SOAR

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SEPTEMBER 2024

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ATTRITABLE UNMANNED AIRCRAFT SYSTEMS: CONCEPTUALIZATION AND KEY PLAYERS

By Deanna C. Milonas, Taylor H. Knight, and Eric Hundman
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DEANNA C. MILONAS, TAYLOR H. KNIGHT, AND ERIC HUNDMAN

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Air domain operations are critical to the U.S. military defense strategy. Military air domain missions use aircraft for tasks like attack; resupply; rescue; intelligence, surveillance, and reconnaissance; etc. Historically, air domain missions required manned aircraft, putting the aviator at risk. In the 1990s, the military began replacing manned aircraft with unmanned aircraft. Unmanned aerial systems (UASs) remove the risk to human aviators and are considered extremely valuable assets. Recently, the value of some UASs has rapidly declined with technological improvements inherent to aerial systems. The cost of some UASs is so low that they are being named attritable.

Attritable systems are viewed as a spectrum ranging from expendable (intended to be lost) to manned (plan to get back) and have become a focus of the U.S. military. In support of a U.S. Department of Defense (DoD) priority for fielding attritable systems, this report provides the state of the art for attritable aircraft for multidomain operations. It begins by setting boundaries on the types of attritable aircraft covered, defined by the missions manned aircraft would conduct, and discusses conceptualization of attritable aircraft within the DoD. The scope and prioritization of attritable aircraft discussed includes UASs in development, prototyped, or readily available.

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ABSTRACT

Air domain operations are critical to the U.S. military defense strategy. Military air domain missions use aircraft for tasks like attack; resupply; rescue; intelligence, surveillance, and reconnaissance; etc. Historically, air domain missions required manned aircraft, putting the aviator at risk. In the 1990s, the military began replacing manned aircraft with unmanned aircraft. Unmanned aerial systems (UASs) remove the risk to human aviators and are considered extremely valuable assets. Recently, the value of some UASs has rapidly declined with technological improvements inherent to aerial systems. The cost of some UASs is so low that they are being named attritable.

Attritable systems are viewed as a spectrum, ranging from expendable (intended to be lost) to manned (plan to get back) and have become a focus of the U.S. military. In support of a U.S. Department of Defense (DoD) priority for fielding attritable systems, this report provides the state of the art for attritable aircraft for multidomain operations. It begins by setting boundaries on the types of attritable aircraft covered, defined by the missions manned aircraft would conduct, and discusses conceptualization of attritable aircraft within the DoD. The scope and prioritization of attritable aircraft discussed includes UASs in development, prototyped, or readily available.

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SECTION 01 NOTE ON TERMINOLOGY

The term "attritable" has been used recently to describe a new class of unmanned platforms, particularly in light of the recent Replicator initiative. The root of attritable comes from attrition and means to "undergo attrition." Attrition is a common military strategy that means "destroying an opponent's forces faster than they can be replaced, while at the same time ensuring one's own rate of loss remains bearable" [1]. When defining these unmanned platforms, attritable should not be confused with expendable, as they are meant to be low cost. The intent of attritable equipment is not to be lost, but a higher rate of loss may be deemed acceptable by the commander.

Platforms mentioned in this report are referred to as attritable. When used in this report, attritable refers to unmanned aerial systems (UASs) that are low cost, emphasize the value of life, and are designed for use in environments where the risk of attrition is higher than acceptable for manned platforms. In addition, the terms "unmanned aerial system (UAS)," "unmanned aerial vehicle (UAV)," and "drone" are used interchangeably throughout the report.

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SECTION 02 INTRODUCTION

Operations in the air domain are critical to the U.S. military defense strategy. Military air domain missions use aircraft for a variety of tasks such as attack; resupply; rescue; intelligence, surveillance, and reconnaissance (ISR); and more. Historically, air domain missions required that the aircraft be manned, putting the aviator at risk. Starting in the 1990s, the military began to replace manned aircraft with unmanned aircraft (UASs), also referred to as uncrewed aircraft.

Manned aircraft are crewed by trained pilots and intelligence specialists, offering the benefits of human decision-making capabilities. UASs remove the risk of the valuable human aviators, but they are still extremely valuable assets. An enduring military adage is, "If you can see it, you can hit it. If you can hit it, you can kill it." With rapid evolution and adoption of UASs, the whole battlefield can now be seen. UASs remove the danger of putting the pilot at risk of injury, capture, or death; can be deployed for longer durations of time in dangerous settings; and are typically cheaper than manned aircraft [2]. According to Bentz [3]:

> The first use of the term "attritable" in official U.S. Department of Defense (DoD) program documentation is found in a 1999 report on the Predator system published by the Director, Operational Test and Evaluation (DOT&E). Through reporting the current state of operational testing, the DOT&E described the Predator system as a "system that operates autonomously, is attritable (air vehicle cost is less than $3.5M), and does not compromise sensitive technology should it be lost over enemy territory" (DOT&E, 1999 [4]). This report suggests that a system's "attritability" is a function of the tolerance of its loss. An attritable system is one [that] is designed such that the user is not unduly averse to the system's loss.

Today, UASs of different shapes and sizes are being used within the military for a variety of missions, all of which come with risks. As the U.S. Special Operations Command has stated, "The rapidly evolving world of unmanned systems has upended modern warfare and is leading to generational changes on the battlefield in a matter of months rather than decades" [5].

For the United States to be able to protect the nation if forced to engage in a near-peer fight, the need for attritable UASs that can be employed in the battlespace and affordably accomplish their missions increases. "The key attribute is that U.S. forces can rapidly reproduce these UASs in the battlefield at a faster (and hopefully more affordable) pace than the enemy can attrit them" [6]. "The key to victory, if the [United States] is forced to engage in a near-peer fight, will rely on the adoption of attritable weapon systems: simplistic in design, rapidly reproducible, and highly lethal" [7].

