AIR UNIVERSITY
THE INTELLECTUAL AND LEADERSHIP CENTER OF THE AIR FORCE

The Maxwell Papers

Spectrum Management

Key to the Future of Unmanned Aircraft Systems?

Mary E. Griswold
Lieutenant Colonel, USAF

Air War College
Maxwell Paper No. 44

AIR WAR COLLEGE

Please send inquiries or comments to
Editor
The Maxwell Papers
Air War College
325 Chennault Circle, Bldg. 1401
Maxwell AFB AL 36112-6006
Tel: (334) 953-7074
Fax: (334) 953-1988
http://www.au.af.mil/au/awc/awcgate/awc-mxwl.htm

AIR UNIVERSITY
AIR WAR COLLEGE

Spectrum Management

Key to the Future of Unmanned Aircraft Systems?

MARY E. GRISWOLD
Lieutenant Colonel, USAF

Air War College
Maxwell Paper No. 44

Air University Press
Maxwell Air Force Base, Alabama

May 2008

This Maxwell Paper and others in the series are available electronically at the Air University Research Web site http://research.maxwell.af.mil and the AU Press Web site http://aupress.maxwell.af.mil.

Disclaimer

Foreword

Today's military operations depend on a very large number of systems to acquire and process critical information needed by combatant commanders to accomplish their mission. Intelligence, surveillance, and reconnaissance systems often provide a much-needed picture that is vital to decision makers. Requests from commanders for information provided by unmanned aircraft systems (UAS) are growing so fast that they are outpacing system availability. The future of these aircraft is of such importance to military operations that in September 2007, Deputy Secretary of Defense Gordon England directed the establishment of a task force to coordinate UAS issues and determine a way ahead in order to resolve differences between the military services and their approaches to these systems.

While the services continue to debate the advantages of one UAS over another or attempt to determine which service would best be able to manage its future, current operations are affected by the challenges caused by inadequate frequency spectrum and bandwidth availability. The most recent Department of Defense UAS road map (August 2005) lists problem areas highlighted by combat operations, including the lack of communications frequencies. Furthermore, a Defense Science Board report identifies constraints on communication bandwidth as an area needing more attention and new development. As UAS capabilities become even more sought after and as the number of these aircraft increases, something must be done to help ensure that the much-needed capabilities they provide are available to war fighters.

One of the most critical major UAS subsystems, communications, allows information to be passed between the aircraft and its ground elements or to other airborne assets; it also enables a UAS to be guided and controlled from virtually anywhere at any time. Bandwidth is needed to support the systems providing data to control the vehicle in flight, including its launch and recovery, and to send data from the onboard sensors or payload to processing centers. Communications systems are the key to the operations of these aircraft and to the successful accomplishment of their missions. Moreover, the ability to pass needed data between components of the systems depends upon available frequencies and adequate bandwidth to move the data as quickly as possible. Technology promises to offer solutions to a number of these challenges, but it is not the only answer for spectrum and bandwidth availability. Other possible solutions include acquiring additional spectrum resources, making changes to acquisition processes, and developing better management tools and processes capable of helping alleviate current difficulties.

In this paper, Lt Col Mary E. Griswold discusses the basics of the electromagnetic spectrum and UAS operations, pointing out how frequency management and bandwidth availability are key to UAS operations. She illustrates this through examples of difficulties encountered during military operations with spectrum and bandwidth issues. Finally, she notes that solutions to the current challenges are found in the employment of both short- and long-term actions in these areas to improve and optimize the use and availability of spectrum support for UAS operations in the future.

As with all other Maxwell Papers, this study is provided in the spirit of academic freedom and is open to debate and serious discussion of issues. We encourage your response.

STEPHEN J. MILLER
Major General, USAF
Commandant, Air War College

About the Author

Lt Col Mary E. Griswold, USAF, is deputy director of operations, 754th Electronic Systems Group, Maxwell-Gunter AFB, Alabama. A career communications officer, she has commanded at the flight and squadron levels and served in support and staff assignments at the wing, center, major command, and joint levels. Prior to becoming a student at Air War College, Colonel Griswold was the chief, Operations Division, Directorate of Communications, Headquarters Air Combat Command, Langley AFB, Virginia. She earned a bachelor's degree in computer science from Birmingham-Southern College, Birmingham, Alabama, and received her commission through the Reserve Officer Training Corps. She holds master's degrees in business administration and management as well as strategic studies. Colonel Griswold is a 2008 graduate of the Air War College.

Abstract

Can the future of highly technical unmanned aircraft systems (UAS) depend on something as minor as frequencies? The answer is an overwhelming yes, and, by the way, frequencies and spectrum management are not minor players in today's global operations.

The Department of Defense's (DOD) *Unmanned Aircraft Systems (UAS) Roadmap, 2005–2030* (Washington, DC: Office of the Secretary of Defense, 4 August 2005) reported an increased demand from combatant commanders for UAS support, stating that the DOD's challenge is "the rapid and coordinated integration of this technology to support the joint fight" (1). This increased demand could be the logical effect of a February 2004 report by the Defense Science Board recommending that the acquisition and operational fielding of unmanned aerial vehicles be accelerated. Despite promoting their increased fielding and use, both documents are open about deficiencies and challenges.

