A Ukrainian soldier stands among a swarm of first-person-view drones. (Photo courtesy of the National Guard of Ukraine)

Defining Swarm

A Critical Step Toward Harnessing the Power of Autonomous Systems

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The beginning of wisdom is the ability to call things by their right names.

—Confucius

Deputy Secretary of Defense Kathleen Hicks unveiled an initiative dubbed "Replicator" in August 2023 to accelerate fielding of autonomous systems at scale aimed at countering the rapid expansion of China's armed forces' capabilities.[1] This

ongoing endeavor signifies a concerted effort by the Department of Defense (DOD) to allocate resources toward the fielding and deployment of all-domain expendable autonomous capabilities at a scale capable of yielding significant impact. The introduction of this initiative is noteworthy, not only for its origin in lessons learned from the war in Ukraine but also in the context of the Pacific theater, where China's increasing military presence poses a considerable threat. However, it is essential to recognize that scale may not be sufficient to counter the mass (i.e., size) of near-peer adversaries, much less the proliferation of unmanned aircraft capabilities globally. For instance, a study by Jack Watling and Nick Reynolds highlights the substantial and unsustainable losses incurred by Ukrainian forces, with estimates suggesting that approximately ten thousand unmanned aircraft are lost per month.[2] This underscores the notion that reliance on scale alone is an insufficient countermeasure. The juxtaposition of a pronounced production advantage and a force size superiority exhibited by U.S. competitors highlights the need for a multifaceted approach. Specifically, recognizing these advantages should prompt a concerted innovation effort focused on optimizing the tactical efficacy of drone technologies and mitigating the existing disparities with near-peer competitors. This imperative is not merely a call to augment production quantities to outproduce adversaries but rather a strategic imperative to leverage innovation as a means of offsetting the competitive advantages. Ultimately, this approach acknowledges that the mere accumulation of quantities is an insufficient response to the complexities of modern warfare, and that a more sophisticated and innovative approach is required to ensure strategic superiority.

A more effective approach would necessitate a major directional shift toward enhanced drone autonomy and collaboration, wherein the current approach of acquiring commercial off-the-shelf solutions with traditionally one-to-one control methodologies is supplanted by more capable and efficient one-to-many architectures. Organizations can amplify their operational capabilities by leveraging autonomy and collaboration to achieve a more competitive posture in an increasingly complex and dynamic environment.

This article hypothesizes that the DOD faces significant obstacles in acquiring and operationalizing autonomy capabilities in drone warfare, with particular emphasis on the development, fielding, and deployment of drone swarms. It provides a concise examination of the historical context and ongoing efforts to overcome these challenges, shedding light on the complexities and nuances inherent in drone warfare. This article also highlights one of the main obstacles, which is the absence of a standardized, DOD-wide definition of swarm within the United States. It illuminates the detrimental consequences of definition ambiguity on the development of drone capabilities.

Ultimately, this article proposes a comprehensive definition of swarm that incorporates the essential parameters and characteristics necessary for inclusion in the *DOD Dictionary of Military and Associated Terms*. By establishing a foundational definition, this research aims to provide a framework for developing drone swarm capabilities, facilitating the creation of a shared understanding and a common operational picture among relevant agencies and stakeholders. This, in turn, is expected to enhance the DOD's ability to design, develop, and deploy effective drone swarm systems, ultimately contributing to the advancement of national security and defense capabilities.

Background

In a report sponsored by the Office of the Secretary of Defense

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over two decades ago, Sean Edwards postulated that the emergence of new technologies and increasing capability of data processing might allow for changes in doctrine, leading to the ability to leverage swarming.[3] Edwards acknowledged a lack of comprehensive appreciation of swarming within military history, and his resulting research project would add to the understanding and potential of it as an approach. Edwards's study on swarming was not a one-off. At the time, the historical discussion around drone technology and the military utility of swarms was surprisingly robust. Two RAND studies, one authored by John Arquilla and David Ronfeldt in 2000 and another by Sean Edwards in 2005, supported his earlier work on the concepts around swarming. In *Swarming and the Future of Conflict*, Arquilla and Ronfeldt described the changing battlefield environment in which the ability to amass forces is limited but potentially mitigated by employing a "swarm force" able to "deal with time-space constraints on military action."[4] Edwards's 2005 work added the demonstrated benefits of swarming against enemy forces, principally engagement simultaneity and convergence from multiple directions.[5] Likewise, in his 2008 thesis, "Swarm Tactics and the Doctrinal Void: Lessons from the Chechen Wars," William Shannon hypothesized the utility of developing swarming concepts by examining the advantages of such approaches during the First and Second Chechen wars against Russia.[6]

