Embracing Autonomy

The Key to Developing a New Generation of Remotely Piloted Aircraft for Operations in Contested Air Environments

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On 22 March 2011, two US Air Force pilots ejected from an F-15E Strike Eagle that crashed in Libya, beginning a complex rescue mission with life-or-death consequences. The US Marine Corps launched a search-and-rescue package of two V-22 Ospreys, two CH-53E Super Stallion helicopters, and two AV/8B Harrier jets. An Osprey rescued one of the pilots after the Harriers dropped two bombs to keep locals away. Rebel forces took in the other pilot, eventually turning him over to US forces.[1]

A few months later, on 21 June 2011, a heavy antiaircraft weapon shot down a US Navy remotely piloted helicopter over Libya, its remains scattered around a stronghold loyal to Mu‘ammar Gadhafi—the object of its surveillance.[2] This time, rather than launching a complex search-and-rescue mission, Navy officials simply expressed disappointment in losing the Fire Scout's full motion video feeds. "The loss of aircrews would have been much worse if that had happened, but operationally it did impact us," said Capt Patrick Smith, Navy and US Marine Corps program manager for Multi-mission Tactical Unmanned Air Systems. "We always want our air vehicles to come back to us. The downside of it is the loss of capability. . . . It does impact what the war fighters have available in their magazine to continue operations."[3]

The contrast between these two incidents highlights the political and military advantage of remotely piloted aircraft (RPA) and the critical need for their evolution if they are to continue to provide an operational edge in an increasingly complex air environment. The Pentagon must fully embrace the concept of autonomy, thus allowing RPAs to perform the more complicated tasks expected of aircraft in the coming decades. Failing to do so would represent a missed opportunity to pursue a new generation of RPAs that could save American lives; potentially outperform their manned counterparts in contested airspace; and multiply political options, giving US leaders the flexibility to choose between a manned or remotely piloted system for surveillance and strike missions, depending on the political and security circumstances.

Today we risk losing the advantages offered by autonomous RPAs. The *United States Air Force Unmanned Aircraft Systems Flight Plan, 2009–2047* predicts that autonomy will compress decision cycles in combat to "micro or nano seconds" by perceiving a situation and acting independently with limited or little human input.[4] Quick decision making could allow autonomous RPAs a decisive operational advantage in fast-moving, information-saturated (i.e., complex) air environments. For these RPAs to advance to this point, however, the flight plan suggests that they must attain "a level of trust approaching that of humans charged with executing missions"—trust built incrementally over time.[5]

Today, RPAs are far from inspiring such confidence. Gen Norton Schwartz, Air Force chief of staff, has plainly stated that autonomous systems are not ready to support development of a next-generation remotely piloted bomber.[6] Lt Gen David Deptula, USAF, retired, who released the flight plan in 2009, questioned whether RPAs would ever garner sufficient confidence from US leadership to perform the most high-threat, politically sensitive missions: "Technologically, we can take [RPA autonomy] pretty far, but it won't be technology that is the limiting factor; it will be policy. . . . For example, will US leadership accede to sending off an aircraft with 12 to 20 2,000-pound bombs and have it independently target and deliver them? How about with nuclear weapons? I don't think so."[7] The international community and the American public have also indicated a distrust of RPA autonomy. The National Air and Space Museum in Washington, DC, was closed on 8 October of this year when protesters tried to enter the building to object to an RPA exhibit.[8] A United Nations report of May 2010 concluded that RPAs promote a "Playstation" mentality toward killing.[9] Questions about trusting remotely piloted technology also raise a broader issue about the direction in which RPAs may take the Air Force. Embracing a new generation of highly autonomous, remotely piloted systems may eventually require a sweeping reinterpretation of what it means to be a pilot or even an Air Force officer—a topic worthy of further exploration.

