AIR WAR COLLEGE

AIR UNIVERSITY

RECOMMENDATIONS FOR AIRBORNE INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE IN THE YEAR 2035

IN

A COST CONSTRAINED ENVIRONMENT

by

Douglas J. Lee, Lt Col, USAF

A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

10 February 2012

DISCLAIMER

Biography

Lieutenant Colonel Douglas Lee is a U.S. Air Force pilot assigned to the Air War College, Air University, Maxwell AFB, Alabama. He graduated from the University of Alabama in 1992 with a Bachelor of Arts degree in History, Embry Riddle Aeronautical University in 2005 with a Masters of Aeronautical Science, and was a distinguished graduate of the Air Command & Staff College in 2006 with a Masters in Military Operational Art and Science. He earned his pilot wings in 1997 and has over 2,100 flying hours in the T-38, AT-38, F-15C, and MC-12W. He was initial cadre for the MC-12W, and stood up and commanded the USAF's first MC-12 squadron in Afghanistan. He has served on a MAJCOM staff and is a graduated squadron commander.

Abstract

There is no crystal ball unveiling the future with perfect accuracy. The USAF must prepare for uncertainty; but it is certain that the future requires global strike capabilities. Effective global strike requires accurate targeting information. Surveillance and reconnaissance conducted in air, space, and cyberspace is the best way to gain this information and turn it into knowledge; all three domains are important, and all are required. In light of increasing technologic change, and fiscal restraints, this paper focuses on the following question: in a severely cost constrained environment, how can the Air Force modernize its existing & emerging assets to perform airborne surveillance and reconnaissance in order to enable global strike in 2035? This paper argues that fiscal realities require a strategy taking advantage of merging new technology on legacy systems. This strategy also requires smart acquisition of new aircraft utilizing game-changing technology such as nanotechnology in order to prepare for the most likely complex adversary scenarios. This is accomplished by addressing current and emerging sensor technology and their different types of collection capabilities. In addition, the different categories of airborne assets that can utilize those sensors, now and in the future are discussed. Those platforms and sensors are then contrasted against likely adversary scenarios to offer a prescription for the USAF. This paper advocates updating existing platforms with new technology rather than designing radically new platforms. The USAF has done this throughout its history, successfully merging legacy systems with emerging technology to accomplish its tasked missions.

Introduction

The ability to strike globally is a core competency of United States Air Force and intelligence, surveillance and reconnaissance ISR is the enabling tool to determine what targets to strike and when.[1] In light of increasing technologic change and fiscal restraints, this paper will focus on the following question: in a severely cost constrained environment, how can the Air Force modernize its existing and emerging assets to perform airborne surveillance and reconnaissance in order to enable global strike in 2035? The following example illustrates the power of, and requirement for, advanced systems in support of surveillance and reconnaissance missions.

Onboard a Rivet Joint RC-135, a sensor operator discovers a priority enemy leader is in the area. An intelligence analyst passes this information to the Combined Air Operations Center, which tasks an MC-12 to conduct an airborne reconnaissance mission to find and fix the individual. The MC-12 successfully locates the target and tracks him to a house. In this situation, military leadership decides to gather more information before reaching a targeting decision, so an MQ-1Predator drone is tasked to execute a surveillance mission tracking his movements. The Predator monitors him for several days across multiple locations. Using this information, an intelligence analyst pieces together the enemy's pattern of life, including several key meetings with other people of interest. Other ISR assets are tasked to monitor those individuals, building a more complete intelligence picture. US military leaders decide to target the first individual and, once surveillance determined he had moved to a location minimizing collateral damage, assign a B-1 to drop conventional weapons. A surveillance asset verifies target destruction and assesses the need for a follow-on strike. This is a typical example of an ISR mission conforming to the current Find, Fix, Target, Track, Engage, and Assess (F2T2EA) model.[2] Arguably this model will exist in 2035, but due to exponential increases in technological capabilities, the speed of execution will likewise increase, compressing the decision making cycle.

Reconnaissance is a specific mission to discover or provide answers to specific questions. For example, a mission sent behind enemy lines to determine the location of command and control facilities, key leaders or troop locations. From recent conflicts, a mission sent to search for an enemy such as Osama Bin Laden is a good illustration. Surveillance is more persistent: a good analogy is a stakeout conducted by the police. A drone monitoring frequently travelled roads watching for explosive emplacement activity is an example of surveillance. Intelligence is the result of information gained through reconnaissance and surveillance. Continuing the previous example, the reconnaissance mission that found an enemy leader, and the subsequent surveillance missions, produced valuable pieces of information. The intelligence portion of ISR ties all those pieces together to build the enemy's pattern of life. Intelligence is the key element in crafting global strike plan, as seen in the presented examples. Key US leaders have said surprise is our deadliest threat; the information and knowledge gained through ISR is the counter to that surprise.

The exact technology available to the USAF in 2035 is difficult to define, but there is no doubt that technology will be dramatically faster and more powerful than what is available today. As exponentially improving technology "shrinks" our planet, there will likely be adversaries attempting to use these new capabilities against the United States. The United States must be able to influence those adversaries anywhere on the globe.

To accomplish this task, this paper is written with the following assumptions. First, due to the lagging economy and national debt, U.S. Defense spending will be fiscally constrained for the foreseeable future creating an environment resulting in lower defense budgets, requiring prioritization of funding requirements.[3] Second, radically new airborne platforms and engines will not be available in 2035 primarily due to historically long acquisition processes and lack of current funding to support USAF scientific research. As an illustration, the DoD 5000 Defense Acquisition System has definitive process and timelines taking an incredibly long time to go from an idea to operational system, and even longer if little money is provided for the program.[4] In fact, new platforms for 2035 need to be in the funding cycle and programmed in the next few years. Both DoD and national research labs are exploring several promising technologies, such as hypersonic vehicles. Scientists do not agree on expected timelines, and most offer substantive differences on viability and major milestones. Therefore, widespread use of radically new aircraft is deemed unlikely and not considered.

These two assumptions yield a situation where the USAF does not have the money or time available to invest in radically new ISR aircraft. The obvious result is the USAF, following a familiar path, should take advantage of emerging sensor technology and apply it to existing platforms to perform future surveillance and reconnaissance missions. For much of its existence, the USAF has remixed older platforms with new technology, and this continues to be a viable strategy. One example is the U-2, first fielded in the 1950s, operates today with recent additions of cutting edge equipment, specifically multi-spectral imaging capability that provides "significantly more utility in discerning imagery used for threat analysis on the ground and on buildings, by detecting and showing changes not readily apparent to the human eye."[5] Another example is the MC-12, a Super King Air twin-engine turboprop first fielded in the 1970s, was melded with modern upgradable sensor packages.[6] This concept has been very successful: a single MC-12 squadron was responsible for the capture or elimination of over 4,000 targets in Afghanistan in just 18 months.[7]

The ISR focus, then, should not be on the platforms, but rather on the surveillance and reconnaissance equipment carried by those platforms. Since technology is improving on an exponential curve, current technology becomes obsolete rather quickly.[8] This affects friend and foe alike. Adversaries will want the latest and greatest "iPhone", and with technology proliferation, this principle applies even in the remotest areas. The USAF must be positioned to track emerging technologies; remixing legacy aircraft with emerging sensor technology is effective and fiscally responsible. As Sir Ernest Rutherford so eloquently stated "We haven't got the money, so we've got to think!"[9]

This paper focuses on how the Air Force can modernize its existing and emerging assets to perform airborne surveillance and reconnaissance to enable global strike in 2035. This is accomplished first by addressing current and emerging sensor technology and their different types of collection capabilities. Next, the paper will focus on different categories of airborne assets that can utilize sensor. Finally, conclusions and recommendations will be provided.

