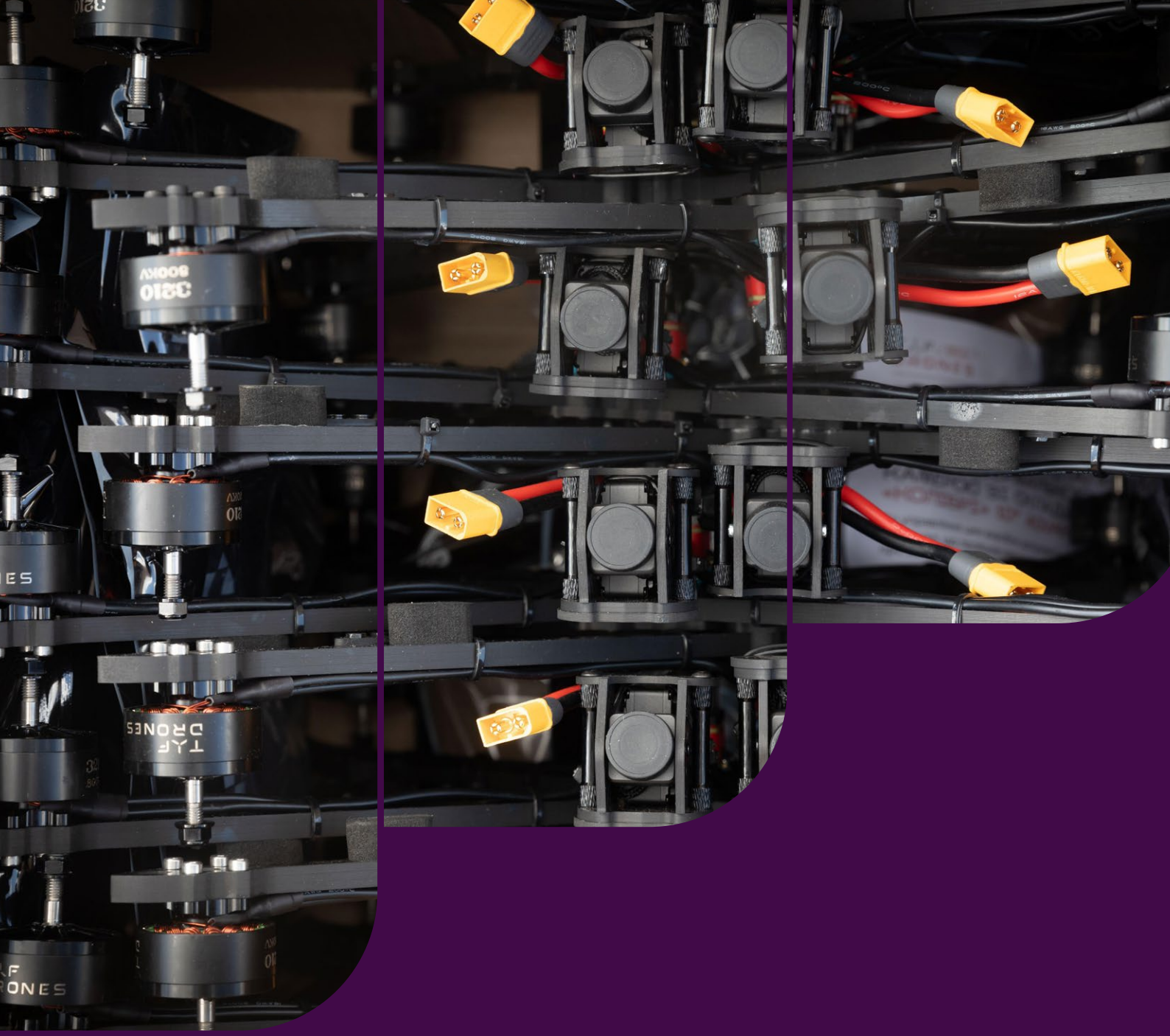

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Drones: Decoupling Supply Chains from China

Robert Tollast

RUSI

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Get in touch

www.rusi.org

enquiries@rusi.org

+44 (0)207 747 2600

The Royal United Services Institute for Defence and Security

61 Whitehall, London

SW1A 2ET

United Kingdom

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Executive Summary

Widespread access to Chinese-origin commercial off-the-shelf drones and components has transformed Ukraine's ongoing conflict with Russia, leading many observers to declare a revolution in affordable precision and materiel mass. This paper outlines the implications of this transformation for NATO and for key Allied multirotor uncrewed aerial system (MUAS) supply chains in upcoming peer conflicts. These supply chains are currently dominated by Chinese inputs. It argues that key Allies and aligned countries must be aware of the serious risk of depending on China for critical UAS material. This research follows several attempts by the Chinese state to capitalise on its dominance in MUAS, notably by holding back batteries (the same kind of cells used in electric vehicles) from the US drone maker Skydio in December 2024 and directing production to Russia and away from Ukraine. Crucially, China is now limiting or closely scrutinising Ukraine's access to other critical MUAS materials – namely, permanent magnets – and more broadly has placed restrictions on germanium exports used for thermal sensors.

This paper seeks to build on research which has mainly examined drone assembly, particularly within Ukraine, and its use on the battlefield. The challenge to mass producing hover-optimised MUAS and high-agility first-person view (FPV) drones has revealed systemic vulnerabilities in the West, stemming from a heavy reliance on Chinese-origin rare earth elements.

Ukraine's demand for drones has skyrocketed; millions of FPVs and interceptor drones, which often rely on the same motors as MUAS, are planned for procurement by 2026. Ubiquitous Chinese-origin drone systems or components include flight controllers, motors and sensors. Nonetheless, non-Chinese production is slowly emerging. China dominates in permanent magnet production for motors, mature semiconductors and sensors. This allows low-cost strategic access for its allies and the ability to disrupt the wider supply chain. Tightening China's export controls, particularly to Ukraine, contrasts with the growing flow of MUAS-related components to Russia and local assembly cooperation.

Key Findings

This paper makes several key findings:

- **NATO allies seeking to develop MUAS production will be hindered in their efforts by near-term material shortages.** Some dual-use material, and particularly permanent magnets made with neodymium iron boron (which are critical for motors), have extremely high and competing civilian demand.
- **Ukraine's affordable 'dronisation' model (widespread adoption of drones throughout ground units) may not be threatened by Chinese restrictions on components in the near-term, but it will be difficult for NATO to substitute components when shortages arise.** The UK- and Latvia-led Drone Capability Coalition goal of providing one million drones for Ukraine will be a major challenge to accomplish without any Chinese input, and the same applies to any US–Ukraine drone alliance or the recently announced UK–Ukraine partnership.
- **The highly flexible, often modular Ukrainian drone design currently facilitates diverse roles at a low cost, from attack and reconnaissance roles to radio relay and logistics.** This approach, rather than one focused on specific drone designs, fuels Ukraine's tactical innovation and allows for rapid adaptation, despite the challenges of electronic warfare and occasional component shortages.
- **There is a potential to transform drone cooperation agreements among democracies into formal drone alliances.** The recently concluded Project LYRA agreement between the UK and Ukraine to facilitate co-production of some drone models, and an agreement between Taiwan and Poland to focus on drone technology are good starting points. However, strengthened drone alliances would be focused not only on assembly – at which Ukraine excels – but also on subcomponent fabrication, by building supply chain resilience for key components. These alliances should be supported at the government level, to boost what is mostly a fragmented global network of private sector cooperation.
- **While partnerships with Ukraine are critical, Ukraine cannot currently be the source of drone supply to the West.** It is unlikely that there will be a surplus of Ukrainian drones soon.
- **NATO governments should follow the lead of the US, whereby the Department of Defense has decentralised drone procurement to army units.** This provided a market signal to small producers and investors that the demand for drones will rise. While such an approach is highly unlikely to match the current scale of China–Russia cooperation on MUAS, it could at least combine part of NATO's current tactical planning for UAS with a viable materiel mass and create a basis for faster trialling of MUAS in NATO forces.
- **Ukraine's consumption of FPV drones is greater than NATO's, revealing a mismatch between current NATO drone strategy and actual battlefield needs.** Combined MUAS procurement numbers by NATO members was only in the tens of thousands through 2025.

Introduction

Russia's full-scale invasion of Ukraine has seen a rapidly expanding rate of drone use on both sides, from tens of thousands per month in 2022 to hundreds of thousands per month in 2024. These mainly consist of multirotor uncrewed aerial systems (MUAS). The relentless demand for components of MUAS and for fully complete MUAS has driven a scramble among Ukraine's and Russia's international partners to supply the combatants. The observable impact of MUAS on the battlefield has also led to many states' attempts to expand the number and diversity of multirotor and other UAS types in their own militaries, with a corresponding requirement to guarantee the supply chains necessary to design, build and assemble competitive UAS now and in the future. This paper explores the difficulties in establishing these supply chains to identify how NATO members can ensure they are ready for the conflicts of the future.

The foremost challenge explored in this paper relates to the efforts of the US, Taiwan, Ukraine, Poland, Canada and Lithuania to remove Chinese-origin components and complete drones from MUAS supply chains, with varying degrees of enforcement. These jurisdictions, due to national security concerns, have aimed to remove Chinese-origin components as part of their attempts to build their own sovereign manufacturing capability.[1] The paper also explores the risk that China will impose tighter restrictions on exports of UAVs, while increasing its concurrent exports to Russia.

In turn, the near-term challenge for countries building sovereign MUAS supply chains is developing economies of scale in production and ensuring access to necessary natural resources, especially rare earth elements (REE). At present, China supplies approximately 80% of the global MUAS market,[2] including complete systems and components. Components are vital for adaptable, modular drone construction, which dominates Ukraine's spirally developed, or rapidly adaptable, approach. China also

1. Apart from the US Defense Innovation Unit's Blue List effort, notable projects supporting domestic production include Australia's Sovereign UAS Challenge and Taiwan's 2022 Drone National Team industrial effort.
2. Matthew Kroenig and Imran Bayoumi, 'A Global Strategy to Secure UAS Supply Chains', Atlantic Council, 25 June 2024, <https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/a-global-strategy-to-secure-uas-supply-chains/>, accessed 11 November 2025.

dominates REE extraction and the processing of metals needed for permanent magnets in drone motors and battery production.[3] The ubiquity of Chinese component supply has fuelled a frontline user-generated MUAS evolution and, ultimately, Ukraine's ambition to procure 4.5 million first-person view (FPV) drones through various channels in 2025.[4] Nevertheless, without the possibility to access these resources outside China, it is not clear if NATO or the US could achieve a comparable scaling of production in a great power conflict.

