Routledge
Taylor & Francis Group

The RUSI Journal

ISSN: 0307-1847 (Print) 1744-0378 (Online) Journal homepage: www.tandfonline.com/journals/rusi20

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To cite this article: Kevin Weller, Christian Janke, Michael Holaschke & Bastian Walthier (2025) Liminal UAV Warfare, The RUSI Journal, 170:6-7, 54-64, DOI: 10.1080/03071847.2025.2589829

To link to this article: https://doi.org/10.1080/03071847.2025.2589829

Published online: 19 Dec 2025.

Research Article
RUSI Journal

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Categorising Littoral UAVs and Their Impact on the Colonisation of the Air Littoral

Kevin Weller, Christian Janke, Michael Holaschke and Bastian Walthier

This article provides an adaptation of the concept of the air littoral that goes beyond a static spatial definition, by considering the continually evolving technological and societal aspects that shape contested airspace. Kevin Weller, Christian Janke, Michael Holaschke and Bastian Walthier argue that there is a link between key technological and operational characteristics embodied by UAV systems, and the expansion, population and contestation of the air littoral. This link needs to be understood to evaluate contemporary and future socio-technological developments in the context of littoral UAVs.

Russia's 2022 full-scale invasion of Ukraine demonstrated the increasing impact that littoral UAVs have on the modern battlefield. Such systems have previously been employed by non-state groups such as the Houthi Movement, Hezbollah, Hamas and the Islamic State. However, such systems are now being produced and fielded on an exceptional scale – and have seen rapid technological innovation. There has been an unparalleled shift that has increased the relevance for littoral UAVs in modern warfare. This trend has been widely recognised and reported throughout the media, and continues to receive substantial scholarly attention.[1]

1. For example, Marcel Plichta and Ash Rossiter, 'A One-way Attack Drone Revolution? Affordable Mass Precision in Modern Conflict', *Journal of Strategic Studies* (Vol. 47, No. 6/7, 2024), pp. 1001–31; Bohdan Ben, 'FPV Drone Tactics Reshape Conventional Trench Warfare in Russo-Ukrainian War', *Euromaidan Press*, 22 March 2024, <https://euromaidanpress.com/2024/03/22/both-ukraine-and-russia-rapidly-increase-the-use-of-fpv-drones-challenging-conventional-trench-fortifications/>, accessed 15 October 2025; Kerry Chávez and Ori Swed, 'Emulating Underdogs: Tactical Drones in the Russia-Ukraine War', *Contemporary Security Policy* (Vol. 44, No. 4, 2023), pp. 592–605; John Grady, 'Ukraine's Experience in Developing Lethal Drones Should be Lesson for NATO, Say Panel', *US Naval Institute*, 18 April 2024, <https://news.usni.org/2024/04/18/ukraines-experience-in-developing-lethal-drones-should-be-lesson-for-nato-says-panel>, accessed 15 October 2025; Dominika Kunertova, 'The War in Ukraine Shows the Game-changing Effect of Drones Depends on the Game', *Bulletin of the Atomic Scientists* (Vol. 79, No. 2, 2023), pp. 95–102; Dominika Kunertova, 'Drones Have Boots: Learning from Russia's War in Ukraine', *Contemporary Security Policy* (Vol. 44, No. 4, 2023), pp. 576–91; Saba Sotoudehfar and Jeremy Julian Sarkin, 'Drones on the Frontline: Charting the Use of Drones in the Russo-Ukrainian Conflict and How Their Use May Be Violating International Humanitarian Law', *International and Comparative Law Review* (Vol. 23, No. 2, 2023), pp. 129–69; Kristen D Thompson, 'How the Drone War in Ukraine Is Transforming Conflict', Council on Foreign Relations, 16 January 2024, <https://www.cfr.org/article/how-drone-war-ukraine-transforming-conflict>, accessed 15 October 2025; Mariano Zafra et al., 'How Drone Combat in Ukraine is Changing Warfare', *Reuters*, 26 March 2024; Maximilian K Bremer and Kelly A Grieco, 'The Air Littoral: Another Look', *Parameters* (Vol. 51, No. 4, 2021), pp. 67–80; Jennifer Kavanagh, 'Arming for the Air Littoral: The Defense Industrial Base and Future Air Warfare', *AETHER: A Journal of Strategic Airpower & Spacepower* (Vol. 3, No. 3, 2024), pp. 25–39; Kevin L Jackson and Matthew R Arrol, 'Defending and Dominating the Air Littoral', *AETHER: A Journal of Strategic Airpower & Spacepower* (Vol. 3, No. 4, 2024), pp. 56–69.