The Air University set the following requirements for attritable systems [8, 9, 10]:

- They are "inexpensive and fielded in the hundreds of thousands of units" [8].
- They "support global persistent awareness, and resilient information sharing, as defined in the U.S. Air Force's [USAF's] 2019 Science and Technology Strategy" [8, 9].
  - The USAF 2019 Science and Technology Strategy defines the goal of global persistent awareness as supporting "continuous and timely knowledge of adversaries throughout the operating environment via distributed sensing across all domains." The goal of resilient information sharing is described as coordinating "across all joint force assets through assured communications and precise positioning, navigation, and timing information resilient to any denial methods" [9].
- They "can be lost, or exposed, with minimal intel gain loss (IGL) and technical gain loss (TGL), emphasizing 'commercial-off-the-shelf' (COTS) sourcing" [8].
  - IGL and TGL are terms used by the U.S. military and intelligence. IGL describes "the problem of deciding whether the value of collecting information from an enemy target is more worthwhile than destroying it" [10].
- They can "be fielded without dedicated manpower and logistics" [8].
- They are "resilient to peer adversary countermeasures as an ISR constellation, when employed in sufficient numbers" [8].
- They "can be 'seeded' in a conflict zone, either preconflict or postconflict" [8].
- They "can be 'donated' to a supported nation without IGL/TGL concerns" [8].

Attritable systems should be viewed as a spectrum ranging from expendable (intended to be lost) to manned (always plan to get back). These systems should be designed with the intent of not being long term but being routinely reusable and low cost. Low cost refers to being cheap enough to use in contested environments where the risk of attrition is higher than acceptable for manned aircraft [11]. This gives the combatant commander a range of risk regarding possible aircraft loss associated with mission completion.

SECTION 03 COST OVERVIEW OF ATTRITABLE UASS

The United States has used unmanned systems for a variety of missions. One example is using small unmanned systems for combat and ISR missions that are particularly vulnerable to attack. UASs used in combat missions are often not recovered, and UASs used for reconnaissance purposes, in the past, have required full or partial recovery.

The use of attritable systems can help fill the gap when "space capabilities are unusable and aerial reconnaissance is not possible without untenable mission risk" [8]. For a UAS to be considered attritable, modifications must be made to the reliability, service of life, and maintenance of the aircraft to make it low cost. Currently, the DoD has not defined a general service life or reduced reliability requirements to allow a UAS to be considered attritable. This leads to the question: How do you determine what it means for a UAS to be deemed attritable?

The USAF has created definitions to identify the range between expendable and sophisticated, as seen in Figure 3-1. Expendable systems can be used once, have a very low cost, and have a loss tolerance that is assured. On the other end, sophisticated systems can be used multiple times, have a high cost, and have a loss tolerance that is very low. According to the USAF, attritable systems can be used between 1 and 100 times, have a low to medium cost, and have a loss tolerance that is varied. Figure 3-1 also notes that attritable systems fall in the cost range of $2–$20M, depending on the system [11].

Additionally, a congressional effort has tasked the USAF and U.S Navy to categorize unmanned aircraft that fly alongside manned aircraft, known as collaborative combat aircraft (CCA), into three categories: (1) expendable, (2) attritable, and (3) exquisite, ranging from $3M to $25M per platform. According to Decker [12]:

> Under the legislation, the cost of an expendable CCA, which lawmakers define as a drone that's designed to be lost after its mission, would be capped at $3M. An attritable CCA, which is meant to fly multiple missions and "may not return," would be capped at $10M. Lastly, an exquisite CCA, which is designed for multiple missions and "not considered an acceptable loss," would be capped at $25M.

