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Unmanned Aircraft Systems: Roles, Missions, and Future Concepts

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Unmanned Aircraft Systems: Roles, Missions, and Future Concepts

SUMMARY

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Unmanned aircraft systems (UAS) have gained increased prominence in U.S. military operations. The Department of Defense (DOD) is currently developing advanced UAS, along with optionally crewed aircraft, as part of its modernization strategy. The roles and missions of UAS are relevant to Congress in authorizing, appropriating, and providing oversight to DOD and the military services for these systems.

Over the past decades, military forces have used UAS to perform various tasks, including

- intelligence, surveillance, and reconnaissance;
- close air support;
- cargo and resupply; and
- communications relay.

Analysts and DOD argue that UAS could replace crewed aircraft for a number of missions, including

- aerial refueling;
- air-to-air combat;
- strategic bombing;
- battle management and command and control (BMC2);
- suppression and destruction of enemy air defenses; and
- electronic warfare (EW).

In addition, DOD is developing several experimental concepts—such as aircraft system-of-systems, swarming, and lethal autonomous weapons—that explore new ways of employing future generations of UAS.

In evaluating appropriations and authorizations for potentially new and future UAS programs, missions, and concepts, Congress may consider the following issues:

- the proliferation of UAS able to function as lethal autonomous weapons and its implications for global arms control;
- costs of future UAS compared with crewed aircraft;
- personnel and skills implications of UAS;
- concepts of operation and employment; and
- the proliferation of uncrewed aircraft technologies.

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Background[1]

The United States has a number of unmanned aircraft systems (UAS) operating across the military services.[2] These aircraft have demonstrated their ability to perform many types of missions and may perform more complex missions in the future. Congress will likely debate and decide whether and how to allocate funds for military UAS in its yearly appropriations and authorization activity, as well evaluate them more broadly in its oversight role.

The U.S. military typically refers to remotely piloted vehicles (RPVs) as unmanned aircraft vehicles (UAVs). UAVs are either a single air vehicle (with associated surveillance sensors) or a UAV system, which typically consists of an air vehicle paired with a ground control station (where the pilot actually sits) and support equipment.[3] With the FY2023 President's budget, the Air Force has begun to use the term "uncrewed" to describe remotely piloted or unmanned aircraft systems.[4] The Air Force made this distinction defining all aircraft flying without an aircrew onboard after it started developing optionally crewed aircraft, like the B-21 Raider.[5] An emerging class of UAS is *loitering munitions*—also called "kamikaze drones"—which serve as a single use aircraft flying for extended periods of time (from dozens of minutes to potentially hours) that can observe and engage targets. This report uses the terms *crewed* and *uncrewed* to distinguish between different types of aircraft, and the term *UAS* for the broader system.

Current Roles of UAS[6]

Since the introduction of more sophisticated UAS in the 1990s,[7] UAS have performed several types of missions that were previously performed solely by crewed platforms. These missions include cargo and resupply; intelligence, surveillance, and reconnaissance; close air support; communications relay; and aerial refueling. The following sections describe how and why the military selected UAS to perform these roles.

Intelligence, Surveillance, and Reconnaissance (ISR)[8]

UAS initially gained prominence in U.S. military operations by performing intelligence, surveillance, and reconnaissance missions. Although the United States has operated intelligence, surveillance, and reconnaissance (ISR) UAS since the 1960s, the United States' use of UAS for such missions became more widespread with General Atomics' development of the MQ-1

[1] This section was written by John R. Hoehn, Analyst in Military Capabilities and Programs.

[2] For more information on UAS programs, see CRS Report R47067, *Unmanned Aircraft Systems: Current and Potential Programs*, by John R. Hoehn and Paul K. Kerr.

[3] This arrangement is applicable for the larger UAS. For smaller UAS, there is typically a single aircraft with a single ground control system.

[4] Department of Defense, "Air Force Officials Hold a Press Briefing on FY23 Air Force Budget, March 28, 2022," press release, March 28, 2022, https://www.defense.gov/News/Transcripts/Transcript/Article/2981330/air-force-officials-hold-a-press-briefing-on-fy23-air-force-budget-march-28-2022/.

[5] For more information on the B-21, see CRS Report R44463, *Air Force B-21 Raider Long-Range Strike Bomber*, by Jeremiah Gertler.

[6] This section was written by John R. Hoehn, Analyst in Military Capabilities and Programs.

[7] For a detailed discussion of these sophisticated UAS, see CRS Report R47067, *Unmanned Aircraft Systems: Current and Potential Programs*, by John R. Hoehn and Paul K. Kerr.

[8] For a more detailed discussion of the role of intelligence, surveillance, and reconnaissance in targeting, see **Appendix** "Intelligence Support of UAS Targeting in Counterterrorism Operations."

Predator—then designated as the RQ-1 Predator—in the 1990s. The military's deployment of UAS in conflicts such as Kosovo (1999), Iraq (2003-present), and Afghanistan (2001-present) has illustrated the advantages and disadvantages of uncrewed aircraft, as discussed below.[9]

The United States military primarily used MQ-1 UAS for reconnaissance and acquisition of potential ground targets in these conflicts. To accomplish this mission, the aircraft operated with a 450-pound surveillance payload, which included two electro-optical (E-O) cameras and one infrared (IR) camera for use at night.[10] Since the MQ-1, several iterations of UAS, including the MQ-9 Reaper, have included more sophisticated ISR sensors. Uncrewed aircraft, like the RQ-4 Global Hawk UAS (**Figure 1**), also fly at higher altitudes and use sophisticated signals intelligence payloads and synthetic aperture radars.[11] Demand for ISR UAS has increased as DOD has procured larger fleets of aircraft.[12] DOD officials and defense analysts state that combatant commanders routinely request more ISR aircraft—in particular UAS, due to their ability to fly for long durations.[13] As the United States has withdrawn from conflicts around the world, the military has increasingly relied on UAS to provide ISR and targeting. For a more detailed discussion on the limitations of UAS targeting in counterterrorism operations, see **Appendix**.

[9] Although the United States withdrew ground forces from Afghanistan in 2021, it continues to operate UAS there as part of its "over the horizon" capability to monitor events. For a more detailed discussion, see the **Appendix**.

[10] U.S. Air Force, "MQ-1B Predator," press release, September 2015, at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104469/mq-1b-predator/; and Thomas P. Ehrhard, *Air Force UAVs: The Secret History*, July 2010, p. 52, at https://apps.dtic.mil/sti/pdfs/ADA526045.pdf.

[11] U.S. Air Force, "RQ-4 Global Hawk Fact Sheet," press release, October 2014, at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104516/rq-4-global-hawk/.

[12] Todd Harrison, *Rethinking the Role of Remotely Crewed Systems in the Future Force*, Center for Strategic and International Security, Washington, DC, March 3, 2021, at https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210303_Harrison_Crewed_Systems.pdf?.jvtWe9BQCElgNfXzzhtirSwpKAwadDH.

[13] Written testimony of Air Combat Command Commander General Herbert J. Carlisle, in U.S. Congress, Senate Committee on Armed Services Subcommittee on Airland, hearings, 114th Cong., 2nd sess., March 16, 2016, at https://www.armed-services.senate.gov/imo/media/doc/Carlisle_03-16-16.pdf. See also Todd Harrison, *Rethinking the Role of Remotely Crewed Systems in the Future Force*, Center for Strategic and International Studies, Washington, DC, March 2021, p. 7, at https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210303_Harrison_Crewed_Systems.pdf?.jvtWe9BQCElgNfXzzhtirSwpKAwadDH.

Figure 1. RQ-4 Global Hawk UAS Landing in Guam

Source: U.S. Air Force photo/Staff Sgt. Nathan Lipscomb, available at https://www.af.mil/News/Photos/igphoto/2002864268/mediaid/5476588/.

Note: An RQ-4 Global Hawk from Andersen Air Force Base, Guam, lands at Misawa Air Base, Japan, May 24, 2014.

Close Air Support (CAS)

DOD has expanded the air-to-ground strike mission of UAS to include close air support (CAS). DOD defines CAS as "[a]ir action by aircraft against hostile targets that are in close proximity to friendly forces and that require detailed integration of each air mission with the fire and movement of those forces."[14] Because of the high risks that CAS poses to friendly forces on the ground due to such proximity, CAS was traditionally performed by crewed platforms, such as the A-10 Thunderbolt II.[15] During operations in Iraq, Afghanistan, and Syria over the past decade, however, the mission set of MQ-9 Reapers has evolved to perform CAS.[16]

As an example of UAS performing CAS, on February 21, 2001, the Air Force launched an AGM-114 Hellfire missile from what was then called an RQ-1 Predator UAS (**Figure 2**), marking the first use of strike UAS. [17] A strike UAS has the capability to launch weapons, such as precision guided missiles against a target. The Air Force's use of the MQ-1 expanded considerably during

[14] Department of Defense, *DOD Dictionary of Military and Associated Terms as of March 2017*, p. 38, at https://www.tradoc.army.mil/wp-content/uploads/2020/10/AD1029823-DOD-Dictionary-of-Military-and-Associated-Terms-2017.pdf.

[15] According to the Air Force the A-10C Thunderbolt II is a "simple, effective and survivable twin-engine jet aircraft that can be used against light maritime attack aircraft and all ground targets, including tanks and other armored vehicles. U.S. Air Force, "A-10C Thunderbolt II," press release, December 2020, at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104490/a-10c-thunderbolt-ii/.

[16] For example, the Air Force states that one of the MQ-9's missions is close air support. The MQ-9's other stated missions include ISR, combat search and rescue, precision strike, convoy and raid overwatch, route clearance, target development, and terminal air guidance. United States Air Force, "MQ-9 Fact Sheet," press release, March 2021, at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/.

[17] In 2002, the Air Force redesignated the Predator "MQ-1," denoting its multirole mission set (i.e., its ability to provide both ISR and strike capabilities). Air Force News Service, "Predator Missile Launch Test Totally Successful," press release, February 26, 2001, at https://web.archive.org/web/20120926012651/http://www.dau.mil/pubscats/PubsCats/PM/articles01/afns1m-a.pdf. For more information on the capabilities of an AGM-114 Hellfire, see CRS Report R45996, *Precision-Guided Munitions: Background and Issues for Congress*, by John R. Hoehn.

the wars in Iraq (2003-2010) and Afghanistan (2001-2021). Following the MQ-1's demonstrated operational capabilities, both the Army and the Air Force developed variants of the UAS, including the MQ-1C Gray Eagle and the MQ-9 Reaper. These aircraft leveraged the original MQ-1 airframe while increasing engine power and armament. Both the MQ-1C Gray Eagle and the MQ-9 Reaper can employ AGM-114 Hellfire missiles, along with GPS-guided and laser-guided bombs.

Figure 2. Air Force MQ-1 Predator Armed with a Hellfire Missile

Source: An MQ-1 Predator armed with an AGM-114 Hellfire missile flies a training mission. U.S. Air Force, available at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104469/mq-1b-predator/.