A UAV takes off from the littoral combat ship USS *Coronado*. There has been an unparalleled shift that has increased the relevance for littoral UAVs in modern warfare. *Courtesy of Stocktrek Images / Alamy*

The uses of such UAVs – either adapted from affordable consumer and prosumer drones (and parts) or explicitly manufactured for warfare – cover many functions. These include ISR – used, for example, to guide artillery strike missions and coordinate troops. They also include conducting immediate strike missions – often using improvised, retrofitted vehicles with explosive devices. As the 'air littoral'[2] has become increasingly populated by such systems, both their density and diversity has increased dramatically. Moreover, the increasing use of the air littoral is not occurring simply due to technological or strategic innovation; rather, it follows from a shift in production logic, a democratisation and de-professionalisation of aerial warfare, and a new relationship between modern militaries and civilian production capabilities. Examples of this trend include – but are not limited to – crowdsourcing of components and the decentralised manufacturing of UAV systems.[3]

Given the increasing diversity – in terms of the technical variation of UAVs, how they are embedded into societies and the logic of their deployment – this article attempts to provide a comprehensive taxonomy of littoral UAVs in five dimensions: weaponisation; guidance; production; lifecycle; and deployment logic. It also contextualises those UAVs within the ongoing colonisation of the air littoral. It argues that the air littoral should be understood in spatial terms, and what this article terms a 'colonisation process'. Hereby, the air littoral, as a liminal space, is being re-shaped, traded, conquered and surrendered between old and new actors of aerial combat.

Literature Review: Systematising Littoral Air Support

In their 2021 paper, Maximilian K Bremer and Kelly A Grieco describe the airspace between ground forces and conventional aerial vehicles – such as

2. Bremer and Grieco, 'The Air Littoral'; Kavanagh, 'Arming for the Air Littoral'.
3. Oona A Hathaway, Catherine Vera and Inbar Pe'er, 'Crowdsourced War', *New York University Law Review*, forthcoming, 2025; Foreign Policy Council 'Ukrainian Prism', 'Blue and Yellow Annex: To the White Paper on the Future of European Defence', *Policy Briefs*, 2025, <https://prismua.org/wp-content/uploads/2025/04/Blue_and_yellow_annex_on_defense.pdf>, accessed 15 October 2025.

DOI: 10.1080/03071847.2025.2589829

fighter and bomber aircraft – as the 'Air Littoral'.[4] Specifically, they refer to airspace below 10,000 feet and draw parallels to maritime littorals, which 'must be controlled to support land and maritime operations and can be supported and defended from the air and/or the surface'.[5] Their perspective is particularly thought provoking. It helps to draw parallels between the air littoral and coastal regions that are liminal spaces.[6]

Some authors, such as David Barno and Nora Bensahel, have taken a different approach.[7] They interpret the increasing relevance of the air littoral as a first step towards the irrelevance of traditional air forces. Others, still, draw comparisons to the historical obsolescence of battleships, even asking 'is this our battleship moment?'[8] The analogy of coastal warfare may also underscore the need to integrate emerging littoral UAVs into existing strategies that address both land and air, without presuming an impending replacement of air forces. Furthermore, and of particular interest to this article, the metaphorical 'coast' – the air littoral – is not just a spatial slice of airspace. Rather, it may be understood as a frontier, a sort of no-man's land, where continuous reconfigurations, adaptations, processes of colonisation and de-colonisation of resources, technologies and tactics are ongoing and represent a constitutive element of this liminal space.

Saba Sotoudehfar and Jeremy Julian Sarkin make a basic distinction between different types of UAVs operating in this littoral airspace. They note that 'The classification of drones utilized in the war between Russia and Ukraine lacks a universally accepted standard'.[9] There have been recent attempts to provide basic – albeit still disconnected – categories that could be used for classification. For example, later in the same article, Sotoudehfar and Sarkin outline two potential lines of distinction: categorising littoral UAVs in terms of their purpose (military and civilian); and their function (for example, ISR, strike missions and transportation). However – and as the authors themselves state – this distinction is complicated by the adaptability of such systems, which prevents a clear determination of civilian/military use or functions.

The analogy of coastal warfare may also underscore the need to integrate emerging littoral UAVs into existing strategies that address both land and air, without presuming an impending replacement of air forces

In contrast to this insightful, but comparatively simple categorisation, Dominika Kunertova attempts to differentiate between types of littoral UAVs.[10] This approach more closely aligns with the current and rather stringent NATO classification of UAVs, in particular introducing the category of loitering munitions.[11] In this context, the addition of the category of loitering munitions to the standard NATO system of classifying UAVs is of interest, as it demonstrates that, while the Class I–III classification system is coherent and definitive, it lacks the depth and nuance required to adequately differentiate current and upcoming littoral UAVs, as a large majority of those fall into Class I and, therefore, no additional value is created by this classification (See Table 1).