The road map lists problem areas highlighted by combat operations, including the lack of communications frequencies; furthermore, the Defense Science Board report identifies communication bandwidth constraints as an area needing more attention and new development. As UASes become even more sought after and as their numbers increase, something must be done to help ensure that their much-needed capabilities are available to war fighters when needed. Frequency management and bandwidth availability are keys to the successful future of UAS operations; this paper recommends the employment of both short- and long-term actions as solutions.

Technology promises to offer solutions to a number of UAS challenges, but that is not the only answer for spectrum and bandwidth availability. A very obvious answer to not having adequate frequencies or bandwidth (but one very difficult to execute) is to acquire more for use by the military, either permanently or temporarily. Unfortunately, treaties and international agreements control spectrum allocation on a global level and are neither easily nor quickly changed. Some future challenges can be alleviated by several possible alterations in the way spectrum-dependent

systems are acquired, and changes in the testing of systems under development offer another possible answer to spectrum supportability. Moreover, better management tools could alleviate future challenges in managing frequencies and bandwidth.

The success of future UAS operations depends on the availability of needed frequencies and bandwidth. Both short- and long-term solutions to current challenges are possible and must be implemented to mitigate the negative effect of these limited resources. The tremendous capabilities that these systems can bring to support the war fighter demand that we solve the current problems and meet the challenges presented by spectrum and bandwidth availability. Electromagnetic-spectrum constraints should not drive the future of UAS employment.

Introduction

As recently as September 2007, Deputy Secretary of Defense Gordon England directed the establishment of a task force to coordinate unmanned aircraft system (UAS) issues and determine a way ahead to provide for "common, joint, and operationally effective UAS programs."[1] Aren't the systems we have now common, joint, and operationally effective? Why the need for a task force, and why did he mention specific areas to address, including streamlining acquisition and management, interoperability, integration of UASes into civil airspace, use of frequency spectrum and bandwidth, and payload and sensor management?[2] The answers are not easy ones; mainly, they concern the issue of increasing demand for these systems and their products, as well as the existing challenges. The communications area of frequency and bandwidth availability represents one case in which these challenges will continue to increase as demand grows.

The Department of Defense's (DOD) *Unmanned Aircraft Systems (UAS) Roadmap, 2005–2030* of August 2005, which reported an increased demand from combatant commanders for UAS support, stated that the DOD's challenge is "the rapid and coordinated integration of this technology to support the joint fight."[3] This increased demand could be the logical effect of a February 2004 report by the Defense Science Board recommending that the acquisition and operational fielding of unmanned aerial vehicles (UAV) be accelerated.[4] Despite promoting the increased fielding and use of these aircraft, both documents are open about deficiencies and challenges. The road map lists problem areas highlighted by combat operations, including the lack of communications frequencies; the Defense Science Board report notes communication bandwidth constraints as an area needing more attention and new development.[5] As UAS capabilities become even more sought after and as the number of these aircraft increases, something must be done to help ensure that they are available to war fighters when needed.

Frequency management and bandwidth availability are keys to the successful future of UAS operations, and the solution to the current challenges is the employment of both short- and long-term actions in these areas. To illustrate the problems and solutions, this paper will first cover some basics of the electromagnetic spectrum and spectrum management that will facilitate the examination of UAS operations. This includes some history of how UASes evolved to their current uses and how they operate. After looking at examples of difficulties experienced in military operations dealing with spectrum and bandwidth issues, the paper concludes with recommendations for improving and optimizing the use and availability of spectrum support for UAS operations in the future.

Electromagnetic Spectrum

To be effective, this discussion first needs to note a few definitions. The electromagnetic spectrum can be defined as the "range of frequencies of electromagnetic radiation from zero to infinity," but this study will consider it the range of frequencies allocated for use by the international community in agreed-upon tables of frequency allocation.[6] *Electromagnetic spectrum, radio frequency* (RF) *spectrum,* and *spectrum* are terms often used interchangeably in discussions of this medium.[7] Radio waves and microwaves, two parts of this vast spectrum, are very important to communications systems, especially military communications, and access to this "critical, finite national resource" is vital to military operations.[8]

Almost as important as access to needed spectrum is spectrum management. Its purpose is to ensure that systems dependent on spectrum are able to perform their designed functions in their designed environment without causing unacceptable interference or being affected by such interference.[9] According to DOD Directive (DODD) 4650.1, *Policy for Management and Use of the Electromagnetic Spectrum,* proper spectrum management "shall be an integral part of, and essential to, military planning, research, development, testing, and operations involving spectrum-dependent systems."[10]

Basics

Electromagnetic radiation is all around us, usually in the form of invisible waves of energy.[11] Communications signals use these waves to transmit data, and the rate per second at which these waves cycle is the signal's frequency (one cycle per second is a hertz, 1,000 cycles per second is a kilohertz, etc.).[12] Figure 1 shows part of the spectrum primarily used by communications systems. Changes in the length of the wave across the spectrum, from very short to very long, cause each subset of the spectrum, or band of frequencies, to have unique characteristics, which can affect how the wave travels through Earth's atmosphere.[13] The superhigh frequency bands, which have extremely short wavelengths, are often called microwaves.[14] Scientists who first discovered these microwave frequency bands during World War II gave them letter designations, which remain in use today.[15] Bandwidth refers to a range of frequencies occupied by a given wave or, most often, the amount of data capable of transmission in a given amount of time.[16]