Sensor Technology

ISR in its most basic context is a quest to provide knowledge to eliminate uncertainty or Clausewitz's fog of war. When airborne ISR is mentioned, most people think of aircraft. However, the aircraft exists only to get the sensors to the right location; it is the sensors that do the work. A good analogy for airborne ISR is the human body. Different categories of airborne intelligence are analogous with human senses. Imagery intelligence, or IMINT, is the eyes. Signals intelligence, or SIGINT, is the ears. Measurement and signature intelligence, or MASINT, is the nose while the aircraft is the arms and legs, putting the sensory organ in the right location to do its job. The human body’s most important element is the brain; in ISR this takes the form of processing, exploitation, dissemination (PED). PED translates data gained from sensors into knowledge or intelligence. This chapter focuses on different types of sensors that perform surveillance and reconnaissance.

Sensors are best divided into categories for discussion. The first sensor deals with what can be seen. The original mission of surveillance and reconnaissance was imagery intelligence or IMINT, “the technical, geographic, and intelligence information derived through the interpretation or analysis of imagery and collateral materials.”[10] Simply put, IMINT is information gained by what is seen. Its uses include pre-strike planning and can be further subdivided into three other categories: visible still images, visible full motion video (FMV), and the non-visible spectrum.

Visible still images were the first mission given to aviation. Pictures were first taken from balloons in 1858. Wilbur Wright took photos from an aircraft in 1909, leading to widespread airborne imagery in the First World War.[11] Until the advent of digital cameras, wet film was the only medium available. Today digital cameras make up the vast majority of systems; however, wet film is still utilized due to its higher resolution. The optical bar camera (figure 1) carried on the U-2 weighs about 100 pounds and a single film roll is two miles long.[12] The camera is so capable due to its 30-inch wide lens, which drives the absolute resolution of the camera. While digital cameras could be built with the same size lens,

Figure 1. Optical Bar Camera on U-2.
Reprinted from the internet:
http://defensetech.org/2011/03/15/u-2-and-global-hawk-deployed-to-survey-japanese-quake-damage/

the data storage and transmit requirements would, for a single mission, be in the "double-digit terabyte range."[13] This exceeds today's capabilities, but technology improvements by 2035 should make this possible.

In 2035, visible still-images will still exist and will allow detailed examination of specific scenes and locations. They will also allow comparison of the same location over time to look for changes and trend information key to pre-strike planning. With the technology improvements, cameras will most likely shrink, be capable of higher resolutions, and be coupled with higher data storage and transmission methods. Emerging gigapixel technology, as an example, allows the joining and mixing of multiple images shot of the same area from different cameras and differing vantage points. Computer programs overlay these images to create an extremely wide-angle view of the area. Today, gigapixel images of Paris have been created from over 2,300 different pictures taken by multiple people and downloaded from the Internet.[14] Gigapixel digital technology will allow three-dimensional rendering of areas to enable incredibly accurate pre-strike planning.

Full motion video (FMV) currently is the most prolific form of ISR. Today, in US Central Command region, there are over fifty combat air patrol (CAP) equivalents of ISR remote piloted aircraft (RPA) with up to ten video streams from each.[15] If a link is present, video can be streamed real-time to an analyst. It can also be stored and downloaded after a mission. The image quality is typically less than that of a still image and, due to bandwidth limitations, even more degraded when streamed real-time.[16] The sense of context in video is its most important attribute; motion can be seen, and direction and speed of movement is obvious, which together tells a story. Using eyesight as an analogy, a movie tells a better story than a picture. But a picture can be examined in detail whereas a movie cannot. Using current growth rates, FMV will be ubiquitous and have far greater resolution in 2035 eliminating the inherent advantage of wet film.

The previous paragraphs have described the categories of images, but it is crucial to understand how sight works. Humans require light to see. For example, radiation transmitted at wavelengths visible to the human eye, enables a reader to see this page. The same is true for

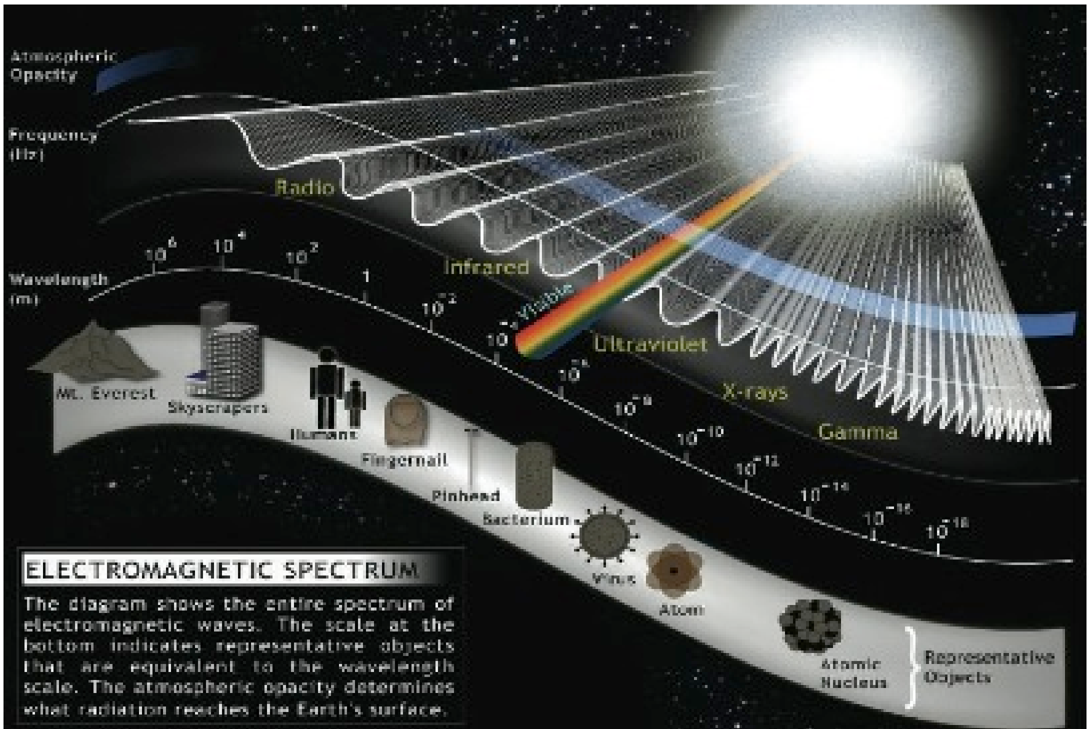

Figure 2. The electromagnetic spectrum comprises all energy. Sensors can be built to track and focus on any portion of the spectrum. Obtained from the internet, http://ds9.ssl.berkeley.edu/LWS_GEMS/2/em.htm

sensors in the visible spectrum, but other electromagnetic spectral regions can be viewed with the right equipment and offer the greatest growth. Electromagnetic energy, as seen in figure 2, has a vast spectrum, and visible light resides only in a small portion.[17] Other sensors take advantage of energy transmitted at different wavelengths, and each has its own advantage.