Though difficult, building stakeholders' confidence in autonomy is essential since, if RPAs are to remain a highly effective option, they will need to act more independently. This article calls on the Pentagon to take the lead in building trust in autonomy through sustained and systematic investment in the development and testing of new, autonomous systems for RPAs. It begins by describing why these aircraft will need more autonomy to operate in the emerging security context. The article then devotes considerable attention to more fully defining the concept of autonomy, arguing that a fuller understanding of the latter as a matter of degree—rather than an all-or-nothing proposition—can mitigate some doubts about independent RPA operations. It also contends that because today's RPAs have not been sufficiently tested in dynamic air environments to determine their true limits, the Pentagon should aggressively fund the development of new verification and validation procedures to build the trust and confidence required to ensure continuation of the momentum for development of autonomous technology. In particular, the article notes that the Air Force's plan to build a new long-range bomber offers a unique opportunity to develop and test autonomous decision aids that can "dial in" various levels of autonomy, depending on the mission.

Threat Assessment: A More Complex Air Environment

The General Atomics Aeronautical Systems, Incorporated (GA-ASI) MQ-1 Predator became the world's first weaponized RPA after live-fire tests in 2001. Since then, both the Predator and the larger, more heavily armed GA-ASI MQ-9 Reaper drones have conducted strike missions. The Central Intelligence Agency (CIA) also uses the Predator to carry out covert or "black" operations against suspected al-Qaeda targets. RPAs conducted 117 strikes on targets in Pakistan in 2010, up from just 53 in 2009.[10] Though capable of carrying arms, these drones spend most of their time conducting intelligence, surveillance, and reconnaissance missions; detecting targets and alerting other strike aircraft to their presence; or identifying threats such as improvised explosive devices to ground forces. These so-called hunter-killer RPAs, with their long-loiter capability, have proven well suited to conducting low-level policing actions in Afghanistan and Iraq.[11]

However, today's RPAs would struggle in enemy-controlled airspace due to a lack of survivability and insufficient capacity to respond to contingencies such as incoming threats and changes in the weather. Operational experience suggests as much: US and North Atlantic Treaty Organization (NATO) allies lost at least 15 RPAs in Kosovo to heat-seeking missiles and fire from door gunners in helicopters flying alongside them.[12] Some of the aircraft lost in the conflict were early models of the Predator.[13] Kosovo represents the last time that allied RPAs faced a highly contested air environment, and the nature of armed RPA missions in Iraq and Afghanistan has not presented a pressing need to adapt to new threats.

To remain integral to US air operations in the future, RPAs must evolve to operate in more dangerous air environments. Indeed, the battlespace will not get any easier for the current generation of RPAs. Without venturing into the perilous business of predicting the nature of future conflicts, one may still make some inferences about the changing character of the global air environment (inferences essential to force planning). The United Kingdom's (UK) Ministry of Defence paints a daunting picture of "congested, cluttered, contested, connected and constrained" airspace.[14] A brief assessment of this environment highlights why the current generation of RPAs needs to evolve.

Most significantly, RPAs will have to operate in more contested airspace. As the current conflicts wind down, the US military is shifting its planning focus from operations in benign airspace to those in contested air environments on a global scale—a change embodied in the Air Force's agreement with the Navy to develop an operational plan known as AirSea Battle. This plan stems from growing US concern that rising powers with access to emerging weapon systems—such as China, Iran, and North Korea—may seek to deny US access to air, sea, and space.[15] Already widely available and posing a serious threat to American aircraft, "double digit" surface-to-air missiles (SAM) such as Russia's SA-10 and SA-20 boast greater engagement range and speeds as well as higher probability of kill than older SAM systems.[16] NATO was so concerned about these systems that it decided against sending Airborne Warning and Control System aircraft into Georgia during the conflict with Russia in 2008 due to the latter's deployment of the SA-20.[17] China possesses both SA-10 and SA-20 missiles.[18] Other SA-20 customers may include Iran, Syria, Libya, and Algeria, among others.[19] It also seems plausible that the recent Fire Scout shoot-down involved a SAM, based on the Navy's description of events. Although still in the developmental stages, next-generation air-to-air threats also represent an emerging challenge. China recently unveiled its new J-20 stealth fighter, and India and Russia have partnered to build a "fifth generation" fighter known as PAK-FA. These fighter development programs aim to incorporate stealth technology and sophisticated radars that allow a pilot to target an adversary beyond visual range (BVR), killing the enemy before the enemy sees him or her. Today America has the corner on the BVR market, but research and development under way in China and Russia could change that status. Lastly, short- and medium-range missiles pose a threat to US overseas bases that station short-range aircraft and provide them with landing and refueling facilities.

