FEATURE

Small Unmanned Aerial Systems and Tactical Air Control

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Dominion of the air domain during war has long belonged to the wealthiest militaries. The complications of placing combatants in the air domain and the lack of terrain to mitigate technological overmatch have made airpower a rich man's game. Increasingly capable small unmanned aerial systems (sUAS) threaten to change this dynamic by providing a pathway for impoverished militaries to contest the air domain at the tactical level, but they also offer advanced militaries opportunities to push the control of air platforms down to lower-ground echelons inexpensively. Nations like the US will need to increase investment in sUAS development and counters to prevent competitors from taking advantage of a capability gap created by the emergence of small systems performing a wider range of conventional airpower missions.

> ***Air Superiority***—That degree of control of the air by one force that permits the conduct of its operations at a given time and place without prohibitive interference from air and missile threats.
>
> ***Air Supremacy***—That degree of control of the air wherein the opposing force is incapable of effective interference within the operational area using air and missile threats.
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Introduction

Advances in small UASs and supporting technologies will democratize access to the air domain and change the current dynamics of air control from a high-end contest to one that spans a larger spectrum of capabilities—from low to high. During the next two decades, these small UASs will increasingly supplement traditional aircraft in the performance of close-air support (CAS), reconnaissance, counterair, communications, and resupply missions. This miniaturization of air platforms will enable commanders to cost-effectively divide and apportion airpower, reducing its scarcity by pushing air assets down to the increasingly lower echelons of control and promoting the division of capabilities. The increased accessibility of airpower will make attaining air supremacy more difficult and air control even more temporal. Traditional contests for the domain between high-end systems or operational air control (OAC) will occur in simultaneity with tactical contests between sUAS platforms and short-range air defenses at lower altitudes for tactical air control (TAC). Increasingly autonomous small systems will make airpower more plentiful and the difficulty of sustaining control of the air domain greater than ever before.

Why Is Airpower Scarce?

No matter how dominant an invading force, few instances in history exist where an opposing army has become "incapable of interference" in a ground campaign. Defeated armies can reform, new bodies of troops can be raised, and partisans can continue effective resistance long after governments have conceded defeat. As Napoleon drove back Russian armies and burned Moscow in 1812, bands of partisans attacked his line of communications.[1] Later, during the Battle of Waterloo, Napoleon found himself flanked by two corps of Prussians who had reconstituted themselves in record time after a serious defeat at the Battle of Ligny two days earlier.[2] The control of the land rarely remains uncontested while adversaries retain the will to resist.

The sea, air, and space, however, can be controlled to the point of limiting effective resistance because of the environmental difficulties of operating forces in those domains.[3] Fortitude, alone, cannot sustain resistance. Unlike on land, sea, air, and space forces can only operate for a limited duration without returning to a logistics node. Sea, air, and space forces cannot scavenge food from adversarial lands as they maneuver, and they cannot refuel their weapon systems from the networks of petrol stations that populate developed countries. Ships require specific port calls for resupply and repair, fuel, and pilot fatigue that prevent aircraft from remaining in the air much beyond 24 hours at a time, and satellites, and spacecraft can only sustain themselves for set periods before falling to earth. The logistical complications of operating in unnatural environments help create scarcity: a situation where the demand for a service surpasses supply.

Despite the difficulties of operating in the air domain, its natural advantages ensure that the demand for airpower remains unsated within the joint force, causing an airpower shortfall. Every infantry company in Iraq or Afghanistan wants air cover midpatrol, and every navy expeditionary strike group desires a P-8 Poseidon's protection against enemy submarines. The nature of the air medium grants aircraft observation over large areas, extends the range of weapon systems and sensors, and allows unrivaled battlespace alacrity.[4] These advantages cause ground and naval forces to request CAS, offensive counterair (OCA), mobility, and airborne reconnaissance in quantities that cannot always be satisfied by traditional aircraft. The expense of fielding aircraft, short endurance of air platforms, a limited number of airfields and runways, and large size of the air domain prevent militaries, particularly resource-constrained ones, from easily upping supply to overcome this airpower deficit.

