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Prototype Warfare in the Maritime Domain: Opportunities and Approaches

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Foreword

RUSI often captures the security zeitgeist in publishing fresh and important work. This paper continues that hard-won tradition. From the provocative premise that peacetime militaries evolve rapidly in war, transforming doctrines and strategies alike, the authors make the case for operational and commercial innovation, speedy adaptation and a military–industrial–technological complex that is fleet of foot and continually aligned with the needs of the war-fighter.

Positioned around the concept of prototype warfare, the paper explores these themes through the lens of the maritime domain, as an exemplar of the wider battlespace. Maritime manoeuvre operations in contested and fast-evolving environments prove to be an ideal canvas for prototype innovation, which the authors unpack with knowledge and flair.

The conclusions – on reshaping defence economic thinking, blending publicly owned or financed means of production with privately backed innovation focused on prototype development – are radical, thought-provoking and timely – especially if you consider, as I do, that war stalks us and we need to be ready. I commend this paper to you.

Dame Penny Mordaunt
Chair of the Board, SubSea Craft Ltd

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One of the authors, John Louth, is a non-executive director of Subsea Craft Ltd; however, he contributed to this paper solely in his capacity as an academic. The paper is an independent product and has undergone RUSI's standard process of blind peer review by subject-matter experts, who recommended it for publication. Interviews with Subsea Craft Ltd personnel informed the paper's case study. The purpose of this case study is to illustrate a methodological approach, rather than to assess or endorse specific defence products.

Executive Summary

Recent conflicts, most notably in Ukraine, have demonstrated that militaries rarely fight with the forces they planned to deploy in peacetime. Capabilities evolve rapidly under combat pressure, driven by urgent operational needs, iterative field modification and close interaction between operators and industry. This paper argues that the Royal Navy must find ways to replicate this adaptive dynamism in peacetime if it is to grapple with an era of resource constraints, technological volatility and evolving strategic commitments.

The paper discusses the concept of prototype warfare: an approach to capability development in which militaries are not merely end-users of finished equipment, but active participants in the iterative refinement of immature systems. Under this model, forces deliberately field early-stage prototypes, accept a degree of failure and waste, and generate value through use, feedback and data. Operators become 'prosumers' – simultaneously consumers of capability and producers of knowledge and intellectual property – allowing rapid adaptation while controlling long-term risk through iteration and selective scaling.

The strategic problem facing the Royal Navy is characterised as 'too much, with too little': a growing range of missions, theatres and contingencies confronted by limited platform numbers and constrained budgets. Traditional responses – designing evermore versatile platforms, pursuing radical doctrinal shifts or adopting high–low force mixes – each carry significant risks and historical pitfalls. This paper argues that no single approach is sufficient. Instead, managing uncertainty requires heterogeneity: a diverse mix of modular, off-board and rapidly adaptable capabilities that can evolve faster than adversary countermeasures.

Prototype warfare offers a way to harness experimentation without resulting in a fleet of experiments that are not scalable. By fielding and iterating capabilities early – particularly software-defined and modular systems – the Royal Navy can more rapidly identify viable capabilities and standardise those solutions that demonstrate operational value. This approach is especially well suited to the maritime domain, where platforms are long lived but payloads, sensors and off-board systems can change rapidly.

The paper finds that the principal barriers to prototype warfare are not technological, but institutional and commercial. Existing procurement processes prioritise assurance, efficiency and risk minimisation, often at the expense of speed, learning and adaptability. Personal liability for senior responsible owners, rigid requirements processes and limited opportunities for operational testing in peacetime all discourage experimentation.

Moreover, defence innovation support is often focused on early-stage seed capital, despite the availability of substantial private funding for high-risk prototyping, which can be more readily secured. This approach is misguided since funding is not likely to be defence's currency in future relationships with the private sector, as opposed to operational data and access to operators, which are.

Drawing on an in-depth case study, the paper demonstrates how privately financed prototyping – backed by family wealth rather than venture capital or state funding – can deliver rapid development cycles, operationally relevant testing and credible engagement with military users. The case illustrates the central importance of use-generated data, digital design tools and close operator–industry collaboration in accelerating capability maturation.

Building on this evidence, the paper argues for a rebalanced model in which:

- **Private capital**, particularly from family offices, finances early-stage prototyping and risk.
- **The military** contributes access, credibility, testing capacity and operational data, rather than primarily funding.
- **The state** intervenes decisively at the scaling stage, potentially through co-ownership of production infrastructure, to deliver speed and mass once a prototype proves its value.

The paper also identifies opportunities arising from multinational frameworks such as AUKUS, including shared testing capacity, cross-adoption of validated prototypes and common digital testing environments to accelerate progression through mid-level technology readiness.

Overall, the paper concludes that maintaining maritime advantage in an era of rapid technological change requires a fundamental shift in how capability is generated. Rather than optimising for certainty and efficiency, defence institutions must prioritise learning, iteration and speed. Prototype warfare offers a structured way to do so – accepting early risk in order to reduce long-term strategic vulnerability. This requires the Royal Navy to act not just as an agile customer, but as an active partner in the production of future combat power.

Introduction

The experience of recent conflict in Ukraine and the Middle East has illustrated a cardinal lesson of conflict: militaries typically do not look like their peacetime selves after a period of war, and the capabilities at their disposal in peacetime often do not carry them past the first battle. This paper explores the challenge of rapid capability development and fielding. It constructs an analysis based on the concept of 'prototype warfare'. This concept envisions forces not merely serving as consumers of military equipment, but being part of the process by which imperfect but rapidly produced products are refined.

Adaptation at speed and sometimes in contact is hardly new. The breakout from the Bocage during the Second World War campaign in Normandy, for example, saw significant technical adaptation, often driven by modifications to vehicles made by units themselves.[1] Similarly, the P-51 Mustang was fielded with a Rolls Royce engine that was not built for war. This enabled it to meet the aims for which it was built.[2]

During Russia's full-scale invasion of Ukraine, Russia learned by the end of 2022 that its initial concepts for employing long-range strike capabilities were simply unsustainable given the inadequate stocks of missiles – such as KH-101 and 3M-14 – at the Russian military's disposal. This led to the evolution of a strike complex combining mass and precision. Russia used one-way attack UAVs – such as the Iranian Shahed-136 – in tandem with more expensive missiles. Similarly, the stresses imposed on the Ukrainian side compelled it to adopt relatively ad hoc solutions across domains. In the air, this saw the Ukrainians fielding systems such as Gravehawk, which fires a Russian R-37 missile from a containerised British-made surface-to-air system. Other examples include a range of strike platforms, including converted A-22 light aircraft used as long-range strike drones.[3] At sea, this dynamic has been exemplified by a cat-and-mouse game between platforms such as the Magura uncrewed surface vehicle (USV)

1. Michael D Doubler, 'Busting the Bocage: American Combined Arms Operations in France', US Army Command and General Staff College, November 1988, pp. 32–34.
2. Paul Kennedy, *Engineers of Victory: The Problem Solvers Who Turned the Tide in the Second World War* (London: Random House, 2013).
3. Anna Desmarais, 'What is Gravehawk, The New Air Defence System That Could Give Ukraine an Edge?', *Euronews*, 18 February 2025, <https://www.euronews.com/next/2025/02/18/what-is-gravehawk-the-new-air-defence-system-that-could-give-ukraine-an-edge>, accessed 6 January 2026.

series (which combine commercial off-the-shelf components and military capabilities) and the Russian Navy's countermeasures (which have included the repurposing of Orlan-10 UAVs for maritime defence).

Once a war starts, finances are made available. Mechanisms, such as urgent operational requirements (UORs), also change, enabling a more rapid rate of capability generation. These two factors enable adaptation and the rapid fielding of capabilities in contact. Rapid innovation in peacetime will require functional substitutes for resources, and incentive structures that otherwise only become available in conflict.