Every current ISR platform with an imagery mission has sensors operating in the infrared (IR) spectrum, enabling them to see as well at night as in the day. This spectrum is divided into different bands, short, medium, and long. Each band has distinct characteristics and micron

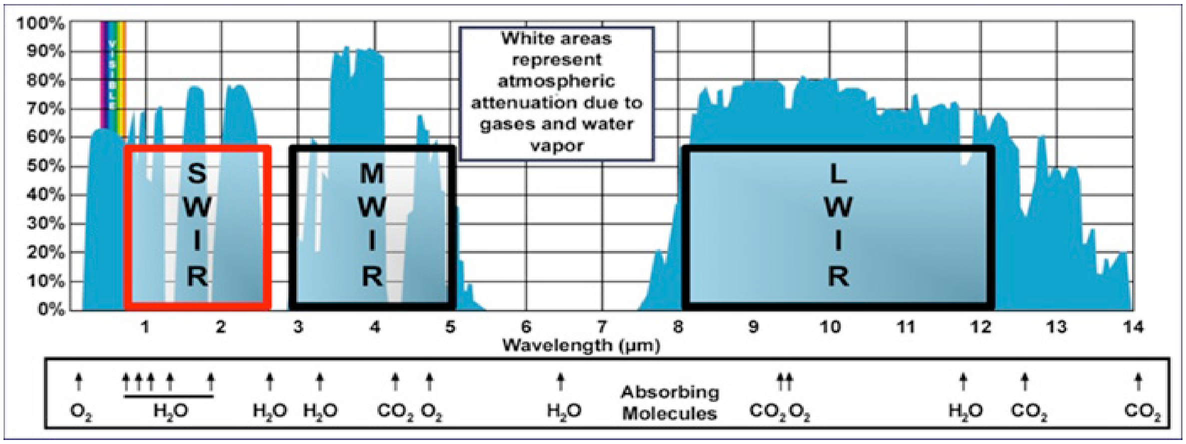

Figure 3 Infrared spectrum bandwidth and wavelengths. Obtained from the internet, http://www.sensorsinc.com/thirdwindow.html

ranges. Medium and long wave IR utilize thermal energy as a source. Short wave IR works with reflected light, and their images are more true to the visible spectrum and much higher quality than medium or long wave IR.[18]

Atmospheric conditions also affect transmission of energy to the sensor in each band. When energy is blocked or degraded, image quality suffers. Think of trying to see on a foggy or hazy day, when polarized sunglasses often enable better sight. The same applies to sensors, different bandwidths or filters enable vision in different conditions; when sensors are integrated it can yield exceptional results.

The ability to see in multiple spectrums simultaneously is the realm of multispectral imaging or hyperspectral imaging, both enabled by increased computer-processing power. Multispectral imaging allows simultaneous collection of selected spectrums, usually 20 or less specific bands, while hyperspectral imaging enables simultaneous collection across 100 or more bands.[19] This allows collection of visible, infrared, and ultraviolet images at the same time, and creates multitudes of options through correlation. "Detection of chemical or biological weapons, bomb damage assessment of underground structures, and foliage penetration to detect troops and vehicles are just a few potential missions."[20] The primary goal of using multispectral/ hyperspectral image data is to "discriminate, classify, identify as well as quantify materials present in the image."[21] The camouflaged vehicle in figure 4 cannot be seen in the visible spectrum (top), but is clearly visible utilizing hyperspectral imaging (bottom).[22] In 2035 it is safe to assume that multiple sensors will be available to even the smallest platform.

Figure 4. Hyperspectral techniques enable the sensor to identify the green vehicle in the trees, they are shown in red in the lower image. Obtained from the internet, http://www.bbc.co.uk/news/10175960

While imagery sensors are analogous with sight, signal sensors correspond to hearing. Imagine the difficulty looking for a needle in a haystack, however if that needle is emitting a noise, it becomes simple. That is the principle of signals intelligence, "intelligence produced by exploiting foreign communications systems and non-communications emitters…. often used for cueing other sensors to potential targets of interest."[23] Sensor pods "enable rapid interception, geo-location and processing of communication signals…even in dense signal environments."[24] Sensor capability is a function of size and power consumption. Current systems range from 25 pound, 30 watt single-channel systems to 1000+ pound, 6000+ watt wideband systems.[25] Signal sensors are advancing at the same rate as the technology they track; as new communications devices are created, so will the ability to track and listen. Since adversaries will undoubtedly need to communicate in 2035, the US must have the ability to intercept and track the devices they utilize. This simple concept is critical since the ability to rapidly acquire and utilize emerging technology is the central theme of this paper.

Measurement and signature intelligence, or MASINT, is "intelligence obtained by quantitative and qualitative analysis of data (metric, angle, spatial, wavelength, time dependence, modulation, plasma, and hydro magnetic) derived from specific technical sensors for the purpose of identifying any distinctive features associated with the emitter or sender, and to facilitate subsequent identification and/or measurement of the same."[26] Using the analogy of a nose, MASINT sensors detect or "sniff" data in six subsets: electro-optical data, radar data, radio frequency data, geophysical data, materials data, and nuclear radiation data.[27] While this list might seem lengthy, it has future implications, since MASINT sensors have the potential to detect underground structures utilizing minute seismic shifts.[28]

The sensors described previously carry a common characteristic: they can be placed on almost any aircraft. When Air Force leaders say every Airman is a sensor, it should be true that every aircraft is a sensor as well. Today all fighter aircraft carry pods capable of some kind of ISR. If the current rate of technological change is an indicator, sensors in 2035 will be smaller, more capable, more efficient, able to be formed into countless shapes, and most importantly, more ubiquitous. The ability to change sensors is like changing eyeglasses for someone who cannot see well, or putting on a different set of clothes to suit a different purpose. Just as someone's eyes, ears, and nose can only be where he is, the aircraft must put the sensors in the correct location for airborne ISR.

Aircraft that can perform ISR

The USAF operates over 5,200 aircraft, and a significant number are capable of surveillance and reconnaissance missions. It is important to understand the categorical attributes of different aircraft types, the environment each type is best suited for, and the sensor types they can carry. Aircraft will be divided into the following categories: ISR, mobility, fighter, and bomber aircraft. Fighters and bombers are best suited for denied airspace, as the other categories can only operate in permissive or semi-permissive airspace.

It is no surprise that ISR aircraft conduct the vast majority of ISR missions in the USAF. Today there are twenty-seven different variants of ISR aircraft in service. They vary in size from the small, remotely piloted, hand-launched aircraft to the large E-4 based on a Boeing 747 platform. For discussion purposes, these aircraft are divided into subcategories: heavy, medium, light, high altitude, and remotely piloted aircraft.

Heavy ISR aircraft are based on the Boeing 707 and 747 platforms. The Boeing 747-based E-4 is "the National Airborne Operations Center for the president, secretary of defense and the Joint Chiefs of Staff or JCS."[29] However, the heavy ISR aircraft mainstays for the USAF are the thirteen different variants of the Boeing 707. They range from the E-3 AWACS tasked with airborne radar surveillance, to the RC-135 flying primarily signals intelligence missions, with its on-board sensor suite "[allowing] the mission crew to detect, identify and geolocate signals throughout the electromagnetic spectrum."[30] They can carry large numbers of people performing high numbers of simultaneous missions. A diverse number of sensors and antennas can be added to these large aircraft, and power requirements are not an issue. However, their size, either through radar or visually, makes them easy to find in the air. This inability to hide makes the business of spying more difficult. As a result, these platforms are primarily used for SIGINT and MASINT missions offset from the target area.

