Maritime MC29, have safety technology to avoid collisions.

ITAR

The International Traffic in Arms Regulations (ITAR) governs "the manufacture, export, and temporary import of defense articles, the furnishing of defense services, and brokering activities involving items described on the [United States Munitions List]" (DDTC, 2025). ITAR regulated equipment may not be exported without a license issued by the Department of State. Moreover, only U.S. persons can develop ITAR controlled technologies in the U.S. This excludes any individual with a temporary visa, such as a student visa, or H-1B work visa. Additionally, technical data must be stored on U.S.-based servers with security controls to prevent leakage to foreign entities. Taken together, these restrictions place a significant burden on organizations to protect ITAR controlled designs and equipment, and restrict their ability to hire or sponsor talent with a temporary visa. Thus, the regulations should only be used when it is in the interests of U.S. defense and not applied broadly.

ITAR and COLREGs

Although COLREGS compliance is a critical safety feature required by law, ITAR regulates COLREGS compliant autonomy, designating it as "Significant Military Equipment" in 22 CFR 120.1:

> ** (4) Control and monitoring systems for autonomous unmanned vessels capable of on-board, autonomous perception and decision-making necessary for the vessel to **navigate while avoiding fixed and moving hazards, and obeying rules-of-the road** without human intervention;*

As written, collision avoidance without COLREGS compliance is not controlled; however as soon as one follows the rules of the road, the technology becomes controlled. In effect, this means that the regulation very narrowly restricts technology specific to COLREGS compliant behavior.

Comparison to other Domains

ITAR regulation of maritime surface rules is unique, as no such equivalent export controls exist for air, ground, or undersea maneuvering. Thus, it is legal to export software that ensures a self-driving car drives on the right side of the road, but it is illegal to export software that drives a boat on the right side of a channel. Because the underlying technology is so similar, there is little to be gained controlling one over the other.

Kamikaze Drones

Explosive drone boats have significantly changed the landscape of naval war, both when employed by Ukrainians against the Russian Navy, and when employed by Houthis against commercial ships (Maltezou, 2024). However, an explosive vessel, which is trying to strike a target, isn't going to maneuver in a manner consistent with COLREGS. Thus, this regulation is not applicable to kamikaze drones.

International Access to Technology

COLREGS compliant software such as MOOS-IvP, including source code and methods, is already broadly available to the public worldwide. Such software can be downloaded by anyone and used on their uncrewed boat. Perplexingly, if a U.S. company installed that same open-source software on a USV they built, they would be restricted from "exporting" the USV without a license.

Conclusions

ITAR restriction of COLREGS compliant autonomy creates a poor incentive structure for industry, and conflicts with established safe maneuvering law. The continued presence of this regulatory hurdle hinders American innovation and hinders safe technology development.

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UNCREWED BOATS

DESIGN BUILD OPERATE

TECHNOLOGY NEEDS

Unmanned Surface Vessels (USVs) have the potential to revolutionize maritime operations, from defense and security to offshore research and logistics. The promise of fleets of autonomous vessels seamlessly navigating the world's oceans sounds like something out of a sci-fi movie, but the reality is that we're not quite there yet. The industry still faces significant technological gaps that limit widespread adoption and full autonomy.

Many of the challenges facing USVs today aren't about proving that autonomy works, it does. Instead, the real issues are about scalability, efficiency, and reliability. Current solutions tend to work in controlled environments but struggle in the unpredictable, ever-changing world of the open ocean. Whether it's enabling intelligent fleet coordination, improving perception systems, or making USVs truly self-sufficient, there's still a long way to go.

So, what's standing in the way of the USV industry reaching its full potential? Let's take a look at the key challenges that still need to be solved, and what's holding them up.

Mission Planning AI

COORDINATING FLEETS, NOT JUST BOATS

Controlling one unmanned vessel is straightforward, but coordinating an entire fleet quickly turns into a logistical nightmare. Operators currently face immense frustration due to manual coordination, resulting in frequent inefficiencies, increased risk of human error, and missed opportunities during critical missions.

The Need: Imagine simply instructing your fleet with a single command like, "Conduct a search of this area with USVs 1-4," and then sitting back as an AI autonomously assigns roles and routes for each vessel. With natural-language interfaces and sophisticated AI systems, fleet operations would become manageable by fewer operators, saving significant time and dramatically improving mission efficiency. For instance, during maritime search-and-rescue operations, fleet-level AI could swiftly assign search grids and adapt dynamically to changing conditions, potentially saving lives by greatly accelerating response times.

What's the Hold Up? Fleet-level autonomy requires highly sophisticated algorithms capable of real-time decision-making, dynamic task allocation, and seamless vessel coordination, technologies still under active research with significant computational demands that have yet to become mainstream in marine contexts.

Open-Source Architectures

BUILDING BLOCKS FOR INNOVATION

Every USV manufacturer currently creates proprietary command-and-control interfaces, often reinventing the wheel, leading to wasted effort, higher costs, and slower innovation cycles. Operators feel constrained by the lack of flexibility and interoperability among current systems.

The Need: Let's face it, if there was an open-source UI and standardized API for USVs, everyone would jump on board immediately. Modular autonomy components, easily assembled like Legos, would accelerate innovation, reduce development costs, and allow users to easily tailor their systems to specific mission needs.

What's the Hold Up? Industry reluctance around intellectual property sharing, concerns about competitive advantages, and the absence of agreed-upon standards have prevented widespread collaboration. Breaking through these barriers requires collective effort and agreement on common industry standards.

Human-Like Navigation

RESPONDING TO OCEAN DYNAMICS

Today's USVs navigate oceans as if they were predictable roadways, often resulting in aborted missions or inefficient routes when encountering rough seas, unexpected currents, or harsh weather conditions.

The Need: AI-driven navigation models that mimic expert human seamanship by dynamically adjusting to environmental factors could dramatically reduce these operational risks. These systems would allow USVs to maneuver gracefully, improve reliability, minimize risk of damage, and ultimately make operations safer and smoother.

What's the Hold Up? Achieving truly adaptive navigation requires advanced modeling, real-time data integration, and sophisticated AI algorithms, still developing and largely unproven in maritime environments.

Short-Range Perception

COMPUTER VISION TO AUGMENT RADAR

Radar is great at spotting distant threats but struggles significantly with close-range detection, especially in cluttered environments. This limitation frequently leads to accidents or costly collisions during common operations like docking, maneuvering in harbors, or operating in congested waterways.

The Need: Robust marine-specific computer vision solutions, leveraging AI-driven low-power visual processing, would greatly enhance obstacle detection at close ranges, significantly improving vessel safety, reducing collisions, and minimizing operator stress.

What's the Hold Up? Reliable marine computer vision systems require specialized datasets and algorithms tailored to challenging sea conditions, still under active development.

Sub-Surface Obstacle Avoidance

SEEING BELOW THE SURFACE

Today's USVs primarily detect obstacles above the waterline, leaving them vulnerable to hidden threats below, like submerged debris, reefs, or shallow seabeds, which can cause severe damage and operational downtime.

The Need: A real-time, AI-enhanced sonar system could help USVs "see" beneath the surface, enabling them to navigate safely in shallow coastal waters or complex marine environments, significantly expanding operational capabilities while minimizing costly collisions.

What's the Hold Up? Real-time sonar data processing and reliable AI classification of underwater obstacles remain significant technological hurdles, demanding continued

research and testing.

Adaptive Autonomy: Diagnosing Failures and Planning Around Them

Most current USVs lack onboard diagnostic intelligence, forcing operators into frequent manual interventions. When issues arise, missions are either prematurely aborted or blindly continued, reducing overall efficiency.

The Need: Intelligent self-diagnostics paired with adaptive mission-planning capabilities would revolutionize USV autonomy. USVs that autonomously assess their health, dynamically reprioritize tasks, and make informed decisions about continuing or aborting missions would drastically enhance reliability, mission success rates, and operational efficiency.

What's the Hold Up? Integrating real-time diagnostics with autonomous decision-making requires highly advanced algorithms and robust onboard computing, capabilities not yet fully matured or widely available.

Digital Twins

MISSION SIMULATION BEFORE LAUNCH

Testing USV missions today feels like rolling dice, actual mission outcomes often differ significantly from predictions, leading to costly delays, operational disruptions, or mission failures.

The Need: High-fidelity digital twins, AI-driven virtual replicas accurately simulating marine environments, would enable operators to test complete missions before deployment, significantly reducing risk and ensuring smoother real-world operations.

What's the Hold Up? Developing digital twins accurate enough for reliable pre-mission testing demands substantial investment in technology, infrastructure, and high-quality data collection.

Acoustic Perception

MEETING MARITIME REGULATIONS

COLREGS regulations explicitly require vessels to maintain a lookout "by sight and hearing." Yet most USVs currently have no capability to "listen," leaving them at risk of regulatory non-compliance and increased collision hazards.

The Need: Integrating advanced hydrophone arrays with AI-driven acoustic analytics could finally enable USVs to detect engine noise, vessel horns, distress signals, and navigational aids reliably. Incorporating these acoustic signals into navigation would significantly enhance collision avoidance and regulatory compliance.