Analysts have debated whether UAS should perform CAS missions. Some argue that ground force troops may not trust UAS to perform these types of missions without harm to friendly forces.[18] According to these analysts, ground troops are more comfortable having a person in the cockpit performing CAS with eyes on the ground to ensure there is no firing on a friendly location. Other analysts, however, argue that UAS are well suited for the CAS mission.[19] They state that most general purpose forces have not had sufficient exposure to UAS platforms when requiring air support (and instead have had more experience with crewed platforms), and these troops, therefore, are more comfortable with crewed CAS missions. These analysts additionally note that, unlike general purpose forces, special operations forces have directed a significant number of uncrewed close air support missions in Iraq and Syria and therefore may be more comfortable calling upon UAS when available.

Communications Relay

During Operation Enduring Freedom, ground forces identified challenges with operating their line-of-sight communications systems in mountainous terrain, which limited the distance that

[18] Jacqueline Schneider and Julia MacDonald, "Why Troops Don't Trust Drones: The 'Warm Fuzy' Problem," *Foreign Affairs*, December 20, 2017, at https://www.foreignaffairs.com/articles/united-states/2017-12-20/why-troops-dont-trust-drones.

[19] Cory T. Andersen, Dave Blair, Mike Byrnes, et al., "Trust, Troops, and Reapers: Getting 'Drone' Research Right," *War on the Rocks*, April 3, 2018, at https://warontherocks.com/2018/04/trust-troops-and-reapers-getting-drone-research-right/.

radio frequencies can travel. In response, in 2008, the Air Force fielded the Battlefield Airborne Communications Node (BACN) to provide a relay for both voice communications and tactical datalinks.[20] The Air Force selected the crewed E-11A—a modified Bombardier Global XRS/6000 series aircraft—as well as older RQ-4 Global Hawk aircraft (subsequently designated the EQ-4) to perform this function due to their long endurance and ability to fly at relatively high altitudes. The first EQ-4s were received the BACN communications payload in 2012,[21] and were retired in FY2021.[22]

Figure 3. EQ-4

Source: The EQ-4 Global Hawk UAS on its first flight after being converted to carry the BACN on February 16, 2018. Northrop Grumman, available at https://news.northropgrumman.com/news/releases/northrop-grumman-delivers-bacn-equipped-global-hawk-to-air-force.

Potential Roles and Missions for UAS[23]

This section discusses potential UAS roles and missions in future military operations. These include aerial refueling, air-to-air combat, combat search and rescue, strategic bombing, battle management command and control, suppression and destruction of enemy air defenses, and electronic warfare.

Aerial Refueling

Using UAS to refuel other aircraft while airborne, especially in locations far away from airbases, can potentially reduce the threat to crewed tankers. The Navy is procuring the MQ-25 Stingray

[20] Air Combat Command, "Battlefield Airborne Communications Node (BACN)," press release, at https://www.acc.af.mil/About-Us/Fact-Sheets/Display/Article/2241383/battlefield-airborne-communications-node-bacn/.

[21] IHS Janes, "Airborne Communications – Battlefield Airborne Communications Node (BACN)," May 18, 2021, https://customer.janes.com/Janes/Display/JC4IA305-JC4IA.

[22] Department of Defense, *FY2022 U.S. Aircraft Procurement Volume II, RQ-4 Mods*, pp. 425-451.

[23] This section was written by John R. Hoehn, Analyst in Military Capabilities and Programs, and Jeremiah Gertler, former Specialist in Military Aviation.

carrier-based UAS for such operations.[24] In addition, the Defense Advanced Research Projects Agency (DARPA) has also conducted research to test the suitability of RQ-4 Global Hawk UAS aircraft as long endurance refueling platforms, but the military services have yet to develop formal requirements for this role.[25]

Air-to-Air Combat

Some relatively early concepts of military UAS sought to carry out fighter operations, engaging with and destroying enemy aircraft. For example, the Navy's Unmanned Carrier-Launched Surveillance and Strike (UCLASS) program intended to develop light-strike capabilities (i.e., using small aircraft to attack targets) in a fighter-sized UAS.[26] More recently, demonstrator programs like the Boeing Loyal Wingman seek to add air combat into the mix of fighter aircraft.[27]

Some recent concepts see uncrewed aircraft operating adjacent to and in coordination with conventional fighters, taking direction from crewed counterparts or autonomously engaging in operations to protect the crewed aircraft. This teaming concept is the focus of the U.S. Air Force Skyborg program (discussed below) and the Airpower Teaming System, which is undergoing trials in Australia.[28] Other concepts rely on a more autonomous model, with uncrewed fighters clearing airspace ahead of attacking crewed fighters or bombers. As with current fighter jets, autonomous combat UAS will seemingly need to be able to discriminate between friendly and hostile aircraft, although other sensor and battle management systems could supply target designation.[29]

Combat Search and Rescue/Casualty Evacuation

Locating and recovering downed personnel, known as search and rescue, as well as aerial casualty evacuation, may involve extended periods of time in high-threat environments. Due to their endurance and reduced size (i.e., no crew), UAS may be well suited for carrying out search missions without being detected or requiring crew relief. In addition, military leaders may potentially accept a greater risk of attrition for UAS in these situations. Such factors could enable the military to station UAS closer to front lines than crewed aircraft, potentially reducing the time needed to locate and evacuate personnel. Rotary-wing UAS would be especially well suited for combat search and rescue/casualty evacuation missions, because DOD currently uses crewed rotary-wing aircraft (helicopters) for such missions.[30] Although UAS could seemingly reduce the

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[24] CRS Report R47067, *Unmanned Aircraft Systems: Current and Potential Programs*, by John R. Hoehn and Paul K. Kerr.

[25] DARPA, "Autonomous High-Altitude Refueling," press release, at https://www.darpa.mil/about-us/timeline/autonomous-highaltitude-refueling.

[26] CRS Report R44131, *History of the Navy UCLASS Program Requirements: In Brief*, by Jeremiah Gertler.

[27] Boeing Australia, "Boeing Loyal Wingman Uncrewed Aircraft Completes First Flight," press release, March 2, 2021, at https://www.boeing.com.au/news/releases/2021/march/boeing-loyal-wingman-uncrewed-aircraft-completes-first-flight.page.

[28] Boeing, "Boeing Airpower Teaming System," press release, at https://www.boeing.com/defense/airpower-teaming-system/.

[29] For example, future UAS could be paired with BMC2 aircraft or crewed fighters like the F-35, leveraging tactical data links like Link 16 or Multifunction Advanced Data Link (MADL) to designate targets. For example, see Paul Scharre, "Commanding the Swarm," *War on the Rocks*, March 25, 2015, at https://warontherocks.com/2015/03/commanding-the-swarm/.

[30] See, inter alia, Paul Scharre, "Left Behind: Why It's Time to Draft Robots for CASEVAC," *War on the Rocks*, August 12, 2014, at https://warontherocks.com/2014/08/left-behind-why-its-time-to-draft-robots-for-casevac/; and Mandy Langfield, "Unmanned K-MAX performs first casevac," *AirMed & Rescue*, April 30, 2015, at

time needed to transport injured personnel to treatment facilities in casualty evacuation missions where troops on the ground are able to place an injured person on board, the lack of a crew would prevent the availability of first aid during the flight.[31]

Cargo and Resupply

DOD has also used UAS in cargo and resupply missions. Notably, the Marine Corps used a UAS helicopter called the K-MAX for operations in Afghanistan.[32] The K-MAX, which was intended to replace ground convoys, flew autonomously to remote outposts carrying up to 6,000 pounds of cargo or supplies.[33] The Navy has experimented with a smaller Volansi VOLY C10 UAS (**Figure 4**) to deliver 20 pounds of cargo over 15 miles.[34]

According to a February 2022 press report, a U.S. ally deployed an uncrewed glider system called Silent Arrow, which is released from a C-130 Hercules transport aircraft and may deliver up to 1,650 pounds of cargo.[35] Silent Arrow is reportedly capable of gliding approximately 40 nautical miles when released at 25,000 feet. A motorized variant, called the GD-2000, is also reported to be capable of launching and recovering from improvised runways (i.e., areas that are not designated to be runways and do not have the requisite improvements, such as pavement and lighting).[36]

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https://www.airmedandrescue.com/latest/news/unmanned-k-max-performs-first-casevac.

[31] See, inter alia, Paul Scharre, "Left Behind: Why It's Time to Draft Robots for CASEVAC," *War on the Rocks*, August 12, 2014, at https://warontherocks.com/2014/08/left-behind-why-its-time-to-draft-robots-for-casevac/; and Mandy Langfield, "Unmanned K-MAX performs first casevac," *AirMed & Rescue*, April 30, 2015, at https://www.airmedandrescue.com/latest/news/unmanned-k-max-performs-first-casevac.

[32] U.S. Congress, Senate Committee on Armed Services, Subcommittee on Seapower, *Marine Corps Ground Modernization and Naval Aviation Programs*, 116th Cong., 1st sess., April 10, 2019, p. 49, at https://www.armed-services.senate.gov/imo/media/doc/19-38_04-10-19.pdf.

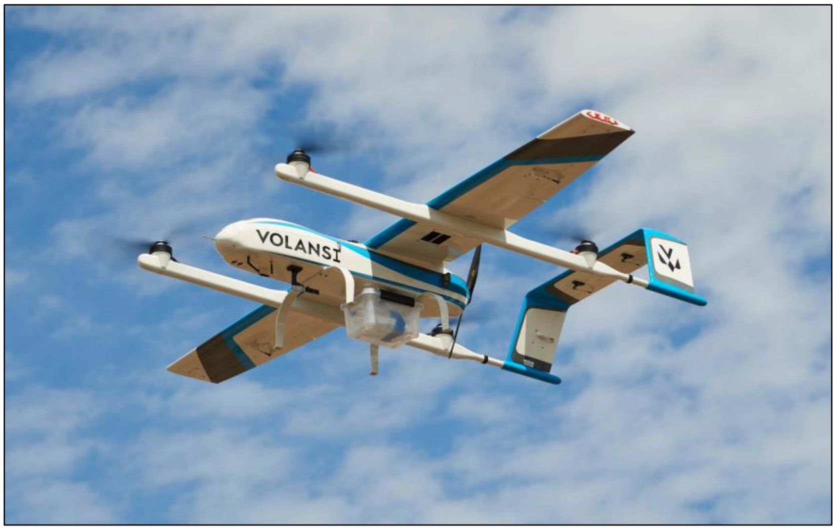
[33] Matthew Cox, "Marine Corps Wants to Upgrade its K-MAX Pilotless Cargo Helicopters," *Military.Com*, April 10, 2019, at https://www.military.com/daily-news/2019/04/10/marine-corps-wants-upgrade-its-k-max-pilotless-cargo-helicopters.html.

[34] Brett Tingley, "Drone Makes First Autonomous Aerial Delivery Between Two Military Vessels," *The Warzone*, August 4, 2021, at https://www.thedrive.com/the-war-zone/41838/drone-makes-first-autonomous-aerial-delivery-between-two-military-vessels.