All of these perils challenge American air dominance. During a speech at the US Air Force Academy in March of this year, former secretary of defense Robert Gates confirmed that the US military no longer can take for granted ownership of the skies in future conflicts: "It would be irresponsible to assume that a future adversary—given enough time, money, and technological acumen—will not one day be able to directly threaten U.S. command of the skies."[20] General Schwartz confirmed the requirement to field new aircraft that can operate in contested airspace in 2010 when he said that the Air Force must balance its budget between assets to fight today's wars "while recognizing that proliferation of anti-access and area-denial capabilities will increasingly challenge America's ability to penetrate contested airspace."[21]

Additionally, as mentioned above, the UK Ministry of Defence warned that the battlespace will become more congested, cluttered, connected, and constrained. Congested airspace is already a major issue in terms of deconflicting the flight paths of manned and remotely piloted platforms, not only in the continental United States but also in combat zones—witness the destruction of an Army RQ-7 Shadow in a collision with an Air Force C-130 over Afghanistan on 15 August 2011.[22] The fact that adversaries hide among civilian populations also clutters the battlespace, presenting a daunting challenge for both manned and remotely piloted aircraft surveillance systems, which will need to sift through large amounts of data to identify targets of interest. Furthermore, the importance of aircraft in establishing communications links and situational awareness in the battlespace reflects the air environment's emerging feature of connectedness. RPAs need large amounts of bandwidth for two-way satellite communications, and they cannot operate without links to their operators. Overall, it is clear that today's RPAs are poorly positioned to accommodate these realities of the battlespace. Even if they did already possess the autonomy necessary to overcome these challenges, they would be severely constrained by major legal and ethical concerns regarding their operations in more demanding combat operations, as noted in the report of the UK Ministry of Defence.[23]

Overcoming this fundamental distrust of autonomy is easier said than done. Yet if the Pentagon takes deliberate steps to develop and test new autonomous decision aids, confidence in autonomous RPAs will likely build over time. After carefully testing and allowing autonomous systems to mature, we would find that their use on board RPAs would almost certainly give the United States and its allies a considerable operational advantage. Indeed, a new generation of these aircraft could actually outperform their manned counterparts in the perilous environment described above.

Autonomy: Key to the Evolution of Remotely Piloted Aircraft

Autonomy will be the driving force behind the development of a new generation of RPAs optimized for more complex air environments, and human *distrust* in autonomy will lie at the heart of limitations on the design and deployment of these aircraft. Given the huge role that autonomy will play in determining the extent to which the US military effectively incorporates new RPAs into its inventory, it is essential to define this concept. Doing so will allow for a practical discussion of how autonomous systems could enhance the design of RPAs in a way that addresses serious and legitimate concerns about their operations in the battlespace.

Currently no universally agreed-upon definition of autonomy exists, but a consensus is emerging in the engineering and scientific community that a good starting point involves viewing it as degrees of RPA independence from human control. In 1978 Thomas Sheridan and William Verplank laid the groundwork for describing autonomy in terms of a continuum of human and machine interaction rather than an all-or-nothing concept (see table on the next page).[24] One end of the spectrum represents full manual control with

Table. Levels of automation in man-computer decision making

Automation Level	*Automation Description*
1	The computer offers no assistance: human does the whole job up to the point of turning it over to the computer to implement.
2	The computer helps by determining the options.
3	The computer helps determine options and suggests one, which the human need not follow.
4	The computer selects action, and the human may or may not do it.
5	The computer selects action and implements it if the human approves.
6	The computer selects action, informs the human in plenty of time to stop it.
7	The computer does the whole job and necessarily tells the human what it did.
8	The computer does the whole job and tells the human what it did only if the human explicitly asks.
9	The computer does the whole job and tells the human what it did if it decides he should be told.
10	The computer decides whether or not to do the whole job. If it decides to do the job, it can determine whether or not to tell the human about it.

Source: Adapted from Thomas B. Sheridan and William L. Verplank, *Human and Computer Control of Undersea Teleoperators* (Cambridge, MA: Man-Machine Systems Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology, 1978), table 8.2, pages 8-17 through 8-19.

no computer assistance, and the other represents full machine control with machines doing everything and ignoring human input.

