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Policy Options for Unmanned Aircraft Systems

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Policy Options for Unmanned Aircraft Systems

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Notes

Unless otherwise specified, all years referred to in this study are federal fiscal years (which run from October 1 to September 30), and costs are expressed in 2011 dollars of total obligational authority.

The costs and quantities in the services' acquisition plans for unmanned aircraft systems are from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011). CBO adjusted the services' cost data using its projection of inflation.

This study includes only unclassified unmanned aircraft systems.

Photos on the cover were provided by the U.S. Army and the U.S. Air Force. The top photo shows an MQ-9 Reaper parked in a hangar. The lower-left photo shows an image of earthquake damage in Haiti taken by a Global Hawk. The lower-right photo shows a typical simulator at a ground station for unmanned aircraft.

Preface

Unmanned aircraft systems have long held great promise for military operations, but technology has only recently matured enough to exploit that potential. Much as the stealth fighter and Patriot missile came to public attention during the 1991 Gulf War, surveillance and missile-attack operations by Predator unmanned aircraft have been well publicized throughout the more recent conflicts in Iraq and Afghanistan. The Department of Defense's (DoD's) 2012 plan calls for purchasing more of the existing unmanned aircraft systems for current operations, improving the systems already in service, and designing more-capable unmanned aircraft systems for the future. At the request of the former chairman of the House Committee on the Budget, the Congressional Budget Office (CBO) compared the costs of DoD's plans and the capabilities those plans might provide for reconnaissance and light attack missions with the costs and capabilities of some alternative options. In keeping with CBO's mandate to provide objective, impartial analysis, this study makes no recommendations.

Bernard Kempinski of CBO's National Security Division prepared the study, with assistance from David Arthur, under the supervision of David Mosher and Matthew Goldberg. Alec Johnson assisted with data collection, and Christopher Murphy helped fact-check the document. The artwork in Summary Figures 1 through 3, Figure 1-1, and the figure in Box 1-1 was done by Bernard Kempinski. Nathan Musick and David Newman, both of CBO, and William R. Thissell of Lanmark Technology, Inc., provided thoughtful comments. (The assistance of external reviewers implies no responsibility for the final product, which rests solely with CBO.)

Amanda Balestrieri edited the study, with assistance from Sherry Snyder, and Chris Howlett proofread it. Maureen Costantino and Jeanine Rees prepared the graphics and page layout, and Maureen Costantino designed the cover. Monte Ruffin printed the initial copies, and Linda Schimmel coordinated the print distribution. The report is available on CBO's Web site (www.cbo.gov).

Douglas W. Elmendorf

Douglas W. Elmendorf
Director

June 2011

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Summary

Over the next 10 years, the Department of Defense (DoD) plans to purchase about 730 new medium-sized and large unmanned aircraft systems based on designs currently in operation, while also improving the unmanned aircraft already in service. By the Congressional Budget Office's (CBO's) estimates, completing the investments in systems for which there are detailed plans will require about $36.9 billion through 2020.

CBO has analyzed eight alternatives to DoD's fiscal year 2012 plan for expanding its fleet of medium-sized and large unmanned aircraft that are designed for reconnaissance and light attack missions. This study presents each alternative's likely effect on forcewide capability and acquisition costs. The alternatives—three for the Air Force and five for the Army—would change the mix of unmanned aircraft systems that are in or nearing production, the way that unmanned systems are assigned to units and operated in geographic areas where units are deployed, or both. The costs of those options would range from $3.7 billion less than DoD's plan through 2020 to $2.9 billion more. They would provide capability in several important dimensions ranging below and above that of the planned fleet.

Existing Systems and Future Plans

DoD currently has more than 6,000 unmanned aircraft. The majority of those aircraft are short-range reconnaissance systems that have a wingspan of a few feet and have handheld controls used by small military units in combat to look "around corners" or "over hills." Spending for those systems represents a relatively small proportion of the total investment planned for unmanned aircraft systems. The bulk of DoD's planned spending is for the more costly medium-sized and large unmanned aircraft systems that are designed to conduct reconnaissance missions or attack ground targets (see Summary Figure 1).

The armed services have developed detailed procurement plans, including estimated quantities and costs, for the unmanned aircraft systems that are in or nearing production.[1] Those plans would increase the inventory of the aircraft by 35 percent over the next 10 years. DoD also is investing in research and development for the next generation of more technologically advanced unmanned aircraft, which will provide improved reconnaissance and attack capabilities and will broaden the types of missions that can be accomplished. As the funding required for near-term systems begins to decline after 2015, funding for the next generation of unmanned aircraft will probably increase. Analyzing the longer-term plans will not be possible until they are defined in more detail.

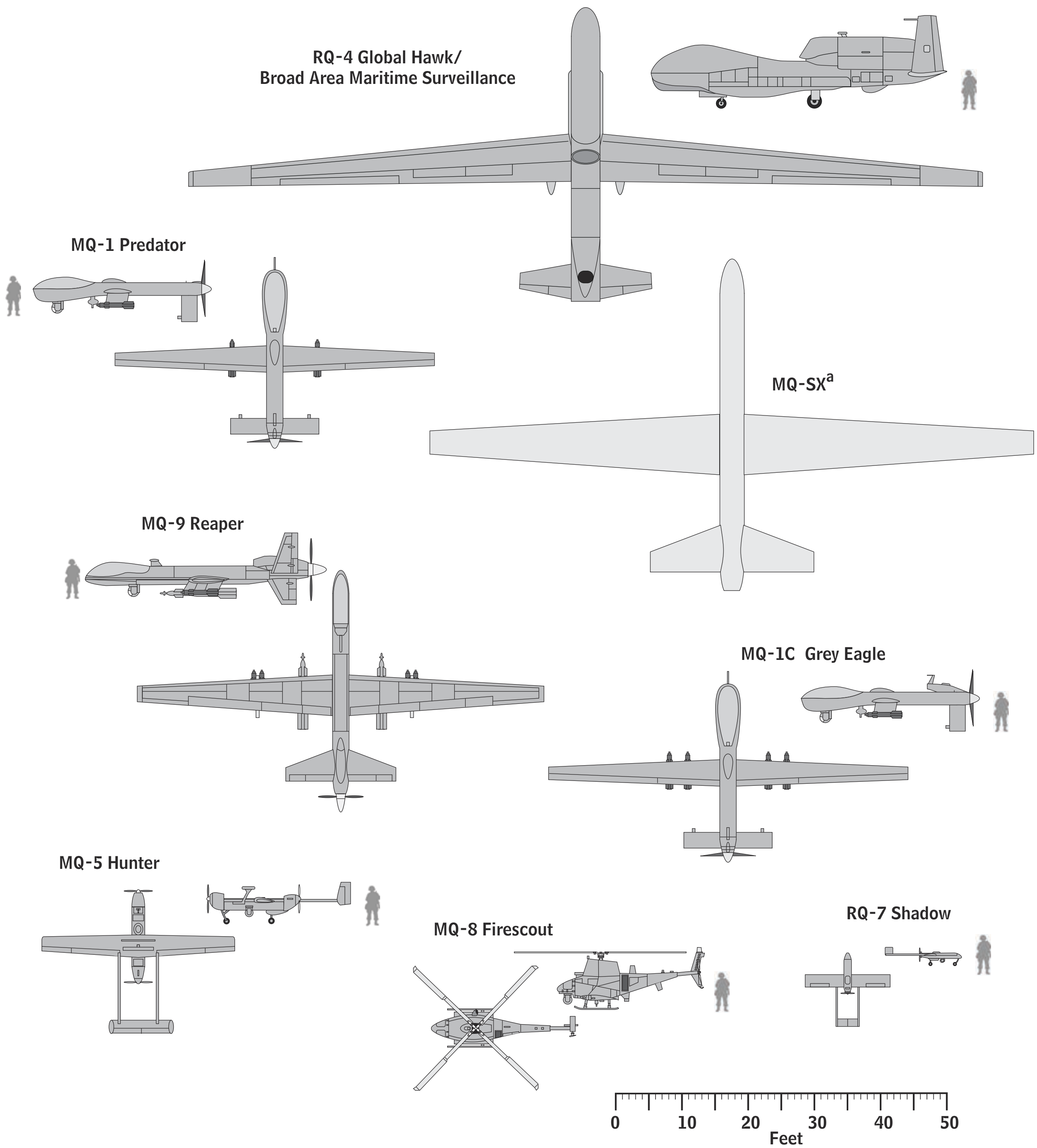
The Air Force's Plans

The Air Force currently operates at least four medium-sized or large unmanned aircraft: Global Hawks, Predators, Reapers, and Sentinels. The largest aircraft is the jet-powered RQ-4 Global Hawk, and the Air Force has 14 of them, according to CBO's information. The most numerous, at approximately 175 aircraft, is the MQ-1 Predator, a piston-engine propeller aircraft that can take still or video imagery and shoot Hellfire missiles. A larger version of the Predator, the turboprop-powered MQ-9 Reaper, is beginning to enter the force, and about 40 have been delivered as of 2011. (The "MQ-" designation for the Predator and Reaper identify them as multimission aircraft capable of reconnaissance and attack

1. The costs and quantities in the services' acquisition plans for unmanned aircraft systems are CBO estimates based on data from the Department of Defense's budget request for fiscal year 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011). CBO adjusted the costs using its projection of inflation.

Summary Figure 1.

Medium-Sized and Large Unmanned Aircraft Designed for Conducting Reconnaissance and Attacking Ground Targets



Source: Congressional Budget Office.

Note: All aircraft are drawn to the same scale. The silhouette figure is a 6-foot-tall soldier, also drawn to scale.

a. The MQ-SX is a notional unmanned aircraft system based on existing aircraft systems that is more capable than the Predator class in speed and altitude and less capable than the Global Hawk class. The illustration shows relative size but does not represent the actual design of the notional aircraft.

Summary Table 1.

Acquisition Cost of Medium-Sized and Large Unmanned Aircraft Systems Under the Department of Defense's 2012 Plan

(Millions of 2011 dollars)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
Air Force											
RQ-4 Global Hawk	1,200	1,060	890	790	810	710	1,160	530	80	60	7,290
MQ-1 Predator	30	10	10	10	a	a	a	a	a	a	60
MQ-9 Reaper	1,700	1,550	1,740	1,440	1,350	1,150	1,060 [b]	1,040 [b]	1,030 [b]	1,010 [b]	13,070
Army											
MQ-1C Grey Eagle	870	1,060	1,040	740	220	90	a	a	a	a	4,020
RQ-7 Shadow	610	250	270	200	300	280	a	a	a	a	1,910
Navy and Marine Corps											
RQ-4 Broad Area Maritime Surveillance	530	560	760	880	900	1,010	1,230	1,260	1,130	1,130	9,390
MQ-8 Firescout	60	70	60	80	80	90	130	160	150	150	1,030
RQ-7 Shadow	90	10	10	10	a	a	a	a	a	a	120
All Services											
Total	**5,090**	**4,570**	**4,780**	**4,150**	**3,660**	**3,330**	**3,580**	**2,990**	**2,390**	**2,350**	**36,890**

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

Note: Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation. The services' cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

a. The Department of Defense has no plans to acquire or modify the specified system in these years.

b. The cost is for the follow-on aircraft the Air Force plans to acquire instead of the Reaper.

missions.) The RQ-170 Sentinel is a stealthy reconnaissance aircraft whose existence has only recently been acknowledged by the Air Force. Most performance characteristics of the Sentinel remain classified.

The Air Force's near-term goals are to increase the number of Global Hawk and Reaper aircraft that can be continuously and simultaneously operated. To meet that goal, the Air Force plans to purchase 288 Reapers (48 per year from 2011 through 2016) and 28 Global Hawks from 2011 through 2018. Documents provided to the Congress by DoD indicate plans to continue purchasing multimission unmanned aircraft after 2016, although the type of aircraft is not specified.[2] On the basis of the information available, CBO assumed that the Air Force's purchases after 2016 would continue at 48 aircraft per year and would comprise either additional Reapers or a follow-on aircraft with range, payload, and cost similar to the Reaper. (Unless making a distinction is necessary, references to the Reaper in this study pertain to both the Reaper itself and the possible follow-on system.) The Air Force is also exploring the characteristics that would be desired in a larger aircraft a generation beyond the Global Hawk.

About $20.4 billion will be needed for the aircraft the Air Force plans to purchase through 2020, CBO estimates: $7.3 billion for Global Hawks and $13.1 billion for Reapers and their follow-on (see Summary Table 1). Costs would average about $2.0 billion per year through 2020.

2. Department of Defense, *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

The Army's Plans

The Army currently operates three medium-sized unmanned aircraft systems: Hunters, Shadows, and Predators. Overall, the Army's inventory includes about 20 MQ-5B Hunters (older aircraft scheduled for retirement by 2013), about 450 RQ-7 Shadows, and about 40 MQ-1 Predators in two versions (specifically, MQ-1 Warrior Alphas and MQ-1C Grey Eagles).[3]

Over the next five years, the Army plans to purchase 20 Shadows to replace losses, upgrade the existing Shadows with tactical data links and a laser targeting system, and purchase 107 more of the medium-altitude Grey Eagles. CBO estimates that those plans will cost about $5.9 billion: $1.9 billion for the Shadows and $4.0 billion for the additional Grey Eagles. In the longer term, the Army is exploring concepts for an aircraft that has greater endurance (that is, can stay in the air for a longer time). It also may decide to resume efforts to increase the capabilities of unmanned aircraft used by combat brigades; those plans were shelved when the Army's Future Combat System was canceled in 2009.

The Navy and Marine Corps' Plans

The Navy is currently testing two new types of aircraft that it hopes to field in the near future—the long-endurance Broad Area Maritime Surveillance (BAMS) aircraft, which is a Global Hawk variant optimized for naval operations, and the MQ-8B Firescout unmanned helicopter. The Navy plans to purchase 36 BAMS aircraft at a cost of about $9.4 billion by 2020 and operate them from a few bases worldwide to provide surveillance of activities on the oceans. The Navy also plans to purchase 61 Firescouts by 2020 at a cost of $1.0 billion; those helicopters will be based on selected surface ships and will provide local reconnaissance and the capability to attack hostile surface targets. The Navy's plans call for purchasing a total of 65 BAMS through 2026 and 168 Firescouts through 2028.

The Marine Corps is in the process of fielding the Shadow to support ongoing operations in Southwest Asia. Thirteen systems (with four aircraft per system) had been delivered by the end of calendar year 2009. The Marine Corps does not plan to purchase additional Shadow systems but instead will spend about $120 million to upgrade some Shadows already in its inventory.

In the longer term, the Navy is exploring concepts for a carrier-based unmanned aircraft, called the Unmanned, Carrier-Launched Airborne Surveillance and Strike aircraft, and is currently flying a demonstrator aircraft to help develop the technologies and procedures needed to operate such an aircraft. The Marine Corps is exploring concepts for a medium-sized system (currently referred to as the Group 4 Unmanned Aircraft System) that would be designed to perform various missions in support of amphibious operations. Both systems might enter service by 2020.

Assessing Policy Options

The Congressional Budget Office examined the implications—both for the capabilities of the armed forces and for DoD's acquisition budget—of eight possible alternatives to DoD's fiscal year 2012 plan (three for the Air Force and five for the Army). Acquisition cost includes the cost of procuring an unmanned aircraft system (the aircraft, sensors, and ground stations), plus the cost of research, development, test, and evaluation.

The options would alter DoD's acquisition plans through 2020 (see Summary Table 2). Three of the options would improve capabilities—as measured by the weight the fleet of aircraft can carry (its payload) and the time the aircraft will be able to remain in the air (its endurance)—for the same cost as DoD's plans. Two options would improve capabilities but would also increase acquisition cost, and three options would reduce cost but would also yield some reduction in capabilities.

The options are meant to illustrate the cost implications of different approaches to enhancing capabilities and are not designed to reach any specific goal or to counter any specific adversaries that might arise in the future. CBO did not examine longer-term options requiring significant technological development because the uncertainty surrounding what could be fielded and what might be needed is too great for a detailed analysis. Nor did CBO examine options for the Navy and Marine Corps—not only because those services will have relatively few unmanned aircraft systems in the near term but also to keep the number of options to a manageable level. In addition, this study does not assess the operation and support costs of the options. In CBO's estimation, those costs would change little in the eight options because

3. In August 2010, the Army adopted Grey Eagle as the official name for the General Atomics MQ-1C. Earlier, the Army had called the system the Extended Range Multi-Purpose (ER/MP) and Sky Warrior. The MQ-1 Warrior Alpha is essentially the same as the Air Force's Predator.

Summary Table 2.

Overview of Options for the Air Force and the Army and Their Cost Relative to the Department of Defense's 2012 Plan

Approach	Option	Cost Relative to DoD's 2012 Plan (Billions of 2011 dollars)
	Air Force	
Buy New, Stealthier Aircraft	1. Buy 224 MQ-SXs and 336 Fewer Reapers[a]	0
	2. Buy 336 MQ-SXs and 336 Fewer Reapers[a]	2.9
	3. Buy 24 MQ-SXs and 24 Fewer Global Hawks[a]	-3.7
	Army	
Buy More-Capable Aircraft	4. Buy 69 Reapers and 78 Fewer Grey Eagles	0
	5. Buy 78 Reapers and 78 Fewer Grey Eagles	0.5
Buy More, Less-Expensive Aircraft	6. Buy 350 Firescouts and 78 Fewer Grey Eagles	0
Change the Way Aircraft Are Operated by Conducting Remote-Split Operations[b]	7. With 42 Fewer Grey Eagles	-1.3
	8. With 36 Reapers and 78 Fewer Grey Eagles	-1.0

Source: Congressional Budget Office.

a. The MQ-SX is a notional unmanned aircraft system based on existing aircraft systems that is more capable than the Predator class in speed and altitude and less capable than the Global Hawk class.

b. In remote-split operations, deployed divisions would have operational control of aircraft from a central fleet rather than be equipped with their own aircraft.

most of the options would require only modest changes in the number of personnel—a major contributor to those costs—and because differences in fuel consumption and the cost of spare parts probably would be minimal.[4]

To compare the capability that could be expected under the options, CBO calculated an aggregate measure—the payload-duration—for each aircraft. Payload-duration is the weight (payload) that an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could be kept there on orbit (duration). In this case, "on orbit" means that the unmanned aircraft is circling the target area continuously.[5]

CBO calculated payload-duration for individual aircraft at orbits positioned at various distances from where the aircraft are based. The distance, or range, to the orbit affects duration: The farther the mission is located from where the aircraft is launched, the less time the aircraft will be able to remain at the target location. The aircraft's endurance and speed also affect duration: The faster the aircraft can travel, the more time it can spend at the target location. Payload capacity serves as a simplified measure of the types and quality of sensors and weapons that an aircraft could carry—under the general assumption that, all else being equal, a greater payload capacity enables the aircraft to carry more-capable sensors and a greater number or variety of weapons. The total payload-duration of all aircraft in the force captures the effects of aircraft inventory, transit speed, endurance, and payload capacity. Payload-duration better captures reconnaissance capability than does the number of orbits because it incorporates the capacity of the aircraft to carry equipment and to spend time on reconnaissance missions.

