Defense Systems
Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Defining Unmanned Aerial Systems (UAS) Swarms

Report Number:
DSIAC-2020-1208
Completed August 2019

DSIAC is a Department of Defense
Information Analysis Center

MAIN OFFICE
4695 Millennium Drive
Belcamp, MD 21017-1505
443-360-4600

REPORT PREPARED BY:
Travis Kneen
Office: DSIAC

ABOUT DSIAC

The Defense Systems Information Analysis Center (DSIAC) is a U.S. Department of Defense Information Analysis Center sponsored by the Defense Technical Information Center. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

DSIAC serves as the national clearinghouse for worldwide scientific and technical information for weapon systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. We collect, analyze, synthesize, and disseminate related technical information and data for each of these focus areas.

A chief service of DSIAC is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. For more information about DSIAC and our TI service, please visit www.DSIAC.org.

ABSTRACT

Unmanned aerial systems (UAS) swarming is a debated term within the Department of Defense (DoD) community and has varied definitions depending on the organization discussing it. The Defense Systems Information Analysis Center (DSIAC) was tasked with researching how different U.S. DoD organizations and U.S. Armed Services define UAS swarms. DSIAC used open sources, conference presentations, and subject matter expert input to collect and summarize published DoD definitions of UAS swarms.

Contents

Table

1.0 TI Request

1.1 INQUIRY

How do different Department of Defense (DoD) organizations define unmanned aerial systems (UAS) swarms?

1.2 DESCRIPTION

The inquirer is studying the effects of and counter-actions for an aggressive UAS swarm.

2.0 TI Response

The U.S. DoD is constantly seeking solutions to reduce the number of warfighters in hostile situations, with unmanned and autonomous weapons being one such solution [1]. However, in a 2017 *NATO Review* magazine article, the authors note that there is no legal or agreed upon definition of autonomous UAS [2]. The authors define swarms as UAS that follow and take tasks from other UAS, but the authors neither specify a minimum number for a swarm nor pinpoint a definition of autonomous UAS [2].

Furthermore, in a 2017 *Joint Forces Quarterly* article, the author, Jules Hurst, states that there is reluctance to begin theorizing about specific swarm tactics as there is no clear developmental path in the technology. Hurst states that nobody knows what swarm combatants will look like or what the capabilities will be, with multiple prototype pathways being explored. Hurst theorizes that there will be two broad categories of future swarm combatants: "fire support swarms" and "maneuver swarms." It is mentioned that swarms should be inserted into the five forms of offensive maneuver recognized under Army doctrine. It is also noted that Air Force and Naval assets will play critical roles in the delivery, sustainment, and cyber protection of UAS swarms on land and in air and sea [3].

In a 2000 RAND Corporation publication on swarming, authors John Arquilla and David Ronfeldt present a definition of swarming that has been referenced in several subsequent publications: "engaging an adversary from all directions simultaneously, either with fire or in force" [4].

The Federal Aviation Administration (FAA) has been a leader in UAS policy on U.S. soil, specifically regarding the operation of an unmanned aircraft (UA) by a pilot in command (PIC) in the National Air Space (NAS). The FAA defines a swarm as "an operation of more than one UA in which all UAs operate in unison to commands from one PIC, who commands them all through a common link" in the Order JO 7200.23A policy [5].

Ben Clough, a control automation technical leader for the Air Force Research Laboratory (AFRL), defined swarming in a 2002 conference publication as "a collection of autonomous individuals relying on local sensing and reactive behaviors interacting such that a global behavior emerges from the interactions." In other words, swarming is an emergent behavior that relies on the interactions of individuals running simple local rules and depends on the local agents having reactive rules arranged in a subsumptive architecture. Swarming was deemed well suited for 1) area search and attack where target distribution and location are not known; 2) surveillance, diversion, and suppression of hostile force's actions; 3) psychological warfare; and 4) system software complexity reduction (as proper algorithms allow the UAS to make collective decisions rather than individual UAS control). He differentiates swarms and teams of robots, which is an important differentiation (Table 1) [1].

Table 1: Comparison of Swarm and Team Attributes [1].

Attribute	Swarm	Team
Temporal	Reactive	Predictive
Composition	Homogeneous	Heterogeneous
Interrelationships	Simple	Complex
Predictability	Probabilistic	Deterministic
Individual Worth	Expendable	Critical
Efficiency	Low	High

The restricted report *Counter-Unmanned Aircraft System (CUAS) Capability for Battalion-and-Below Operations* [6] was presented by Lieutenant Colonel Albert A. Sciarretta, the Chair on the National Academies of Sciences, Engineering, and Medicine's Committee for Battalion-and-Below Operations. The National Academies of Sciences, Engineering, and Medicine describe swarms as operator-enabled or software-enabled coordinated groups of UAS. In this report, the authors define a swarm as a group of 40 or more small UAS (sUAS) where the following criteria are met:

- The group seems to act as a unit, but each individual executes local behaviors.
- Not all members know the mission.
- Swarming members communicate with one another.
- Each sUAS will not focus on a designated position, but rather will position itself relative to other sUAS.

The report also has predictions for three time frames: immediate (2017−2019), intermediate (2020−2022), and emerging (2023−2025). These predictions are discussed in the classified version of the report [7].