[35] Brett Tingley, "Autonomous Resupply Gliders Made Successful Deliveries On Their First Overseas Deployment," *The War Zone*, February 2, 2022, at https://www.thedrive.com/the-war-zone/44111/autonomous-resupply-gliders-made-successful-deliveries-on-their-first-overseas-deployment, and Silent Arrow, "Silent Arrow® Autonomously Delivers 1,026 Pounds of Cargo," press release, January 31, 2022, at https://silent-arrow.com/news-%26-media/f/silent-arrow%C2%AE-autonomously-delivers-1026-pounds-of-cargo.

[36] Brett Tingley, "Autonomous Resupply Gliders Made Successful Deliveries On Their First Overseas Deployment," *The War Zone*, February 2, 2022, at https://www.thedrive.com/the-war-zone/44111/autonomous-resupply-gliders-made-successful-deliveries-on-their-first-overseas-deployment.

Figure 4. Volansi VOLY C10



Source: A Volansi VOLY 10 series vertical takeoff and landing UAS carrying a cargo payload, available at https://www.thedrive.com/the-war-zone/41838/drone-makes-first-autonomous-aerial-delivery-between-two-military-vessels.

Strategic Bombing

The Air Force intends for the next generation of U.S. bombers—such as the B-21 Raider Long-Range Strike Bomber—to be optionally crewed, allowing remote operation for conventional strike missions into heavily defended areas.[37] The optionally crewed B-21 aircraft, with an intercontinental range and large payload, provides a capability distinct from existing strike UAS, which can strike only small, single-point targets. Optionally crewed aircraft—including the B-21 Raider—[38] lack some advantages of uncrewed aircraft, because the optionally crewed aircraft must include the weight and space necessary for people and their life support.

[37]See CRS Report R44463, *Air Force B-21 Raider Long-Range Strike Bomber*, by Jeremiah Gertler, for additional information on the B-21 aircraft. See also, Tyler Rogoway and Joseph Trevithick, "Document Confirms B-21 To Be Delivered Optionally Manned And Nuclear Capable," *The War Zone*, November 8, 2017, at https://www.thedrive.com/the-war-zone/15902/document-confirms-b-21-to-be-delivered-optionally-manned-and-nuclear-capable. U.S. doctrine requires aircraft on nuclear missions to be manned. For more information on U.S. strategic forces, see CRS Report RL33640, *U.S. Strategic Nuclear Forces: Background, Developments, and Issues*, by Amy F. Woolf.

[38] Northrop Grumman, "Northrop Grumman's Optionally-Manned Firebird Demonstrates Operational Flexibility," press release, April 6, 2021, at https://news.northropgrumman.com/news/releases/northrop-grummans-optionally-manned-firebird-demonstrates-operational-flexibility and https://www.aurora.aero/centaur-optionally-piloted-aircraft/.

Battle Management Command and Control (BMC2)

Current BMC2 platforms, such as the E-3 Sentry AWACS and E-8 JSTARS,[39] carry an array of sensors and a crew to translate those sensor inputs and direct friendly aircraft and forces.[40] Current concepts for replacing the E-3 focus on crewed platforms.[41] Including the same sensor suite on an uncrewed platform, with the operational crew on the ground or in another aircraft but receiving the same sensor inputs, could reduce the potential threat to the crew.[42]

Some UAS also operate at significantly higher altitudes than current crewed systems, increasing the area their sensors can cover and improving survivability.[43] The longer endurance of some UAS likely improves mission efficiency by requiring fewer aircraft to maintain the same coverage.

Suppression and Destruction of Enemy Air Defenses

Suppression and destruction of enemy air defenses is the first and most dangerous part of an air campaign, because attacking aircraft generally face enemy air defense networks at their full capability. In addition to expendability, UAS offer a number of advantages for such missions. Large numbers of small UAS engaging enemy air defenses could overwhelm these defenses and compel an adversary to use many of its weapons against small, comparatively low-value targets. Such swarming tactics—discussed in greater detail below—could also direct many attacking aircraft to the target and confuse responders.[44] Because most modern air defense systems are designed for combatting crewed aircraft, UAS could create a novel problem for enemy forces, particularly when operated in unconventional ways. These methods include rapid changes in speed or direction, or high g-loadings (i.e., the amount of forces the aircraft encounters) that

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[39] According to the Air Force, the E-3 Sentry "AWACS provides situational awareness of friendly, neutral and hostile activity, command and control of an area of responsibility, battle management of theater forces, all-altitude and all-weather surveillance of the battle space, and early warning of enemy actions during joint, allied, and coalition operations." The Air Force states the E-8 JSTARS primary mission "is to provide theater ground and air commanders with ground surveillance to support attack operations and targeting that contributes to the delay, disruption and destruction of enemy forces." U.S. Air Force , "E-3 Sentry (AWACS)," press release, September 2015, at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104504/e-3-sentry-awacs/, and U.S. Air Force, "E-8C Joint Stars," press release, September 2015, at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104507/e-8c-joint-stars/.

[40] See CRS Report R44108, *U.S. Command and Control and Intelligence, Surveillance, and Reconnaissance Aircraft*.

[41] See CRS In Focus IF12045, *Replacing the E-3 Airborne Warning and Control System (AWACS)*, by John R. Hoehn and Jeremiah Gertler.

[42] Lawrence A. Stutzriem, *Reimagining the MQ-9 Reaper*, Mitchell Institute, V. 30, Arlington, VA, November 2021, at http://mitchellaerospacepower.org/wp-content/uploads/2021/11/Reimagining_the_MQ-9_Reaper_Policy_Paper_30-1.pdf.

[43] Operating at higher altitudes increases survivability because the aircraft continues to fly at a relatively fast rate, requiring an air defense missile to intercept at a longer range than would be required for a medium-altitude intercept. This is a similar trait to using satellites like the Global Positioning System to enable radio navigation. H. M. J. Cantalloube, "High altitude terrain correlation navigation resetting by nadir looking synthetic aperture radar," Progress In Electromagnetics Research Symposium, 2017, pp. 3252-3257, at https://ieeexplore.ieee.org/document/8262318. Cemil Tepeck and Isa Navruz, "The effects of frequency and altitude on radar performance with surface ducting," 22nd Signal Processing and Communications Applications Conference (SIU), 2014, pp. 2202-2205, at https://ieeexplore.ieee.org/document/6830701. At certain altitudes, aircraft are out-of-range of ground-based air defense systems.

[44] Paul Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for New American Security, Washington, DC, October 2014, at https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf?mtime=20160906082059&focal=none.

would not be possible with a human aboard.[45] In addition, electronic measures can make UAS to appear as larger, more threatening aircraft to radar and other sensors, further complicating a defender's responses.[46]

Electronic Warfare[47]

Uncrewed aircraft could also serve as electronic warfare platforms,[48] designed to be outfitted with radio frequency jamming equipment capable of interfering with adversary electronics. Expendable UAS could be more favorable to use in electronic warfare because jamming equipment requires sufficient power to interfere with electronic equipment. As a result, when an aircraft is jamming an adversary's radio frequency, its electromagnetic signature increases. An adversary, consequently, can detect electronic warfare aircraft more easily than regular aircraft that do not emit high-power radio frequencies. Uncrewed aircraft could therefore mitigate the risk posed to crewed aircraft should potential adversaries destroy the aircraft in response to the effects of jamming.

Although the United States has not publicly discussed using uncrewed aircraft for electronic warfare, DOD has developed cruise missiles for this mission, which are essentially designed as single-use aircraft. The Air Force, for example, developed the Miniature Air Launched Decoy (MALD) and the Miniature Air Launched Decoy-Jammer (MALD-J), air-launched cruise missiles designed to mimic larger aircraft radar signatures and modified to jam adversary integrated air defenses.[49] Some analysts have speculated that UAS could similarly serve in electronic warfare capacities.[50]

[45] Ibid.

[46] Raytheon Missiles & Defense, "MALD Decoy," press release, at https://www.raytheonmissilesanddefense.com/what-we-do/naval-warfare/advanced-strike-weapons/mald-decoy.

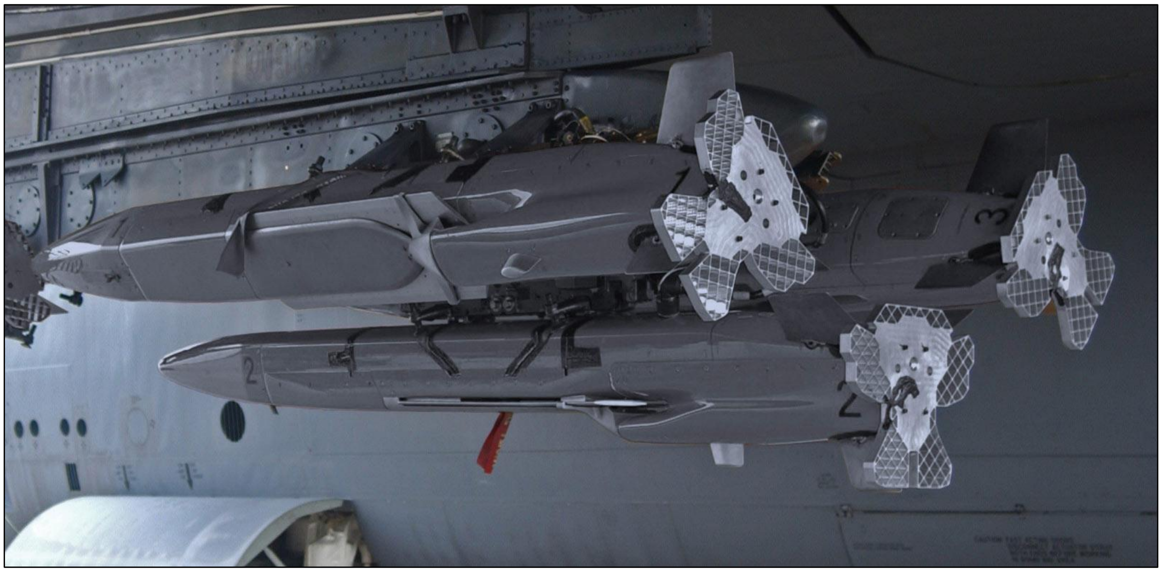
[47] For additional information about electronic warfare, see CRS In Focus IF11118, *Defense Primer: Electronic Warfare*, by John R. Hoehn.

[48] For more information on airborne electronic warfare, see CRS Report R44572, *U.S. Airborne Electronic Attack Programs: Background and Issues for Congress*, by John R. Hoehn.

[49] U.S Air Force, *FY2017 Aircraft Procurement Line Item 76 War Consumables*, at https://apps.dtic.mil/procurement/Y2017/AirForce/U_P40_76_BSA-4_BA-7_APP-3010F_PB_2017.pdf.

[50] Mark Gunzinger, *Sustaining America's Strategic Advantage in Long-Range Strike*, Center for Strategic and Budgetary Assessments, Washington, DC, September 14, 2010, p. 69, at https://csbaonline.org/uploads/documents/2010.09.14-Sustaining-Americas-Strategic-Advantage-in-Long-Range-Strike.pdf.