This categorisation distinguishes between a variety of UAVs. However, it does not sufficiently account for the increasing operational and technical complexity introduced by emerging UAVs, for which Sotoudehfar and Sarkin sought to account. For example, while typical 'first person view drones'

4. Bremer and Grieco, 'The Air Littoral'.
5. Joint Chiefs of Staff, 'Joint Maritime Operations', Joint Publication 3-32, 8 June 2018, incorporating change 1 on 20 September 2021, p. 23f.
6. Branden W Gulick, 'Liminality: Opportunities in the Transition Space of the Air Littoral', *AETHER: A Journal of Strategic Airpower & Spacepower* (Vol. 3, No. 3, 2024), pp. 68–79.
7. David Barno and Nora Bensahel, 'Drones, the Air Littoral, and the Looming Irrelevance of the U.S. Air Force', *War on the Rocks*, 7 March 2024, <https://warontherocks.com/2024/03/drones-the-air-littoral-and-the-looming-irrelevance-of-the-u-s-air-force/>, accessed 15 October 2025.
8. James C Slife, 'Airpower at Any Scale', *AETHER: A Journal of Strategic Airpower & Spacepower* (Vol. 3, No. 3, Fall 2024), pp. 5–9.
9. Sotoudehfar and Sarkin, 'Drones on the Frontline', p. 140.
10. Kunertova, 'The War in Ukraine Shows the Game-Changing Effects of Drones Depends on the Game'.
11. See Table 1 for the standard NATO UAV Classification System. Here, the primary differentiating factor is UAV weight (Class 1 <150 kg; Class 2 <600 kg; Class 3 >600 kg).

(FPVs) – according to this classification – would most likely be considered Class I 'Mini' UAVs (see Table 1), their weight is usually below 15 kg. As a result, their normal deployment is not necessarily restricted to tactical subunits, and may instead expand to tactical units or even tactical formations.

In this sense, the three approaches discussed above – Sotoudehfar and Sarkin's focus on the purpose of a UAV, the NATO classification focus on weight classes (see Table 1), and Kunertova's mixed approach – do not seem to adequately differentiate emerging littoral UAVs in a way that creates insights or perspectives on their deployment or limitations. To facilitate such insights, this article argues that a two-step process is required: first, to outline dimensions that combine technological

Table 1: NATO's UAV Classification System

UAV Classification Table						
Class	**Category**	**Normal Employment**	**Normal Operating Altitude**	**Normal Mission Radius**	**Primary Supported Commander**	**Example Platform**
Class I (less than 150 kg)	Small >20 kg	Tactical Unit (employs launch system)	Up to 5,000 ft AGL	50 km (LOS)	BN/Regt, BG	Luna, Hermes 90
	Mini 2–20 kg	Tactical Sub-unit (manual launch)	Up to 3,000 ft AGL	25 km (LOS)	Coy/Sqn	Scan Eagle, Skylark, Raven, DH3, Aladin, Strix
	Micro <2 kg	Tactical Pl, Sect, Individual (single operator)	Up to 200 ft AGL	5 km (LOS)	Pl, Sect	Black Widow
Class II (150–600 kg)	Tactical	Tactical Formation	Up to 10,000 ft AGL	200 km (LOS)	Bde Comd	Sperwer, Iview 250, Hermes 450, Aerostar, Ranger
Class III (more than 600 kg)	Strike/ Combat	Strategic/ National	Up to 65,000 ft	Unlimited (BLOS)	Theatre COM	–
	Hale	Strategic/ National	Up to 65,000 ft	Unlimited (BLOS)	Theatre COM	Global Hawk
	Male	Operational/ Theatre	Up to 45,000 ft MSL	Unlimited (BLOS)	JTF COM	Predator B, Predator A, Heron, Heron TP, Hermes 900

Source: NATO Standardization Office, 'Allied Joint Doctrine for Unmanned Aircraft Systems', ATP 3.3.8, Edition A, Version 1, 2010.

Abbreviations: high altitude long endurance (HALE); medium altitude long endurance (MALE); above ground level (AGL); mean sea level (MSL); line of sight (LOS); beyond line of sight (BLOS); tactical patrol/platoon individual (Tactical PI); battalion (BN); regiment (Regt); battlegroup (BG); company (Coy); squadron (Sqn); platoon (Pl); section (Sect); brigade commander (Bde Comd); commander (COM); joint task force commander (JTF COM).

and operational distinctions that can be used for a comprehensive overview of littoral UAV types; and second, to contextualise those in the air littoral as a field of contested liminal airspace where technological requirements, limitations in physical space, involved actors and operational requirements intersect.

Five Dimensions to Differentiate Littoral UAVs

In the following section – to provide the groundwork for constructing the concept of the air littoral as a contested, liminal space – this article introduces five key categories for classifying littoral UAVs: weaponisation; guidance; production; lifecycle; and deployment logic. These five categories have been chosen to form a taxonomy that applies to most UAVs. This taxonomy combines technological (such as maximum take-off weight, or range), operational (such as scale of production and cycle of innovation) and tactical (such as use cases and system adaptability in the field) aspects. This differentiation, therefore, takes the middle ground between 'hard', measurable factors – such as the guidance system used in a UAV – and 'softer' factors – such as a system's adaptability/probable role in deployment. In a sense, this categorisation aims to combine the rather straightforward, quantitative approach found in the NATO STANAG 4670 classification with the qualitative approach used in classifying UAVs, such as Sotoudehfar and Sarkin's.