Ross Arnold, a senior research engineer from the U.S. Army Combat Capabilities Development Command Armaments Center (CCDC-AC), wrote a draft research paper on swarming robotics titled "What is Swarming Robotics, and Why Swarms?" [8]. He defines a robot swarm as a group of three or more robots that perform tasks cooperatively while receiving limited or no control from human operators. The author also expounds upon this definition and provides examples of swarms versus non-swarms [9]. The subject matter expert noted that the definition may evolve as the draft is revised, though a presentation of the work can be found in "Applying Multi-Agent Swarm Artificial Intelligence to Armament Systems" [10].

Although there does not seem to be a consensus on the definition of UAS swarms, all preliminary definitions mention multiple UAS (anywhere from 2 to 40+) that use individual behaviors to work as a unit. The ideology stems from nature, as seen in the swarming behavior of wolves, ants, fish, or bees, as is explained by Maj. Andrew William Sanders in his monograph, *Drone Swarms* [11].

3.0 Further Reading

1. *The American Way of Swarm: A Machine Learning Strategy for Training Autonomous Systems* [12]

This Naval Postgraduate School thesis presents novel strategic frameworks that can train UAS algorithms to be effective at decentralized execution, rather than the current algorithms that limit the speed and flexibilities of swarms. The authors summarize the history of swarming and describe examples of existing swarms. They propose that using wargames and machine learning techniques can assist in optimizing UAS decision making.

2. *AI, Robots, and Swarms: Issues, Questions, and Recommended Studies* [13]

The author explores state-of-the-art artificial intelligence (AI), machine-learning, and robot technologies (including swarming) in this publication, including the history of the technologies and recommended future studies. Robotic swarms are described and examples of hardware- and software-based swarms are discussed. An individual robot in a swarm is described as autonomous; situated in the environment; capable of sensing their local environment and other nearby robots; able to communicate locally with other robots; unaware of the global state of the environment and other robots; and able to cooperate with other robots to perform a given task.

REFERENCES

[1] Clough, B. T. "UAV Swarming? So What are Those Swarms, What are the Implications, and How Do We Handle Them?" Conference Paper, AFRL-VA-WP-TP-2002-308, Distribution A. Air Force Research Laboratory. https://apps.dtic.mil/dtic/tr/fulltext/u2/a405548.pdf, 2002.

[2] Dyndal, Col. G. L., LtCol T. A. Berntsen, and S. Redse-Johansen. "Autonomous Military Drones: No Longer Science Fiction." *NATO Review Magazine*. https://www.nato.int/docu/review/2017/Also-in-2017/autonomous-military-drones-no-longer-science-fiction/EN/index.htm, 28 July 2017.

[3] Hurst, J. "Robotic Swarms in Offensive Maneuver." *Joint Forces Quarterly*, 4th Quarter 2017, pp. 105−111. https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-87/jfq-87_105-111_Hurst.pdf?ver=2017-09-28-093018-793, 2017.

[4] Arquilla, J., and D. Ronfeldt. *Swarming and the Future of Conflict*. RAND Corporation. https://www.rand.org/pubs/documented_briefings/DB311.html, 2000.

[5] Federal Aviation Administration. "Air Traffic Organization Policy: Unmanned Aircraft Systems (UAS)." Order JO 7200.23A. U.S. Department of Transportation. https://www.faa.gov/documentLibrary/media/Order/JO_7200.23A_Unmanned_Aircraft_Systems_(UAS).pdf, 27 June 2017.

[6] National Academies of Sciences, Engineering, and Medicine. *Counter-Unmanned Aircraft System (CUAS) Capability for Battalion-and-Below Operations: Abbreviated Version of a Restricted Report*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24747. 2018.

[7] Sciarretta, A. A. "Challenges for Countering Individual and Multiple Small UASs That Are Weaponized or In Non-Weaponized Modes." Presented at the *Counter UAS USA Summit*, Pentagon City, VA, 12−14 March 2019.

[8] Arnold, R., K. Carey, B. Abruzzo, and C. Korpela. "What is Swarming Robotics, and Why Swarms?" U.S. Army Combat Capabilities Development Command Armaments Center (CCDC-AC), Draft Publication, 2019.

[9] U.S. Army Combat Capabilities Development Command Armaments Center (CCDC-AC). Senior Research Engineer. Email Correspondence. July 2019.

[10] Arnold, R.D. "Applying Multi-Agent Swarm Artificial Intelligence to Armament Systems." U.S. Army CCDC(AC). https://slideplayer.com/slide/17517741/, 5 June 2019.

[11] Sanders, Maj. A. W. *Drone Swarms*. Monograph. School of Advanced Military Studies, United States Army Command and General Staff College. https://apps.dtic.mil/dtic/tr/fulltext/u2/1039921.pdf, 2017.

[12] Schuety, C. W., and L. E. Will. *The American Way of Swarm: A Machine Learning Strategy for Training Autonomous Systems*. Thesis. Naval Postgraduate School. https://apps.dtic.mil/dtic/tr/fulltext/u2/1069733.pdf, December 2018.

[13] Ilachinski, A. "AI, Robots, and Swarms: Issues, Questions, and Recommended Studies." CNA Solutions. https://www.cna.org/cna_files/pdf/DRM-2017-U-014796-Final.pdf, January 2017.