What's the Hold Up? Acoustic sensing faces major challenges such as high ambient noise levels, complex signal processing requirements, and reliable integration into autonomy algorithms, all areas needing ongoing research and improvement.

NAVIGATING THE INNOVATION CHALLENGE

BALANCING POWER, ENDURANCE, AND STANDARDIZATION IN USV DEVELOPMENT

By John Hurwitz

The Uncrewed Surface Vehicle (USV) industry is on the cutting edge of maritime technology, driving rapid innovation to address diverse needs in defense, research, and commercial applications. From coastal surveillance and mine detection to oceanographic data collection, USVs are becoming indispensable in their versatility. However, this rapid innovation poses a significant challenge to developers, manufacturers, and operators: the need to balance advancements in sensor integration, battery performance, and operational endurance with consistent product quality and long-term scalability.

A key factor in maintaining this balance is standardization, both within individual USV platforms and across the broader industry. By emphasizing robust product documentation, modular designs, and interoperable components, the USV industry can achieve a future where platforms evolve smoothly across generations while opening the door to broader compatibility—much like USB standards in consumer electronics or unified standards for subsea connectors put forth by the American Petroleum Institute (API). An added benefit to standardizing is that the sooner the industry conforms and collaborates in some ways the more quickly it can advance in others, moving the entire USV industry forward.

Rapid Innovation vs. Consistent Product Quality

Rapid innovation has propelled USVs to the forefront of maritime operations, but innovation without consistency can lead to critical setbacks. Each new platform generation brings new capabilities, but without adequate documentation and standardization, the transition from one generation to the next can create compatibility gaps, operational inefficiencies, and increased costs.

For example, a USV outfitted with a proprietary sensor integration framework might perform well in its initial deployment but require significant re-engineering when newer sensors or communication systems emerge. If each subsequent generation demands bespoke solutions, scalability becomes a bottleneck and innovation is no longer sustainable. This is particularly problematic for defense and commercial organizations that need reliable, long-term platforms that can evolve seamlessly and become parts of larger fleets without overhauling entire fleets every year.

To address this, manufacturers must invest in meticulous product documentation and robust version control. Detailed records of hardware configurations, software updates, and sensor compatibility are crucial to ensuring that future generations can integrate with legacy systems and legacy systems are fully integrated across each version of a platform. Additionally, designing USVs with modular architectures and open communication standards allows operators to replace, upgrade, or reconfigure sensors without compromising platform usability. This approach not only ensures consistent product quality but also simplifies maintenance and reduces training requirements for operators.

Standardization: Lessons from Consumer Electronics

Standardization has long proven its value in other industries, such as consumer electronics and personal computers. USBs and electrical outlet standards offer near universal interfaces that enable broad interoperability between devices, significantly reducing complexity for end-users and manufacturers alike. On a larger commercial scale the American Petroleum Institute has created global standards for many of the manufacturing and operations areas its members conduct that have not only provided for easier integrations, but have also improved safety and reliability for an entire industry. These standards have revolutionized how technologies evolve, making devices more user-friendly and adaptable while simultaneously driving down costs through economies of scale.

The USV industry stands to benefit from a similar approach. Currently, the lack of standardization in sensor integration is one of the most significant hurdles. Sensors for sonars, side scans systems, cameras, UUV docking systems, and UAS Launch and Recovery systems often require unique power and data interfaces. These bespoke solutions increase production costs and limit cross-platform compatibility, hampering operational flexibility, and the problem must be addressed from both sides: manufacturers of USVs and companies providing the sensors. The ability to reduce and streamline connections will reduce integration time and complexity, leading to greater uptime for all. Can you imagine if a server center used a different network cable to each computer that connected to it, or ISPs had their own proprietary connectors in every location they provided internet to? The fact that they don't is a product of standardization and conformity to a single, solid product, and removes the inefficiencies and decision debt of too many options is often where young industries can find themselves.

NORBIT's Sensor Integration Unit (SIU) demonstrates the potential of multi-sensor configurability. NORBIT's SIU enables operators to connect a wide range of sonar systems, cameras, and other devices to a single unit, reducing complexity while maximizing operational flexibility, and is connected using a single network cable and accepting a voltage range covers 12v and 24v systems. With the recent acquisition of Ping DSP and Innomar, NORBIT's SIU could develop even more flexibility and adaptability across the sonar space. Imagine a topside sonar control unit that could interface with any sonar head and as well as the versatility to integrate with any USV.

By adopting more standardization efforts like these, the USV industry can ensure that platforms not only evolve smoothly within their own generations but also integrate effectively with third-party sensors and systems. This would enable operators to tailor USVs for specific missions without being locked into proprietary technologies.

The Trade-Offs of Innovation

Balancing Power, Endurance, and Integration

Even with standardization, USV designers must continue navigating the inherent trade-offs of power, endurance, and sensor integration. A platform designed to accommodate a variety of sensors needs sufficient battery capacity to power them, while still maintaining operational endurance and quality speed. This is especially challenging as missions grow more complex and demand higher data collection and processing capabilities.

Consider a multi-role USV tasked with surveillance, environmental monitoring, and communications relay over a multi-day deployment. Advanced sonar systems for seabed mapping, cameras for surface

reconnaissance, and satellite uplinks for real-time data transmission each contribute to the vessel's total power draw. The temptation to load as many sensors as possible is counterbalanced by the risk of overburdening the battery and degrading mission endurance. Adding to this complexity, the vessel must maintain sufficient propulsion power to navigate environmental conditions and evade threats.

A WAM-V 22 USV from OPT recently completed a multi-day deployment with a hydrographic survey payload (both real and simulated) and operated under full load for more than 220 nm. The payloads included were a sound velocity profiler with deployment winch, multibeam echosounder, sub-bottom profiler, satellite communications, cell radio and ip radio communication, and a remotely integrated marine diesel generator for prolonged battery endurance. This is a great example of where the industry is headed and standardizing similar setups so that it is repeatable and reliable will help drive this industry to grow better and faster. Repeatability and consistency is paramount when delivering USVs now and in the future. In the future, as we standardize and improve endurance capabilities, USVs could become more like small research vessels or naval ships but, for the time being, maintaining quality over quantity has to be our focus. If we are unable to properly document and maintain consistency, we will never reach these goals.

Standardization offers an important solution here. By adopting standardized, low-power interfaces designers can reduce the energy demands of sensor systems. Modular payload bays and lightweight sensor components further alleviate power burdens while enhancing configurability. For example, a standardized power and data interface would allow operators to swap out high-power radar systems for lower-power thermal cameras in missions where endurance is a higher priority. This level of flexibility ensures that USVs can adapt to mission requirements without compromising performance.

More exciting integrations with aerial drones, like RedCat's Teal 2, or underwater systems like the BlueHalo Defender currently demand highly customized solutions but if we standardize launch and recovery platforms across the USV industry these integrations become easier and more accessible. As a result, the entire industry is able to grow and step into it's next evolution, whatever that might be.

A Future of Scalable and Adaptable USVs

The future of USV development hinges on the ability to balance rapid innovation with consistent product quality, and standardization offers a pathway to achieving this balance. Modular designs, universal interfaces, and open communication standards will enable platforms to evolve seamlessly across generations while maximizing mission flexibility.

As the industry looks ahead, the parallels to connectors like USB and ethernet cables and other standardized technologies are clear. Just as these standards revolutionized consumer electronics, similar frameworks in the USV sector can unlock new levels of interoperability and efficiency. By embracing standardization, the industry can ensure that rapid innovation and consistent product quality are no longer opposing forces but complementary goals driving the future of maritime operations.

STANDARDIZATION ISN'T OPTIONAL - IT'S THE FUTURE OF MARITIME AUTONOMY

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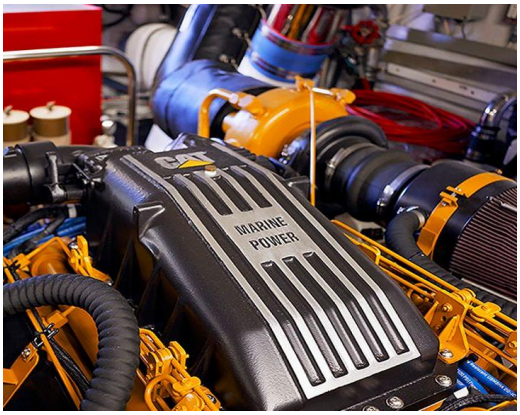
Selecting the right engine type for an Unmanned Surface Vessel (USV) is about more than just power, it's about logistics, fuel availability, maintenance cycles, and mission longevity. A USV operating near a naval fleet has different refueling options than one conducting months-long autonomous monitoring in remote waters. Some fuels, like diesel, are readily available for military operations, while others, like hydrogen, face significant infrastructure and handling challenges.