Figure 5. ADM-160A Miniature Air-Launched Decoy (MALD)



Source: Raytheon Technologies, available at https://www.raytheonmissilesanddefense.com/capabilities/products/mald-decoy.

Advantages and Disadvantages of Unmanned Aircraft Systems

UAS offer both advantages and disadvantages when compared with crewed aircraft, including differences in aircraft performance, risk tolerances associated with UAS operations, and communications requirements, as discussed below.

Aircraft Performance

A primary difference between crewed and uncrewed aircraft is the performance characteristics of each. Improved engineering techniques enable aircraft designs limited mostly by accommodations and safety for human pilots, rather than by material or structural elements.[51] For example, uncrewed aircraft do not require cockpits, life support, or other systems necessary for crewed aircraft.[52] The absence of these elements reduces the weight of uncrewed aircraft and may enable different, more aerodynamically unstable aircraft designs.[53] As a result, uncrewed aircraft can fly for longer periods of time (limited by the oil lubricants in the engine) and potentially fly at higher speeds and handle more g-forces—a measure of acceleration (a factor in determining aircraft maneuverability)—than humans could tolerate.[54]

[51] Department of Defense, *Unmanned Systems Roadmap 2007-2032*, Washington, DC, December 10, 2007, pp. 19-20, at https://rosap.ntl.bts.gov/view/dot/18247.

[52] Life support systems include oxygen systems, cabin pressurization, and ejection seats.

[53] Unstable aircraft design means the aircraft would leave controlled flight without direct control inputs. Aircraft like the B-2 Sprit would be unable to fly without flight control computers providing constant inputs to maintain controlled flight. Paul Scharre, *Robotics on the Battlefield: Part I: Range, Persistence, and Daring*, Center for New American Security, Washington, DC, May 21, 2014, p. 10, at https://www.cnas.org/publications/reports/robotics-on-the-battlefield-part-i-range-persistence-and-daring.

[54] Department of Defense, *Unmanned Systems Roadmap 2007-2032*, Washington, DC, December 10, 2007, pp. 19-20, https://rosap.ntl.bts.gov/view/dot/18247. See also Paul Scharre, *Robotics on the Battlefield: Part I: Range, Persistence, and Daring*, Center for New American Security, Washington, DC, May 21, 2014, https://www.cnas.org/publications/

Risk Tolerances

UAS platforms incur different types of risk than traditional crewed platforms. Among other factors, UAS appear to have a higher propensity to be involved in a Class A mishap (DOD defines a Class A mishap as causing $2.5 million or more worth of damage, the total destruction of an aircraft, or an accident resulting in a fatality).[55] Because UAS are involved in Class A mishaps more often, military planners would likely need to include more UAS in the force structure than comparable numbers of crewed aircraft. The risks of potential adversaries gaining access to advanced U.S. military technologies could also increase, due to more potential mishaps in enemy-held areas. In some instances, crewed aircraft have bombed UAS crash sites to prevent adversaries from examining U.S. technologies.[56]

These risks of technological exploitation, however, may be offset by the reduced risk to personnel and the attendant decreased demand for retaliatory strikes. Some analysts argue that UAS reduce the risk of potential escalation.[57] These analysts state "emerging norms regarding the consequences of shooting down a drone, though clearly still in the early stages, suggest that states distinguish between the shooting down of manned and unmanned systems."[58] Iran shot down a Navy MQ-4C UAS in the Persian Gulf in 2019. According to a Navy press briefing, the aircraft was flying in the area to monitor the Strait of Hormuz for Iranian threats to commercial shipping. DOD officials characterized the attack as "an attempt to disrupt our ability to monitor the area following recent threats to international shipping and free flow of commerce."[59] The Trump Administration at the time reportedly contemplated retaliatory strikes on Iran for destroying a U.S. aircraft, but seemingly determined to not respond.[60] Similarly, the Air Force reportedly flew an RQ-170 UAS in Pakistan in 2011 during the special operations raid on Osama bin Laden.[61] During this operation, the RQ-170 operated in "contested airspace" in which the Pakistani military operated sophisticated air defenses.[62] The decision to use an uncrewed platform might have been made, in part, to reduce the risk of military casualties.

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reports/robotics-on-the-battlefield-part-i-range-persistence-and-daring.

[55] CRS Report R47067, *Unmanned Aircraft Systems: Current and Potential Programs*, by John R. Hoehn and Paul K. Kerr, and Department of Defense, Mishap Notification, Investigation, Reporting, and Record Keeping, DoDI 6055.07, Washington, DC, June 6, 2011, at https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/605507p.pdf..

[56] For example, see U.S. Air Forces Central Command, "MQ-9 crashes in northern Syria," press release, July 5, 2016, https://www.af.mil/News/Article-Display/Article/823888/mq-9-crashes-in-northern-syria/platform/hootsuite/.

[57] Michael Horowitz, "Separating Fact from Fiction in the Debate over Drone Proliferation," *International Security*, vol. 41, no. 2 (Fall 2016), pp. 7-42, https://direct.mit.edu/isec/article/41/2/7/12140/Separating-Fact-from-Fiction-in-the-Debate-over.

[58] Ibid.

[59] U.S. Air Forces Central Command, "MQ-9 crashes in northern Syria," press release, July 5, 2016, at https://www.af.mil/News/Article-Display/Article/823888/mq-9-crashes-in-northern-syria/platform/hootsuite/.

[60] Michael D. Shear et al., "Strikes on Iran Approved by Trump, Then Abruptly Pulled Back," *New York Times*, June 20, 2019, at https://www.nytimes.com/2019/06/20/world/middleeast/iran-us-drone.html.

[61] "RQ-170 Stealth Drone Used in Bin Laden Raid," *Military.Com*, May 18, 2011, at https://www.military.com/defensetech/2011/05/18/rq-170-sentinel-stealth-drone-used-in-bin-laden-raid..https://www.military.com/defensetech/2011/05/18/rq-170-sentinel-stealth-drone-used-in-bin-laden-raid.

[62] Pakistani air defenses at the time included the Soviet-developed SA-2 and the French-developed Crotale missile. International Institute for Strategic Studies, *Military Balance 2012*, London, UK, March 2012, p. 274.

Communications Requirements[63]

Another design difference between crewed and uncrewed aircraft is the need for secure communications (i.e., encrypted radios) to control uncrewed aircraft.[64] UAS require a human operator to control its flight and its weapons capabilities.[65] Depending on the UAS mission, two types of communications may be required. For operations flying within approximately 50 miles from a home base, line-of-sight communications may be used, typically when UAS take off or land, since there is no time delay. Aircraft flying beyond 50 miles from a home base require beyond-line-of-sight (BLOS) communications—which in turn require links to satellite communications. Although crewed aircraft similarly rely on communications to coordinate operations, such aircraft do not need constant communications systems to maintain controlled flight.[66]

One potential risk to UAS is the disruption or jamming of control communications by adversaries.[67] To mitigate risks to the aircraft due to enemy jamming, some UAS can be programmed to return to their home base using global position system (GPS) navigation if their control signal is jammed. Another potential risk associated with UAS operations is an adversary hacking the aircraft to perform a different mission. In this scenario, an adversary would conduct a cyberattack (using radio frequencies) on the aircraft to enable the adversary to gain control of it.[68] Most military UAS, finally, rely on GPS signals for navigation. If an adversary were to jam GPS signals, the UAS may be unable to navigate to its intended destination.

Experimental Concepts[69]

In addition to existing DOD concepts of operation for UAS, a number of experimental concepts relating to the future use of UAS are in development. These include system-of-systems, artificial intelligence (AI)-enabled manned-unmanned teaming, swarming, and lethal autonomous weapon systems. Although discussed separately below, these concepts will likely overlap as they—and the technologies associated with them—mature.[70]

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[63] For a more detailed discussion of communications, see CRS Report R46564, *Overview of Department of Defense Use of the Electromagnetic Spectrum*, coordinated by John R. Hoehn.

[64] While encrypted radio signals were not an initial requirement for UAS operations, U.S. forces found Iraqi insurgents were gaining access to unencrypted MQ-1 Predator video feeds. As a result, U.S. forces began encrypting these signals to prevent adversaries from gaining access to U.S. intelligence. Mike Mount and Elaine Quijano, "Iraqi insurgents hacked Predator drone feeds, U.S. official indicates," *CNN*, December 17, 2009, at http://www.cnn.com/2009/US/12/17/drone.video.hacked/index.html.

[65] U.S. Air Force, *Flight Operations, Air Force Manual (AFMAN) 11-202 Volume 3*, Washington, DC, January 10, 2022, p. 270, at https://static.e-publishing.af.mil/production/1/af_a3/publication/afman11-202v3/afman11-202v3.pdf.

[66] Uncrewed aircraft can be programmed to fly a specific route, potentially reducing the need for satellite communications to maintain control; however, these systems still require GPS for navigation purposes. Crewed aircraft can operate with paper maps and therefore theoretically operate without any communications systems.

[67] For a more detailed discussion of electronic warfare, see CRS In Focus IF11118, *Defense Primer: Electronic Warfare*, by John R. Hoehn.

[68] For a broader discussion of the convergence between cyber and electronic warfare, see CRS In Focus IF11292, *Convergence of Cyberspace Operations and Electronic Warfare*, by Catherine A. Theohary and John R. Hoehn.

[69] This section was written by Kelley M. Sayler, Analyst in Advanced Technology and Global Security.

[70] For example, any UAS—including lethal autonomous weapons and the platforms discussed in the "AI-Enabled Manned-Unmanned Teaming" section of this report (e.g., Skyborg, Valkyrie)—could potentially be integrated into a system-of-systems or swarm.

Aircraft System-of-Systems

System-of-systems (SOS) refers to "a collection of systems, each capable of independent operation, that interoperate together to achieve additional desired capabilities."[71] These systems may be deployed on separate aircraft, including crewed, optionally crewed, and uncrewed aircraft. For example, although little open-source information exists about the Next Generation Air Dominance (NGAD) program, DOD reportedly intends for NGAD to enable air superiority through a "portfolio of technologies" that forms an SOS.[72] Secretary of the Air Force Frank Kendall has stated that NGAD "will include a crewed platform teamed with a much less expensive, autonomous, uncrewed combat aircraft employing a distributed, tailorable mix of sensors, weapons, and other mission equipment."[73] This approach would allow commanders to compose aircraft packages for each mission to mitigate risk and maximize the likelihood of mission success. The SOS approach is additionally intended to allow spiral software development, in which NGAD software and hardware can be continuously upgraded or replaced.[74]

AI-Enabled Manned-Unmanned Teaming

Manned-unmanned teaming (MUMT) pairs crewed aircraft with uncrewed aircraft to leverage the strengths of each. The U.S. military has previously fielded MUMT applications involving remotely piloted UAS;[75] however, it is now exploring more advanced, AI-enabled MUMT applications in which one or more UAS operate in conjunction with—but autonomously from—crewed aircraft. These applications include mission support and autonomous *dogfighting*, or air-to-air combat maneuvering.