Peacetime innovation is salient today as there is an acknowledged mismatch between the capabilities at the disposal of the Royal Navy and its considerable commitments. This mismatch is partly a question of strategy and regional prioritisation – an aspect which the recent Strategic Defence Review (SDR) has aimed to address through its 'NATO First' orientation. However, the problem of the British Royal Navy's maritime capacity remains, even within a single region framework. As illustrated by recent combat in the Middle East, which involved conflicts from the Red Sea to Lebanon, geographical prioritisation in the context of the UK's SDR does not rule out the emergence of circumstances which compel the Navy to fight a war other than the one for which it is optimising.[4]

The Royal Navy has focused on developing a hybrid fleet that comprises both crewed and uncrewed systems. This is a response to both the challenge of mass and the potential requirement for rapid adaptation in a context where 'platforms' cannot change, but what is on and around them can.[5] This requires a methodology for delivering capabilities at the speed of relevance.

This paper explores the UK's strategic challenge within the maritime environment, which can be characterised as 'too much, with too little'. The paper considers the concept of prototype warfare, and to what extent this concept needs a reformed and regenerated commercial ecosystem. It then describes the commercial ecosystem that could deliver prototype warfare. The characteristics of this system are a greater reliance on sources of private wealth that are not typically tapped by defence (for example, family wealth funds) and the participation of the military as an actor in the process of commercial development rather than as just a consumer.

4. Ministry of Defence (MoD), 'Strategic Defence Review 2025 – Making Britain Safer: Secure at Home, Strong Abroad', 2025.
5. For a useful primer on navy thinking, see MoD, 'Maritime Operating Concept', 2022, pp. 50–60.

Methodology

The authors based their findings on an in-depth study of Subsea Craft Ltd. This organisation is an appropriate case study and vignette of a wider phenomenon across the defence enterprise. The company is a UK-based technology small-to-medium-sized enterprise (SME) that offers capability solutions to support maritime manoeuvre in contested environments. The Subsea Craft Ltd model has been used as a case study because its approach to product development has not been driven by a requirements process. Both military and industrial subject-matter experts identified the importance of moving from a procurement process based on military requirements to one based on industry-generated solutions to end-user-informed operational challenges. This transition was seen as important if the UK is to generate the protean force to which the Navy aspires.[6]

Specific products which were studied for this paper include VICTA, a next-generation maritime delivery platform capable of high-speed surface transit before rapidly transitioning to a wet, sub-surface asset for the covert delivery of operators or mission-critical equipment packages. The authors also considered the MARS craft, an uncrewed surface vessel designed for launch from medium-to-large surface ships where access is contested; and CADDIS, a subsurface-launched UAV which provides ISR.[7] The case of Subsea Craft Ltd provides lessons on product development cycles which can be as short as 100 days.

The paper's findings are further informed by discussions in a workshop held at RUSI in London on 24 June 2025 that was conducted with subject-matter experts from the Royal Navy and industry. The authors also reviewed secondary literature, and conducted 15 semi-structured interviews with both naval practitioners and representatives from the defence industrial sector. These interviews focused on understanding both how the demand signal presents barriers to delivery (in the case of naval practitioners), and emerging solutions (in the case of interviews with industry).

6. Insights from several participants at the RUSI workshop on prototype warfare, London, 24 June 2025.
7. Subsea Craft Ltd, <www.subseacraft.com>, accessed 19 September 2025.

The Strategic Challenge: Too Much, With Too Little

Historically, navies facing the strategic challenge of overstretch have attempted to resolve it in several ways. As the Royal Navy envisions its transformation into a protean force capable of adapting to uncertainty in an agile way, it will have to consider how it can balance the strengths and weaknesses of different approaches to managing uncertainty.[8]

The first approach has been to pursue a degree of versatility in the design of vessels sufficient to enable the same capabilities to play multiple roles. An early example of this is Admiral John 'Jacky' Fisher's effort to develop the big-gun battle cruiser. This was an answer to the question of how Britain could simultaneously protect global sea lines of communication (SLOC) and confront a quantitatively comparable German High Seas Fleet in home waters. The cruiser, with its combination of speed and heavy armament, was envisioned as being able to both overmatch dreadnought-type battleships and provide protection for SLOCs.[9] A modern analogue in approach, if not form, is the Royal Navy's ongoing effort to use the containerised Persistent Operational Deployment System (PODS). In theory, a PODS carries various capabilities – ranging from uncrewed underwater vehicles (UUVs) to electronic countermeasures – aboard vessels such as the Type 26 and Type 31. The aim is to make these vessels more versatile and adaptable.[10]

The second approach to addressing a mismatch between capacity and required outputs has been to pursue a paradigm shift in how outputs are defined and achieved. A 'paradigm shift' is distinguished from a 'major evolutionary change' as it involves an organisation changing its definition of success rather than its approach to delivering it. Examples include Apple's disruption of the mobile phone market after making access

8. For a useful primer on managing uncertainty, see Barry R Posen, 'Foreword: Military Doctrine and the Management of Uncertainty', *Journal of Strategic Studies* (Vol. 39, No. 2, 2016), pp. 159–73.
9. John Tetsuro Sumida, *In Defence of Naval Supremacy: Finance, Technology, and British Naval Policy 1889–1914* (Abingdon: Routledge, 1993).
10. Royal Navy, 'Maritime Modularity Concept', 2022.

to an app ecosystem the centrepiece of the iPhone's competitiveness.[11] One might also consider the early 20th-century French Jeune École as an example of a paradigm shift: it redefined success for the French Navy (at least in part) in terms of coastal defence and commerce raiding, as opposed to engagements between battlefleets.[12] In a similar vein, the US's Defense Advanced Research Projects Agency mosaic warfare concept envisions using large numbers of single-purpose systems to overwhelm an opponent with decision complexity (as opposed to simply out-scouting and shooting faster, as in traditional net-centric concepts). This might be viewed as paradigm shifting.[13]

A third approach involves attempting to solve certain problems at low cost to allow for the more effective concentration of scarcer resources elsewhere. One potential example comes from the period before the First World War. Then, a British concept envisioned using flotillas of torpedo boats in secondary theatres – such as the Mediterranean – where it was assumed that they would operate under the protection of the French Navy. Admiral Elmo Zumwalt's concept of a 'high-low mix' similarly envisioned the use of several cost-effective palliatives to the challenge of protecting SLOCs against the large Soviet fleet.[14]

Each approach to managing uncertainty comes with its own set of risks and rewards. It is also likely that the Royal Navy will need to pursue all three approaches in tandem. Radically new technologies have conferred considerable advantages for early adopters in the past. However, there are several instances where too much radicalism has imposed considerable costs on force design. Consider the fate of the Jeune École, which, in the words of one rueful admiral, left France with 'a fleet of experiments'.[15] While many of the core ideas behind the school were sound, the failure to account for certain factors, ranging from the endurance of torpedo boats to potential countermeasure, limited its value.