Acquiring Spectrum Resources

International treaties control global use of the spectrum, along with laws and regulations for use within the United States and its possessions, all of them dividing the spec-

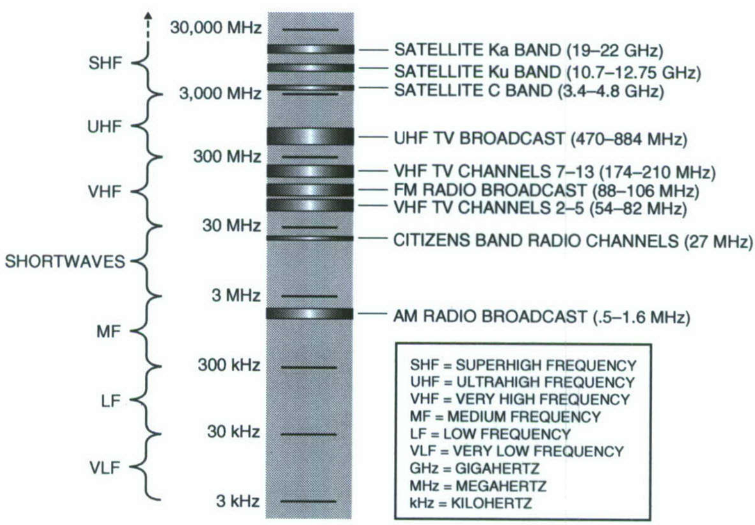

Figure 1. Electromagnetic spectrum. (Adapted from Mark Long, "Frequencies for Satellite Communications," http://www.mlesat.com/Article9.html [accessed 13 December 2007].)

trum into sections defined by the type of service using it (e.g., radio navigation or fixed satellite), type of user (government or nongovernment), and region of the world (there are three regions).[17] Because spectrum is a finite resource, competition has begun between competing interests, and governments who control it are being pressured to "sell off" or allocate bandwidth to commercial interests.[18] Those portions remaining become more congested and more difficult to deconflict among users.[19] Acquiring sufficient spectrum and bandwidth to support military operations continues to be challenging, but this environment in which national government is pressured to reallocate current government and military portions of the spectrum for commercial or private use will present even greater challenges.[20]

The finite nature of spectrum resources makes it necessary to closely control use of the allocations currently owned by the military. Both a frequency allocation and a frequency assignment must be obtained by any new US government system desiring to use any portion of the spectrum; usually, a new system will not be allowed to interfere with an existing system having an equal- or higher-priority assignment.[21] *Spectrum supportability* is the term for an assessment of whether or not the spectrum that is needed to support a system continuously from development through testing and into operational use is available—or will be available.[22] It requires a system to have at least an equipment-spectrum certification, a reasonable assurance that sufficient frequencies are available from host nations to support operations, and an electromagnetic-compatibility consideration.[23] A system receives an equipment-spectrum certification from authorities in nations where the system has the potential to operate, after their review of information on its technical characteristics. The certification indicates whether or not the system meets the nation's spectrum-management requirements.[24]

The process of developing spectrum-dependent systems is strictly controlled in order to help ensure continued availability. DODD 4650.1 states that spectrum-dependent equipment or systems shall not be developed or procured without reasonable assurance that required electromagnetic spectrum is or shall be available to support the development, testing, and operation of that equipment or system; it further notes that no spectrum-dependent "off-the-shelf" system shall be purchased or procured without the assurance that spectrum supportability has been or can be obtained.[25] In order to ensure that this guidance is followed, acquisition processes added required steps to address the allocation of spectrum for a system in design or development (fig. 2). Necessary work to obtain spectrum supportability should be started as early as possible and occur during the technology-development phase of system acquisition.[26] Other steps prevent a system from going into the development and demonstration phase or the production and deployment phase unless it has a spectrum-supportability determination completed or a waiver granted by increasingly higher levels of government acquisition officials.[27] DOD guidance also requires systems purchased off the shelf or through other-than-normal acquisition processes to have a spectrum-supportability determination before they are acquired.[28] This process is made more difficult because most systems are designed within the United States and meet US requirements, but there is normally no way to predict where the systems may be used outside the United States.[29] These potential limitations of spectrum availability and use in other countries must be considerations during the development and purchase of systems, including UASes.[30]

Operations of Unmanned Aircraft Systems

Citing an agreed-upon definition of the terms in use will ensure common understanding in the discussions to follow. Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms*, defines an unmanned aircraft as "an aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming" and a UAV as 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."[31] It further states that a UAS includes the component parts needed to control an unmanned aircraft, including all the necessary equipment, personnel, and network capability.[32] Even though they have distinct differences, in many in-