4. Some options would require modest changes in the number of personnel. Option 6 for the Army, for example, would increase the number of unmanned aircraft operators, but CBO assumed that the Army would provide those people from existing ranks, as it has done when adopting other unmanned aircraft systems. Conversely, Options 7 and 8 would require fewer personnel, but those savings are not included in CBO's analysis.

5. The orbit may also be called a continuous, persistent, or loitering orbit, in which the aircraft remains on station, waiting for orders to perform a required mission. In military parlance, an aircraft orbit is known as a combat air patrol, or CAP.

Options for the Air Force

CBO's options for the Air Force examine the implications of more quickly developing and fielding a new aircraft that would have improved payload-duration plus other characteristics such as a lower chance of being detected (stealth) and higher speed—traits that would be advantageous in conflicts against technologically capable adversaries.

Under the options, the Air Force would purchase a notional MQ-SX—an aircraft that would have some characteristics consistent with those the Air Force is considering for its proposed MQ-X—in lieu of some of the Reapers or Global Hawks in current plans. The MQ-SX postulated by CBO would be a jet-powered aircraft about one and a half times the size of the Reaper with an airframe designed to be more difficult to detect and target by air-defense systems. Relative to the Reaper, the larger size of the MQ-SX would enable it to carry a greater payload (sensors, weapons, or fuel); jet power would allow the aircraft to reach its destination (a target or orbit location) in less time; and stealth features would improve its ability to operate in defended airspace.[6] CBO's cost estimate for the notional MQ-SX assumes modest improvements in stealth relative to that of Global Hawks, Predators, and Reapers. A highly stealthy design would probably cost more.

Option 1—Buy 224 MQ-SXs and 336 Fewer Reapers (Same Cost). Instead of purchasing 480 Reapers, the Air Force would buy only 114 (336 fewer) and would also buy 224 MQ-SX aircraft to arrive at the same overall acquisition cost as its current plan. Although the option would yield a smaller inventory of multimission unmanned aircraft, the force's total payload-duration would remain about the same relative to current plans for orbits at short range because the speed and payload advantage of the MQ-SX would compensate for the smaller inventory (see Summary Figure 2). Payload-duration would improve about 35 percent relative to current plans at intermediate ranges (1,500 nm) by 2020 because the higher speed of the MQ-SX would increase the proportion of time it could spend on station relative to the slower Reaper. Payload-duration would be unchanged at long range (2,500 nm) because only the Global Hawk has significant capability at that range.

Option 2—Buy 336 MQ-SXs and 336 Fewer Reapers (Higher Cost). The Air Force would substitute purchases of 336 Reapers with 336 MQ-SXs. The number of aircraft purchased each year would remain almost unchanged through 2020 but would shift from all Reapers in 2011 to all MQ-SXs by 2015. Relative to the Air Force's 2012 plan, the total cost would increase by about $2.9 billion because the MQ-SX would be more expensive than the Reaper. Although the Air Force's total inventory of MQ-type unmanned aircraft systems would remain essentially unchanged under this option, the larger size and higher speed of the MQ-SX relative to the Reaper would result in a force capable of maintaining a payload-duration at intermediate ranges that was 67 percent higher by 2020 than under the Air Force's plan. Furthermore, the improved survivability of the MQ-SXs could make them more useful in environments posing a greater threat.

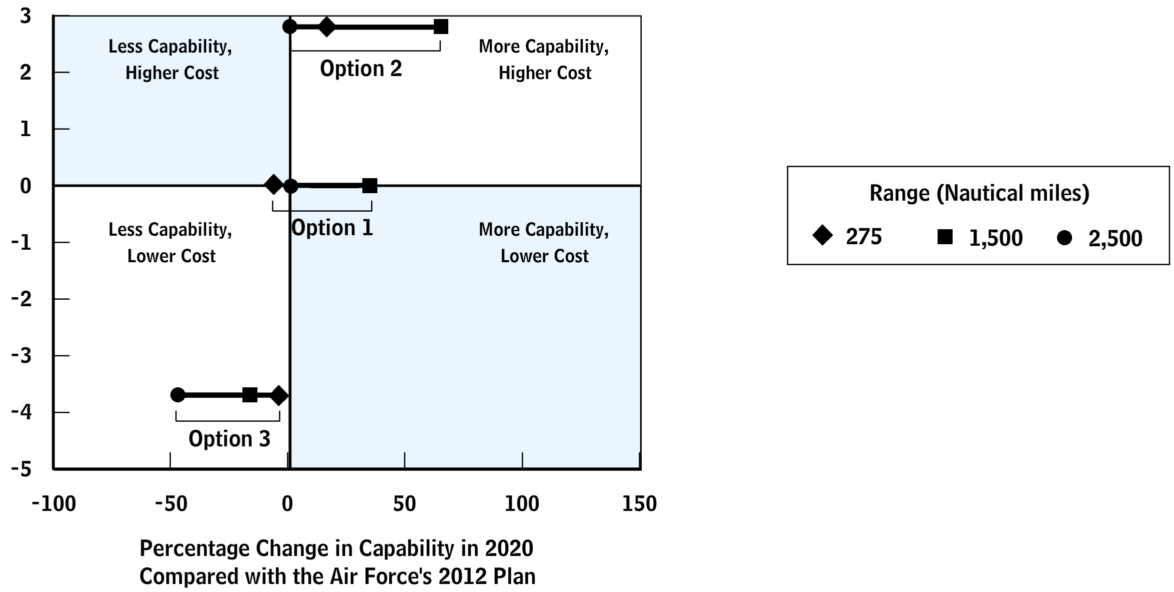
Option 3—Buy 24 MQ-SXs and 24 Fewer Global Hawks (Lower Cost). Starting in 2012, the Air Force would buy 24 fewer Global Hawks and the same number of MQ-SXs. Although the total number of aircraft purchased would be nearly the same as under the Air Force's current plans, the total cost would decrease by about $3.7 billion. The overall payload-duration would be reduced at all ranges under Option 3 because the MQ-SX would be slower (and therefore take longer to reach the target area), have less endurance, and have a slightly lower payload than the Global Hawk. In addition, the sensors available with the MQ-SX might be less effective than those designed for the Global Hawk, but with further investment it might be possible to modify Global Hawk sensors for use on the MQ-SX. Although payload-duration would decrease, weapons payload would increase because the Global Hawk is not currently configured to carry weapons. Also, the stealth features of an MQ-SX might enable it to operate in defended airspace that would be too hazardous for a Global Hawk.

6. At least two aircraft that might meet those criteria are flying today—the General Atomics Avenger and the RQ-170 Sentinel. The two aircraft have significant differences: the Avenger resembles a Global Hawk with the addition of airframe shaping for stealth, whereas the Sentinel has a tailless design resembling the B-2 bomber. Aircraft at this stage of development could enter production more quickly than would be possible if starting from scratch.

Summary Figure 2.

Change in Capability at Different Ranges and in Acquisition Cost in 2020 Under CBO's Options for the Air Force

(Billions of 2011 dollars)



Source: Congressional Budget Office.

Notes: The overall approach of the options would be to buy new, stealthier aircraft, as follows:

- Option 1—Buy 224 MQ-SXs and 336 Fewer Reapers
- Option 2—Buy 336 MQ-SXs and 336 Fewer Reapers
- Option 3—Buy 24 MQ-SXs and 24 Fewer Global Hawks

The MQ-SX is a notional unmanned aircraft system based on existing aircraft systems that is more capable than the Predator class in speed and altitude and less capable than the Global Hawk class.

Capability is measured as payload-duration—a comparative performance metric developed by CBO. It measures the weight (payload) an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration). The symbols in the figure represent that capability for the overall fleet in orbits at three distances from the airbase (275, 1,500, and 2,500 nautical miles) for each option.

The figure compares payload-duration at different ranges with cost, but each option has other advantages and disadvantages not reflected in the comparison.

Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation.

Options for the Army

CBO examined five options for the Army. Two (Options 4 and 5) explore the implications of buying systems that are more capable than the ones the Army plans to buy. A third (Option 6) examines the effects of buying a greater quantity of less capable systems. Two others (Options 7 and 8) illustrate the effects of changing the way that unmanned systems are assigned to military units and are operated in the theater of combat: Instead of being equipped with their own aircraft, deployed divisions would be given operational control of aircraft from a central fleet. That approach, called remote-split operations, is one the Air Force has used successfully with its unmanned aircraft. Options 7 and 8 would result in savings from buying fewer aircraft because of the remote-split technique. None of the five options consider systems or concepts that are in the early stages of development, such as the Long Endurance Multi-Intelligence Vehicle—an unmanned airship that the Army is currently investigating.

Option 4—Buy 69 Reapers and 78 Fewer Grey Eagles (Same Cost). The Army would replace future purchases of 78 Grey Eagles with 69 larger, more costly Reaper aircraft to arrive at the same overall acquisition cost as its current plan. The Grey Eagles already purchased would remain in service. Because of its greater payload, range, and endurance, the Reaper would provide 53 percent to 86 percent greater payload-duration by 2020 than the Grey Eagle (see Summary Figure 3). Although the Reaper costs more than the Grey Eagle, the difference in unit cost is less than one might expect, because the aircraft is only part of the system being purchased. Both systems require essentially the same ground stations and communications links. Another advantage of the Army's buying Reapers rather than continuing to develop its own unique system is that doing so would increase commonality between the Air Force and Army systems. Commonality could reduce production costs because economies of scale affect the manufacturing process. CBO did not include any such savings in its calculations.

Option 5—Buy 78 Reapers and 78 Fewer Grey Eagles (Higher Cost). The Army would replace future purchases of 78 Grey Eagles with the same number of larger, more costly Reaper aircraft. The Grey Eagles already purchased would remain in service. CBO estimates that this option would provide 67 percent to 105 percent more payload-duration than the Army's plan but would cost about $520 million more.

Option 6—Buy 350 Firescouts and 78 Fewer Grey Eagles (Same Cost). The Army would purchase 350 MQ-8 Firescout unmanned helicopters and 78 fewer Grey Eagles to arrive at the same overall acquisition cost as the 2012 plan. The Grey Eagles already purchased would remain in service. The range and payload of the Firescouts are much lower than those of the Grey Eagle, but because the Firescouts cost less, the Army could purchase more of them.[7] The resulting payload-duration of Option 6 would be 60 percent greater than that of the 2012 plan at a range of 40 nm but would fall to about half that of the plan at 650 nm.

Option 7—Conduct Remote-Split Operations with 42 Fewer Grey Eagles (Lower Cost). The Army would change the way it assigns and operates unmanned aircraft in combat theaters. It would centralize its force of medium-altitude unmanned aircraft systems in operations referred to as remote-split—an approach that has worked well for the Air Force in Iraq and Afghanistan. Deployed divisions would be given operational control of aircraft from a central fleet, instead of being equipped with their own aircraft. Although the aircraft would be under the control of the division commander, they could be operated over satellite links from the United States or other secure locations.

In this option, the Army would buy 42 fewer Grey Eagles, saving $1.3 billion relative to the 2012 plan. A set of 113 Grey Eagles would provide support for up to six divisions on the ground—about the size of the peak U.S. deployment in Operation Iraqi Freedom—and three additional division sets would be available for special operations, training, or holding in reserve. Although the Army would have less overall payload-duration at all ranges compared with its 2012 plan, deployed units would have the same payload-duration as they would under that plan because the divisions would have the same number of aircraft supporting them, although those aircraft would be operated centrally in the geographic areas where units are deployed.

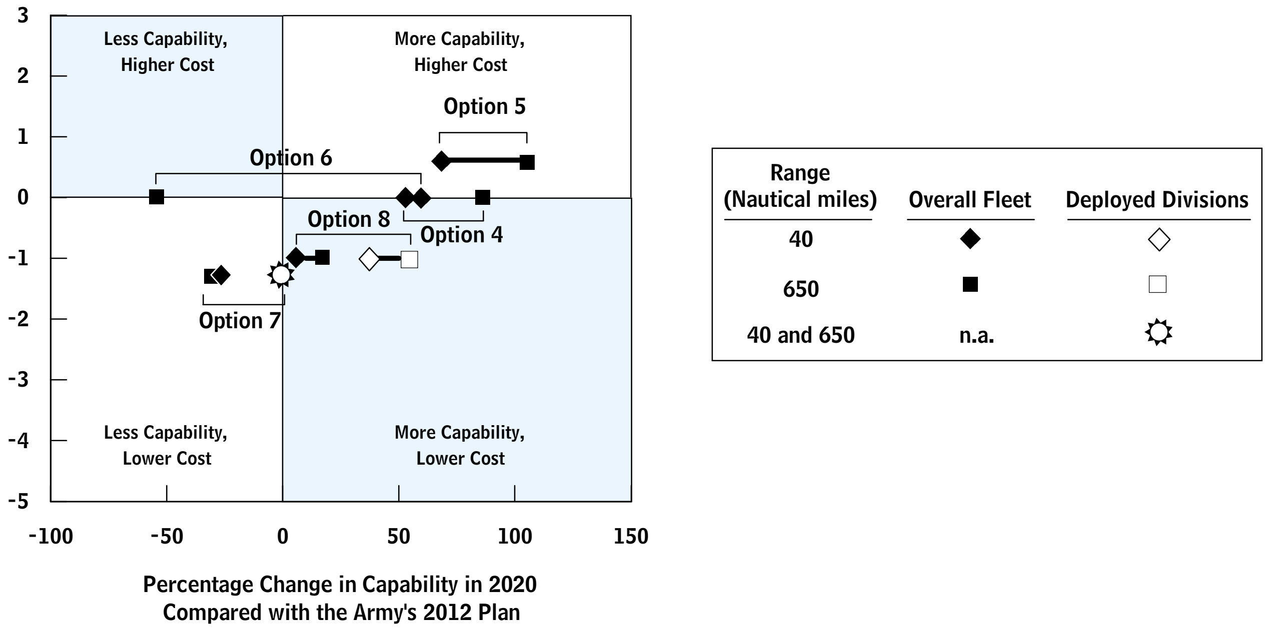
Option 8—Conduct Remote-Split Operations with 36 Reapers and 78 Fewer Grey Eagles (Lower Cost). The Army would adopt remote-split operations, as in Option 7, but would replace some of the Grey Eagles with Reapers: The same-size force of 113 medium-altitude unmanned aircraft would consist of 77 Grey Eagles and 36 Reapers. As in Option 7, the fleet of unmanned aircraft would be able to support up to six divisions on the ground, and three additional division sets would be available for special operations, training, or holding in reserve. Under this option, deployed units would have 37 percent to 56 percent greater payload-duration at short and long ranges, respectively, than in Option 7 and the Army's plan. This approach would cost $1.0 billion less than the Army's plan.

7. The Class IV MQ-8 Firescout is a small helicopter and therefore does not require a runway from which to operate. Option 6 would replace the division-level Grey Eagle with the Firescout, which could be assigned to either a division or separate brigades. The Army has considered purchasing Firescout for its combat brigades but has not yet done so.

Summary Figure 3.

Change in Capability at Different Ranges and in Acquisition Cost in 2020 Under CBO's Options for the Army

(Billions of 2011 dollars)



Source: Congressional Budget Office.

Notes: Under the options, the Army would buy more-capable aircraft (Options 4 and 5); buy more, less-expensive aircraft (Option 6); or change the way aircraft are operated (Options 7 and 8), as follows:

- Option 4—Buy 69 Reapers and 78 Fewer Grey Eagles
- Option 5—Buy 78 Reapers and 78 Fewer Grey Eagles
- Option 6—Buy 350 Firescouts and 78 Fewer Grey Eagles
- Option 7—Conduct Remote-Split Operations with 42 Fewer Grey Eagles
- Option 8—Conduct Remote-Split Operations with 36 Reapers and 78 Fewer Grey Eagles

Capability is measured as payload-duration—a comparative performance metric developed by CBO. It measures the weight (payload) an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration). The symbols in the figure represent that capability for the overall fleet in orbits at two distances from the airbase (40 and 650 nautical miles) for each option. Options 7 and 8 show a further comparison of capability for deployed divisions, in case the Army decides to employ the remote-split technique (in which deployed divisions would have operational control of aircraft from a central fleet rather than be equipped with their own aircraft).

The figure compares payload-duration at different ranges with cost, but each option has other advantages and disadvantages not reflected in the comparison.

Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation.

n.a. = not applicable.

CHAPTER

1

Existing Unmanned Aircraft Systems and Future Plans

From 2011 to 2020, the Department of Defense (DoD) plans to buy 730 medium-sized and large unmanned aircraft systems that are designed for conducting reconnaissance missions or for attacking targets on the ground.[1] The Congressional Budget Office (CBO) estimates that acquiring those systems will cost about $36.9 billion over 10 years.