Medium sized ISR aircraft are based on five different ISR versions of the C-130 platform.[31] They primarily fly signal intelligence missions, though some aircraft have been modified to fly imagery missions, including hyperspectral.[32] Like heavy aircraft, they are large, generating enough power to accommodate most sensor packages and can carry sufficient personnel to operate multiple missions simultaneously.

Light ISR aircraft are primarily the MC-12, there are 37 of these platforms in service.[33] It is the USAF’s newest manned ISR platform, performing both imagery and signals intelligence missions.[34] Due to its smaller size and power generation ability, it has restrictions on sensor types it can carry. This is mitigated by new technology and sensors, evidenced by over 4,000 targets captured or eliminated in just 18 months of Afghanistan operations.[35] The MC-12 clearly makes the point; legacy platforms are highly effective merged with cutting-edge technology.

The U-2 is the USAF’s only manned aircraft performing high altitude ISR. It was designed in the 1950s and still in high demand today. The U-2 is a “single-seat, single-engine, high-altitude/near space reconnaissance and surveillance aircraft providing signals, imagery, and electronic measurements and signature intelligence, or MASINT.”[36] The U-2’s service ceiling is above 70,000 feet and its long and narrow wings allow it to stay aloft close to the endurance of the human pilot while carrying large payloads. The ability to fly near-space, providing a wide field of view, gives an excellent vantage point to conduct ISR. Considering the aircraft has been in continuous service for over fifty years and its service life was again extended, it is easy to understand the need of this capability.[37]

All of the aircraft discussed to this point were designed between 1950 and 1970, and all have been continuously modified to meet emerging missions and capabilities. If an aircraft designed and built over 60 years ago, merged with cutting edge technology, can be tremendously effective on the modern battlefield, it serves as a useful predictor for 2035. This remixed technology when combined with increasing numbers of unmanned platforms is a viable strategy.

Remotely Piloted Aircraft (RPA) are the ISR backbone in today's USAF. The major versions are the MQ-1, MQ-9, and RQ-4 and there is little doubt that RPAs will be important to the future of the USAF. As one measure, "within two to three years, Air Force officials predict, drone pilots will outnumber F-16 pilots, numbering as high as 1,100 pilots."[38] Both the MQ-1 and 9 aircraft perform imagery and signals intelligence missions.[39] Relatively small, they can perform missions much closer to their targets; however this limits the type and number of sensors they can carry. Technology will make this better in the future. The RQ-4 is a high altitude aircraft performing the same mission set as the U-2; however its payload and capability is not currently as capable. The Air Force has decided to rely on the manned U-2 for the next 10-15 years, due to excessive costs and lack of capability associated with the RQ-4.[40] All of these drones can fly longer sortie durations than their manned counterparts and are not limited by human needs. Ironically, the major RPA advantage is that a human is not in the aircraft and in harms way; the main RPA disadvantage is that a human is not in the aircraft, which makes determining situational context more difficult.

There are other USAF remotely piloted aircraft that can operate in denied airspace, although little is officially published about them. The RQ-11, Scan Eagle and Wasp III are all small RPAs.[41] Their wingspan varies from 10 feet on the Scan Eagle down to 28 inches on the Wasp III. They are imagery platforms designed for close in surveillance and depend on their small size for survival; however, that small size naturally limits their payloads, at least based on current technology levels. The RQ-170 is a stealthy drone designed to penetrate denied airspace.[42] Little public knowledge is available on the capabilities of the RQ-170, other than it is capable of IMINT.[43] Recently an RQ-170 drone crashed well within Iranian borders, potentially yielding valuable data to a US adversary.[44]

Mobility aircraft consist of transport and refueling aircraft; they fly more sorties than any other USAF aircraft.[45] The USAF possesses over 700 of these aircraft, varying in size from the small C-12, C-21, & C-130 to the large KC-135, C-17, & C-5 platforms.[46] These large aircraft are able to fly thousands of miles, stay airborne for extended durations and carry large payloads. They routinely transit the globe, often over or near locations where valuable intelligence could be gathered. Due to their size, they could carry current ISR equipment with very little modification, which makes them appear like ideal candidates for an ISR platform.

However, mobility aircraft do not have an ISR mission, mainly due to restrictions created by their primary mission. Mobility aircraft transport people and equipment around the globe, enabling other services and combatant commanders. Mobility aircrews must file their flight plans and apply for diplomatic clearance to cross each applicable country.[47] Within the diplomatic clearance request, aircrews must list their manifest and mission. If crews were to list surveillance and reconnaissance, then some countries would likely deny over flight, affecting their primary mission of moving passengers and equipment. Additionally, many countries prohibit aerial photography and use of other sensing equipment.[48] US military mobility aircraft could perform these missions in a clandestine manner but if discovered, would likely mean undesired effects, such as future restrictions placed on these types of aircraft similar to those placed on fighter and attack aircraft.

There are over 1,200 fighter and attack aircraft currently in the USAF inventory.[49] They are relatively small and require either forward basing or aerial refueling to reach distant target sets. Faster than other aircraft, some like the stealthy and super-cruise capable F-22, are capable of penetrating denied airspace. All fighter aircraft can carry external pods, such as a Sniper pod used to visually acquire targets, ostensibly to aid in the target's destruction.[50] It is equally capable, when used as an ISR sensor, of performing what is called non-traditional ISR.[51] A key advantage to fighter aircraft is their ability to penetrate denied airspace; when dual tasked with an ISR mission they are able carry ordnance enabling immediate strike upon target acquisition. Although very capable, fighter aircraft are relatively small and have little open "real estate" to add ISR equipment, unless that equipment is placed in external pods.

Bomber aircraft are critical to the USAF's ability to strike globally. There are 150 intercontinental range bomber aircraft, consisting of B-1, B-2, and B-52 aircraft.[52] The low observable B-2 was designed to penetrate denied airspace. The B-1 and B-52 aircraft are not stealthy and rely on assistance from systems like the ADM-160 Miniature Air Launched Decoy (MALD) to penetrate denied airspace.[53] These aircraft can also carry large payloads including electronic warfare systems to help defeat enemy air defenses. They are large enough to carry most ISR systems. Currently the B-1 and B-52 can carry the same surveillance pods as current fighters enabling non-traditional ISR missions. Considering strike missions, it would radically accelerate the kill chain if ISR capabilities were wedded to the same platform conducting the strike. The USAF has already ceded this point when discussing the upcoming long-range strike family of aircraft.[54]

It is important to consider how ISR equipment is attached to the aircraft. Pods come in many shapes and allow rapid onload and offload of different sensors tailored to different mission sets. Sensors can be attached directly to the aircraft including the wing or fuselage. However, anything attached externally to an aircraft negatively affects stealth and overall range due to aerodynamic drag. Inside the aircraft, equipment is also required, such as processors, tuners, and power sources. Transmission capability is required if real-time data is desired off the aircraft. This can vary from a simple antenna to a satellite dish, but the quality of transmission is a function of type and availability of bandwidth.