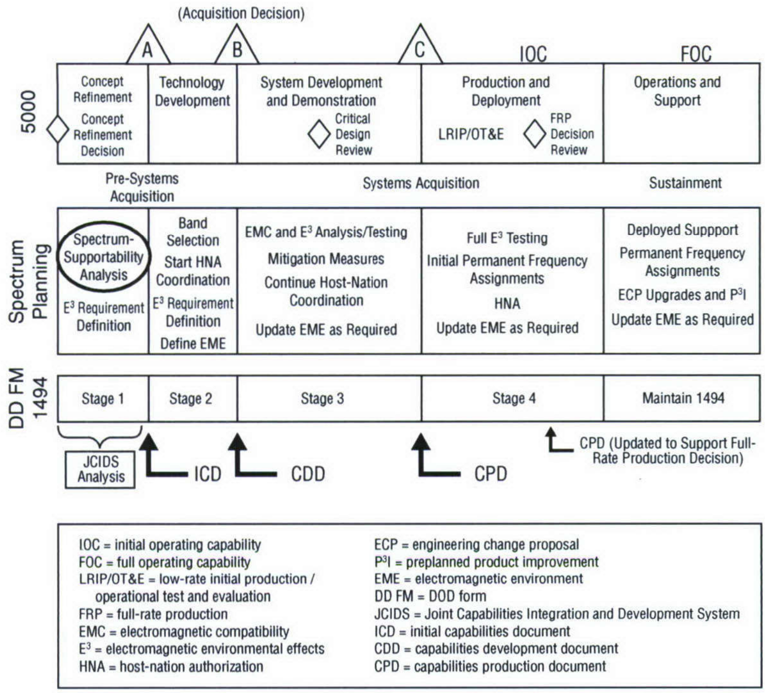

Figure 2. Spectrum management and the acquisition process. (Adapted from Joint Program Executive Office Joint Tactical Radio System [JPEO JTRS], "JTRS Overview for CCEB [Combined Communications Electronics Board] Spectrum Task Force," 3 May 2006, 31, http://jpeojtrs.mil/files/tech_overview/CCEB_JTRS.pdf.)

stances the terms *UAS* and *UAV* are used interchangeably. However, definitions don't describe how these systems got to today's military operations and how they work, which are keys to understanding the challenges they face. A bit of history can give us an idea of how they came to be, and some basics on system operations can begin to build insight into the complex issues surrounding them.

History

UAS beginnings are much earlier than one might expect. In 1918 Elmer Sperry, in partnership with the US Navy, demonstrated the first powered, unmanned flight with a naval aerial torpedo and led the way for future development in unmanned flight.[33] The 1920s saw the US military progress to using remote radio control of an unmanned aircraft, and during the 1930s and '40s, remotely operated target drones were used in a variety of training areas.[34] Drones continue to be valuable assets to the US military today for research and testing as well as training. Technological advancements equipping them with advanced navigational systems resulted in the development and use of surveillance and reconnaissance UAVs in the 1950s and '60s.[35] The SD-1 Observer, developed by Northrop Grumman and equipped with externally mounted cameras, was the first tactical-reconnaissance UAV; this technology, the basis for adapting target drones into surveillance and reconnaissance platforms, was just the beginning.[36]

Continuing research resulted in advancements in technology and capabilities. The 1960s saw the introduction of the Air Force's Lightning Bug, based on target-drone technology from the Ryan Aeronautical Firebee, which was able to conduct longer flights than previous UAVs and at higher altitudes.[37] First used in Vietnam in 1964, the Lightning Bug completed over 3,400 tactical surveillance and reconnaissance missions during the war, gathering imagery on valuable military targets, including enemy surface-to-air-missile sites and locations of prison camps.[38]

Outside the United States, Israel did much UAV research and development in the 1970s, developing the Scout for military use.[39] It was the first "genuine remotely controlled UAV prototype with adequate sensors and stable electro-optic systems required for functionality on a small platform" and could operate at 15,000 feet, performing missions up to six hours.[40] It proved hugely successful in Israel's war with Lebanon in 1982, locating Syrian air-defense resources and gathering electronic signals and frequencies used during Israeli attacks to destroy air-defense sites.[41] Noting Israel's success in the use of UAVs, the United States and other nations began development of their own programs, but US UAVs did not see significant military use again until Operation Desert Storm in the 1990s.[42]

Developed in the 1980s, the Pioneer was one of the first major US UAVs, considered the first generation of UAVs using RF technology.[43] In 1994 the Air Force first used the Predator, which became a tremendous asset to operations in Bosnia in 1995.[44] It has also performed operational missions in Kosovo, Afghanistan, and Iraq, in addition to missions in the United States to support border patrol.[45] In 2002 a Predator conducted its first operational missile launch, targeting and destroying a vehicle believed to be carrying suspected terrorists and thus offering another example of evolution in the capabilities of UASes.[46]

The Global Hawk, another system in the current fleet of Air Force UASes, made its first flight in 1998 and has supported combat operations around the globe, flying thousands of hours in operational missions.[47] The first unmanned, powered vehicle to fly across the Pacific Ocean, doing so in 2001, it is one of many UASes continuing to play a big part in ongoing operations.[48] Data gathered in September 2004 showed over 100,000 flight hours by approximately 20 types of US and coalition UASes supporting Operations Enduring Freedom and Iraqi Freedom.[49] UAS operations continue to reflect the importance of their capabilities in military operations.