All of the U.S. military services are actively considering a large increase over the long term in their inventories of unmanned aircraft systems and in the types of missions those systems would perform. In a 2009 Air Force publication, for example, missions for unmanned aircraft systems were envisioned to expand from today's missions of reconnaissance and attacking ground targets to a much wider array of missions, including personnel recovery, airborne refueling, medical evacuation, and missile defense.[2]

Although conceptual plans for expanding unmanned aircraft systems over the long term are limited only by the availability of technology and the imagination of planners, near-term programs have been focused primarily on unmanned aircraft systems designed for reconnaissance missions and for light attack of targets on the ground.[3] That more limited focus is driven largely by the need to support counterinsurgency operations in Iraq and Afghanistan but also by the need to develop additional technologies to enable unmanned aircraft systems to perform more functions. Several aircraft—ranging in size from the Global Hawk, which has a wingspan of 131 feet, to small systems that can be carried in backpacks—are being openly developed or purchased. In addition, the Air Force has acknowledged development work on some classified systems, including the RQ-170 Sentinel, a stealthy unmanned aircraft system.[4]

This study analyzes the effects on capability and acquisition cost of eight alternatives to DoD's near-term plans for expanding its fleet of medium-sized and large unmanned aircraft that are designed for reconnaissance and light attack missions. Those systems have been openly acknowledged by DoD and have been fielded or could be fielded in the near future. The aircraft differ in endurance, speed, altitude, payload, and cost. Because they are unmanned, they can undertake new missions and reduce the risks of traditional missions. Near-term acquisition plans for those medium-sized and large systems are sufficiently well defined to make it possible to estimate the capabilities that could be provided for different levels and types of investment. Those systems also represent the greater part of planned investments for unmanned aircraft in the near term. In contrast, longer-term plans are so general at this time as to be little more than a list of missions that such systems could be built to fly; those plans will require further refinement before a meaningful analysis of alternatives is possible.

1. This study uses the term "reconnaissance" generically to describe all intelligence, surveillance, and reconnaissance (ISR) missions. The military defines reconnaissance as an operation that uses assets to observe an area to collect information; it further defines surveillance as the systematic observation of a particular area. Once the information from those operations has been analyzed and evaluated, it is referred to as intelligence.

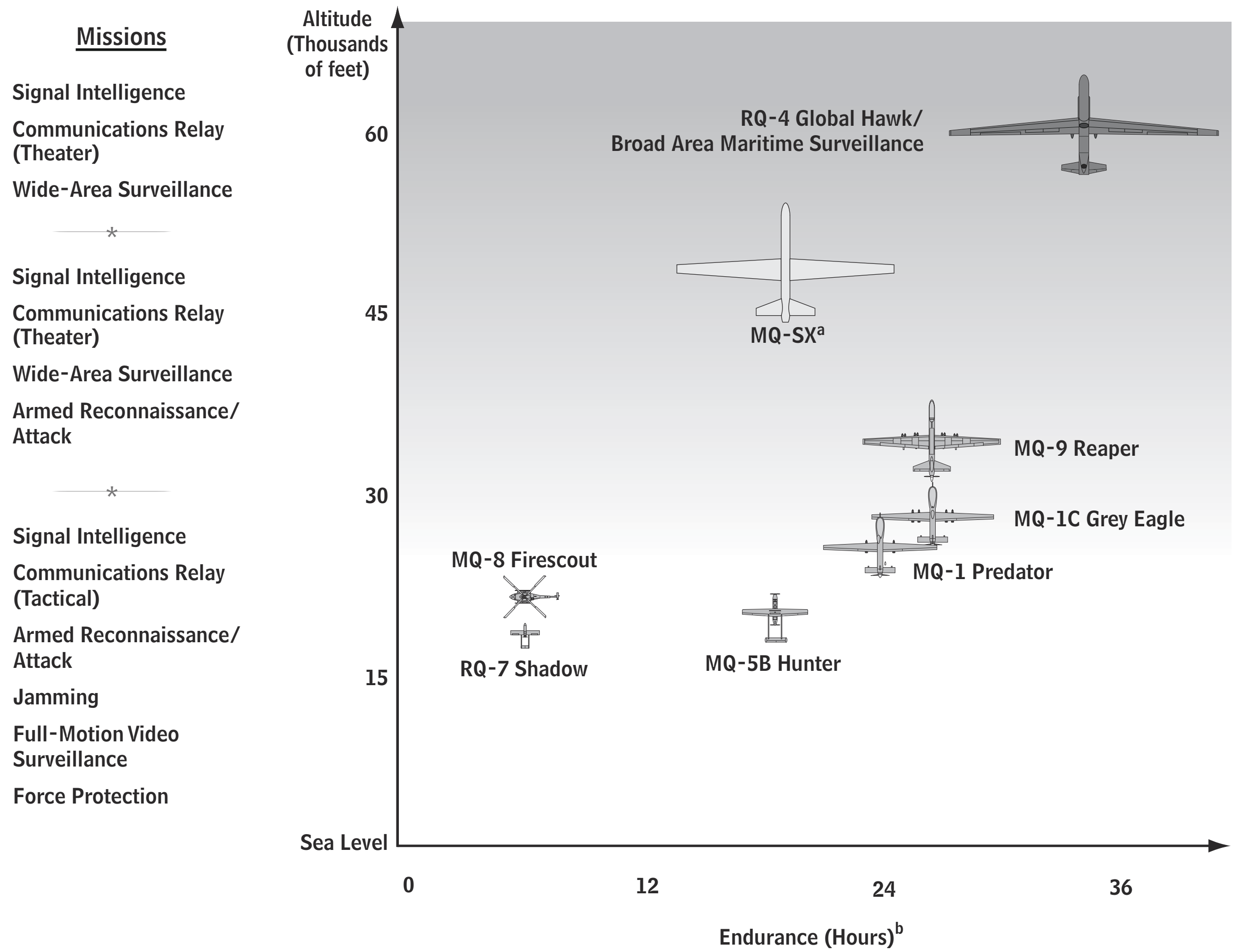
2. U.S. Air Force, Headquarters, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009–2047* (May 18, 2009).

3. The term "light attack" is used here to denote the ability of today's unmanned aircraft systems to carry small numbers of relatively light weapons. For example, the Reaper can carry two 500-pound (lb) guided bombs and four 100-lb Hellfire missiles. In contrast, the F-16 fighter jet can carry four 2,000-lb bombs or eight 500-lb bombs in some configurations, although it usually carries fewer weapons to increase its range.

4. Office of the Secretary of the Air Force, Directorate of Public Affairs, "RQ-170 Sentinel" (Air Force fact sheet, December 2, 2010), www.af.mil/information/factsheets/factsheet.asp?ID=16001.

Figure 1-1.

Missions Performed by Unmanned Aircraft, by Altitude and Endurance



Source: Congressional Budget Office.

Note: The missions can usually be accomplished at all altitudes; the current unmanned aircraft perform the missions as shown.

a. The MQ-SX is a notional aircraft. The illustration shows the types of missions it could perform and the altitude at which it would operate but does not reflect an actual design.

b. Endurance is the maximum length of time an aircraft can spend in the air.

Missions

The Congressional Budget Office's (CBO's) analysis focuses on capabilities of unmanned aircraft systems for reconnaissance and light attack missions, recognizing that those systems could also be used for many other missions. In reconnaissance missions, an aircraft uses its sensors to detect and observe objects on land or sea, or to intercept and analyze electronic emissions from ground, sea, or air sources. A properly designed medium-sized or large unmanned aircraft can perform a variety of reconnaissance missions. The aircraft vary by the altitudes at which they fly, but most missions can be accomplished at different altitudes. (However, some reconnaissance missions may require specific unmanned aircraft because of the aircraft's size, operating characteristics, or sensors.) Therefore, CBO's analysis can consider combinations of various types of aircraft to accomplish the same missions. The important variations are the length of time the aircraft can remain in the air (endurance, see Figure 1-1) and the amount of weight they can carry (payload). Reconnaissance missions can be combined with attack missions if the systems can carry weapons. Alternatively, if the primary objective of a mission is to destroy a particular target, the system may carry a full load of weapons, thus reducing its endurance and, perhaps, the number of sensors on board.

For many missions, the complications inherent in removing pilots from aircraft—in particular, the need for ground stations and the transmission of large amounts of data via satellite—are worth the effort. The advantages most commonly cited by proponents of unmanned aircraft fall into three categories:

- Enabling missions that would be constrained by the physiological limitations of a human crew (usually for long-endurance missions or for extreme maneuvers that subject the aircraft and pilot to accelerations many times the force of gravity),
- Saving pilots' lives during dangerous missions or reducing the political risks that result when pilots are captured, and
- Lowering costs by eliminating the aircraft systems needed to support a pilot (such as oxygen, climate controls, and ejection seats) and by enabling the design to be less airworthy than if crews were on board.

Although removing pilots from aircraft can offer advantages in those areas, it also can introduce disadvantages. The appendix provides additional details on missions and further discussion of the reasons for using unmanned aircraft systems.

Existing Systems

The types of unmanned aircraft in operation today in the U.S. military vary widely. Current systems are generally grouped into three categories based essentially on size:

- Large aircraft, which have the wingspan of a commercial airliner. They fly at high altitude (50,000 to 60,000 feet) and have very long endurance (up to 36 hours in the air).
- Medium-sized aircraft, which range in size from the single-engine Cessna up to fighter aircraft. They fly at medium altitude (30,000 to 45,000 feet) and can have long endurance (18 to 24 hours).
- Small (or tactical) unmanned aircraft systems, which can be operated by small military units in the field. In many cases, they do not require runways but instead can be catapulted from vehicles or hand-launched by soldiers like remote-control hobby airplanes. They fly at low altitude (below 10,000 feet) and have short endurance (1 to 10 hours).

Although specific aircraft can be designed to emphasize particular attributes, larger aircraft tend to stay in the air for a longer time, fly at faster speeds, operate at higher altitudes, and support more-capable and heavier payloads of sensors and weapons.

The Department of Defense currently has more than 6,000 unmanned aircraft and is continuing to acquire more. The majority of those aircraft are short-range reconnaissance systems that have a wingspan of a few feet and have handheld controls used by small military units to look "around corners" or "over hills." Less numerous, but more expensive, are the medium-sized and large unmanned aircraft systems fielded or in development for the Air Force, the Army, and the Navy and Marine Corps (see Table 1-1).

Air Force Systems

The Air Force currently operates three types of medium-sized and large unmanned aircraft systems for which inventories and general performance characteristics are unclassified: the RQ-4 Global Hawk, the MQ-1 Predator, and the MQ-9 Reaper (referred to in this study as the Global Hawk, the Predator, and the Reaper).

The largest system is the turbofan-powered Global Hawk, and the Air Force has 14 of them in its inventory in 2011. The Global Hawk does not carry weapons: It is only a reconnaissance aircraft. The Global Hawks currently in operation carry optical and radar sensors for imaging objects on the ground and other sensors for detecting electronic emissions. Seven of the Global Hawks carry electro-optical and infrared sensors and a synthetic aperture radar; six carry an improved electro-optical and infrared sensor suite plus the synthetic aperture radar; and one will be retrofitted to also carry the Advanced Signals Intelligence Package for intercepting electronic transmissions. Plans also call for a later version of the Global Hawk to carry a more advanced synthetic aperture radar.

Table 1-1.

Characteristics of Medium-Sized and Large Unmanned Aircraft Systems Fielded or Under Development

Type of Aircraft	Propulsion[a]	Wingspan/ Body Length (Feet)	Service Ceiling[b] (Feet)	Transit Speed (Knots)[c]	Airfield Requirement	Endurance (Hours)	Maximum Payload (Pounds)	Armament
				Large, High-Altitude Global Hawk Variants				
Air Force RQ-4A (Block 10) Global Hawk	Turbofan	116/44	65,000	340	Paved	35	2,000	None
Air Force RQ-4B (Blocks 20, 30, 40) Global Hawk	Turbofan	131/48	60,000	320	Paved	36	3,000	None
Navy RQ-4 Broad Area Maritime Surveillance	Turbofan	131/48	60,000	320	Paved	30	3,200 (Internal); 2,400 (External)	None
				Medium-Sized, Medium-Altitude Predator Variants				
MQ-SX[d]	Turbofan	65/45	50,000	270	Paved	18	2,750	Varies up to one 2,000-lb guided bomb
Air Force MQ-1B Predator	Piston engine	55/27	25,000	100	Paved	24/20[e]	450	2 Hellfire missiles
Air Force MQ-9 Reaper	Turboprop	66/36	30,000	190	Paved	21/17[e]	3,750	Varies up to two 500-lb guided bombs; 4 Hellfire missiles
Army MQ-1C Grey Eagle	Piston engine[f]	56/28	29,000	150	Paved	26/15[e]	800	4 Hellfire missiles
				Other Medium-Sized, Medium-Altitude Systems				
Navy MQ-8 Firescout (Army version, Class IV)	Turboshaft	28/30	20,000	125	None	5	600	Under development
Army and Marine Corps RQ-7 Shadow	Rotary engine[f]	14/11	20,000	110	Dirt or grass	5	60	None
Army RQ-7C Shadow	Rotary engine[f]	20/11	18,000	110	Dirt or grass	5[g]	110	Under development
Army MQ-5B Hunter	Two piston engines	34/23	18,000	110	Paved	18	280	None

Source: Congressional Budget Office based on data from the Department of Defense.

Note: lb = pounds.

a. Systems use aviation fuel unless otherwise specified.

b. The service ceiling is the maximum routine altitude at which an unmanned aircraft flies.

c. A knot is a unit of speed equal to one nautical mile per hour.

d. The MQ-SX is a notional unmanned aircraft system based on existing aircraft systems that is more capable than the Predator class in speed and altitude and less capable than the Global Hawk class.

e. Endurance values are for surveillance versus armed reconnaissance missions (surveillance/armed reconnaissance); those values are lower when aircraft carry weapons.

f. These aircraft use heavy fuel—a standard fuel also used in the Army's ground vehicles.

g. Endurance is 5 hours with a 110-lb payload and 10 hours with a 45-lb payload.

The most numerous system in the Air Force is the Predator. The 2011 force includes about 175 of that piston-engine propeller aircraft, which can take still or video imagery and shoot Hellfire missiles. A larger version of the Predator, the turboprop-powered Reaper, is beginning to enter the force, and about 40 have been delivered as of 2011. The Reaper offers greater range and payload than the Predator. Because they carry weapons, Reapers can perform reconnaissance and light attack missions. By carrying fewer weapons, the aircraft can stay in the air longer or carry additional sensors.

Army Systems

The Army currently operates three medium-sized unmanned aircraft systems: the RQ-7 Shadow and the MQ-5B Hunter (referred to in this study as the Shadow and the Hunter) and a small number of Predator variants. Hunters were first fielded in the 1990s as reconnaissance aircraft that carried infrared and visible spectrum cameras. Some were later converted to carry the small GBU-44 precision attack weapon. About 20 Hunters remain in the inventory, but the Army plans to retire them by 2013.

The most numerous system in the Army's inventory is the Shadow. A smaller aircraft with a 60-pound payload, the Shadow carries infrared and visible spectrum cameras for day- and nighttime reconnaissance. In 2009, the Army completed purchases of 115 Shadow systems, each having four aircraft. Those aircraft are primarily operated at the brigade level (the echelon below division) within the Army's force structure because their shorter range is suited to the limited operating area of a brigade. As of 2011, the Army is upgrading its Shadows with improved communications systems and laser designators for guiding weapons fired by other platforms, such as artillery. The Shadow does not carry its own weapons, but the Army is working on developing that capability.

The Army purchased about 50 Predator class unmanned aircraft systems from 2004 through 2010 in three different versions called Warrior Alpha, MQ-1C Grey Eagle Block 0, and MQ-1C Grey Eagle. The first two aircraft are early, less capable preproduction versions of the Grey Eagle. The Army intends to operate those aircraft at the division echelon because they have the necessary range to cover the larger area typically assigned to a division (compared with that assigned to a brigade). In counterinsurgency operations like those in Iraq and Afghanistan, the distinction between echelons blurs because military units operate in small groups that can be widely scattered. Even a Grey Eagle might at times support a small unit in contact with an enemy.

Navy and Marine Corps Systems

The Navy is currently testing two new types of aircraft it hopes to field in the near future: the MQ-8 Firescout unmanned helicopter (referred to in this study as the Firescout), and the long-endurance Broad Area Maritime Surveillance (BAMS) aircraft, a variant of the Global Hawk modified to suit maritime operations. Although test versions of Firescout and BAMS aircraft have been delivered to the Navy, they have not officially entered operational service as of 2011.

The Marine Corps fielded the Shadow to support ongoing operations in Southwest Asia. Thirteen systems (with four aircraft per system) had been delivered by the end of calendar year 2009.

Future Plans

In DoD's 2012 budget request, acquisition funding for research, development, test, and evaluation and for procurement of currently planned medium-sized and large unmanned aircraft systems totals about $4.6 billion for 2012. That total captures about 90 percent of DoD's request of $5.1 billion for all unmanned aircraft systems in 2012 (see Figure 1-2).

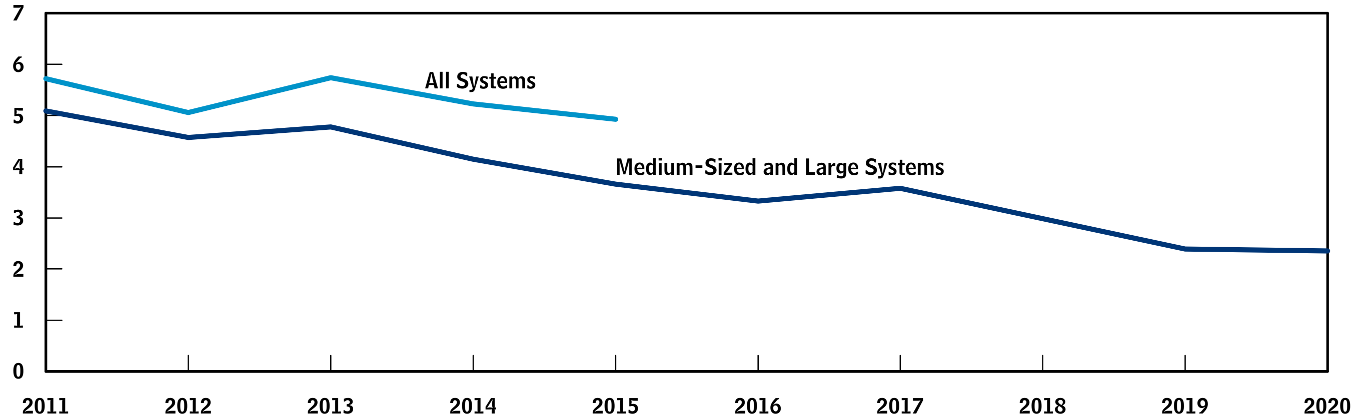
Under DoD's budget, funding for currently planned medium-sized and large systems would range between $3.7 billion and $5.7 billion annually over the next five years and would tend to decrease over time (except for a small increase in 2017), falling to just $2.4 billion by 2020. That profile reflects DoD's goal to acquire and deploy existing types of unmanned aircraft systems as quickly as possible to support ongoing counterinsurgency operations. DoD's total requested funding for unmanned aircraft systems probably will not fall if new programs to develop more advanced aircraft come into being in later years.