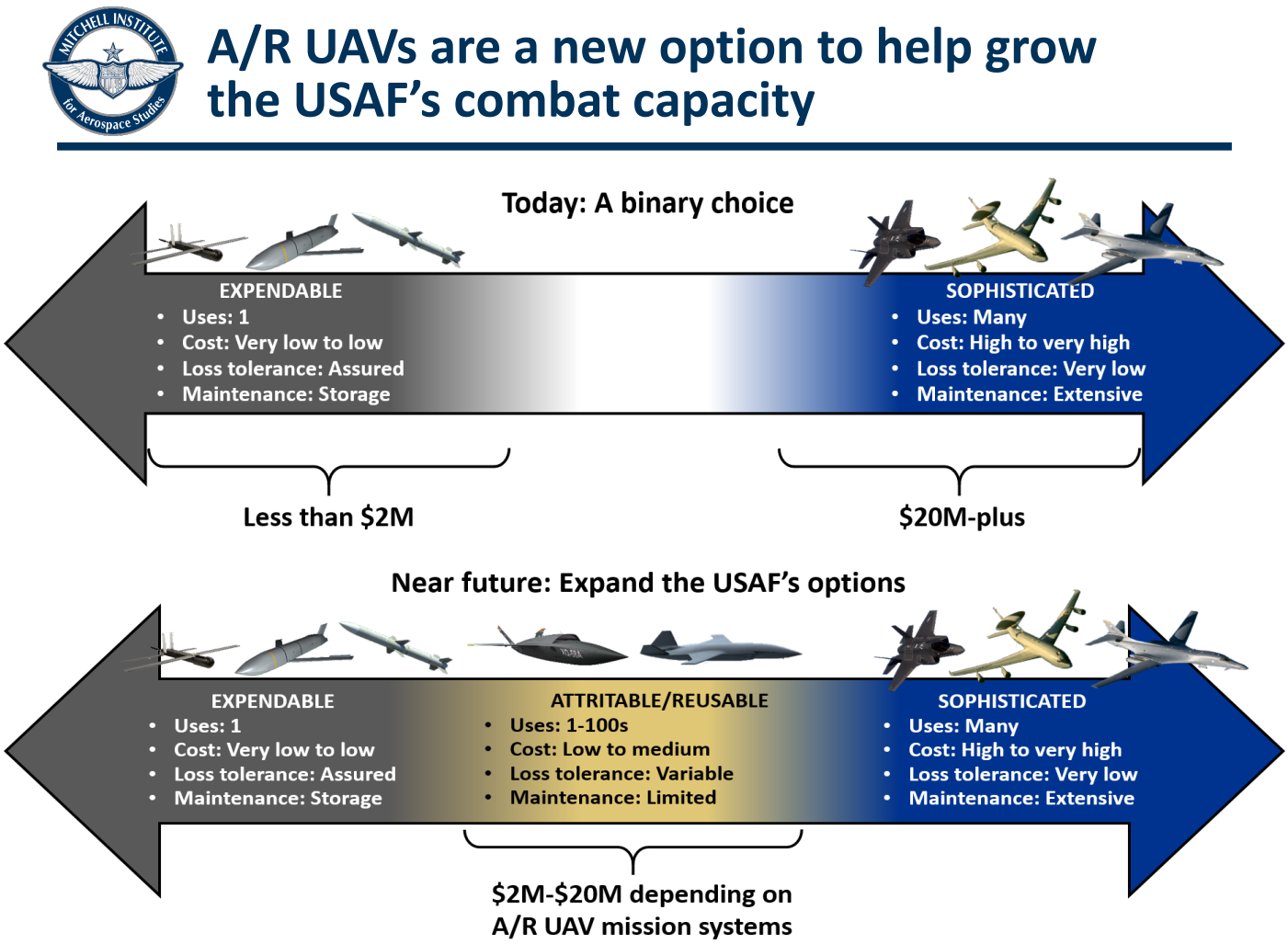

Figure 3-1. Attritable/Reusable UAVs Are a New Option to Help Grow the USAF's Combat Capacity *(Source: Gunzinger and Autenried [11])*.

SECTION 04 CONCEPTUALIZATION OF ATTRITABLE UASS WITHIN THE DOD

The DoD has taken note of the danger that small, cheap drones pose on the battlefield and has devoted considerable energy in recent years to building up its counter-small unmanned aircraft system (sUAS) capabilities. However, it has made less progress in developing concepts for its own use of attritable sUASs. The DoD is in an experimental phase of developing concepts for attritable sUAS employment, with efforts primarily centered in the U.S. Army and USAF. Such drones are primarily used for ISR in a variety of ways, but there is also interest in using them as loitering munitions, counterdrone assets, and airpower support. The most prominent DoD effort to develop, procure, and employ attritable sUAS, the Replicator initiative announced in August 2023, is in its infancy. Several questions remain about what kinds of attritable unmanned platforms will be its focus and how successful it will be in accelerating the Pentagon's procurement processes.

4.1 CONCEPTUALIZATIONS

In the U.S. (DoD), conceptualizations of use cases for "attritable" sUAS—defined by the DoD as those costing between $2M to $20M—are very much still in development [13]. While equipment and concepts for countering sUAS are more developed than the use of sUAS—although there remains no coherent all-of-government approach to countering small drones [14]—concepts for using attritable sUAS systems remain scattered and have not generally been formalized, even at the service level. As the Center for New American Security's Director of Studies Paul Scharre has stated in his testimony to the House Armed Services Committee's Subcommittee on Cyber, Innovative Technologies, and Information Systems, "low-cost attritable platforms and autonomous systems are both paradigm-busting concepts inside the [DoD]" [15]. Much work remains to be done in busting those paradigms and conceptualizing military use of these quickly emerging tools.

The Army, for instance, still lacks an overarching conceptual framework for using this kind of drone. It still needs to "define what roles, requirements, and capabilities are held at theater-level commands, the tactical corps, and the division level" [16]. Missions currently being explored for sUAS are using them to drop munitions [17]; using them as loitering "one-way drone" munitions themselves [18]; using them as short-range support for individual soldiers' reconnaissance efforts [19]; and, perhaps most prominently, using them for expanding ISR capabilities in a variety of ways.

The Army's priorities for UAS-based reconnaissance are laid out in some specificity in the Joint Small Uncrewed Aircraft Systems Capability Development Document issued in June of 2023 [20]. This document identifies specific system and performance attributes for the Army's desired short-range reconnaissance (SRR), medium-range reconnaissance (MRR), and long-range reconnaissance (LRR) needs. The Army has selected the Skydio X2D (RQ-28A is the platform's military designation) as its current SRR UAS platform—that

platform had its maiden flight in late March 2024 [21]—and it is in the final stages of selecting a replacement platform, which is to be deployed starting in fiscal year (FY) 2026. The Army has not yet selected MRR or LRR UAS platforms, but it plans to begin procuring them starting in FY2026 and FY2027, respectively. While the Skydio RQ-28 is attritable according to the DoD's definition—it starts at around $39,800—it is not yet clear whether the MRR and LRR capabilities will be similarly inexpensive [22]. Future research and development efforts are needed to close the gap on MRR and LRR capabilities.

The USAF is also deeply interested in the use of UAS platforms, but, similar to the Army, its concepts for using them remain scattered and experimental. One approach is encapsulated in the USAF Next-Generation Air Dominance program, which is aimed in part at producing uncrewed CCA to supplement the force's other airborne capabilities. While this program was intended to be complementary to the Replicator initiative, Secretary of the Air Force Frank Kendall indicated that, although they would be much less expensive than an F-35, they would still be just above the DoD's cost threshold for attritability [23].