Equally, attempting to hedge against uncertainty by creating the conditions for future platform evolution can introduce considerable costs within platforms themselves. Examples include the US Navy's littoral combat ship. This was meant to act as a modular platform, but, partially because of this, its costs ballooned while many of its envisioned functions proved difficult to deliver within the parameters of the vessel design.[16] High-low mixes of different vessel types, similarly, can prove very expensive,

11. Juha-Antti Lamberg et al., 'The Curse of Agility: The Nokia Corporation and the Loss of Market Dominance in Mobile Phones: 2003-2013', *Business History* (Vol. 63, No. 4, 2019), pp. 1–32.
12. Erik J Dahl, 'Net-Centric Before Its Time—The Jeune École and Its Lessons for Today', *Naval War College Review* (Vol. 58, No. 4, 2005), pp. 109–35.
13. On the subject of mosaic warfare, see Bryan Clark, Daniel Patt and Harrison Schramm, 'Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems to Implement Decision Centric Operations', CSBA, 2020.
14. Steve Wills, 'The Perils of an Alternative Navy Force Structure', CIMSEC, 3 October 2016, <https://cimsec.org/perils-alternative-force-structure/>, accessed 6 January 2026.
15. Clark, Patt and Schramm, 'Mosaic Warfare'.
16. US Government Accountability Office (GAO), 'Littoral Combat Ship: Actions Needed to Address Significant Operational Challenges and Implement Planned Sustainment Approach', GAO-22-105387, February 2022.

and the requirements of combat at sea can considerably drive up the costs of the 'low' end of the force mix – a problem which bedevilled Zumwalt's vision.[17]

Heterogeneity as a Means of Managing Uncertainty

Managing uncertainty effectively requires a trade-off between adaptability and optimisation for specific contingencies. A body of research suggests that systems which benefit from convexity – a tendency to improve, rather than collapse, under conditions of volatility – are often heterogenous – involving multiple dissimilar and sometimes redundant components – and involve large numbers of rapid failures. Both research and market ecosystems stand out as examples.[18] The management of major projects carries similar lessons. Projects often succeed when they are sufficiently modular such that sub-component elements carried out in parallel reinforce one another through learning. For example, successful metro construction projects have often outperformed comparable projects by having multiple teams working in parallel and transferring lessons about failures.[19] This is also observable in defence acquisition. In the US, defence projects that involved testing prototypes up to Technology Readiness Level 6 (TRL 6) – testing a prototype in an operationally relevant environment – before programme initiation saw costs shrink rather than grow.[20]

In the context of defence, however, several barriers remain. These limit the benefits that would otherwise stem from the volatile context. Most notably, to undertake parallel production entails both redundancy and a heterogeneity of approaches, both of which are barriers to achieving large-scale and secure production. An example of this is the production of UAVs in Ukraine. There, a range of startups and volunteer organisations fund and produce UAVs. The emerging ecosystem has many of the characteristics of an anti-fragile system – one which benefits from unexpected change which favours at least some of its constituent parts – but scaling the production of any single model has proven difficult.[21] Moreover, in a context where updates have to be conducted on a six-week cycle to adapt capabilities to adversary

17. Wills, 'The Perils of an Alternative Navy Force Structure'.
18. Ethan Nikhookar, Mohsen Varsei and Andreas Wieland, 'Gaining from Disorder: Making the Case for Antifragility in Purchasing and Supply Chain Management', *Journal of Purchasing and Supply Management* (Vol. 27, No. 3, 2021).
19. Bent Flyvbjerg, 'Make Megaprojects More Modular', *Harvard Business Review* (November–December 2021).
20. William R Fast, 'Effectiveness of Competitive Prototyping and Preliminary Design Review Prior to Milestone B', Naval Postgraduate School, <https://dair.nps.edu/bitstream/123456789/1197/1/SYM-AM-14-137.pdf>, accessed 21 October 2025.
21. Vitaliy Goncharuk, 'Ukraine Isn't the Model for Winning the Innovation War', *War on the Rocks*, 12 August 2025, <https://warontherocks.com/2025/08/ukraine-isnt-the-model-for-winning-the-innovation-war/>, accessed 6 January 2026.

electronic warfare and in which a weak link can compromise entire systems to cyber-attack, assurance and standardisation are of critical importance.[22]

Force designers face a key challenge: many of the things which limit their ability to embrace a heterogenous (and thus adaptable) force mix exist for good operational reasons. For example, there is the requirement for assurance in data standards. However, this is not an automatic barrier to using a prototype in training or in an air-gapped architecture, should it be fielded. This will prove easiest to achieve with off-board systems which require limited integration with a vessel's command software. However, even deeper integration can be achieved on designated test-bed vessels which need not be integrated into the wider fleet architecture. For example, recent experiments in converting container ships for military use in the People's Republic of China (PRC) might, irrespective of the real operational utility of such an auxiliary, demonstrate how containerised systems might be tested.[23] Software-based solutions which use a message broker to move data between systems can also be used to avoid cyber compromise even when integrating different systems. Currently, however, circumventing existing processes even for well-understood and secure technologies – or because the promise of a capability justifies the risk – is only possible if the senior responsible owner (SRO) of a programme is willing to take personal risks – such as personal liability.[24]

Organisationally, the requirement to demonstrate value represents an additional barrier to the rapid testing and fielding of capabilities, since rapid experimentation involving multiple failures represents an inherently wasteful process.[25] Factors such as the level of risk to life that is tolerated in certain types of early physical testing are also worth considering.

Moreover, the inherent qualities of naval platforms – which must be integrated systems by design – are a specific service-level source of rigidity. Hedges – such as the incorporation of more modular features into a vessel's design – do exist, but they often represent an up-front cost for vessel size and complexity and can be inconsistent with the characteristics needed for role specialisation.

22. Sidharth Kaushal, Justin Bronk and Jack Watling, 'Pathways Towards Multidomain Integration for UK Robotic and Autonomous Systems', *RUSI Occasional Papers* (October 2023), p. 18, <https://www.rusi.org/explore-our-research/publications/occasional-papers/pathways-towards-multi-domain-integration-uk-robotic-and-autonomous-systems>, accessed 6 January 2026.
23. Tyler Rogoway, 'Chinese Cargo Ship Packed Full of Modular Missile Launchers Emerges', *The Warzone*, 25 December 2025, <https://www.twz.com/sea/chinese-cargo-ship-packed-full-of-modular-missile-launchers-emerges>, accessed 15 January 2026.
24. Author interview with Steve Prest, online, 27 August 2025.
25. A point made at the RUSI workshop on prototype warfare, London, 24 June 2025.

Finally, and perhaps most importantly, the limited volatility described by theorists of anti-fragility does not necessarily exist for militaries in peacetime. Limited volatility requires conditions stringent enough to produce failure (and thus improvement) but in which failure is localized and thus not system wide. Consider, for example, how markets succeed even though many individual firms fail. In an ecosystem characterised by both monopsony and a requirement to deliver specific outcomes on time and within regulatory boundaries, these conditions can prove difficult to achieve.

Rigorous testing and operational evaluation can (and does) occur and typically produces systems which perform well (as evidenced by the performance of Western systems in Ukraine). However, the levels of volatility which induce controllable failures – because the assumptions on which a capability was fielded were challenged (rather than because the capability failed a well-parametrised test) – typically do not exist in peacetime. Without this, there is a real risk of mutation without selection whereby a range of experimental capabilities cannot be down selected because the steady drumbeat of testing and failure which enables selection and scaling is not easily achieved in peacetime and absent the less structured tests which conditions similar to real world use provide, a system's deficiencies may be less apparent, as learned with many western systems in Ukraine.[26]

26. Oleksandr Ihnatenko, 'The Underexploited Potential of Ukrainian Defence Tech', ASPI, 17 February 2025, <https://www.aspistrategist.org.au/the-underexploited-potential-of-ukrainian-defence-tech/>, accessed 15 January 2026.

Prototype Warfare

In recent years, the concept of prototype warfare has emerged as a mooted solution to the requirement for rapid change.[27] The concept of prototype warfare entails a reframing of the relationship between industry and operators. Since use and feedback are critical to information, operators are producers of value withing this framework rather than consumers of a product. Their use of immature prototypes creates value for companies which, in turn, have incentives to fund and support this use without state support. A procurement model that involves fielding capabilities earlier in their development cycle and then developing them makes financial sense: replacing physical systems is likely to become cheaper. In effect, a cycle of continuous iteration can make it easier to derive the benefits of heterogeneity while controlling for its risks if militaries can use and iterate (or scrap) capabilities on a rapid basis. This leads to an initially heterogenous mix of capabilities that can be standardised and scaled rapidly as needed.