Understanding the current types of sensors and the aircraft that carry them is important when considering what might be available in the future. The preceding two chapters clearly show that melding sensors to aircraft create capable airborne ISR platforms. Sensors are the enabler of this equation, and ever-increasing technological improvements will yield much more capable sensors. Proven aircraft with decades-old designs enabled by cutting-edge technology can, in the right environments, execute state-of-the-art surveillance and reconnaissance missions. It is important to understand these missions revolve around the sensor; aircraft exist to put the sensor at the right location at the right time. Current funding decisions and aircraft life extensions yield a situation where the aircraft in the current USAF inventory will still be in service in 2035. Continually modifying those legacy aircraft, both manned and unmanned, with state-of-the-art sensors is an effective strategy, especially in a fiscally constrained environment. The fact that the USAF already engages in this practice makes the point that the Air Force already subscribes to this logic. The USAF should focus a majority of its effort on a select few aircraft to meet the most dangerous future threats the nation could face. The USAF already follows this prescription, and it should be successful in the future. This is clear when considering future threats in the next chapter.

Recommendations

There are multiple options for what the USAF should do to prepare for the future. In order to frame the question of how the USAF should use existing and emerging platforms to conduct global strike, it is crucial to understand the potential international environment and likely threats in 2035. No one can say for certain what the world will look like in 2035. Considering exponential technology growth rates and corresponding impacts from globalization, it is safe to say the world will be much more connected. Adversaries across the globe could threaten the United States with off-the-shelf technology; national leadership needs the ability to hold them at risk, no matter where they sit. DoD experts have stated, "[d]uring this era, the United States has assumed a new joint expeditionary posture with fewer forward-based forces and most of its combat power based on sovereign soil."[55] To narrow the problem, this paper will only consider three general categories: first, a near-peer nation-state; second, a nation-state with significantly less capability; and third, a non-state actor.

While the operating environment may change, and systems may be different, airborne ISR will still be required in 2035. The USAF uses the find, fix, target, track, engage, and assess model, and ISR is crucial to the find, fix, and assess portions. Cyber and space based surveillance and reconnaissance will take on more importance and will be more prolific in 2035, especially in denied airspace areas. Surveillance assets in space and cyber are quite adept at finding the target. However those assets are not the best to fix the target during the final portions of the kill chain; this is where airborne ISR is often the best option. The question is not whether one category is better, but rather how best to integrate and synchronize the different options.

Most likely the current categories of sensors (IMINT, SIGINT, MASINT) will still be required. Sensors will be smaller, faster, and more capable while utilizing less power and could be installed on any conventional sized aircraft. Additionally, with advances in nanotechnology and work by DARPA, smaller platforms should be available.[56] The USAF has stated in congressional testimony that the majority of its aircraft inventory will be made up of legacy weapons systems, therefore current systems will be described before addressing radically new technology.[57] Operating under the assumption that sensors can be placed on any aircraft, then the potential operating environment should drive the type of platform utilized.

A near-peer nation-state is the most difficult problem. A near peer, by definition has robust anti-access capabilities presenting serious challenges to any offensive action. Compounding the problem is the long distance to the target area created by the likely retrenchment of US strike forces back into the CONUS. A near-peer's airspace is protected by modern air defense systems composed of surface to air missiles, augmented by capable fighter aircraft. In order to penetrate denied airspace, an aircraft requires speed, stealth, advanced electronic warfare, or better yet, a mixture of all three.[58] Considering the current USAF inventory, only the B-2 bomber and F-22 & F-35 fighter aircraft meet those requirements. If the target is outside fighter aircraft range from either forward basing or aerial refueling, that leaves only the B-2. Recognizing this problem, both the Secretary and Chief of Staff of the Air Force have committed to investing in a new family of long-range strike aircraft.[59] The USAF current Deputy Chief of Staff for Operations stated, "depending upon its payload, the new bomber will be able do everything from electronic attack to intelligence, surveillance, and reconnaissance and will be key to the U.S. military services' emerging Air Sea Battle doctrine."[60] Few details are available, so it can only be assumed that it will be both stealthy and fast. The F-22 & F-35, B-2, or the future long-range bombers are options for near-peer conflicts, and all should be capable of carrying any required sensor.

If global strike is required against a less capable nation state, this becomes a significantly easier problem. The key difference is while that airspace might be semi-permissive, it would not be denied. Notice that the condition of the government is not mentioned (*i.e.*, thriving or failed state), but rather the characteristics of the airspace. This can be equated to recent operations in Libya, Iraq, or Afghanistan. Any current or projected ISR, fighter, or bomber aircraft could be utilized, and the best platform to perform the required mission could be chosen. An earlier Blue Horizon study clearly substantiated the argument that if we prepare for the worst-case scenario then the lesser-included cases will fall into line.[61] Thus, if we prepare for the near peer then the challenges of fighting a less capable state will be easier.

Non-state actors or individuals are by definition not a nation; they are located, however, in one of the two previous categories of nation-states. The method for targeting them is a function of whether they reside in a near-peer with denied airspace, or a nation state whose airspace does not pose a significant challenge. The key problem in dealing with non-state actors, leaving aside attribution, is the political ramifications of targeting an individual or groups within a perhaps non-offending nation; this is outside this paper's scope, but it is a critically important issue. It is assumed that political issues have been addressed and the only area of concern for this category is the type of airspace. As stated in the previous two categories, it is the airspace type, whether denied or not, that drives the platform.

Therefore, the core problem is an ISR mission in the denied airspace of a near-peer to enable global strike. If done in conjunction with a strike then the F-22, B-2 or the future long-range bomber would suffice. A pre-strike ISR mission could be performed either by an RQ-170 or aircraft in the long range strike family. These assets should and could be modified with emerging sensors to perform the ISR mission, most likely in conjunction with global strike itself since these platforms could also execute the strike. Modifying legacy aircraft is relatively easy; the best recent example is the MC-12. This thirty-year-old platform was in combat utilizing cutting edge equipment just eight months after a requirement was defined and decision was made.[62] Therefore, it is logical to assume that rapid acquisition techniques could be used to acquire sensors and modify legacy aircraft. Additionally, sensors will benefit from more powerful computer processers to enable cueing from one sensor to another, such as cueing an IMINT sensor to a SIGINT or MASINT target, which enables visual tracking. Further, advances in communication systems will enable cueing from off-board sources. Unfortunately this only addresses ISR in what would be a fleeting or short duration mission, essentially reconnaissance. It does not address persistent surveillance, required to build patterns of life and holistic intelligence pictures. That requires another solution.

A recurring theme of improving technology is that better and faster products are typically much smaller than their preceding types. For example one of the main bombers in World War II was the B-17, with a wing area of 1,400 square feet and could carry about 8,000 pounds of bombs.[63] The main tactical fighter-bomber today is an F-15E; with a wing area of 608 square feet that is less than half the size of the B-17 yet it can carry about 25,000 pounds of ordnance.[64] Not only can the F-15E carry more with a smaller platform, it can do so flying faster, farther, and deliver it precisely in all weather conditions. This is enabled by one central concept, exponentially improved technology. That same theme will apply to sensor technology, with projected advances in such areas as nanotechnology; it is well within reasonable expectations to have sensors that could fit on insect- to small-bird-sized platforms. In 2007, a Blue Horizons paper concluded the technology was viable.[65] Recently, DARPA demonstrated an "extremely small, ultra lightweight air vehicle system (less than 15 centimeters and 20 grams) with the potential to perform indoor and outdoor military missions."[66] If a hummingbird-sized platform (figure 5) can be built today, imagine what can be built in 20 years. It is easily within the realm of the possible to have insect-sized platforms.