While organizations like the U.S. Air Force Research Laboratory (AFRL) and the Air Force Big Safari Office are supporting the development of and experimentation with several small drones in USAF roles, there has, so far, been little public discussion of concepts and use cases for attritable sUAS platforms within the USAF. One exception arose in April of 2024 from the director of the Special Programs Division at Air Mobility Command, Maximilian K. Bremer, who argued that the USAF should rely on small, inexpensive drones to operate in the "air littoral" below the level where most fighters and bombers operate [24]. He notes that the USAF will need "creative new ideas and tactics" for employing sUAS and implies that he thinks the USAF is falling behind the Army in adopting them.

While the Navy and U.S. Marine Corps are both experimenting with small drones, the Marine Corps aviation plan does not mention small tactical drones at all [25]. Although the Navy flies a few UASs and issued a request for information on attritable UASs in late 2023 [26, 27], it appears more focused on surface and underwater platforms [28]. Oversight of small drone use in both the Navy and the Marines resides in Naval Air Systems Command. There have been several developments in conceptualizing the use of attritable drones at the joint force level. The Pentagon, for instance, envisions them as part of its plan to integrate intelligence and data from the full range of ISR platforms available to the DoD, called Combined Joint All-Domain Command and Control (CJADC2). For FY2025, the DoD requested $1.4B in funding for this program, which has already reached the minimum viable capability identified for it by the Chief Digital and Artificial Intelligence Office [29]. Lawmakers, however, appear to believe that the program's scope needs to be narrower. "The concept of CJADC2 is great…but it's an area where the concept is ahead of where we need to be to enable that" [30].

Debate also continues about how centralized drone operations should be in the DoD and each force. Some argue for more centralized, streamlined organizations working to conceptualize and incorporate drone (and counterdrone) technology, broadly speaking. In early 2024, lawmakers on the House Armed Services Committee Tactical Air and Land Forces Subcommittee expressed a hope that the Pentagon would "designate a new go-to senior official to oversee, review, and advance all the military's pursuits to counter emerging and intensifying threats from small drones" [31].

The same is true of using (as opposed to countering) drones; the House Armed Services Committee, in a draft FY2025 defense policy bill, wanted the Army to establish a dedicated drone corps responsible for "integrating these systems across the Army; providing specialized training

for units; and leading research, development, test, and evaluation efforts" [32]. Similarly, the head of an Army unit tasked with experimenting with new drone technologies and tactics noted recently that the United States might want to copy Ukraine's use of dedicated drone units. He argued that this could create a useful "culture of competition" [33]. The commander of the Defense Contract Management Agency at Boeing, an Army officer himself, agrees [34].

However, Undersecretary of the Army Gabe Camarillo thinks setting up a dedicated drone corps is the wrong approach to the problem of emerging drone technologies. Instead, he thinks the Army needs to continue "experimenting with different parts of different formations to understand how to best deploy them" [32]. Others have proposed combining ISR drone capabilities with electronic warfare and attack options in a "multifunctional reconnaissance company" [33].

Finally, it is worth noting that some disagreement persists about how revolutionary attritable drones will be. The broad consensus in the DoD seems to be that this has been a revolutionary development in that it will "democratize access to the air domain and change the current dynamics of air control from a high-end contest to one that spans a larger spectrum of capabilities" [35]. However, some analysts both in and outside of DoD disagree. Paul Lushenko, a professor at the U.S. Army War College, argues that drones are "strategically ineffective" [36], an argument with which Stacie Pettyjohn at the Center for a New American Security broadly agrees [37]. Others argue, for instance, that small, attritable UASs are not suited to U.S. strategic needs—"a war with a competitor like China… requires more advanced and survivable drones" [38].

4.2 REPLICATOR INITIATIVE

The highest-level effort to develop and integrate small, attritable UASs into U.S. military forces is the Replicator initiative, announced by Deputy Secretary of Defense Kathleen Hicks on 28 August 2023 [39]. Explicitly aimed at countering China, the program has multiple goals. The first goal is to quickly develop, procure, and deploy thousands of "all-domain, attritable-autonomous (ADA2)" systems within the next 18–24 months. The second is to speed up the traditionally glacial pace of developing and acquiring a new technology for the Pentagon. As Deputy Secretary Hicks noted in June of 2024, "the key to Replicator was 'transforming internal processes'…[and]…'bureaucracies need to be shown that new ways of doing things are possible.'"

ADA2 systems aim to be less expensive than traditional UAVs, emphasize the value of life, and can be "improved with substantially shorter lead times" [40]. The accelerated timeline incorporates working to leverage U.S. industry and technology partners to deliver thousands of attritable UAVs to the DoD by 2025.

According to the Deputy Secretary Hicks, "because the PRC (People's Republic of China) has spent decades building a modern military designed to do one thing, overmatch [the United States]" [41], Replicator is critical in matching their output. In a January 2024 speech, she also stated that what typically takes the DoD 2–3 years was accomplished in 5 months [40], including developing acquisition strategies, analyzing what resources are needed to deliver ADA2s, and creating a budget and reprogramming request to submit to Congress.

Relatively little information about the specific platforms being selected for inclusion in the Replicator initiative has been made public. The Defense Innovation Working Group screens and recommends systems for inclusion, and the first tranche of such platforms was reportedly identified internally in January 2024. The next tranche was reportedly slated to be identified by late summer 2024 [42, 43].