Innovation

Then–Secretary of Defense Chuck Hagel delivered a keynote speech on 15 November 2014 at the Reagan National Defense Forum in which he outlined a new Defense Innovation Initiative:

> The new Innovation Initiative will draw on the lessons of previous offset strategies and ensure that America's power-projection capabilities continue to sustain our competitive advantage over the coming decades. To achieve this, we are pursuing several lines of effort.
>
> Our technology effort will establish a new Long-Range Research and Development Planning Program that will help identify, develop, and field breakthroughs in the most cutting-edge technologies and systems—especially from the fields of robotics, autonomous systems, miniaturization, big data, and advanced manufacturing, including 3D printing. This program will look toward the next decade and beyond.
>
> In the near-term, it will invite some of the brightest minds from inside and outside government to start with a clean sheet of paper, and assess what technologies and systems DoD ought to develop over the next three to five years and beyond.[7]

In a subsequent War on the Rocks article written by Paul Scharre in 2015, he laid out a vision of the future with autonomy rather than teleoperation, swarm-on-swarm aerial battles, and swarms collaborating to "create simple formations."[8] Flash forward to 2023, and the U.S. Army announced its initiative to integrate robots into its fighting formations. This plan, as described by Jon Harper in DefenseScoop, starts with an architecture of human-machine integration that includes a four-to-one span of control over robotic platforms and other systems with varying degrees of autonomy.[9] Another Army initiative, the Low Altitude Stalking and Strike Ordnance program, is an Army Futures Command-directed requirement designed to increase the lethality of infantry brigade combat teams in light of lessons emerging from the Ukraine war. According to Harper, Low Altitude Stalking and Strike Ordnance capability includes rounds, fire control, and a ground data link.[10] A critical oversight in these initiatives is the absence of a swarm capability that enables the transition from a one-to-one or one-to-few teleoperated, or first-person view to a one-to-many paradigm. The incorporation of swarm capability is essential for effectively countering the anticipated mass of forces in conflict scenarios like those envisioned in the European or Pacific theaters, where the sheer scale of opposing forces necessitates a more robust and scalable autonomous system architecture.

Impediments

There has been a significant escalation in attention to drone warfare in recent years, with a notable surge within the U.S. military. Specifically, over the past five years, the U.S. Army, the joint force, and the DOD have exhibited an exponential increase in focus on unmanned aircraft systems (UAS) and its potential applications in modern warfare.[11] This heightened

“Despite the rapid maturation of drone technology worldwide, the development, fielding, and adoption of swarms in the United States remain hindered by a significant impediment.”

interest can be attributed to the rapidly evolving nature of drone technology and the growing recognition of its potential to revolutionize military operations and enhance national security.