Ukraine's strategic approach to UAS in war contrasts with most Western approaches. For reference, the British Army took delivery of only 3,000 FPV drones in August 2025, while the US military has ordered 10,000 in 2025, including drones for training.[5] According to one expert in the British Army,[6] FPVs have a potentially high accident and equipment failure rate, due to a high training burden; this means that the deployable number of units is even lower. Ukraine's struggle is not a template for the next war for Western powers (although the Chinese military is aggressively pursuing 'dronisation'). However, at current rates of loss in Ukraine, these British and US MUAS procurements would only last several days.[7]

Many observers of the Russo-Ukrainian war have noted the extremely low cost of MUAS, in some cases several hundred dollars per unit.[8] One interviewee at a US firm currently increasing production says this low-cost point, excluding Chinese components, is a difficult goal to reach unless production, and subsequent economies of scale, are vastly increased.[9] The 2026 US Army budget estimate for the 2026 fiscal year notably calls for 1,057 bundle packs of two 10-inch FPVs and four 5-inch drones, including a ground controller and goggles, for $34,846 – amounting to several thousands of dollars per drone, although each unit cost is not specified.[10] In all, the

3. Craig Hart, 'Mapping China's Strategy for Rare Earths Dominance', *Atlantic Council*, Issue Brief, 13 June 2025, <https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/mapping-chinas-strategy-for-rare-earths-dominance/>, accessed 23 July 2025.
4. Ukraine's drone ecosystem – consisting of suppliers from the private sector, government and NGOs – is highly fragmented. This figure is, therefore, probably an indicator rather than a firm number, although there is currently a major drive to consolidate the sector. See *Reuters*, 'Ukraine to Sharply Raise Purchases of Home Produced FPV Drones in 2025', 10 March 2025.
5. Craig Langford, 'MOD Confirms British FPV Drone Procurement Figures', *UK Defence Journal*, 8 June 2025, <https://ukdefencejournal.org.uk/mod-confirms-british-fpv-drone-procurement-figures/>, accessed 23 July 2025; SAM.gov, 'Uncrewed Aircraft Systems (UAS) for the United States Army', 8 July 2025, <https://sam.gov/opp/3364e60e80d54ca1aa38779e63cda29d/view>, accessed 23 July 2025.
6. Author interview with British Army officer, London, 22 June 2025.
7. John S Van Oudenaren and Peter W Singer, 'China's Burgeoning Drone Arsenal Shows Power of Civil-Military Fusion', *Defence One*, 17 June 2025, <https://www.defenseone.com/ideas/2025/06/chinas-drone-arsenal-shows-power-civil-military-fusion/406118/>, accessed 23 July 2025.
8. Allen Frazier, 'How Ukraine's Drone War is Forcing the U.S, Army to Rewrite its Battle Doctrine', Military.com, 19 October 2025, <https://www.military.com/feature/2025/10/19/how-ukraines-drone-war-forcing-us-army-rewrite-its-battle-doctrine.html>, accessed 22 October 2025.
9. Author interview with US drone company executive, London, 7 May 2025.
10. US Department of the Army, 'Department of Defense Fiscal Year (FY) 2026 Budget Estimates', Justification Book Vol. 1, June 2025, p. 4, <https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2026/Discretionary%20Budget/Procurement/Aircraft%20Procurement%20Army.pdf>, accessed 23 July 2025.

combined production volume of three leading US MUAS manufacturers as of July 2025 was approximately 48,000 units per year, while Taiwan's tactical UAS production is expected to reach 10,000 units through 2025, the equivalent of the 2025 US Army request.[11] The US and Taiwan are at the forefront of bringing drone production onshore, although Taiwan is also keen to build bilateral drone partnerships.[12] Cognisant of supply chain risks, some countries (in particular, Poland) are already deepening MUAS cooperation with Taiwan and looking at co-production.[13] The challenge of building an MUAS supply comparable to China's will be steep: in late 2024, China's Da-Jiang Innovations (DJI) claimed that 400,000 of its agriculture drones were in use globally.[14] If Ukraine provides even a small indicator of how MUAS will be used in the next peer conflict, then Allied current production falls far short of requirements.

Increasing the scale of secure supply will be a slow process. Alongside Poland, countries including Canada and Lithuania are moving closer to the US policy on drones, with Lithuania banning Chinese drones in 2024.[15] The US has compiled a strict Blue List, an inventory of drones and components compliant with Section 848 of the 2020 National Defense Authorisation Act (NDAA), which bans 'flight controllers, radios, data transmission devices, cameras, or gimbals' or 'uses a ground control system or operating software' of Chinese-origin.[16] The 'red-free' drone, as it is referred to in Taiwan, already exists and there are several MUAS available on the market. However, multiple firms have struggled to procure certain categories of components, which could present near-term bottlenecks and price volatility.[17] This paper charts China's first-mover advantage in terms of MUAS production in the Russo-Ukrainian war and explains the implications and risks of this advantage for Western drone production.

11. Author interview with DSET (Democracy, Society and Emerging Technology) analyst, London, 9 May 2025; see also Dan Schere, 'Army Wants to Field 10,000 UAVs a Year Costing Under $2000 Each', *Inside Defense*, 7 July 2025, <https://insidedefense.com/insider/army-wants-field-10000-uavs-year-cost-under-2000-each>, accessed 30 July 2025.
12. Author interview with DSET, London, 9 May 2025.
13. Agnieszka Barteczko and Yian Lee, 'Poland Becomes Top Importer of Taiwanese Drones, Skirting China', *Bloomberg*, 25 September 2025, <https://www.bloomberg.com/news/articles/2025-09-25/poland-becomes-top-importer-of-taiwanese-drones-skirting-china>, accessed 26 September 2025.
14. This claim cannot be taken at face value; however, there were an estimated 251,000 agri-drones in China in 2024. See Mandy Zuo, 'Nowhere to Go But Up: China's Farming Drones Take Root as Industry Grows', *South China Morning Post*, 2 January 2025, <https://www.scmp.com/economy/china-economy/article/3292917/nowhere-go-chinas-farming-drones-take-root-industry-grows>, accessed 14 October 2025.
15. Žygintas Abromaitis, 'No More Chinese Phones or Drones: New NatSec Rules Weigh on Lithuanian Institutions', *Lietuvos Radijas ir Televizija*, 8 December 2024, <https://www.lrt.lt/en/news-in-english/19/2336581/no-more-chinese-phones-or-drones-new-natsec-rules-weigh-on-lithuanian-institutions>, accessed 14 October 2024.
16. US Congress, 'S.1790 – National Defense Authorization Act for Fiscal Year 2020', 116th Congress, 2019–2020, 20 December 2019, <https://www.congress.gov/bill/116th-congress/senate-bill/1790/text>, accessed 23 July 2025.
17. *Taipei Times*, 'Expert Lauds Taiwan's Uncrewed System Tech', 24 September 2024, <https://www.taipeitimes.com/News/taiwan/archives/2025/09/24/2003844334>, accessed 24 September 2025.

Structure

This paper has three chapters. The first chapter charts China's first-mover MUAS advantage in supplying both Ukraine and Russia. The second chapter examines the importance of design flexibility over form factor, which is a critical aspect for understanding drone supply chains. The third chapter highlights supply chain bottlenecks for critical components, focusing on three categories: core electronics, sensors and motors, and the challenge of increasing the scale of production through bilateral and multilateral drone alliances for sovereign production (which is distinct from the efforts to send drones of any origin to Ukraine). The paper concludes with recommendations for Western governments and organisations that aim to enable cooperation and innovation in uncrewed systems, along with enabling efforts such as NATO's multinational capability delivery initiatives. These recommendations include a stronger focus on Allied production of defence raw material inputs, which requires concrete action from members. Jurisdictions including the US, Taiwan, Lithuania, Canada and Poland have thus far moved towards developing sovereign manufacturing capacities. However, non-Chinese substitutes remain expensive, with certain components costing up to 10 times more.

Methodology and Limitations

This paper is based on unstructured interviews with 18 experts in MUAS design, manufacturing and deployment. Many of these experts have worked on drone projects in Ukraine with NDAA-compliant, or Blue List-certified, components. Several experts have been involved in government-backed sovereign UAS production efforts, as well as counter-UAS. Several other experts generously gave their time to inform the paper but cannot be cited as sources: in most cases, these experts were serving officers in the British Army. Interviews were held in-person in London or Guildford, or between May and October 2025.

This paper adopts a focused approach by examining hover-optimised MUAS which are mainly used for reconnaissance, bombing, resupply and radio relay – and FPVs, which are faster, more agile and can conduct similar missions (albeit, mainly, in precise one-way attacks). While this paper's focus is narrow, some of the drone components discussed overlap with those used on larger classes of drones, such as Russia's Lancet,

Molniya and Geran, and particularly interceptor drones increasingly used by Ukraine to strike fixed-wing drones such as Russia's Geran-2.[18]

The research for this paper faces certain limitations, including a lack of access to commercially sensitive information on the production of certain drone components. Some interviewees highlighted that certain sensitive information could not be quoted, for example, when relating to trials of equipment. No sensitive information appears in this paper, and quotations are anonymised except in several instances where participants agreed to be named. In addition, open source research was used to assess supply chain vulnerabilities – in some cases, to observe chip origin markings on flight controllers. Country-level study of chip origin is limited, since many datasheets for semiconductors do not list the country of fabrication.

18. According to Ukraine's Defence Ministry, the Molniya drone contains the STM32F405 processor for its flight controller, a device commonly found on flight controllers for quadcopter FPVs. See Ukraine Ministry of Defence, « Маршрут « Хмеймім-Ульяновськ » — росіяни відходять із Сирії, вони використали конвой літаків » ['Route "Khmeimim-Ulyanovsk" – The Russians are Retreating from Syria, they Used a Convoy of Planes'], 24 December 2024, <https://t.me/DIUkraine/4990>, accessed 23 July 2025. Similarly, Foxeer FPV cameras have been found on Geran-2 drones.

Ukraine's Uncrewed Mass Revolution

The Strategic Impact of UAS on the Battlefield

To understand why MUAS supply chains have strategic importance, it is necessary to explore the evolution of the varied and ongoing adaptation of Ukrainian and Russian systems. This dynamic continues to drive debate on UAS more generally, and on the extent to which the West must adopt UAS on a large scale. When evaluating the transformative impact of UAS on the battlefield, retired US General David Petraeus asserted, on the one hand, that Ukraine's 'no-man's land … has to be the most lethal in history'.[19] Sceptics of this drone-inflicted lethality, on the other hand, include French Army Chief of Staff General Pierre Schill, who in June 2024 said that drones were 'a moment in history'.[20] Regardless of which view is correct, there are two critical points to consider. First, there is an emerging consensus that greater adoption of UAS is inevitable (a trend illustrated by military historian Ben Connable).[21] Second, when analysing sovereign production challenges, it is clear that China has been able to use its advantages in the mass production of UAS to become a critical actor in the Ukraine conflict.[22] These points, therefore, lead to the following questions: will Western powers be able to replicate Ukraine's model of combining precision and mass, and can they do so at a low cost?

19. *Kyiv Security Forum,* 'Ex-CIA Director Petraeus: Ukrainian UAVs are Lethal and the Future of Any Warfare', 4:00, YouTube, 2 June 2025, <https://www.youtube.com/watch?v=bl_RDLsve58>, accessed 23 July 2025.
20. Rudy Ruitenberg, 'Small Drones Will Soon Lose Combat Advantage, French Army Chief Says', *Defense News,* 19 June 2024, <https://www.defensenews.com/global/europe/2024/06/19/small-drones-will-soon-lose-combat-advantage-french-army-chief-says/>, accessed 23 July 2025.
21. Ben Connable, *Ground Combat: Puncturing the Myths of Modern War* (Washington, DC: Georgetown University Press, 2025), p. 239.
22. Samuel Bendett, 'Warfare Rewritten: From DIY Drones to State-Scale Swarms', *Drone Wars* podcast, 10:15, 9 July 2025. , <https://www.youtube.com/shorts/kkJYp5N199g>, accessed 7 November 2025

Opportunities and Challenges of Replicating Ukraine's Drone Model

Sceptics of the 'commercial off-the-shelf' (COTS) revolution often suggest it may only be specific to the war in Ukraine, because the Ukrainian air force has been largely suppressed, athough the Russians have also struggled to achieve air dominance – thereby creating a mutual need for mass drone use.[23] Opposing ground forces rely on drone systems in times of shortages of artillery or anti-tank guided missiles (ATGM), or when lacking close air support; however, drones are currently not a substitute for conventional fires.[24] Drone sceptics often concede that tactical drones are 'powerful additions' to combined arms, or that despite the challenges facing drones, FPV sorties typically see a 30% success rate.[25] Evidence suggests that this is contingent on a number of factors, including proper tactics, techniques, procedures, favourable weather and operator training.[26] Poor operator training can result in a far lower success rate. Either way, a consensus is emerging that MUAS at lower echelons are vital for enabling what is sometimes called 'the transparent battlefield'.[27]

Other observers argue that dronisation indeed constitutes a broader military revolution, which provides cheap precision and materiel mass, shortens kill chains at the lowest level, forces heavy dispersal of forces, rapidly punishes attempts to concentrate and warrants entirely new force designs.[28] This revolutionary perspective, which is shared by the US Department of Defense (DoD), suggests that COTS models may play a strong role in mass drone adoption.