Interestingly, while early reports indicated that Replicator would be focused in part on surveillance capabilities [40] and there is substantial demand within DoD for a longer-range (likely fixed wing) ISR platform [44], the first tranche selected under Replicator reportedly focuses on four other types of sUAS: (1) interceptors, (2) counterdrone assets, (3) unmanned surface vessels, and (4) loitering munitions [18]. The only publicly revealed UAS in that first tranche of selected drones is AeroVironment's Switchblade 600, a loitering munition that reportedly costs around $100,000 [45]. This is the first of multiple tranche capabilities that will add to the ADA2 portfolio.

As the Replicator initiative was, in part, born from the continued rivalry with the PRC, the current Russo-Ukraine conflict has also played an important role in its development and continuation. Replicator is the first major push to drive combat collaborative aircraft and other collaborative platforms toward using attritable systems, so there is a renewed surge in research and development in this area. Identifying key organizations focusing on changing, updating, and improving systems in a considerably shorter amount of time is critical to the Warfighter, the DoD, and the U.S. government. Section 5 provides summaries of organizations that are impact players in attritable UASs that can also be considered for use in the Replicator initiative, with specific application to the DoD.

SECTION 05 IMPACT PLAYERS

The organizations discussed in this section were found to have projects, research, patents, or technology that support, or have the potential to support, DoD efforts. They include organizations with research or technology being done in the DoD, U.S. government, industry, and academia.

5.1 AEROVIRONMENT™

AeroVironment's™ Switchblade® 600 is a loitering munition that has been selected for the first tranche of the Replicator initiative. The Army plans to buy and field 1,000 Switchblade® 600 drones by 2025—the only named system that has been selected for the Replicator program [45]. The Switchblade® drone has been featured in the Russo-Ukraine conflict, Syria, and Iraq [45]. The loitering munition is "a man-portable, extended-range loitering munition system equipped with an anti-armor warhead for engaging larger, hardened targets at greater distances [and] aims to accelerate all-domain, attritable autonomous systems to Warfighters at speed and scale" [46].

The Switchblade® 600 is deployed "via tube launch and can fly, track, and engage non-line-of-sight targets," also allowing operators to abandon and recommit to the mission as needed. According to AeroVironment's™ senior vice president of loitering munitions, the Switchblade® 600 can operate in "heavily contested battlespace, at very low costs and high levels of resiliency" while increasing the ability to produce large numbers of the system to meet DoD needs [46].

5.2 USAF

The USAF is researching, developing, and testing multiple attritable UAVs. The goal is to generate combat airpower, increase combat capacity, increase survivability of USAF Warfighters, and create affordable and modular "options for acquisition and operations." The USAF suggests that attritable UAVs have the most combat value when "used for electromagnetic warfare, persistent [command, control, intelligence, surveillance, and reconnaissance] C2ISR, and other non-kinetic missions." Attritable UAVs will also increase operational risk tolerance in contested areas when teamed with manned fighters. Missions and their effects include [11]:

- Counterair sweeping to defeat threats and strikes.
- Increasing survivability against air-to-air and surface-to-surface threats by supporting penetrating strikes.
- Sustaining defensive counterair operations to protect tankers and high-value airborne assets from long-range fighters and threats.
- Providing early warning of enemy air operations in highly contested environments when using sensors.

The research and technology being used by the USAF is summarized in the subsequent sections.

5.2.1 Low-Cost Attritable Aircraft Technology (LCAAT) Program

The LCAAT provides "vehicle concepts, methods, and tools for designing" attritable UAVs. One example is the XQ-58A, developed under the LCAAT's Low-Cost Attritable Strike Demonstration (LCASD) Joint Capability Technology Demonstration [11]. The LCASD team designed, developed and tested the XQ-58A for the first time in 2019 and continued to test and demonstrate flights in 2021 [47]. Recently, the USAF has referred to LCAAT as "affordable runway-independent [UAVs]" [48]. However, for this report, LCAAT will be used as mentioned in most of the research.

The LCAAT program also oversees the Design for Manufacture of Attritable Aircraft Primary Structure (DMAAPS) program, designing and testing an attritable aircraft fuselage and wings [49]. To manufacture the aircraft's parts, the team with DMAAPS collaborated with the University of Dayton Research Institute (UDRI), Kratos, A&P Technology, and Hawthorne Composites. This allowed parts to be designed and created at a low cost with a focus on future testing and demonstrations.

5.2.2 The Off-Board Sensing System (OBSS)

AFRL solicited input for a low-cost, attritable UASs in February 2021 [13]. The OBSS aimed to use sensors to extend range and sensing during missions, while prioritizing human life. Another goal of the OBSS Flight Demonstration program is to demonstrate an open architecture UAV to meet the goal of "rapid time to market and low acquisition cost" [50].

Working with Kratos, AFRL began designing and developing an option for the OBSS to "deploy less expensive UAS" that are not expected to be in service for a lifetime. The OBSS is being developed to optimize mission capability over cost and life, with a focus on affording to acquire, develop, and deploy large numbers to meet "near-peer adversary threats." Kratos aims to offer an answer to the OBSS call on the lower range of the cost spectrum (close to $2M), while providing "a high-performance-versus-cost-system solution" [13].

The OBSS program used information from the LCASD program, the first demonstration in the product line, to aid in design and manufacturing technology [47]. The LCASD proved UAVs can "be designed against a notional set of requirements for limited life, built to achieve low-cost targets, and flown in a short period of time" [50].

The OBSS aims to use "scalable and responsive manufacturing technology" for attritable UAVs while testing in varied environments. A goal is to build future iterations from a "common, U.S.-government-owned system architecture," allowing for quick adaptations [50].