Mission Support

UAS may be employed in a mission support role for crewed aircraft, a concept that is often referred to as "loyal wingman." The Air Force program Skyborg is intended to support this concept and expected to develop UAS capable of autonomously collecting data and performing other missions—such as target identification and electronic warfare—to increase the situational awareness and lethality of crewed aircraft.[76] According to a 2020 Air Force contracting notice,

[71] See MITRE, "Systems Engineering Guide: System of Systems," at https://www.mitre.org/publications/systems-engineering-guide/enterprise-engineering/systems-of-systems.

[72] Department of Defense, *Fiscal Year (FY) 2022 Budget Estimates, Air Force Justification Book of Research, Development, Test and Evaluation, Volume II*, p. 335, at https://www.saffm.hq.af.mil/Portals/84/documents/FY22/RDTE_/FY22%20DAF%20J-Book%20-%203600%20-%20AF%20RDT%20and%20E%20Vol%20II.pdf?ver=KpJJbVq68o32dSvkjuv_Iw%3d%3d.

[73] John A. Tirpak, "Details Emerge on New Unmanned Long-Range Bomber and Fighter Projects," *Air Force Magazine*, March 3, 2022, at https://www.airforcemag.com/details-emerge-on-new-unmanned-long-range-bomber-and-fighter-projects/.

[74] John A. Tirpak, "New Force Design: NGAD Needed Soon, F-22 Sunset Begins in 2030," *Air Force Magazine*, May 13, 2021, at https://www.airforcemag.com/new-force-design-ngad-needed-soon-f-22-sunset-begins-in-2030/.

[75] For example, the Army has fielded AH-64 Apache helicopters with software packages that allow the pilot to control the flight path and sensors of certain Army UAS. See Belinda Bazinet, "Upgraded Apache helicopters begin fielding to Soldiers in Korea," U.S. Army, January 10, 2020, at https://www.army.mil/article/253180/upgraded_apache_helicopters_begin_fielding_to_soldiers_in_korea.

[76] "Skyborg," Air Force Research Laboratory, at https://afresearchlab.com/technology/vanguards/successstories/skyborg. One variant, the Off-Board Sensing Station (OBSS), is to "extend a [crewed] fighter's sensing range and also potentially carry additional weapons for that aircraft." John A. Tirpak, "Kratos, General Atomics Get Contracts for 'Off-Board Sensing Station' Unmanned Fighter Escort," *Air Force Magazine*, October 26, 2021, at

Skyborg UAS are to be low-cost, reusable platforms with "minimal logistical footprints" to enable rapid deployment in combat.[77] Skyborg is also to feature an "open architecture" design that allows the modular integration of various sensor, communication, and other technologies.[78]

Skyborg could be paired with other uncrewed platforms such as Valkyrie, a stealthy, low-cost UAS that could similarly provide mission support for crewed aircraft. For example, Valkyrie has been tested as a communications gateway for F-22 and F-35 fighter aircraft.[79] The Air Force has also experimented with using Valkyrie as a launch platform for smaller UAS that could potentially perform "electronic warfare, signals intelligence, counter-UAS, and intelligence, surveillance and reconnaissance, and [could] be outfitted to produce kinetic effects"[80] (**Figure 6**). Valkyrie is reportedly capable of carrying up to four GBU-39B Small Diameter Bombs, a 250-pound-class guided air-to-surface weapon.[81]

https://www.airforcemag.com/kratos-general-atomics-contracts-unmanned-fighter-escort/.

77 Joseph Trevithick, "The Fight For the Air Force's 'Skyborg' Artificial Intelligence Equipped Drones Has Begun," *The Drive*, May 19, 2020, at https://www.thedrive.com/the-war-zone/33567/the-fight-for-the-air-forces-skyborg-artificial-intelligence-equipped-drones-has-begun.

78 Department of Defense, *Fiscal Year (FY) 2022 Budget Estimates, Air Force Justification Book of Research, Development, Test and Evaluation, Volume I*, p. 214, at https://www.saffm.hq.af.mil/Portals/84/documents/FY22/RDTE_/FY22_PB_RDTE_Vol-I.pdf?ver=DGijGVofWq4jnTnOLuU5Bg%3d%3d.

79 The F-22 and F-35 are equipped with two different low-probability-of-intercept/low-probability-of-detection (LPI/LPD) systems for exchanging data in stealth mode, and thus cannot communicate directly over LPI/LPD systems. Joseph Trevithick, Thomas Newdick, and Tyler Rogoway, "Stealthy XQ-58 Drone Busts The Networking Logjam Between F-22 And F-35," *The Drive*, December 15, 2020, at https://www.thedrive.com/the-war-zone/38168/stealthy-xq-58-drone-busts-the-networking-logjam-between-f-22-and-f-35.

80 Valerie Insinna, "Valkyrie drone launches even smaller drone from inside payload bay," *Defense News*, April 5, 2021, at https://www.defensenews.com/air/2021/04/05/the-valkyrie-drone-launches-an-even-smaller-drone-from-inside-its-payload-bay/.

81 Brett Tingley and Tyler Rogoway, "Kratos Says Secret 'Off-Board Sensing Station' Unmanned Aircraft Will Be Transformative, *The Drive*, August 5, 2021, at https://www.thedrive.com/the-war-zone/41849/kratos-says-secret-off-board-sensing-station-unmanned-aircraft-will-be-transformative. For additional information about the capabilities of the GBU-39B Small Diameter Bomb, see U.S. Air Force, "GBU-39B Small Diameter Bomb Weapon System," at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104573/gbu-39b-small-diameter-bomb-weapon-system/.

Figure 6. Valkyrie UAS Deploys ALTIUS-600 Small UAS

Source: U.S. Air Force, available at https://www.af.mil/News/Photos/igphoto/2002617611/.

Autonomous Dogfighting

DARPA is currently exploring the concept of autonomous dogfighting—in which artificial intelligence could be used to conduct air-to-air combat maneuvers—in its Air Combat Evolution (ACE) program. ACE seeks to "build human trust in AI," such that a single human pilot may direct multiple UAS.[82] According to DARPA, this outcome could enable a division of labor "in which higher-level cognitive functions (e.g., developing an overall engagement strategy, selecting and prioritizing targets, determining best weapon or effect, etc.) may be performed by a human, while lower-level functions (i.e., details of aircraft maneuver and engagement tactics) [are] left to the autonomous system."[83]

DARPA hosted the AlphaDogfight Trials, which tested AI algorithms that could enable autonomous dogfighting, in August 2020.[84] During the trials, participating teams submitted algorithms designed to simulate an F-16 fighter jet in air-to-air combat. The top algorithm was then tested against an Air Force fighter pilot flying an F-16 simulator, with the algorithm winning all five simulated dogfights due to its ability to make "aggressive and precise maneuvers the human pilot couldn't outmatch" or would not undertake due to risk.[85] DARPA reportedly plans to test autonomous dogfighting algorithms in commercial UAS in FY2022 through FY2023 before transitioning to combat aircraft in FY2023 and FY2024.[86]

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[82] "AlphaDogfight Trials Foreshadow Future of Human-Machine Symbiosis," DARPA, August 26, 2020, at https://www.darpa.mil/news-events/2020-08-26.

[83] "Air Combat Evolution (ACE)," DARPA, at https://www.darpa.mil/program/air-combat-evolution.

[84] "AlphaDogfight Trials Foreshadow Future of Human-Machine Symbiosis," DARPA, August 26, 2020, at https://www.darpa.mil/news-events/2020-08-26.

[85] Ibid.

[86] Thomas Newdick, "AI That Bested Air Force Pilot In "Digital Dogfights" Headed For L-39 Jet Trainer," *The Drive*, July 26, 2021, at https://www.thedrive.com/the-war-zone/41683/ai-that-bested-air-force-pilot-in-digital-dogfights-

Swarming

Swarming refers to cooperative behavior—generally enabled by artificial intelligence and networked communications—in which a group of UAS autonomously coordinates to accomplish a mission.[87] Notional swarming concepts range from large formations of low-cost UAS that could overwhelm adversary defensive systems (see the "Suppression and Destruction of Enemy Air Defenses" section above) to smaller, more tailored formations that could execute electronic attack or ISR missions. Some analysts argue that swarms could have several advantages over individually deployed UAS, such as the ability to easily disperse combat power. This ability could in turn complicate an adversary's ability to target and neutralize the swarm, thus creating an unfavorable cost-exchange ratio for the defender.[88] Similarly, swarms of low-cost UAS could provide a less expensive alternative to traditional weapons systems.[89] Swarms could also reduce personnel requirements and costs by enabling a single servicemember to operate numerous UAS at the same time. Finally, swarms could retain combat power "as individual platforms are attrited, as opposed to a sharp loss in combat power if a single, more exquisite platform is lost."[90]

The U.S. military has a number of swarm programs under development. For example, Low-Cost UAV (Unmanned Aerial Vehicle) Swarming Technology (LOCUST), an Office of Naval Research (ONR) program, seeks to mature swarm technology for Raytheon's portable, tube-launched Coyote UAS. According to Navy budget documents, ONR has successfully launched 33 Coyote UAS in 40 seconds and flown them in a "coordinated swarm."[91] Reports indicate that the Coyote is capable of carrying a variety of different payloads, including electronic warfare systems or explosive warheads, and could be deployed on a range of ground-, air-, and sea-based platforms.[92]

DARPA's OFFensive Swarm-Enabled Tactics (OFFSET) program, which conducted its final field experiment in December 2021, similarly sought to mature technologies to enable swarms of up to

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headed-for-l-39-jet-trainer.

[87] Paul Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for a New American Security, October 2014, at https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf.

[88] An unfavorable cost-exchange ratio would occur if, in an attempt to neutralize the swarm, the defender uses a countermeasure (e.g., missile interceptor[s]) with an aggregate cost that is higher than the aggregate cost of the swarm. For additional information about the relationship between swarms and cost-exchange ratios, see Paul Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for a New American Security, October 2014, pp. 20-21, at https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf. An unfavorable cost-exchange ratio can also occur in countering a single UAS. For example, a U.S. ally reportedly used a $3 million Patriot surface-to-air missile to shoot down a $200 UAS. See Chris Baraniuk, "Small drone 'shot with Patriot missile,'" *BBC*, March 15, 2017, at https://www.bbc.com/news/technology-39277940.

[89] For example, one Patriot surface-to-air missile costs approximately $3 million, while one Coyote UAS costs approximately $15,000 (without a warhead). A swarm of 100 Coyote UAS would therefore cost approximately half as much as a Patriot missile, all else being equal. See Joseph Trevithick, "Army Buys Small Suicide Drones To Break Up Hostile Swarms And Potentially More," *The Drive*, July 17, 2018, at https://www.thedrive.com/the-war-zone/22223/army-buys-small-suicide-drones-to-break-up-hostile-swarms-and-potentially-more#:~:text=Coyote's%20relatively%20low%20cost%20could,trim%20that%20cost%20back%20further.

[90] Paul Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for a New American Security, October 2014, p.14, at https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf.