Expense per combatant: Modern aircraft are expensive to build and maintain, and the pilots who operate them require long, expensive training to operate their platforms effectively. This limits the number of aircraft that armed forces can supply in a conflict and the speed with which they can be replaced. The procurement of a squadron of 12 F-35A Lightning II fighters will cost the US government more than $1.1 billion dollars at current prices.[5] The assembly of each jet requires 43,000 man-hours—the effort of more than 20 people working full-time for a year—to create a fighter jet out of almost 300,000 components sourced from 1,100 suppliers.[6] Considering that only about 15 countries in the world spend more than $20 billion on defense each year,[7] the acquisition and maintenance of a state-of-the-art air force is out of reach for almost all countries except the very wealthiest. The need for highly-trained crews greatly adds to these expenses. In 2011, USAF pilots required one-to-two years of training at a cost of between $600,000–$2.6 million dependent on the platform they flew.[8] More recently, Lt Gen Gina M. Grosso, the USAF deputy chief of staff for manpower and personnel services, told the House Armed Services Committee that training a fifth-generation fighter pilot could cost up to $11 million.[9]

Modern military aircraft also have tremendous maintenance and fuel costs. The cost per flying hour (CPFH), a summation of operation and support costs, range from approximately $5,000 a flight hour for the A-10C Warthog to almost $60,000 an hour for the B-2A Spirit. The F-35A has a CPFH of more than $17,000.[10] These high costs, long production, and longer training cycles compel joint force commanders (JFC) to ration airpower and ensure that it supports only their highest mission priorities, particularly during initial attempts to establish air supremacy/superiority.

Duration: After a nation successfully develops and builds aircraft and trains pilots to fly them proficiently, they receive a highly capable weapon system with short endurance. Without aerial refueling, most fourth- and fifth-generation fighter aircraft have a combat radius of less than 700 miles.[11] Even when aerial refueling permits longer flights, fighter and attack aircraft are limited by the relatively small amount of ordnance they can carry onboard, and unlike combatants in the land and sea domain, aircraft cannot rearm mid-mission. The complexity of piloting aircraft reduces the endurance of these platforms even further. The USAF mandates that pilots receive 12 hours of crew rest before a mission outside of exceptional circumstances.[12] Even superlative examples of air endurance come across as minute compared to combatants in other domains. The longest military bombing run in history lasted 44 hours. Relative to ships at sea, which routinely conduct operations for months at a time, or grizzled infantrymen, this endurance level falls short of combatants in other domains. Modern aircraft constitute a highly effective but fleeting presence on the battlefield, and the small numbers of planes available to most air forces restrict a military's ability to take advantage of the air domain's benefits.

Limited runways and specialized support: Unlike land and sea forces, air combatants cannot be supplied while operating in their domain. They have to descend to earth and assume a vulnerable state on land. Aircraft return to airfields often for refueling, rearmament, recrewing, and maintenance. The limited number of airfields available to air operations and extensive operational support requirements constrict the supply of airpower. This constriction becomes more severe if airfields are located far from where aircraft conduct operations. Gravitational forces acting on aircraft and the severe consequences of a mechanical failure during flight require aircraft to receive maintenance more often than other vehicles, further limiting airpower availability. Furthermore, airfields constrain aircraft dispersion, making them vulnerable to attacks by precision-guided or cluster munitions by enemy forces attempting to seize air control during any stage of a conflict but primarily during its opening phase.

Size of domain: With the exception of space, air remains the largest physical domain in warfare. Water covers 71 percent of the earth's surface, but the air domain covers all of it.[13] The small number of combatants that operate in the air makes airpower a scarce resource for the JFC attempting to control the domain within the joint operational area. Because of this, the JFC controls air forces through centrally planned measures like air tasking orders that define altitudes, locations, and missions for aircraft within the operational area during a 24-hour cycle.

Effect of Airpower Scarcity

Collectively, these four dynamics constrain the supply of airpower capabilities in quantities that satisfy demand from joint forces. The resource costs and difficulties of designing, manufacturing, sustaining modern aircraft, and training individuals to fly them, ensures that the number of aircraft on the battlefield remain relatively small.