Notwithstanding the increase in research and media attention devoted to drones and swarms, the DOD's continued lack of a swarm capability—and the absence of a program of record—represents a significant missed opportunity to leverage a potentially transformative technology. This raises a pertinent question: Given the rapid pace of development and the extensive history of study on the subject, why has the DOD been hesitant to adopt the concept of swarming fully? A plausible explanation lies in the inherent complexity of swarming technology. As highlighted in an article for IEEE (Institute of Electrical and Electronics Engineers), authors Ross Arnold et al. identify eight persistent challenges (software architecture, swarm hardware, replicable design, deployment, communications, testing, information fusion, and cooperative intelligence) that require continued research and development, underscoring the difficulties associated with realizing swarm capabilities.[12] These challenges likely contribute to the DOD's cautious approach in implementing swarming technology, emphasizing the need for sustained investment in research and development to overcome the technical hurdles and to unlock the potential of swarm-based systems. Technologically, swarming is by no means easy. Notwithstanding the challenges associated with swarming technology, advancements and demonstrations by DOD organizations like the Defense Advanced Research Projects Agency have yielded promising results. More specifically, programs like OFFensive Swarm-Enabled Tactics, System-of-Systems Enhanced Small Unit, and preceding efforts like Gremlins, and Fast Lightweight Autonomy have been instrumental in driving innovation and overcoming the technical hurdles impeding the deployment of large-scale uncrewed systems.[13] These endeavors have accelerated the development of critical technologies and provided a robust foundation for addressing the challenges of swarming. Consequently, the successes achieved through these and other programs instill a high degree of confidence that the technical obstacles to swarming are surmountable. The pursuit of swarming technologies is not unique to the United States, as other nations are actively engaged in also developing and maturing these capabilities. For instance, the Indian army has leveraged emergency procurement powers to acquire advanced drone systems, while China continues to aggressively pursue the development of drone swarm capabilities, underscoring the growing recognition of the strategic importance of these technologies.[14] Furthermore, the purported deployment of artificial intelligence-enabled swarms in the summer of 2021 by Israel Defense Forces constitutes a seminal milestone in the maturation of swarming technologies, marking the first reported combat employment of such systems.[15] The fact that multiple countries are concurrently advancing their swarming capabilities highlights the emergence of these technologies as a key component of contemporary military strategy with the potential to impact the character and conduct of future conflicts significantly.

Despite the rapid maturation of drone technology worldwide, the development, fielding, and adoption of swarms in the United States remain hindered by a significant impediment. This impediment centers around the absence of a universally accepted DOD definition of swarm, which, in turn, precludes the establishment of standardized terminology and nomenclature. This lack of semantic consistency poses a substantial barrier as it impedes the creation of a clear requirement, facilitates ineffective communication, and hinders coordination and innovation among diverse stakeholders. The resultant inconsistent use of terminology can lead to confusion, misinterpretation, and duplication of effort, ultimately, stifling the advancement of research and development. Therefore, an accepted DOD definition is essential for establishing a common lexicon, facilitating

effective communication, and enabling the development of a standardized framework for developing, testing, and evaluating swarm capabilities.

Impact

The Joint Requirements Oversight Council's Joint Capabilities Integration and Development System (JCIDS) is the primary framework to evaluate capabilities, identify gaps, and prioritize requirements.[16] This process also enables the conduct of DOTMLPF-P (doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy) analysis, which informs the development of mitigation strategies to address identified shortfalls. The initiation of the JCIDS process typically commences with a capability-based assessment, a DOTMLPF-P examination, or the identification of an operational need. A common thread among these approaches is defining a specific capability to catalyze JCIDS.

Without a standardized definition, any analysis or assessment of swarm capability is likely to be inconsistent, incomplete, or even overlooked. The lack of a unified definition also increases the risk of confusion and misunderstanding among operational user communities, leading to ungrounded operational analysis and ineffective capability development. The existence of multiple, disparate definitions can further exacerbate the issue, resulting in a fragmented and incoherent approach to swarm capability development.

The dearth of a DOD-wide definition has significantly hindered the progress of swarm technology, relegating it to conceptual demonstrations and "firework displays" rather than a mature, warfighter-ready capability. Moreover, the absence of a clear and concise definition has also prevented the JCIDS process from being effectively applied to swarm capability development, slowing the transition of swarm technology from the experimental phase to operational deployment. Establishing a standardized definition is essential to rectify this situation, providing a foundation for coherent capability development, effective operational analysis, and ultimately, the fielding of swarm capabilities that can offer a significant advantage to a warfighter.

Swarm

The term "swarm" is beset by a lack of standardization in its definition despite its widespread usage in both colloquial and technical contexts, including governmental and military domains. The complexities inherent in defining swarm are further compounded by its linguistic properties, specifically its status as a noun-verb or verb-noun word, which can lead to semantic ambiguity and concomitant difficulties in interpretation. To mitigate this issue, it is essential to establish a clear distinction between the noun and verb forms and to explicitly delimit the scope of the present discussion to the noun variant.