Unmanned Aircraft System Basics

In order to begin to discuss the difficulties and challenges of UAS employment, we must have a basic understanding of the components of a UAS and how it works. As described in its definition, mentioned earlier, a UAS is made up of a number of parts or components, including the aircraft itself as well as all the support systems. One of the most critical major subsystems—communications—allows information to be passed between the aircraft and its ground elements or to other airborne assets, enabling a UAV to be guided and controlled from virtually anywhere at any time.[50] Bandwidth is needed to support the systems providing data to control the UAV in flight, including its launch and recovery, and to send data from the onboard sensors or payload to its processing centers.[51] These communications are done primarily through the use of RF applications, including both line of sight (LOS) and beyond line of sight (BLOS) systems and data-link communications.[52]

A data link is a pathway to send data between entities or, according to JP 1-02, "the means of connecting one location to another for the purpose of transmitting and receiving data."[53] A UAS data link typically consists of an RF transmitter and a receiver, an antenna, and modems to link these parts with the sensor systems.[54] For UASes, data links serve three important functions: (1) as uplinks from the ground station and/or a satellite to send control data to the UAV, (2) as downlinks from the UAV to send data from the onboard sensors and telemetry system to the ground station, and (3) as a means for allowing measurement of the azimuth and range from the ground station and satellite to the UAV to maintain good communications between them.[55] Efforts to standardize data links have resulted in the use of the common data link (CDL), typically a full-duplex, wideband data link when used by UASes, usually jam resistant and secure.[56] The CDL is the DOD standard for high-capacity data communications of airborne sensor data.[57] These links connect the ground station with the UAV via direct, point-to-point links or use satellite communications (SATCOM) in either X or Ku bands.[58] They can pass uplink command and control data at rates ranging from 0.2 to 2 megabits per second (Mbps) and downlink data from the onboard sensors at rates from 10 to 274 Mbps.[59]

The system specifics of UASes continue to evolve with improvements in technology. The Pioneer of the 1980s used C-band and ultrahigh frequency (UHF) LOS communications for its uplink as well as C-band LOS for its downlink.[60] Its data rate of 7.317 kilobits per second (Kbps) was extremely slow when compared to today's possible rates and was the result of limitations in spectrum as well as limited power available in the small, lightweight vehicle.[61] Today's Global Hawk UAS is made up of the aircraft, the launch and recovery element (LRE), and the mission control element (MCE).[62] The LRE controls the aircraft using LOS CDL, LOS UHF, and BLOS UHF radios, while the MCE uses narrow-band LOS UHF radio and UHF SATCOM with Inmarsat backup for command and control.[63] Although the MCE can control the aircraft with the same capabilities of the LRE, it is also responsible for control of the onboard sensors and receipt and distribution of the sensors' products transmitted from the aircraft to the MCE using either LOS CDL or Ku-band SATCOM.[64] Figure 3 illustrates the parts of the Global Hawk system and communications paths between the elements.

Predator operations use similar concepts as well. Performing functions similar to those of parts of the Global

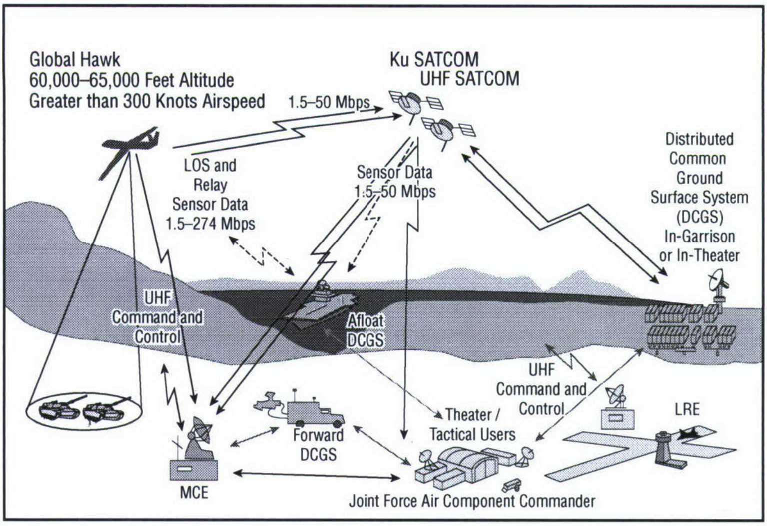

Figure 3. Global Hawk communications architecture. (Adapted from *Unmanned Aircraft Systems [UAS] Roadmap, 2005–2030* [Washington, DC: Office of the Secretary of Defense, 4 August 2005], C-3.)

Hawk system, the Predator UAS has its aircraft, a ground control station (GCS), and an LRE. Having a purpose similar to that of the Global Hawk MCE, the GCS consists of equipment to control flight operations and sensor payload using LOS data-link and Ku-band SATCOM data-link equipment as well as VHF/UHF radios.[65] The Predator LRE contains enough equipment to successfully launch and recover the aircraft, controlling it during takeoffs and landings using the LOS data link, which must be maintained until it transfers control to the GCS because the LRE has no BLOS communications capabilities.[66]

Communications systems are key to the operations of UASes as well as the successful accomplishment of their missions. The ability to pass needed data between components of the systems depends upon available frequencies and adequate bandwidth to move the data as quickly as possible. For takeoff and landing operations, data-link requirements are only in the several-Kbps range, while requirements to transmit sensor data from the onboard sensors can exceed 250 Mbps.[67] Bandwidth requirements continue to increase. Estimated requirements for future capabilities in 2015 and beyond are 548 Mbps for Global Hawk sensor data and 44.7 Mbps for Predator.[68]

Issues with Spectrum Support in Military Operations

Difficulties in acquiring adequate spectrum and bandwidth to support military operations have negatively affected the mission and are documented as far back as Desert Storm and up to ongoing operations in Afghanistan and Iraq. In order to develop solutions, we must examine the problems and their causes.