The attractiveness of prototype warfare is related to a second trend- the tendency for software, rather than hardware, to define system performance. This partially reflects the fact that many components will become easier to manufacture over time due to several interlocking developments which will make securing inputs and manufacturing components cheaper. Additive manufacturing, for example, may make the production of bespoke components – such as the gas rudders on missiles or some of the components of sensors – considerably faster and less labour intensive.[28] To use another example, flash graphene synthesis holds the potential to convert graphene from sources such as waste.[29] Finally, automated manufacture is perhaps the most mature shift in production methods. It has been demonstrated by states such as the

27. Peter Layton, *Prototype Warfare, Innovation and the Fourth Industrial Age* (Canberra: Air Power Development Centre, 2018).
28. Sidharth Kaushal, John Louth and Andrew Young, 'The Exoskeleton Force: The Royal Navy in the Indo-Pacific Tilt', *RUSI Occasional Papers* (November 2022), <https://www.rusi.org/explore-our-research/publications/occasional-papers/exoskeleton-force-royal-navy-indo-pacific-tilt>, accessed 6 January 2026; Md Jarir Hossain et al., 'Additive Manufacturing of Sensors: A Comprehensive Review', *International Journal of Precision Engineering and Manufacturing-Green Technology* (Vol. 12, 2025), pp. 277–300.
29. Paul A Advincula et al., 'Flash Graphene from Rubber Waste', *Carbon* (Vol. 178, June 2021).

PRC, where large parts of the production lines for the PL-15 air-to-air interceptor missile appear to have been automated.[30]

In addition, software-defined solutions may reverse the growing gulf between defence products and those employed in the wider economy. It was possible in the 1940s for entities such as automobile manufacturers to engage in the production of defence capabilities. However, today, many of the subcomponents in a modern platform are too bespoke. Software-defined solutions – currently being trialled in roles such as correcting errors in low-cost inertial navigation systems and gleaning data from low-fidelity sensors – may reverse this trend.[31] This is because less sophisticated hardware is rendered effective by software, and such software is likely to be easier to increase in scale and require manufacturing capabilities that are less bespoke.

However, software requires data which in turn requires use. This is costly, less in terms of financial investment in the product and more in terms of work hours associated with experimentation and providing available testing grounds. Proponents of prototype warfare argue that where the cost of producing capabilities declines and the determinant of system quality is its use and iteration, the operator might best be viewed as a 'prosumer' – someone who both uses a product and generates intellectual property (IP).[32] This is akin to the client–vendor relationship seen in IT, where customers effectively sell their data for subsidised access.

There is much to commend about prototype warfare in principle. The concept of prototype warfare aligns well with the wider principles of generating anti-fragility and modularity within major projects. It also enables a feedback loop between prototyping and doctrine. The rebuttal of prior doctrinal assumptions is often not a top-down process. Rather, it is the accumulation of lessons learned that ultimately reach a tipping point. This then drives a shift in assumptions, something true of knowledge creation more generally.[33] Theorists and writers of doctrine then codify these lessons in a manner that is generalisable across a force.[34] For example, modern Western SEAD (suppression of enemy air defences) doctrine codified lessons learned from when bomber-centric approaches were tested in the Vietnam War and when the Israeli Air Force confronted Egypt's Soviet-made integrated air defence systems

30. International Defence Analysis, 'China Showcases Robotic Production of PL-15E Missiles', 14 May 2025, <https://internationaldefenceanalysis.com/china-showcases-robotic-production-of-pl-15e-missiles/>, accessed 6 January 2026.
31. Pablo Raul Yanyachi et al., 'OpenNavSense Platform: A Low-Cost, Open-Source Inertial Navigation System for the Evaluation of Estimation Algorithms', *HardwareX* (Vol. 21, 2025).
32. Layton, *Prototype Warfare*.
33. John T Kuehn and Frank Hoffman, 'Review Essay—Adaptation and the School of War: "Mars Adapting: Military Change During War"', *Naval War College Review* (Vol. 74, No. 4, 2021); Thomas S Kuhn, 'The Structure of Scientific Revolutions', in *International Encyclopedia of Unified Science* (Chicago, IL: University of Chicago, 1962).
34. Andrew F Krepinevich Jr, *The Origins of Victory: How Disruptive Military Innovation Shapes the Fate of Great Powers* (New Haven, CT and London: Yale University Press, 2023), pp. 477–500.

in 1973.[35] The lessons accumulated to such an extent that a paradigm shift – in what made an aircraft effective – occurred. This shift in turn drove the emergence of requirements that led to modern stealth.

There is also considerable historical evidence that even rigorously tested capabilities often have to be adapted in the field, and that the ability to achieve this is an important determinant of military effectiveness. Adaptation can take the form of modifying and developing a capability to contend with a new tactical challenge. The US Air Force did just this with the F-86 Sabre during the Korean War when the aircraft was fitted with an automated 30mm cannon on the basis of experiments conducted in the field.[36] Alternatively, it may involve finding a new use case for an existing capability. Examples of this include: the US Navy's decision to repurpose its submarine fleet as a highly lethal tool for commerce raiding during the Second World War (with this role driving a doubling in the fleet's size); the Imperial Japanese Navy's use of its torpedo boats (originally procured for coastal defence) in high-risk, high-reward attacks on bases such as Port Arthur during the Russo-Japanese War; and the use of the failed hedgehog anti-submarine warfare (ASW) mortar for shore bombardment on D-Day.[37] A wider mix of capabilities thus provides an organisation with the flexibility to make changes which it cannot anticipate in advance, but for which it can identify a likely requirement. Often, this involves accepting a degree of waste to avoid disincentivising experimentation. For example, venture capital firms that continue to invest after an initial period of failure often enjoy greater returns from innovation conducted by firms in their portfolio.[38]

Nevertheless, the spectre of the fleet of experiments remains. This is particularly salient in a context where the affordability of recent defence equipment plans has received considerable scrutiny and where the Royal Navy needs to retain the ability to fight tomorrow.[39] The question of how an inherently 'wasteful' model can be afforded is discussed in the following section.

35. *Ibid.*
36. Frank Hoffman, *Mars Adapting: Military Change During War* (Annapolis, MD: Naval Institute Press, 2018), p. 122.
37. Kuehn and Hoffman, 'Review Essay—Adaptation and the School of War'; David C Evans and Mark R Peattie, *Kaigun: Strategy, Tactics, and Technology in the Imperial Japanese Navy, 1887–1941* (Annapolis, MD: Naval Institute Press, 1991), p. 87; observation by participant at the RUSI workshop on prototype warfare, London, 24 June 2025.
38. Xuan Tian and Tracy Yue Wang, 'Tolerance for Failure and Corporate Innovation', *Review of Financial Studies* (Vol. 27, No. 1, 2014), pp. 211–55.
39. National Audit Office (NAO), *The Defence Equipment Plan 2023–2033*, HC 315 (London: NAO, 2023), pp. 7–8.

How Defence Can Enable a 'Prosumer' Model

The approach of prototype warfare described above embraces, to a limited degree, inefficiency. This is anathema to the focus on generating value for the taxpayer. Moreover, the model of procuring a small number of prototypes from SMEs may not be an entirely viable one where the expected returns needed to cover costs in areas such as AI and mesh networking are often very high.[40] In effect, defence needs to find a way to generate redundancy without unnecessary financial waste, and become a uniquely important part of the framework without becoming its most significant actor: a triangulation between conflicting imperatives. There are several pathways towards achieving this, some of which have already been demonstrated with less novel capabilities.