By doing so, it becomes possible to exclude the attributes and connotations associated with the verb form, such as swarming, swarm behaviors, and swarm intelligence, which often imply dynamic and adaptive processes, and notions of autonomy, independence, and complex behavioral characteristics. This exclusion enables a more precise and nuanced definition of swarm as a noun, unencumbered by the extraneous connotations and implications that are typically implied by the verb form.

The importance of establishing a clear and concise definition of the noun form cannot be overstated. It is essential for facilitating effective communication, coordination, and innovation among stakeholders, including researchers, developers, and operators. A standardized definition of swarm would provide a common lexicon and framework for understanding, thereby enabling the development of a shared understanding and a cohesive approach to swarm capability development within the DOD.

Furthermore, a well-defined and widely accepted definition would serve as a foundation for the development of swarm-related concepts, doctrines, and technologies, and would provide a basis for evaluating the efficacy and potential of swarm capabilities in various contexts. Ultimately, establishing swarm as a noun is a necessary precursor to developing a robust and effective swarm capability and is essential for unlocking the full potential of swarming technologies in support of national security objectives.

A comprehensive review of authoritative U.S. governmental sources—including the *U.S. Government Compendium of Interagency and Associated Terms*, the *DOD Dictionary of Military and Associated Terms* (*DOD Dictionary*), and the Terminology Repository—reveals a notable absence of a standardized definition for swarm.[17] This omission is striking, given the widespread

usage and increasing relevance of swarming concepts in various scientific, technological, and military contexts.

It is essential to acknowledge that the lack of a formal definition in these authoritative sources does not imply that definitions of swarm do not exist or are not utilized within the DOD or other relevant communities. On the contrary, the term is ubiquitous in science and technology literature, and each definition employed by a particular community or discipline is intentionally crafted to convey specific meaning and context.

Consequently, these definitions exhibit a considerable range of complexity and nuance, spanning from simplistic to intricate and multifaceted. For example, Arnold et al.'s definition—"a group of three of more robots that perform tasks cooperatively with limited human intervention"—is narrowly focused.[18] In contrast, Marco Dorigo et al. include a broader scientific structure to define swarm robotics as being inspired by the self-organization found in natural systems like insect colonies and fish schools, aiming for robotic systems that are more robust and adaptable than those of individual robots.[19] This diversity of definitions is not surprising, given the multidisciplinary nature of swarming concepts, which encompass fields like biology, physics, computer science, and engineering. The resultant variability in definitions underscores the need for a standardized and widely accepted definition to facilitate effective communication, coordination, and innovation.

The absence of a unified definition also highlights the challenges associated with developing a shared understanding of swarming concepts and their applications, particularly within military operations and national security. As the DOD and other organizations continue to explore the potential of swarming technologies, establishing a clear and concise definition will be essential for ensuring a common framework for understanding, developing, and deploying these capabilities.

A soldier assigned to 1st Battalion, 4th Infantry Regiment, prepares a swarm of TS-M800 drones during Combined Resolve 25-1 in Hohenfels, Germany, on 4 February 2025. The U.S. Army is implementing its Transforming in Contact initiative during Combined Resolve 25-1, utilizing new technologies and systems designed to enhance its warfighting readiness and ability to respond to crisis or conflict. (Photo by Sgt. Collin Mackall, U.S. Army)

Confusion

A review of existing literature reveals a notable diversity in the definitions of swarm, with varying degrees of emphasis on collaboration, autonomy, and collective behavior. For instance, a 2018 report by the National Academies of Sciences, Engineering, and Medicine relied heavily on the requirement for collaboration, implying that a swarm is characterized by the coordinated efforts of multiple entities working toward a common objective.[20] Similarly, researchers presenting at the 2023 IEEE International Conference on Pervasive Computing and Communications Workshops defined swarm as "a group of drones that collaborate to accomplish a common goal," further emphasizing the importance of cooperative behavior.[21]

In contrast, the aforementioned 2018 report from the National Academies of Sciences, Engineering, and Medicine proposed a more nuanced definition, characterizing a swarm as "a group of 40 or more small UAS (SUAS)" that "act as a unit with individual behaviors," "communicate with one another," and "position themselves relative to other sUAS."[22] This definition

highlights the complexity and sophistication of swarming systems, which involve the coordination of numerous individual entities that interact and adapt to their environment in a decentralized manner.