5.2.3 XQ-67A

AFRL's Aerospace Systems Directorate successfully tested the XQ-67A OBSS in February 2024, an autonomous collaborative platform (ACP) [2]. The XQ-67A is a variant of the attritable XQ-58A (offered by Kratos). The XQ-67A uses the common chassis approach for its design and aims to allow other UASs "to be rapidly replicated on a standard genus chassis" [47]. This can save time and money by "leveraging standard substructures and subsystems" and allows the capability of adding a variety of kits to the airframe [47].

The XQ-67A's first successful flight was at the General Atomics Gray Butte Fight Operations Facility in California. This is one step closer to providing fast delivery of "affordable, advanced capability to the Warfighter" [47]. The Low-Cost Attritable Aircraft Platform Sharing (LCAAPS) program provided technology and research to the OBSS program, which resulted in the development and testing of the XQ-67A. A "rapid time-to-market and low development cost" [47] approach to building aircraft is moving away from traditional methods and lends itself to developing attritable UAVs.

5.2.4 Project Skyborg

The XQ-58A Valkyrie, originally developed by AFRL and Kratos as part of the LCASD program, carried over to USAF's Project Skyborg and completed a successful flight series in 2022 [51].

The USAF is leveraging fighter jets accompanied by artificial-intelligence (AI)-enabled, combat attritable UAVs to minimize high-risk missions [52]. This allows missions to be more strategic in allocating UAVs to high-risk missions to minimize threats to life. They do not require a runway for landing or takeoff. Therefore, once a mission is finished, personnel can locate and retrieve the UAV at an off-base location. The UAVs are for reconnaissance and combat missions and are advertised as compact and inexpensive to develop. This allows the USAF to develop and "deploy a large fleet" [52]. As of 2022, LinQuest, a space systems technology provider, began a $48M task order under Phase III Small Business Innovation Research (SBIR), with a performance period of 5 years [53].

The Skyborg team demonstrated a test flight of the Skyborg autonomy core system (ACS) on a Kratos UTAP-22 tactical UAV on 29 April 2021 [54]. Details of this system can be found in Section 5.6.

5.3 BAE SYSTEMS

In 2022, BAE Systems released two internally funded and developed UAVs designed to be expendable and replaceable, referred to as UAS Concept Design 1 and 2 [55]. UAS Concept Design 1 is small and versatile and used for ISR. It has a fixed-wing design and operates at 30,000 ft with a 40-kg payload for up to 4 hr. It can cruise at 0.5 Mach and is rail launched and recovered by parachute. UAS Concept Design 2 is a medium-sized UAS described as attritable but able to conduct over 100 missions. Design 2 has a maximum altitude of 40,000 ft, a fixed-wing design, and an internal payload of 500 kg, and it can fly up to 5 hr. It has a cruise speed of 0.74 Mach and conventional takeoff and landing that works on land or in maritime environments.

5.4 BOEING

Boeing has a contract with the Royal Australian Air Force to develop the Airpower Teaming System (ATS) for use with the loyal wingman "clean-sheet" design, which is being tested in Australia [56]. With the cost to be between $2M and $3M, it aims to meet current definitions and needs of an attritable aircraft. The ATS was named the MQ-28A Ghost Bat, is low-cost, and is "designed to work as a smart team with existing military aircraft to complement and extend airborne missions" [57]. Boeing suggests the low cost of the design allows airmen to put it on the front line when teamed with manned aircraft for an ISR mission. It measures 38 ft long and flies more than 2,000 NM. AI technology lets it fly on its own or with supporting crewed aircraft, allowing it to stay far enough apart from the crewed aircraft. It is Boeing's first uncrewed system to be designed and developed in Australia [57].

5.5 GENERAL ATOMICS

General Atomics is developing two attritable drones under the Air Launched Effects program, with the goal of launching the drones from other UAVs or helicopters. The first is the Eaglet, "an expendable drone designed for single use" and the second is the larger Sparrowhawk®, intended for multiple flights and missions [58]. These attritable UAVs will launch, recover, and refuel from a MQ-9 (a conventional drone) and give the DoD, particularly the USAF, a way to monitor the front and across enemy lines. One intended use is to employ readily available attritable drones "to strike targets found by an attritable drone fleet" [58].

5.5.1 Sparrowhawk®

Being an sUAS, the Sparrowhawk® is hard to spot by adversaries when in contested environments, allowing it to be ideal for ISR missions. When launched from the MQ-9, or similar aircraft, the Sparrowhawk® [59]:

- Provides collaborative autonomy for kill chain closure.
- Distributes and disaggregates sensors across the battlefield.
- Operates below the weather sensor coverage.

The Sparrowhawk® is 10.8 ft long, has a wingspan of 14 ft, and weighs 500 lb. Additional specifications are listed in Table 5-1. As far as development status goes, the design, first article fuselage build, and captive carry are complete. The subsystem integration, first flight, recovery demonstration, and airborne recovery are still in progress.

Table 5-1. Specifications of General Atomic's Sparrowhawk® *(Source: General Atomics [59])*

Endurance	10+ hr
Range	500 NM
Fuel	JP-8
Propulsion	Hybrid Electric
Maximum Altitude	25,000 ft
Speed	801–150 kts indicated air speed

5.5.2 Gambit

General Atomics was awarded $17.8M in the fall of 2021 to develop a prototype for AFRL's OBSS program [60]. The system debuted in March 2022 and is named Gambit. This platform is expected to look like a "miniature fighter jet" and aims to be a "fast pilotless aircraft still survivable enough to operate in front of fighter jets in contested environments" [60]. According to a press release by General Atomics [61]:

> The Gambit Series aircraft will validate the "genus/species" concept first developed by AFRL as part of the LCAAPS program focused on building several aircraft variants from a common core chassis. LCAAPS is a major air vehicle effort under AFRL's Autonomous Collaborative Enabling Technologies (ACET) portfolio, which is focused on developing technologies for ACPs.