From the perspective of the US, the mass adoption of MUAS is envisioned in the context of how Taiwan could defend itself against China. Bob Work, a former US deputy secretary of defense, proposed that a 'hellscape' of uncrewed systems – involving a vast number of drones – in the Taiwan Strait could help to hinder a Chinese

23. Stacie Pettyjohn, 'Evolution Not Revolution: Drone Warfare in Russia's 2022 Invasion of Ukraine', Center for New American Security, 8 February 2024, <https://www.cnas.org/publications/reports/evolution-not-revolution>, accessed 23 July 2025.
24. Bill Murray, 'Beyond the Hype: Why Drones Cannot Replace Artillery', *Small Wars Journal*, 5 May 2025, <https://smallwarsjournal.com/2025/05/05/beyond-the-hype-why-drones-cannot-replace-artillery/>, accessed 23 July 2025; Oleksandra Molloy, 'Drones in Modern Warfare: Lessons Learnt from the War in Ukraine', *Australian Army Occasional Paper* (No. 29, October 2024), <https://atos-eu.org/2024/10/29/drones-in-modern-warfare-lessons-learnt-from-the-war-in-ukraine/>, accessed 23 July 2025.
25. Murray, 'Beyond the Hype'; Jakub Jajcay, 'I Fought in Ukraine and Here's Why FPV Drones Kind of Suck', *War on the Rocks*, 26 June 2025, <https://warontherocks.com/2025/06/i-fought-in-ukraine-and-heres-why-fpv-drones-kind-of-suck/>, accessed 23 July 2025.
26. Author interview with a drone company executive, London, 27 May 2025.
27. Michael Posey and Chase Metcalf, 'Deception on the Transparent Battlefield', *Small Wars Journal,* 9 November 2025, <https://smallwarsjournal.com/2025/09/11/deception-on-the-transparent-battlefield/>, accessed 14 October 2025.
28. Vincent Tourret, *Design, Destroy, Dominate. The Mass Drone Warfare as a Potential Military Revolution*, IFRI Papers (Paris: Institut français des relations internationales, 2025).

invasion.[29] China, meanwhile, appears to have bolder ambitions and has reportedly ordered one million MUAS by 2026.[30]

Even before Russia's full-scale invasion, the war in Donbas heralded China's first-mover advantage in the drone 'startup' culture. Drones were used on both sides of the conflict and MUAS were used in several different ways.[31] In fact, three years after Russia's annexation of Crimea, Ukraine had deployed large R18 octocopters (costing $20,000) – also known as bomber drones – and modified them to drop RKG-1600 anti-tank grenades. Bomber drone designs are closely based on agriculture drones sold by Ukrainian companies such as Reactive Drone, which also sold Chinese components.[32] These bomber drones include powerful motors and electronic speed controllers from a Shenzhen-based supplier, ruggedised for outdoor use in farming.[33] Ukraine's largely modular drone construction preferences, which predated the 2022 invasion, closely followed Chinese drone industry trends, which featured 90-day design cycles and user-generated feedback.[34]

In turn, Russia's full-scale invasion of Ukraine in 2022 rapidly accelerated what US Futures Command head General James E Rainey called, during the 2025 Kermit Roosevelt lecture at RUSI, a 'spin cycle' of tactical change.[35] According to the Ukrainian

29. John Grady, '"Hellscape" Swarms Could be a Cost-Effective Taiwan Defense, Says Report', *USNI News*, 1 July 2024, <https://news.usni.org/2024/07/01/hellscape-swarms-could-be-as-cost-effective-taiwan-defense-says-report>, accessed 23 July 2025.
30. Dylan Malyasov, 'China Places Massive Order for Kamikaze Drones', *Defence Blog*, 22 December 2024, <https://defence-blog.com/china-places-massive-order-for-kamikaze-drones/>, accessed 23 July 2025.
31. Dada Lyndell and Andrey Zayakin, 'Skolkovo DIY: How Russia Manufactures FPV Drones to Kill Ukrainians', *The Insider*, 9 April 2024, <https://theins.ru/en/society/270648>, accessed 23 July 2025. As early as 2015, the Ukrainian defence tech firm Aerorozvidka described the use of encrypted video transmission and radio frequency direction-finding tactics to kill drone operators. See Patrick Tucker, 'Ukraine's Drone Warriors', *Atlantic Council*, 10 March 2025, <https://www.atlanticcouncil.org/blogs/natosource/ukraine-s-drone-warriors/>, accessed 23 July 2025.
32. Anastasia Boychenko, « «Нехай гине залізо, а не наші люди». Як українська Аеророзвідка перемагає окупантів у «війні дронів» » ['"Let the Iron Perish, not Our People." How Ukrainian Air Intelligence is Defeating the Occupiers in the "Drone War"'], *ШоТам* 22 June 2022, <https://shotam.info/nekhay-hyne-zalizo-a-ne-nashi-liudy-yak-ukrainska-aerorozvidka-peremahaie-okupantiv-u-viyni-droniv/>, accessed 23 July 2025; Reactive Drone, « Запчасти для дронов » ['Drone Parts'], <https://reactivedrone.eu/product-category/zapchasti-dlya-dronov/>, accessed 23 July 2025.
33. The Hobbywing motors, identifiable by a distinctive X branding followed by the numbered version, are widely used on bomber and heavy-lift drones, designed for agricultural use in wet weather conditions and used by both sides in the Russo-Ukrainian War. For motors on display, see *Regnum News Agency*, 'Putin Inspected Drone Prototypes at the STC Site in St. Petersburg', 9 September 2024, <https://regnum.ru/news/3917195>, accessed 24 October 2025; Sofiia Syngaivska, 'Russia Introduces the Buran Drone, a Versatile Aerial Platform Designed for Cargo, Reconnaissance, and Attack Missions', *Defence Express*, 28 September 2024, <https://en.defence-ua.com/weapon_and_tech/russia_introduces_the_buran_drone_a_versatile_aerial_platform_designed_for_cargo_reconnaissance_and_attack_missions-12008.html>, accessed 24 October 2025.
34. Harry McNabb, 'Eight Reasons Why Chinese Drone Manufacturers are Dominating the Industry', 30 September 2016, <https://dronelife.com/2016/09/30/eight-reasons-chinese-drone-manufacturers-dominating-industry/>, accessed 30 July 2025.
35. James E Rainey, 'Recording: Kermit Roosevelt Lecture: The Future of Conflict and US Army Modernisation', RUSI, 2 May 2025, <https://www.rusi.org/members-event-recordings/recording-kermit-roosevelt-lecture-future-conflict-and-us-army-modernisation>, accessed 10 October 2025.

NGO Come Back Alive, Ukraine's forces deployed 'thousands' of Chinese DJI Mavic drones on the Kyiv axis, while numerically limited Russian drone reconnaissance focused on deep strikes for the country's struggling air campaign, or supported localised artillery bombardment.[36] Ukraine's rapid adoption of MUAS subsequently gave its forces greater flexibility in targeting, albeit at shorter ranges than Russia's reconnaissance-strike complex (RCS). Mavic quadcopters are accessible to users and optimised for hovering. They allow light formations to disrupt armoured columns by using integrated munitions in 3D-printed housing and by dropping equipment or directing artillery.[37] During the response to the initial invasion, Mavics dropped grenades on formations lacking point defences, which were often unaware they were under attack until after they had been struck. Ukrainian bomber drones attacked Russian armour at night, using mid-range thermal cameras, [38] such as during the battle for Hostomel Airport.

Chinese DJI Phantoms, Mavics and Matrice drones came with proprietary software for flight control and reached Ukraine (despite a stated Chinese ban on DJI exporting MUAS to the war in Ukraine). Ukrainian government procurement of DJI drones – alongside Ukraine's famous civilian and military drone procurement networks – was relatively small, constituting only 2,372 units in one announced purchase from March 2022.[39] Ukrainian officials explained that export restrictions on some Western drones (US International Traffic in Arms Regulations[40]) complicated Ukrainian procurement, thereby cementing China's importance in the supply chain. Yet, there were signs that Ukraine was also struggling in the face of Chinese export restrictions. One Ukrainian drone operator described how, in late 2022, the country's procurement of Chinese drones via a third country was intercepted, resulting in an unsuccessful bidding war with the suppliers and the Russians.[41]

36. *Militarnyi*, « Дрони зроблені в Україні: розвідники, бомбери та далекобійні камікадзе » ['Drones Made in Ukraine: Reconnaissance, Bombers and Long-Range Kamikazes'], 3 January 2024, <https://militarnyi.com/uk/articles/drony-zrobleni-v-ukrayini-rozvidnyky-bombery-ta-dalekobijni-kamikadze/>, accessed 23 July 2025.
37. Julian Borger, 'The Drone Operators Who Halted Russian Armoured Vehicles Heading for Kyiv', *The Guardian*, 28 March 2025.
38. David Hambling, 'Every. Single. Drone. Fighting in Russia's War Against Ukraine', *Popular Mechanics*, 23 June 2022, <https://www.popularmechanics.com/military/a40298287/drone-fighting-ukraine-war-russia/>, accessed 15 October 2025.
39. Haye Kesteloo, 'Ukraine Buys Thousands of DJI Drones to Help Fight Off Russians', DroneXL, 1 April 2022, <https://dronexl.co/2022/04/01/ukraine-buys-thousands-of-dji-drones/>, accessed 23 July 2025.
40. US Department of State, Directorate of Defense Trade Controls, 'The International Traffic in Arms Regulations (ITAR)', <https://www.pmddtc.state.gov/ddtc_public?id=ddtc_kb_article_page&sys_id=24d528fddbfc930044f9ff621f961987>, accessed 15 October 2025.
41. Author interview with a Ukrainian drone specialist, London, 2 April 2025.

Ukraine was, however, increasingly aware of the risk of its dependency on China. For example, Russia could exploit a device called AeroScope, which revealed the location of operators using a 'remote ID' function.[42] DJI claimed this could not be disabled, but the Ukrainians eventually bypassed Aeroscope's data transmission with a firmware modification to their drones, which was a tactic also used by the Russians.[43] As a result, the evolution of MUAS increasingly expanded into a software-defined struggle as well as a hardware one. As early as March 2022, DJI users complained of a 'stealth' firmware update that blocked attempts to undo automatic software updates, which soon became a trend in the conflict.[44] Meanwhile, open-source software ExpressLRS, which optimises radio links at a long range, was modified by the Ukrainians to support a wider range of frequency bands to limit electronic warfare (EW), enhancing the functionality of DJI drones for combat use.[45] DJI firmware, by one account, was then modified 40 times in two years of war.[46] By the summer of 2022, DJI drones were navigating by pre-programmed waypoints to mitigate the impact of EW signal jamming and were regularly reprogrammed by both sides – mainly to override factory settings, such as altitude restrictions, for the civilian market.[47] Lacking alternatives, Ukraine was forced to adapt Chinese MUAS equipment to ensure the safety of its frontline forces.