The lack of available bandwidth to transmit data is a fundamental problem. In Desert Storm, DOD satellites provided only 75 percent of the bandwidth needed during peak capacity, with the remainder provided by North Atlantic Treaty Organization systems and leased from commercial satellites.[69] Demand for bandwidth in Operation Allied Force was more than twice that used in Desert Storm, and even after optimizing the available military bandwidth, the Defense Information Systems Agency (DISA) still had to contract for more than $20 million in commercial satellite bandwidth.[70] During Enduring Freedom, Lt Gen Harry Raduege Jr., the director of DISA at the time, observed that "we're supporting one-tenth the number of forces deployed during Desert Storm with eight times the commercial SATCOM bandwidth" and that "Global Hawk consumed five times the total bandwidth used by the entire US military in the Gulf."[71] Recently, the current director of command, control, communications, and computer systems for US Central Command (CENTCOM/J6) was quoted as saying, "It's astronomical how much satellite communications we have over in our [area of responsibility]"; he also talked about the "unbridled proliferation" of systems requiring satellite bandwidth.[72]

A host of additional challenges affects UAS operations. Simultaneous operations of two Predators from Bosnia during Allied Force required 6 Mbps of bandwidth for each to support dissemination of its video, severely stressing available resources and necessitating preemption of lower priorities when the Predators were operating.[73] Predator and Global Hawk operations in Afghanistan and Iraq continue to highlight the critical nature of SATCOM to UASes. The high data rates required for the systems' imagery products cannot be supported by DOD satellites, so channels are leased from commercial satellites to provide the needed data.[74] With this comes great dependence on other-than-military resources that are subject to unavailability due to purchase by others or refusal of service from private vendors.[75] Operations also show that the limited number of available frequencies often restricts the number of airborne UAVs to one at a time, even though abundant capability exists to operate more of them simultaneously.[76] According to a US Central Command Air Forces staff member, there are only two assigned frequency sets for use in Balad, Iraq, which limits the number of unmanned aircraft operated and launched from the airfield.[77] Other problems include the loss of a communications link to an unmanned aircraft due to frequency interference, usually caused by friendly sources or by the urban environment of current operations.[78]

Availability of frequencies for use in deployed operations and interference to systems are always sources of difficulty. As explained earlier, control of spectrum allocation and use of spectrum-dependent systems are up to each country, within its borders, and can vary from nation to nation. Frequencies authorized for use in one country may not be authorized for use in another.[79] In Iraqi Freedom, the Army's Hunter UAV did not operate for the first 30 days in-theater because it was awaiting frequency deconfliction in order to obtain operational frequencies to use.[80] An improperly configured UAV payload caused interference, resulting in problems with the UAV's downlink communications during operations in the Balkans.[81] An electronic-countermeasure system supporting Iraqi Freedom experienced friendly interference from a UAV because the aircraft deployed without first receiving spectrum support and failed to acquire it after arriving in-theater.[82] Can anything be done to alleviate these problems?

Recommendations

According to Renee Puels, the DOD's UAV road map lists objectives for better defining the role of UAVs in military operations out to the year 2030, noting that technology is the "enabler" for reaching most of the objectives.[83] Technology promises to offer solutions to a number of UAS challenges, but it's not the only answer for spectrum and bandwidth availability. Other possible solutions include acquiring additional spectrum resources, making changes in the acquisition system, and conducting other process-related actions capable of helping alleviate today's difficulties.

Utilizing Technological Advances

Advances in electromagnetic-spectrum technology offer future solutions to problems with military and UAS bandwidth availability. One such advance is optical data links, or lasercom, with bandwidth possibly two to three times greater than that of RF systems, low probability of intercept, 30–50 percent less weight than comparable RF systems, and resistance to interference and jamming.[84] Lightweight electro-optical systems with low power requirements can also be a benefit to UASes.[85] Unfortunately this technology has not progressed as rapidly as desired because there continue to be problems acquiring and maintaining a link due to insufficient pointing, acquisition, and tracking technology; furthermore, no current technology is capable of supporting the data rates.[86]

Technological advances in other areas could offer advantages as well, but they are not readily available currently. Applications enabling sensors to cover large surveillance areas would select for transmission only the data of interest. This would decrease current downlink requirements.[87] A similar effort to reduce needed downlink-bandwidth rates involves data compression, possibly having near-term effects, but the technology could still benefit greatly from improvements.[88]

Acquiring More Spectrum

A very obvious answer to having inadequate frequencies or bandwidth (but one very difficult to execute) entails acquiring more for use by the military, either permanently or temporarily. As discussed earlier, treaties and international agreements control spectrum allocation on a global level, a process managed by the World Radiocommunication Conference.[89] The United States began to address UAS spectrum issues at the international level by proposing an agenda item at the next conference to consider the impact that UASes will likely have on spectrum requirements.[90] The US proposal states that UAV use around the world is expected to experience tremendous growth over the next 10 years and that, despite the potential need for more spectrum in the aeronautical-mobile and/or aeronautical-mobile-satellite use areas, studies should be conducted to assess potential requirements and identify frequency bands that would best support those requirements.[91] Previous studies done in response to an agenda item in a prior conference made several conclusions affecting the future of UAS operations: (1) significant growth is projected in this section of aviation, (2) future UAS use will include operations in nonsegregated airspace, (3) when operating in nonsegregated airspace, these aircraft must be safely integrated and use the same operational practices as manned aircraft, and (4) additional communications requirements will be needed in order to ensure safety.[92] The studies also noted that short-term increases can possibly be absorbed with existing allocations but that much larger deployments of UAVs will require additional spectrum.[93]