5.6 KRATOS

Kratos was awarded a $37.7M contract from the Air Force Life Cycle Management Center Fighters and Advanced Aircraft Directorate Aircraft Program Executive Office for Skyborg Delivery Order 2, for testing and delivering the XQ-58A Valkyrie UAS to the USAF [62]. As mentioned in Section 5.2.2, Kratos is working on the OBSS solicitation from AFRL to provide a low-cost attritable UAS. Kratos is also working on an Autonomous Attritable Aircraft Experimentation (AAAx) campaign to support the Skyborg ACS. The ACS performed "foundational behaviors necessary to characterize safe system operation" during what is being called Milestone 1 of the AAAx [54]. The ACS "responded to navigational commands, while reacting to geofences, adhering to aircraft flight envelopes, and demonstrating coordinated maneuvering" [54]. This was the first step of testing events and experiments planned for the ACS.

According to the president of the Kratos UAS Division, the UTAP-22 Mako is a "key tactical attritable UAS" that has been used in military demonstrations since 2015. The Mako is part of Kratos' tactical UAS family, which also includes the XQ-58A Valkyrie and Gremlins and has "potential for attritables in the tactical mission area" [62].

5.7 NORTHROP GRUMMAN

Northrop Grumman created the concept of an attritable UAS in 2021, named the Model 437 UAS [63]. This UAS will have a potential cost of $5–6M, putting it in the low-cost category when it comes to UASs. The UAS will have a 400-lb fuel capacity, a 3,000-NM range, an 8,000–10,000-lb maximum takeoff weight, and a cruise speed of 0.8 Mach [63, 64].

5.8 YATES ELECTROSPACE CORPORATION

In 2023, Silent Arrow, developed by Yates Electrospace Corporation, was awarded an SBIR contract by AFWERX to develop a long-range-powered cargo attritable UAV, the Silent Arrow contested logistics system, 300 NM (CLS-300) UAS [65]. This uses a propulsion unit and propeller system at a low enough cost to be called attritable by the company. The CLS-300 can take off from multiple ground surfaces, including naval vessels and unimproved surfaces [65]. It can be released from the air and can travel up to 10 times faster than Silent Arrow's GD-2000—their heavy payload, attritable cargo delivery UAS. Propulsion tests are planned for 2024, with flight tests in the latter part of 2024.

Silent Arrow also offers two heavy payload cargo delivery UASs with disposable platforms that fit the definition of attritable for the purpose of this report: (1) the GD-2000 and (2) the GD-2000 WB. The GD-2000 is marketed as an attritable glider UAS for cargo delivery designed to carry 1,500 lb of cargo up to 35 NM when deployed from a cargo aircraft [65]. It can be used for resupply and relief aid for humanitarian crises, aerial delivery missions to avoid improvised explosive devices, and to combat wildfires without risking human life [66].

5.9 SKYDIO

Skydio has shipped over 45,000 drones since November 2019, including Skydio S2/2+, X2, and X104X10 [67]. The company has recently increased manufacturing capacity by 10 times and can now produce 2,000 drones per month [68]. This is a key component of having a UAV classified as scalable and attritable. Skydio drones are used for a variety of missions by every branch of the DoD, by Five Eyes militaries, and throughout the North Atlantic Treaty Organization. Skydio serves over 2,000 customers across three primary sectors, to include federal governments and military, public safety and local governments, and critical infrastructure and utilities.

Skydio offers two drones that can be classified as attritable: (1) the X10D and (2) the X2D. The X10D, Skydio's newest defense drone costs approximately $25k, has a deployment time under 40 s, and has a 40-min battery life [69]. It offers modular, high-resolution visual and radiometric thermal cameras and incorporates a forward-looking infrared Boson+ sensor to obtain high thermal imaging. The X10D includes NightSense, allowing 24/7 operations with zero-light navigation, onboard AI, and obstacle avoidance technology that lowers the cognitive load for quick decision-making and custom-designed navigation lenses for 360° visibility [69]. It can be used for scouting convoys and battlefield maneuvers and can build two-dimensional and three-dimensional (3-D) models on board, in real time, and with its 3-D scanning. An open, modular architecture design provides additional options such as Robotics and Autonomous Systems—Air compliance and open micro-air vehicle link protocol (better known as MAVLink), which allow third-party and U.S. government flight application software, as well as external payloads [69]. Skydio has approximately 1,000 drones operating in Ukraine, including on the front lines by Ministry of Interior (MOI) units. Ukraine's MOI requested thousands of Skydio's X10 to replace their current fleet of Chinese drones [67].

Skydio's X2D won the U.S. Army's Short-Range Reconnaissance (SSR) program of record, tranche 1 [70], and is currently competing for SRR's tranche 2 with the new X10D [71]. The X2D is also part of the Marine Corps Short-Range, Short-Endurance program and the Defense Innovation Unit's AI for Small Unit Maneuvers program, which allows multidrone operations [72]. In addition to the tactical ISR use case, Skydio's drones are used by the DoD for perimeter and base security operations, as well as asset inspections and maintenance.

5.10 TEAL DRONES

Teal Drones is looking to leverage its Teal 2 drone to meet the Replicator initiative's demands [73]. It has

a $5.2M contract to provide 344 copies of the Teal 2 "to the Defense Logistics Agency (DLA), who is acquiring the drones for [USAF] security forces." It is currently working with the Army on possible uses for an ISR drone for the SRR capability. Teal's DLA contract states that 344 Teal 2s will be delivered over a 2-month period. Teal's current production capacity is between 100 and 200 drones per month, a years' average output would be 1,800 drones. The Replicator initiative's goal of thousands per month has companies, such as Teal, ramping up their production to meet the demand, targeting 1,000 systems per month with the current facility, and anticipating adding additional facilities to help reach this goal.