For the last 40 years, world-class militaries have trended toward consolidating combat roles and exquisite capabilities into multimission aircraft, further driving up costs. During the Vietnam War, the F-4 Phantom fighter-bomber cost roughly $20 million per aircraft (2018 dollars).[14] Today, an F-35A joint strike fighter costs almost five times that amount.[15] While the F-35's stealth attributes, advanced sensor package, and electronic warfare/communications suite provide necessary advantages in air-to-air combat or strike missions that involve penetrating sophisticated air defenses, they are less useful in low-threat environments. In these situations, the exquisiteness of the aircraft contributes to airpower scarcity. A single F-35A can carry roughly 18,000 pounds of air-to-ground ordnance and support a single CAS request at a time. For the same procurement cost, five F-4s could carry almost 75,000 pounds of ordnance and simultaneously support five engagements in different areas of the battlefield.[16] This clustering of capabilities within expensive airframes reduces the ability of the commander to divide capabilities across the battlefield at need. Combat power offered by an infantry company can be subdivided into platoons and squads, but the intelligence, CAS, strike, or transportation abilities offered by modern aircraft are tied to indivisible, expensive platforms. This link creates strong opportunity costs for committing aircraft to a mission that are only partially overcome by their speed, an enabler that allows aircraft to travel between missions at faster rates than vehicles from other domains. The consolidation of capabilities in high-priced air-to-air combatants drives up the price of entry for weaker states. Developing nations are loathe to risk their air forces against first-world powers during conflict even when tactical opportunities present themselves because of the high cost of defeat in terms of monetary and pilot investment.[17] If airpower is scarce for the richest militaries in the world, it is much more so for the poorest.

Small Unmanned Aerial Systems Can Reduce Scarcity

While small UASs will never completely replace larger manned or unmanned or adequately meet all airpower mission requirements, they can and will help satiate the demand for high-end systems at the tactical level. Current small UASs have great difficulty operating in adverse weather and lack the capacity or celerity of their larger brethren. These small UASs will never drop enormous munitions like the 30,000 pound (lb.) GBU-57A/B Massive Ordnance Penetrator or transport tanks like the C-17 Globemaster III, but as their capability grows in concordance with leaps in computing power, sensor technology, artificial intelligence, and other autonomy-enabling technologies, they will gain the capacity to fill a majority of tactical airpower roles at a reduced cost. A smartphone gives us the capacity to perform 70–80 percent of our required computing tasks but rarely do we require access to more powerful devices. Future sUAS platforms, respectively, have the potential to satisfy a significant portion of small-unit airpower demands. Instead of relying on low numbers of exquisite assets to support ground operations, units at the battalion-level and below will have direct control over lower-cost sUAS platforms that supplement the capabilities of legacy aircraft.

During the next decade, improvements in computer perception and cognition will allow small unmanned aerial systems to perform more independent actions without human control and minimal guidance.[18] Nascent technologies like computer vision will increasingly allow autonomous vehicles to self-navigate across the battlefield, identify objects on their own, and interact with those objects according to rules set under human direction.[19] Cheap, commercially available drones can already use satellite navigation to transit between points without human control, and hobbyists have begun using freeware computer vision algorithms like YOLO (You Only Look Once) to provide object recognition capabilities with sub-$1000 investments.[20] As engineers refine algorithms designed for sUAS sensors, and training data becomes more available through drone proliferation, these open-source algorithms will grow in effectiveness. Nation-state investment in sUAS computer vision will only mature it more quickly. In 2017, the DOD took the first step by greenlighting Project Maven, an Undersecretary of Defense for Intelligence effort to grant tactical- and medium-altitude intelligence, surveillance, and reconnaissance (ISR) platforms computer-vision capabilities.[21]

In parallel with private sector efforts to expand machine object recognition capabilities, government-funded, private sector, and university researchers are working to improve machine-to-machine communications in aerial platforms. In July 2015, Dr. Timothy Cheung of the Naval Postgraduate School led an effort to simultaneously launch 50 small unmanned aerial drones capable of acting cooperatively in a swarm through Wi-Fi communication, all controlled by one pilot.[22] And in 2018, Intel Corporation preprogrammed 300 small drones to fly cooperatively for the Super Bowl halftime show.[23] Once configured for military tasks, this level of automation could reduce the number of pilots and level of training required to control aircraft, particularly if drone flights are permitted to incur more risk without human passengers. If automation advances to a point where small unmanned aerial systems do not require piloting, ground forces could easily control their own organic air assets without intermediaries, increasing their ability to quickly leverage airpower capabilities during small-unit operations. As the mission profile of small UASs grow, the demand for this organic control will likely rise in parallel.