Tasked with researching and summarizing the different DOD and armed services definitions of swarm, the Defense Systems Information Analysis Center revealed a striking lack of consensus from its 2019 report.[23] By examining six sources released between 2000 and 2019, the report highlighted the diversity of definitions and the need for a standardized understanding of swarm. This finding underscores the challenges associated with developing a shared understanding of swarming concepts and its applications.

The existence of multiple disparate definitions underscores the need for a comprehensive and widely accepted definition that can facilitate effective communication, coordination, and innovation across different stakeholders and communities. The development of such a definition will require a nuanced understanding of the complex interactions and behaviors that characterize swarming systems and a thorough examination of the various contexts in which these systems are employed. Ultimately, a standardized definition will be essential for unlocking the full potential of swarming technologies and ensuring their effective integration into military operations and national security strategies.

Inclusion

The absence of a definition for swarm in the *DOD Dictionary* is a significant omission, particularly given the document's role as a foundational reference for joint doctrine. As an authoritative source, the *DOD Dictionary* is intended to provide a standardized lexicon that facilitates a common understanding among military personnel, thereby enabling the joint force to organize, plan, train, and execute operations effectively.

The *DOD Dictionary* aims to establish a shared vocabulary, ensuring that military personnel across different branches, specialties, and echelons can communicate effectively and operate from a common frame of reference. Including definitions for key terms and concepts is essential for achieving this goal, as it enables military personnel to understand and apply doctrine, tactics, techniques, and procedures in a consistent and coordinated manner.[24]

Beyond the operational rationale for inclusion is purpose and policy. As a matter of purpose, the *DOD Dictionary* is designed to supplement "standard English-language dictionaries and standardizes military and associated terminology to improve communication and understanding within DOD with other United States Government departments and agencies and among the United States and its allies."[25] Including swarm is in alignment with that purpose.

Using the established criteria from Chairman of the Joint Chiefs of Staff Instruction 5705.01H, *Standardization of Military and Associated Terminology*, swarm satisfies the applicable nineteen policy criteria for consideration as an approved military term and inclusion in the *DOD Dictionary*. Importantly, the term meets the following criteria:

- "The term in a commonly accepted English-language dictionary is inadequate for DOD use."
- "The term is of general military significance."
- "An approved joint term with a similar definition does not exist."[26]

The term in a commonly accepted English-language dictionary is inadequate for DOD use. In its noun form, "swarm" is defined in the *Merriam-Webster Dictionary* as

> 1.a. a great number of honeybees emigrating together from a hive in company with a queen to start a new colony elsewhere
> 1.b. a colony of honeybees settled in a hive
> 2.a. a large number of animate or inanimate things massed together and usually in motion: Throng
> 2.b. a number of similar geologic features or phenomena close together in space or time[27]

The prevailing dictionary definitions are insufficient within the DOD context, as they exhibit significant shortcomings.

First, these definitions fail to provide specificity regarding the minimum number of objects that constitute a swarm, thereby permitting disparate interpretations and hindering the ability to conduct comparative analyses of emerging capabilities. This lack of clarity undermines the development of a standardized understanding of swarm concepts, which is essential for evaluating and integrating swarm technologies into military operations.

Second, the existing definitions focus on the spatial proximity of component entities, emphasizing their

physical closeness rather than the nature of their control or coordination. This emphasis on proximity rather than control obscures the critical distinction between a swarm and other collective entities like a group or a formation. It neglects the complex interactions and organizational structures that characterize swarm systems.

Third, the inclusion of behavioral characteristics in these definitions unnecessarily complicates the term and blurs the distinction between the noun "swarm" (referring to the collective entity itself) and the verb "to swarm" (describing the act of moving or behaving in a swarm-like manner). This conflation of the noun and verb instances introduce ambiguity and confusion, making it challenging to develop a precise and consistent understanding of swarm concepts and its applications in a military context.

To accurately capture the complexities of swarm systems, the DOD definition of swarm must rectify the existing deficiencies and provide a more sophisticated and contextually relevant understanding of this multifaceted concept. Such a definition should be informed by the current capabilities and practices within the DOD, acknowledging the existing landscape of swarm-related technologies and operations.