The Teal 2 costs between $13k and $17k per unit, depending on the requirements. This "includes the aircraft, ground station, radios, payload, spares etc." Teal anticipates being able to increase production of drones to meet Replicator's timeline of 18–24 months.

5.11 QINETIQ

QinetiQ is developing the Jackdaw UAS, which is marketed as a "low-cost, high-performance, disposable UAS" [74]. It is set to be available in the mid-2020s. Jackdaw aims to be used for reconnaissance, electronic warfare, airborne decoy, and threat representation. It can be used in manned and unmanned teaming situations to lower "operational risk and increase combat mass by rapidly deploying large numbers of UAS in scenarios currently dependent upon small numbers of expensive crewed aerial platforms." Jackdaw prioritizes human life while lowering costs, allowing it to fall into the attritable UAS category.

Jackdaw's platform specifications can be found in Table 5-2. Missions will include air, maritime, and land, as well as combinations of the three.

Table 5-2. Jackdaw UAS Specifications *(Source: QinetiQ [74])*

Endurance	3+ hr
Internal Payload	30 kg
Maximum Altitude	30,000 ft
Speed	400 kts

5.12 SIERRA NEVADA CORPORATION (SNC)

SNC offers the Launched Effects (LE) Aircraft system as a "low-risk, low-cost, high-value solution" for ISR missions. It has been launched from fixed- and rotary-winged aircraft for various missions including [75]:

- Battlefield Delivery
- Electronic Attack and Cybereffects Delivery
- Below-Cloud-Deck ISR
- Long-Rang Penetration of Denied Areas
- Mission Reconnaissance
- Pursuit of Multiple Delivery Targets

The LE UAS is foldable, with a wingspan of 13 ft, a quiet electric propulsion, a beyond-line-of-sight datalink for extended reach, and a "secure [radio frequency] RF [line-of-sight] LOS digital datalink from aircraft to host aircraft and control station" [75]. Additionally, "the radio and [electro-optical/infrared] EO/IR payloads are installed outside [the] payload bay, leaving ample room for munitions and additional payloads for Maritime target prosecution" [76]. The platforms can use glide and powered flight, and the range is up to 400 NM when deployed from [a] tactical high-altitude balloon (T-HAB) [76].

5.13 SKYFISH

Skyfish offers an attritable quadcopter UAS, named the Osprey, for ISR purposes [77]. The Osprey is just 14 lb, can fly up to 1 hr with a 45-mph maximum air speed, and is equipped with high-resolution photogrammetry. In-flight geotagging allows the

Osprey to be used for critical infrastructure and ISR applications, while the ×80 zoom on its near-infrared and long-wave infrared ISR attachment allow for accurate locations. Due to its minimal cost compared to traditional UASs, this has potential to be categorized as attritable.

Skyfish also produces an attritable heavy-duty drone for carrying payloads, called the M6 [78]. The M6 has an empty weight of 23 lb and is designed for a maximum payload of 12 lb. It can carry 10 lb for 30 min and has a maximum speed of 45 mph. It can also be used to support the Sony alpha series of cameras, as well as thermal and light detection and ranging. This system is considered attritable based on its lightweight build for heavy-duty jobs, according to Skyfish.

5.14 UDRI

UDRI offers system-level capabilities for its LCAAT program, including operations research, system life-cycle analysis, alternative analyses, and in-theater simulation. Ongoing research projects include [79]:

- Low-Cost Design and Integration
- LCAAT Clean-Sheet Design (including structurally integrated antennas)
- Alternate Takeoff and Landing Angle of Attack
- Automated Aerial Refueling Studies
- Innovative Manufacturing for Design
- LCAAT Wing Structural Design and Manufacturing Demonstration
- LCAAT Braided Fuselage Demonstration
- LCASD

Researchers at UDRI are working on all aspects of LCAAT, from vehicle conceptual design to system integration, to manufacturing. Under the DMAAPS program, UDRI researchers designed "a low-cost attritable aircraft fuselage and wings" using a "design-for-manufacture approach to meet the form, fit, and function of a high subsonic unmanned military aircraft." AFRL tested the design in 2021 at Wright-Patterson Air Force Base and gave insights that "allow AFRL to continuously improve technological advances" in attritable UAS research. The DMAAPS program "addresses affordability and speed of design and build" when it comes to needing large quantities of attritable systems for DoD use [80].

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SECTION 06 CONCLUSIONS

Although it has been recognized that the phrase "attritable unmanned aircraft systems" varies by situation, there is still not a clear, concise definition. "Additionally, the [House Armed Services] committee acknowledges the difficulty of classifying UAS into weight-based categories as expendable or attritable, considering the different sensor and munition configurations they can carry" [81]. This has led the subcommittees to task the defense secretary along with the Army, USAF, and Navy secretaries, to provide a briefing to lawmakers before 1 December 2024, to address this confusion, which will outline how the DoD categorizes UASs as "attritable." The briefing should include a definition for each branch of the military, along with a unit dollar amount for each group of UASs.

While some disagreement remains about how useful attritable sUASs will be at the strategic level, the DoD generally agrees they will be an important tool in future arsenals. They are already widely used at multiple levels of the joint force to supplement traditional ISR missions. However, other concepts for use of such drones remain in an experimental stage, and the effectiveness of high-level efforts to speed up the process of developing, procuring, and employing them remains to be seen.

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