Defense contractors have already begun miniaturizing weapon, intelligence, and electronic warfare payloads for use on small unmanned aerial vehicles (UAV) in anticipation of their growing battlefield roles. Raytheon's Pyros, 6 kilogram glide bombs with GPS, inertial, and laser guidance options for deployment from small UAVs, even have a fuse programmable for airburst, delay, or point detonation.[24] Lockheed Martin's Shadow Hawk, a similar micro precision-guided munition (PGM), weighs just 11 lb. Both of these weapon systems could easily be carried by commercial drones like the DJI MG-1, a $15,000 sUAS with a payload capacity of 22–26 lb.[25] The Japanese company PRODRONE's PD6B-AW-ARM can carry almost twice as much as the MG-1 and obtain altitudes of 16,000 feet.[26] Commercially-available drones could easily be carried into battle by land forces with micro-PGMs and quickly deployed for dynamic air support.

Intelligence and electronic warfare payloads continue to shrink as well. Small UAVs, like the 40 lb. Insitu Scan Eagle, carry electro-optical or infrared sensors to support intelligence collection.[27] Drones can also carry additional intelligence payloads beyond imagery sensors.[28] The US company V-Star Systems created a signals intelligence package that weighs just 2 lb. and consumes only 25 watts of power. Like the micro-PGMs above, many commercially-available small UASs can lift these payloads, providing an avenue to field inexpensive aerial intelligence platforms.[29]

Progressive miniaturization of PGMs, intelligence sensors, and perception-enabled autonomy will allow small UASs to fill tactical CAS, ISR, tactical resupply, electronic attack, and communications missions currently reserved for large UAVs (groups 4 and 5) or manned assets.[30] The simultaneous increase in capability and greater commercial availability offers an avenue for militaries to reduce the scarcity of airpower. The sUAS platforms can be acquired and sustained for a fraction of the price of modern manned aircraft.[31] And increasingly, commercial and military semiautonomous sUAS platforms reduce the need for highly trained pilots.[32] The compactness of small UASs makes launch and recovery possible from almost any location, and their reduced weight and lack of embedded pilot could allow them to stay in the air longer without rest. This combination of traits could substantially reduce airpower shortages that small units routinely face at the tactical level by providing a cost-effective means of filling in air coverage gaps.

Expense per combatant. UAVs and small UASs can be procured and sustained for much lower amounts than modern manned aircraft through public or private channels.[33] Extremely capable UAVs, like the MQ-9 Reaper (group 5) have similar procurement costs to manned vehicles—roughly $16 million per aircraft, but cost less to operate, just $486 PFH in FY 2018.[34] Group 3 small UASs, like the RQ-7 Shadow ($750,000 per unit) or Scan Eagle ($100,000 per aircraft), cost significantly less to procure than larger UAVs and have even lower operational costs. Multiple, and in some cases dozens or hundreds, of group 1 and group 2 unmanned systems, can be procured for the cost of a single F-35A flight hour.[35]

Table 1. Current DOD UASs and group definitions

DOD unmanned aerial systems by group

Category	*Group*	*Weight*	*Max altitude*	*Speed*
sUAS	1	0–20 lb.	1,200 ft AGL*	<100 kn
sUAS	2	21–50 lb.	3,500 ft AGL	<250 kn
sUAS	3	<1,320 lb.	18,000 ft AGL	<250 kn
UAS	4	>1,320 lb.	18,000 ft	undefined
UAS	5	>1,320 lb.	18,000 ft	undefined

* Above ground-level

(Source: Derived from DOD, Unmanned Systems Integrated Roadmap FY2011–2036)

The cost of training pilots for a sUAS is also drastically lower than manned aircraft. All US military services except the USA use commissioned officers to fly manned aircraft because of aircraft expense and the high potential for aerial accidents. These systems are less difficult to fly and less expensive to lose, opening the possibility that all US services could use enlisted personnel to control small UASs or automate flight for tremendous cost savings.[36] The USAF spends $135,000 to train each UAS pilot, far less than other fixed-wing platforms.[37] Opening up more UAS pilot positions to enlisted personnel could drive these costs down even further and broaden the pool of potential pilots. As machine perception grows, and semiautonomous vehicles gain the ability to perform simple wartime tasks while they self-navigate, the piloting requirements for aerial vehicles will decline drastically. If the amount of direction required continues to decrease, militaries will find additional utility from employing large numbers of small, self-guiding aircraft capable of performing missions independently or with limited guidance.