[91] Department of Defense, *Fiscal Year (FY) 2022 Budget Estimates, Navy Justification Book of Research, Development, Test and Evaluation, Volume II, Budget Activity 4*, p. 170, at https://www.secnav.navy.mil/fmc/fmb/Documents/22pres/RDTEN_BA4_Book.pdf.

[92] David Hambling, "U.S. Navy Destroys Target With Drone Swarm—And Sends A Message To China," *Forbes*, April 30, 2021, at https://www.forbes.com/sites/davidhambling/2021/04/30/us-navy-destroys-target-with-drone-swarm—and-sends-a-message-to-china/?sh=4c62b0d92df1.

250 UAS and/or uncrewed ground systems.[93] This capability is intended to support military personnel operating in complex urban environments.[94] DARPA is also exploring a concept for a UAS swarm called Gremlins (**Figure 7)** that could be launched from—and recovered in-flight by—a C-130 transport aircraft or other airborne platform.[95] Military personnel could then refurbish and relaunch the Gremlins within 24 hours.[96] According to DARPA, "the gremlins' expected lifetime of about 20 uses could provide significant cost advantages over expendable systems by reducing payload and airframe costs and by having lower mission and maintenance costs than conventional platforms, which are designed to operate for decades."[97]

Figure 7. Gremlin UAS Swarm

Source: DARPA, available at https://www.darpa.mil/program/gremlins.

Lethal Autonomous Weapon Systems

Although no internationally agreed-upon definition of Lethal Autonomous Weapon Systems (LAWS) exists, DOD Directive 3000.09 defines LAWS as a class of weapon systems capable of both independently identifying a target and employing an onboard weapon to engage and destroy it without manual human control. This concept of autonomy is also known as "human out of the loop" or "full autonomy."[98] The directive contrasts LAWS with human-supervised, or "human on

[93] "OFFensive Swarm-Enabled Tactics (OFFSET)," DARPA, at https://www.darpa.mil/work-with-us/offensive-swarm-enabled-tactics.

[94] Ibid.

[95] DARPA reportedly envisions that the Gremlin launch platform (e.g., C-130 transport aircraft) would "stay out of range of enemy air defenses," while the Gremlin swarm would "fly into danger and conduct missions such as intelligence, surveillance, reconnaissance or electronic warfare" before returning to the launch platform. See Stephen Losey, "DARPA nabs Gremlin drone in midair for first time," Defense News, November 5, 2021, at https://www.defensenews.com/unmanned/2021/11/05/darpa-nabs-gremlin-drone-in-midair-for-first-time/.

[96] Stephen Losey, "DARPA nabs Gremlin drone in midair for first time," *Defense News*, November 5, 2021, at https://www.defensenews.com/unmanned/2021/11/05/darpa-nabs-gremlin-drone-in-midair-for-first-time/.

[97] "Gremlins," DARPA, at https://www.darpa.mil/program/gremlins.

[98] For a discussion of various concepts of autonomy, see Paul Scharre and Michael C. Horowitz, *An Introduction to Autonomy in Weapon Systems*, Center for a New American Security, February 13, 2015, at https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/Ethical-Autonomy-Working-Paper_021015_v02.pdf?mtime=

the loop," autonomous weapon systems, in which operators have the ability to monitor and halt a weapon's target engagement.[99]

LAWS would likely require computer algorithms and sensor suites to classify an object as hostile, make an engagement decision, and guide a weapon to the target. Although these systems are not yet in widespread development,[100] they could enable military combat operations in communications-degraded or -denied environments in which traditional systems are unable to operate.

Potential Issues for Congress[101]

As Congress considers the future roles of UAS, it may examine a range of issues, including lethal autonomous weapons and arms control, cost comparisons of future UAS with crewed aircraft, personnel and skills implications, concepts of operation and employment, and the proliferation of uncrewed technologies. The following sections provide a framework for Congress to analyze programs in its role for authorizing and appropriating funding, and to enable Congressional oversight of UAS programs.

Lethal Autonomous Weapons[102]

Approximately 30 countries and 165 nongovernmental organizations have called for a preemptive ban on lethal autonomous weapons to address ethical concerns, such as a perceived lack of accountability for the use of such weapons and a perceived inability to comply with the law of armed conflict's proportionality and distinction requirements.[103] In addition, some analysts have raised concerns about the potential operational risks posed by lethal autonomous weapons.[104] These risks could arise from "hacking, enemy behavioral manipulation, unexpected interactions with the environment, or simple malfunctions or software errors."[105] All automated systems may

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[99] Another category is semi-autonomous, or "human in the loop," weapon systems that "only engage individual targets or specific target groups that have been selected by a human operator." Department of Defense Directive 3000.09, "Autonomy in Weapon Systems," updated May 8, 2017, at https://www.esd.whs.mil/portals/54/documents/dd/issuances/dodd/300009p.pdf. See also Paul Scharre and Michael C. Horowitz, *An Introduction to Autonomy in Weapon Systems*, Center for a New American Security, February 13, 2015, at https://s3.us-east-1.amazonaws.com/files.cnas.org/documents/Ethical-Autonomy-Working-Paper_021015_v02.pdf?mtime=20160906082257&focal=none.

[100] Some analysts have argued that certain loitering munitions such as the Israeli Harpy meet the United States' definition of LAWS. See, for example, *Defense Innovation Board, AI Principles: Recommendations on the Ethical Use of Artificial Intelligence by the Department of Defense - Supporting Document*, October 2019, p. 12, at https://media.defense.gov/2019/Oct/31/2002204459/-1/-1/0/DIB_AI_PRINCIPLES_SUPPORTING_DOCUMENT.PDF. In addition, although a United Nations report concluded that Turkey's deployment of the STM *Kargu-2* constitutes the first use of a lethal autonomous weapon system in combat, the U.N. described the *Kargu-2* as being "*programmed* to attack targets" [emphasis added]. For this reason, it is unlikely that the *Kargu-2* meets the U.S. definition of LAWS. United Nations Security Council, "Letter dated 8 March 2021 from the Panel of Experts on Libya established pursuant to resolution 1973 (2011) addressed to the President of the Security Council," March 8, 2021, p. 17, at https://undocs.org/S/2021/229.

[101] This section was written by John R. Hoehn, Analyst in Military Capabilities and Programs, unless otherwise noted.

[102] This subsection was written by Kelley M. Sayler, Analyst in Advanced Technology and Global Security.

[103] See CRS In Focus IF11294, *International Discussions Concerning Lethal Autonomous Weapon Systems*, by Kelley M. Sayler.

[104] See, for example, Paul Scharre, "Autonomous Weapons and Operational Risk," Center for a New American Security, February 2016, at https://www.cnas.org/publications/reports/autonomous-weapons-and-operational-risk.

[105] Ibid.

be vulnerable to such risks; however, such risks could be greater in LAWS because the human operating the system would likely be unable to terminate engagements—potentially resulting in wider-scale or more numerous instances of fratricide, civilian casualties, or other unintended consequences.[106] Some analysts have raised additional concerns that LAWS could be combined with swarm technology to produce weapons of mass destruction.[107] For example, analyst Zachary Kallenborn has argued that such systems could be used to inflict casualties on infantry units or massed civilians, or as genocidal weapons targeting particular ethnic groups.[108] In the latter use case, operators could potentially pair LAWS with biometric databases to enable the systems to target particular individuals or particular groups of people.[109] LAWS could be used similarly to improve dispersal mechanisms for chemical, biological, radiological, or nuclear agents.[110]

Those analysts supporting a preemptive ban on LAWS have—in addition to the law of armed conflict—appealed to the Martens Clause, which appears in the 1899 Hague Convention preamble and states that weapons use should conform to the "principles of humanity and the dictates of the public conscience."[111] They argue that LAWS contravene that requirement; however, other analysts have noted that using the Martens Clause to ban a weapons system would be unprecedented, and furthermore, that the legal status of the Martens Clause is questionable and instead constitutes "merely a recognition of 'customary international law.'"[112]

Other analysts and a number of national governments[113]—including the U.S. government[114]—oppose a preemptive ban on LAWS.[115] These parties have noted the potential humanitarian benefits of such weapons, which may be able to "strike military objectives more accurately and with less risk of collateral damage or civilian casualties" than traditional systems.[116] Opponents of a ban further contend that human operators will remain accountable for systems' deployment and

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[106] Ibid.

[107] Zachary Kallenborn, *Are Drone Swarms Weapons of Mass Destruction?*, United States Air Force Center for Strategic Deterrence Studies, May 6, 2020, at https://media.defense.gov/2020/Jun/29/2002331131/-1/-1/0/60DRONESWARMS-MONOGRAPH.PDF.

[108] Ibid., p. 20.

[109] For additional information on biometric technologies and how they might be integrated into LAWS, see CRS In Focus IF11783, *Biometric Technologies and Global Security*, by Kelley M. Sayler.

[110] Zachary Kallenborn and Phillip C. Bleek, "Swarming destruction: drone swarms and chemical, biological, radiological, and nuclear weapons," *The Nonproliferation Review*, vol. 25, January 2, 2019, at https://www.tandfonline.com/doi/full/10.1080/10736700.2018.1546902.

[111] Bonnie Docherty, *Heed the Call: A Moral and Legal Imperative to Ban Killer Robots*, Human Rights Watch, August 21, 2018, at https://www.hrw.org/report/2018/08/21/heed-call/moral-and-legal-imperative-ban-killer-robots#.

[112] Paul Scharre, *Army of None: Autonomous Weapons and the Future of War* (New York: W.W. Norton & Company, 2018).

[113] For a discussion of specific country positions on LAWS, see CRS In Focus IF11294, *International Discussions Concerning Lethal Autonomous Weapon Systems*, by Kelley M. Sayler.

[114] In this instance, the position of the U.S. delegation to the United Nations Convention on Certain Conventional Weapons (UN CCW)—the primary forum for international discussions of LAWS—is characterized as "the U.S. government" position. The U.S. delegation to the UN CCW includes representatives of the Departments of State and Defense and is authorized to engage in UN CCW discussions on behalf of the U.S. government.

[115] If this position were to change, and the executive branch were to instead pursue an international treaty on LAWS, then the Senate would be called upon to provide advice and consent.