Starting in 2022, Ukraine also received small numbers of US Teal Golden Eagle quadcopters, including models of the first Blue List drone (15 units of this drone in April 2022, and a shipment of another 200 one year later) and similarly small numbers of the Skydio X2 model in September 2022.[48] Unlike their Chinese counterparts, these drones were all ruggedised to DoD military specifications, or Mil Spec standards, which are benchmarks for shock proofing and resistance against temperature extremes and water ingress. The drones also came with strongly encrypted

42. DJI Enterprise, 'DJI AeroScope Enables Remote ID in an Unmanned Traffic Management System', <https://enterprise.dji.com/news/detail/aeroscope-enables-remote-id-in-utm-system>, accessed 15 October 2025.
43. Jeffrey A Edmonds and Samuel Bendett, 'Russia's Use of Uncrewed Systems in Ukraine', CNA, 15 March 2023, <https://www.cna.org/analyses/2023/05/russias-use-of-drones-in-ukraine>, accessed 23 July 2025.
44. Sean Hickey, 'DJI are Forcing Updates to Prevent Third Party Apps?', *Geeksvana*, podcast, 22 March 2022, <https://www.youtube.com/watch?v=OQe0hsexx_s>, accessed 23 October 2025.
45. *SUAS News*, 'Beware of This DJI FPV Update', 1 March 2022, <https://www.suasnews.com/2022/03/beware-of-this-dji-fpv-update/>, accessed 23 July 2025; ExpressLRS also manufacture modules to make MUAS compatible with the software. See Juan Chulilla, 'Ukraine is the First Hackers' War', *IEEE Spectrum*, 10 April 2024, <https://spectrum.ieee.org/ukraine-hackers-war>, accessed 23 July 2025.
46. David Hambling, 'British Software Will Protect Ukrainian Drones from Cyber Attack', *Forbes*, 20 March 2025, <https://www.forbes.com/sites/davidhambling/2025/03/20/british-software-will-protect-ukrainian-drones-from-cyber-attack/>, accessed 23 July 2025.
47. David Hambling, 'DJI Consumer Drones are Still Russian Soldiers' Favourite', *Forbes*, 10 March 2025, <https://www.forbes.com/sites/davidhambling/2025/03/10/dji-consumer-drones-are-still-russian-soldiers-favorite/>, accessed 23 July 2025.
48. Hambling. 'Every. Single. Drone. Fighting in Russia's War Against Ukraine'.

communication links and AI-assisted navigation.[49] These NDAA-compliant drones had quality sensors: the Golden Eagle was equipped with a high-resolution (640 x 512) thermal camera, yet it came at a high price ($14,800 each, including the controller, in 2022).[50] By comparison, the DJI Mavic 3T had a thermal sensor of the same resolution (albeit with lower sensitivity), for a unit cost of around $5,000 in 2022, which included the controller. Both drones were capable of around 30 minutes' flight and obstacle avoidance.[51]

Ukraine's adoption of Chinese drones and components led to a user-developer ecosystem around China-origin MUAS, which probably contributed to a user bias among some Ukrainians – a notion later backed by Skydio CEO, Adam Bry – that US MUAS 'don't perform as well',[52] combined with anecdotal evidence of US systems having a high failure rate and low accessibility.[53]

This perception was reinforced by the failure of some Western firms to work closely with Ukrainian operators. Western firms thereby missed out on rapid tactical evolution which was needed immediately, but which could take months to arrive from suppliers abroad: from quick software updates to hardware changes (such as a new antenna supporting different frequency bands).[54] In an interview, the drone expert David Kovar

49. Redcat Holdings, 'Teal Drones Secures Purchase Order for Golden Eagle Drone Units from NATO Member Country for Deployment in Ukraine', press release, 4 April 2022, <https://ir.redcatholdings.com/news-events/press-releases/detail/57/teal-drones-secures-purchase-order-for-golden-eagle-drone-units-from-nato-member-country-for-deployment-in-ukraine>, accessed 23 July 2025; Drone Nerds, 'Rugged, Agile, American Made – The Teal Golden Eagle', 14 October 2022, <https://enterprise.dronenerds.com/blog/government/rugged-agile-american-made-the-teal-golden-eagle/>, accessed 23 July 2025; Hambling, 'Every. Single. Drone. Fighting in Russia's War Against Ukraine'.
50. Ripping It Outdoors, 'Teal Golden Eagle Thermal Quadcopter Drone Bundle with Teal Air Control (TAC)', 1 December 2022, <https://rippingitoutdoors.com/products/teal-golden-eagle-quadcopter-drone-bundle-with-teal-air-control-tac>, accessed 23 July 2025.
51. For an explanation of thermal camera sensitivity, see Dan Walker, 'Comparing the Sensitivity of Thermal Imaging Camera Modules', *Tech Briefs*, 13 November 2023, <https://www.techbriefs.com/component/content/article/49385-comparing-sensitivity-of-thermal-imaging-cameras-modules>, accessed 23 July 2025; DJI, 'The New DJI Mavic 3 Enterprise Series Sets Ultimate Standard for Portable Commercial Drones', 27 September 2022, <https://www.dji.com/newsroom/news/the-new-dji-mavic-3-enterprise-series-sets-ultimate-standard-for-portable-commercial-drones>, accessed 23 July 2025; Malek Murison, 'Comparing DJI's Thermal and Night Vision Drones', DJI, 27 June 2022, <https://enterprise-insights.dji.com/blog/dji-thermal-night-vision-drones-comparison-side-by-side>, accessed 23 July 2025.
52. Liza Brovko, 'WSJ: In War, American Drones have Proven to be Expensive and Unreliable. So Ukraine Buys Chinese Ones', *Babel UA*, 10 April 2024, <https://babel.ua/en/news/105887-wsj-in-war-american-drones-have-proven-to-be-expensive-and-unreliable-so-ukraine-buys-chinese-ones >, accessed 23 July 2025.
53. Author interview with an MUAS consultant, London, 27 May 2025. This was not always the case – in an article from August 2022, one Ukrainian operator praised Skydio's autonomous navigation. See АрміяInform, « «Війна дронів»: про ефективність застосування БПЛА на полі бою » ["'Drone War": On the Effectiveness of Using UAVs on the Battlefield'], 4 August 2022, <https://armyinform.com.ua/2022/08/04/vijna-droniv-pro-efektyvnist-zastosuvannya-bpla-na-poli-boyu/>, accessed 23 July 2025.
54. *Silicon Curtain*, 'We're Not Ready for the Revolution in Drone Warfare', YouTube, 8 July 2025, <https://www.youtube.com/watch?v=u6y-vGZ8oWc&t=1142s>, accessed 23 July 2025.

characterised US and Western firms' failure to work closely with Ukrainians early in the conflict as a 'missed opportunity' for the US to trial and iterate development of MUAS.[55]

As Chinese MUAS gained ubiquity, Russia revised its tactics. By late 2022, Russia increasingly used Chinese DJI systems alongside its attempts at domestic production. In October 2022, Russia's Almaz-Antey announced production of the Dobrynya FPV, a racing drone widely believed to be based on China's Nazgul Evoque F5, with additional waterproofing.[56] While Almaz-Antey rebranded the UAS itself, it made no effort to change brand markings on the ground control station. These markings indicated that the station was a TX12 made by Shenzhen-based Radiomaster, which is a device commonly used by both sides of the conflict.[57] Such adaptations became a trend, with Russia notably attempting to localise production of the Autel EVO Max 4T drone starting in 2023, which Autel touts as having AI target recognition and EW resistance.[58]

By the time of the Russian offensive in Donbas in the summer of 2022, the Russians were praising increased MUAS adoption because it compressed their targeting cycles and multiplied the accuracy of artillery. Artillery remained their most lethal capability, accounting for around 70% of Ukrainian casualties until at least August 2023.[59] Russia purchased drones and components directly from China and also drones from third parties, a supply chain that the US tried to break. As a result, in April 2023, the US Treasury sanctioned Aeromotus, a UAE-based reseller of DJI products to Russian importers, which, according to the Office of Foreign Assets Control, had been assisting Moscow 'since the beginning of Russia's war in Ukraine'.[60] Nevertheless, as a consequence of this mostly non-constricted supply chain, some Russian units had a large enough number of DJI products to be able to expend cheaper DJI Mini drones in

55. Author interview with drone expert David Kovar, London, 26 April 2025.
56. Parth Satam, 'Russia's "Chinese Copy" Drone for Basic Battlefield Roles in Ukraine War Slammed for Lacking Ingenuity', *Eurasian Times*, 9 December 2022, <https://www.eurasiantimes.com/russias-chinese-copy-drone-for-basic-battlefield-roles-in-ukraine-war/>, accessed 23 October 2025.
57. Focus.UA, « В России обещают поставить военным тысячи « сказочных » дронов: как они помогут солдатам » ['Russia Promises to Supply the Military with Thousands of "Fairytale" Drones: How They Will Help Soldiers'], 25 November 2022, <https://focus.ua/digital/538432-v-rossii-obeshchayut-postavit-voennym-tysyachi-skazochnyh-dronov-kak-oni-pomogut-soldatam>, accessed 23 July 2025. Astracom, another Russian firm, used this tactic again in February 2023, marketing its Patriot K30T as domestically produced, yet experts assess it was probably a copy of Autel's EVO II Pro V3 model. For further information on vendor information for the Dobrinya, which comes with the TX12, see Dobrynya, 'Dobrynya UAV', <https://dobrinya.goz.ru/>, accessed 23 October 2025.
58. Alberto Nardelli, 'Russian Drone Documents Draw Line from China to Ukraine's Skies', *Bloomberg*, 8 July 2025, <https://www.bloomberg.com/news/articles/2025-07-08/china-s-suppliers-key-for-russian-drones-in-war-against-ukraine-documents-show>, accessed 23 July 2025.
59. Isabelle Khurshudyan, Mary Ilyushina and Kostiantyn Khudov, 'Russia and Ukraine are Fighting the First Full-Scale Drone War', *Washington Post*, 2 December 2022; Aaron Epstein et al., 'Putting Medical Boots on the Ground: Lessons from Ukraine and Applications for Future Conflict with Near-Peer Adversaries', *Journal of the American College of Surgeons* (Vol. 237, No. 2, August 2023), pp. 364–73.
60. Haye Kesteloo, 'DJI Reseller Aeromotus in Dubai Targeted with OFAC Sanctions', *Drone XL*, 17 April 2023, <https://dronexl.co/2023/04/17/dji-reseller-aeromotus-ofac-sanctions/>, accessed 23 July 2025.

their efforts to probe enemy EW.[61] Meanwhile, Ukraine continued to build networks of third-party resellers; in October 2023, Ukrainian Prime Minister Denys Shmyhal claimed his country was purchasing 60% of DJI's production.[62]

As both sides experienced an erratic artillery ammunition supply and changing artillery combat readiness throughout 2023 – in addition to high losses of the systems – MUAS took on greater importance.[63] FPVs drove a fundamental tactical shift. Ukraine initially used them to fly munitions into vulnerable points on armoured vehicles, artillery systems, bunkers, communications, EW and engineering equipment, and soft-skinned vehicles and personnel. Soon, they were holding enemy troop and vehicle concentrations at risk anywhere from 5 to 20 km from the forward line of troops. Longer (more than 40 km) ranges were enabled by radio relays, and in 2023, Ukraine assembled around 600,000 FPVs.[64]