The first pathway is the use of exports as a hedge against capabilities lacking immediate relevance. The idea of exporting capabilities to save costs is hardly novel. However, case studies where a capability was developed entirely for the purpose of export deserve more attention. It is often presumed that a capability must be fielded with one's own forces to be viable. But this is arguably not the case. Germany's Type 209 submarine was designed purely as an export product and is the world's most widely sold conventional submarine.[41] Notably, the lessons learned during construction of the Type 209 directly fed into future German capabilities, such as the Type 212 submarine, when the German Navy's requirements changed.

Moreover, the existence of a large community of users has driven iterations in the development of the vessel. It has now been adapted to meet a range of customer-specific requirements. This has then fed back into the production of the Type 209 and successor classes. Export customers have effectively acted as prosumers. So, if a prototype can be used to generate an export capability in addition to a more bespoke asset for the Royal Navy, it should be eligible for support from sources other than the defence budget. Mechanisms such as the Defence and Security Accelerator (DASA) and the British Business Bank might be encouraged to support the limited acquisition of prototype capabilities at lower TRLs.[42] This would fit within the wider remit of the British Business Bank given its focus on SMEs.

Furthermore, while considerable attention is paid to the development or adaptation for export of capabilities already in service with the armed forces, less is paid to the prospect of capabilities being supported for the explicit purpose of being exported. To an extent, this is understandable, particularly for platforms. However, if the Navy expects to build its future force around a PODS carrying a range of sensors and

40. Kaushal, Louth and Young, 'The Exoskeleton Force', Chapter I.
41. David Miller, *Submarines of the World* (London: Crown, 1991).
42. Speech given by Brad Pietras at the RUSI Integrated Air and Missile Defence Conference 2025, London, 24 April 2025.

weapons/effectors, there is wider scope for this model. Capabilities such as certain types of containerised sensors and effectors can be repurposed for partners with different use cases. A containerised missile in a PODS could as easily be part of a coastal defence system (something the UK is unlikely to need) as a shipboard weapons suite. This approach is perhaps best illustrated by the Israeli defence industrial sector. It exported £14 billion in 2024, with over half of these exports comprising deals valued at less than $100 million.[43] This reflects the fact that much of what Israel exports is sensors and munitions adapted to customer use cases. Israeli Spice guidance kits are used on bombs delivered from Russian-made aircraft in the service of countries such as India, and Israeli Phalcon radar has been attached to airborne warning and control systems based on the Russian IL-76.[44] This could serve as the model for PODS.

The second pathway is making peacetime experimentation a standing line of effort within the navy itself, rather than an intermittent activity. This would entail using one's own forces as prosumers. A model which saw operators regularly employ immature capabilities to feed data back to their owners would consume time and tradeoffs with other standing tasks would have to be made. In addition, sharing underlying data would require a government owned environment to host this information securely. However, shifting the relationship between companies and the military can also allow some of the financial challenges associated with rapid prototyping to be circumvented. Additionally, given the competitive advantages a company can generate through access to military led experimentation, the military would enjoy greater negotiating power with respect to considerations such as access to data. This could be analogized to other scenarios in which the ability of the state to tilt the playing field has been a means to incentivise cooperation across companies and between companies and the state.[45]

The issue of financial waste can be circumvented since companies have both the means and incentive to self fund prototyping- access to operators and information is the currency the state should trade in. In the context of rapid prototyping, funding is arguably the least important contribution that a military can make for SMEs: credibility and experience matter more. Indeed, the state can bolster start-up credibility through low-cost displays of interest. For example, in the US, small business innovation research funding is positively correlated with a firm's ability to secure venture capital support, even if funding is only related to phase 1 – that is, small sums devoted to initial research.[46] Another underlying problem that many of these

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43. Emanuel Fabian, 'Israeli Arms Sales Break Record for 4th Year in Row, Reaching $14.8 Billion in 2024', *Times of Israel*, 4 June 2025, <https://www.timesofisrael.com/israeli-arms-sales-break-record-for-4th-year-in-row-reaching-14-8-billion-in-2024/>, accessed 15 January 2026.
44. *Israel International News*, 'India Acquiring Israeli AWACS', 22 May 2019, <https://www.israelnationalnews.com/news/131503>, accessed 6 January 2026.
45. For example, consider the Japanese economic model of the mid- to late 20th century in which selective access to credit was a means of compelling companies to cooperate. See Robert Gilpin, *The Political Economy of International Relations* (Princeton, NJ: Princeton University Press, 1987), p. 219.
46. Sabrina T Howell et al., 'Opening Up Military Innovation: Causal Effects of "Bottom-Up" Reforms to U.S. Defence Research', *NBER Working Paper Series* (No. 28700, 2021).

enterprises face is that, in the words of one expert, 'their product is broken upon arrival'.[47] In the world of software, this is acceptable since a capability can be iteratively fixed. However, it requires repeated use by customers. For hardware, without the feedback which accompanies use, iteration is effectively impossible.[48] In fact, militaries typically represent the sole entity capable of employing a capability in an operationally realistic context. Currently, although SMEs are involved in exercises such as REPMUS, their capabilities are often separated from the main exercises as a safety measure.[49] These factors, coupled with a lack of specific metrics for defining effectiveness, often limit feedback opportunities for innovation. Novelty itself is a poor metric for value.[50]

The devotion of capacity to exercises is a major enterprise and this dynamic is unlikely to change in situations where tier-1 vessels are being employed. However, there are avenues for the employment of other platforms as experimental test beds. This is already being attempted with platforms such as the XV Patrick Blackett but arguably might be scaled up and extended to vessels such as offshore patrol vessels or even the Type 31, which is modular enough to fit a range of capabilities, but which is unlikely to be survivable in high intensity combat, even in a context where a sub-peer opponent such as the Houthis is involved. As for second-tier vessels, these might deliver greatest value if they spent a larger proportion of their time acting as test bed platforms instead of being deployed. There is contemporary evidence for the notion that the most useful approach that a military can take for an enterprise is to validate its capabilities in a context that the enterprise cannot hope to replicate. The opportunities for learning provided by Task Force Kindred in Ukraine stand out as an exemplar.[51] There is also historical evidence for the notion that capacity and not money is a navy's best contribution. One might consider the effect of Admiralty endorsement on both the capacity to generate private funding for the Argo rangefinder and the export interest that this capability generated.[52] Indeed, the importance of narrative is often critical to driving the adoption of new technologies (both for better and for worse) and militaries are the primary drivers of narratives regarding which technologies are of interest on the modern battlefield.[53]

47. Speech given by Brad Pietras at the RUSI Missile Defence Conference 2025, London, 24 April 2025.
48. *Ibid.*
49. Author interview with David Burton, NATO ASW Barrier Programme, online, 7 July 2025.
50. *Ibid.*
51. Task Force Kindred supports the development of the Ukrainian Armed Forces. Insight provided by a participant at the RUSI workshop on prototype warfare, London, 24 June 2025.
52. Sumida, *In Defence of Naval Supremacy*, pp. 350–95.
53. See Brent Goldfarb and David A Kirsch, *Bubbles and Crashes: The Boom and Bust of Technological Innovation* (Stanford, CA: Stanford University Press, 2005), p. 3.

Emerging Opportunities to Drive Innovation

In the context of the AUKUS arrangement, three additional avenues which might enable more rapid capability development are opening.

First, there is scope for a capability validated in one of the three states to be initially adopted (and thus kept commercially viable) in another. Examples include the aborted project to develop the US railgun, which appears to have been successfully brought forward (albeit independently) by Japan.[54] A framework which de-risks the sale of IP could better allow a concept to be moved between AUKUS partners until it either reached maturity or was scrapped. This could be analogous to how civilian aircraft certifications are accepted on a cross-national basis.