Mark Maybury, the Air Force's chief scientist, put these degrees of autonomy in the context of RPA design, describing four levels of human control: (1) "no autonomy" (i.e., complete manual control of the RPA); (2) "partial automation," with a human "in the loop" manually performing some tasks; (3) "supervisory control," with a human in the loop overseeing or guiding tasks, or selecting among possible alternative actions; and (4) "full autonomy," with no human intervention other than starting or canceling an action.[25]

The scientific community widely acknowledges Sheridan and Verplank's levels of automation as a starting point for describing autonomy in terms of degrees of human control. Viewing autonomy as a continuum frees RPA designers and operators to develop and employ decision aids for these aircraft at varying levels of autonomy on a case-by-case basis, depending upon the RPA's mission.[26] In the context of a next generation of RPAs, the existence of such distinctions invalidates the notion of having to choose only between a manned "manual control" aircraft and a "fully autonomous" RPA.

Although Sheridan and Verplank's definition is useful for understanding that autonomy entails something more than all or nothing, it does not fully flesh out two other very significant dimensions of autonomy: mission complexity and environmental complexity (see figure on the next page). Mission complexity measures an autonomous system's ability to perform various missions and tasks, ranging from those at the lower level (e.g., simple sensors and actuators supporting basic flight control and guidance, such as maintaining altitude) to those at the higher campaign level (e.g., planning or operating multiship RPA actions such as distributed search, tracking, and weapons engagement).[27] Environmental complexity measures an autonomous system's ability to adapt and respond to changes in the environment, such as terrain and climate variations as well as the availability of communications.

The multidimensional definition is important because it conveys the reality that RPAs must do more than operate independently from human control; after all, so can a washing machine.[28] Effective RPA autonomy involves developing decision aids that can work independently, understand the air

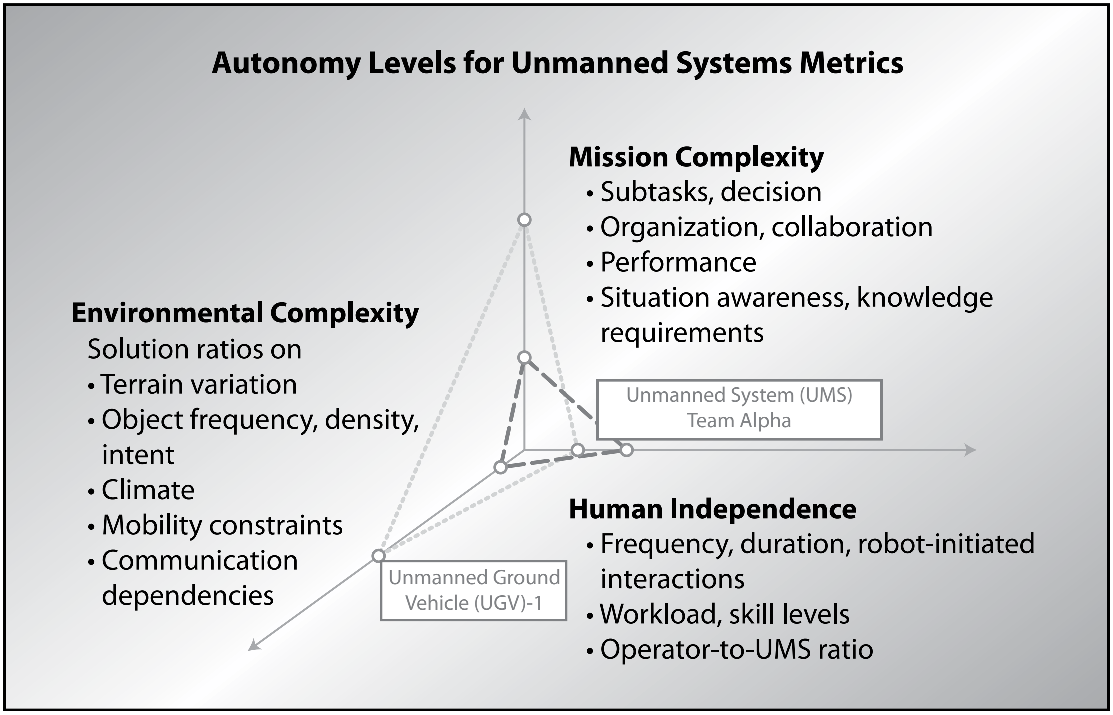

Figure. The three dimensions of autonomy. (Adapted from Hui Min-Hang, "Autonomy Levels for Unmanned Systems [ALFUS]," National Institute of Standards of Technology, ALFUS Working Group, slide 8, accessed 23 July 2011, http://www.nist.gov/el/isd/ks/upload/ALFUS-BG.pdf.)

environment, and operate effectively in that environment with other systems.