Figure 4. Hummingbird UAV with cutout showing wing size. Obtained from the internet http://www.darpa.mil/Our_Work/DSO/Programs/Nano_Air_Vehicle_(NAV).aspx and http://www.lockheedmartin.com/products/nano-air-vehicle.html

Those platforms will need sensors that are equally small. According to J.R. Wilson, "Among the host of possibilities for military nanotech are miniaturized ISR applications known as 'smart sand' or 'smart dust.' They can be configured as electronic noses the size of a grain of sand, able to analyze the immediate environment, identify chemical compositions, and report to a monitoring system."[67] Processors to control both the aircraft and sensor will have to be equally as small. "Researchers at the U.S.-funded MITRE Corporation and Harvard University have developed the world's first programmable nano-processor, a square chip of silicon that could fit within the diameter of a typical human hair."[68] If it is possible to have very small platforms, carrying equally small sensors, then these platforms can be used to great effect in denied airspace.

What if sensors were attached directly to weapons? In effect the USAF already does this with laser-guided or GPS-guided munitions. If IMINT, SIGINT or MASINT sensors were married to a weapon, it would shorten the kill chain. If small ISR platforms were in essence weapon themselves, they could be utilized like miniature kamikazes once the desired target was acquired, such as the Low Cost Autonomous Attack System program.[69] Changes to technology could easily lead to changes in missions.

It is a losing proposition for an adversary forced to defend against platforms as small as birds and insects that appear indigenous. These platforms could easily conduct long-term surveillance and reconnaissance developing the patterns of life critical to effective targeting of individuals. This solves the problem of persistent ISR, especially in denied airspace. Utilizing miniature assets to develop patterns of life would be very effective when integrated with other USAF assets. For example, miniature assets could maintain persistent surveillance of locations, such as tunnel or building entrances. "Dr. Siva Banda, senior scientist for control theory with the Air Force Research Laboratory (AFRL) Air Vehicles Directorate, described the purpose and value of 'fly on the wall' nano-air vehicles that 'are unobtrusive, evasive and lethal, inexpensive but capable, able to rapidly respond, are persistent and have insect-like maneuverability.'"[70] Simply put, they change the equation defining denied airspace.

This chapter makes it is clear that the USAF in 2035 should have a range of options utilizing both legacy and emerging technology. It is impossible to determine exactly what type of platform will be required or, for that matter, what specific sensor it ought to carry. However, the USAF will need platforms to penetrate denied airspace not only for strike missions, but surveillance and reconnaissance missions to gain the requisite intelligence. Merging radically new technology with legacy systems is a prescription for success that the USAF has already subscribed to, and in an austere fiscal environment, it is the most logical path into the future.

The USAF already modifies existing aircraft with emerging technology, enabling them to conduct missions well outside their original design parameters. This simple concept is key to the USAF future success in regard to ISR. No radical design program needs to be devised for ISR platforms; the platform is not the critical part of a successful ISR formula. The sensor is the key. The USAF can, and should, take advantage of emerging sensor technology as it becomes available. Key to this point is that many of the "things" which sensors will track in 2035 are not yet invented. Therefore, defining and programming for equipment to track the unknown is not a tenable plan, especially in a fiscally constrained environment. However, continually modifying existing or planned aircraft with new sensors is a tenable and proven plan. That is the point of this paper. The hardest problem faced by the USAF of today, or in the future, is penetrating and operating in denied airspace of a near-peer threat. However, platforms either exist or are already planned to solve this problem. Modifying those platforms to conduct ISR with emerging sensors solves a significant portion of the ISR problem as well. Technology advances in data transmission through air and spaced based assets should also yield more capability to integrate all ISR platforms. If the USAF acquires emerging micro vehicles to conduct persistent ISR in denied environments, it completes a recipe for success.

Conclusion

This paper advocates updating existing platforms with new technology rather than designing radically new platforms. This is done primarily due to the budgetary constraint driving fiscal responsibility and that inability to devote money to many different platforms. The USAF already appears following this logic, evidenced by the Chief's testimony to Congress:

“specific systems such as the F-35A, the centerpiece of our future tactical air combat capability; KC-46A, the backbone of our worldwide power projection capability and thus our Nation’s global expeditionary posture; and the Long-Range Strike family of systems, all represent substantial elements of our overall suite of capabilities and thus must all be pursued through disciplined—and certainly efficient—modernization efforts.” The USAF has done this throughout its history, successfully merging legacy systems with emerging technology.

At the beginning of this paper, a hypothetical mission was described utilizing current technology. Imagine in 2035, a terrorist leader is walking along a street in a remote African country. The terrorist is talking in his native dialect to his cell leaders on a skin-embedded communication device; the conversation revolves around a planned attack on a US embassy in a nearby country. This particular terrorist organization is high on the list of enemy organizations tracked by the US government. The terrorist leader has been under surveillance for the last two weeks after being discovered by a USAF ISR aircraft, conducting surveillance of a house occupied by another terrorist. This aircraft was perched on the branch of a nearby tree, and looked like a local bird. It carried both IMINT and SIGINT sensors, which enabled visual acquisition of the target, and recording of conversations within the monitored house. An intelligence analyst, a world away in the central US, was able to identify the terrorist leader. When the terrorist leader left the house, the aircraft followed him on fully-charged solar batteries. An F-22 participating in a multi-lateral exercise in a neighboring country could be re-tasked for a strike mission. Emerging technology makes this scenario well within reasonable reach.

There is no crystal ball unveiling the future with perfect accuracy. The USAF must prepare for uncertainty; but it is certain that the future requires global strike capabilities.

Effective global strike requires accurate targeting information. Surveillance and reconnaissance conducted in air, space, and cyberspace is the best way to gain this information and turn it into knowledge. All three domains are important, and all are required. This paper argued fiscal realities require a strategy taking advantage of merging new technology on legacy systems, and smart acquisition of new aircraft utilizing game-changing technology such as nanotechnology.

Bibliography

"12 Miles High, Changing Course", n.d. http://www.airforce-magazine.com/MagazineArchive/Pages/2009/February%202009/0209course.aspx.

"1st Baron Rutherford of Nelson Ernest Rutherford Quotes - 29 Science Quotes - Dictionary of Science Quotations and Scientist Quotes", n.d. http://www.todayinsci.com/R/Rutherford_Ernest/RutherfordErnest-Quotations.htm.

"A Tanker-Spyplane for the RAF? | Defense Tech", n.d. http://defensetech.org/2011/04/15/a-tanker-spyplane-for-the-raf/.

Abatti, J.M. *Small Power: The Role of Micro and Small UAVs in the Future*. DTIC Document, 2005.

"Advancements in Full-Motion Video for Military UAS Surveillance Applications :: Nasa Tech Briefs", n.d. http://www.techbriefs.com/component/content/article/8504.

"AeroVironment, Inc. (AV) : UAS Advanced Development Center: Black Widow (UAV) : UAS Advanced Development Center : AeroVironment, Inc. (AV)", n.d. http://www.avinc.com/uas/adc/black_widow/.

"AFDD1.pdf". US Air Force, October 14, 2011. www.e-publishing.af.mil/shared/media/epubs/AFDD1.pdf.

"Air Force Intelligence and Security Doctrine", n.d. http://www.fas.org/irp/doddir/usaf/index.html.

"Airborne SIGINT Payloads for Manned and Unmanned Aircraft." *Northrop Grumman*, 2012. http://www.is.northropgrumman.com/products/airborne_SIGINT_payloads/assets/Airborne_SIGINT_Payloads.pdf.

"AircraftProctPlan2012-2041_052511-1.pdf", n.d.

"AircraftProctPlan2012-2041_052511.pdf", n.d.