By November 2023, Russia was reportedly operating FPVs equipped with thermal cameras, and using what the Ukrainian drone expert Serhii 'Flash' Beskrestnov identified as being starlight cameras – amplifying visible light from the moon or stars, rather than infrared light.[65] The Night Eagle 3 model that Russia used was made by the Hong Kong-based manufacturer Runcam. In turn, a race had begun to obtain disposable, night-capable FPVs, which was previously unthinkable due to the high cost of thermal cameras with resolution adequate for conducting night attacks.[66]

A subsequent deluge of Chinese components on to the market for drones saw FPVs become cheaper than unguided artillery shells. Costs were less than $500 for some FPVs, or several thousands of dollars for larger reconnaissance and bomber drones. One should note, however, that prices of both shells and drones have fluctuated considerably: FPV production costs often do not include labour, ground control, goggle prices and/or explosive payload. In addition, numerous observers often fail to appreciate how many drones are lost to EW, accidents, inclement weather or operator

61. Edmonds and Bendett, 'Russia's Use of Uncrewed Systems in Ukraine'.
62. Elisabeth Gosselin-Malo, 'Ukraine Continues to Snap Up Chinese Drones for its Defence', C4ISRNET, 23 October 2023, <https://www.c4isrnet.com/global/europe/2023/10/23/ukraine-continues-to-snap-up-chinese-dji-drones-for-its-defense/>, accessed 24 July 2025.
63. Russia had reported artillery shortages in early 2023; by September 2023, Moscow began efforts to secure additional ammunition from North Korea. See Natasha Bertrand, Oren Liebermann and Alex Marquardt, 'Russian Artillery Fire Down Nearly 75%, US Officials Say, in Latest Sign of Struggles for Moscow', *CNN*, 10 January 2023, <https://edition.cnn.com/2023/01/10/politics/russian-artillery-fire-down-75-percent-ukraine/index.html>, accessed 23 July 2025; *BBC News*, 'Ukraine War: Shell Shortages Force Us to Limit Firing, Ukrainian Troops Tell BBC', 14 December 2023.
64. Mariam Halstian, 'A First Point View: Examining Ukraine's Drone Industry', *Georgetown Security Studies Review*, 15 May 2025, <https://gssr.georgetown.edu/the-forum/regions/eurasia/a-first-point-view-examining-ukraines-drone-industry/>, accessed 24 July 2025.
65. Oleksandr Yan, 'New Threat: FPV Drones Adapt for Night-Time Operations', *Militarnyi*, 24 November 2023, <https://militarnyi.com/en/articles/new-threat-fpv-drones-adapt-for-night-time-operations/>, accessed 23 July 2025.
66. Julia Struck, 'Russia's Night Drones Pose a Serious New Threat to Ukraine's Troops', *Kyiv Post*, 14 December 2023, <https://www.kyivpost.com/post/25459>, accessed 24 July 2025.

failure.[67] Moreover, the estimate that over 10 FPVs are typically required to destroy a tank could be increasing, partially due to up-armoured vehicles sometimes requiring scores of hits to destroy them – although in such instances, vehicles are armoured to the point of losing visibility and mobility.[68]

In June 2024, China publicly reasserted export bans of drone technology for military use and did so again in December of that year. However, its export data still skews heavily in favour of Russia. There had been reports of drone components spiking three times in price by early 2024, underlining the competition which both sides faced in obtaining parts.[69] Nevertheless, direct drone shipments from China to Russia were valued at $14.5 million in the first six months of 2024, which was 72 times the value of direct procurement from China by Kyiv, and there were reports of Chinese companies restricting exports to Ukraine under pressure from Chinese authorities.[70] Yet, what really drove MUAS trends in the conflict was the sourcing of components for adaptable modular drones rather than the purchase of complete systems – a question which has had significant implications for NATO drone employment.

67. Andrew Dunn-Lobban, 'Cheap Drones and Mass Precision: The Tactical Relevance of the Australian Army in Modern Combined Arms', *The Cove*, 1 October 2025, <https://cove.army.gov.au/article/cheap-drones-and-mass-precision-tactical-relevance-australian-army-modern-combined-arms>, accessed 10 November 2025; Jon-Wyatt Matlack, Sebastian Schwartz and Oliver Gill, 'Ukraine's Drone Ecosystem and the Defence of Europe: Lessons Lost Can't be Learned', LSE Ideas, April 2025, <https://www.lse.ac.uk/ideas/publications/Research-Reports/Ukraine's-Drone-Ecosystem-and-the-Defence-of-Europe-Lessons-Lost-Can't-be-Learned>, accessed 24 July 2025; Jack Watling and Nick Reynolds, 'Tactical Developments During the Third Year of the Russo–Ukrainian War', RUSI, February 2025, <https://www.rusi.org/explore-our-research/publications/special-resources/tactical-developments-during-third-year-russo-ukrainian-war>, accessed 24 July 2025.
68. Dev.UA, '"These are No Longer Barns, but Entire Bunkers". Ukrainian Military Showed a Russian "Monster Tank" that Took 60 FPV Drones to Neutralize', 10 July 2025, <https://dev.ua/en/news/lytsari-zdolaly-chudovysko-1752157950>, accessed 24 July 2025.
69. David Hambling, 'Ukraine Makes Drone Flight Controllers, Breaking Free of China', *Forbes*, 15 February 2024, <https://www.forbes.com/sites/davidhambling/2024/02/15/ukraine-makes-drone-flight-controllers-breaking-free-of-china/>, accessed 24 July 2025.
70. Paul Mozur and Valerie Hopkins, 'Ukraine's War of Drones Runs into an Obstacle: China', *New York Times*, 30 September 2023. In early 2024, Ukraine was still announcing small procurements of Chinese drones, including 4,200 DJI Mavic 3E announced on 21 May, but this has been an increasingly rare occurrence. See Richard Thomas, 'Ukraine Buys Another 4,200 DJI Mavic Drones', *Army Technology*, 28 May 2024, <https://www.army-technology.com/news/ukraine-buys-another-4200-dji-mavic-drones/>, accessed 24 July 2025.

A Revolution in Flexible Design

Modularity and Tactical Adaptation in Drone Design

Alongside increased FPV procurements by both sides, the use of larger MUAS, bomber-style drones – interchangeably employed for reconnaissance, target acquisition and bombing with modified grenades or modified anti-tank guided missiles – has continued. This wide array of use cases illustrates the importance of construction, which is often described as a modular over rigid system design. Modularity, for example, allows a drone frame to be modified for radio relay or repeater functions. Such modifications to extend radio transmission ranges can, as a result, also extend an FPV's strike ranges. Drones used for bombing can be fitted with high-resolution sensors to direct FPV operators to optimum targets or can be modified to act as motherships, or headquarters, for FPVs.[71] In the case of heavy-lift drones, highly modular design is found in civilian applications, such as the DJI F100 agricultural drone, which can be rapidly adapted for sensing or carrying different agricultural loads.[72]

Following a trend of adopting Ukrainian tactics, Russia built rapidly adaptable bomber drones of its own, some of which were displayed at a September 2024 exhibition with X8 motors from the Shenzhen-based manufacturer Hobbylift.[73] Rapid adaptability through a changing component ecosystem feeds into an almost-constant tactical evolution on the battlefield. One such evolution is the fibre-optic drone, whose cable connects to the flight controller, cannot be jammed by EW and thus does not require a

71. Tyler Rogoway, 'Ukraine's Baba Yaga Drones Now Appear Capable of Launching Guided Munitions', *TWZ*, 2 August 2024, <https://www.twz.com/air/ukraines-baba-yaga-drones-now-appear-capable-of-launching-guided-munitions>, accessed 24 July 2025; Mariano Zafra, 'How Drone Combat in Ukraine is Changing Warfare', *Reuters*, 26 March 2024.
72. DJI, 'DJI Agras T100', <https://ag.dji.com/t100>, accessed 24 July 2025.
73. *URA.RU*, « Путин определил будущее беспилотников в России » ['Putin has Determined the Future of Drones in Russia'], 19 September 2024, <https://ura.news/articles/1036289795>, accessed 24 July 2025.

radio frequency (as that can be disrupted). Ukrainians seeking to procure fibre-optic cable from China for their FPVs have reported being outbid by Russian buyers – despite having already had their offer for the item accepted.[74] Competition for key material is likely to intensify: Ukraine and Russia both require brushless drone motors for dedicated drone interceptors, and the same design can power heavy-lift drones.

The net effect of China's monopoly on the supply of inexpensive components and complete systems has been to offer cost-effective precision and lethality on a large scale. The revolutionary aspect of flexible design endures, even when factoring in severe drone expenditure, such as in early July 2025, when 60 drones were reportedly used to destroy one Russian up-armoured tank fitted with a mine roller.[75] These drones from China still cost considerably less than an ATGM with non-line-of-sight (NLOS) capability, such as the $250,000 SPIKE NLOS.

Furthermore, there are indications that flexible modifications of MUAS will continue. AI-powered computer vision is increasingly used to conduct automated targeting, which is being deployed at increasing ranges (although such drones constitute a small percentage of systems in use, due to the complexity of computer vision training). The most powerful NVIDIA Single Board Computer (SBC) chips have now made this feature more accessible. MUAS with SBCs can support almost entirely inertial navigation (without GPS or reliance on radio links) which, aside from mitigating EW, also lowers the operator's training burden.[76] Some of the most widely produced AI-enabled flight controllers contain microcontrollers, which are described in the next chapter.

Expanding Roles and Applications of MUAS

The use of MUAS continues to expand, enabled by astonishing creativity of users and the flexibility of the component ecosystem. MUAS have been used for dropping supplies and cutting logistics kilometres from the frontline. Both sides in the Russo-Ukrainian war now widely use FPVs to intercept fixed-wing ISR drones, attacking kill chains and launching them from mothership Class 3 drones, such as the GOGOL-M, to extended ranges.[77] MUAS have notably been fitted with PVP-50 mines (analogous to the US Claymore mine) and have dropped thermite on treelines to burn out enemy forces.[78] They have also been fitted with thermobaric warheads and anti-tank warheads taken

74. *The Economist*, 'How New Drones are Sneaking Past Jammers on Ukraine's Front Lines', 5 May 2025.
75. The tank in question, attacked near Torets, was covered with a cage, chain mail and 'porcupine' rods. See Dev.UA, '"These are No Longer Barns, but Entire Bunkers"'.
76. Author interview with a drone company executive, London, 27 May 2025.
77. Taras Safronov, 'Attacking Enemy with FPV Drones, Ukraine Develops GOGOL-M Carrier-Drone', 30 May 2025, <https://militarnyi.com/en/news/attacking-enemy-with-fpv-drones-ukraine-develops-gogol-m-carrier-drone/>, accessed 24 July 2025.
78. Fermin Torrano, 'Inside the Drone Workshop Engineering Ukraine's Deadly Vampires', *The Telegraph*, 30 November 2024.

from ATGMs. MUAS have likewise been used to find minefields or to hunt other MUAS; they are sometimes fitted with shotguns and are particularly effective for hunting valuable bomber drones – by crashing into them, dropping nets on their propellers, or even striking them with sticks. Ukraine's Bulava FPV has been fitted with a grenade launcher and bomber drones on both sides have been fitted with RPG-18 launchers.[79] In other instances, FPVs have been launched from uncrewed boats with fibre-optic cable attachments to attack air defence systems on the shore, or have been adapted to use commercial cell networks – the most famous example being Operation *Spiderweb*, a Ukrainian special operation on 1 June 2025, which struck Russian strategic bombers.[80]

By late 2024, both Russian and Ukrainian official sources claimed that UAS account for over 70% of personnel and equipment losses on each side. As both sides move to rectify their own artillery deficiencies, it is conceivable that this trend could revert towards higher losses from artillery. However, considering the importance of MUAS in the RCS, it remains to be seen whether artillery will reclaim its dominant role.