To facilitate comparisons of the capability of various systems, CBO constructed a measure called payload-duration—defined as the weight (payload) that an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration). The systems were analyzed according to the payload-duration they could provide for orbits positioned at various distances from the airbase from which they would operate. (See Box 1-1 on page 8 for more detail about payload-duration.)

Figure 1-2.

Acquisition Cost of Medium-Sized and Large Unmanned Aircraft Systems and of All Systems Under the Department of Defense's 2012 Plan

(Billions of 2011 dollars)



Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

Notes: Acquisition cost is the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation. The services' cost data have been adjusted using CBO's projection of inflation.

DoD did not report, nor did CBO estimate, the acquisition cost of all systems beyond 2015.

Air Force's Plans

The Air Force's near-term goals are to increase the number of Global Hawk and Reaper aircraft that can be continuously and simultaneously operated. To meet that goal, the Air Force plans to purchase 288 Reapers (48 per year from 2011 through 2016) and 28 Global Hawks from 2011 through 2018. Documents that DoD provided to the Congress with its 2012 budget request indicate plans to continue buying multimission unmanned aircraft after 2016, although the type of aircraft is not specified.[5] On the basis of the information available, CBO assumed that the Air Force's purchases after 2016 would continue at 48 aircraft per year and would comprise either additional Reapers or a follow-on aircraft with range, payload, and cost similar to the Reaper. (Unless a distinction is necessary, references to the Reaper in this study pertain to both the Reaper itself and the possible follow-on system.)

About $20.4 billion will be needed to purchase those aircraft, CBO estimates: $7.3 billion for Global Hawks, $13.1 billion for Reapers, and about $60 million to complete production of Predators (see Table 1-2). Those costs would average about $2.0 billion per year through 2020.

Of the 38 Global Hawks purchased through 2010, 14 are operational. The remaining aircraft have not yet been delivered or are waiting for their sensors to be tested. Under its 2012 plan, the Air Force will have purchased a total of 66 Global Hawks by 2018, although CBO estimates that about 7 of those aircraft could be lost to attrition from accidents or enemy action by then.[6] When the planned Global Hawks are fully operational, the Air Force expects to retire its remaining U-2S manned reconnaissance aircraft, although some or all of those aircraft may remain in service if needed to augment Global Hawks or any other high-altitude reconnaissance systems that might be deployed by that time.[7]

5. Department of Defense, *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011). CBO adjusted the costs using its projection of inflation.

6. DoD does not publish an estimate of attrition losses. CBO used attrition rates based on historical values provided by the Air Force and the Army.

7. The U-2S carries some sensors not currently planned for the Global Hawk, and some missions may need a pilot on board.

Table 1-2.

Quantity and Cost of Acquisitions Under the Air Force's 2012 Plan

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
						Quantity					
RQ-4 Global Hawk	4	3	3	3	1	1	6	7	0	0	28
MQ-1 Predator	0	0	0	0	0	0	0	0	0	0	0
MQ-9 Reaper	48	48	48	48	48	48	48 [a]	48 [a]	48 [a]	48 [a]	480 [a]
Total	**52**	**51**	**51**	**51**	**49**	**49**	**54**	**55**	**48**	**48**	**508**
					Cost (Millions of 2011 dollars)[b]						
RQ-4 Global Hawk	1,200	1,060	890	790	810	710	1,160	530	80	60	7,290
MQ-1 Predator	30	10	10	10	c	c	c	c	c	c	60
MQ-9 Reaper	1,700	1,550	1,740	1,440	1,350	1,150	1,060 [a]	1,040 [a]	1,030 [a]	1,010 [a]	13,070 [a]
Total	**2,930**	**2,620**	**2,640**	**2,240**	**2,160**	**1,860**	**2,220**	**1,570**	**1,110**	**1,070**	**20,420**

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

a. Data are for the follow-on aircraft the Air Force plans to acquire instead of the Reaper.

b. Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation. The Air Force's cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

c. The Air Force has no plans to acquire or modify the specified system in these years.

At the beginning of 2010, Predators were the Air Force's predominant medium-sized unmanned aircraft for reconnaissance and light attack missions. The Air Force estimates that its fleet of unmanned aircraft will be able to fly 50 continuous orbits by the end of 2011 and 65 orbits by 2013 and that the more-capable Reaper will account for an increasing fraction of those orbits over time.[8] (The last of the Predators were purchased in the 2009 budget, but some small modifications are still planned.)

The Air Force plans to stop buying Reapers in 2016 and, in 2017, to start purchasing a follow-on medium-sized unmanned aircraft system. Although the Air Force has not yet identified what the follow-on aircraft will be, in estimating payload, endurance, and cost CBO has assumed that the aircraft will be similar to the Reaper; accordingly, discussions about the Reaper in this study also apply to the follow-on aircraft, unless making the distinction is necessary. (For example, a follow-on to the Reaper is likely to have improved stealth characteristics.) In 2020, the Air Force's inventory (incorporating losses due to attrition) would include about 600 Predators and Reapers that would be capable of sustaining more than 100 continuous orbits, CBO estimates (see Figure 1-3 on page 10).[9]

In addition to a larger number of aircraft and the corresponding increase in the number of orbits, the effectiveness of the aircraft on orbit will increase, on average, because the aircraft to be added under the Air Force's plan will be more capable than most of the aircraft in the force today. The extent to which the improved performance will make military operations more effective will depend on the types of missions and targets that present themselves in the future.

The later-version Global Hawks have a 50 percent larger payload capacity than the original model and are slated to carry improved electro-optical and infrared sensors. Some will also carry sophisticated signals intelligence sensors or significantly improved synthetic aperture radar being developed by the Multi-Platform Radar Technology

8. The Air Force uses a planning factor of four aircraft per continuous orbit, so 50 such orbits would require 200 aircraft.

9. Using historical data and the Air Force's projections, CBO estimates that about 81 Predators and 52 Reapers will be lost through accidents or retirement by 2020.

Box 1-1.

Payload-Duration as a Comparative Measure of Capability

To facilitate comparison of the capability that can be expected under various plans for acquiring unmanned aircraft, the Congressional Budget Office (CBO) constructed a measure called payload-duration—that is, the weight (payload) that an aircraft could carry to a mission's location (orbit), multiplied by the amount of time the aircraft could stay there on orbit (duration). Duration equals endurance (the maximum length of time that an aircraft can spend in the air) minus time in the transit phase, where total transit time is two times the range divided by transit speed (see the figure on the opposite page).

Payload-duration does not capture all aspects of performance that are relevant. However, it is a very useful measure for comparing the performance of two or more fleets under various options for the fleet's composition.

For orbits positioned at various distances from the airbase from which the systems operate, CBO calculated the payload-duration that each alternative fleet of unmanned aircraft systems for each service could provide—that is, the sum of the payload-duration for each aircraft in that fleet.[1] In those calculations, transit time depends on the distance to the target area and the speed of the aircraft. Faster aircraft reach the target area more quickly and can spend more of their endurance time in the orbit phase. In cases in which an aircraft can carry different payloads with varying endurance, as the Reaper and the Grey Eagle can, CBO used a distribution of payload weights and associated endurance based on planning factors provided by each of the armed services.

Fleetwide payload-duration captures the benefits of inventory, transit speed, endurance, and payload capacity. Payload capacity serves as a simplified measure of the types and quality of sensors and weapons that could be carried—under the general assumption that, all else being equal, a greater payload capacity offers the opportunity to carry more-capable sensors and a greater number or variety of weapons. For simplicity, the payload-duration metric counts all pounds of payload—sensors or weapons carried internally or on external racks—equally. Although the components of payload are to some extent interchangeable, current aircraft are limited to carrying specific sensors, weapons, or both. Nevertheless, the aggregate metric provides a useful measure of capacity for the overall fleet.

In the future, in-flight refueling could increase payload-duration at all ranges, and the Department of Defense is exploring technologies for automated aerial refueling. However, none of the aircraft systems considered in this study can be refueled in flight.

1. CBO's estimates of payload-duration are based on total aircraft inventory for each service. In actuality, some fraction of each fleet will be unavailable for operations at any given time because of maintenance or upgrades. However, because the fraction of aircraft unavailable is likely to be similar across the options, payload-duration is a suitable measure for comparing the fleets' capabilities.

Continued

Insertion Program. At the same time, the Air Force's future medium-altitude fleet will make the transition from one dominated by Predators to one dominated by Reapers, which fly at higher speeds and carry heavier payloads. The increased payload capacity can be used to carry more weapons or new sensors, such as the Gorgon Stare video sensor, which can look in several directions at once.

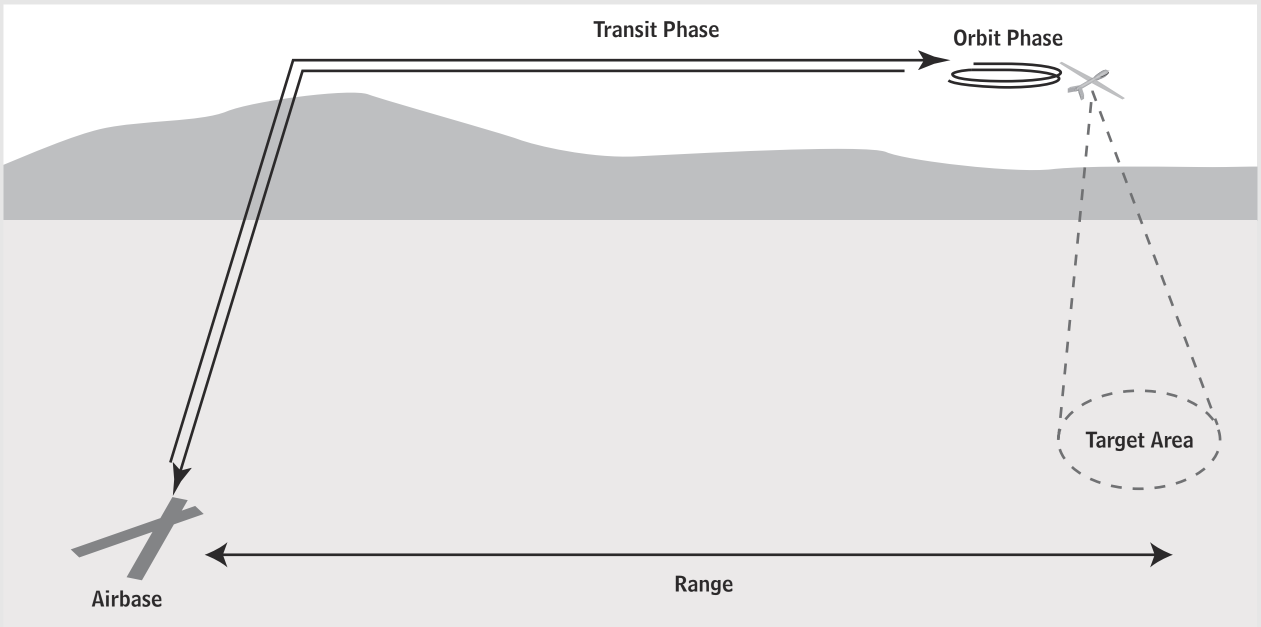
As a generalized measure of the projected increases in capabilities from the Air Force's plans, CBO estimated payload-duration at three ranges from airbases to target areas. Typically, the ranges from airbases in a theater of deployment are zero to 650 nautical miles (nm), compared with 1,500 nm for airbases in a geographic region of deployment and 2,500 nm for airbases outside that region.[10] By 2020, CBO estimates, the increase in

10. A distance of 650 nm would probably be at the high end for airbases in a theater of operations. Closer airbases could be available, and commanders might prefer to base aircraft with shorter endurance at those locations.

Box 1-1. **Continued**

Payload-Duration as a Comparative Measure of Capability

Phases of Flight for Unmanned Aircraft



Source: Congressional Budget Office.

payload capacity for the Air Force fleet would be substantial, and the largest effects would be at ranges between 275 and 650 nm, where Reapers and Global Hawks can remain in continuous orbits for long durations (see Figure 1-4 on page 11).

The Army's Plans

The largest programs for unmanned aircraft systems in the Army's 2012 budget request are the purchase of 107 Grey Eagle medium-altitude aircraft and 20 Shadows as well as upgrades to the existing fleet through 2016 (see Table 1-3 on page 12).[11] CBO estimates that completing those programs would cost about $5.9 billion—$4.0 billion for the Grey Eagle and $1.9 billion for Shadow upgrades. Those costs would average $1.0 billion per year over the 2011–2016 period. The Army has a long-term plan for a follow-on medium-sized system starting in about 2026.

The Army plans to buy 20 additional Shadows to replace losses and also intends to upgrade its existing Shadows with a laser target designator and a new tactical communications data link for both the aircraft and the ground station. The upgrade of the laser target designator began in 2008, and the data link modernization began in 2010. The Army plans to upgrade the entire Shadow fleet.[12]

The Grey Eagle is a version of the Predator with a slightly more powerful engine and slightly larger payload. The Army plans to equip up to 10 combat aviation brigades with Grey Eagle systems, and the remaining aircraft will support special operations and undertake other missions.[13]

The Army has roughly 490 medium-sized unmanned aircraft in its inventory in 2011 (see Figure 1-3 on page 10).

11. That total does not include the Grey Eagle aircraft the Army purchased before 2011, but it does include three purchased with funding for overseas contingency operations in 2011 to replace aircraft lost through attrition.

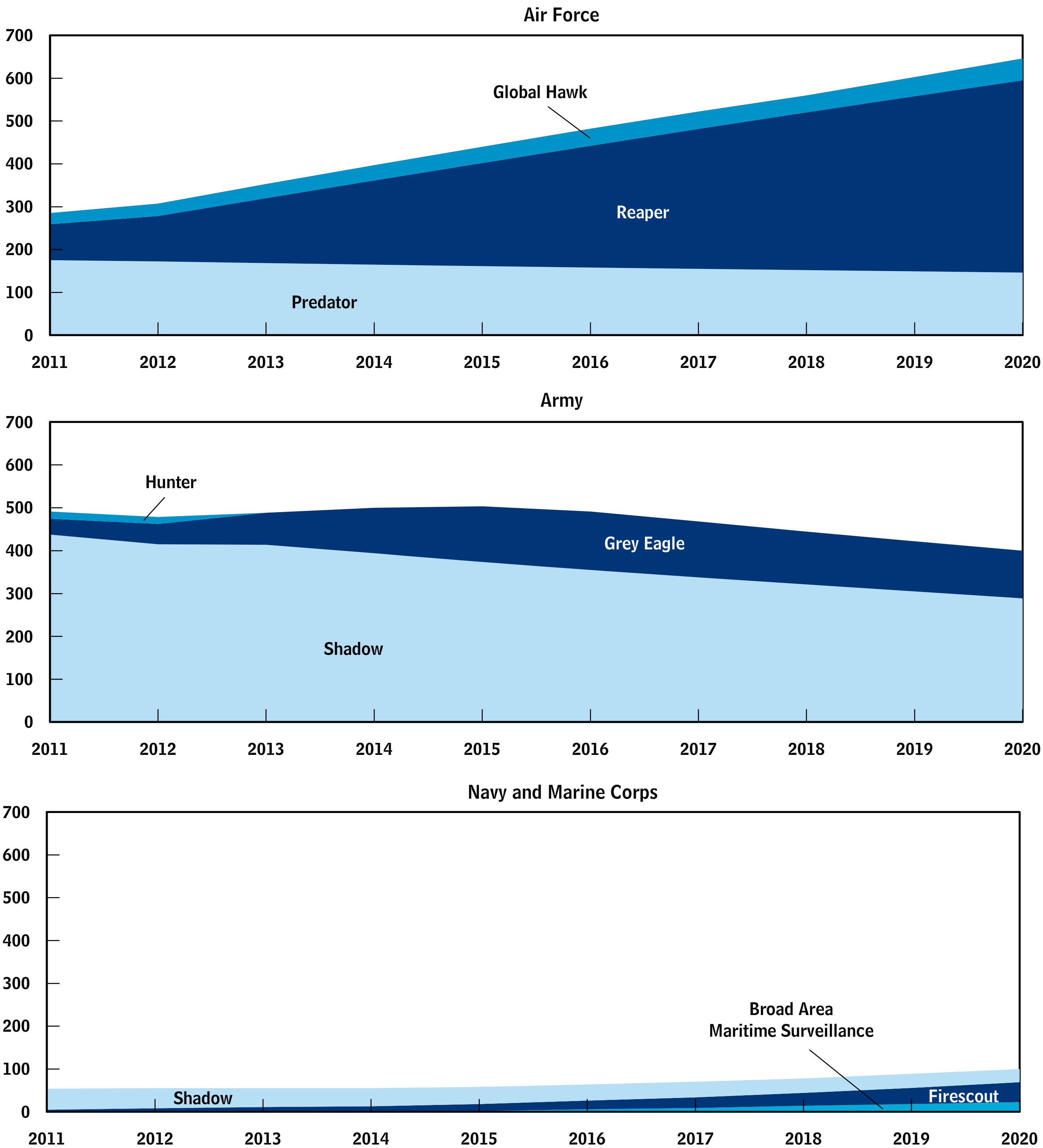
12. The Army may also upgrade the Shadow's wings to increase its payload, but that decision has not yet been made.

13. A combat aviation brigade is part of an Army division; thus, it reports directly to an Army division commander when a division deploys as a unit.

Figure 1-3.