Weaponisation

Weaponisation is the first distinction drawn by this article. It distinguishes between armed and unarmed UAVs. Both refer to the use of uncrewed aerial vehicles (no matter the size or type) for purposes of warfare. However, it is necessary to distinguish between drones that are only used for reconnaissance purposes and do not carry a weapon systems (UAV warfare), and drones that either carry weapon systems or function as weapon systems themselves (armed UAV warfare).

This first distinction categorises UAVs in terms of their intended purpose, as well as technical constraints, such as the ability (or inability) to carry explosives. While technical limitations have an impact – for instance, on maximum take-off weight (MTOW), operational endurance and range – it should be noted that there is usually at least some room for adaptation. Unarmed commercial UAVs, especially multicopters may be, and often are, retrofitted with improvised weapons/explosive devices. This first distinction is, therefore, both technical and operational, as the capabilities of armed versus unarmed UAVs, their dependence on other systems (such as artillery) and the flexibility of their deployment require distinct operational considerations.

In a way, this first distinction may be read as a condensed version of Sotoudehfar and Sarkin's differentiation of UAVs according to their purpose in warfare. While Sotoudehfar and Sarkin list a variety of different uses,[12] the approach presented in this article simplifies and specifies this differentiation, according to the UAV's potential to carry weapon systems or function as a weapon system. The distinction between armed and unarmed UAV warfare is also made elsewhere.[13] However, a systematic introduction has so far been missing from the relevant literature.

It is also relevant to note that the difference between armed and unarmed UAVs is not always immediately apparent. This is especially the case for non-standardised UAV systems (see later in this article for a discussion of improvised UAVs). Moreover, this distinction is harder still when seen from the point of view of an opposing force, which may struggle to determine if a drone is armed or not. This challenge raises the possibility of UAVs being used for coercion, harassment and as decoys. In these cases, the mere possibility of UAVs being armed is itself sufficient to provoke a strong defensive response. Provoking opposing forces into such a reaction may, therefore, be used to either deplete defensive capabilities, as a means of psychological warfare or as a part of an ISR mission – to encourage defending forces to reveal their positions as they engage incoming UAVs.[14]

Guidance

Modes of UAV guidance – namely drones that are FPV and those that are not – are a second distinction. FPV UAVs – usually referred to as simply 'FPV drones' or 'racing drones' – are commonly presented as a

12. Sotoudehfar and Sarkin, 'Drones on the Frontline', p. 147–54.
13. For example, Marcel Plichta and Ash Rossiter, 'A One-Way Attack Drone Revolution? Affordable Mass Precision in Modern Conflict', *Journal of Strategic Studies* (Vol. 47, Issue 6/7, 2024), pp. 1001–31.
14. For a dedicated discussion of coercion as a part of UAV operations, see Amy Zegart, 'Cheap Fights, Credible Threats: The Future of Armed Drones and Coercion', *Journal of Strategic Studies* (Vol. 43, No. 1, 2020), pp. 6–46.

rather recent innovation in the context of warfare. Since 2022, they have been popularised during the Russo-Ukrainian War. However, even UAVs such as the US-produced and -deployed MQ9 are, in a sense, FPV UAVs as they are partially piloted by humans from the perspective of the UAV itself.

While it might seem odd to group two apparently very different UAV systems – small, often improvised multicopters, and multi-million-dollar uncrewed aircraft – together, their guidance logics are similar even though they differ vastly in other respects. As for non-FPV UAVs, those include systems, which might, for example, use GNSS (global navigation satellite system), INS (inertial navigation system), infrared, passive/active radar and other guidance systems without requiring a sustained datalink to a human operator to direct a UAV to a pre-defined target. However, distinctions based on the means of guidance are not necessarily clear. There may be a combination of different modes of guidance. For example, a UAV may use GPS guidance to approach a target area and then transition to FPV control for further adjustments or precision strikes. Furthermore, the increasing capabilities of non-FPV UAVs blur the line between such UAVs and other weapon systems, such as cruise missiles.

For the purposes of this article, the term 'FPV UAV' is used to refer exclusively to the small, often improvised and easily transportable multicopter drones. These are adapted from the hobbyist and racing scene, and popularised in the Russo-Ukrainian War. This approach aligns with the contemporary terminology used in other research articles, and does not include other partially FPV-controlled systems, such as the MQ-9. Approaches that include partial FPV systems are internally coherent and useful for future investigations. However, they are at odds with the contemporary association with 'FPV drones' as relatively small, inexpensive, often single-use littoral UAVs and should, therefore, be used carefully as a definite category, despite being technically unambiguous.