Duration: Despite their size, a sUAS can rival the endurance of larger UAVs or manned systems—albeit carrying much smaller payloads. In 1998, a 28 lb. Aerosonde drone crossed the Atlantic Ocean after being launched off the roof of a car. It consumed a mere 1.8 gallons of fuel during its 26-hour flight.[38] Another group 2 UAS, the Scan Eagle, can stay airborne for more than 20 hours, far longer than most manned aircraft without refueling.[39] Additionally, the low cost of small UASs permits them to be fielded in numbers that allow them to be rotated on and off mission in a manner that precludes mission interruption. Swarms or flocks of small systems may fulfill the same mission of MQ-9s with better geographic and temporal coverage at a fraction of the cost.

Limited runways and operational support: The size of small unmanned aerial systems permits them to be launched from innumerable locations from air, land, or sea. This mobility allows them to avoid being targeted at fixed airfields or prevented from launch by the enemy's preemptive bombing of runways. The sUAS can take off vertically, be released from larger aircraft, use pneumatic and slingshot launchers, or make use of small stretches of flat terrain to get airborne. This flexibility allows their launch and recovery element (LRE) to travel around the battlespace to avoid threats and reduce flight time to their mission locations. The scale of the sUAS also minimizes the infrastructure required to support flight operations. Even support systems for group 3 UAVs can be carried around on small trailers with less difficulty than a towed 105 mm howitzer. Iterative engineering work on launch and recovery systems will likely make them even more mobile and compact. Future sUAS operators may have specially tailored vehicles to support their aircraft, aiding them in the speedy deployment of their vehicles for operational effect. The USN has already created pneumatic launchers capable of deploying large swarms of small unmanned aerial systems in seconds.[40] Variants of this technology could be used to quickly push out airpower on demand, hiding the sUAS capability until its moment of need to protect it from counterunmanned aerial system (C-UAS) efforts or OCA.

Size of domain: Small UASs will struggle with the size of the aerial domain but may be less impacted than larger, more expensive aircraft because they likely can cover more air space due to the low cost of fielding systems. The control of small UASs will also likely occur at lower echelons allowing supported forces to have better control over their ISR, CAS, and resupply aircraft. The size of the air domain will still be an impediment to increasing the supply of airpower, but supported forces should be able to employ air assets in their support more quickly due to their potential organic control and collocation. Soldiers, Sailors, Airmen, and Marines may even have the capacity to locally print small UASs in near- real-time through deployed three-dimensional printers to meet demand.[41]

Implications of sUAS Democratization in the US Air Domain

If sUAS development continues on the trajectory outlined in the USAF's *Small Unmanned Aircraft Systems (sUAS) Flight Plan: 2016–2036: Bridging the Gap between Tactical and Strategic*, small UAVs will lower the price of access to the aerial domain and broaden the range of actors able to take advantage of the domain's unique attributes. Enemy forces previously unable to contest the air domain or utilize aerial strike, reconnaissance, electronic attack against US forces will have an affordable means of doing so. The widespread enemy employment of small UASs will continue to stimulate US investment in C-UAS and short-range air defense (SHORAD) that have been absent from US arsenals for decades. Additionally, if small UASs continue to expand their capabilities to conduct a variety of traditional airpower missions effectively, the US military will need to invest in airborne platforms and air-to-air munitions specifically designed to conduct counterair missions against small UAVs. Enemy development of capable small systems would exploit a current gap in American capabilities geared toward high-end air combat and endanger US ability to achieve air control.[42]

Contesting Enemy sUAS Capabilities and Tactical Air Control

In 2000, fewer than 17 countries employed aerial drones for military purposes. By 2015, 75 countries had drones in their arsenals.[43] As the accessibility of drones grows through commercial innovation, and platforms become cheaper and more capable, almost all militaries will employ small UASs in expanding roles. Nonstate actors like the Islamic State have already showcased the ability to weaponize DJI Phantom drones with 40 mm grenades.[44] Actors with more substantial research and development budgets will quickly exceed this mark.[45]

As nations improve the intelligence sensors and micro-PGMs on sUAS platforms, the US military will need to mature its SHORAD and C-UAS capabilities to protect ground troops from enemy sUAS CAS and surveillance. The US may even need to invest in sUAS-based OCAs to protect ground forces vulnerable during maneuver and to overcome innate range advantages that air platforms have over ground assets. Typically, air-to-ground munitions can outrange ground-to-air munitions acquired at similar cost because they are released at higher elevations, permitting them additional flight time before gravity pulls them to earth. Additionally, as intelligence sensor payloads improve, tactical UAVs will have collection capabilities beyond the range of ground-based counterunmanned aerial system defenses, necessitating the deployment of UAVs designed and equipped for counterair missions.