[116] See, for example, U.S. Government, "Humanitarian Benefits of Emerging Technologies in the Area of Lethal Autonomous Weapons," March 28, 2018, at https://ogc.osd.mil/Portals/99/Law%20of%20War/Practice%20Documents/US%20Working%20Paper%20-%20Humanitarian%20benefits%20of%20emerging%20technologies%20in%20the%20area%20of%20LAWS%20-%20CCW_GGE.1_2018_WP.4_E.pdf?ver=O0lg6BIxsFt57nrOuz3xHA%3D%3D.

for ensuring that the systems' use complies with international humanitarian law.[117] Finally, some argue that a preemptive ban on LAWS could inhibit research into technologies that may provide civilian benefits (e.g., eldercare robots).[118]

As it conducts oversight, Congress may seek additional information about LAWS, to include holding congressional hearings or requiring DOD to report certain information related to LAWS—such as U.S. decisions to develop or field LAWS, DOD efforts to mitigate the operational risks posed by LAWS, or threats posed by adversaries' development of LAWS—to the relevant congressional committees.[119] Congress may also seek to conduct oversight of the use of certain enabling technologies for LAWS, such as artificial intelligence or biometric technologies. For example, Congress could require DOD to brief the relevant congressional committees on the department's efforts to ensure that data training sets have been ethically collected and sufficiently tested for bias.[120]

Cost of Future UAS Compared with Crewed Systems

The net cost of UAS, relative to crewed aircraft, depends on several factors, and Congress may consider the potential cost of uncrewed aircraft compared with crewed counterparts. Although the development costs of some uncrewed aircraft may be high because they require leveraging relatively immature technologies (as was the case with the RQ-4 Global Hawk),[121] the operations and sustainment costs of uncrewed aircraft may likely be lower than crewed aircraft.[122] As a result, comparing similar numbers of aircraft and their capabilities, uncrewed aircraft may cost less over their lifecycle than a comparable crewed platform. As a result, while uncrewed aircraft may have a larger operations and maintenance cost overall when compared to crewed aircraft, the flying hour cost per aircraft may be lower (i.e., uncrewed aircraft may be flying more as a result of lower costs to operate per hour). For example, when comparing costs for close air support aircraft, DOD states the reimbursement rate (the cost per hour to "rent" an aircraft from DOD) for an MQ-9 is $652 per hour for DOD users, while an A-10C costs $8,130 per hour.[123]

[117] See, for example, U.S. Government, "Human-Machine Interaction in the Development, Deployment and Use of Emerging Technologies in the Area of Lethal Autonomous Weapons Systems," August 28, 2018, https://docs-library.unoda.org/Convention_on_Certain_Conventional_Weapons_-_Group_of_Governmental_Experts_(2018)/2018_GGE%2BLAWS_August_Working%2BPaper_US.pdf.

[118] See, for example, Government of Japan, "Possible outcome of 2019 Group of Governmental Experts and future actions of international community on Lethal Autonomous Weapons Systems," March 22, 2019, at https://docs-library.unoda.org/Convention_on_Certain_Conventional_Weapons_-_Group_of_Governmental_Experts_(2019)/CCW_%2BGGE%2B.1_%2B2019_%2BWP3%2BJAPAN.pdf.

[119] See, for example, Section 247 of the FY2019 NDAA (P.L. 115-232).

[120] See, for example, Section 5708 of the FY2020 NDAA (P.L. 116-92). For additional information about AI and algorithmic bias, see CRS Report R45178, *Artificial Intelligence and National Security*, by Kelley M. Sayler.

[121] For example, see Department of Defense, *Selected Acquisition Report (SAR), RQ-4 Global Hawk*, DD-A&T(Q&A)823-252, Washington, DC, December 31, 2010, p. 4, at https://nation.time.com/wp-content/uploads/sites/8/2012/03/dod-gh-2010-sar.pdf.

[122] Congressional Budget Office, *Usage Patterns and Costs of Unmanned Aerial Systems*, 57090, Washington, DC, June 1, 2021, at https://www.cbo.gov/system/files/2021-06/57090-UAS.pdf.

[123] This analysis assumes that aircraft performing close air support would be supporting a DOD user. The Office of the Secretary of Defense Comptroller does denote different hourly reimbursement rates for other federal users, Foreign Military Sales Users, and others in its annual reimbursement rate calculations. See Letter from Office of the Secretary of Defense Comptroller for Program/Budget, "Memorandum for Fiscal Year (FY) 2022 Department of Defense (DOD) Fixed Wing and Helicopter Reimbursement Rates," October 1, 2021, at https://comptroller.defense.gov/Portals/45/documents/rates/fy2022/2022_b_c.pdf.

In addition, smaller uncrewed aircraft used for intelligence, surveillance, and reconnaissance missions could be equipped with less expensive, less capable sensors than those installed in crewed aircraft, while increasing the number of sensors providing information. At an individual level, this arrangement might result in uncrewed aircraft that are less capable than crewed aircraft; however, the cost benefit may enable the sensors to be aggregated, providing a more detailed and responsive picture of the battle space. The Air Force, in particular, argues that lower cost uncrewed aircraft could potentially help mitigate crewed and uncrewed aircraft inventory shortfalls,[124] which is a continual congressional concern.[125]

In evaluating emerging UAS programs, through its authorization and oversight functions, Congress has several potential options to explore this issue. First, Congress may consider passing legislation seeking additional information on the impact of UAS on DOD's aircraft force structure. For example, the FY2015 National Defense Authorization Act (NDAA) required the Comptroller General to conduct a study to evaluate Air Force close air support alternatives.[126] Congress has also historically required DOD to provide a 30-year aircraft plan, which has not been delivered to Congress publicly since 2018.[127]

Personnel Implications

UAS may require an equal or greater number of military personnel than their crewed counterparts. For example, although MQ-9 UAS are uncrewed, the Air Force currently requires 49 personnel in a mission command element and 59 personnel forward deployed to launch, recover, and maintain four aircraft (a total requirement of 108 personnel for four MQ-9 UAS, or 27 personnel per aircraft).[128] The Air Force requires 61 personnel (or 56% of the total requirement for four aircraft) to perform maintenance for these aircraft. It is unclear what the personnel requirements are for more sophisticated UAS like the RQ-170.[129]

The total number of personnel required to operate UAS may increase in the future, along with a different ratio of skills required to operate those systems. For example, although most current uncrewed aircraft are nonstealthy turboprop aircraft, future uncrewed aircraft with stealth features and/or turbojet propulsion would likely have different maintenance requirements to maintain the engine along with ensuring stealth coatings are in sufficient condition. Although future UAS may need fewer pilots, weapons systems officers, and navigators, DOD may require additional intelligence and command-and-control personnel to process increased data and manage uncrewed assets (particularly with the implementation of manned-unmanned teaming).

Congress, through its authorization and oversight functions, has several options regarding this potential issue. First, Congress may consider potentially passing legislation seeking a report

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[124] Abraham Mahshie, "Kendall: Air Force Has an 'Affordability Problem' As It Tries to Meet Capability Gap," *Air Force Magazine*, June 1, 2022, at https://www.airforcemag.com/kendall-air-force-has-an-affordability-problem-as-it-tries-to-meet-capability-gap/.

[125] For example see P.L. 116-92§143.

[126] P.L. 113-291 §132.

[127] 10 USC §231a. For more information see CRS In Focus IF10999, *Defense's 30-Year Aircraft Plan Reveals New Details*, by Jeremiah Gertler.

[128] Todd Harrison, *Rethinking the Role of Remotely Crewed Systems in the Future Force*, Center For Strategic and International Studies, Washington, DC, March 3, 2021, at https://www.csis.org/analysis/rethinking-role-remotely-crewed-systems-future-force#:~:text=A%20typical%20MQ%2D1%20or,as%20shown%20in%20Table%201.

[129] For more information on the RQ-170 see CRS Report R47067, *Unmanned Aircraft Systems: Current and Potential Programs*, by John R. Hoehn and Paul K. Kerr.

comparing personnel requirements between crewed aircraft and UAS from DOD. For example, section 165 of the FY2021 NDAA required DOD to create a roadmap explaining "the anticipated mix of manned and unmanned aircraft, number of platforms, and associated aircrew and maintainers for support of United States Special Operations Forces."[130] Second, the Armed Services committees may consider authoring report language accompanying the NDAA to seek additional information on this issue. For example, the Senate Armed Services Committee report accompanying the FY2020 NDAA requested the Army to provide a briefing to the defense committees to outline its requirements for UAS pilots and maintainers.[131] Third, the Armed Services Committees may consider a committee hearing to consider testimony from experts in the field. For example, the House Armed Services Committee held a hearing on March 29, 2017, to receive testimony from DOD experts on the military's pilot shortage problem.[132]

Proliferation of Uncrewed Technologies

More than 95 countries reportedly operated some sort of uncrewed military aircraft in 2021, compared with 60 countries in 2010.[133] Historically, the United States has produced the most sophisticated UAS (e.g., the MQ-1 Predator, the RQ-4 Global Hawk, and the RQ-170 Sentinel), including UAS with advanced sensors and/or stealth features.[134] However, in recent years, Iran, Israel, China, and Turkey have demonstrated increasing levels of sophistication in their approaches to uncrewed technologies, with Iranian, Turkish, and Chinese UAS featuring prominently in recent military operations. For example, Iran demonstrated its ability to launch sophisticated attacks with uncrewed aircraft in September 2019, when Houthi rebels in Yemen—using Iranian supplied aircraft and missiles—attacked two Saudi oil refineries.[135] Iran has also reportedly exported uncrewed aircraft to Hamas and rebel forces in Syria.[136] The Turkish-developed Baykar Bayraktar TB2 was used in military operations during the conflict between Armenia and Azerbaijan in 2020, and has been used in Ukraine in 2022.[137] Similarly, Libyan forces are reported to have used both Turkish and Chinese systems.[138] According to one press

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130 P.L. 116-283 §165.

131 U.S. Congress, Senate Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2020*, 116th Cong., 1st sess., June 11, 2019, S. Rept, 116-48 (Washington: GPO, 2019), p. 56.

132 U.S. Congress, House Committee on Armed Services, Subcommittee on Military Personnel, *Military Pilot Shortage*, 115th Cong., 1st sess., March 29, 2017, 25-095 PDF (Washington: GPO, 2017), at https://www.govinfo.gov/content/pkg/CHRG-115hhrg25095/html/CHRG-115hhrg25095.htm.

133 Ibid.

134 Ibid.

135 Ben Hubbard, Palko Karasz, and Stanley Reed, "Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran," *New York Times*, September 14, 2019, at https://www.nytimes.com/2019/09/14/world/middleeast/saudi-arabia-refineries-drone-attack.html.

136 Seth J. Franztman, *Iran's drones are clones. Now they're being used in multiple conflicts.*, The Atlantic Council, Washington, DC, November 18, 2021,at https://www.atlanticcouncil.org/blogs/iransource/irans-drones-are-clones-now-theyre-being-used-in-multiple-conflicts/.

137 Jack Destsch, "The U.S. Army Goes to School on Nagorno-Karabakh Conflict," *Foreign Policy*, March 30, 2021, at https://foreignpolicy.com/2021/03/30/army-pentagon-nagorno-karabakh-drones/. Derek Gatopoulos and Suzan Fraser, "Cheap but lethal Turkish drones bolster Ukraine's defenses," *Associated Press*, March 17, 2022, at https://apnews.com/article/russia-ukraine-middle-east-africa-libya-europe-ecb9e820ea4bddb4464d7e8cb40e82fc.