"Airforce-magazine.com Homepage", n.d. http://www.airforce-magazine.com/Pages/HomePage.aspx.

"Airpower Stats Through September 2011", n.d. http://www.airforce-magazine.com/datapoints/2011/Pages/DP100711airpower.aspx.

"AN/AAQ-28(V) LITENING Targeting Pod", n.d. http://www.es.northropgrumman.com/solutions/litening/index.html.

"Applications of Multispectral/hyperspectral Imaging Technologies in military--《Infrared and Laser Engineering》2007年01期", n.d. http://en.cnki.com.cn/Article_en/CJFDTOTAL-HWYJ200701003.htm.

"B-17 Flying Fortress : Definition of B-17 Flying Fortress and Synonym of B-17 Flying Fortress (English)", n.d. http://dictionary.sensagent.com/b-17+flying+fortress/en-en/.

Batey, Angus. "ISR Needs Put Fighters in Surveillance Role." *Aviation Week*, February 2, 2011. http://www.aviationweek.com/aw/jsp_includes/articlePrint.jsp?headLine=ISR%20Needs%20Put%20Fighters%20in%20Surveillance%20Role&storyID=news/dti/2011/02/01/DT_02_01_2011_p36-283449.xml.

"Can Technology Save the Military From a Data Deluge? | Popular Science", n.d. http://www.popsci.com/technology/article/2011-11/can-technology-save-military-its-technology.

Carlisle, Herbert. "Fiscal Year 2012 Combat Aviation Programs Update." Combined Statement to House Armed Services Committee. Washington DC, November 2011.

Church, Aaron. “RPA Ramp Up”, June 2011. http://www.airforce-magazine.com/MagazineArchive/Pages/2011/June%202011/0611RPA.aspx.
“Civilian (Looking) Spy Planes | Defense Tech”, n.d. http://defensetech.org/2011/06/22/civilian-looking-spy-planes/.
“Conference Detail for Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications IX”, n.d. http://spie.org/app/program/index.cfm?fuseaction=conferencedetail&conference_id=966973&event_id=957483&list=1.
“CSAF Vector 2011.pdf”, n.d.
D’Agostino, D.M. *Intelligence, Surveillance, and Reconnaissance: Actions Are Needed to Increase Integration and Efficiencies of DOD’s ISR Enterprise*. DTIC Document, 2011.
Davis, W.A. *Nano Air Vehicles: A Technology Forecast*. DTIC Document, 2007.
“Defense Acquisition Guidebook [DAG]”, n.d. https://dag.dau.mil/Pages/Default.aspx.
“Defense Secretary Panetta: Message”, August 3, 2011. http://www.defense.gov/home/features/2011/0711_message1/.
“Department of Defense Instruction, Number 5000.02”. Department of Defense, December 8, 2008.
Deptula, D. *Air Force Unmanned Aerial System (UAS) Flight Plan 2009-2047*. DTIC Document, 2009.
Deptula, D.A., and M. Francisco. “Air Force ISR Operations: Hunting Versus Gathering.” *Air & Space Power Journal* 24 (2010): 13–17.
Deptula, D.A. *Global Distributed ISR Operations: The Changing Face of Warfare*. DTIC Document, 2009.
Director, F.T. “Office of the Secretary of Defense.” *The Implementation of Network-Centric Warfare* (2005).
“Do the Math: Megapixel Recording Adds up | 2011-01-31 | SDM Magazine”, n.d. http://www.sdmmag.com/articles/86098-do-the-math-megapixel-recording-adds-up.
“DoD Electronic Foreign Clearance Guide”, n.d. https://www.fcg.pentagon.mil/.
“DON CIO News: Unmanning Unmanned Systems”, n.d. http://www.doncio.navy.mil/ContentView.aspx?ID=1756.
Donley, Michael, and Schwartz, Norton. “Fiscal Year 2012 Air Force Posture Statement”, February 17, 2011. www.au.af.mil/au/awc/awcgate/af/posture2011.pdf.
Dudley, Richard. “USAF Cancels Block 30 RQ-4 Global Hawk | Defense Update.” *Defense Update*, January 29, 2012. http://defense-update.com/20120129_usaf-cancels-block-30-rq-4-global-hawk.html.
“Enhanced Full-Motion Video Advances Military UAS Surveillance”, October 2010. http://www.zmicro.com/news/articles/enhanced-full-motion-video-advances-military-uas-surveillance.html.
“Expanding the Vision of Sensor Materials”, n.d. http://www.nap.edu/openbook.php?record_id=4782&page=62.
“Factsheets : AN/ASQ-236 Radar Pod”, n.d. http://www.af.mil/information/factsheets/factsheet.asp?id=17303.
“Factsheets : B-1B Lancer”, n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=81.
“Factsheets : B-2 Spirit”, n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=82.

"Factsheets : B-52 Stratofortress", n.d. http://www.af.mil/information/factsheets/factsheet.asp?id=83.
"Factsheets : E-4B", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=99.
"Factsheets : EC-130H Compass Call", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=190.
"Factsheets : F-15E Strike Eagle." *U.S. Air Force Official Website*, n.d. http://www.af.mil/information/factsheets/factsheet.asp?id=102.
"Factsheets : MC-12", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=15202.
"Factsheets : MQ-1B Predator", n.d. http://www.af.mil/information/factsheets/factsheet.asp?id=122.
"Factsheets : RC-135V/W Rivet Joint", n.d. http://www.af.mil/information/factsheets/factsheet.asp?id=121.
"Factsheets : RQ-11B Raven", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=10446.
"Factsheets : RQ-170 Sentinel", n.d. http://www.af.mil/information/factsheets/factsheet.asp?id=16001.
"Factsheets : Scan Eagle", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=10468.
"Factsheets : U-2S/TU-2S", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=129.
"Factsheets : Wasp III", n.d. http://www.af.mil/information/factsheets/factsheet.asp?fsID=10469.
"Fast Forward | Gannett Government Media | Defensenews.com", n.d. http://www.defensenews.com/article/20111001/C4ISR01/110010308/Fast-forward.
"Find, Fix, Track, Target, Engage, Assess", n.d. http://www.airforce-magazine.com/MagazineArchive/Pages/2000/July%202000/0700find.aspx.
"FISCAL YEAR 2012 AIR FORCE POSTURE STATEMENT.pdf", n.d.
"GAO Calls Defense ISR Programs Fragmented, Wants Tighter Management - SIGNAL Magazine", n.d. http://www.afcea.org/signal/articles/templates/Signal_Article_Template.asp?articleid=2643&zoneid=318.
Geis, John, Kinnan, Christopher, Hailes, Ted, Foster, Harry, and Blanks, David. "Future Capabilities and Technologies for the Air Force in 2030, Executive Summary", July 1, 2009. http://www.au.af.mil/au/awc/awcgate/cst/csat65.pdf.
"Gen. Norton Schwartz - Defense News", n.d. http://www.defensenews.com/story.php?i=4441029.
Gill, Victoria. "BBC News - Defence Lab Reveals Ultimate CCTV." *BBC News*, May 27, 2010. http://www.bbc.co.uk/news/10175960.
"Global Hawks Planned to Replace U-2 in 2015 | Defense Media Network", n.d. http://www.defensemedianetwork.com/stories/global-hawks-to-replace-u-2-in-2015/.
"Global Warfare Symposium", n.d. http://www.afa.org/events/NatlSymp/2011/GWS2011_scripts.asp.
"Goodrich ISR Systems (Sensors Unlimited) - InGaAs Near and Short Wave Infrared (SWIR) Cameras, Arrays, and Photodiodes", n.d. http://www.sensorsinc.com/.
"Goodrich to Upgrade U-2 Mission Payload With Multi-Spectral Sensors | Defense Update", n.d. http://defense-update.com/20110330_syers2a.html.