One of the main advantages of FPV systems – for example, single-use FPV quadcopters such as the Iranian Shahed 136 – is their adaptability to changing mission requirements and the opportunity to leverage pilot skill and on-the-spot thinking to circumvent defences, identify and strike high-value targets, and open up opportunities for follow-on strikes. For example, fibre optically controlled multicopters can be employed to sabotage jamming equipment and, therefore, allow wirelessly operating multicopters to carry larger payloads to execute follow-up missions. Despite such benefits, FPV systems create additional challenges. These include the need to train qualified pilots, the need for additional infrastructure such as ground stations which, depending on the technology used, may be traceable by opposing forces, datalink vulnerabilities and electronic warfare. In comparison, non-FPV systems, especially those employing highly jamming-resistant guidance systems – such as inertial navigation – may be prepared and launched without requiring highly trained pilots, be less vulnerable to electronic warfare and need less stationary ground infrastructure.

Production

The third distinction differentiates modes of UAV manufacturing, separating improvised and non-improvised means of UAV warfare. Here, the FPV multicopter UAV – as understood in contemporary literature, and in its armed form as a compact loitering munition – stands out as the most prominent example. The purpose of this distinction is to go beyond differentiating between actors who do and do not have access to the financial and industrial resources to develop standardised military UAVs in an industrial setting.[15] Rather, the aim is to show a latent democratisation of warfare that is especially inherent to the adaptation of FPV multicopter technology.

> One of the main advantages of FPV systems is their adaptability to changing mission requirements and the opportunity to leverage pilot skill and on-the-spot thinking

In this sense, improvised UAVs – as well as the actors employing them – reflect an openness in aerial warfare. This type of warfare comes with both significant costs (less efficient de-centralised production, a lack of standardisation that increases the risk that systems will have limited interoperability, and possible dependence on crowdsourced components) and substantial advantages (difficulties in targeting de-centralised production, a lack of standardisation allowing for quick adaptations to changes in battlefield conditions, and the potential for disruptive innovations and the ability to scale substantially due to crowdsourced components).

15. Sebastian Ritchie, *Industry and Air Power: The Expansion of British Aircraft Production, 1935-41* (London: Routledge, 1997).

This distinction is again fundamentally aligned with Sotoudehfar and Sarkin's differentiation between purpose-built military UAVs and consumer UAVs adapted for military purposes.[16]

From a sociological perspective, it is worth noting that improvised UAV manufacturing may be understood as increasing societal resilience. Following the 4-R model of resilient states,[17] the benefits and costs of improvised UAV manufacturing may be understood as falling into the following categories:

- **Robustness** of the military industrial base through democratisation of the required knowledge base for UAV manufacturing.
- **Redundancy** of manufacturing capabilities through decentralisation.
- **Resourcefulness** in design and manufacturing by using commonly available materials/technologies.
- **Rapidity** in UAV innovations to adapt to changing requirements.

While Kavanagh has already identified production at scale and continuous innovation as key aspects to improving capabilities in the air littoral,[18] applying the 4-R model provides further insights into how such production at scale may be realised. For example, this might be achieved by designing for manufacturability with commonly available materials/technologies and/or by establishing redundant, decentralised manufacturing capabilities.

Even though this increased resilience is valuable – especially for a defending actor in an asymmetric military conflict, such as in the war in Ukraine – it should be noted that the democratisation of knowledge/means to UAV warfare may also empower non-state actors such as extremist or terrorist groups. In this sense, 'littoral UAV warfare' may also be interpreted as UAV warfare on the border of democratised and centralised professional arms production. This trend may, as a result, be understood as 'unleashing the military potential of the civilian production base',[19] framing it as an 'arsenal of democracy'.[20] At the same time, this proliferation empowers civilians to manufacture and use littoral UAVs for any purpose they choose.

Lifecycle

The fourth distinction relates to the UAV's expected lifecycle and differentiates between single-use and multi-use weapon systems. Applied to armed UAVs, the former is usually associated with terms such as 'kamikaze drones' or 'loitering munitions', and the latter usually linked to larger UAV platforms, such as the Bayraktar TB2. However, multi-use systems may also include recently introduced and easily portable FPV 'bombing drones'. These are intended to drop (modified) munitions such as hand grenades, mortar rounds, other grenades and IEDs. This distinction, therefore, builds on Kunertova's definition of different 'drone games',[21] Marcel Plichta and Ash Rossiter's notion of the 'one-way attack drone revolution',[22] and Andre Haider's description of such UAVs as fundamentally expendable.[23]

It should be noted that the actual UAV lifecycle may be different from the designed UAV lifecycle. Multi-use UAVs may be lost on their first deployment, for example because of jamming. Single-use systems may, under certain circumstances, be recovered for future use, especially when resources are scarce. In this sense, a UAV-lifecycle concerns design considerations. These include factors such as cost of production and projected or real numbers of fielded systems, as well as whether a UAV can be easily adapted from one type of use to another – for example, from a single-use to multi-use system.