The term is of general military significance. The military significance of swarming technologies has been extensively demonstrated across the DOD through decades of research, development, and experimentation. The efficacy of swarming concepts has been consistently validated through various studies, simulations, and field tests, highlighting their potential to revolutionize modern warfare. Evidence supporting this potential includes historical analysis, such as Edwards's twenty-five-year-old review of swarming tactics throughout military history—ranging from ancient horse-archer battles to the urban combat in Mogadishu in 1993, a more recent 2018 National Academies report on the threat of coordinated, collaborative groups and swarms, and in live experiments like the aforementioned Defense Advanced Research Projects Agency OFFSET program which in November 2022 demonstrated single operator control of 130 drones during an experiment at Fort Campbell, Kentucky.[28]

In addition, the international community has witnessed the employment of swarming technologies in various conflict zones around the world. News reports and commentary from global media outlets have highlighted the use of drones in conflicts such as the Armenia-Azerbaijan dispute over the Nagorno-Karabakh region, the civil wars in Yemen and Sudan, and the ongoing war in Ukraine.[29] Additionally, there have been numerous reports of drone attacks against Israel, underscoring the growing threat posed by swarming technologies in modern conflict.[30]

The accumulation of evidence from various sources, including research and development, experimentation, and real-world conflicts, demonstrates the military significance of swarming technologies and highlights the need for a standardized definition and understanding of swarm.

An approved joint term with a similar definition does not exist. A document review of the *DOD Dictionary* and current joint doctrine publications—encompassing publications like joint operations, joint intelligence, and specific functional area manuals revealed no entries for the term swarm.

Alignment with emerging concepts and technologies. The imperative to counter adversarial advancements in drone technology and the DOD's concerted effort to accelerate innovative concepts in autonomy serve as compelling evidence of the necessity for a standardized definition. The swift advancement of drone technology and its burgeoning dissemination among adversarial entities, coupled with the DOD's intensified focus on countermeasures, underscores the imperative of establishing a standardized definition. The exponential growth of drone capabilities and their increasing adoption by adversaries has created a complex and dynamic threat landscape, necessitating the development of effective countermeasures and strategies.

Interpretation

As previously noted in a 2019 Defense Systems Information Analysis Center report, a comparative analysis of various definitions of swarm revealed certain commonalities, including the notion that a swarm typically consists of multiple UASs (greater than two) and that individual behaviors must combine to achieve unity of effort.[31] This report highlighted the importance of establishing a standardized definition to facilitate a common understanding among stakeholders.

Building on this research, a more recent article published in the *Journal of the Joint Air Power Competence Centre* identified several key criteria that

Soldiers assigned to the 3rd Battalion, 320nd Field Artillery Battery, 3rd Brigade Combat Team, 101st Airborne Division, react to a drone swarm attack during Exercise Combined Resolve 24-2 at the Joint Multinational Readiness Center near Hohenfels, Germany, on 29 May 2024. (Photo by Sgt. 1st Class Brandon Nelson, U.S. Army National Guard)

can be used to define swarm.[32] These criteria, developed through a comprehensive review of existing literature and expert opinion, provide a framework for understanding the complex and dynamic nature of swarming technologies. The perspective of the article's authors, Haider and Schmidt, emphasizes the importance of identifying a "common denominator" in defining a swarm, resonating within this article's central premise.[33] Specifically, their focus on the "outside appearance" of a swarm rather than its "inner workings" or verb tense, aligns with the approach taken in this article, which is prioritizing the definition of the noun form over its associated verb forms or internal dynamics.[34] This approach is grounded in the recognition that a definition of swarm is essential for facilitating a common understanding among stakeholders, particularly within military operations. The definition proposed by Arnold et al. relies on three key criteria—size, control, and interaction—and provides further support for the approach.[35] By emphasizing the importance of these criteria, Arnold et al. highlight the need for a definition that captures the essential characteristics while also acknowledging the complexities and nuances of swarming behaviors. Similarly, the definition offered in this article is bound by a set of elements that distinguish it from civilian definitions and incorporate the military context as required by policy. These elements, which include the number of UASs involved, the level of autonomy and decentralization, and the degree of coordination and cooperation among individual UAS, provide a framework for understanding the unique challenges and opportunities presented by swarming technologies in a military context.