This multifaceted view of autonomy lends itself well to describing RPA operations in complex air environments. These platforms may need a high degree of independence from a human to operate quickly in response to changes in such environments, from weather patterns to pop-up threats like a mobile SAM. Mission complexity would also become important if, for example, a swarm of RPAs were operating together to conduct distributed identification, tracking, and prosecution of that SAM.

Further fleshing out the multidimensional definition of autonomy, one can identify specific ways in which decision aids would enable RPA operations. Activity in congested airspace, for example, would benefit from the development of new air- and ground-based collision-avoidance systems. After the recent collision of an RQ-7 with a C-130, mentioned previously, the Army noted that a sense-and-avoid technology now under development could have prevented the mishap.[29]

The Small Sense and Avoid System (SSAAS), under development by the Army in partnership with AAI, a Textron Systems operating unit that makes the Army's RQ-7 Shadow, includes three electro-optical cameras mounted on the nose of the Shadow, designed to collect live video feeds of the airspace. High-speed processors identify moving objects in the video and then send that information to the flight-control system and ground operators. The initial concept of operations for the technology involves the ground operator's receiving data about an object in the Shadow's flight path and then redirecting the

RPA. Over the long term, however, autonomous decision aids will come into play. Ultimately, SSAAS seeks to maneuver the aircraft first and then inform the operator.[30]

RPA activity in cluttered operational scenarios, in which friendly and enemy forces are intermingled, also could benefit from new autonomous decision aids that can improve situational awareness. The Navy, for example, is installing the Telephonics RDR-1700B maritime radar on the Fire Scout, which will allow the RPA to track vessels at a greater standoff range. Able to cue an electro-optical/infrared camera, the radar can track more than one vessel at a time, so Fire Scout operators will need new autonomous decision aids to help determine which target they should single out for further electro-optical/infrared tracking.[31]

Moreover, enhanced RPA autonomy will enable more connectedness—another essential ingredient for operating in complex air environments. The Navy's Unmanned Combat Air System Demonstration program will build on the success of the automated takeoff and landing system installed on the manned F/A-18 Hornet fighter jet to develop an RPA—the X-47B—that can take off and land on a carrier deck.[32] With no pilot in the cockpit, the RPA needs more robust communications links to remain in contact with the carrier throughout the flight envelope, rather than just on approach, so that the aircraft can try to land again if it skips the arresting hook on the carrier deck. Additionally, a new automated messaging system will allow the carrier's air traffic control to send messages to the X-47B about its operations in congested airspace around the carrier.[33] Even though automated messaging will increase connectedness, it is also important to note that other autonomous decision aids will reduce RPAs' requirements for connectedness, removing their tether to vulnerable satellite and Global Positioning System (GPS) data links. (Alternatives to the GPS currently under investigation at the Air Force Institute of Technology include radio beacons as well as man-made and naturally occurring signals of opportunity, such as magnetic fields and vision aiding.)[34]

Lastly—and perhaps most significantly, given the emergence of new air-based threats—autonomy will be essential to the operation of RPAs in contested airspace. In this dynamic environment, autonomy will allow RPA weapons to respond to threats—such as SAMs—quickly and efficiently without waiting for a human operator to make every incremental decision. In one extreme example, autonomous decision aids could enable an electronic jamming system to detect an enemy signal, determine an electronic response, and jam the signal before a human RPA operator has time to react. In the near term, autonomous decision aids could simply identify incoming frequencies and defer a decision on how to respond to the human operator.