When comparing the designs of single- and multi-use multicopter systems, single-use systems are often constructed with expendable materials and components. They prioritise cost and time for manufacturing and assembly over longevity and performance. Manufacturers such as Donaustahl have leveraged plug-and-play controller designs.[24]

16. Sotoudehfar and Sarkin, 'Drones on the Frontline', p. 140.
17. Applying Charlie Edwards, *Resilient Nation* (London: Demos, 2009).
18. Kavanagh, 'Arming for the Air Littoral', pp. 27–33.
19. Slife, 'Airpower at Any Scale'.
20. Slife, 'Airpower at Any Scale'.
21. Kunertova. "The War in Ukraine Shows the Game-Changing Effect of Drones Depends on the Game', p. 100.
22. Plichta and Rossiter. 'A One-Way Attack Drone Revolution? Affordable Mass Precision in Modern Conflict'.
23. Andre Haider, 'Unmanned Aircraft System Threat Vectors', in *A Comprehensive Approach to Countering Unmanned Aircraft Systems* (Kalkar: Joint Air Power Competence Centre, 2021), <https://www.japcc.org/books/a-comprehensive-approach-to-countering-unmanned-aircraft-systems/>, accessed 15 October 2025.
24. See for example: <https://www.donaustahl.com/technologie>, accessed 15 October 2025.

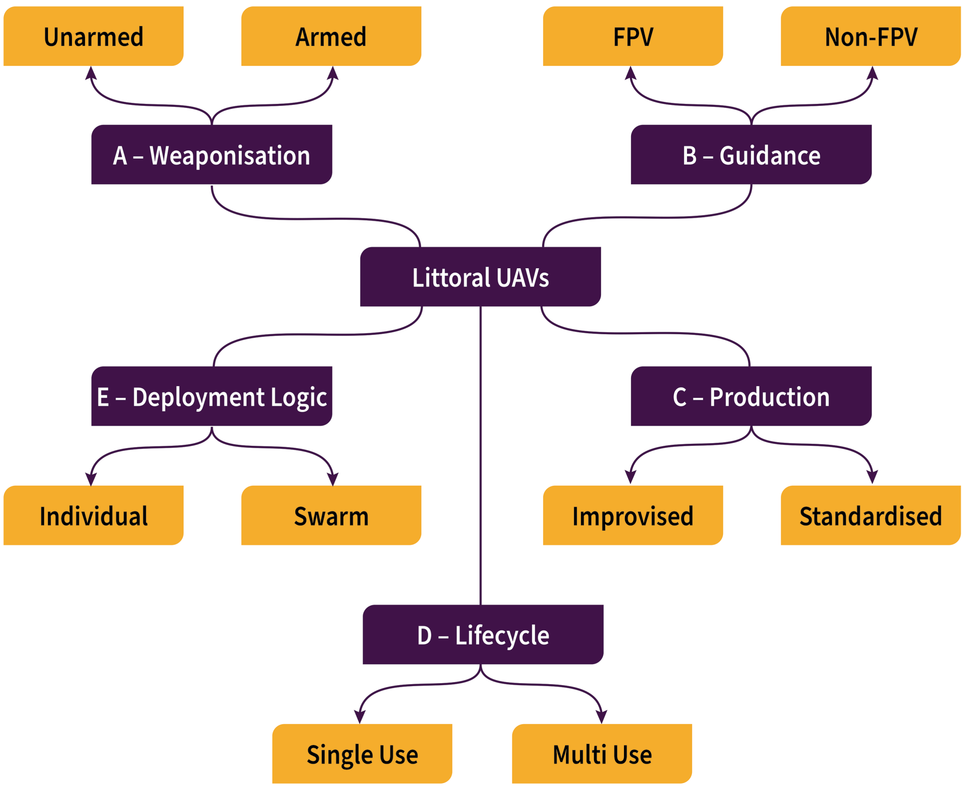
The approach of such manufacturers also largely eliminates error-prone soldering operations. In turn, this has substantially decreased assembly times and the required skillset of personnel – who are frequently volunteers – using their hardware. Despite those obvious advantages for mass manufacturing, such systems may be less suited for adaptation into multi-use platforms as their performance and ability to be modified is limited. Especially for future multicopter systems – whose platform-like characteristics lend themselves well to modifications – it will be crucial to navigate the gap between ease of assembly and cost-reduction, and maintaining a certain degree of adaptability. In this context, systems designed for easily exchangeable components – possibly designed to leverage 3D-printing technology for on-the-spot modifications – may provide key advantages.

Deployment Logic

This fifth and final distinction differentiates UAVs in terms of single versus swarm-based deployments. In line with the previous distinction between single- and multi-use systems, it is important to further differentiate between systems adapted to swarm deployment and those designed for it. Saturation attacks are now common. They employ a variety of different UAVs, often Shahed-like systems in combination with other ordinance such as cruise missiles or ballistic missiles. However, these attacks may be understood as an adaptation of a swarm-like deployment logic. They lack means of intelligent swarm coordination. In the future, true swarms may be facilitated by AI algorithms.