Additionally, different propulsion types offer distinct advantages and trade-offs, from gasoline's high-speed responsiveness to diesel turbine efficiency in hybrid-electric systems. Below, we examine the strengths, weaknesses, and logistical considerations of various USV power sources.

Diesel Engines

THE WORKHORSE OF LONG-DURATION USVS

Diesel is the most widely used fuel in maritime operations, offering proven reliability, high energy density, and long operational endurance. It is the standard fuel for the U.S. Navy, meaning DoD-affiliated USVs can refuel easily within existing fleet logistics. Diesel also benefits from a well-established global supply chain, making it easy to store, transport, and resupply for long missions.



Cat® marine diesel engine.

Caterpillar Inc. "Marine Diesel Engines | Marine Generator Systems." Caterpillar, https://www.cat.com/en_US/by-industry/marine.html.

The downsides of diesel include high emissions, noise, and reliance on a finite fuel source. Additionally, while diesel is widely available for military and commercial maritime use, it is less accessible for civilian organizations in remote areas, requiring fuel tankers or land-based storage facilities.

Best Suited For:

- Larger vessels with enough space for auxiliary oil filtration systems.
- Long-range operations where refueling is part of existing fleet operations.
- Offshore environments where diesel fuel is readily available.

Gasoline Engines

THE HIGH-POWER, HIGH-MAINTENANCE OPTION



The Seven Marine 627Sv

Van Hemmen, Pim. "Say Goodbye to Seven Marine's Outboards." *Soundings Online*, November 6, 2020. https://soundingsonline.com/news/say-goodbye-to-seven-marines-outboards/.

Gasoline engines are powerful and responsive, making them well-suited for high-speed USVs that require quick acceleration and maneuverability. Gasoline is also lighter and more energy-dense per unit weight than diesel, allowing for smaller, more compact engine designs that work well in fast, agile vessels.

However, gasoline has serious drawbacks in maritime applications. The U.S. military does not widely use gasoline for shipboard operations, meaning logistical support is far less robust than for diesel-powered vessels. Additionally, gasoline is far more flammable, increasing the fire risk on board. Gasoline engines also require more frequent maintenance than diesel engines, making them less suitable for long-endurance missions.

Best Suited For:

- High-speed interdiction vessels requiring rapid acceleration.
- Short-range tactical vessels operating in controlled environments.
- Small, fast vessels that need lightweight engines with high power-to-weight ratios.

Electric Engines

THE SILENT OPERATOR

Electric propulsion offers zero-emission, near-silent operation, making it ideal for covert surveillance, marine research, and short-range missions. Battery-powered USVs require minimal mechanical maintenance, reducing downtime and operational costs.

However, battery life is a major limitation. Electric USVs are limited by battery capacity, requiring frequent recharging or dockside battery swaps. The lack of mobile charging infrastructure in open-water environments means that fully electric USVs are often restricted to nearshore or fleet-supported operations. Additionally, battery weight and degradation over time affect long-term viability.



RAD Propulsion's electric drive system, designed for seamless integration into uncrewed surface vessels (USVs) and maritime autonomous surface ships (MASS), supports the growing demand for low-carbon, connected, and autonomous marine systems.
(Photo: RAD Propulsion)

Source: RAD Propulsion. "Robotics." *RAD Propulsion*, https://radpropulsion.com/robotics/.

Best Suited For:

- Covert missions where acoustic stealth is critical.
- Marine research, environmental monitoring, and conservation-focused operations near shore.
- Slower vessels, or ones which require shorter sprint duration.

Diesel Turbines

EFFICIENT BUT MAINTENANCE-INTENSIVE

Diesel turbines offer high power output with excellent energy efficiency at sustained speeds, making them useful for large USVs requiring continuous high power. Unlike piston-based diesel engines, turbines don't require lube oil, which significantly reduces maintenance intervals, a major advantage for autonomous vessels that need to stay at sea for extended durations.

However, diesel turbines have strict operational requirements. They require a robust, positively pressurized air intake and filtration system to prevent debris and salt spray contamination, which can severely degrade performance. While turbines are fuel-efficient at high loads, they are less efficient at low power settings, making them better suited for hybrid-electric configurations where they serve as a generator rather than direct propulsion.

Best Suited For:

- Larger vessels with enough space for auxiliary air filtration systems.
- In a Hybrid-electric system where turbines serve as generators charging barriers for use on electric propulsion motors.
- High-power vessels that require continuous operation at sustained speeds.

Hybrid Engines

THE BEST OF BOTH WORLDS

Hybrid propulsion systems combine the endurance of diesel with the efficiency and quiet operation of electric power, creating a versatile solution for multi-mission USVs. These systems allow vessels to operate in electric mode at low speeds, reducing noise and fuel consumption, while diesel power is engaged when higher speeds or extended range is needed. By blending both power sources, hybrid USVs can extend operational range while reducing overall emissions and fuel costs.

The trade-off is increased system complexity, hybrid USVs require integrated energy management systems, adding technical and maintenance challenges compared to standalone diesel or electric engines.

Best Suited For:

- Vessels require flexible energy management for varied mission profiles.
- Operations that need extended range and fuel efficiency.
- Support vessels operating alongside manned ships where power flexibility is key.

SOLAR

THE UNLIMITED POWER SOURCE

Solar-powered USVs rely on photovoltaic panels to generate electricity, offering a renewable, silent, and emission-free power source. This makes solar propulsion ideal for long-endurance missions, particularly in scientific research, environmental monitoring, and persistent surveillance applications. Since sunlight is unlimited, solar-powered USVs have the potential for indefinite operation, as long as weather conditions allow.

The DataXplorer™ uncrewed surface vehicle (USV) by Open Ocean Robotics is a solar-powered vessel designed for persistent ocean monitoring. (Photo: Open Ocean Robotics)

Open Ocean Robotics. "Surface Vehicles." *Open Ocean Robotics*. https://www.openoceanrobotics.com/surface-vehicles



However, solar energy has significant limitations. It is highly weather-dependent, meaning that cloud cover or nighttime operation drastically reduces power generation. Solar panels also require significant deck space, limiting their feasibility for smaller USVs or vessels with heavy payloads. Furthermore, energy storage is a challenge, batteries must store excess energy for nighttime operation, adding weight and maintenance requirements.

Best Suited For:

- Persistent, low-power operations such as oceanographic research and marine conservation.
- Long duration monitoring stations that require indefinite station-keeping.
- Vessels with large deck areas to accommodate solar panels.

Hydrogen

THE HIGH-EFFICIENCY BUT INFRASTRUCTURE-LIMITED OPTION

Hydrogen fuel cells offer a high-energy-density, zero-emission alternative to traditional fuels, making them an attractive option for environmentally friendly, long-duration USVs. Hydrogen propulsion is efficient, quiet, and scalable, making it a potential game-changer for autonomous vessels that require clean energy sources.

However, significant challenges exist. Hydrogen infrastructure is limited, making fuel availability a major hurdle, particularly for remote or military operations. Hydrogen also requires high-pressure storage tanks, adding complexity and limiting payload capacity. Additionally, hydrogen reacts violently with oxygen and can combust when in contact with water, requiring specialized handling and safety systems.

Best Suited For:

- Green-energy initiatives in commercial, research, and government projects.
- Long-duration vessels where refueling stations exist or are planned, and risks are mitigated.
- Applications where silent operation and zero emissions are priorities.

HULL MATERIALS

STRENGTHS, WEAKNESSES, AND USE CASES

Choosing the right hull material for an Unmanned Surface Vessel (USV) is a critical design decision that impacts performance, durability, cost, and long-term maintenance. While steel, aluminum, composites, and HDPE are all viable materials, each one excels in different applications based on factors like weight efficiency, strength, production feasibility, repairability, and resistance to harsh environments. Below is a breakdown of five common hull materials used in USV construction.

Steel

THE HEAVY-DUTY POWERHOUSE



The historic steel Battleship Texas, the last surviving warship to serve in both world wars.

KUT News Staff. "This is No Game: Battleship Texas." KUT News, June 12, 2012. https://www.kut.org/austin/2012-06-12/this-is-no-game-battleship-texas.

Strengths: Steel is the strongest and most impact-resistant material used in vessel construction. It can withstand harsh sea conditions, making it ideal for large naval vessels, icebreakers, and military applications that demand extreme durability. Steel is also widely available and relatively inexpensive for large-scale shipbuilding. Field repairability is another advantage, as steel can be easily welded and modified in shipyards worldwide.

Weaknesses: The main drawback of steel is its weight, which significantly impacts fuel efficiency and speed. It is also highly prone to corrosion in saltwater environments, requiring constant maintenance, coatings, and cathodic protection. Production is time-intensive, requiring heavy industrial processes, skilled welders, and extensive fabrication efforts. While repairable, ongoing maintenance costs can be high.

Ideal Use Cases: Steel is best suited for large military and commercial vessels, such as naval warships, logistics support vessels, cargo ships, and motherships for deploying USVs. It is rarely used for small to mid-sized autonomous vessels due to its weight, maintenance needs, and slower production cycles.