Number within swarm. This element is needed to link to other definition characteristics without identifying a minimum (> 1) or maximum number.

Interaction. Internal interactions or coordinated activities are characteristics without mentioning how those actions are achieved (e.g., autonomy).

Span of control. Differentiates a swarm from a formation in which more than one operator is needed to control the objects.

Architecture. Linked to the span of control and reinforces the necessity of coordinated activity.

> My proposed definition of swarm follows: *An assembly that operates cooperatively to commands from a single operator in charge through a common architecture.*

A comprehensive review of existing U.S. government definitions reveals that the sole formal articulation of a swarm definition is encapsulated within the 2017 Federal Aviation Administration (FAA) Order JO 7200.23A, *Unmanned Aircraft Systems*.[36] This definition provides a foundational understanding of swarm operations, characterizing them as "an operation of more than one Unmanned Aircraft (UA) in which all UAs operate in unison to commands from one Pilot in Charge (PIC), who commands them all through a common link."[37] This definition serves as a baseline for understanding swarm operations, but its applicability to the DOD context is limited by its focus on civilian aviation operations.

To develop a definition more congruent with the specific needs and operational contexts of the DOD, this article's research proposes a modified definition that builds upon the FAA's definition while incorporating the DOD's distinctive elements and requirements. This proposed definition aims to provide a more sophisticated and nuanced understanding of swarm operations, one that is grounded in the unique challenges and opportunities presented by the DOD's operational environment. The DOD's operational context, characterized by complex and dynamic scenarios, necessitates a definition that accounts for the distinctive characteristics of military swarm operations, including autonomous systems, decentralized command and control, and the need for adaptability and resilience in the face of uncertainty.

Therefore, the proposed definition seeks to incorporate elements that include the number and type of unmanned systems involved, the level of autonomy and decentralization, and the degree of coordination and cooperation among individual systems. By incorporating these elements, this proposed definition aims to provide a more comprehensive and nuanced understanding of swarm operations specifically tailored to the DOD's unique needs and requirements. Additionally, it will facilitate the development of effective countermeasures and strategies, support the integration of swarming technologies into existing operational frameworks, and enable the advancement of the DOD's future military capabilities.

My proposed definition of swarm follows:

An assembly that operates cooperatively to commands from a single operator in charge through a common architecture.

Regarding the aforementioned elements of this definition, "assembly" indicates the number within the swarm, "operates cooperatively" describes interaction and coordination, and "commands from a single operator in charge" refers to the span of control.

Closing

This article's research engages in a rigorous and systematic examination of a diverse array of swarm definitions, encompassing both civilian and military spheres and the term's contemporary relevance within the military context. Through a comprehensive synthesis of the findings, a refined and nuanced definition of swarm is formulated, one that preserves the essential elements of the existing FAA definition while also integrating the contextual subtleties necessary to facilitate its effective application within the DOD.

The development of a universally accepted definition is of paramount importance, as it constitutes a necessary precursor to the efficient progression of the acquisition process and the resolution of the semantic ambiguities that hinder effective utilization. The absence of a standardized definition has resulted in a lack of clarity and consistency in its application, thereby impeding the ability to communicate effectively and to develop a shared understanding of the concept.

Establishing a clear and concise definition is essential for facilitating the development of effective strategies, tactics, and procedures for employing swarming technologies. Furthermore, a standardized definition will enable the efficient allocation of resources,

the optimization of acquisition processes, and the enhancement of interoperability among different systems and platforms.

Moreover, establishing a universally accepted definition of swarm will have far-reaching implications for the DOD's ability to operate effectively in a rapidly evolving and increasingly complex operational environment. The development of swarming technologies is a key aspect of the DOD's strategy for maintaining a competitive advantage. A definition of swarm will enable the DOD to develop effective countermeasures and strategies, to integrate swarming technologies into existing operational frameworks, and to enhance its military capabilities in the years to come. ■

Notes

Epigraph. Quoted in J. B. Veale Jr., "The Beginning of Wisdom Is the Ability to Call Things by Their Right Names. Confucius," *Journal of the American Academy of Gold Foil Operators* 17, no. 2 (1974): 49–55.

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