Inventory of Medium-Sized and Large Unmanned Aircraft Under the Department of Defense's 2012 Plan

(Number of aircraft)

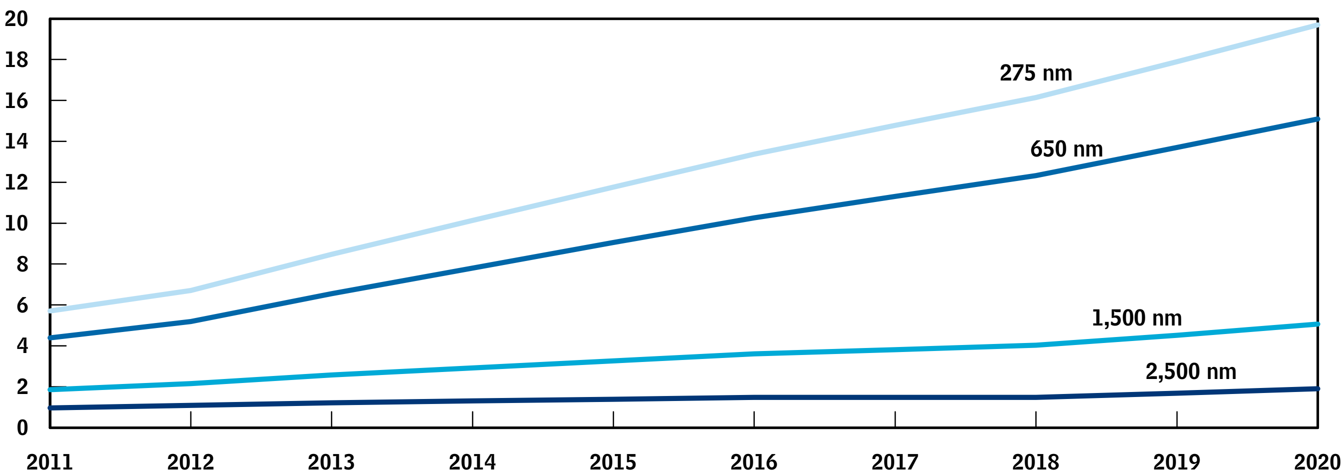


Source: Congressional Budget Office.

Figure 1-4.

Payload-Duration at Various Ranges Under the Air Force's 2012 Plan

(Millions of pound-hours)



Source: Congressional Budget Office.

Notes: The ranges, expressed in nautical miles (nm), measure the distance from the aircraft's airbase to orbit. All but the shortest range (275 nm) correspond to the maximum distances the Predator (650 nm), Reaper (1,500 nm), and Global Hawk (2,500 nm) can operate from their airbase.

Payload-duration is a comparative performance metric developed by CBO to measure overall capability. It measures the weight (payload) an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration).

The inventory will remain roughly constant over the next four years as deliveries of Grey Eagles compensate for estimated attrition losses and the retirement of Hunters.[14] CBO estimates that unless the Army buys additional aircraft, attrition will reduce the inventory of Shadows and Grey Eagles to about 400 aircraft by 2020.[15]

Except for the Grey Eagle, which has a satellite relay for longer ranges, the effective range of the Army's unmanned aircraft systems, as currently equipped, is the line-of-sight communications range between the aircraft and their ground station. That line-of-sight range depends on the altitude at which the aircraft are able to fly; higher altitudes offer longer line-of-sight distances to ground stations to overcome terrain features and the curvature of the Earth. By contrast, the Air Force's unmanned aircraft systems are not subject to that constraint because all are equipped with the satellite communications needed for theaterwide and global operations.

Although inventory would remain nearly constant over the next several years under the Army's current plans, payload-duration would increase substantially as more Grey Eagles entered the force (see Figure 1-5 on page 13). Although the much greater endurance and payload of the Grey Eagle make it the dominant system in the future from a payload-duration perspective, the much larger inventory of Shadows enables a greater dispersion of sensors across the battlefield. Roughly speaking, the performance of each Grey Eagle offers missions of longer endurance over broader areas, whereas the large inventory of Shadows offers the ability to fly large numbers of more geographically constrained missions carrying a smaller payload. For example, the Shadow might perform a tactical mission with a limited scope, such as inspecting a route for obstacles or enemy forces before a ground unit

14. On the basis of the Army's data on losses, CBO assumed a constant rate of 5 percent attrition per year for Army systems.

15. The Class IV unmanned aircraft system, an Army version of the Firescout helicopter, had been slated to provide a reconnaissance or light attack capability to combat brigades beginning about 2015, but the Army canceled it along with the Future Combat System program in 2009.

Table 1-3.

Quantity and Cost of Acquisitions Under the Army's 2012 Plan

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
					Quantity						
MQ-1C Grey Eagle	29	36	28	14	0	0	0	0	0	0	107
RQ-7 Shadow[a]	0	20	0	0	0	0	0	0	0	0	20
Total	**29**	**56**	**28**	**14**	**0**	**0**	**0**	**0**	**0**	**0**	**127**
					Cost (Millions of 2011 dollars)[b]						
MQ-1C Grey Eagle	870	1,060	1,040	740	220	90	c	c	c	c	4,020
RQ-7 Shadow[a]	610	250	270	200	300	280	c	c	c	c	1,910
Total	**1,480**	**1,310**	**1,320**	**940**	**520**	**370**	**c**	**c**	**c**	**c**	**5,940**

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

a. From 2011 to 2015, the Army plans to upgrade existing RQ-7 Shadows and purchase 20 aircraft to replace combat losses.

b. Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation. The Army's cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

c. The Army has no plans to acquire or modify the specified system in these years.

moves, whereas the Grey Eagle might perform a continuous surveillance mission of a high-value target that might move over a large area.[16] In addition, the Grey Eagle can include weapons in its payload, whereas the Shadow currently cannot. The Army is developing small air-to-ground weapons to be carried on modified Shadows. The cost of that modification is not included in this study.

Navy and Marine Corps' Plans

The Navy plans to purchase about 68 unmanned aircraft as part of the Broad Area Maritime Surveillance program and would purchase 36 of that total by 2020 (see Table 1-4 on page 13 and Figure on page 10). The BAMS aircraft will be a version of the Global Hawk modified for maritime patrol. Although two test aircraft have undergone service test and evaluation, full production will not begin until 2015. Operating from just a few airbases worldwide, those aircraft will be used to maintain a general awareness of activities on the oceans.

The Marine Corps does not plan to purchase additional Shadow systems and instead will upgrade some existing systems. In the longer term, the Marine Corps is exploring concepts for a medium-sized system—notionally called the Group 4 UAS—that would be designed to perform various missions in support of amphibious operations.

To support the operations of surface ships, the Navy plans to purchase about 61 Firescout unmanned helicopters by 2020 (in addition to the 14 purchased before 2011). The Firescout will operate from selected surface ships—especially the new littoral combat ships—to provide local reconnaissance and antiship capability.[17] The Navy is testing several Firescouts for their suitability on ships, but the aircraft has not yet entered the fleet. The Navy will have a modest payload-duration until 2016, when deliveries of BAMS and Firescouts begin to increase (see Figure 1-6 on page 14). The Navy is also exploring concepts for a carrier-based unmanned aircraft, including the so-called Unmanned, Carrier-Launched Airborne Surveillance and Strike aircraft, that might enter service by 2020.

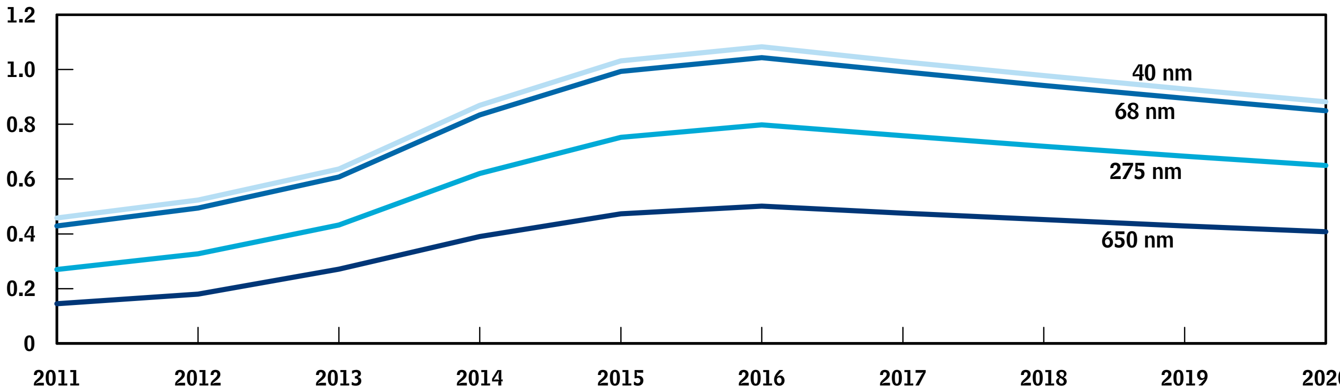
16. A Grey Eagle could perform the limited mission too if it did not have another task with a higher priority, whereas a Shadow would not be capable of the longer range and greater endurance of some of a Grey Eagle's missions.

17. The littoral combat ship is a new class of Navy warship that is small, fast, and easier to maneuver than larger ships. For more information, see Congressional Budget Office, letter to the Honorable John McCain about analyzing the cost implications of the Navy's plans for acquiring littoral combat ships (December 10, 2010).

Figure 1-5.

Payload-Duration at Various Ranges Under the Army's 2012 Plan

(Millions of pound-hours)



Source: Congressional Budget Office.

Notes: The ranges, expressed in nautical miles (nm), measure the distance from the aircraft's airbase to orbit. The ranges correspond to the maximum distances the Firescout (40 nm), Shadow (68 nm), and Grey Eagle (275 nm, or 650 nm with satellite relay) can operate from their airbase.

Payload-duration is a comparative performance metric developed by CBO to measure overall capability. It measures the weight (payload) an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration).

Table 1-4.

Quantity and Cost of Acquisitions Under the Navy and Marine Corps' 2012 Plan

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
						Quantity					
MQ-8 Firescout	3	3	3	5	5	6	6	10	10	10	61
RQ-4 BAMS	0	0	0	4	4	5	5	6	6	6	36
RQ-7 Shadow[a]	0	0	0	0	0	0	0	0	0	0	0
Total	**3**	**3**	**3**	**9**	**9**	**11**	**11**	**16**	**16**	**16**	**97**
						Cost (Millions of 2011 dollars)[b]					
RQ-4 BAMS	530	560	760	880	900	1,010	1,230	1,260	1,130	1,130	9,390
MQ-8 Firescout	60	70	60	80	80	90	130	160	150	150	1,030
RQ-7 Shadow[a]	90	10	10	10	c	c	c	c	c	c	120
Total	**680**	**640**	**830**	**970**	**980**	**1,100**	**1,360**	**1,420**	**1,280**	**1,280**	**10,540**

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

Note: BAMS = Broad Area Maritime Surveillance.

a. From 2011 to 2014, the Navy and Marine Corps plan to upgrade existing RQ-7 Shadows, resulting in no additional aircraft but involving an acquisition cost.

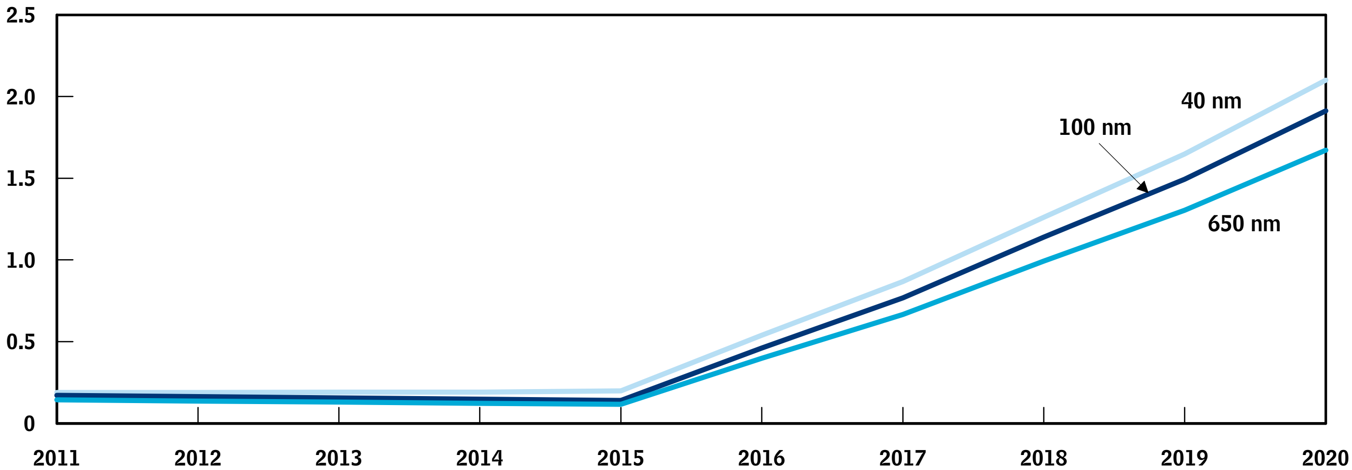
b. Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation. The Navy and Marine Corps' cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

c. The Navy and Marine Corps have no plans to acquire or modify the specified system in these years.

Figure 1-6.

Payload-Duration at Various Ranges Under the Navy and Marine Corps' 2012 Plan

(Millions of pound-hours)



Source: Congressional Budget Office.

Notes: The ranges, expressed in nautical miles (nm), measure the distance from the aircraft's airbase to orbit. The range of 40 nm corresponds to the maximum distance the Firescout can operate from its airbase. The longer ranges (100 nm and 650 nm) represent the distances the Broad Area Maritime Surveillance system might cover.

Payload-duration is a comparative performance metric developed by CBO to measure overall capability. It measures the weight (payload) an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration).

CHAPTER

2

Assessing Policy Options

In addition to its analysis of the Department of Defense's 2012 plans for procuring unmanned aircraft systems, the Congressional Budget Office examined how alternatives to those plans might affect the capability of the armed forces and the budgetary cost. In the past several years, plans for fielding unmanned aircraft systems have changed more substantially from year to year than has been typical for other types of weapon systems. That variability results from several factors, including:

- A reevaluation of priorities in DoD's February 2010 *Quadrennial Defense Review Report*,
- A tension between designing systems tailored for counterinsurgency and systems tailored for conventional force-on-force military operations (a tension that is exacerbated by DoD's having to develop and refine how it operates unmanned aircraft systems in the midst of existing conflicts), and
- Questions about which performance characteristics are preferable and how much capability is appropriate (questions that are more difficult to answer in the case of unmanned aircraft systems because those systems largely represent a new capability, not the replacement and improvement of a previously established capability that is already familiar to planners and operators).

The options CBO examined—three for the Air Force and five for the Army—involve changes in acquisition plans that could be made in the near term to shift the mix of capabilities in the force over the next decade.[1] The analysis explores the trade-offs between added (or reduced) capability and cost among the options relative to DoD's 2012 plan. In addition, this study does not assess the operation and support costs of the options. In CBO's estimation, those costs would change little under the eight options because some of the options would require only modest changes in the number of personnel—a major contributor to those costs—and because differences in fuel consumption and the cost of spare parts probably would be minimal.[2]

The options in this study are meant to illustrate the comparative cost and capabilities created by different approaches over the next 10 years and are not designed to reach any specific goals or counter any specific adversaries that might arise in the future. CBO did not examine longer-term options for unmanned aircraft systems that would require significant technological developments, because what could be fielded and what might be needed remain too speculative for a detailed analysis.[3]

1. CBO did not examine any alternatives for the Navy and Marine Corps because they will have relatively few unmanned aircraft systems in the near term and because CBO wanted to keep the number of options to a manageable level.

2. Some options would require modest changes in the number of personnel. Option 6 for the Army, for example, would increase the number of unmanned aircraft operators, but CBO assumed that the Army would provide those people from existing ranks, as it has done when adopting other unmanned aircraft systems. Conversely, Options 7 and 8 would require fewer personnel, but those savings are not included in CBO's analysis.

3. For example, the Army planned several types of unmanned aircraft systems as part of the Future Combat System program. The Army canceled that program in 2009 but is still considering how to integrate its innovative technologies into new systems. The Navy is moving toward integrating long-range unmanned aircraft systems into its maritime patrol force, is planning to operate unmanned helicopters from the deck of many ships in the fleet, and is developing the X-47B unmanned carrier aircraft demonstrator, a possible candidate for the Unmanned Carrier Launched Airborne Surveillance and Strike System. The Marine Corps is exploring the use of unmanned helicopters for resupplying its expeditionary forces and plans to have those aircraft support its units in Afghanistan.

Options for the Air Force

The Air Force's procurement plans outlined in DoD's 30-year aviation plan focus on expanding the fleets of Global Hawks for long-range reconnaissance and Reapers for multimission reconnaissance and light attack.[4] (Citing uncertainties about future threats and the rapid evolution of aircraft technologies, DoD's 30-year aviation plan offers firm programmatic details only through 2016 and more general objectives only through 2020.) The near-term focus on the proven Reaper is consistent with efforts to expand as rapidly as possible the capabilities that are in demand in current conflicts. In the future, however, other characteristics (particularly the ability to operate in defended airspace) may become more important and may be reflected in the follow-on aircraft planned after 2016.

CBO's options for the Air Force look at the implications of a more rapid development and fielding of unmanned aircraft systems that have characteristics that could be advantageous in a conflict against a more technologically capable adversary. The Air Force is exploring concepts and requirements for such an aircraft—commonly referred to as the MQ-X in discussions of future plans—and aerospace companies, anticipating the Air Force's interest, have made varying levels of investment in developing the next generation of multimission unmanned aircraft systems. For example, General Atomics Aircraft Company (the manufacturer of Predator, Reaper, and Grey Eagle) has built a flying prototype of the Avenger, an aircraft aimed at filling that role. Lockheed Martin has developed the stealthy RQ-170 Sentinel, which has been flying and could also fill that role, but details about that aircraft are classified.

In CBO's options, the Air Force would purchase a notional "MQ-SX"—an aircraft that would have some characteristics similar to those under consideration for the proposed MQ-X—in lieu of some of the Reapers or Global Hawks in current plans. The MQ-SX postulated by CBO would be a jet-powered (turbofan) aircraft about one and a half times the size of the Reaper with an airframe designed to be more difficult for air-defense systems to detect and target. The larger size would enable the MQ-SX to carry a greater payload (sensors, weapons, or fuel); jet propulsion would allow the aircraft to reach its destination (a target or orbit location) in less time; and stealth features would improve its ability to operate in defended airspace. Less certain is how CBO's notional MQ-SX would compare with the possible follow-on to the Reaper, purchases of which could begin in 2017 according to DoD's long-term aircraft procurement plan. For the purpose of calculating payload, endurance, and cost, CBO has assumed that the follow-on aircraft would be similar to the Reaper but would probably include improved stealth characteristics. CBO estimated the cost of the notional MQ-SX by scaling up the cost of the existing Reaper airframe to account for the change in size and for the addition of stealth features for improved survival in defended airspace. CBO's cost estimate for the notional MQ-SX assumes modest efforts to improve stealth characteristics relative to the Global Hawk, Predator, and Reaper. A highly stealthy design would probably cost more. Ancillary equipment that can contribute substantially to the cost of unmanned aircraft systems (for example, ground stations and communications systems) is assumed to be similar to that of the Reaper. At least two aircraft that might meet those criteria are flying today (the Avenger and the RQ-170 Sentinel). All three options for the Air Force assume that an aircraft at a similar stage of development would be adopted and could enter production quickly with little funding for research and development beyond that already planned.