Aluminum

THE VERSATILE WORKHORSE



The Metal Shark 38 Defiant is a versatile patrol boat featuring an aluminum hull, inboard diesel engines, and waterjet propulsion.

Metal Shark Aluminum Boats. "Patrol boat - 38 DEFIANT." NauticExpo. https://www.nauticexpo.com/prod/metal-shark-aluminum-boats/product-28473-322168.html.

Strengths: Aluminum is a lightweight and corrosion-resistant alternative to steel, making it an excellent

choice for medium-to-large USVs that need long endurance, speed, and structural durability. It is easy to weld and fabricate, allowing for flexibility in hull designs. Its corrosion resistance is superior to steel, particularly when anodized or coated, making it well-suited for marine environments.

Weaknesses: While aluminum is more resistant to corrosion than steel, it is still susceptible to electrolysis, requiring proper insulation and coatings. It is not as strong as steel, making it prone to denting and structural fatigue over time. Fabrication requires skilled labor, and welding aluminum is more complex than steel, increasing initial production costs.

Ideal Use Cases: Aluminum is the go-to material for long-range USVs, particularly for defense, reconnaissance, and commercial applications. It is commonly used in patrol boats, medium-to-large survey USVs, and endurance-focused vessels that operate in high-sea states for extended periods.

Composites

THE HIGH-PERFORMANCE & SCALABLE SPECIALIST

Strengths: Composites, such as fiberglass and carbon fiber, offer superior strength-to-weight ratios, making them ideal for high-speed USVs while also providing a low radar signature and optimized performance hull forms. They are highly resistant to corrosion, require minimal maintenance, and can be hydrodynamically optimized for efficiency. With proper planning, composites can be highly scalable, as mold production allows for rapid hull replication in large quantities. Lower production volumes can be achieved with less costly molds, making composites adaptable to both low and high production scales.

Weaknesses: The high initial tooling cost of composites makes low-rate production expensive unless amortized over large runs. Manufacturing requires molds, curing processes, and specialized expertise, limiting initial scalability without investment in multiple high-quality molds. Field repairs are challenging, as damaged composite hulls require resin-based patching rather than simple welding. Additionally, composites can crack under extreme impact forces, unlike metals or HDPE.



The fiberglass boat construction process involves applying layers of fiberglass fabric saturated with resin over a mold to create a strong, durable hull structure.

Rudow, Lenny. "Boat Building Basics: Fiberglass, Resin, Composites And Cores." Boats.com, February 8, 2022. https://www.boats.com/how-to/boat-building-construction-resin-fiberglass-cores/.

Ideal Use Cases: Composites are ideal for high-speed USVs, stealth missions, and specialized research vessels. They are commonly used in lightweight surveillance drones, racing-style autonomous vessels, and

high-end naval applications where speed, stealth, and hydrodynamic performance are priorities.

HDPE (Vacuum Molded)

THE MASS-PRODUCTION CHAMPION

Strengths: Vacuum-molded HDPE (rotomolding, thermoforming) is fast to produce, inexpensive, and completely corrosion-proof. It is also highly impact-resistant, making it an excellent choice for rugged, high-volume USVs. This production method allows for extremely fast and repeatable manufacturing, reducing unit costs significantly.

Weaknesses: Vacuum-molded HDPE lacks structural stiffness, making it unsuitable for larger vessels or high-speed applications. Hull shape and complexity are limited by mold constraints, meaning design flexibility is reduced compared to welded HDPE or aluminum. Additionally, vacuum-molded HDPE is difficult to repair in the field without specialized plastic welding tools. The initial investment in molds is high, making it cost-effective only for large production runs.

Ideal Use Cases: Vacuum-molded HDPE is perfect for small USVs that need to be mass-produced and deployed in rugged conditions. It is commonly used for coastal surveillance drones, autonomous security craft, and environmental monitoring vessels.

HDPE (Welded Sheets)

THE DURABLE, LOW-MAINTENANCE CONTENDER

Strengths: Sheet-welded HDPE offers greater structural rigidity than vacuum-molded HDPE while retaining the same corrosion resistance, impact durability, and low radar signature. Unlike vacuum-molded hulls, welded sheets allow for larger, more complex hull designs, making HDPE viable for mid-sized USVs. Field repairs are possible with the right plastic-welding tools, making it easier to maintain in remote operations. It also matches aluminum in production speed while being completely corrosion-proof.



Tideman Boats' high-speed HDPE workboats demonstrate exceptional durability and performance in various challenging environments.

Tideman Boats. "Gallery." *Tideman Boats*, https://tidemanboats.com/gallery/.

Weaknesses: While stronger than vacuum-molded HDPE, welded sheets are still not as stiff as aluminum or composites, making high-speed or open-ocean applications more difficult. Production is slower than vacuum molding, increasing costs for low-production runs. Additionally, welded HDPE hulls require specialized fabrication expertise.

Ideal Use Cases: Welded HDPE is a great choice for mid-sized USVs that need durability, impact resistance, and low maintenance. It is often used in long-endurance survey vessels, coastal patrol USVs, and environmental monitoring applications.

HULL TYPES & CHARACTERISTICS

UNDERSTANDING THE PERFORMANCE TRADEOFFS

The hull of a vessel is its most fundamental design element, shaping its performance, stability, and operational effectiveness. Whether a vessel is built for high-speed interception, long-endurance reconnaissance, or offshore research, the right combination of hull characteristics determines how efficiently it moves, how well it handles rough seas, and how much cargo or equipment it can carry.

While it may seem straightforward to classify hulls by shape or number of hulls, naval architecture is an intricate and highly technical field. Every design choice involves trade-offs between speed, efficiency, maneuverability, and durability, and no single configuration excels in every scenario. To fully document every possible hull design, optimization strategy, and real-world consideration would require a multi-volume textbook series. Instead, this section provides high-level descriptions and general rules of thumb to introduce the core principles of hull selection and optimization.

At its core, hull design is shaped by four key factors:

1. **Hull Type** – Refers to the number of hulls (monohull, catamaran, trimaran), which establishes base stability, deck space, and structural layout. A vessel's hull type dictates how it balances stability, speed, and payload capacity.
2. **Hydrodynamic Behavior** – Defines how the hull interacts with water, primarily categorized as displacement, planing, or semi-displacement. This determines whether the vessel plows through the water for endurance, lifts onto the surface for speed, or balances both for versatility.
3. **Hullforms** – Variations in hull shape, such as V-bottom, flat-bottom, and round-bottom, impact wave handling, fuel efficiency, maneuverability, and seakeeping in rough waters. The right hullform ensures the vessel performs optimally in its expected operating environment.
4. **Other Hull Features** – Enhancements like stepped hulls, wave-piercing bows, can refine performance, reduce drag, improve stability, or optimize fuel efficiency for specialized applications. However, they come with trade-offs in complexity, maintenance, and mission suitability.

While hull type affects stability and space, hydrodynamic behavior determines efficiency and endurance, hullforms refine handling and maneuverability, and additional features enhance performance for specific conditions.

Ultimately, there is no single "best" hull, only the right combination of hull type, hydrodynamic behavior,

hullform, and features to meet the specific mission at hand. The following sections explore each of these elements in detail, breaking down their strengths, weaknesses, and real-world applications to help navigate the complex decisions of vessel design.

Hull Design Is like The Foundation of a House

Every boat, whether manned or unmanned, has one primary challenge, it must move through water as efficiently as possible. But water doesn't like to be moved. It pushes back with resistance, slowing the vessel down and demanding more power from the propulsion system. The way a hull is designed determines how well it overcomes these forces, affecting speed, endurance, and fuel efficiency.



Catamaran offshore racing vessel TNT Custom Marine.

"Hi-Performance Boat Operation – Part 1: Hull Types." *TNT Custom Marine*, June 2019. https://tntcustommarine.com/2019/06/hi-performance-boat-operation-part-1-hull-types/.

A boat must fight three main types of resistance: air resistance, wave resistance, and water friction (also known as hydrodynamic drag). At slow speeds, wave resistance is minimal, but water friction is high, meaning that hulls designed for endurance, like displacement hulls, are shaped to glide smoothly with minimal effort. At high speeds, friction is still a factor, but wave resistance becomes the bigger challenge, which is why planing hulls are built to lift out of the water and ride on top of it rather than push through.

A key concept in hull efficiency is wetted surface area, the portion of the hull that stays submerged. The more of the hull that's in the water, the more friction it has to overcome, which means more power and more fuel consumption. This is why slender, streamlined hulls tend to be more efficient for endurance, while stepped hulls, and planing designs reduce drag at higher speeds. Additionally, how weight is distributed across a vessel affects how efficiently it moves, too much weight forward or aft can increase drag, making a boat work harder to maintain speed.

Understanding these hydrodynamic forces is essential to selecting the right hull type, hullform, and features. The following sections will break down how different hull designs manage these challenges and optimize vessel performance.