Short-term acquisition of bandwidth and spectrum support can provide an easier answer, but, as discussed earlier, it has risks. Lease or purchase of bandwidth from commercial sources is very expensive, and sources may not be immediately available to meet mission requirements. Vendors able or willing to provide adequate bandwidth at the needed place and time could jeopardize mission accomplishment if we rely on them as the sole means of obtaining additional spectrum support.[94]

Changing Acquisition Processes

Future challenges can be alleviated by several possible changes in the way spectrum-dependent systems are acquired. As described earlier, the current acquisition process for spectrum allocation ties accreditation of spectrum support to a specific device, propagating the inflexibility of spectrum assignments.[95] This process could be made more flexible by accrediting classes of equipment within certain parameters to operate within a constrained range of frequencies, which would then be assigned and managed by the gaining service or organization. This, however, would require drastic changes to the current DOD processes as well as extensive coordination across a number of federal entities, both of which would be very time-intensive endeavors with potentially uncertain results.

Changes in the testing of systems under development offer another possible answer to spectrum supportability. Systems acquired as commercial, off-the-shelf products are normally tested using US commercial spectrum; when used by the military, they still maintain the lower priority given to nongovernment systems and may be prohibited for use outside the United States.[96] To decrease fielding and operational problems, we should implement plans to transfer these systems to military-use spectrum or to limit their purchase if different spectrum support cannot be obtained. In discussing communications challenges and bandwidth constraints in his area of responsibility, the CENTCOM/J6 remarked that systems should be designed and tested "in a bandwidth-constrained environment first, as opposed to running them in the Beltway or running them just over fiber."[97]

Developing Better Management Tools and Processes

If a commander is not aware of spectrum- and bandwidth-availability problems that affect mission accomplishment, he or she cannot prioritize use of available resources to best support the overall mission. Much like programs that provide airspace situational awareness, spectrum-management functions must have tools available to provide needed situational awareness in order to track this valuable resource and provide needed information to leadership. CENTCOM communicators see the need for tools to manage and deconflict spectrum, based on priorities established by theater leadership.[98] Operational trade-offs have been made in UAV operations when multiple systems must share the same frequencies—one mission must end so that another can get airborne.[99] Planners not only need automated tools to allocate available bandwidth to achieve the best possible result, but also require the ability to conduct a "what if" analysis of various scenarios to identify potential problems and solutions.[100] We should also conduct research to develop new tools for this purpose or to modify existing ones in order to provide an accurate, real-time, usable representation of electromagnetic-spectrum resources.

Conclusion

The success of future UAS operations depends on the availability of needed frequencies and bandwidth. Both short- and long-term solutions to current challenges are possible and must be implemented to mitigate the negative effect of these limited resources. By looking at the basics of electromagnetic spectrum, spectrum management, and UAS operations, this paper has shown the critical relationships among them. Examples of difficulties experienced in military operations dealing with spectrum and bandwidth issues illustrated their importance. We must evaluate short-term solutions, such as purchasing bandwidth from commercial vendors, and long-term solutions, such as using optical data links or acquiring permanent frequencies for military use. Moreover, we must integrate them into an immediate remedy for the current problems with UAS operations and optimize the use and availability of spectrum support for UAS operations in the future.

Development and deployment of UASes continue at an ever-increasing rate and appear to assume not only that needed spectrum and bandwidth will be available for these systems when needed, but also that commanders understand how this finite resource will affect their operations.[101] The tremendous capabilities that these systems can bring to support the war fighter demand that we address and mitigate the current problems and challenges with spectrum and bandwidth availability. Electromagnetic-spectrum constraints should not drive the future of UAS employment.

Notes

1. Gordon England, deputy secretary of defense, to secretaries of the military departments; chairman of the Joint Chiefs of Staff; undersecretaries of defense; commanders of the combatant commands; assistant secretaries of defense; general counsel of the Department of Defense; director, Administration and Management; and director, Program Analysis and Evaluation, memorandum, 13 September 2007.

2. Ibid.

3. *Unmanned Aircraft Systems (UAS) Roadmap, 2005–2030* (Washington, DC: Office of the Secretary of Defense, 4 August 2005), 1.

4. *Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, February 2004), cover memo.

5. *Unmanned Aircraft Systems (UAS) Roadmap*, 45; and *Defense Science Board Study*, cover memo.

6. Department of Defense Directive (DODD) 4650.1, *Policy for Management and Use of the Electromagnetic Spectrum*, 8 June 2004, 9.

7. Ibid.

8. Ibid., 2.

9. Ibid., 10.

10. Ibid., 2.

11. Mark Long, "Frequencies for Satellite Communications," 1, http://www.mlesat.com/Article9.html (accessed 13 December 2007).

12. Ibid., 2.

13. Ibid.

14. Ibid., 3.

15. Ibid.

16. *Wikipedia: The Free Encyclopedia*, s.v., "Bandwidth (Signal Processing)."

17. *Unmanned Aircraft Systems (UAS) Roadmap*, C-17.

18. Lt Col Kurt A. Klausner, "Command and Control of Air and Space Forces Requires Significant Attention to Bandwidth," *Air and Space Power Journal* 16, no. 4 (Winter 2002): 72.