Second, the relative compatibility of operational testing and evaluation among the three states might allow them to pool capacity for testing. No individual military has sufficient spare capacity to devote large numbers of platforms to testing on a long-term basis. However, assuming spare capacity is available to different partners at different times, partner militaries could, in principle, rely on one another to test nascent capabilities. While this would sometimes raise concerns over IP – probably reinforced by the experience of past defence projects such as ASRAAM – physical access to facilities and testing ranges could still prove useful. Analogous models already exist in some contexts. For example, both Rheinmetall and Hanhwa have formed consumer families where IP from operator use is shared across the family of users (with this cost in IP being offset by lower unit costs).[55]

Third, the AUKUS arrangement presents opportunities for cheaper and faster prototyping which does not consume as much human or material capacity if, for example, participants cooperate to develop shared (or at least standardized) digital testing environments. Synthetic testing should play a greater role in allowing the steps between TRL 4 and TRL 8 to be skipped – essentially allowing more time for direct operational testing. It is somewhat unconvincing to argue that nuclear weapons can be fielded purely based on digital simulation (as has been the case since the signing of the Comprehensive Nuclear-Test-Ban Treaty).[56] For conventional capabilities, digital simulations are even more limiting: conventional capabilities must go through real-world testing in multiple stages. State-owned environments in which, for example, digital twins of prototype capabilities can be tested could significantly drive down the costs of testing.

54. *Japan Today*, 'Japanese Ship-Mounted Railgun Successfully Hits Target in Test', 24 September 2025, <https://japantoday.com/category/national/japanese-ship-mounted-railgun-successfully-hits-target-in-test>, accessed 6 January 2026.
55. Insight provided by a participant at the RUSI workshop on prototype warfare, London, 24 June 2025.
56. Stephen Losey, 'Experts: Full Nuclear Testing Would Backfire on the US', *Defense News*, 5 November 2025, <https://www.defensenews.com/global/the-americas/2025/11/05/experts-full-nuclear-weapons-tests-would-backfire-on-us/>, accessed 15 January 2025.

Exposure of a system to operationally realistic circumstances is certainly important and remains something which can primarily only be achieved in a physical environment. That said, steps such as subcomponent validation need not be. The computing power to do this at very high fidelity will probably have to be held centrally, given the costs, much as is the case for nuclear weapons. The ability to both develop and lease out modelling and simulation capacity could be an important defence offer to the developers of capabilities.

Whichever avenue is used, the validity of an approach that embraces early risk in testing prototypes is demonstrable. In particular, the early support a state can provide – in the form of enabling the testing of a system by making facilities and personnel available – can be of critical importance. In a sample of 50 defence acquisition cases across several states, early operational testing correlated negatively with time to the initial operating capability/full operating capability more strongly than variables such as financing and requirement churn.[57]

The three avenues discussed would require three preconditions to be met. The first is the requirement for mechanisms to transfer the data gleaned from prototyping. It is easier to experiment before a capability becomes a programme of record, and thus when much about this capability becomes classified. However, the underlying processes involved in the testing of capabilities are also inherently sensitive. Expanding access to clearances for SMEs is thus likely to be necessary.

Second, risk mitigations would need to be embraced. Rapid and user-led testing can involve risk to life. However, personal risk can often be balanced against rewards. An informed individual can weigh these two considerations. Although specific enabling policy guidance would be required, such a policy would not be a major departure from existing practice and is already the case for Royal Navy divers who are paid bonuses per dive.[58]

The final precondition is the implementation of a financial mechanism which can underwrite a process of rapid development and eventual scaling. The case study business (Subsea Craft Ltd) was funded in the development years, pre-revenue, by private family wealth. This remains an untapped source of funding for financing low-TRL prototypes.[59] The next chapter of this paper covers this emerging financing model for the prototype force.

57. Author-generated figures. More detail can be provided on request. It should be noted that programme complexity is an important factor that is difficult to measure. This can limit the value of these findings in isolation.
58. Observation by former Royal Navy diver at the RUSI workshop on prototype warfare, London, 24 June 2025.
59. Low-TRL prototypes are relatively immature capabilities and technologies.

A Commercial Ecosystem for Prototype Warfare

A commercial ecosystem to enable rapid prototyping requires two components. The first is a network of actors capable of supporting early testing and the second is the capacity to scale capabilities once selected. This chapters discusses both of these components.

Private wealth is an untapped source of support for prototyping. In 2024, global assets under management by hedge funds were valued at $4.5 trillion.[60] In contrast, funds under management by private family offices were valued at $6 trillion, and the private equity buy-out market is valued at $4.7 trillion.[61] While the focus of much work in the field has been on venture capital, private wealth, as illustrated by the case study used in this paper, can allow for prototyping at scale within defence budgets. Private family offices tend to have relatively high risk tolerances for their investment portfolios due to their lower liquidity needs, and are increasingly active as direct investors.[62] It is unlikely that defence will be the only sector which can compete for this source of investment. However, even a portion of the wealth held within this sector would represent a significant financial base for companies involved in prototype warfare.

A second pathway to resolving the challenge of rapid early prototyping might be the renting of capabilities by the state. Procurement from a single source is often complex; instead, an intermediary organisation could purchase and then rent out a system to the state, which would be quicker and present fewer procedural hurdles. An argument has been made that the model that some funds, such as that of the investment bank JP Morgan, apply to the ownership of commercial vessels – in which an asset is essentially

60. Carolina Mandl, 'Hedge Fund Industry Reaches 4.5 Trillion in 2024', *Reuters*, 24 January 2025, <https://www.reuters.com/business/finance/hedge-fund-industry-reaches-45-trillion-2024-2025-01-24>, accessed 26 January 2026.
61. David Oakley, 'How the Family Office Became One of the World's Fastest Wealth Generators', *Financial Times*, 11 July 2024; Patrik Hayoz, Bingbing Ge and Alfredo De Massis, 'Research on Family Offices: What is the Way Forward? A Systematic Literature Review', *Journal of Family Business Strategy* (Vol. 16, No. 3, 2025).
62. Affinity, 'The Evolution of Family Office Direct and Co-Investing', 5 June 2023, <https://www.affinity.co/blog/family-offices-direct-investing>, accessed 14 December 2025.

rented from the bank – could be applied to military shipping.[63] There is some scepticism of the application of this model to frontline vessels – this may well be 'a bridge too far' for most states. However, the model could be a viable approach to the ownership of prototypes, albeit with specific provisions for the fact that capabilities 'rented' will in many instances be broken, since experimentation implies damage.[64] Since most investment banks do not actually expect to receive an asset back at the end of its lease, damage incurred to a system would represent a somewhat nominal cost. However, this model would presuppose the need for a different approach to damage liability for assets, and this approach must be subjected to strenuous experimentation. One mitigation, for example, might entail a sharing of liability for damaged prototypes, much in the way that liability for cost overruns on major programmes of record is split between defence and the private sector.

The challenge of scale is one to which more traditional actors within defence will be more relevant than SMEs and there is a case for a division of labour within the market along these lines. One of the major shifts in the production of microchips was the separation of design and production. This concept was pioneered by figures such as Morris Chang, who envisioned fabrication plants that built designs provided by other firms. This concept led to the emergence of Taiwan's TSMC, the world's largest dedicated semi-conductor foundry.[65] Since entities dedicated purely to production did not have stakes in the competition to produce better designs, they were willing to share their IP with TSMC. In turn, TSMC became a much more efficient producer of chips than any of the in-house laboratories which entities such as Intel maintained up to that point.

Today, this may carry lessons for the relationship both between SMEs and primes and, more controversially, between SMEs, the state and private finance. The capacity of defence primes to act purely as producers of capability rather than as designers might represent one pathway towards resolving the challenge of scaling technology which SMEs can develop but not produce. This would hinge on whether primes would be willing to purchase products at lower TRLs and act as, in effect, portfolio managers and integrators of IP developed elsewhere. However, this would effectively shift the challenge of buying redundant and initially non-performing production capabilities on to a defence prime rather than the state. This is not unheard of, and several primes are currently investing in redundancy in other ways – for example, the stockpiling of long-lead items.