Hull Types

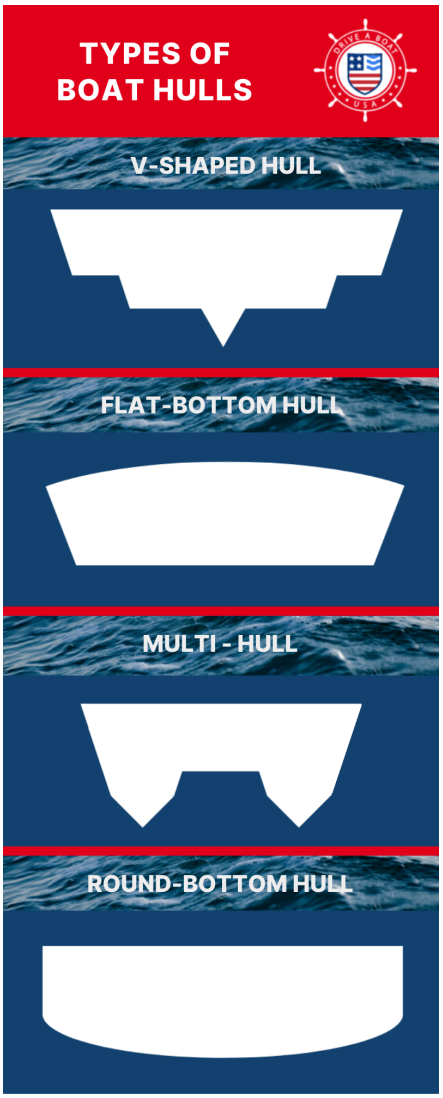


Illustration of different boat hull types, including displacement and planing hulls, each designed for specific performance characteristics and water conditions.

Drive a Boat USA. "Boat Hull Types and Shapes." *Drive a Boat USA*, June 22, 2023.https://driveaboatusa.com/blog/boat-hull-types-and-shapes/.

The number of hulls or "Hull Type" in a vessel plays a crucial role in stability, efficiency, speed, and operational capability. While traditional monohulls remain the most common hull type, multi-hull configurations, such as catamarans (dual-hull) and trimarans (triple-hull), offer distinct advantages depending on the mission requirements. Choosing the right hull type requires careful consideration of the trade-offs between stability, maneuverability, fuel efficiency, and payload capacity.

Monohulls: The Versatile Standard

Monohulls are the simplest and most widely used hull type. They feature a single hull, making them easy to construct, highly adaptable, and cost-effective across a wide range of applications. Their streamlined shape reduces drag, improving fuel efficiency at low-to-moderate speeds.

However, monohulls are more prone to rolling motion, especially at low speeds or in rough seas, which can impact sensor performance and crew comfort. They also have less deck space than multi-hull vessels, which can limit their ability to carry larger payloads.

Best suited for:

- Low speed efficiency and below deck payload capacity are critical.
- Compact size, moderately high speeds, and the greatest maneuverability.
- Open ocean deep-water operations and endurance where stability is less important.

Catamarans

THE STABLE MULTIROLE PLATFORM

Catamarans have two parallel hulls, providing exceptional lateral stability, increased deck space, and reduced drag at high speeds. The wider stance makes catamarans ideal for sensor platforms, hydrographic surveys, and passenger transport, as they provide a more

stable working environment in various sea conditions.

Despite these benefits, catamarans are prone to slamming in heavy seas, especially at high speeds. They also require more space when docking and can be more complex and costly to build due to their additional structural reinforcements.

Best suited for:

- High-speed vessels where top deck space is important.
- Offshore vessels require a stable platform moderately high sea state.
- Long endurance with reduced motion for sensors.

Trimarans

THE MULTI-PURPOSE POWERHOUSE

Trimarans feature three hulls, combining the stability of catamarans with the speed and efficiency of monohulls. The narrow central hull minimizes drag, while the outriggers enhance stability and deck space. Trimarans are often used in military, logistics, and offshore industries, where a balance of speed, endurance, and payload flexibility is needed.

However, trimarans are more complex and expensive to construct. Their wider beam makes docking more challenging, and their structural design must account for stress distribution across three hulls.

Best suited for:

- Vessels with greater fuel efficiency at higher speeds.
- Multi-role platforms where adaptability and deck space are critical.
- Vessels that demand both stability and long-range endurance.

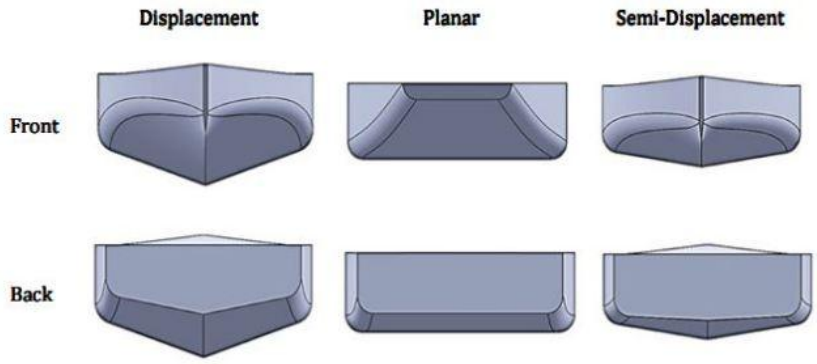
Hydrodynamic Behavior

A vessel's hydrodynamic behavior determines how it moves through water, directly influencing speed, fuel efficiency, endurance, and stability. While the number of hulls primarily affects stability and deck space, the hydrodynamic design dictates water resistance, maneuverability, and wave-handling characteristics.

At its core, hydrodynamic behavior determines whether a vessel pushes through the water, lifts onto the surface, or balances both behaviors. A displacement hull relies on buoyancy to move efficiently at low speeds, maximizing fuel economy and endurance, ideal for long-range operations. A planing hull, on the other hand, is designed to lift onto the water's surface at higher speeds, significantly reducing drag but consuming more power in the process. Semi-displacement hulls serve as a hybrid, allowing for moderate-speed operation without fully sacrificing endurance, a compromise between efficiency and agility.

Selecting the right hydrodynamic behavior is essential for matching mission requirements. A long-endurance survey vessel or oceanographic research platform benefits from the smooth, fuel-efficient glide of a displacement hull, while fast-response or tactical vessels require the speed and maneuverability of a planing hull. For vessels operating in variable conditions, semi-displacement hulls provide flexibility across different speed ranges.

The following sections will examine the most common hydrodynamic categories, explaining their advantages, trade-offs, and ideal applications, helping you determine the best hull performance profile for your needs.



Small-scale models of different hull shapes, displacement, planing, and semi-displacement, used by the University of Colorado Denver Solar Splash Team to determine the most efficient design for their solar-powered boat.

LYNX. "Model Testing." SS LYNX, February 19, 2016. https://sslynx.wordpress.com/2016/02/19/model-testing/.

Displacement Hulls

THE ENDURANCE WORKHORSE

Displacement hulls are built for stability, efficiency, and endurance. Unlike high-speed hulls that skim the surface, displacement hulls plow through the water, relying on buoyancy rather than hydrodynamic lift. This makes them highly fuel-efficient at low speeds, allowing for long-range operations with minimal power consumption. These vessels can carry heavy payloads while maintaining smooth, controlled movement, even in rough seas.

However, their large wetted surface area creates significant drag, limiting top speeds. Displacement hulls are not built for rapid acceleration or maneuverability, making them unsuitable for fast-response or interdiction missions.

Best suited for:

- When a high payload capacity and fuel efficiency is required over long distances.
- Vessels that need steady, predictable movement for sensor and data collection operations.
- Low speeds but require stability in offshore conditions.
- When comfort and fuel efficiency are prioritized over speed.

Planar Hulls

THE HIGH-SPEED SPRINTER

Planar (commonly referred to as "planning") hulls are designed for agility and speed. At low speeds, they behave like displacement hulls, but as speed increases, they lift onto the water's surface, reducing drag and allowing for rapid acceleration. These hulls are used in high-speed interdiction, coastal patrol, and fast-response operations where quick maneuvering is essential.

Despite their speed advantages, planing hulls have high power demands, reducing fuel efficiency. They also slam into waves at high speeds, making them unstable in rough conditions and limiting their effectiveness in offshore or open-ocean environments.

Best suited for:

- Vessels where top speed and agility are the primary concerns.
- Vessels that perform short, direct routes are required in relatively calm waters.
- When there's a need for rapid deployment, minimal transit time, and high maneuverability.
- When speed and performance outweigh fuel economy need.

Semi-Displacement Hulls

THE HYBRID PERFORMER

Semi-displacement hulls combine the efficiency of displacement hulls with the speed benefits of planing hulls, making them a versatile choice for vessels requiring both moderate speed and long-range endurance. They operate efficiently at low speeds like displacement hulls but can push beyond hull speed, achieving partial lift to reduce drag and increase speed without the full fuel penalties of planing designs. This makes them well-suited for long-endurance patrol vessels, fast ferries, and military ships that demand a balance of range and agility. Additionally, semi-displacement hulls tend to offer better seakeeping than planing hulls, as they maintain more water contact at higher speeds, providing a smoother, more stable ride in offshore and rough-sea conditions.