A larger aircraft is able to carry various combinations of larger sensors, heavier weapon loads, or additional fuel for improved endurance. In addition to heavier total weapon loads, a larger aircraft could potentially carry larger individual weapons that would enable the aircraft to attack additional types of targets. For example, a wider array of targets would be vulnerable to an MQ-SX if that aircraft was designed to accommodate 2,000-pound class weapons, which are beyond the Reaper's capacity.[5]

Higher speed enables an aircraft to spend a smaller proportion of its time in transit and more time on orbit and to increase the size of its orbit for surveillance. For example, if close support for ground forces required that an orbiting aircraft release a weapon no more than five minutes after receiving the order, a faster aircraft could respond from a greater distance. As a result, fewer aircraft might be required overall to cover a given area.

4. Department of Defense, *Aircraft Procurement Plan: Fiscal Years 2012–2041* (submitted with the 2012 budget, March 2011).

5. The Reaper can carry 3,000 pounds of weapons in all, but they must be distributed over four external carry points, thus limiting the weight of the heaviest weapon it can carry.

In brief, CBO compared the cost and capability (measured by payload-duration) of its options for the Air Force relative to those of the service's current plan in 2020 at three ranges: 275, 1,500, and 2,500 nautical miles (see Table 2-1). Option 1 would cost the same as the Air Force's plan (by design) but would improve payload-duration by about 35 percent at intermediate range and reduce it by about 5 percent at short range; it would have no effect on long-range payload-duration. Option 2 would boost payload-duration even more—by about 67 percent at intermediate range and 17 percent at short range—but it would cost $2.9 billion more than Option 1 and the Air Force's 2012 plan. Option 3 would save $3.7 billion relative to the plan but would reduce payload-duration by about 4 percent at short range, 17 percent at intermediate range, and 45 percent at long range.

Option 1: Buy 224 MQ-SXs and 336 Fewer Reapers (Same Cost)

Under Option 1, the Air Force would replace purchases of 336 Reapers with 224 larger, more costly MQ-SX aircraft for roughly the same overall acquisition cost as in the service's 2012 plan. Although the option would result in about 110 fewer multimission unmanned aircraft than in current plans—a reduction of about 20 percent—payload-duration would be nearly equal to or better than in current plans because the faster transit time of the MQ-SX would increase the proportion of time on station (on orbit). Payload-duration would be about 35 percent higher at intermediate range and only a few percent lower than current plans at short range.

The attractiveness of Option 1 depends on the usefulness of the additional payload and stealth features of the MQ-SX for future operations by unmanned aircraft. In light attack missions, unmanned aircraft are typically useful when a small number of precision weapons are sufficient—for example, when attacking terrorist hideouts or supporting small ground patrols that encounter unexpected resistance. Situations requiring heavier fire (for example, a major offensive) are often predictable, and support comes from more traditional means, such as ground artillery or manned strike aircraft. Even if the need for heavy fire is unexpected, lightly armed unmanned aircraft can serve as first responders, buying time until heavier support can arrive.

The value of possible stealth features in new aircraft designs will similarly depend on how multimission unmanned operations evolve. Aircraft flying in the presence of advanced air defenses and having little or no support from forces designed to suppress or destroy those defenses require substantially more elaborate (and expensive) defensive features than do aircraft operating after air defenses have been neutralized. Furthermore, avoiding detection is more difficult for orbiting missions—such as those currently flown by Predators and Reapers in the uncontested airspace over Iraq and Afghanistan—because defenders have repeated opportunities to detect an aircraft and develop a picture of where and how the aircraft is being operated.[6] Current practices for unmanned aircraft may not be feasible in better-defended airspace, even when the aircraft have some stealth characteristics.

Option 2: Buy 336 MQ-SXs and 336 Fewer Reapers (Higher Cost)

The Air Force would buy 336 MQ-SXs and 336 fewer Reapers in Option 2. The number of aircraft (Reapers plus MQ-SXs) purchased each year would remain nearly unchanged through 2020 but would gradually shift from all Reapers in 2011 to all MQ-SXs in 2017. The total number of aircraft purchased would be about the same as under current plans, but the total cost would increase by about $2.9 billion.

Although the Air Force's total inventory of MQ-type aircraft would remain essentially unchanged, the larger size and higher speed of the MQ-SX relative to the Reaper would result in a force capable of maintaining a payload-duration at a range of 1,500 nm that, by 2020, would be 67 percent higher than that of the planned force. As in Option 1, the improved survivability of the MQ-SX, owing to its stealth features, could make it more useful in higher-threat environments.

6. The destruction of an F-117A stealth fighter over Serbia in 1999 by a surface-to-air missile of older design may have resulted in part from intelligence reports that warned the defenders when F-117s were departing from Italy and in part from the Air Force's use of predictable routes that allowed defenders to focus their defenses in a much smaller area. It may not be possible to make an unmanned aircraft stealthy enough to orbit for extended periods of time in well-defended airspace without being detected. CBO did not assess the stealth capabilities of the aircraft in relation to possible air defenses employed by future adversaries.

Table 2-1.

Differences Between Options for the Air Force and Its 2012 Plan, 2011 to 2020

	Air Force's Plan	Option 1	Option 2	Option 3
			Difference in Number Purchased	
Reaper	480	-336	-336	0
MQ-SX[a]	0	224	336	24
Global Hawk	28	0	0	-24
			Characteristics Compared with Plan	
Improved Survivability with Stealth Features	n.a.	Yes	Yes	Yes
Increased Strike Capability	n.a.	Possible[b]	Possible[b]	Yes [c]
			Difference in Cost (Billions of 2011 dollars)	
Acquisition Cost[d]	20.4	0	2.9	-3.7
			Percentage Difference in Capability (Payload-duration)[e]	
In 2015				
At 275 nm	n.a.	-1	-1	-2
At 1,500 nm	n.a.	4	4	-7
At 2,500 nm	n.a.	0	0	-16
In 2020				
At 275 nm	n.a.	-5	17	-4
At 1,500 nm	n.a.	35	67	-17
At 2,500 nm	n.a.	0	0	-45

Source: Congressional Budget Office.

Notes: Under all three options, the Air Force would buy new, stealthier aircraft, as follows:

- Option 1—Buy 224 MQ-SXs and 336 Fewer Reapers
- Option 2—Buy 336 MQ-SXs and 336 Fewer Reapers
- Option 3—Buy 24 MQ-SXs and 24 Fewer Global Hawks

n.a. = not applicable.

a. The MQ-SX is a notional aircraft that would have some characteristics consistent with ones under consideration for the Air Force's proposed MQ-X. The MQ-SX postulated by CBO would be a jet-powered aircraft about one and a half times the size of the Reaper.

b. A wider array of targets would be vulnerable to an MQ-SX if it was designed to accommodate 2,000-pound weapons, which are beyond the Reaper's capacity. The Reaper can carry 3,000 total pounds of weapons, but they must be distributed over four external carry points, which makes 750 pounds the heaviest weapon it can carry.

c. The MQ-SX would be designed to carry weapons, which the Global Hawk does not do.

d. Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation.

e. Payload-duration is the weight (payload) that an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration).

Option 3: Buy 24 MQ-SXs and 24 Fewer Global Hawks (Lower Cost)

The Air Force would replace the remaining purchases of 24 high-altitude Global Hawks with the same quantity of medium-altitude MQ-SXs, starting with purchases in 2012. Although the Air Force would buy the same total number of aircraft as under current plans, the total cost would fall by about $3.7 billion.

Option 3 would reduce the overall payload-duration at all ranges (by 4 percent to 45 percent) because the MQ-SX is not as fast as the Global Hawk (and would therefore spend more time in transit between its airbase and orbit location) and has shorter endurance and a slightly smaller payload. However, the greater stealth—and thus improved survivability—of the MQ-SX compared with that of the Global Hawk could make it more useful in defended airspace, depending on the effectiveness of those defenses and the missions the aircraft was expected to perform. The need for unmanned aircraft to operate in defended airspace would depend on whether other weapon systems can take on that role.

A combination of Global Hawks and MQ-SXs would provide the long-range unmanned aircraft force with a mix of stealth capabilities. The existence of the recently acknowledged RQ-170 Sentinel indicates that the Air Force has already fielded such a mix.[7] Option 3 would provide more stealthy aircraft overall.

The MQ-SX may not be able to carry all the specialized sensors that are planned for the later versions of the Global Hawk aircraft that they would replace under Option 3, although the MQ-SX would offer a strike capability that the Global Hawk does not. In its cost estimate for the MQ-SX, CBO assumed that the aircraft would be fielded with sensor systems consistent with MQ-type aircraft operations, not the more expensive systems currently carried by the Global Hawk. The MQ-SX should have sufficient capacity to carry the Global Hawk sensors, but the Air Force would have to purchase them and then integrate them into the aircraft, requiring further investment. In addition, some of the more expensive sensors, such as synthetic aperture radars, may not be useful on a stealthy aircraft if they emit signals that reveal the aircraft's presence and possibly its location.

7. Office of the Secretary of the Air Force, Directorate of Public Affairs, "RQ-170 Sentinel" (Air Force fact sheet, December 2, 2010), www.af.mil/information/factsheets/factsheet.asp?ID=16001.

Options for the Army

The Army's current procurement plans for unmanned aircraft systems focus on small and medium-sized systems. The small systems use portable unmanned aircraft with handheld controls for tactical reconnaissance by frontline combat soldiers. Although the small systems are the most numerous type of unmanned aircraft systems in the Army's inventory, they represent less than 10 percent of the service's 2012 budget for such systems. CBO's options for the Army focus on the medium-sized systems the service uses for reconnaissance and light attack missions. The aircraft and ground stations in those systems are more capable and also more expensive than the ones in small systems.

CBO's five options for the Army to purchase medium-sized unmanned aircraft look at the implications of three strategies:

- Buying more-capable unmanned aircraft (Options 4 and 5),
- Buying a larger number of less-capable unmanned aircraft (Option 6), or
- Changing the way unmanned aircraft are operated by conducting remote-split operations (Options 7 and 8).

CBO did not consider systems or advanced concepts that are in the early stages of development, such as the Long Endurance Multi-Intelligence Vehicle—an unmanned airship (an aircraft that is lighter than air) that the Army is currently investigating. In addition, CBO used shorter ranges (40, 275, and 650 nm) in analyzing options for the Army than it used for the Air Force because the Army's missions for unmanned aircraft systems, such as supporting brigades and divisions, tend to require shorter ranges.

The first two options for the Army demonstrate the implications of purchasing the more capable (and more expensive) Reaper instead of the Grey Eagle (see Table 2-2). To keep the cost the same as in the Army's plan, Option 4 would buy fewer Reapers than the number of Grey Eagles the Army plans to buy. It would boost capability (as measured by payload-duration) by 2020 by about 53 percent at short range (40 nm) and by about 86 percent at long range (650 nm).

Table 2-2.

Differences Between Options for the Army and Its 2012 Plan, 2011 to 2020

	Army's Plan	Option 4	Option 5	Option 6	Option 7	Option 8
				Difference in Number Purchased		
Grey Eagle	107	-78	-78	-78	-42	-78
Reaper	0	69	78	0	0	36
Firescout	0	0	0	350	0	0
				Characteristics Compared with Plan		
Adds Remote-Split Operations[a]	n.a.	No	No	No	Yes	Yes
Change in Tactical Flexibility	n.a.	Less [b]	Less [b]	More [c]	Same	Less [b]
Same Fuel Type	n.a.	No	No	No	Yes	No
Increased Commonality with Other Services[d]	n.a.	Yes	Yes	Yes	No	Yes
				Difference in Cost (Billions of 2011 dollars)		
Acquisition Cost[e]	5.9	0	0.5	0	-1.3	-1.0
				Percentage Difference in Capability (Payload-duration)[f]		
In 2015						
At 40 nm	n.a.	60	60	-31	-19/0 [g]	13/51 [g]
At 275 nm	n.a.	74	74	-49	-22/0 [g]	19/59 [g]
At 650 nm	n.a.	95	95	-48	-22/0 [g]	31/74 [g]
In 2020						
At 40 nm	n.a.	53	67	60	-27/0 [g]	3/37 [g]
At 275 nm	n.a.	65	82	-54	-30/0 [g]	7/42 [g]
At 650 nm	n.a.	86	105	-54	-29/0 [g]	17/56 [g]

Source: Congressional Budget Office.

Notes: Under the options, the Army would buy more-capable aircraft (Options 4 and 5); buy more, less-expensive aircraft (Option 6); or change the way aircraft are operated (Options 7 and 8), as follows:

- Option 4—Buy 69 Reapers and 78 Fewer Grey Eagles
- Option 5—Buy 78 Reapers and 78 Fewer Grey Eagles
- Option 6—Buy 350 Firescouts and 78 Fewer Grey Eagles
- Option 7—Conduct Remote-Split Operations with 42 Fewer Grey Eagles
- Option 8—Conduct Remote-Split Operations with 36 Reapers and 78 Fewer Grey Eagles

n.a. = not applicable.

a. In remote-split operations, deployed divisions would have operational control of aircraft from a central fleet rather than be equipped with their own aircraft.

b. Tactical ground mobility is reduced because the Reaper cannot be carried on the Army's standard tactical trucks.

c. The vertical takeoff and landing capability of the Firescout helicopter increases tactical flexibility.

d. Commonality between the Air Force (Reaper) and the Navy (Firescout) could lead to a future reduction in costs.

e. Acquisition cost includes the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation.

f. Payload-duration is the weight (payload) that an unmanned aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration).

g. The percentage change in payload-duration for Options 7 and 8 is shown for all divisions versus deployed divisions (all/deployed). For remote-split operations, payload-duration is lower than in the Army's plan for divisions that are not deployed.

Option 5 would provide even more capability but would cost $520 million more than the 2012 plan. By purchasing the same number of Reapers that the Army had planned for Grey Eagles, that option would provide nearly 67 percent more payload-duration at short range than the Army's plan and about 105 percent more at long range.

A third alternative for the Army, Option 6, would buy fewer medium-range aircraft and increase the number of shorter-range unmanned aircraft at the same cost as in the Army's plan. Specifically, Option 6 would buy Firescout unmanned helicopters and fewer Grey Eagles, providing 60 percent more capability at short range but about one-half the capability of the Army's planned force at long range.

The other two options for the Army, Options 7 and 8, would centralize management of the Army's medium-altitude unmanned aircraft using an approach that has worked well for the Air Force. Instead of being equipped with their own aircraft, deployed divisions would be given operational control of aircraft from a central fleet, in a technique called remote-split operations. Although the aircraft would be under the control of the division commander, they could be operated over satellite links from the United States or other secure locations. Only the ground-support crews would deploy to the theater of operations with the unmanned aircraft; flight crews could remain in a central location. Remote-split operations would reduce the logistical burden that unmanned aircraft place on a deployed division, because much of the infrastructure for those aircraft could remain at their home base. By using remote-split operations, the Army could purchase fewer aircraft because the size of the fleet could be matched to the maximum number of divisions that might be deployed at any given time instead of to the total number of divisions in the Army's force structure.

Options 7 and 8 illustrate how the remote-split approach could reduce costs by using fewer Grey Eagles. Option 7 would cost $1.3 billion less than the Army's plan. Option 8, which would purchase Reapers instead of Grey Eagles starting in 2012, would also reduce costs but by a smaller amount than in Option 7.

With remote-split operations, the capability of deployed divisions in Option 7 would be the same as under the Army's plan. Option 8 would increase the capability of the deployed divisions relative to Option 7 and still cost $1.0 billion less than the Army's plan. Under both options, the capability of the overall force (including divisions not deployed) would be lower.

Option 4: Buy 69 Reapers and 78 Fewer Grey Eagles (Same Cost)

The Army would replace future purchases of 78 Grey Eagles with 69 larger, more costly Reaper aircraft for the same overall cost as in the 2012 plan. The 48 Grey Eagles purchased through 2011 would remain in service.

The Grey Eagle is an improved version of the Predator, but compared with the Reaper it is smaller and slower and has less range and payload capacity. The Army is developing the Grey Eagle as a unique version of the Predator to meet its own stated requirements. In particular, the Army requires that the Grey Eagle be able to take off and land automatically, be transportable on land via standard Army transport trucks, and burn the same heavy fuel as its ground vehicles (thereby avoiding the need to have two types of fuel on hand).

The Reaper does not meet those requirements, but that may not be as large an issue as one might expect. The Reaper requires a conventional runway to take off and land, so transport must be available to take it to a suitable airfield. As currently designed, it is too big to fit on the Army's standard tactical trucks, but it can travel on non-tactical trucks such as tractor trailers. The Army does not intend to drive the trucks carrying the Grey Eagle or the Reaper cross-country on rough terrain, so transport using nontactical trucks should be feasible. In addition, Reapers use jet fuel rather than heavy fuel and operate out of fixed airbases where the same fuel is used by other aircraft, so the fact that the Reaper's engines do not use heavy fuel may not pose a logistical problem.

Being smaller and less powerful, the Grey Eagle can carry only about a quarter of the Reaper's payload, and it also has a shorter range. Unless it uses a satellite relay, its range is limited to 275 nm by the need to maintain a line of sight with its data link. (When using its satellite relay, the Grey Eagle can increase its range to 650 nm.) The Reaper has a faster air speed than the Grey Eagle, which not only gives it more time to orbit in the target area (on station) because of a shorter transit time, especially at longer ranges, but also allows it to switch more quickly to other targets.

Both the Reaper and the Grey Eagle can carry weapons in addition to their surveillance equipment. The Reaper has a larger maximum payload, however, and a longer time on station when equipped with weapons. The Grey Eagle's effective range and time on station is sharply reduced when it carries weapons. For example, at a range of 68 nm, the Grey Eagle can remain on station for 26 hours when performing surveillance without weapons. If it carries two Hellfire missiles—the usual payload in an armed reconnaissance mission—its time on station drops by nearly half, to 14 hours. If it carries four Hellfire missiles in an attack mission, the time on orbit drops even further, to 6 hours.