In summary, Ukraine is widely seen as having mastered the flexible design and assembly of MUAS – its drones can be tailored to a vast array of tactical situations. In this regard, Russia copied Ukraine. The extent to which NATO wishes to follow this model will have strong implications for NATO security in its MUAS supply chains.

79. Parth Satam, 'Drone-on-Drone War Ensues as Ukrainian UAV with Wooden Stick Tries Disabling Russian ZALA Drone', *The Aviationist*, 7 August 2024, <https://theaviationist.com/2024/08/07/drone-on-drone-war-ukraine/>, accessed 24 July 2025; Yuri Zoria, 'Ukrainian FPV with Onboard Grenade Launcher Makes its First Confirmed Kill (Video)', *Euromaidan Press*, 14 May 2025, <https://euromaidanpress.com/2025/05/14/ukrainian-fpv-with-onboard-grenade-launcher-makes-its-first-confirmed-kill-video/>, accessed 24 July 2025; Kapil Kajal, 'Ukraine Repurposes Quadcopter Drone to Fire Soviet-Era RPG-18 Anti-Tank Missiles', *Interesting Engineering*, 13 September 2024, <https://interestingengineering.com/military/ukraine-drone-anti-tank-missile>, accessed 24 July 2025.
80. Howard Altman, 'Ukraine's Uncrewed Surface Vehicles are Now Launching Bomber Drones to Attack Crimea', 3 July 2025, <https://www.twz.com/news-features/ukraines-uncrewed-surface-vessels-are-now-launching-bomber-drones-to-attack-crimea>, accessed 24 July 2025.

Critical Multirotor Drone Components

Semiconductors

According to an FPV manufacturer involved in Australia's Sovereign UAS Challenge, 'silicon [semiconductors are] one of the biggest challenges' to address in the supply chain.[81] For MUAS, critical hardware includes flight controllers (FCs): the brains of the drone**,** housing several silicon semiconductors. Because of the vulnerability presented by Chinese supply chain dominance, the numerous Ukrainian attempts to locally assemble FCs have struggled to expunge Chinese semiconductors and are likely to have involved processors fabricated in China, with a manufacturing origin spread across Europe and East Asia.[82]

FCs translate radio signals into commands for motors and calculate speed and heading from an array of inbuilt sensors and navigation aids, including gyroscopes, accelerometers and GPS receivers, while electronic speed controllers (ESCs) convert these signals into thrust for the motors. While FCs and ESCs are usually separate (although they are still connected in a stack and can be integrated), they were grouped for the purposes of this analysis as posing a semiconductor supply chain challenge.

Smarter FCs – as the brains of the drone – are rapidly leading to smarter systems. FCs, such as Auterion's Skynode range, also support AI-assisted navigation and LTE (mobile network) connectivity and are produced in Texas and Kyiv. While this is encouraging, only a small percentage of tactical drones used in the conflict have autonomous lock-on-target capability. This has not deterred AI development. Ukrainian firms such as Twist Robotics are working on the capability to autonomously target infantry, suggesting that the use of AI modules could surge. This does not, however, obviate the

81. Author interview with a drone company executive, London, 27 May 2025.
82. Catarina Buchatskiy and Ihor Fedirko, 'Building the Arsenal', Snake Island Institute, 10 October 2025, <https://www.snakeisland.org/reports/68e571b2a2c7854986bd7634>, accessed 23 October 2025.

need for other components, such as sensors that connect to the AI module, which are often sourced at a low cost from China.[83]

The Chinese firm SpeedyBee has dominated FC use in Ukraine, at least until Ukraine recently began assembling FCs domestically. Even then, some of these domestically assembled drones are simply analogues of SpeedyBee FCs (using similar chips), according to one vendor.[84] Yet, assessing the provenance of different parts is challenging: while some chips display markings of origin, many do not, and foundry information is often lacking on chip datasheets. A 2024 US Chamber of Commerce survey of 200 companies manufacturing circuit boards in the US reported that 44% of companies could not 'determine whether [or not] their products contained any chips manufactured by PRC-based foundries'.[85] This constitutes a significant consideration for any further study on semiconductor supply chain security.

There are also grey areas within critical component production. STMicroelectronics – a leading European manufacturer of processors described by one professional as 'industry standard',[86] and found in many NDAA-certified FCs, as well as those made by Chinese companies such as Foxeer – has recently expanded chip production in China, stating that the move is vital to keep costs competitive.[87] Widely used in many civilian applications, STMicroelectronics's STM32 processors are designed to support a large number of Universal Asynchronous Receiver/Transmitter (UART) ports, which enable connections to features such as GPS receivers.[88] China now benefits from localised production of this processor, while its ArteryTek AT32 MCU has emerged as a comparable competitor, further strengthening the country's domestic supply of this critical type of chip.[89] A further challenge to constructing FCs for FPVs while using non-Chinese components is the cost. In 2025, some NDAA-compliant controllers were priced at over $90, with a speed controller recommended for pairing with the device costing an additional $90, which outprices comparable Speedybee stacks distributed by a Ukrainian supplier for $70. One US FPV flight controller was available from a distributor for $160. (These comparisons are approximate due to price fluctuations.)

83. AuterionGS, 'AI Note for Skynode GX', <https://www.defenseadvancement.com/company/auterion-government-solutions/ai-node-for-skynode-gx/>, accessed 24 July 2025; Daniel Boffey, 'Killing Machines: How Russia and Ukraine's Race to Perfect Deadly Pilotless Drones Could Harm Us All', *The Guardian*, 25 June 2025.
84. FlyMod, 'Flight Control Stack VYRIY F405V2 50A', <https://flymod.net/en/item/fc_vyriy_stack_f405>, accessed 24 July 2025.
85. Bureau of Industry and Security, US Department of Commerce, 'BIS Publishes Assessment on the Use of Mature-Node Chips', 6 December 2024, <https://www.bis.gov/press-release/bis-publishes-assessment-use-mature-node-chips>, accessed 24 July 2025.
86. Author interview with industry professional, London, 23 May 2025.
87. SemiMedia, 'ST to Manufacture STM32 MCUs in China', 17 December 2024, <https://www.semimedia.cc/18168.html>, accessed 24 July 2025.
88. Kiwi Quads, 'F3 vs F4 vs F7 Flight Controllers – What's the Difference?', 17 May 2020, <https://kiwiquads.co.nz/f3-vs-f4-vs-f7-flight-controllers-whats-the-difference/>, accessed 24 July 2025.
89. Oscar Liang, 'Introducing AT32: Game-Changer for Affordable Flight Controllers and ESCs', 2 January 2024, <https://oscarliang.com/at32-flight-controllers/>, accessed 10 October 2025.

On the FC circuit board itself, there is one high performance laminate used in some FPV circuit boards because of its properties in supporting high-frequency transmission. The material is made by the US-headquartered Rogers Corporation, which has a strong manufacturing presence in China. This does not signify that NDAA-compliant components contain China-origin parts. Rather, it serves to highlight the extent of Western dependency on China's low-cost production. In a similar case, an NDAA-compliant transceiver that allows frequency-hopping for EW countermeasures is made by a US-headquartered company, which is partnered with a leading state-owned chip company in China, Fudan Microelectronics.[90]

Even Taiwan, the world leader in semiconductor fabrication, is not immune from the challenge of building an independent supply chain, largely due to the high domestic production costs involved. It does, however, have some core strengths in the field, such as the RP2040 processor. Taiwan's TSMC uses a 40-nanometre process for the chip, which can be integrated with the Raspberry Pi Pico microcontroller, which can in turn be integrated into FCs.[91]

These Taiwanese SBCs, fitted between a camera and an FC, can be used for machine vision, autonomous navigation and targeting. Conversely, China's Orange Pi SBC – often seen as a lower-cost alternative to Raspberry Pi systems – has also been seen on some Russian FPV drones to enable autonomous flight, thereby mitigating EW.[92]

90. For sources on US–China cooperation on specialised semiconductors that have dual uses, see Celine Lee, Andrew Kidd and Bruce Schneier, 'Reprogramming the Future: The Specialized Semiconductors Reshaping the Global Supply Chain', *Atlantic Council*, Issue Brief, 11 June 2025, <https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/reprogramming-the-future-the-specialized-semiconductors-reshaping-the-global-supply-chain/>, accessed 10 October 2025.
91. Note that the Pico is assembled in Inazawa, Japan. See Tim Hanewich, 'Taking Flight with the Raspberry Pi Pico & Micro Python: DIY Quadcopter Drone', 14 October 2023, <https://timhanewich.medium.com/taking-flight-with-the-raspberry-pi-pico-micropython-diy-quadcopter-drone-61ed4f7ee746>, accessed 24 July 2025.
92. Dmytro Sazonov, 'How to Build the Eyes of an Autopilot for FPV Combat Drone', *Illumination's Mirror*, 16 June 2025, <https://medium.com/illuminations-mirror/how-to-build-the-eyes-of-an-autopilot-for-fpv-combat-drone-bbf13d605a9f>, accessed 24 July 2025; Yuri Zoria, '"They Evolve": Ukraine Tests FPV Drone Featuring Target Detection, Lock-On, and Tracking System', *Euromaidan Press*, 21 April 2024, <https://euromaidanpress.com/2024/04/21/they-evolve-ukraine-tests-fpv-drone-featuring-target-detection-lock-on-and-tracking-system/>, accessed 24 July 2025.

The issues above serve to illustrate China's cost advantage, which is an enduring problem for the COTS model in semiconductors. This is especially relevant for mature chips, which use 40-nanometre processes commonly found in flight controllers. A mature semiconductor fabrication plant in Taiwan has 20% higher operating costs than a similar plant in China, due to lower labour costs and higher subsidies in China.[93] According to Taiwan's Institute for Democracy, Society and Emerging Technology, video transmission chips purchased by Taiwanese firms can cost up to 10 times more than those designed by DJI and made by Chinese suppliers.[94]

Motors

Brushless motors for FPVs were identified by an expert interviewed for this paper[95] as another critical supply chain challenge, because of China's dominance in permanent magnet production. Specifically, China is dominant in the production of neodymium. This rare earth metal has a strong holding force, which produces a powerful turning force in response to changes in the electric current, allowing for agile drone flight.[96] While China produces around 90% of global neodymium, non-Chinese supply is slowly increasing, with one expert suggesting that orders for drones could include a clause for non-Chinese magnets, but this would come 'at ten times the cost'.[97] A UK drone producer also identified securing the supply of non-Chinese motor magnets as another considerable challenge.[98] The production runs announced by Russian drone companies regularly tout Russian sovereign assembly, despite having the Chinese motor brands Brother Hobby or Hobby Flight visibly labelled on their motors. One interviewee singled out motors as an extremely fragile point in the supply chain.[99] Some experts interviewed for this paper, including one permanent magnet company representative,[100] believe that supply crunches and high prices for non-Chinese supply (including for REE) cannot be solved in the near term. This is due to the complex regulatory,