However, semi-displacement hulls do not fully achieve the speed and efficiency benefits of a pure planing hull. While they can exceed displacement speeds, they never fully rise out of the water, meaning they still experience higher drag at top speeds than planing designs. This makes them less fuel-efficient when operating at maximum speed. They are also highly sensitive to weight, if overloaded, they behave more like displacement hulls and lose their speed advantages; if too light, they may not maintain the stability and comfort expected for long-duration operations. These trade-offs make semi-displacement hulls a compromise solution, ideal for missions that require flexibility across a range of speeds and conditions but not extreme efficiency in any single category.

Best Suited For:

- Vessels that need a balance of speed and endurance.
- Where efficiency and reduced motions & accelerations are priorities.
- When vessels require long-range travel with moderate-speed capability.

Hullforms

Beyond the number of hulls and hydrodynamic behavior, additional hullforms and design features can further enhance a vessel's efficiency, stability, or maneuverability. These modifications influence how a hull interacts with water, optimizing it for specific conditions and operational demands.

For example, a V-bottom hull improves wave-cutting ability, making it ideal for offshore operations, while a flat-bottom hull maximizes shallow-water access but sacrifices seakeeping in rough seas. Stepped hulls enhance planing efficiency by reducing wetted surface area allowing vessels to lift out of the water, drastically reducing drag and increasing speed, commonly referred to as "on step".

Choosing the right hullform and additional features depends on the vessel's mission profile and operational environment. Additional features like stepped hulls can highly beneficial for speed-focused vessels to complement the hull stability, seakeeping, and performance at speeds for their designed operating environment and mission. These refinements can transform a vessel's handling, endurance, and efficiency, making them a critical design consideration alongside the primary hull type and hydrodynamic behavior.

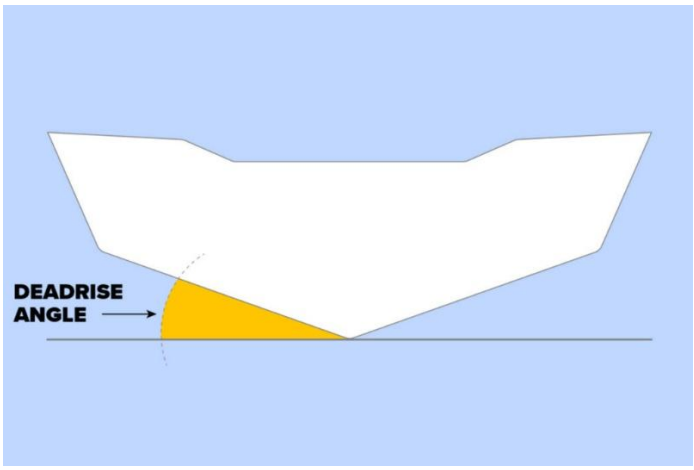
The following sections will explore common hullforms and additional design features, detailing their advantages, trade-offs, and best applications, helping to refine the selection process for optimal vessel performance.

V-Bottom Hulls

THE OFFSHORE PERFORMER

V-bottom hulls are an evolution of planing hulls, designed to slice through waves rather than slam into them. With a sharper entry angle, these hulls reduce wave impact, making them more stable at high speeds in rough conditions. This makes them highly effective for offshore patrols, naval escort vessels, and reconnaissance operations in unpredictable seas.

The trade-off is a deeper draft, which limits access to shallow waters. Additionally, while more stable than a standard planing hull, they still require significant power to maintain speed.



Maritime Page. "Boat Deadrise Explained – Understanding Boat Hull Design." Available at: https://maritimepage.com/boat-deadrise-explained-understanding-boat-hull-design

Deadrise refers to the angle between the horizontal plane and the hull surface at the keel (bottom centerline) of the boat. On a V-bottom hull, this angle determines how deep or shallow the "V" shape is from bow to stern.

A higher deadrise (e.g., 20°+) creates a sharper V, which cuts through waves more smoothly—ideal for rough water and high-speed stability.

A lower deadrise (e.g., under 10°) results in a flatter hull, which improves stability at rest and is better for calm, shallow waters.

Essentially, more deadrise = smoother ride in waves, while less deadrise = better stability at rest and shallows.

Best suited for:

- Offshore workboats and crew transfer vessels that operate in moderate-to-high sea states.
- Search and rescue (SAR) boats where stability at high speeds is critical.
- High-performance offshore fishing boats designed for deep-sea sport fishing.

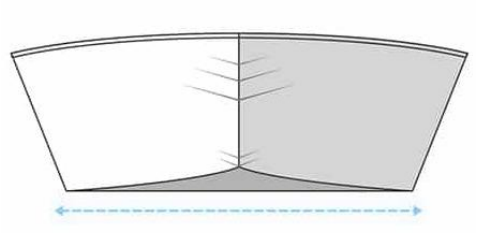
Flat-Bottom Hulls

THE SHALLOW-WATER SPECIALIST

Flat-bottom hulls prioritize stability and shallow-water performance over speed and seakeeping ability. They have minimal draft, allowing them to operate in environments where deeper-hulled vessels would run aground. This makes them ideal for riverine operations, amphibious USVs, and nearshore survey vessels.

BOATsmart! *Boat Hull Types.*

Available at: https://www.boatsmartexam.com/knowledge-base/article/boat-hull-types/



However, flat-bottom hulls become unstable in rough seas due to their lack of deep hull penetration, causing excessive bobbing and rolling in waves. Additionally, they generate significant drag at higher speeds, making them inefficient beyond moderate velocities.

Best suited for:

- Riverboats and inland cargo barges that navigate shallow waterways.
- Amphibious landing craft used for beach landings and logistics transport in shallow waters.
- Nearshore workboats and water taxis where maneuverability in tight spaces is needed.

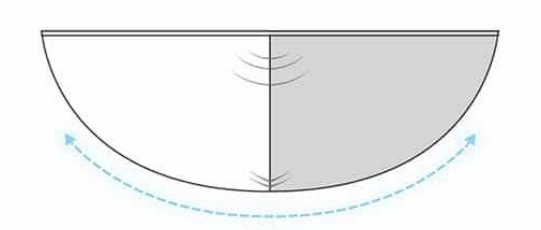
Round-Bottom Hulls

THE SMOOTH OPERATOR

Beyond the number of hulls and hydrodynamic behavior, hullform design plays a critical role in how a vessel interacts with water, influencing efficiency, stability, and maneuverability. Different hullforms are optimized for specific conditions, whether it be cutting through waves, minimizing drag, or maximizing buoyancy in shallow waters.

For example, a V-bottom hull improves wave-cutting ability, making it ideal for offshore operations and rough-sea conditions, whereas a flat-bottom hull provides excellent shallow-water access at the cost of stability in turbulent conditions. Round-bottom hulls enhance fuel efficiency and smooth motion at low speeds, making them ideal for long-range endurance vessels.

Choosing the right hullform depends on the vessel's operational environment and mission priorities. Round-bottom hulls provide efficient movement over long distances, making them the go-to choice for sailboats, and canoes as they allow the vessel to "roll" with the waves.



BOATsmart! Boat Hull Types.

Available at: https://www.boatsmartexam.com/knowledge-base/article/boat-hull-types/

Best suited for:

- Survey vessels needing long-endurance efficiency.
- When fuel economy is critical for steady, predictable movement.
- When prioritizing a reduction in slamming forces, over speed.

Other Hull Features

While hullforms define how a vessel interacts with water at a fundamental level, additional hull features can significantly optimize efficiency, stability, speed, and seakeeping. These features are designed to reduce drag,

improve wave handling, increase fuel economy, or enhance maneuverability, depending on the mission's operational requirements.

For vessels that need to maximize speed, options like stepped hulls help reduce water resistance and improve efficiency at higher velocities. For vessels that operate in rough seas, wave-piercing designs can cut through waves more effectively, improving comfort and fuel efficiency. While these features provide clear advantages, they also come with trade-offs, such as higher maintenance requirements or reduced effectiveness in certain conditions.

Below are some of the most commonly used hull-enhancing features, along with their benefits, drawbacks, and ideal applications.

Stepped Hulls

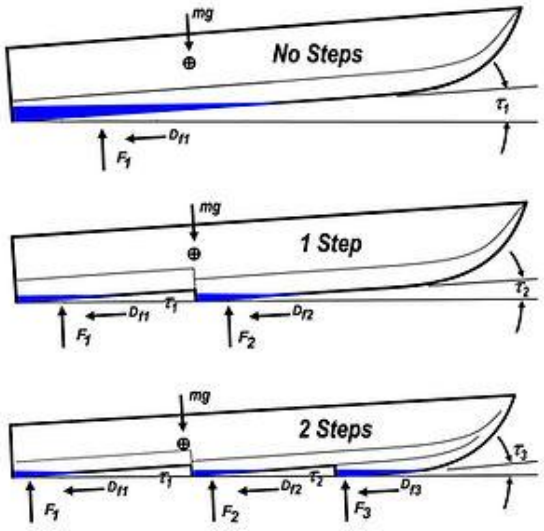
THE EFFICIENCY BOOSTER

Stepped hulls take the best aspects of planing hulls while improving efficiency. By incorporating transverse steps along the hull bottom, they break up water adhesion and reduce drag, resulting in better fuel economy, higher speeds with less power, and a reduction in slamming due to the cavitation created beneath the hull. These hulls offer an advantage in moderate-speed applications where power consumption and efficiency are key concerns.