All of these innovations in autonomy have the potential to increase decision speed dramatically. According to the Air Force's 2010 science and technology road map, in a fast-changing and contested air environment, autonomous decision making could enable "operational advantages over adversaries who are limited to human planning and decision speeds."[35] RPA autonomy may also provide a key advantage as war becomes "too complex for a human to direct," requiring autonomous decision aids to handle information overload.[36] Retired general James Cartwright, former vice-chairman of the Joint Chiefs of Staff, notes that the "competitive" edge provided by RPAs "is in the cognitive power we can put into those platforms to operate and inter-operate with each other without intervention of a human being."[37] In other words, autonomous RPAs could allow the United States to sort through the complexities of decision making in combat—a process described by military strategist John Boyd as the observe, orient, decide, act loop—more quickly than an opponent, striking before the adversary can respond.

Roadblocks to the Deployment of Autonomous Systems

Given the significant advantages offered by autonomous systems, it seems that, from a purely technological perspective, we should develop and add a new generation of RPAs to the US aircraft inventory. Deployment of a highly capable robotic aircraft fleet holds the promise of meeting or exceeding the Pentagon's requirements for operating in complex air environments, reducing risk to American lives, and creating new options for decision authorities. However, doing so depends upon Pentagon decision makers agreeing on the degree of autonomy needed by new types of RPAs and then deciding on whether they are willing to make the investment necessary to adequately fund research, development, and testing of the appropriate autonomous systems.

As discussed earlier, autonomy is an "adjustable" concept that one can employ to varying degrees, depending upon the role of an aircraft and its mission—a critical point because of the tendency to view autonomy as an all-or-nothing proposition. For example, an influential report on long-range strike from the Center for Strategic and Budgetary Assessments claimed that without either full autonomy or a human making all decisions on the ground, a remotely piloted bomber would be little better than a (reusable) cruise missile.[38] The argument maintains that such a bomber will not exert an operational advantage in contested airspace until it has the "true autonomy" necessary to respond at least as quickly and efficiently as a human. Thus the bomber would need autonomous decision aids at least as capable of the same 360-degree situational awareness and rapid-response time that a pilot brings to the cockpit. By this standard, the bomber must have sensors to understand a dynamic threat situation and highly autonomous systems to make decisions about target cueing and weapons release as quickly as a human could.

However, one cannot say without question whether only "true" autonomy would allow a bomber to operate effectively in such an environment. Although true autonomy may lie beyond the limits of today's technology, remotely piloted bombers capable of highly autonomous operations in some level of contested airspace are certainly within reach.[39] Industry is already prototyping new autonomous decision aids to enable the use of these platforms in such situations. According to Michael Leahy, Common Mission Management Systems program manager at Northrop Grumman, "The ability [of an RPA] to go in, route around threats like ground radars, integrated air defense systems, and other threats, to then recognize those threats and retask itself, has already at some levels been demonstrated and is today in the prototyping stages."[40]

As these decision aids continue to mature, the question of how much trust one should place in remotely piloted systems becomes increasingly urgent. The CIA hesitated to deploy the first armed Predator due to concerns about unproven technology as well as ethical and legal issues.[41] More autonomous RPAs optimized for high-risk environments will fuel similar apprehensions. The possibility that RPAs might have to operate with a mix of manned and remotely piloted platforms raises the issue of fratricide, just as the prospect of a remotely piloted bomber carrying nuclear weapons (in which case nuclear surety and safety requirements would come into play) brings up questions about mission reliability.

To move forward with the development of a new generation of RPAs, decision makers must recognize that one can adjust the degree of their autonomy in accordance with the role and mission and that robust testing can build trust in autonomous decision aids. If they wish to advance beyond prototyping, Pentagon officials have to determine whether they are ready to foster a research and development environment that promotes breakthroughs in remotely piloted systems. In particular, we must bring into play comprehensive computer simulations and live-testing programs to establish trust in the safety and reliability of autonomous RPA operations.

Institutionalized testing procedures will become even more important as innovation allows for more rapid and independent RPA decision making. A report by the UK Ministry of Defence on the future of RPAs predicts that fielding artificially intelligent RPAs—totally independent from human control—

could be anywhere from five to 15 years away and that this capability will likely raise not only ethical but also legal problems with their operational deployment. The report questions whether such an RPA could make targeting decisions based on guiding principles of the Laws of Armed Conflict, such as proportionality and distinction.[42]

Clearly, the deployment of a new generation of more autonomous RPAs depends upon their ability to give the United States a military advantage without risking lives. Without robust testing procedures, such platforms optimized for use in complex battlespaces will likely lose political and financial support to more technologically mature manned aircraft options or "optionally manned" designs. Granted, such options might complete the mission, but they do not offer some of the major advantages of autonomous RPAs.