19. Ibid.

20. Mario Lucchese, Dr. C. Leslie Golliday Jr., and Dr. Anil N. Joglekar, "Operational Evaluation of Electromagnetic Environmental Effects (E3): New DOT&E [Director, Operational Test and Evaluation] Policy Calls for More Systematic Assessment of E3," *PM*, May–June 2000, 42, http://www.dau.mil/pubs/pm/pmpdf00/luccm-j.pdf.

21. *Unmanned Aircraft Systems (UAS) Roadmap*, C-17.

22. DODD 4650.1, *Policy for Management and Use*, 10.

23. Ibid.

24. Ibid.

25. Ibid., 3.

26. Ibid.

27. Ibid.

28. Ibid.

29. *Unmanned Aircraft Systems (UAS) Roadmap*, C-17.

30. Ibid.

31. Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 12 April 2001 (as amended through 4 March 2008), 569, http://www.dtic.mil/doctrine/jel/new_pubs/jp1_02.pdf.

32. Ibid.

33. Renee Puels, "Unmanned Aerial Vehicles (UAVs) Enabled by Technology," Student Publication for TCOM 598, Independent Study of Telecommunications (Fairfax, VA: George Mason University, December 2006), 2, http://telecom.gmu.edu/studPub.html (accessed 18 October 2007).

34. Ibid., 2–3.

35. Ibid., 3.

36. Ibid.

37. Ibid.

38. Ibid.

39. Ibid., 4.

40. Ibid.
41. Ibid., 4–5.
42. Ibid.
43. Ibid., 20–21.
44. Ibid., 22.
45. Ibid.
46. Ibid.
47. Ibid., 24.
48. Ibid.
49. *Unmanned Aircraft Systems (UAS) Roadmap*, i.
50. Puels, "Unmanned Aerial Vehicles," 6–7.
51. *Defense Science Board Study*, 23.
52. Ibid.; and Puels, "Unmanned Aerial Vehicles," 6, 20.
53. JP 1-02, *Department of Defense Dictionary*, 142.
54. Puels, "Unmanned Aerial Vehicles," 19.
55. Ibid.
56. *Unmanned Aircraft Systems (UAS) Roadmap*, C-7, C-8.
57. Ibid., C-7.
58. Ibid., C-7, C-8, C-14.
59. Ibid., C-8.
60. Puels, "Unmanned Aerial Vehicles," 20–21.
61. Ibid.
62. *Unmanned Aircraft Systems (UAS) Roadmap*, C-2.
63. Ibid.
64. Ibid.
65. Ibid.
66. Ibid.
67. *Defense Science Board Study*, 23.
68. Ibid.
69. Klausner, "Command and Control," 5.
70. Ibid.
71. Ibid., 3.
72. Quoted in Rita Boland and Robert K. Ackerman, "Innovation, Diversification Define CENTCOM Communications," *SIGNAL*, November 2007, 22, http://www.afcea.org/signal/articles/templates/Signal_Article_Template.asp?articleid=1427&zoneid=219.
73. Klausner, "Command and Control," 3.
74. *Unmanned Aircraft Systems (UAS) Roadmap*, C-11.
75. Ibid.
76. Ibid., 68.
77. John DeBerry, US Central Command Air Forces A6X, Shaw AFB, SC, to the author, e-mail, 29 October 2007.
78. *Unmanned Aircraft Systems (UAS) Roadmap*, 68.
79. *The U.S. Air Force Remotely Piloted Aircraft and Unmanned Aerial Vehicle Strategic Vision* (Washington, DC: Department of the Air Force, 2005), 14, http://www.af.mil/shared/media/document/AFD-060322-009.pdf.
80. "Operation Outreach," *CALL* [Center for Army Lessons Learned] *News Letter*, no. 03-27 (October 2003): 6, http://www.fas.org/irp/agency/army/call1003.pdf.
81. Lucchese, Golliday, and Joglekar, "Operational Evaluation," 42.

82. Brig Gen Gregory L. Brundidge, director of communications, Langley AFB, VA, to Air Combat Command (ACC)/CC and ACC/CC IOI mailing list, e-mail, 19 January 2007.

83. Puels, "Unmanned Aerial Vehicles," 35.

84. Ibid., 25.

85. Ibid., 26.

86. *Unmanned Aircraft Systems (UAS) Roadmap*, 50; and Puels, "Unmanned Aerial Vehicles," 27.

87. *Defense Science Board Study*, 23.

88. *Unmanned Aircraft Systems (UAS) Roadmap*, 50.

89. Frederick R. Wentland, associate administrator, Office of Spectrum Management, to Mr. John Giusti, Federal Communications Commission, memorandum, 7 November 2006, 1.

90. Ibid.

91. Ibid., 3–4.

92. Ibid., 2.

93. Ibid.

94. Klausner, "Command and Control," 7.

95. *Department of Defense Net-Centric Spectrum Management Strategy* (Washington, DC: Office of the Assistant Secretary of Defense [Networks and Information Integration] and Department of Defense Chief Information Officer, 3 August 2006), 9.

96. *Unmanned Aircraft Systems (UAS) Roadmap*, C-16.

97. Quoted in Boland and Ackerman, "Innovation, Diversification," 24.

98. Ibid.

99. Klausner, "Command and Control," 7.

100. Ibid., 7–8.

101. Ibid., 6.