At present, the US military is inadequately prepared to contest control of the airspace with a foe who emphasizes the development of a sUAS force capable of mobile launch. C-UAS systems provide strong protection for fixed sites, but maneuvering ground forces could prove more vulnerable to drone attack. High-end systems like the F-22 Raptor, F-35, F-15 Eagle, F-16 Falcon, and F/A-18 Hornet have been specifically designed to wage war against other manned aircraft and have a limited ability to adapt to the proliferation of smaller drone assets. Air-to-air missiles like the AIM-7 Sparrow, AIM 9X Sidewinder, and AIM-120 advanced medium-range air-to-air missile have limited utility against groups 1-to-3 UAS, and the opportunity cost of using a $125,000 AIM-7 to engage a $15,000 drone would be immense, particularly if an opposing force deployed drones in quantities that dwarfed the number of munitions fixed-wing aircraft can carry.[46] Even the flight time of fourth- and fifth-generation aircraft is too valuable to expend on engaging small unmanned aerial systems. Current US air defense systems like the MM-104 Patriot missile system have similar cost asymmetries with commercial small UASs. The $3 million air-to-surface missiles make financially inefficient drone interceptors.[47]

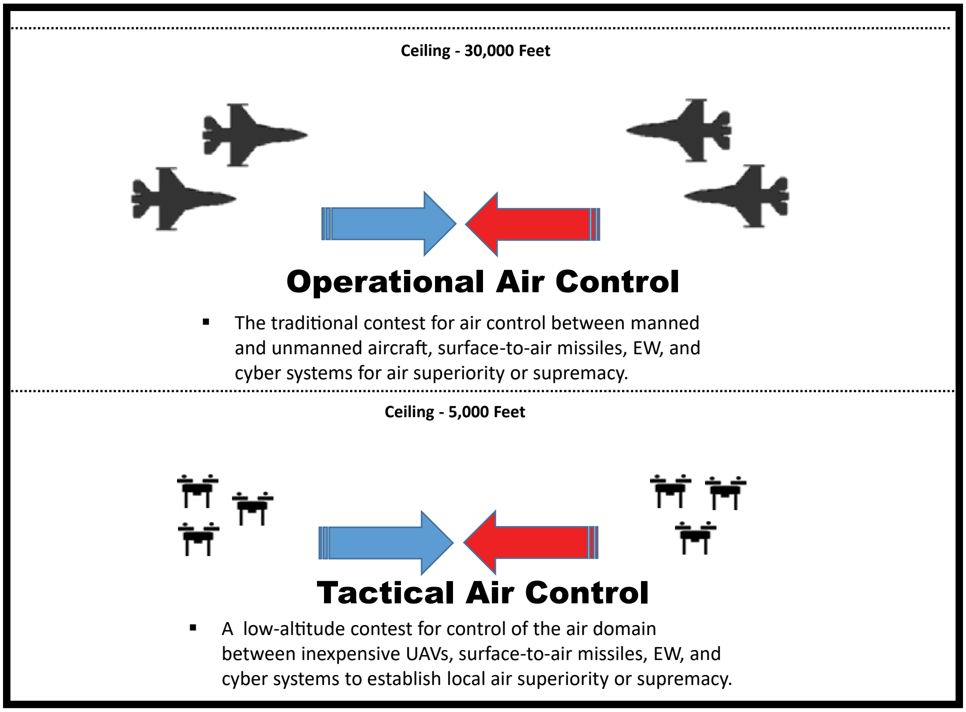
Modern fighters could target sUAS launch vehicles on the ground, but launchers may be as concealable as a small field artillery piece or potentially, a man-portable surface-to-air missile launcher. This concealability and mobility would allow sUAS threats to persist on the battlefield long after US airpower neutralized enemy aircraft that relied on standard-length runways. Locating and targeting mobile small UAS launchers could prove even more challenging than SCUD hunting during the first Gulf War.[48]

In effect, this capability gap between small UASs and fourth- and fifth-generation aircraft could result in two distinct contests for air control, a traditional one between air superiority fighters and air defense systems (OAC) and another at lower altitudes between multitudes of less expensive drones and shorter-range air defenses (TAC) (see fig 1).