Requirements of the Long-Range Bomber: The Importance of Innovation in Autonomous Systems

Concerns about the development of autonomous systems are playing out in the Pentagon's decision to build an optionally manned long-range bomber. This design appears to represent a compromise between those who believe that autonomous RPAs are ready to operate in complex air environments and those who do not. Dr. Mark Lewis, former chief scientist of the US Air Force, compared this configuration to "the age of the sail," referring to the nineteenth century practice of putting both steam engines and sails on ships, the sail serving as a backup in case the engine failed.[43]

One the one hand, as mentioned earlier, General Schwartz does not believe that RPA technology has evolved sufficiently to permit effective operations in contested airspace: "Current technology does not allow for the type of fully autonomous and dynamic systems that are required in an opposed and degraded network environment."[44] On the other hand, as recently as the summer of 2011, General Cartwright asserted the readiness of a remotely piloted bomber for operational deployment: " 'Nobody has shown me anything that requires a person in that airplane,' he said. That applies, too, if the future bomber carries out the nuclear mission, he said. 'I don't remember the last time I manned an ICBM or SLBM or a cruise missile, so I'm not sure I understand that logic.' "[45]

An optionally manned design allows the Pentagon to begin to explore the possibilities of more autonomous RPAs without fully committing to their use in contested air environments. In its report, the Center for Strategic and Budgetary Assessments says that an optionally manned bomber will provide "mission flexibility," flying without a crew for long durations in high-threat areas and flying with a crew when pop-up threats, fleeting targets, and nuclear targets demand the presence of humans.[46] Given the need to further develop and test autonomous systems for threatening environments, perhaps this cautious approach makes sense (although one can certainly debate the financial benefits of adopting a hybrid design). That said, an optionally manned design could easily become little more than a political label while in practice the bomber ends up optimized for a pilot in the cockpit and flies most of its missions in a manned configuration. This scenario would represent a major missed opportunity to develop and test autonomous decision aids that will increase the safety and effectiveness of remotely piloted systems.

A closer examination of the benefits of a remotely piloted bomber—equipped with sufficient autonomous decision aids—demonstrates the importance of sustaining momentum for the development and testing of highly autonomous RPAs. Pentagon officials have described requirements only in general terms: a "long-range, nuclear-capable penetrating bomber" that will "have the option of being piloted remotely."[47] That said, one can still identify some broad requirements for the bomber, based on the Pentagon's AirSea Battle operational scenario and the UK Ministry of Defence's analysis of increasingly complex air environments.

Given these assumptions, the bomber likely will need significant capability in at least four areas: range and persistence, survivability, independence of action, and affordability. An analysis of these attributes indicates that, when the technology is ready, a highly autonomous, remotely piloted bomber could deliver at least the same level of capability as—if not more than—a manned version.

In range and persistence—perhaps the most critical of all the requirements—one finds the biggest advantage that RPAs have over manned platforms.[48] Because US military bases overseas face threats from ballistic missiles, the new bomber will have to fly great distances from locations in the continental United States. The absence of human limitations on flight time (such as the need to eat, sleep, and go to the bathroom) increases the range of a remotely piloted system. Innovations in autonomous aerial refueling also create the possibility of further extending those ranges.[49]

Once the bomber reaches the area of operations, persistence becomes paramount. In 2010 General Schwartz said that long-range strike assets must be able to "gain access to, and then loiter in, potentially denied or contested airspace, in order to find, fix and track high value targets."[50] A remotely piloted bomber could loiter for extended periods of time to identify targets, possibly retask dynamically to hit emerging targets, and conduct battle damage assessment after an attack. Like a manned bomber, it could also return in the event of a mission cancellation.