Compared with the Grey Eagle, the Reaper has shorter endurance when unarmed but longer endurance when carrying weapons. At the range of 68 nm, for example, the Reaper can perform unarmed surveillance for roughly 20 hours, about 20 percent less time than the Grey Eagle. Its time on station for the armed reconnaissance mission (with two Hellfire missiles) is roughly 16 hours, compared with 14 hours for the Grey Eagle. It can stay on station about 13 hours for the attack mission—much longer than the 6 hours managed by the Grey Eagle. Furthermore, the Reaper can carry four Hellfire missiles plus two GBU-12 500-pound bombs for an attack mission, compared with only four Hellfire missiles for the Grey Eagle.

At longer ranges, where the Grey Eagle uses a satellite relay, the comparison is even more favorable to the Reaper. At 650 nm, the Grey Eagle can remain on station for about 14 hours for surveillance and about 3 hours for armed reconnaissance. It cannot perform the attack mission at that range because, with the extra payload, the transit time would be greater than the Grey Eagle's overall endurance. By comparison, at that distance, the Reaper can remain on station for about 14 hours for surveillance, 10 hours for armed reconnaissance, and 7 hours for attack. The Army does not claim any capability for Grey Eagle past 650 nm. By contrast, the Reaper can fly more than 1,600 nm, although it can perform a surveillance mission (without attack capability) for less than 2 hours at that range.

Because of its greater range and endurance with a heavier payload, the Reaper provides more payload-duration at all ranges than the Grey Eagle. Under Option 4, total payload-duration would be 65 percent greater in 2020 at 275 nm than under the Army's plan and would exceed the capability in that plan at all other ranges as well.

The Air Force is developing a new sensor called Gorgon Stare that will allow unmanned aircraft to observe a wider area by looking in several directions at once. An unmanned aircraft equipped with Gorgon Stare will potentially be more effective in surveillance missions, and the Air Force expects to equip some of its Reapers with the new sensor. The Grey Eagle cannot carry that sensor, and the Army plans to use Gorgon Stare on larger, manned surveillance aircraft.[8] If the Army purchased Reapers instead of Grey Eagles, it would be able to use Gorgon Stare on its unmanned aircraft too.

Another advantage of having the Army buy the Reaper as opposed to continuing to develop its own unique Grey Eagle system would be that it would increase commonality between Air Force and Army systems. That commonality could eventually reduce production costs because economies of scale affect the manufacturing process. Conversely, adding a new type of aircraft to the Army's fleet could increase operating costs for training, spare parts, and tools. CBO did not include those savings or costs in its calculations.

Option 5: Buy 78 Reapers and 78 Fewer Grey Eagles (Higher Cost)

Under Option 5, the Army would replace planned future purchases of 78 Grey Eagles with the same number of larger, more costly Reapers. The Grey Eagles already purchased would remain in service, and the overall number of aircraft would remain the same. CBO estimates that this option would increase capability but would cost about $520 million more than the Army's 2012 plan (see Table 2-2 on page 20).

As in Option 4, the Reaper provides greater capability than the Grey Eagle at all ranges. In this option, the payload-duration for the fleet at 650 nm would be 105 percent greater in 2020 than under the current plan. Payload-duration in Option 5 would also exceed that in the Army's plan at shorter ranges.

Option 6: Buy 350 Firescouts and 78 Fewer Grey Eagles (Same Cost)

This option would purchase 350 Firescout unmanned helicopters and would forgo buying 78 of the Grey Eagles in the Army's 2012 plan. The total acquisition cost would

8. Options involving manned aircraft that currently or might also perform reconnaissance missions were outside the scope of this study.

be about the same as in the Army's plan. The Grey Eagles the Army has already purchased would remain in service.

In early 2009, the Army decided to cancel the brigade-level Class IV Firescout unmanned aircraft system (similar to the Navy's Firescout) as part of the cancellation of the Future Combat System. Because the Firescout is a small helicopter, it does not require a runway to operate, and the Army initially intended to have the system support brigades.[9] Option 6 replaces the division-level Grey Eagle with the Firescout, which might be assigned to a division or to a brigade, although it lacks the long range that might be needed for some missions in a division's typical area of responsibility.

The range and payload of the Firescout are much lower than those of the Grey Eagle, but because the Firescout is less costly, the Army could purchase many more of them. The resulting payload-duration in Option 6 would be nearly 60 percent greater than that in the Army's plan in 2020 at a range of 40 nm, but at longer ranges the payload-duration would be only about one-half that in the plan. Because of the time required to develop the aircraft, payload-duration would drop in 2014 and 2015 as production of the Firescout got under way.

The larger number of aircraft in Option 6 might make the overall force more resilient when sustaining losses from enemy activity or accidents. It would also distribute unmanned aircraft more densely across the battlefield, allowing more tactical units to receive dedicated unmanned aircraft support, compared with the support provided by smaller numbers of Grey Eagles. Because the Firescout does not require a runway, it may be able to operate closer to the supported units, thus compensating for its shorter range. That method of allocating assets might be better suited to supporting operations conducted by smaller military units scattered over a wide area, such as in the counterinsurgency operations in Iraq and Afghanistan. The Firescout might also be modified to carry a limited amount of supplies to soldiers in remote locations that have no access to runways.

Another advantage of this option is that it would allow the Army and the Navy to share a common aircraft. In its analysis, however, CBO did not consider any cost savings that might be gained from that commonality. More unmanned aircraft in the air at any time will require more ground stations and controllers. Although the cost estimates for this option include the costs of procuring those extra systems, they do not reflect the potential increase in operation and support costs that the Army would incur as a result of the extra systems and personnel.

Option 7: Conduct Remote-Split Operations with 42 Fewer Grey Eagles (Lower Cost)

Under this option, the Army would adopt the Air Force's approach of using remote-split operations and buy 42 fewer Grey Eagles to take advantage of efficiencies that such an approach would provide. Specifically, the Army would buy 65 new, enhanced Grey Eagles instead of 107 under its current plan; it would also have the 48 already purchased (including 24 slightly less capable early versions). That fleet of 113 medium-sized unmanned aircraft would provide enough capacity to support six divisions on the ground (the peak U.S. deployment in Operation Iraqi Freedom) and three additional divisions in special operations or training. Any unused aircraft would be held in reserve. The reduced fleet of Grey Eagles would cost $1.3 billion less than the Army's plan, assuming that the production rate remained the same but ended in 2012.

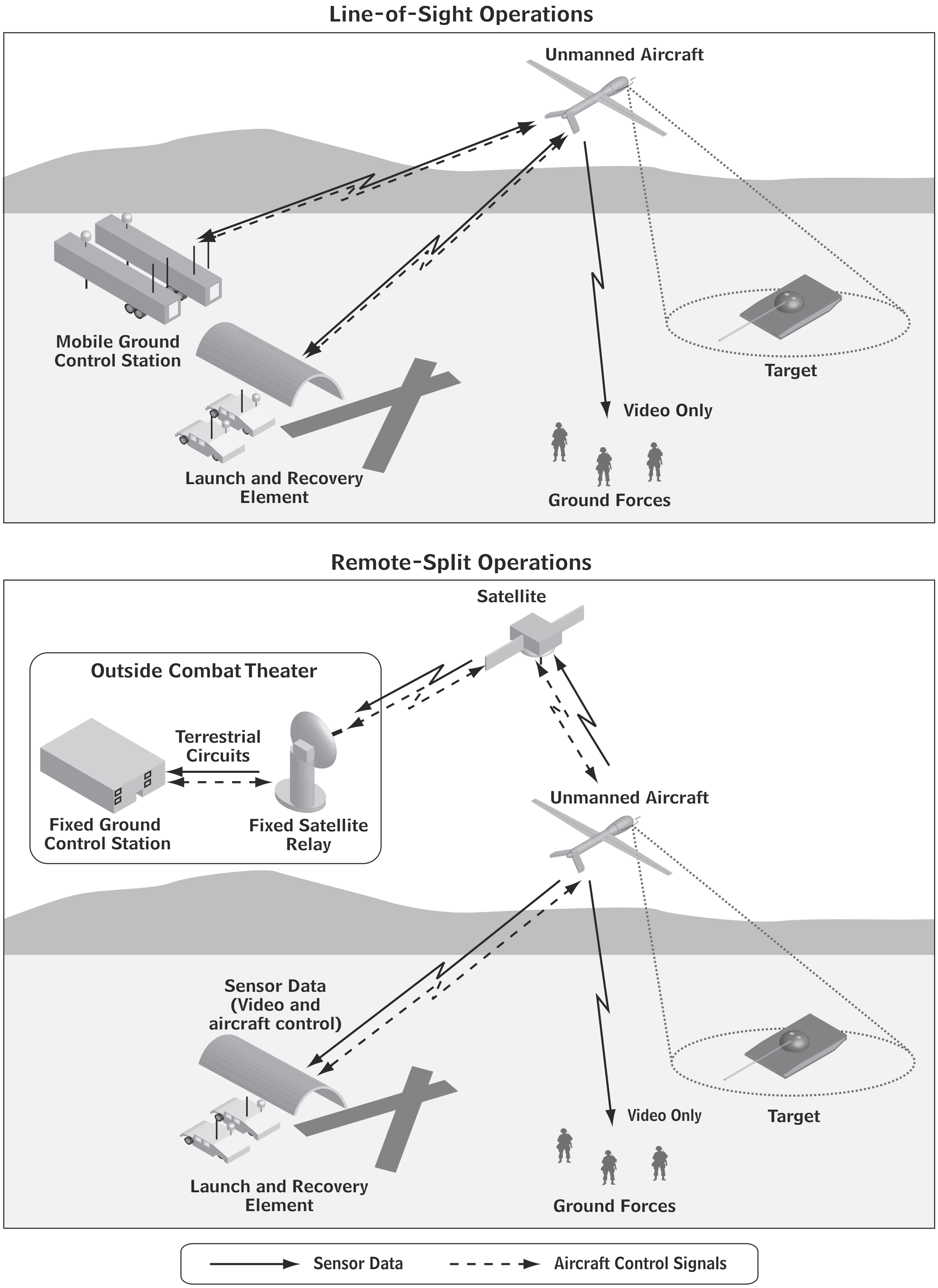
The Army plans to assign 12 Grey Eagles to up to 10 of its combat divisions and to retain additional sets for special operations forces and training; the Grey Eagles would operate from locations in the combat theater, usually using line-of-sight control from their own division.[10] By contrast, the Air Force operates its medium-sized and large unmanned aircraft systems from the continental United States or Europe using remote-split operations. (For a comparison of line-of-sight and remote-split operations, see Figure 2-1.) The Air Force uses line of sight only during takeoff and landing, the points at which controllers in the combat theater operate the aircraft. The

9. The most recent plan, in 2009, was to buy five systems (20 Firescout helicopters) for each of the 73 brigades in the Army as a whole (active plus National Guard), for a total of 1,460 aircraft. However, another plan in some Army documents stated that the service would purchase eight systems (32 aircraft) for each of the Army brigades, for a total of 2,336 aircraft. See Andrew Feickert, *The Army's Future Combat System: Background and Issues for Congress,* CRS Report for Congress RL32888 (Congressional Research Service, August 3, 2009), p. 8.

10. The Grey Eagle system includes a satellite relay for longer-range operations in the combat theater.

Figure 2-1.

Methods of Controlling Unmanned Aircraft Systems in a Combat Theater



Source: Congressional Budget Office.

Air Force then transfers control of the aircraft and sensors to operators in the United States using satellite communications links. The need for local Air Force controllers could be reduced further if the Air Force adopted the automatic takeoff and landing system it is currently developing for its unmanned aircraft, but some ground crews would always have to be deployed with the aircraft to service them between missions.

The Army rarely deploys all its divisions at one time, and divisions that are not deployed do not need extensive unmanned aircraft support except for training purposes. A small set of unmanned aircraft employed continuously in a remote-split operation might be able to provide the same amount of support to military units that are deployed as would a larger fleet of unmanned aircraft assigned to all divisions simultaneously, whether the divisions were deployed or not.

This option would use fewer unmanned aircraft systems—and therefore fewer operators and ground-support soldiers—than does the Army's plan. However, the unmanned aircraft could potentially be operated for longer periods under this option because they would remain in the combat theater to support newly deployed units while other units returned home. The reduced set of deployed soldiers providing ground support, who service and maintain the unmanned aircraft systems, would rotate as needed, perhaps on a separate schedule from the soldiers in the rotating combat units. The option might require extra sets of ground crews compared with current plans in order to maintain fresh crews deployed in the combat theater, but most of the unmanned aircraft operators and intelligence operators would remain in the United States.

The Army prefers to have its divisional unmanned aircraft systems under the control of the division commander they support. Option 7 would maintain that control relationship: Although the option would not locate the medium-sized unmanned aircraft systems with their division, the systems would remain under that division's operational control.

Under this option, the smaller Army fleet of medium-sized unmanned aircraft would have lower payload-duration at all ranges compared with the 2012 plan. However, a portion of the smaller fleet of aircraft in this option would be based in the combat theater rather than with each division whether or not the division was deployed, and the option would therefore provide the same capability in the combat theater as the Army's 2012 plan.

Option 8: Conduct Remote-Split Operations with 36 Reapers and 78 Fewer Grey Eagles (Lower Cost)

Option 8 is similar to Option 7 in that the Army would adopt remote-split operations but differs by buying 78 fewer Grey Eagles and adding 36 Reapers. As a result, this option would also yield a fleet of 113 medium-sized unmanned aircraft but with a different composition: 36 Reapers, 29 new Grey Eagles, and the 48 Grey Eagles already purchased (including 24 slightly less capable early versions of Grey Eagles).

As in Option 7, a fleet of that composition would be able to support six divisions on the ground and three additional divisions in special operations or training, and any unused aircraft would be held in reserve. As in Options 4 and 5, this option has the possible disadvantage that the Reaper requires a different type of fuel than the Army's ground vehicles use (jet fuel instead of heavy fuel), but it does use the same fuel as the Army's other aircraft. A Reaper on its transport truck is also less mobile than a Grey Eagle on an Army tactical truck, but that reduced mobility may not be an issue because the aircraft can be remotely based at locations with better road networks.

The reduced set of Reapers and Grey Eagles under Option 8 would cost $1.0 billion less than the Army's 2012 plan. The fleet would have more capability (payload-duration) than Option 7 and the Army's plan after 2015 because it would include Reapers instead of Grey Eagles. In terms of the payload-duration of aircraft provided in the combat theater to deployed forces, Option 8 would have 37 percent to 56 percent more capability in 2020 than under the 2012 plan even though it would have 42 fewer aircraft overall.

Appendix: Missions Conducted by Unmanned Aircraft Systems and Reasons for Using Them

The Department of Defense (DoD) defines an unmanned aerial vehicle as "a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly by itself (autonomously) or be remotely piloted, can be expendable or recoverable at the end of flight, and can carry a lethal or nonlethal payload." DoD further specifies that "ballistic and semi-ballistic missiles, cruise missiles, and artillery projectiles are not considered unmanned aircraft vehicles."[1] The term "unmanned aerial vehicle" is the current official DoD nomenclature that has replaced the previously (but still commonly) used term "remotely piloted vehicle." This Congressional Budget Office study uses the term "unmanned aircraft system" to emphasize the fact that those complex systems include ground stations and other components besides the aircraft itself.

Such unmanned systems can undertake various missions, although the analysis in this study focuses primarily on capabilities for reconnaissance and light attack missions. Because they are unmanned, the aircraft can sometimes undertake new types of missions, reduce the risks of traditional missions, and potentially lower costs relative to manned missions. The types of missions a system will perform shape the requirements for endurance, speed, altitude, and payload—all of which affect the system's cost.

1. Department of Defense, *DoD Dictionary of Military and Associated Terms,* Joint Publication 1-02 (November 8, 2010, as amended through January 31, 2011), www.dtic.mil/doctrine/dod_dictionary/.

Although unmanned aircraft systems do not carry a person on board, in most cases they are piloted and usually need personnel at a ground station to operate the aircraft and the systems, such as sensors, that the aircraft carries. Current policy requires a human operator to fire weapons carried on unmanned aircraft. Ground operators rely on communications systems to send control commands to the aircraft and to receive flight and sensor data from it. The communications links can require a significant amount of data, the ability to transfer it rapidly (bandwidth), or both—especially for full-motion video and broad-spectrum signal intelligence missions (in which the system monitors enemy signals)—potentially complicating or limiting operations.

For long-distance missions in which the unmanned aircraft are beyond the controllers' line of sight, intermediate communications relays are necessary, usually in the form of satellites. Operations are not always possible where those satellite links do not exist: Some aircraft intended for use close to the ground station are not equipped for satellite communications, and the line-of-sight limitations of their communications system confine them to operating over smaller areas. In addition, the time lag associated with lengthy communications links usually results in a corresponding lag between a controller's input and the aircraft's response. Such time lags can be problematic for missions, such as air-to-air combat, that may require near-instantaneous reaction time on the part of a remote operator.

Types of Missions

The analysis in this study focuses on the capabilities of unmanned aircraft systems for reconnaissance and light attack missions. The systems can also be used in a wide variety of other missions. The intended missions have critical implications for the systems' complexity and cost.

Reconnaissance

Most unmanned aircraft systems perform reconnaissance missions, using sensors to detect and observe objects on land or sea or to intercept and analyze electronic emissions from ground, sea, or air sources. Although the aircraft component of an unmanned aircraft reconnaissance system is important, the sensors and communications equipment are equally vital and can dictate the system's overall performance. Sensors used on unmanned aircraft must balance the need for high resolution or sensitivity with the demands for the smallest possible system that will fit into the available aircraft and not add too much weight to the payload.

The performance of an unmanned aircraft system depends on the combination of the altitude at which it flies and the resolution and sensitivity of its sensors. In general, aircraft that fly at higher altitudes require larger sensors with higher resolution and sensitivity. Smaller systems that fly at lower altitudes can use smaller sensors and still be effective.

A subset of reconnaissance, force protection, is a form of sentry duty that may be performed by an unmanned aircraft system. Small, low-altitude systems usually perform that mission, although sometimes a medium-sized system is employed.