93. Bill Wiseman et al., 'Semiconductors Have a Big Opportunity—but Barriers to Scale Remain', McKinsey and Company, 21 April 2025, <https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductors-have-a-big-opportunity-but-barriers-to-scale-remain>, accessed 24 July 2025.
94. Hong-Lun Tiunn et al., 'Drones for Democracy: U.S.–Taiwan Cooperation in Building a Resilient and China-Free UAV Supply Chain', DSET, 16 June 2025, <https://dset.tw/en/research/drones-for-democracy-the-strategic-imperative-for-u-s-taiwan-uav-cooperation/>, accessed 24 July 2025.
95. Author interview with drone expert, Guildford, 6 May 2025.
96. Nayan Seth, 'Mind the Tech Gap: Why China's Rare Earth Dominance Persists', *New Security Beat*, 29 August 2024, <https://www.newsecuritybeat.org/2024/08/mine-the-tech-gap-why-chinas-rare-earth-dominance-persists/>, accessed 24 July 2025; IEF, 'What is Neodymium's Role in the Energy Transition?', 17 July 2024, <https://www.ief.org/news/what-is-neodymiums-role-in-the-energy-transition>, accessed 24 July 2025.
97. Author interview with Mike Dewhirst, Guildford, 6 May 2025.
98. Peter Felstead, 'Drone Evolution Looks to Bring Effective Sovereign UK Capability to FPV Market', 11 July 2025, <https://euro-sd.com/2025/07/major-news/45355/drone-evolution-fpv-solutions/>, accessed 23 July 2025.
99. Author interview with a senior executive UAS manufacturer, London, 27 May 2025.
100. Author interview with permanent magnet company representative, London, 10 September 2025.

technical and environmental challenges surrounding REE production.[101] Japan, which sources neodymium from Malaysia, was identified by one source as a neodymium iron boron (NdFeB) magnet supply option for MUAS, although the origin of the constituent metals was not cited.[102]

Because of the supply challenges surrounding REE, car manufacturing firms in the EU – which are dependent on permanent magnets – have stockpiled devices. Meanwhile, the EU itself is planning stockpiles of REEs for magnetisation. European production of rare earth permanent magnets is expected to reach 2,000 tonnes this year, mainly consisting of neodymium (although the initial orders will go towards the automotive industry).[103]

Producing the motors themselves is not challenging, with 3D printing of motor housing and hand assembly possible, even for dedicated hobbyists.[104] Indeed, the modularity of MUAS construction is highly accessible, but that can create a misconception about how simple it is to mass-produce MUAS. One expert noted that the overall challenge was in replicating quality at a high production volume, rivalling the way China's manufacturing is organised, automated and quality controlled. As Allan Evans, CEO of the drone company Unusual Machines, said in an interview:

> "It's a manufacturing at scale problem, and that is what the Chinese have spent 30 years getting better at, and there's expertise there – not necessarily in technology. If anybody can build their own motor, can they [also] build 10,000 motors that are all the same with a testing mechanism, in a way that has very low variation within standards, and meets a certain cost basis?[105]

Despite the challenge of achieving cost-efficient mass production, NDAA-compliant FPV motor manufacturers, such as Rotor Lab in Australia, have now entered the market to supply one US firm as of September 2025. Meanwhile, in the US, the REE magnet supplier Arnold Magnetics has developed an undisclosed supply chain for

101. Sara Hussein, 'Rare Earth Production Outside China "Major Milestone"', *Japan Times*, 23 May 2025, <https://www.japantimes.co.jp/business/2025/05/23/companies/australia-rare-earth-production-milestone/>, accessed 24 July 2025.
102. Author interview with a representative of company specialising in FPVs, London, 30 September 2025.
103. Sebastien Ash and Kana Inagaki, 'Europe's First Production Plant for Rare-Earth Magnets Opens', *Financial Times,* 19 September 2025; Jeanna Smialek, 'The French Seaside Factory Trying to Break China's Chokehold on Rare Earths', *New York Times,* 7 August 2025.
104. HomeMade Projects, 'How to Make a Brushless DC Motor | DIY BLDC Motor', YouTube, 12 May 2024, <https://www.youtube.com/watch?v=OZarwftUh8w>, accessed 24 July 2025.
105. Author interview with Unusual Machines CEO Allan Evans, London, 23 April 2025.

NDAA-compliant neodymium magnets.[106] Yet, as neodymium magnet production increases outside China, similar vulnerabilities to the electric vehicle market are likely to arise, due to the high demand for REE magnets across multiple sectors.[107]

In short, the demand for NdFeB magnets is likely to grow, not only in the civilian sector – which includes demand for electric vehicles, commercial aircraft and wind turbines – but in the defence sector as well, since they are used in missile guidance, flight control systems on aircraft and for some radars. Because of this sharp demand increase, NATO states are likely to face constraints, such as high price volatility, when choosing to invest in different capabilities, including MUAS. This is due to limited Western production and to China's options to limit exports of NdFeB magnets, which may, in the future, influence the extent to which Western users adopt MUAS, and drones in general.

Sensors and Gimbals

The exponentially rising use of MUAS in the Russo-Ukrainian war has been accompanied by rising demand for compact sensor technology. Drone camera production has been diversifying, with companies such as Sony increasingly providing purpose-built cameras to feature on NDAA-compliant drones.[108] This diversification is likewise seen in drone construction in Ukraine, where one interviewee described building drone cameras from Japanese components at a significantly higher cost than with Chinese parts (although they did not specify which company made the components).[109] This follows a trend where Ukraine has expanded from domestic to thermal camera assembly, minimising inputs by companies such as the Shenzhen-based Foxeer. For example, Ukraine's Kurbas-256 is domestically made and can be fitted to an FPV; however, its resolution is low, at 256 x 192 (a drawback that is mitigated by good sensitivity).[110]

106. *AInvest*, 'Unusual Machines Acquires Rotor Lab for $7M to Boost Drone Motor Production and US Manufacturing', 13 July 2025, <https://www.ainvest.com/news/unusual-machines-acquires-rotor-lab-7m-boost-drone-motor-production-manufacturing-2507/>, accessed 24 July 2025; Arnold Magnetics Technologies, 'Product: Neodymium Iron Boron Magnets', <https://www.arnoldmagnetics.com/products/neodymium-iron-boron-magnets/>, accessed 24 July 2025.
107. Christina Amann, Nick Carey and Kalea Hall, 'Auto Companies "in Full Panic" Over Rare-Earths Bottleneck', *Reuters*, 9 June 2025.
108. AUVSI, 'Unusual Machines Announces NDAA Compliant FPV Drone Camera', press release, 30 January 2025, <https://www.auvsi.org/news/unusual-machines-announces-ndaa-compliant-fpv-drone-camera/>, accessed 24 July 2025. Experts say that good-quality resolution and high pixel count for thermal imaging devices starts at a resolution of around 640 x 512. See Szymon Kamiński, 'Choosing a Thermal Imager – Type, Parameters (Chapter 1)', WMASG, 3 March 2023, <https://wmasg.com/en/articles/view/21504>, accessed 24 July 2025.
109. Author interview with drone industry consultant, London, 16 May 2025.
110. Odd Systems, 'Kurbas–256', <https://oddsystems.io/en/>, accessed 24 July 2025.

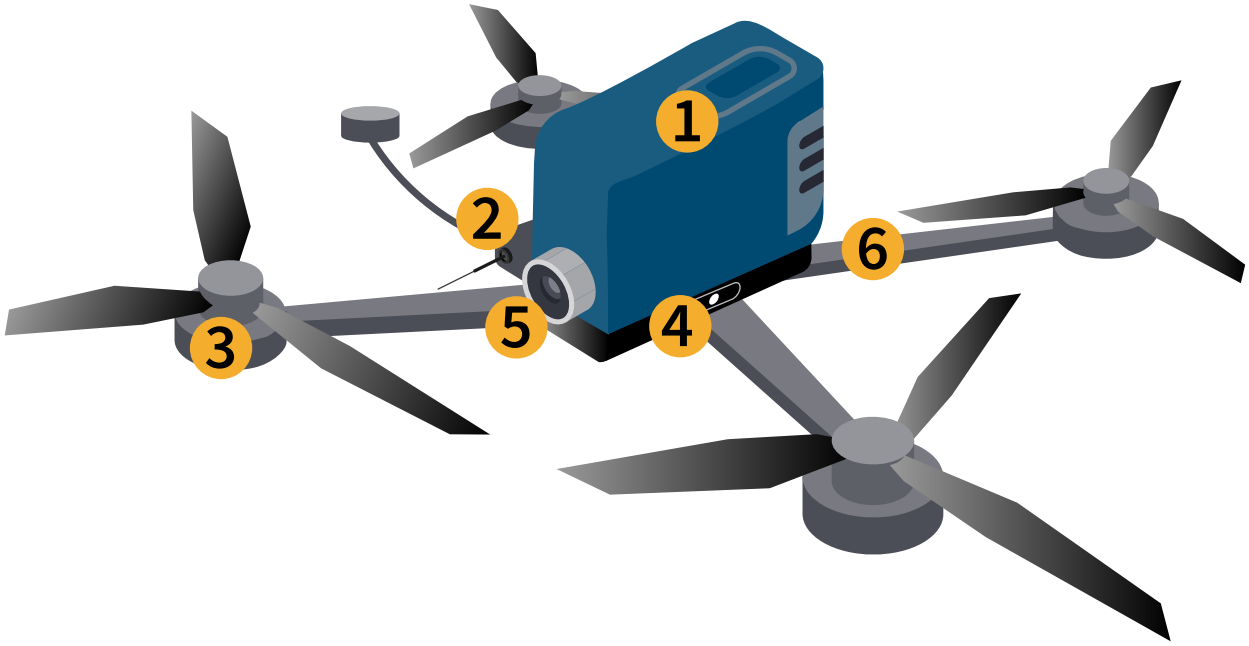
One drone producer and expert interviewed for this paper observed that 'you can buy a Chinese camera, or you can build your own, but it's multiple times the price to do so [to have] zero Chinese components'.[111] The Fat Shark Aura Analog FPV Camera, for example, incorporates complementary metal oxide sensors, which are made by Sony; Sony also supplies the NDAA-compliant Draganfly.[112] Sony is currently in the process of moving 90% of its camera production from China to Thailand.[113]

As with motors, however, China is able to leverage its dominance of germanium supply, a material which is used in lenses for infrared cameras. 'Most of those lenses are produced in China', one interviewee explained, 'and we were talking to a thermal camera manufacturer in North America who said they were having major issues getting hold of germanium because of the US–China trade war'.[114] Germanium is needed for higher-resolution thermal cameras made for military applications; because of the dependence on China, the US Defence Logistics Agency has invested in solutions to reduce the amount of germanium needed in thermal lenses.[115] South Korea also constructs infrared sensors for MUAS, but like the US, it is dependent on China for germanium.[116]

Drone cameras also rely on miniaturised, lightweight gimbal mounts, or devices that stabilise sensors during flight. The gimbal market was once dominated by DJI, and several interviewees identified gimbals as challenging to manufacture. However, the gimbal market is now seeing entrants such as Gremsy, a manufacturer headquartered in Ho Chi Minh City.[117] Taiwanese researchers have identified gimbal manufacturing, which requires high levels of precision, as one of their UAS supply chain strengths.[118]

111. Author interview with drone industry consultant, London, 16 May 2025.
112. Rotor Riot, 'Aura Analog FPV Camera – NDAA', <https://rotorriot.com/products/aura-analog-fpv-camera>, accessed 24 July 2025; Draganfly, 'Draganfly Unveils New NDAA Compliant "FlexForce" Modular FPV System Following US Military Demonstrations & Training', 7 May 2024, <https://draganfly.com/press-release/draganfly-unveils-new-ndaa-compliant-flexforce-modular-fpv-system-following-us-military-demonstrations-training/>, 24 July 2025.
113. Edwin Shri Bimo, 'More Japanese Companies Start Moving Production from China to Southeast Asia', *China Global South Project*, 5 December 2024, <https://chinaglobalsouth.com/2024/12/05/more-japanese-companies-start-moving-production-from-china-to-southeast-asia/>, accessed 24 July 2025.
114. Author interview with drone industry consultant, London, 6 May 2025.
115. Peter Fretty, 'Optics Industry Addresses the Germanium Issue', Laser Focus World, 25 July 2024, <https://www.laserfocusworld.com/optics/article/55127439/lightpath-technologies-inc-optics-industry-addresses-the-germanium-issue>, 24 July 2025.
116. Author interview with a representative from an infrared sensor production company, London, 28 September 2025.
117. Gremsy, <https://gremsy.com/?srsltid=AfmBOoqX0OnBxikWGeuAeIPqVztz1wQdyvSeeEKEQttCzHA4W-QQB9Au>, accessed 24 October 2024.
118. Author interviews with DSET analyst, London, 9 May 2025.