The proliferation of new air threats such as double-digit SAMs demands that the new bomber be highly survivable. Obviously the remotely piloted option eliminates any risk to aircrews. Of course, to complete its mission effectively, the aircraft would still need stealth characteristics, the ability to reroute its flight path to avoid SAMs, and self-protection systems. In terms of stealth, a remotely piloted design eliminates the cockpit, thereby making for a smaller aircraft that could have a less-detectable radar cross section.[51] Although some question exists about the degree of reduction in that cross section, an autonomous RPA clearly has the potential to adopt the decision aids necessary to let it reroute around SAMs as well as employ jamming and air-to-air-missiles—and do so more quickly than a human could.

Independence of action would allow the bomber to quickly and responsively employ self-protection and route around threats in hostile airspace. Such independence calls for major—but attainable—advances in autonomy already being demonstrated piecemeal across the aviation industry, as described above. If effectively tested and integrated into a remotely piloted design, autonomous decision aids could enable development of a bomber with "cognitive" capability and decision speed surpassing that of a human. Eventually, autonomous systems could allow independence to the extent that perhaps only one human in the loop could operate several RPAs flying together in a "swarm." Researchers at the Massachusetts Institute of Technology are investigating such swarming concepts today, as are personnel at General Atomics, maker of the MQ-1 Predator and MQ-9 Reaper.[52]

Finally, in these times of fiscal austerity (the Pentagon budget is expected to flatten over the coming decade), keeping costs down becomes an important consideration.[53] A remotely piloted bomber, made smaller by eliminating the cockpit and cabin, could offer an advantage here as well. Most savings, however, would come in the form of reductions in life-cycle costs associated with flight hours since pilots would not need to maintain currency in the bomber, and in expenses associated with sorties and attrition rates, the number of which would decline because of the remotely piloted bomber's greater endurance.

Conclusion

Despite the clear operational advantages of more autonomous RPAs, this article does not insist that the Pentagon develop a totally independent bomber. Rather it urges that we embrace autonomy in RPAs by recognizing the adjustable nature of autonomous decision aids and realizing the importance of investing more time and attention in testing procedures that can build trust in these systems. Development of a remotely piloted bomber offers an excellent opportunity to mitigate any lingering distrust—assuming a sincere commitment to such a viable option—since the process will necessarily involve the evolution and testing of new autonomous decision aids. Furthermore, building an optionally manned bomber could dispel the all-or-nothing view of autonomy and validate its adjustability to the mission set.

We must maintain the momentum for developing and testing autonomous decision aids. By failing to fully embrace advances in autonomy, we miss an opportunity to pursue a new generation of RPAs that could save American lives by taking a pilot out of the cockpit, potentially outperforming manned aircraft, and creating new military options for US leaders. The Pentagon should ensure that the optionally manned bomber has a robust "remotely piloted" development and testing plan. Moreover, the Air Force and other services should take seriously the call to develop new verification and validation procedures for highly autonomous RPAs even though they represent "a major challenge . . . that may require a decade or more to solve."[54] However, bringing attention, time, and funding to this important research area will contribute to the development of an RPA fully capable of performing some of airpower's riskiest, most sensitive missions more effectively than a manned aircraft—backed by the full confidence of military and civilian leaders and the American people. ✪

Notes

1. Luis Martinez et al., "Inside the Rescue Mission: U.S. Air Force Pilots Eject from Malfunctioning F-15E Jet," *ABC News*, 22 March 2011, http://abcnews.go.com/International/us-fighter-jet-crashes-benghazi/story?id=13191505.

2. Sam LaGrone, "AUVSI 2011: Fire Scout Was Shot Down by Ghadaffi Forces, Says NAVAIR," *Jane's Defence Weekly*, 18 August 2011, http://search.janes.com/Search/documentView.do?docId=/content1/janesdata/mags/jni/history/jni2011/jni74578.htm@current&pageSelected=janesNews&keyword=fire%20scout&backPath=http://search.janes.com/Search&Prod_Name=JNI&.

3. Capt Patrick Smith (Navy and US Marine Corps program manager for Multimission Tactical Unmanned Air Systems), telephone interview by the author, 25 August 2011.

4. Headquarters US Air Force, *United States Air Force Unmanned Aircraft Systems Flight Plan, 2009–2047* (Washington, DC: Headquarters US Air Force, 18 May 2009), http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA505168&Location=U2&doc=GetTRDoc.pdf.

5. Ibid., 41.

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