138 In particular, the *Washington Post* reported that Chinese-developed uncrewed aircraft offered a cheaper alternative with similar capabilities to the U.S.-developed MQ-9 Reaper. Sudarsan Raghavan, "In Libya, cheap, powerful drones kill civilians and increasingly fuel the war," *Washington Post*, December 22, 2019, at https://www.washingtonpost.com/world/middle_east/libyas-conflict-increasingly-fought-by-cheap-powerful-drones/2019/12/21/a344b02c-14ea-11ea-bf81-ebe89f477d1e_story.html.

report, Chinese-developed uncrewed aircraft were cheaper than the U.S.-developed MQ-9 Reaper and had similar capabilities.[139] The continued proliferation of these systems could influence the future of U.S. export policy and the ability of the United States to control access to advanced UAS technologies. Export controls of military UAS are governed by multilateral export controls, namely the Missile Technology Control Regime (MTCR), along with national export controls managed by the State Department.[140] Both the Biden Administration and the previous Obama and Trump Administrations have proposed changes to these export controls to make U.S. manufacturers more competitive in the international UAS market.[141] Congress, as part of its constitutional authority to provide advice and consent on treaties, as well as in its oversight function, may consider potential changes to MCTR and other treaties.

[139] Sudarsan Raghavan, "In Libya, cheap, powerful drones kill civilians and increasingly fuel the war," *Washington Post*, December 22, 2019, at https://www.washingtonpost.com/world/middle_east/libyas-conflict-increasingly-fought-by-cheap-powerful-drones/2019/12/21/a344b02c-14ea-11ea-bf81-ebe89f477d1e_story.html.

[140] CRS Report R47067, *Unmanned Aircraft Systems: Current and Potential Programs*, by John R. Hoehn and Paul K. Kerr.

[141] For more information see CRS In Focus IF11069, *U.S.-Proposed Missile Technology Control Regime Changes*, by Paul K. Kerr.

Appendix. Intelligence Support of UAS Targeting in Counterterrorism Operations[142]

Intelligence support for UAS counterterrorism operations has inherent limitations. U.S. government research and development programs are meant to address some of these limitations. For example, the United States Army and the Intelligence Advanced Projects Research Agency (IARPA) have been pursuing technologies to improve aircraft endurance and enhance image quality, with the goals of longer dwell time over target areas and clearer, more stable UAS video and imagery.[143] In the meantime, the limitations of UAS platforms have significant political and ethical implications, particularly regarding efforts to minimize the distance to target areas and to reduce the risk of human error in interpreting imagery. From an ethical perspective, a limited intelligence capability in a target area increases the risk of errors in interpreting imagery for targeting. In areas like Afghanistan, the already challenging task of intelligence support to time-sensitive targeting becomes more difficult in tactical situations where intelligence sources and infrastructure, as well as local intelligence partnerships, are limited.

Basing access is an important political consideration because UAS basing may have to be negotiated with countries in close proximity to a target area, or may require long transit times that limit the extent to which a UAS can observe an area. Presently, the United States has in Afghanistan neither an extensive organic intelligence capability, nor the strong international partnerships that it had in the past. According to the Commander of Central Command, General Kenneth McKenzie, "As we go forward in our ability to create what we call the ecosystem that allows you to see what is going on the ground and put all that together, it is going to get a lot harder to do that, particularly in places like Afghanistan."[144]

The August 2021 U.S. military withdrawal from Afghanistan raises questions about how effectively the intelligence community can support counterterrorist operations from "over the horizon," meaning over a landlocked country where intelligence coverage is limited.[145] U.S. officials have reportedly acknowledged that the withdrawal from Afghanistan has resulted in the loss there of 90% of UAS intelligence collection capabilities.[146] Moreover, regardless of proximity to a target area or anticipated advances in UAS technology, intelligence support of counterterrorism operations will continue to depend on a human interface: analysts responsible for interpreting video and still images and integrating other possible sources, such as tactical human and signals intelligence.

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[142] This section was written by Michael E. Devine, Analyst in Intelligence and National Security.

[143] See U.S. Army SBIR/STTR, Unmanned Aircraft System (UAS) Full Motion Video (FMV) Enhancement, at https://www.armysbir.army.mil/topics/unmanned-aircraft-system-uas-full-motion-video-fmv-enhancement/. See also Robert K. Ackerman, "IARPA Strives for Innovative Portable Power Sources," *Signal Magazine, AFCEA*, October 7, 2021, at https://www.afcea.org/content/iarpa-strives-innovative-portable-power-sources.

[144] Testimony of General Kenneth McKenzie, *Hearing to Receive Testimony on the Conclusion of Military Operations in Afghanistan and Plans for Future Counterterrorism Operations*, United States Senate Armed Services Committee, September 28, 2021, at https://www.armed-services.senate.gov/imo/media/doc/21-73_09-28-2021.pdf.

[145] See, for example, Michael Hirsh, "U.S. Military Concedes It's Unready to Fight Terrorism from 'Over the Horizon'" *Foreign Policy*, September 30, 2021, at https://foreignpolicy.com/2021/09/30/over-the-horizon-counterterrorism-afghanistan-united-states-flying-blind/.

[146] Warren P. Strobel, Gordon Lubold, and Michael R. Gordon, "U.S. Pledge to Fight Terrorists in Afghanistan will be Harder without Boots on the Ground," *Wall Street Journal*, August 31, 2021, at https://www.wsj.com/articles/u-s-s-pledge-to-fight-terrorists-in-afghanistan-will-be-harder-without-boots-on-the-ground-11630402200.

An August 29, 2021, MQ-9 Reaper UAS strike in Kabul that killed at least 10 Afghans—including 7 children—which was incorrectly interpreted by analysts as targeting an imminent terrorist threat, underscores the difficulty of targeting in such an environment.[147] General McKenzie acknowledged challenges in acquiring actionable intelligence in this situation: "We did not have the luxury of developing pattern of life."[148] An investigation by the Inspector General of the Air Force, Lieutenant General Sami Said, concluded that "confirmation bias and communication breakdowns" were factors in analysts incorrectly interpreting UAS surveillance video.[149]

When limited to airborne sensors, "developing a pattern of life" entails increasing the UAS dwell time over a potential target—more easily achieved in a permissive environment, or by having greater proximity to the target area than the United States currently has in Afghanistan. According to media reporting, to date the United States has been unsuccessful in negotiating the use of bases in neighboring countries for UAS operations over Afghanistan, although Pakistan is continuing to permit overflights of its territory.[150] A significant concern for Pakistan in particular is the political cost of allowing base access, which is strongly opposed by the general public.[151] Obstacles to establishing and maintaining a layered intelligence architecture in the region to support reliable UAS counterterrorist operations comes at a time when, according to Chairman of the Joint Chiefs of Staff, General Mark A. Milley, a reconstituted Al Qaeda "with aspirations to attack the United

[147] Matthieu Aikins, Christoph Koettl, Evan Hill, and Eric Schmitt, "Times Investigation: U.S. Drone Strike Suggests No ISIS Bomb," *New York Times*, September 10, 2021 (updated October 16, 2021), at https://www.nytimes.com/2021/09/10/world/asia/us-air-strike-drone-kabul-afghanistan-isis.html. Defense officials later admitted that the suspected terrorist was, in fact, Zemari Ahmadi, an aid worker who had no affiliation with the Islamic State and who, at the time of the strike, was transporting colleagues to and from work, and loading canisters of water onto his truck to bring to his family. DOD officials admitted to making a "tragic mistake," and Secretary of Defense Lloyd Austin ordered an investigation to determine "the degree to which strike authorities, procedures, and processes need to be altered in the future." The United States' inability to benefit from strong international partnerships on the ground is compounded by indications, reported in the media, of small numbers of personnel formerly with Afghanistan's intelligence service, the National Directorate of Security (NDS), supporting the Islamic State-Khorasan Province. See Yaroslav Trofimov, "Left Behind after U.S. Withdrawal, Some Former Afghan Spies and Soldiers Turn to Islamic State," *Wall Street Journal*, October 31, 2021, at https://www.wsj.com/articles/left-behind-after-u-s-withdrawal-some-former-afghan-spies-and-soldiers-turn-to-islamic-state-11635691605. This article also reported that the United States was providing some intelligence on Islamic State-Khorasan to the Taliban government.

[148] Ibid.

[149] U.S. Department of Defense Transcript: "Pentagon Press Secretary John F. Kirby and Air Force Lt. Gen. Sami D. Said Hold a Press Briefing," November 3, 2021, at https://www.defense.gov/News/Transcripts/Transcript/Article/2832634/pentagon-press-secretary-john-f-kirby-and-air-force-lt-gen-sami-d-said-hold-a-p/. In the press briefing, Lt. Gen. Said described confirmation bias as a condition in which someone (such as an analyst) consciously or subconsciously interprets a situation or an image in a certain way, and views all subsequent information related to it through the same lens. It has also been defined as a phenomenon that is the "result of an over-reliance on one source of intelligence at the expense of integrating multiple channels of information." See Sarah Kreps and Paul Lushenko, "US Faces Immense Obstacles to Continued Drone War in Afghanistan," TechStream, Washington DC: Brookings, October 19, 2021, at https://www.brookings.edu/techstream/us-faces-immense-obstacles-to-continued-drone-war-in-afghanistan/. See also Alex Horton, Dan Lamothe, and Karoun Demirjian, "Botched Drone Strike that Killed 10 Civilians in Kabul was not a Result of Criminal Negligence, Pentagon Says," *The Washington Post*, November 3, 2021, at https://www.washingtonpost.com/national-security/2021/11/03/kabul-drone-strike-inspector-general-report/.

[150] Mark Mazzetti and Julian E. Barnes, "C.I.A. Scrambles for New Approach in Afghanistan," *New York Times*, June 6, 2021, updated August 27, 2021, at https://www.nytimes.com/2021/06/06/us/politics/cia-afghanistan-pakistan.html. See also Michael Hirsh, "U.S. Military Concedes."

[151] Ibid. Pakistan's foreign minister, Shah Mehmood Qurshi, reportedly declared in July 2021, "I want to tell Pakistanis that no U.S. base will be allowed by Prime Minister Imran Khan so long as he is in power." The United States had used Shamsi airbase in Pakistan for UAS operations targeting Al Qaeda until being told to leave in 2011 following the U.S. raid on Osama bin Ladin's Pakistan compound and an incident in which a NATO strike mistakenly killed dozens of Pakistani soldiers along the border with Afghanistan.

States is a very real possibility" in the next 12 to 36 months.[152] For the time being, the closest base for prospective UAS operations over Afghanistan is Al Udeid Airbase, Qatar, which requires significant aircraft fuel consumption in transit over the Persian Gulf and Pakistan, and consequently limits the amount of time that can be spent observing the target area.[153]

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[152] Statement of General Mark A. Milley, *Hearing to Receive Testimony on the Conclusion of Military Operations in Afghanistan and Plans for Future Counterterrorism Operations*, United States Senate Armed Services Committee, September 28, 2021, at https://www.armed-services.senate.gov/imo/media/doc/21-73_09-28-2021.pdf.

[153] Sarah Kreps and Paul Lushenko, "US Faces Immense Obstacles to Continued Drone War in Afghanistan," TechStream, Washington, DC: Brookings, October 19, 2021, at https://www.brookings.edu/techstream/us-faces-immense-obstacles-to-continued-drone-war-in-afghanistan/.