Light Attack

Unmanned aircraft systems that carry weapons—called multipurpose systems by the Air Force—have proved to be effective in attacking ground targets. They can be configured to carry fewer or more weapons depending on their mission; the weight of the weapons payload affects the aircraft's endurance (that is, how long it can stay in the air). In an armed reconnaissance mission, an unmanned aircraft carries a few weapons in case it needs to strike an unpredictable target, but the emphasis is on reconnaissance and endurance. Conversely, in an attack mission, an unmanned reconnaissance aircraft carries a full load of weapons, which reduces its endurance but enables it to destroy a particular target.

Electronic Warfare

Unmanned aircraft can be extremely useful in electronic warfare, especially when acting as airborne communications relays and when gathering signal intelligence. They may also be able to function as airborne jammers and electronic decoys. Those missions are an important part of the overall intelligence-gathering effort.

By virtue of the high altitude at which they fly and their long endurance, unmanned aircraft systems can be effective communications relays. An airborne unmanned aircraft with proper equipment can extend the range of communications for tactical systems.[2] The extended communications range is especially useful when military units using low-power portable tactical radios operate over a widely dispersed area, as is typical in counterinsurgency warfare.

Gathering information by listening to enemy radios and monitoring enemy radars is an important mission in modern combat operations, including counterinsurgency.[3] Insurgent fighters use not only mobile and satellite phones for communication but also sophisticated military radios. Intercepting their communications and analyzing the content is therefore essential to locating them.[4] Unmanned aircraft systems can be very useful in such intelligence-gathering missions because the high altitude at which they fly and the length of time they can stay in one place makes it possible to intercept most signals from a very long range. However, some electronic signals are too weak to reach an aircraft flying at a high altitude; intercepting weaker signals requires a receiver flying at a lower altitude that can operate closer to the signal's source. Because of those technological limitations, it is impossible to design a single solution for all of the military's signal intelligence missions.

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2. For example, the Army's Shadow unmanned aircraft system can use a Harris Falcon III radio to relay both tactical Single Channel Ground and Airborne Radio System (SINCGARS) signals and ultrahigh frequency signals to a distance of 95 miles (82 nautical miles). See Joris Janssen, "Harris Radio on UAV Provides Aerial Comms Relay for U.S. Army," *Aviation Week and Space Technology* (blog entry, February 15, 2008).

3. Department of the Army, *Counterinsurgency*, Field Manual 3-24 (December 15, 2006), Appendix E.

4. Usman Ansari, "Pakistan Puts UAVs at Center of Technology Effort," *Defense News*, November 10, 2008, www.defense-news.com/story.php?i=3811950.

Other Missions

Unmanned aircraft systems have the potential to perform a number of other missions normally associated with manned aircraft, such as search and rescue; mapping; bomb detection and destruction; firefighting; reconnaissance for nuclear, chemical, or biological weapons of mass destruction; support of special operations; marine interdiction (preventing ships from entering a sea area); emplacement of obstacles, such as mines; and psychological warfare.

Impact of Missions on System Requirements

For missions that require operating from an airbase at a greater distance from the target location or remaining on station for a greater length of time, longer endurance is needed. Missions that may involve rapid shifts of location benefit from higher speeds, which allow aircraft to spend less time in transit from their airbase to a surveillance orbit, or from one orbit to another.

Some missions are best accomplished with a greater field of view from a given location, and flying at higher altitudes can provide that capability. For example, the maximum line of sight from an aircraft flying at 60,000 feet to a target at sea level is nearly 500 kilometers (km), meaning that objects on the ground within that radius would be potentially in view of the aircraft's sensors. The corresponding maximum line of sight for an aircraft flying at 30,000 feet would be about 350 km. Greater line of sight offers the potential to view a larger area from a given location, which can be particularly important if the unmanned aircraft is looking into areas that lie within restricted airspace (across international borders, for example).

Operating at a higher altitude and greater range requires a larger payload to carry more-sophisticated but heavier sensors, because smaller, lighter sensors have a limited ability to gather detailed information at such long ranges. The more-capable sensors have to accommodate larger, higher-resolution cameras, for example, or larger antenna arrays for detecting electronic emissions; the sensors are therefore heavier and require more power to run. Meeting the size, weight, and power demands of more-capable sensors requires larger (and more expensive) aircraft.

Reasons for Using Unmanned Systems

For many missions, the complications inherent in operating an aircraft without a pilot (in particular, the need for ground stations and the transmission of large amounts of data via satellite) are worth the effort. However, the advantages—enabling new missions by overcoming physical constraints, reducing risks to pilots, and lowering the cost of aircraft—are also accompanied by disadvantages.

Enabling New Missions

An aircraft's performance is often constrained by the physical limits of the human body. In aerial combat, for example, high-g maneuvers—which subject the aircraft and pilot to accelerations many times the force of gravity—might be necessary when engaging with an enemy fighter or trying to avoid enemy fire from the ground. The greater maneuverability that could be included in the design of an unmanned aircraft might be useful in some circumstances. Consequently, extreme maneuverability is a characteristic that may be incorporated into future generations of unmanned strike aircraft or unmanned fighters.[5]

Most of today's larger unmanned aircraft systems (and those planned for the future) take advantage of the absence of a human crew to accomplish longer and more-dangerous missions. Although aerial refueling can extend the flight range of a manned aircraft, the length of time the aircraft can be kept in the air is primarily constrained by the endurance of its crew. The Air Force estimates a limit of about 12 hours for the pilot of single-seat aircraft (such as a fighter or a U-2 reconnaissance aircraft). Longer missions are possible if multiple crew members are on board. For example, B-2 strategic bombers flew round-trip missions of greater than 30 hours from Whiteman Air Force Base in Missouri to strike targets in Kosovo in the 1990s and flew similar missions to Iraq in 2003 and to Libya in 2011. To accomplish those missions, a third pilot accompanied the two primary crew members to relieve them and prevent fatigue. Having accommodations for extra crew members requires a much larger (and thus more expensive) aircraft than the mission might otherwise need. The Air Force estimates that even when crews are rotated, 40 hours is the longest a manned

5. Some proponents think that unmanned aircraft will eventually be able to engage in full-fledged air-to-air combat. Although it is unlikely that such combat could be undertaken by unmanned systems in the near future, a stealthy unmanned fighter equipped with air-to-air radar and weapons could carry out simpler missions such as detecting and shooting at other aircraft. Therefore, unmanned strike aircraft might eventually be equipped with a limited air-to-air capability for self-defense.

mission could last. Such long flights also expend the pilots' allowance for flight hours per day and month and so raise costs for manpower.[6]

The nature and duration of missions carried out by reconnaissance aircraft have changed over time. In the past, the most common missions—those that involved flying to a target, photographing it, and returning to base—usually required between 12 and 40 hours of flight time with aerial refueling to reach any location on Earth. In 2011 and beyond, however, the armed services expect a greater emphasis on keeping aircraft continuously on surveillance over areas of interest. Much of that emphasis stems from recent counterinsurgency operations in Iraq and Afghanistan, where aircraft conducting surveillance missions have proved to be effective against "fleeting" targets that appear unexpectedly and then quickly return to hiding.[7] Those "persistence" missions give commanders not only an almost real-time view of areas of interest but also the ability to rapidly target a specific location for observation or attack because an aircraft is always in the vicinity. In many cases, even a slow aircraft such as the Predator, if it is orbiting nearby, can provide a quicker response than a faster manned aircraft that might need to be called from some distance away.

Of course, manned aircraft can be (and have been) used for that type of persistent reconnaissance or strike coverage. Large aircraft such as the E-3 Airborne Warning and Control System (AWACS) and the E-8 Joint Surveillance and Target Attack Radar System (JSTARS), which have the potential to rotate crews and refuel in flight, can remain aloft for extended periods. For example, JSTARS missions over Iraq have typically lasted between 10 and 20 hours. The military, however, has only a small number of those aircraft—they are costly to build and operate, they are vulnerable to antiaircraft weapons and therefore can operate only in secure airspace, and they do not carry weapons. Although they also provide surveillance of large areas of sky or ground, their sensors have typically not been appropriate for the type of surveillance and targeting needed in counterinsurgency operations, which focus on individuals or small groups.

Fighter aircraft have been used when necessary to provide persistent coverage (for both reconnaissance and attack missions) in areas where threats from air defenses are or might be present and where multiple surveillance orbits must be flown to ensure that aircraft are close enough to rapidly reach any location where they might be needed. Because fighters fly faster and can reach targets more quickly, they can operate in more widely separated areas than can slower aircraft, reducing the number of orbits needed. But fighters also have shorter endurance than current unmanned aircraft, and flying the smaller number of orbits might require a larger number of fighters.[8] Other disadvantages of using fighter aircraft in persistent orbits include the need for extensive tanker support for aerial refueling, the rapid expenditure of aircrews' allowed flying hours, and the draw of fighter resources away from other missions.[9]

Reducing Risks

Unmanned aircraft are useful in situations in which the likelihood is high that the aircraft could be lost to enemy fire or in which the diplomatic consequences of an aircrew's being captured would be sufficiently serious to deter the use of manned aircraft even if the chance of loss was low. Suppressing enemy air defenses is a particularly hazardous mission; aircraft assigned to that mission must seek out and engage enemy surface-to-air missiles or air-defense artillery sites and suppress or destroy them. Although some aircraft might be destroyed in a successful suppression campaign, overall aircraft losses would be lower because the aircraft that followed would be able to

6. Department of Defense, *Unmanned Aircraft Systems Roadmap, 2005–2030* (August 4, 2005), p. 2.

7. In the past, orbiting missions could be accomplished only in the absence of effective enemy air defenses. As a result, they were not emphasized in planning for conventional force-on-force conflicts, which were DoD's primary focus. In the current counterinsurgencies in Iraq, Afghanistan, and Pakistan, there are no effective enemy air defenses, and even slow unmanned aircraft can fly with relatively little risk of being shot down.

8. The number of aircraft needed to maintain a continuous orbit for 24 hours a day depends on many factors, including the distance of the orbit from the airbase, transit speed, endurance, and maintenance time between missions. In addition, weapons payload might be a factor if targets arise frequently enough to exhaust an aircraft's store of weapons before it reaches the limit of its endurance.

9. In addition to limits on the maximum duration of a sortie (that is, a mission or attack by a single plane), medically established limits are also imposed on the total number of hours aircrews can fly over any 30- or 90-day period. A crew's performance has been shown to degrade with too much flying, although the limits can be relaxed or waived if necessary during wartime. Experience with current counterinsurgency operations suggests that operators of unmanned aircraft systems might require similar limits.

attack their assigned targets with increased chances of survival. Reflecting the importance placed on those missions, the air campaigns over Bosnia and Kosovo and the Northern/Southern Watch operations in Iraq saw nearly one-quarter of air-combat missions dedicated to suppressing air defenses.[10] The services are exploring unmanned aircraft systems that would have the necessary speed, stealth characteristics, targeting systems, and weapons to successfully attack modern air-defense systems.

Reconnaissance missions in areas that have capable and active air defenses can also be among the most hazardous. For those missions, aircraft—in many cases flying unarmed and alone—operate over enemy territory to collect information from photographs, radar images, or electronic signals about enemy activity. In the Vietnam and Arab–Israeli Wars, aircraft and aircrews on reconnaissance missions suffered the highest loss rates.[11]

Even in peacetime, manned aircraft conducting reconnaissance missions have been shot down or otherwise lost. The loss or capture of a pilot (and other aircrew members) in those circumstances can have profound diplomatic implications beyond the single reconnaissance mission. For example, the downing of a U-2 aircraft in 1960 and the forced landing of an EP-3E Aries II electronic surveillance aircraft in China in 2001 illustrate the political costs of losing manned aircraft on reconnaissance missions. In contrast to the diplomatic crises associated with those events, the losses of seven unmanned Firebee and D-21 aircraft over China during the 1970s and of numerous Predators over Iraq, Afghanistan, and Pakistan in recent years were almost unnoticed beyond the countries' militaries; similarly, the shooting down of an Iranian Ababil 3 unmanned aircraft by the United States over Baghdad in February 2009 was not a major diplomatic event.[12]

A risk associated with any aircraft is the unintended civilian casualties that sometimes accompany airstrikes. Unmanned airstrikes, by the nature of their centralized control, tend to receive closer scrutiny by the military chain of command before a target is engaged than do strikes by traditional manned aircraft or missiles. That higher level of oversight should reduce unintended casualties, but it may not eliminate the problem. Many analysts believe that using unmanned aircraft systems in counterinsurgency operations to strike targets without first cross-checking and coordinating target data with either the host country or other information sources can lead to civilian casualties. Some observers state that unmanned aircraft systems cannot be expected to conduct strike missions without appropriate ground-based intelligence support, although the problem also applies to manned aircraft strikes.[13]

Potentially Lowering Costs

Unmanned aircraft systems are usually less expensive than manned aircraft. Initial concepts envisioned very low-cost, essentially expendable aircraft. As of 2011, however, whether substantially lower costs will be realized is unclear. Although a pilot may not be on board, the advanced sensors carried by unmanned aircraft systems are very expensive and cannot be viewed as expendable. In addition, the design of unmanned aircraft systems must be safe and reliable enough not to pose an unacceptable danger to forces operating with them. For example, an unmanned aircraft built to operate from an aircraft carrier must be able to land no less safely and reliably than its manned counterpart.

Moreover, excessively high losses of aircraft can negate cost advantages by requiring the services to purchase large numbers of replacement aircraft. Early unmanned aircraft systems were plagued by high attrition rates because of problems with the reliability of engines and difficulties with remotely piloted takeoffs and landings in which operators lacked the "seat-of-the-pants" feel available to a pilot in an aircraft. The MQ-1 Predator, which has a single engine and few redundant avionics systems, had an accident rate of 28 mishaps per 100,000 flight hours during its early deployment—more than triple the rate of 8.2 per 100,000 flight hours for general aviation single-piston engine aircraft. The Air Force has been able to reduce the accident rate on the Predator to 7.6 mishaps per 100,000 flight hours by providing more training to

10. Christopher Bolkcom, *Military Suppression of Enemy Air Defenses (SEAD): Assessing Future Needs,* CRS Report for Congress RS21141 (Congressional Research Service, May 11, 2005).

11. Department of Defense, *Unmanned Aircraft Systems Roadmap, 2005–2030*, p. 2.

12. Rod Nordland and Alissa Rubin, "U.S. Says It Shot Down an Iranian Drone Over Iraq," *New York Times*, March 17, 2009, p. A10 (New York edition).

13. Jane Perlez, "Pakistan Rehearses Its Two-Step on Airstrikes," *New York Times*, April 16, 2009, p. A10 (New York edition).

operators and by improving data links and other aspects of reliability.[14] With the introduction of the larger and more capable MQ-9 Reaper, the Air Force has adopted a more conventional approach and now includes reliability systems such as triple-redundant flight controls and back-up communications links, but such systems increase the cost of the aircraft. New technologies, such as an automated landing capability, offer the potential to further reduce losses due to accidents.

Unmanned aircraft systems operating in civilian airspace also need high levels of reliability to ensure the safety of people on the ground and in other aircraft. Aircraft developers are therefore adding expensive systems to unmanned aircraft—such as sense-and-avoid cameras, transponders, and improvements in airworthiness and reliability—to meet the Federal Aviation Administration's requirements for certification.

The support systems required for unmanned aircraft, such as ground stations, add costs that are not associated with manned aircraft. For example, in the Air Force's 2010 budget request, funding for ground stations and communications systems for the Reaper was about 10 percent of the funding requested for the aircraft themselves. Of course, ground stations should not experience much, if any, attrition. Consequently, average expenditures on ground stations per aircraft purchased will probably decrease once DoD has reached its desired inventory. Future unmanned aircraft could also be designed to operate with existing (perhaps slightly modified) ground stations.

14. Eric Mathewson, Colonel, U.S. Air Force, "MQ-1B Predator and MQ-9 Reaper" (program briefing for Congressional Budget Office staff, June 2009).

Part of the difficulty in comparing the cost of unmanned aircraft systems with their manned equivalents is identifying a manned equivalent. The absence of accommodations for a pilot is not the only reason aircraft like the Reaper are about one-sixth the cost of the F-16. The F-16 is many times faster, is much more maneuverable, and can carry much heavier payloads than the Reaper. Consequently, although the Reaper might be more efficient than the fighter in an orbiting role in support of ground troops when only small numbers of weapons are needed, it cannot accomplish most of the other missions required of fighters (notably air-to-air combat).

The cost of manned combat aircraft in 2011 is in part the product of several decades of incorporating multiple capabilities into each aircraft. The intention was to reduce the overall number of aircraft and pilots required, thereby defraying the costs of the new aircraft. Although that logic may have held true for conflicts between conventional military forces (in which an aircraft could be confronted with a capable adversary at any time), some aspects of the new counterinsurgency operations may be more efficiently accomplished by more-specialized unmanned aircraft.

Having specialized unmanned aircraft systems can also reduce costs. For example, those aircraft can substitute for expensive, high-performance aircraft, such as fighters, in orbiting missions that do not require great speed or maneuverability. The services have expressed concern about the increased wear and tear that operations in Iraq and Afghanistan have placed on fighter (and other) aircraft. In addition to having lower operating costs per flight hour, specialized unmanned aircraft systems can reduce flight hours for fighter aircraft and thereby decrease replacement costs over time.

Glossary

acquisition cost: the cost of procuring air vehicles, sensors, and ground stations, plus the cost for research, development, test, and evaluation.

duration: the amount of time an aircraft can be kept on orbit.

endurance: the total amount of time an unmanned aircraft can stay in the air.

ground station: the location from which the flight of an unmanned aircraft is controlled and from which the data it collects is analyzed and displayed.

line of sight: an unobstructed optical or electromagnetic path between a sensor and a target.

on station: on orbit.

orbit: an unmanned aircraft patrol over a geographically or electronically defined location. Most unmanned aircraft rely on forward motion for lift and thus must circle to stay over a particular area.

payload-duration: the weight (payload) that an aircraft could carry to a location, multiplied by the amount of time the aircraft could stay there on orbit (duration).

payload: the amount of weight (weapons, sensors, and so on) that an unmanned aircraft can carry.

range: the distance from the originating airbase to the orbit location, expressed in nautical miles.

remote-split operations: operations in which deployed divisions would have operational control of aircraft from a central fleet rather than be equipped with their own aircraft.

transit time: the time it takes an aircraft to travel from the airbase to the orbit location and back.

unmanned aircraft: a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles.

unmanned aircraft system (UAS): an unmanned aircraft plus the necessary equipment, communications network, ground stations, personnel, and infrastructure to control it.