63. Remarks made by JP Morgan Executive at RUSI workshop on the Royal Fleet Auxiliary, London, December 2024.
64. *Ibid.*
65. Chris Miller, *Chip War: The Fight for The World's Most Critical Technology* (New York, NY: Simon and Schuster, 2022), p. 167.

The Role of the State in Scaling Mature Prototypes

For the defence sector to be attractive for both innovators and investors, its acquisition processes should be better aligned with the incentives of these stakeholders. While there are multiple avenues to delivering technologies at mid-TRLs, these technologies must eventually be scaled.

The two areas where the state can add greatest direct value are the ability to act as a part of the iteration process, and scaling. State investment is not a prerequisite for developing technology to mid-TRLs. It can, however, play a crucial role in providing the infrastructure to take a prototype past that point. This would require investment not in specific products, but rather in the infrastructure for testing and scaling systems; this infrastructure could then be applied to systems identified as being potentially valuable.

In Europe and the US, defence acquisition reform in the past 30 years has focused predominantly on avoiding inefficiencies and waste. The emphasis of support to experimental products was on limited funding to nascent systems – precisely the area where support can be secured from elsewhere. The need for scaling at speed was missing from the reform agenda. This characteristic suddenly became critical following Russia's full-scale invasion of Ukraine and the policy imperative to recapitalise militaries in Europe. There is a correlation between urgency and innovation that has escaped decision-makers until relatively recently, and a dawning recognition that the insertion of prototype capability into the frontline can prove battle-winning. For example, the Ukrainian Navy and Security Service of Ukraine achieved the effective eviction of the Russian Navy from Sevastopol by using Magura USVs, Storm Shadows launched from Su-24s (which were not built to carry them), Neptune missiles (which had not reached full operating capability at the war's outset) and long-range UAVs – effectively a force of prototypes.[66]

The UK Defence Solution Centre (UKDSC) was conceived as an initiative to be jointly funded by government and industry. It offered niche technologies quickly to the armed forces and championed exports to friendly states. The focus was on collaborations to enable the fielding of innovative solutions at the earliest point possible. However, the process by which UKDSC and the Centre for Defence Enterprise (now DASA) ran competitions for support to capabilities at TRL 3–4 and sought to collaborate with the British Business Bank to set up a defence venture capital fund proved challenging. The iterative competition model in which financing is secured at specific TRLs is an

66. Sidharth Kaushal, 'Lessons From the Black Sea and Red Sea on the Use and Design of Future Fleets', *RUSI Commentary*, 9 August 2024, <https://www.rusi.org/explore-our-research/publications/commentary/lessons-black-and-red-sea-use-and-design-future-fleets>, accessed 15 January 2026.

onerous requirement for relatively limited funding. Specific, measurable outcomes also remain unidentified and a barrier to collective engagement.[67]

This relatively cautious approach contrasts with the approach taken by the Australian government with Anduril's Ghost Shark UUV. This saw the Australian government act as a partner and co-financier of the scaling of the capability.[68] Critically, the Australian government's primary role was in supporting the scaling of a capability, not its early development. A significant amount of money was spent decisively, rather than being spread across multiple bets over a long period of time.

In effect, the state benefits from an approach whereby it lends capacity but not finances to experimentation and iteration – supporting the testing of platforms financed from elsewhere – while committing finances to delivering the economies of scale that only a large entity can deliver.

Defence reform in the UK indicates that the state recognises both that the world has changed fundamentally and that capabilities are required which can evolve quickly and cheaply at component, sub-system and system levels.[69] There is also a growing bifurcation between the capacity for production and the capacity for software development in an environment where some (although not all) capabilities involve comparatively simple hardware and complex software. In this environment, there is a case for direct state ownership (at least in part) of production capacity. In the authors' view, this would make the state a partner in scaling a product rather than just a customer. After all, the argument made against state ownership on the basis that state ownership hinders innovation is less valid for defence items for which production is not an especially complex or innovative part of the process.

An example that partially shows this approach lies again in Australia's production of the Ghost Shark UUV: the state part-financed the production facilities. This approach has also been taken by other jurisdictions in other fields. For example, the Taiwanese administration provided 30% of TSMC's seed capital, and also played a role in securing the remainder. Many of the capabilities associated with future rapid production – such as additive manufacturing – are currently not cost-effective due to factors such as the use of expensive metals in printing. Consequentially, many private sector initiatives to achieve additive manufacturing at large scale have died out. There is therefore a relatively strong case for accepting the cost of maintaining capabilities which will have much longer-term utility in part ownership with companies – emulating aspects of the Ghost Shark model – since the state has a unique capacity to invest in productive assets

67. Department for Business, Energy & Industrial Strategy, 'Ipsos Mori – Evaluation of UKDSC', 2018, p. 32.
68. Australian Government Department of Defence, 'Albanese Government to Accelerate Production Readiness of Ghost Shark Program', 5 August 2024, <https://www.minister.defence.gov.au/media-releases/2024-08-05/albanese-government-accelerate-production-readiness-ghost-shark-program>, accessed 15 January 2026.
69. MoD, 'Defence Secretary's Speech on Defence Reform', 18 February 2025, <https://www.gov.uk/government/speeches/defence-secretarys-speech-on-defence-reform--2>, accessed 15 January 2026.

which do not turn a profit in any given quarter. State ownership of production, but not of design or software, could allow the state to become a partner in an enterprise, taking advantage of the fact that the most important aspects of IP are not the physical productive capacity of a company. Moreover, should the state act as the producer of hardware designs it does not own, the incentives at a company level to couple hardware and software decrease, since hardware sales generate less value than software. This decoupling is often more difficult to achieve when the same company produces both things, as shown by the US Department of Defense in the context of the replicator programme.[70]

Characteristics of an Effective Procurement System

This paper acknowledges that considerable and sometimes contradictory research has been undertaken on defence innovation, acquisition and the generation of future military capabilities.[71] Nevertheless, the following characteristics of an effective procurement system would be supported by the majority of the available literature and the evidence assessed in this paper.

- Continual innovation and rapid, advanced technological insertion into defence systems are critical to the West's military advantage. This is more significant, strategically, than good commercial supplier management, the husbandry of resources or the continual, ever-present generation of efficiencies: all of which are no longer priorities. Some aspects of what might enable an effective approach run directly counter to the logic of immediate value for the taxpayer. Examples include state co-ownership of scaling.
- Major systems need to be conceptualised and designed overtly as open systems, enabling the development and deployment of new technologies. Modular capabilities such as VICTA need to integrate into both an existing order of battle and an emerging one, operating as both a modular and a standalone asset. Many of the approaches which are taken to reduce the risk in the procurement of major platforms may not be appropriate for the procurement of modules. A procurement model built around modules which fit on platforms might benefit from an accelerated approach to supplier selection which is typically not appropriate for platforms themselves given the risks of optimism bias in larger projects.[72]

70. Richard Haley, Michael Harteveldt and Ethan Kessler, 'Is Replicator Replicable?', Harvard Kennedy School, September 2025, pp. 23–25.
71. Henrik Heidenkamp, John Louth and Trevor Taylor, 'The Defence Industrial Ecosystem: Delivering Security in an Uncertain World', *RUSI Whitehall Reports*, 2-11 (June 2011).
72. Flyvbjerg, 'Make Megaprojects More Modular'.