However, they struggle in rough conditions due to potential loss of lift in heavy seas. They can also be difficult to control during sharp maneuvers, making them less effective for highly dynamic tactical operations or missions requiring extreme agility.

A stepped hull uses one or more notches along the bottom of the hull to introduce air beneath the boat, reducing drag by decreasing the wetted surface area. Each step resets the water flow and creates a new planing surface, which generates its own lift force (F_1, F_2, etc.) to help support the boat's weight. This allows the hull to ride higher, increase speed, and improve fuel efficiency.

As the number of steps increases, so does the number of lift points, but this also alters the boat's trim and handling. Each lift force acts at a different position along the hull, creating unique moment arms (D_1, D_2, etc.) that shift the center of pressure aft. While this boosts performance, it can reduce low-speed stability and make high-speed handling more sensitive—requiring precise tuning and balance to get right.



Boat Blurb. "The Definitive Guide to Stepped Hulls." Available at: https://www.boatblurb.com/post/the-definitive-guide-to-stepped-hulls

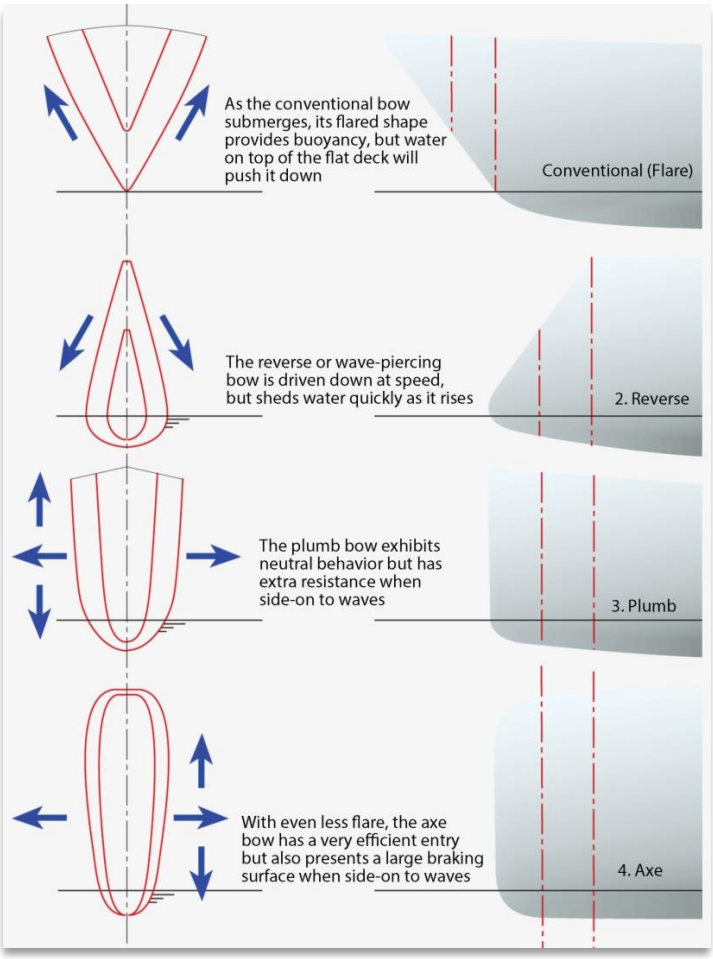
Best suited for:

- Operating at moderate speeds to balance speed and fuel savings.
- Traveling in high-speed straight lines.
- Reduction in slamming forces at high speeds.

Wave-Piercing Hulls

CUTTING THROUGH THE CHAOS

Wave-piercing hulls are designed with a sharp, elongated bow that allows them to cut through waves rather than ride over them. This reduces vertical motion (pitching) and wave resistance, improving fuel efficiency and ride comfort in rough seas. These hulls are particularly effective for high-speed ferries, naval vessels, and offshore workboats, where maintaining speed and stability in turbulent waters is critical.



Reverse Bow: Cuts cleanly through waves with minimal upward lift, reducing pitching and improving efficiency in rough seas. Ideal for performance sailing and multihulls needing a longer waterline and smoother ride.

Plumb Bow: Vertical stem offers a balance between wave penetration and forward volume. Increases waterline length for better speed potential and performs well in general-purpose cruising across mixed sea states.

Axe Bow: Combines wave-piercing efficiency with more volume above the waterline to reduce pitching. Useful for offshore or high-speed vessels where a smoother ride is needed without sacrificing internal volume.

Sail Magazine. *"A Look at Wave-Piercing Bows on Multihulls."*
Available at:
https://www.sailmagazine.com/multihulls/a-look-at-wave-piercing-bows-on-multihulls

NicePNG. *"A Look at Wave-Piercing Bows on Multihulls."*
Available at:
https://www.nicepng.com/ourpic/u2w7i1i1r5o0a9t4_a-look-at-wave-piercing-bows-on-multihulls

Despite their ability to handle rough water efficiently, wave-piercing hulls can lack buoyancy in extreme conditions, making them prone to burying the bow into waves (submarining) if not properly designed. They

also tend to be less maneuverable at low speeds and require specialized hull reinforcement to handle high-impact forces.

Best suited for:

- Vessels that need to maintain efficiency in rough conditions.
- Vessels operating in turbulent waters.
- Where minimizing pitching is required.

PROPULSION TYPES

Selecting the right propulsion system is just as critical as choosing the engine itself. A vessel's propulsion setup directly influences maneuverability, efficiency, fuel consumption, and mission performance. While traditional propeller-based propulsion remains the most widely used system, advancements in jet drives, pod drives, stern drives, and azimuth thrusters offer specialized advantages for different operating conditions.

Each propulsion method comes with distinct trade-offs. Jet drives excel in shallow waters and high-speed operations, but they are more susceptible to debris fouling. Outboard motors provide cost-effective, easy-to-replace solutions, but they are less fuel-efficient for long-duration missions. Pod and azimuth drives offer unmatched maneuverability, making them ideal for dynamic positioning and precise station-keeping, though they require higher upfront investment and maintenance. Meanwhile, contra-rotating and loop propellers improve efficiency and thrust, but add mechanical complexity.

For high-endurance missions, propellers, stern drives, and hybrid-electric systems provide the best fuel efficiency and reliability. For shallow-water or high-speed applications, jet drives and surface-piercing propellers are often preferred. Additionally, emerging technologies such as hydrogen propulsion and rim-driven thrusters may redefine efficiency and sustainability in the coming years.

The following sections break down the most common and specialized propulsion types, detailing their strengths, weaknesses, and best use cases to help determine the best fit for a USV's mission and operational environment.

Sail

THE INFINITE ENDURANCE OPTION

Sail-powered USVs are becoming increasingly common in long-duration, energy-independent applications. Unlike traditional fuel-powered vessels, sail propulsion provides nearly infinite endurance, making it an attractive option for oceanographic research, weather monitoring, and environmental surveillance. Many modern sailing USVs use rigid sails rather than traditional fabric sails, offering better durability, automation potential, and integration with onboard sensors.



The U.S. Navy testing a Saildrone unmanned surface vehicle (USV) in the Gulf of Aqaba, operating at sea for over 30 days to assess its intelligence, surveillance, and reconnaissance (ISR) capabilities.
(Photo: Saildrone)

Source: The Maritime Executive. "Sail-powered USV tested in Persian Gulf." *MySailing*, January 30, 2022. https://www.mysailing.com.au/sail-powered-usv-tested-in-persian-gulf/.

However, the effectiveness of sails in USVs remains a topic of debate. While wind power eliminates fuel dependence, it introduces aero- and hydrodynamic challenges that can impact stability, maneuverability, and mission flexibility. Unlike manned sailing vessels that can make real-time adjustments, USVs rely on automated sail-trimming systems, which add mechanical complexity and potential failure points. These automated systems must continuously adjust to wind shifts, and failures in the control mechanisms can leave a vessel unable to maneuver effectively.

Sailing USVs also suffer from limited maneuverability compared to engine-driven systems. Wind direction constrains movement, requiring complex wind tracking and sail adjustments that increase transit time and reduce mission flexibility. Additionally, sailing alone is rarely sufficient, unless navigating the open ocean, most sailing USVs incorporate auxiliary electric propulsion for maneuvering in low-wind environments, precise station-keeping, and navigating confined spaces.

While rigid sails introduce drag and could reduce hydrodynamic efficiency, they also serve a unique advantage, their height above water makes them an ideal mounting point for perception equipment, communication antennas, and long-range sensors. This can enhance situational awareness, particularly in surveillance and remote monitoring roles.