In a contest between an actor that emphasized the deployment of small UASs and another that fielded more traditional aircraft, both parties could experience superiority at different levels of air control. While operational air superiority will arguably always have more battlefield impact than tactical air superiority, sUAS-derived TAC could shape the outcomes of small-scale land and sea engagements. An infantry platoon entering an engagement with a situational awareness advantage from superior sUAS coverage has a better chance of winning a gunfight.[49] Ground units with organic sUAS CAS or electronic warfare abilities would have an even greater advantage.

Although an sUAS-driven contest for TAC would have many of the characteristics of contests between high-end platforms, the faster rate at which small UASs can be deployed to the battlefield, the potential for the use of mobile launch systems, and likelihood of control at lower echelons may make the competition for TAC more dynamic and air superiority more temporary than historical contests. Unlike large fixed-wing manned or unmanned aircraft, dozens of smaller drones can be airdropped, pneumatically launched, or slung into the sky in a matter of minutes by current support apparatus.

Squad or platoon-sized units can even hand-carry small UASs into combat. Future battlefields could see squadrons of dozens, hundreds, or thousands of drones launched into the air by mobile LREs to aid ground units requiring air support or to pursue airpower missions of their own. This ability to rapidly surge air assets to specific areas of the battlefield will degrade the potential for militaries to preserve air dominance with certainty over large areas, even if opponents possess superior aircraft technology. A mobile sUAS LRE could remain hidden by operating under emissions control conditions and suddenly release individual UAVs or a swarm of drones to impact operations at a critical moment or as enemy air defense gaps are identified.

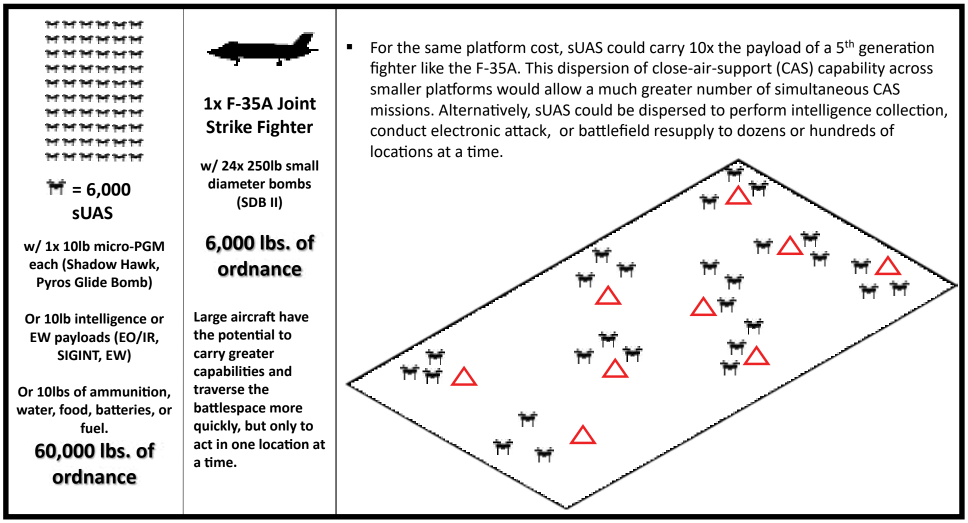


- The traditional contest for air control between manned and unmanned aircraft, surface-to-air missiles, EW, and cyber systems for air superiority or supremacy.

- A low-altitude contest for control of the air domain between inexpensive UAVs, surface-to-air missiles, EW, and cyber systems to establish local air superiority or supremacy.

Figure 1. Two levels of competition for air control
(Source: Derived from Raytheon, "Arming the F-35," modified from a graphic by Christopher Desrocher, "Aircraft of Atlantic Trident 2017")

Also, sUAS swarms could be configured to conduct emergency CAS for troops in contact, resupply a unit isolated by enemy forces through a decentralized supply drop, conduct reconnaissance in force before a major land or naval attack, form a redundant aerial communications network, or participate in a mass electronic warfare or cyber attack. At a more tactical level, small groups of small UASs could be quickly deployed to facilitate a local breakthrough or gain a temporary advantage in firepower or an awareness to support decisive maneuvers. Again, small UASs cannot replace larger airframes, but could be used to complement them by supporting tactical airpower missions that fall outside commander priorities or provide small maneuver units a semblance of persistent air cover.