- The financing of capability-specific technology demonstrators should be shared between government and industry, with development to at least TRL 3 probably financed by private capital. For example, policies that align family wealth offices to technological innovators and startups should be developed. Moreover, in future, as part of the proof of concept, maritime capabilities should be supported by an enhanced Ministry of Defence innovation fund, with a frontline command (or proxy) offering, for example, range support and open water facilities. Additionally, in the context of defence reform, this frontline sponsor should take the lead in discussions with regulatory authorities and the national armament directorate, as prototypes test and reshape the boundaries of the respective regulator's knowledge, experience and capabilities.
- The government's approach to risk management within defence acquisition needs to evolve. Disruptor businesses will not be able to achieve more advantage unless the levels of personal liability currently assumed by SROs change. For example, the Navy accelerator could usefully recommend specific projects or subcomponents of projects for a fast-track trajectory where SRO liability for authorising more rapid processes is waived since the responsibility for this choice has been made on an institutional basis.
- While it will of course remain necessary to maintain at least minimal safety standards, an approach that accepts more risk to prototyping modules and offboard capabilities – such as UUVs – probably has greater risk of financial failure as well as risk to platforms and personnel. There is an argument that some of the money devoted to defence innovation might be better spent remunerating individuals involved in testing prototypes in a manner commensurate to the risk, not unlike deployment bonuses or, as mentioned earlier, the bonuses offered to Navy divers.

Many arguments for greater risk aversion that apply to larger platforms are less applicable to what goes on them or can be deployed from them. The frequently cited argument that financial losses are not acceptable to the public overlooks the fact that very few members of the public engage directly with the subject of procurement beyond major platforms. Western publics are also generally more likely to support defence spending than Western politicians.[73]

73. Peter Trubowitz and Brian Burgoon, *Geopolitics and Democracy: The Western Liberal Order from Foundation to Fracture* (Oxford: Oxford University Press, 2023).

The Case Study of Subsea Craft Ltd

The specific case study of Subsea Craft Ltd serves to illustrate some of the broader principles articulated so far.[74] While just a single case study, it is a useful illustration of the principles discussed in broader terms in practice.

The Centrality of Private Risk to Rapid Prototyping

Subsea Craft Ltd has used extensive simulation, computer modelling, tank- and wind-tunnel testing to develop the VICTA prototype. All the work undertaken was financed privately by a family office sympathetic to defence and national security. The company integrates advanced technologies in relation to hull design and materials, composites, propulsion and batteries, advanced life support systems, acoustics, seating solutions for transit and deployment, mission command and craft control systems.

The ability of Subsea Craft Ltd to achieve this outcome with private capital is indicative of the potential that can be drawn from the private wealth management sector. Moreover, unlike the pensions sector (often mooted as a source of financing for defence), the private wealth management sector is less structurally averse to working with defence.

The scale at which private capital can support early innovation, up to TRL 3 (and possibly beyond), suggests that innovation funds could be better employed in generating the capacity for prototyping and scaling rather than in providing seed funding for companies, where other funding sources are available.

The Physical and The Virtual

VICTA has been iteratively improved based on data insights and digital management, all designed deliberately into the programme from the outset. For technology-rich design and manufacturing sectors other than defence, many companies have championed digital thread applications for product lifecycle management.[75] There are a number of assessed benefits for VICTA's military customers. The first is an improved end-user experience, proven and continually updated through digital design and management principles. The second is the fact that agility and innovation are enabled through data and information sharing, virtual collaboration, and costs control through simulation.[76] For Subsea Craft Ltd, direct employment by end users was a mechanism

74. John Louth and Peter Roberts, 'The VICTA Vision, Next Generation Capability – Adaptable, Affordable, Resilient', Subsea Craft Ltd, unpublished paper prepared for the Society of Naval Architects and Marine Engineers, 2020.
75. John Louth and Adrian Spragg, 'UK Future Combat Air: A Programme Management Imperative', *RUSI Journal* (Vol. 164, No. 4, 2019), pp. 46–59.
76. Explored during a series of semi-structured interview with Subsea Craft Ltd design and development personnel, 15–18 September 2025.

for iterating the product. The most important military contribution, to reiterate an argument made above, was usage and the data that emerged from it.

The experience of Subsea Craft Ltd lends itself to the case for aggressive, even damaging, prototyping where a digital thread can pass data directly to the producer. Moreover, the ability to control costs through simulation provides an argument for moving capabilities from TRL 3 to physical testing earlier, since many of the most salient risks (for example, risk to life) can be mitigated through simulation, while other risks should be accepted as part of the development model.

Partnering and Team of Teams

The delivery of VICTA's design demonstrated the potential for the organic development of partnerships within a project without the requirement for an onerous subcontracting process. The craft has been developed using advanced capabilities from several leading maritime technology providers from around the world. BMT was commissioned to provide independent assurance through the safety case with the craft being built to Lloyds' Register certification and survey compliance.

The ability of Subsea Craft Ltd to engage successfully with several allied militaries demonstrates that many of the steps associated with assurance can be taken by private actors ahead of government acquisition. While state-level certification will probably be needed, broader standards with which private companies and teams can comply ahead of putting products on the market might take the place of rigidly defined requirements. It is within the gift of many companies backed by sufficient private capital to save time by achieving rough consistency with state-level standards on their own initiative.

A single case study has obvious limitations. However, in the context of the evidence base discussed earlier in this paper, a model begins to emerge whereby private finance can enable initially speculative technological development to proceed as prototypes. The case study provides some insights into the principles which might guide future defence procurement. Matching that finance to the kernel of an idea – with the right people organised to execute – should be an important line of development for defence reform, and feature at the heart of future defence acquisition. With a few exceptions, such as that of this case study, this is profoundly different from what has been completed to date.

Conclusion and Recommendations

The Royal Navy has stated its desire to produce a hybrid fleet of crewed and uncrewed platforms around a protean core of crewed platforms that can be adapted to purpose. This idea has considerable value as both a means of managing resource constraints and a hedge against uncertainty. It can also serve as a means of linking specific naval concerns to wider national strategic priorities such as the prosperity agenda. Delivering this vision will, however, require the Navy to act as more than just an agile customer. Instead, the Navy must increasingly become a part of a process of production where it is as much a producer of knowledge as a consumer of a final product.

Instead of focusing on money spent on small experimental projects (useful though this is), the Navy should primarily focus on setting the conditions through which it can contribute to a process of rapid prototyping. This would enable the evolution of products which will be initially imperfect but which will be iterated. While other sources of money exist, only defence can generate knowledge in this way.

The Royal Navy's capability accelerator can contribute to this process by acting as a vehicle for the allocation of testing capacity (in terms of both platforms and personnel), rather than financing. The Navy can, in effect, be a partner in capability development. This will require preparatory work to build mechanisms to understand when human capacity and platforms should be allocated to testing a platform and how tests can be made as rigorous as possible. It would involve having a view to generating data, rather than assessing a platform's purchase value.

This approach could dovetail with a wider one where the market intelligence capability within the Department of Business and Trade and UKDSC shifts focus from platform export (as seen in the Type 26 and Type 31) to supporting an approach whereby at least half of defence value is generated through the sale of modules in deals worth less than $100 million – this emulates the case in Israel. Since both the protean force model and module export require the capacity to integrate capabilities with a heterogenous mix of platforms, open architecture standards should characterise most PODS procurement.

Scaling, however, is an area where the state can play a more direct role. Partial state ownership of physical production should be considered – an approach in some ways comparable to (though arguably more radical than) that which the Australian government took with Ghost Shark. One of the traditional arguments against state ownership – that it limits innovation – is less pertinent for capabilities that do not rely on exquisite hardware components in many (although not all) instances, but are instead valuable because of the complex digital IP and software which underpins them. There is no reason that the state cannot directly deliver the simpler, hardware element (in several instances the less important element) more cheaply than alternative sources.

In effect, then, a synergy can be achieved between an ecosystem of privately funded innovators which require the capacity to test and scale and a traditional defence ecosystem which can achieve the latter functions. Rather than driving innovation per se, the state and the Navy should provide the mechanisms for iterating it and for turning innovative products into scalable military platforms.

About the Authors

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