There are possible ethical concerns on whether such systems comply with existing Rules of Engagement and the Laws of Armed Conflict. From a technical, performance-based perspective, for maximum effectiveness, autonomous systems – especially those operating in swarms – require effective coordination with other weapons systems and the human operators deploying them. Even when short of this capability, they can lower the requirements for operator/pilot training, further limiting the risks of using highly trained personnel. As Haider puts it, 'Minimizing the risk of losing a human

Figure 1: Proposed Operational Taxonomy



Source: Authors generated.

pilot has been the driving factor for developing UAS [uncrewed aerial systems]'.[25] Naturally, this minimisation strategy should focus on removing the pilot both from the aircraft and immediate danger altogether. While autonomous/swarm-based solutions may achieve this, there have been other attempts to create distance between operators and UAVs by other means – such as conventional satellite communication or, more recently, using the Starlink system.

Summary of Dimensions

Figure 1 summarises the five dimensions that can be used to distinguish types of military drones. It provides a comprehensive overview that can be leveraged for the analysis that follows in the remainder of this article: that of the air littoral as a liminal space of aerial colonisation. This taxonomy may be used to both categorise existing drone systems and speculate on other potential systems, including those that involve combinations that are logically possible but may not yet be deployed. This would highlight what use such a drone might have in a combat scenario and how it might fit into the context of contemporary or future drone warfare.

The Colonisation of the Air Littoral: From Airspace to Air Liminal

With this differentiation, one key aspect that connects all five dimensions is that of the ongoing colonisation process of the air littoral. This process is expressed, for example, in the expanding capabilities of new UAV systems, the ongoing reconfiguration and integration of industrial and civil production of littoral UAVs, and the processes of adapting and improvising UAV platforms compared with the mass manufacturing of others. It is also reflected in the integration of emerging air-littoral tactics into existing military structures, on the one hand, and the democratisation of air-littoral warfare, on the other. In other words, understanding the air littoral exclusively as an airspace that is clearly defined by an upper ceiling of 10,000 ft may not adequately grasp the complexity of this airspace and the actors operating within it.[26] This spatial component can, of course, be extended beyond a maximum altitude and applied proximally in the transportability of, for example, FPV multicopters and their speed of deployment. This binds them spatially closer to the deploying force than would be the case with a traditional air force. However, this spatial component may not be sufficient to understand the accelerated colonisation process of the air littoral.

Drawing from Brandan Gulick, applying the concept of liminality enables an understanding of the air littoral as a contested area that is not sufficiently defined in exclusively spatial terms.[27] Instead, it requires a broader understanding of 'littoral', as a region that is best defined in relation to the ongoing colonisation efforts by a variety of actors and technologies. This shifts the perception of the air littoral: moving from a static understanding of the air littoral as a slice of air space that is fundamentally the same as any other layer of air space, to one where it is as a liminal region that is procedurally negotiated and re-colonised by military and non-military actors simultaneously. Naturally, this process did not start with the contemporary diversification of littoral UAVs and involved actors – nor will it end with it. Bremer and Grieco give the historical example of the Kosovo War. In that conflict, the airspace below 15,000 ft remained highly contested due to Serbia's anti-aircraft artillery and MANPADS (man air-portable air defence systems) despite apparent air superiority having been achieved.[28]

This also applies to the contemporary notion of the air littoral. However – understood as a liminal space – it is not only contested in terms of air control but in terms of the actors, technologies, expectations, motivations and narratives of littoral warfare. Therefore, for the air littoral, the answer to Slife's question – 'How can airpower work together with our sister services to achieve victory together?'[29] – cannot be answered in terms of simply adapting a specific strategy or UAV technology into a given army or air force. Rather, it requires collaborative efforts by everybody who has a stake in it – states, militaries and civilians – across all stages – including technological innovation and conceptual groundwork. The relevant 'Sister Services' – as Slife puts it – will be clearly identifiable.

This article, therefore, concludes that a new way of negotiating the air littoral, which includes

25. Haider, 'Unmanned Aircraft System Threat Vectors', p. 47.
26. Bremer and Grieco, 'The Air Littoral'; Kavanagh, 'Arming for the Air Littoral'; Jackson and Arrol, 'Defending and Dominating the Air Littoral'.
27. Gulick, 'Liminality'.
28. Bremer and Grieco, 'The Air Littoral', pp. 69–71.
29. Slife, 'Airpower at Any Scale', p. 9.

both military and non-military actors, needs to be found to collaboratively colonise this liminal space. This process would also seek to understand the proximation and colonisation processes and incorporate these into the air littoral as top-down and bottom-up efforts – in a literal and a sociological sense.