Figure 1: FPV Drone Supply Chain Vulnerabilities



1 Batteries:
Pack of 18650 Li-ion cells

Also used in electric vehicles, these can be obtained from South Korea and Japan, but China dominates anode and cathode production, including in extraction, and the production of spherical graphite. South Korea is launching its own spherical graphite production.

2 Video and radio receivers:

Powerful transmitters and receivers incorporate radio frequency crystal oscillators, components where China has a cost advantage, although there is increasing production outside of China.

3 Permanent magnet synchronous brushless motors:

Neodymium mining and processing is dominated by China with small production in Australia and processing in Malaysia. There are mining and refining projects in Estonia and the US, and small refining capacity in Canada.

4 Flight controller and ESC:

Chips for processing flight data and sending instructions to speed controllers, which control motors, can be fabricated in Europe, Taiwan and the Philippines, but several major producers have strong business links to China.

5 Camera (day, thermal):

Germanium production for infrared sensors is dominated by China. Export curbs to the US in 2023 hit Europe, cutting supply by 40%. Cost of daytime cameras made outside China is higher but Sony controls 50% of the global CMOS market. Germanium is also used in fibre-optic cable production.

6 Frame:

China has supplied much of the Computer Numerical Control (CNC) machines for cutting carbon fibre into drone frames. China has a cost advantage in carbon fibre production but the global supply chain is diverse.

Sources: Mila Tanghe, 'Europe's Scramble for Military Minerals.' CEPA, 12 May 2025, <https://cepa.org/article/europes-scramble-for-military-minerals/>, accessed 10 November 2025; Jeffrey Matthews, 'Sony Keeps Lead in Apple's iPhone Image Sensors Amid Long-Term Uncertainty', 10 September 2025, <https://library.techinsights.com/public/sectioned-blog-viewer/4835f548-3260-4804-9a68-d727e9a8c205>, accessed 10 November 2025.

Conclusion

In identifying difficulties to building drones free of Chinese components, interviewees for this paper have singled out component categories that were challenging to source, due to deficiencies in mature semiconductor fabrication and the REEs examined above earlier. These deficiencies have, according to three interviewees, raised certain component prices by up to 10 times.[119]

The 10 July 2025 DoD memorandum was hailed as a long-awaited positive signal to existing drone production lines in the US.[120] Reformed procurement cycles and the potential cutting of bureaucracy might enable a rapid generation of orders and a subsequent upscaling of operations. Such reforms may, in turn, limit China's control of the drone supply chain. However, as this paper has outlined such a goal will not be achievable without stronger international cooperation across the entire MUAS supply chain – from mining to unit production – not just assembly. Similarly, several interviewees for this paper expected the stronger US demand signal to be felt across the MUAS supply chain, from mining operations to flight control processor production – although such transformation would not be a quick process. 'You don't just have to bring back the wafer production', said one US drone company executive, referring to chip production. 'You must then drive enough volume to create this whole secondary ecosystem, such as chip packaging and testing, and get it all the way through to shipping'.[121]

119. Author interview with Michael Dewhirst, Guildford, 6 May 2025; author interview with Hong-Lun Tiunn, London, 26 April 2025.
120. US Secretary of Defense, 'SUBJECT: Unleashing America's Drone Dominance', policy memo, 10 July 2025, <https://media.defense.gov/2025/Jul/10/2003752117/-1/-1/1/unleashing-u.s.-military-drone-dominance.pdf>, accessed 27 June 2025.
121. Author interview with drone company CEO, London, 5 May 2025.

What emerges from drone manufacturing alliances forged among non-authoritarian countries will probably be different from what has been seen in Ukraine so far, not least because of a higher unit cost of systems**.** Both the author and the participants interviewed for this paper broadly see three potential opportunities for countries seeking to decouple their drone supply chain from China, but they warn that building resilient supply chains would also take years. These opportunities include:

- Increase the scale of capacity through coordinated production.
- Improve international cooperation on innovation.
- Settle on a middle ground for drone manufacturing alliances between two extremes of either Ukraine-style COTS generation of cheap mass, or a shift to a greater standardisation.

Opportunities

Increase the Scale of Capacity Through Coordinated Production

Allied states can build more resilient hardware supply chains for drones, mitigating the impact of a major disruption, such as a crisis in the Pacific that would interrupt shipping in East Asia. Before such a crisis occurs, Europe should take steps to manufacture flight controllers and assemble the devices at scale, because it currently has some capacity and design expertise. It is cost that has driven producers to establish production in China, rather than considerations of national self-reliance. Greater realisation of this should heighten debate on hardware coalitions among Allied partners, particularly Taiwan and European countries with semiconductor fabrication capacity. However, higher costs per unit are inevitable compared with Ukraine's affordable COTS model.

This rebalancing of the supply chain could benefit the West in general. An example of this is the cooperation between the US-headquartered Auterion and Ukraine, which was born of US Agency for International Development (USAID) during President Joe Biden's administration. Co-production has delivered soaring volumes of their AI 'strike kit'.[122] Skynode is also used by a UK-based drone startup contacted for this paper. Similar cooperation should be wrapped into an enduring bilateral framework, rather than more limited arrangements such as the USAID-backed cooperation. The US, meanwhile, has a small NdFeb magnet production capacity, with the DoD backing projects underpinned by guaranteed high prices paid by the government, to mine-and-refine firm MP Minerals Corp. Nevertheless, while its ambition is self-sufficiency, US

122. Sylvia Pfeifer, Laura Pitel and Christopher Miller, 'Software Group Auterion to Ship 33,000 AI Drone "Strike Kits" to Ukraine', *Financial Times*, 27 July 2025.

production of NdFeB magnets in 2025 will only cover around 10% of US demand across all sectors.[123] As noted, this demand is driven by the automotive and renewable energy sectors. According to estimates by this paper's author and by the drone expert Michael Dewhirst,[124] if the total announced procurement of drones between Ukraine and NATO goes ahead, it could require around 576 tonnes of permanent magnets a year by 2027. This would amount to almost 30% of Europe's annual magnet production if these drones were FPVs. Since the acquisitions will include larger drones, this percentage could be significantly higher. To compare this to demand in the civilian sector, wind turbines can each require several hundred kilograms of NdFeB magnets, and wind farms such as the UK's Hornsea 3 can involve several hundred turbines.[125]

Improve International Cooperation on Innovation

A potential US–Ukraine drone production partnership could boost the resilience of drones built with modular design. The Canadian Draganfly drone reportedly has part of its electronics built in Taiwan and supports 5-, 7- and 10-inch configurations; it is marketed as a 'Swiss Army knife'. International collaborations based on organic demand – such as the Taiwan–Japan drone partnership for public sector drones, the Latvia–Taiwan military partnership for UAS or a recent UK–Ukraine partnership to build interceptor drones – could bring greater market stability. Helping to support demand could mitigate a repeat of China's alleged dumping of MUAS systems and components that crashed prices by 70% in 2015.[126] Strategic efforts need to focus on software evolution as much as hardware, a problem that organisations such as NATO's Defence Innovation Accelerator for the North Atlantic would be well-placed to examine.

Settle on a Middle Ground for Drone Manufacturing Alliances Between Two Extremes

Either manufacturers will pivot towards Ukraine-style COTS generation of cheap mass – which in some instances has seen very low yields of fully functioning drones off production lines – or a shift to a greater standardisation, ruggedisation and exquisite capability of drones at a high price point. One interviewee noted that some Chinese MUAS firms had been damaged by extremely low prices, which helped them to secure their market share but compromised the quality of their production. Certain

123. Glenn Zorpette, 'Advanced Magnet Manufacturing Begins in the United States', *IEEE Spectrum*, 9 February 2025, <https://spectrum.ieee.org/advanced-magnet-manufacturing-in-us>, accessed 25 September 2025.
124. Author interview with Michael Dewhirst, London, 24 August 2025.
125. Renas Sidahmed, 'Wind Turbines Drive REE Pricing not EVs', ACF Equity Research, 15 June 2023, <https://acfequityresearch.com/wind-turbines-drive-ree-pricing-not-evs/>, accessed 26 September 2025.
126. *Focus Taiwan*, 'Taiwan, Japan Drone Makers Sign MOU for Supply Chain Cooperation', 25 March 2025, <https://focustaiwan.tw/business/202503250019>, accessed 24 July 2025.

Chinese producers, for example, preferred replacing faulty parts for customers, finding it cheaper than implementing batch testing for quality control:

> "That [approach to assembly] changed in Ukraine because they're using these things, their volumes are there, so their supply lines are there, so everything else shows up … Because when you're producing 4 million [drones] … you get this tight feedback loop, you get very good very quickly. It's an efficient marketplace demand engine.[127]

In the future, Western producers might indeed opt for greater ruggedisation and capability, but at the risk of losing the affordable element of cheap mass, which has proven so lethal in Ukraine.

None of these suggested courses of action are straightforward. It is critical for Western governments to strengthen cooperation across supply chains to minimise single points of vulnerability. Within NATO, the Multinational Capability Delivery Initiatives – which have seen agreement among members to stockpile defence material inputs – require concrete action from members, and perhaps similar actions to the US DoD's move to secure neodymium supply by guaranteeing prices.[128]

Furthermore, several interviewees believed that Ukraine did not have a 'surplus' of drones for export,[129] although discussions between Kyiv and Washington may explore this possibility.

Another interviewee advocated for a greater standardisation of drone manufacturing in general, which Kyiv is now implementing, attempting to reduce the number of available FPV types and producers.[130] The West does not need a large ecosystem of drone companies, which has rather been an outgrowth of Ukraine's Army of Drones in response to Russian aggression. What heightens efficiency in manufacturing is scale: by manufacturing volumes of 30,000 drones per month, some of the larger companies in Ukraine have significantly improved their yields.[131] Yet, the near-term challenge will be getting even remotely close to those production levels. Before Western powers and Allies can reach such a point, defence planners may have to work out how to 'fight tonight' while planning for conflict that will see intensive use of UAS, and particularly MUAS.

127. Author interview with European drone company executive, London, 7 May 2025.
128. NATO, 'NATO Allies Step up Multinational Capability Delivery Cooperation', 24 June 2025, <https://www.nato.int/cps/en/natohq/news_236514.htm>, accessed 1 October 2025.
129. Author interview with drone industry consultant, Guildford, 6 May 2025; author interview with industry consultant, London, 16 May 2025.
130. Author interview with drone company CEO, London, 25 May 2025.
131. Author interview with drone company executive, London, 25 May 2025.

About the Author

Robert Tollast is a researcher in the Land Warfare research group at RUSI. Previously, he was an Assistant Foreign Editor at *The National* in Abu Dhabi and Military Affairs Reporter. He has also worked in risk analysis focused on the Middle East in the private sector and has advised the Iraqi Ministry of Foreign Affairs.

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