Best Suited For:

- Long-endurance missions requiring complete energy independence.
- Environmental monitoring and oceanographic research where precise location is not important.
- Vessels requiring an elevated structure for sensor placement and communications.
- When speed and maneuverability is lowest priority.

Jet Drive

HIGH-SPEED & SHALLOW-WATER PERFORMANCE

Jet drives work by drawing in water and expelling it at high velocity, offering exceptional maneuverability and

high-speed operation. Unlike propellers, jet drives do not have exposed blades, reducing the risk of harming marine life or entanglement. They are also highly effective in shallow waters, as they don't extend below the hull.

However, jet drives are less fuel-efficient than propellers and require higher maintenance due to their sensitivity to debris and marine growth. They can be noisier than other propulsion types, making them less ideal for stealth or research applications.

The USMI SWCC Military Riverine Assault Boat (RAB) is a 33-foot aluminum-hulled vessel designed for swift and agile operations in riverine and near-shore environments. Equipped with twin Yanmar diesel engines and Hamilton jet drives, it achieves speeds exceeding 40 knots.

Police and Tactical Supply. "USMI SWCC Military Riverine Assault Boat RAB." *Police and Tactical Supply*, https://policeandtacticalsupply.com/product/usmi-swcc-military-riverine-assault-boat-rab/.



Best Suited For:

- High-speed missions requiring quick maneuverability.
- Shallow-water operations where propellers would be at risk.
- Maritime security, patrol, and interception roles.

Stern Drive

THE BALANCE OF EFFICIENCY & MANEUVERABILITY

Stern drives, also known as inboard/outboard (I/O) drives, combine the power of an inboard engine with the maneuverability of an outboard drive unit. This setup offers good efficiency and better control than traditional inboard propulsion, making it a versatile choice for mid-sized USVs.

However, stern drives require more maintenance than fixed propeller shafts or jet drives, and they are less common in commercial and military vessels, making spare parts and servicing less accessible. Their moving components are vulnerable to impact damage in shallow or debris-filled waters.



Golden Arrow Marine. *"Volvo Penta Aquamatic Sterndrive Diesel Range D6 – DPH (300/340/380/400 HP)."*
Available at: https://www.goldenarrow.co.uk/product/volvo-penta-aquamatic-sterndrive-diesel-range-d6-dph-300-340-380-or-400-hp/

Best Suited For:

- Operations requiring a mix of efficiency and maneuverability.
- Vessels operating in both deep and shallow waters.
- Mid-range USVs needing flexibility in propulsion control.

Pod Drive

THE PRECISION MANEUVERABILITY SOLUTION

Pod drives, such as azimuth thrusters, provide unmatched maneuverability by allowing the propulsion unit to rotate 360 degrees, eliminating the need for a traditional rudder. This system significantly improves handling, especially in tight spaces, making it ideal for research, survey, and precision operations.

However, pod drives are expensive, mechanically complex, and require specialized maintenance. They are less common in smaller vessels due to cost and power requirements, and their moving components require regular servicing.

Boats.com. *"Pod Drives Explained: Volvo Penta IPS, Cummins Zeus, ZF Marine, and CAT."*
Available at: https://www.boats.com/boat-buyers-guide/pod-drives-volvo-penta-ips-cummins-zeus-zf-marine-cat/



Best Suited For:

- Vessels requiring precise station-keeping and dynamic positioning.
- Survey, research, and high-end maritime applications.
- Maneuvering in constrained or crowded environments.

Azimuth Thrusters (Z-Drive)

PRECISION MANEUVERABILITY

Azimuth thrusters, also known as Z-drives, are 360-degree rotatable propulsion units that eliminate the need for rudders, providing exceptional maneuverability. By rotating the entire drive unit, vessels can move in any direction without reversing the propeller, making them ideal for dynamic positioning and precision movement in confined or unpredictable waters. This technology is commonly used in tugboats, offshore support vessels, and specialized USVs requiring station-keeping.

However, azimuth thrusters come with trade-offs. They are mechanically complex, increasing maintenance requirements and system costs. Their high exposure to underwater impacts makes them vulnerable to damage in shallow or debris-filled waters, and they often require stronger structural mounting compared to traditional fixed-shaft propellers.



Professional Mariner. *"Schottel Introduces New Medium-Sized Azimuth Thrusters."* Available at: https://professionalmariner.com/schottel-introduces-new-medium-sized-azimuth-thrusters/

Best Suited For:

- Precise movement and dynamic station-keeping,
- Large, high-endurance vessels requiring efficient maneuvering without additional rudders.
- Vessels needing rapid course corrections in confined spaces.

Outboards

THE COST-EFFECTIVE, SIMPLE SOLUTION

Propellers are the most common propulsion system for both manned and unmanned vessels. They offer high efficiency and fuel economy at a wide range of speeds, making them ideal for long-endurance applications

in deep waters. Propeller systems are also well-understood, easy to maintain, and widely available, ensuring that repair and replacement parts are accessible worldwide.

However, propellers pose risks to marine life and are susceptible to fouling from marine growth, ropes, and debris, which can reduce efficiency and cause mechanical issues. In shallow water, propellers are prone to damage from ground impact, limiting their use in certain coastal and riverine operations.

Best Suited For:

- Cost-sensitive vessels that need easy maintenance and quick replacements of engines.
- Smaller vessels operating nearshore or inland waters.
- Short-duration operations where fuel efficiency is less critical.



OXE Marine. *"OXE Diesel Outboard Engines."* Available at: https://oxeoutboards.com/oxe-diesel-outboard-engines/

Standard Propeller

THE STANDARD FOR MARITIME PROPULSION



406 Prop Shop. "The Benefits of Proper Propeller Balancing." Available at: https://406propshop.com/the-benefits-of-proper-propeller-balancing/

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Best Suited For:

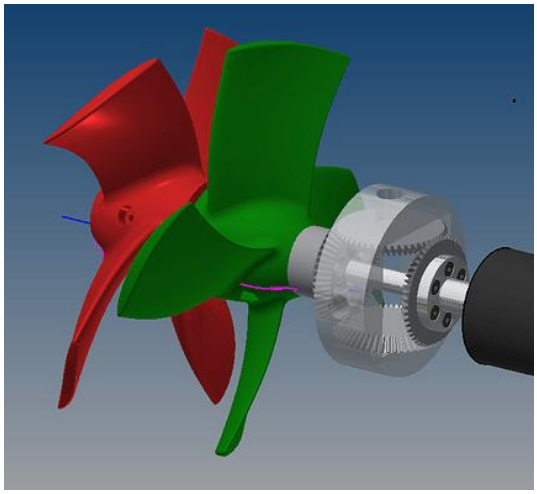
- Long-duration USVs operating in deep waters.
- Maritime logistics, research, and survey vessels.
- Operations where fuel efficiency is a priority.

Contra-Rotating Propellers (CRP)

MAXIMIZING EFFICIENCY & THRUST

Contra-rotating propellers (CRP) feature two propellers rotating in opposite directions on the same axis, improving propulsion efficiency by counteracting rotational energy losses. This setup reduces turbulence, increases thrust, and enhances energy efficiency, making CRPs well-suited for high-performance naval vessels, high-speed ferries, and long-endurance USVs.

The primary drawbacks are increased mechanical complexity and maintenance requirements. The dual-propeller system requires precise synchronization, meaning higher installation and operational costs. Additionally, debris or entanglement in the propellers can lead to difficult repairs compared to simpler, single-propeller designs.



Foil Zone Forum. "Contra-Rotating Propeller." Available at: https://foil.zone/t/contra-rotating-propeller/2276

Best Suited For:

- High-speed USVs and naval applications requiring enhanced thrust and efficiency.
- Long-endurance missions where reducing energy losses is critical.
- Vessels that require stable acceleration and optimized fuel consumption.

Loop Propellers

EFFICIENT, HIGH-THRUST PROPULSION

Loop propellers are a specialized variant of standard propellers designed to improve thrust and efficiency while reducing cavitation. These systems enclose the propeller blades in a duct or loop, improving water flow and increasing propulsion efficiency at low speeds. They are often used in tugboats, icebreakers, and research vessels that need high thrust with minimal energy loss.

Loop propellers provide better protection against debris and ice, making them ideal for harsh environments. However, they add weight, complexity, and cost compared to open propeller designs, and they reduce high-speed efficiency, making them less suitable for fast-moving vessels.

Toroidal propellers, characterized by their looped, ring-shaped blades, offer significant noise reduction and increased efficiency in both aerial and marine applications by minimizing vortices and tip cavitation.

Blain, Loz. "Looped propellers: A noise-killing game changer in air and water." New Atlas, January 26, 2023. https://newatlas.com/aircraft/toroidal-quiet-propellers/



Best Suited For:

- Low-speed, high-thrust applications.
- Operations in environments with high debris.
- Missions requiring precise thrust control and optimized water flow.

THANK YOU

WE APPRECIATE YOUR TIME SPENT READING.



If you'd like to learn more or participate next year
we'd love to hear from you.

https://janusdefense.com/contact/

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