= 6,000 sUAS

w/ 1x 10lb micro-PGM each (Shadow Hawk, Pyros Glide Bomb)

Or 10lb intelligence or EW payloads (EO/IR, SIGINT, EW)

Or 10lbs of ammunition, water, food, batteries, or fuel.

60,000 lbs. of ordnance

1x F-35A Joint Strike Fighter

w/ 24x 250lb small diameter bombs (SDB II)

6,000 lbs. of ordnance

Large aircraft have the potential to carry greater capabilities and traverse the battlespace more quickly, but only to act in one location at a time.

- For the same platform cost, sUAS could carry 10x the payload of a 5th generation fighter like the F-35A. This dispersion of close-air-support (CAS) capability across smaller platforms would allow a much greater number of simultaneous CAS missions. Alternatively, sUAS could be dispersed to perform intelligence collection, conduct electronic attack, or battlefield resupply to dozens or hundreds of locations at a time.

Figure 2. Diffusion of capabilities through sUAS deployment

(Source: Dave Gandy, "Fighter Jet Silhouette")

Inexpensive small UASs could be used disposably en masse by brigades, battalions, or companies and still cost less than the manufacture of a single fifth-generation fighter. The USN's Low-Cost Unmanned Aerial Vehicle Swarming Technology (LOCUST) costs roughly $15,000 per vehicle. Almost 6,000 LOCUST small UASs could be purchased for the price of a single F-35A.[50] Instead of concentrating airpower capabilities in a single expensive platform, the JFC could divide these 6,000 small UASs to fulfill strike, intelligence collection or electronic attack missions across hundreds of areas on the battlefield at once, directly affecting tactical outcomes for supported forces (see fig 2). Alternatively, commanders could vertically stack hundreds or thousands of small UASs in a small area, enabling a concentration of combat power inconceivable with manned vehicles for reasons of pilot safety and aircraft size. This division of airpower capabilities into smaller platforms may allow controllers to achieve efficiency in the allocation of aircraft made impossible today by supply constraints and investment in exquisite platforms over larger numbers of utility aircraft.

Conclusion

The development and proliferation of small UAVs capable of playing traditional airpower roles at the tactical level will complicate contests for air control by decreasing costs of fielding aerial combatants. Foreign powers incapable of procuring fifth-generation fighter aircraft may increasingly turn toward smaller unmanned platforms to prevent opponents from holding complete dominion of the air domain. These small UASs will not match the capabilities of modern manned aircraft, but their portability and low cost may allow them to sustain a greater presence in the battlespace and create an environment where US forces face enemies with persistent air cover provided by small UAVs.

As sUAS technologies develop, the US military must not only adapt short-range air defenses to deal with them as emerging threats but also pioneer the expansion of sUAS roles in CAS, reconnaissance, tactical resupply, electronic warfare, counterair, and communications. The US cannot simply counter enemy drones; it needs to cleverly apply sUAS technology in ways that provide supported ground and sea forces decisive tactical advantages and prevent enemies from gaining tactical air control, no matter its duration. The US has led the world in sUAS development; now it must broaden the practical application of small UASs to ensure we preserve our capability to control the air domain at the tactical level. ✪

Notes

1. David G. Chandler, *The Campaigns of Napoleon* (London: Weidenfeld and Nicolson, 1966).
2. Ibid.
3. The cyber domain, like land, has such a low-cost entry that it may be nearly impossible to dominate as well, at least if countries maintain their connections to the World Wide Web during a conflict.
4. Glenn A. Kent and David Ochmanek, "Defining the Role of Airpower in Joint Missions" (Santa Monica, CA: RAND Corporation, 1998), 10, https://www.rand.org/pubs/monograph_reports/MR927.html.
5. Lockheed Martin F-35 Lightning II, "How Much Does the F-35 Cost?: Producing, Operating and Supporting a 5th Generation Fighter," accessed 5 October 2018, https://www.f35.com/about/cost .
6. Marcus Weisgerber, "F-35 Production Set to Quadruple as Massive Factory Retools," *Defense One*, 6 May 2016, http://www.defenseone.com/business/2016/05/f-35-production-set-quadruple-massive-factory-retools/128120.
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