Outlook: Perspectives on Cross-Colonising the Air Littoral

This article has understood the air littoral as a liminal space where a variety of actors and expectations – for example, militaries, civil companies and backyard tinkerers – intersect. This concluding section aims to outline three possible approaches that might benefit cross-colonisation of the air littoral, where resources beyond the traditional scope of aircraft manufacturers and air forces might be bundled to form a more holistic and grounded approach. These three approaches are: (1) littoral communication and literacy; (2) participatory formats such as defence hackathons; and (3) design for backyard manufacturing. While these are inevitably connected and hence depend on one another, the perspectives chosen – (1) knowledge based, (2) community based and (3) technology based – nevertheless deserve separate analyses.

Littoral Communication and Literacy

This refers to creating and maintaining communication channels and a shared knowledge basis among actors involved in the colonisation of the air littoral. While public collaboration, for example, can be an asset for empowering means of production, this requires a clear understanding from all sides. For example, it might require an army and a given community to jointly know what kind of technology is required, what can be supplied and what infrastructures might facilitate this process.

In essence, creating littoral communication and literacy is about promoting open communication and flows of information. These are not only top-down; they are also inherently bottom-up. The specifics of such a configuration change over time and – with changing requirements – there might be more or less need for this sort of exchange. However, it is essential for all involved actors to understand the liminal nature of littoral spaces – such as the air littoral – and the potential for productive cross-colonisation that it affords. On classic multi-domain operation, Kevin L Jackson and Matthew R Arrol noted that 'While not always perfect, and assisted by a unified departmental chain of command, the green-water Navy functions in the littoral because of the trust built between its forces and the Marine landing force it supports'.[30] Such trust – between departments and entirely different actors in the air littoral – will be needed to empower proper littoral communication and literacy.

Defence Hackathons

Littoral communication and literacy can be complemented by dedicated formats, such as defence hackathons. These may be employed to identify potentially relevant actors in the air liminal and current challenges or trends. They can also be used to collaboratively search for possible solutions. Conceptually, there is no reason why such formats cannot be (or should not be) grassroot movements. That said, they could benefit from a stricter top-down logic, at least when it comes to the provision of adequate spaces, materials, the connection with industry and defence partners, among others. At the same time, it will be essential to strike a balance between open and closed formats, especially when implementing challenges for the participants to solve. Previous research on this topic has shown that the negotiation between clear goal formulation and openness to disruptive innovations is crucial.[31]

Design for Backyard Manufacturing

Design for manufacturing (DFM) is a crucial aspect to the engineering of any scalable product. However, at the next level down, it is important to further differentiate between what might be termed 'design for industrial manufacturing' and 'design for backyard manufacturing' (DFBM). For example, while a multicopter design might be able to be quickly produced in a facility that is equipped with specialised machines or tools – such as computer numerical control (CNC) mills or selective laser sintering (SLS) printers – the scalability of such a design falls apart once those machines or tools are no longer available like in the case of a trade embargo or the loss of critical infrastructure. In this sense, DFBM might involve purposely designing a product for the usage of rather basic and widely

30. As in Jackson and Arrol, 'Defending and Dominating the Air Littoral', p. 60.
31. Kevin Weller and Michael Holaschke, 'The "Open Enough Challenge" — Investigating Tensions in Open Innovation Approaches to Aerospace R&D', *Science, Technology and Innovation* (Vol. 19, No. 1, 2024), pp. 1–14.

available tools and machines, such as FFF-3D-printers, for manufacturing. This may not achieve the same level of output when compared with industrial manufacturing but provide superior resilience against the elimination of production capabilities.

Conclusion: Opportunities in Systematising Liminal Spaces

This article had an alternative take on the concept of the air littoral by exploring it as a socio-technological, contested space. It provided a systematisation of UAVs currently deployed in the air littoral and differentiated them according to weaponisation, guidance, production, lifecycle and deployment logic. These five dimensions were derived from previous attempts, which were either insightful but too vague, or specific but added little value. The approach chosen in this article combined a case-oriented perspective with clearly defined categories. This allowed for analytical insights, while still enabling the abstraction of those insights beyond individual UAV case studies.

Subsequently, this initial systematisation sees the air littoral as a liminal space. As such, categorising UAVs is a matter of distinct physical features – such as MTOW – while also considering how they are embedded, for example, in terms of the underlying modes of production and their place in a broader, societal context.

In the final step, the article examined the rationale of the air littoral as the air liminal. The article articulated that there are a variety of associated actors – militaries, non-state-organisations, industries and backyard engineers – who intersect and colonise the littoral space. This allows for both a more holistic understanding of this airspace – one that goes beyond an exclusively spatial approach – and for the implementation of dedicated approaches to harness the productive potential of this intersection. The article then outlined three distinct opportunities that can be used to capitalise on this potential for cross-colonisation. It pointed to formats such as defence hackathons, concepts such as littoral literacy and design approaches such as design for backyard manufacturing to combine technological innovation, crowdsourcing and societal resilience. ■

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