"Goodrich Wins U2 Multi Spectral Sensor Upgrade Contract", n.d. http://www.goodrich.com/Goodrich/Enterprise/News/InFocus-Archive/Goodrich-Wins-U2-Multi-Spectral-Sensor-Upgrade-Contract.
"Gov't Funds Nature-inspired Mini-spy Planes - CBS News", n.d. http://www.cbsnews.com/stories/2011/03/01/scitech/main20037593.shtml.
Hylton, Todd. "Defense Science Offices, Nano Air Vehicle (NAV)." DARPA, n.d. http://www.darpa.mil/Our_Work/DSO/Programs/Nano_Air_Vehicle_(NAV).aspx.
"Hyperspectral Sensors - The Flying Eyes That See the Invisible - Popular Mechanics", n.d. http://www.popularmechanics.com/technology/military/planes-uavs/hyperspectral-sensors-the-flying-eyes-that-see-the-invisible.
"Hyprspec.pdf", n.d.
"Imaging Applications of SWIR (Short Wave Infrared)", n.d. http://www.sensorsinc.com/whyswir.html.
"IMINT - Hyperspectral Imaging", n.d. http://www.globalsecurity.org/intell/library/imint/hyper.htm.
"IMINT 101 - Introduction to Imagery Intelligence", n.d. http://www.fas.org/irp/imint/imint_101.htm.
"Intelligence Programs and Systems - Alphabetical Listing", n.d. http://www.globalsecurity.org/intell/systems/list.htm.
"ISR Data Links - ViaSat", n.d. http://www.viasat.com/isr-data-links.
"Joint Electronic Library JEL, Joint Publications", n.d. http://www.dtic.mil/doctrine/new_pubs/jointpub.htm.
"JOINT SPECTRUM INTERFERENCE RESOLUTION (JSIR) PROCEDURES.pdf", n.d.
Kopp Carlo. "Evolving Technological Strategy In Advanced Air Defense Systems." *Joint Forces Quarterly*, April 2010.
"L-3 Communications WESCAM", n.d. http://www.wescam.com/products/products_services_mx15ithd.asp.
Leverett, Cory. "MC-12 Reaches Major Milestones in Afghanistan." *U.S. Air Force Official Website*, November 11, 2011. http://www.af.mil/news/story.asp?id=123278230.
"Lieutenant General David Deptula | The Edgefighter", n.d. http://edgefighter.com/tag/lieutenant-general-david-deptula/.
"Living With A Star: 2: Energy From The Sun: EM Spectrum." *The University of California*, n.d. http://ds9.ssl.berkeley.edu/LWS_GEMS/2/em.htm.
"Lockheed Martin C-130 'Shadow Harvest' Variant (United States) - Jane's Electronic Mission Aircraft", n.d. http://articles.janes.com/articles/Janes-Electronic-Mission-Aircraft/Lockheed-Martin-C-130-Shadow-Harvest-variant-United-States.html.
"Lockheed Martin Introduces Multiple ISR Aircraft and Ground Configurations for Military and Non-Military Customers | Lockheed Martin", n.d. http://www.lockheedmartin.com/news/press_releases/2011/3_1_11_AdditionalAMLOptions.html.
"Lockheed Seeks to Export Shadow Harvest Spy System for C-130s", n.d. http://www.flightglobal.com/news/articles/lockheed-seeks-to-export-shadow-harvest-spy-system-for-333319/.
"Low Cost Autonomous Attack System (LOCAAS)", n.d. http://www.globalsecurity.org/military/systems/munitions/locaas.htm.

"Lt.General D. Deptula - Air Force ISR in a Changing World - PPT Presentation.", n.d. http://www.militaryphotos.net/forums/showthread.php?178580-Lt-General-D-Deptula-Air-Force-ISR-in-a-changing-world-PPT-presentation.

Majumdar, Dave. "Long-range Bomber Will Be 1 Aircraft, Not Many - Air Force News | News from Afghanistan & Iraq - Air Force Times." *Air Force Times*, July 15, 2011. http://www.airforcetimes.com/news/2011/07/defense-long-range-bomber-will-be-1-aircraft-not-many-071511/.

———. "The Story of the Optical Bar Camera - C4ISRJournal.com - Military Intelligence, Surveillance, Reconnaissance", September 9, 2010. http://www.c4isrjournal.com/story.php?F=4740831.

"Micro Imagers For Sensing On Nano Air Vehicles: Science Fiction in the News", n.d. http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=2173.

"Micro-Hyperspec Imaging Sensors with High Dynamic Range for Harsh Environments.", n.d. http://www.headwallphotonics.com/integrated_micro-hyperspectral-imaging-devices.asp.

"MIT Lincoln Laboratory: ISR Systems and Technology", n.d. http://www.ll.mit.edu/mission/isr/ISRsystems.html.

"Nano Air Vehicle." *Lockheed Martin*, n.d. http://www.lockheedmartin.com/products/nano-air-vehicle.html.

"Nano Hummingbird | It's a Bird! It's a Spy! It's Both - Los Angeles Times", n.d. http://articles.latimes.com/2011/feb/17/business/la-fi-hummingbird-drone-20110217.

"National Aeronautics and Space Administration." *My NASA Data*, n.d. http://mynasadata.larc.nasa.gov/glossary.php?&word=electromagnetic%20spectrum.

"National Telecommunications & Information Administration", n.d. http://www.ntia.doc.gov/legacy/osmhome/roosa1.html.

News Desk. "Insect Sized UAV in Defense Labs :: Weekly Blitz." *Blitz Comprehensive Tabloid Weekly*, August 21, 2011. http://www.weeklyblitz.net/1678/insect-sized-uav-in-defense-labs.

"Northrop Secretly Develops Spy Plane in San Diego | SignOnSanDiego.com", n.d. http://www.signonsandiego.com/news/2011/may/09/nothrop-secretly-develops-surveillance-plane-san-d/.

"Northrop Unveils ISR Aircraft - World - Economy - Dalje.com", n.d. http://dalje.com/en-economy/northrop-unveils-isr-aircraft/357436.

"Obama Asks Iran for RQ-170 Sentinel Drone Back - ABC News", n.d. http://abcnews.go.com/Blotter/obama-asks-iran-rq-170-sentinel-drone-back/story?id=15140133#.Twy4S5iXO-I.

"Official Site of the U.S. Air Force - Factsheets", n.d. http://www.af.mil/information/factsheets/index.asp.

"Pakistan Tells U.S. To 'Vacate' Air Base As Border Strike Inflames Tensions | Fox News", n.d. http://www.foxnews.com/politics/2011/11/26/deadly-border-strike-inflames-tensions-between-us-pakistan/.

"Paris 26 Gigapixels - Interactive Virtual Tour of the Most Beautiful Monuments of Paris", n.d. http://www.paris-26-gigapixels.com/index-en.html.

Peck, Michael. "Nanoprocessor Challenge - C4ISRJournal.com - Military Intelligence, Surveillance, Reconnaissance." *C4ISR Journal*, May 12, 2011. http://www.c4isrjournal.com/story.php?F=6080151.

“Professional Aerial Photographers Association (PAPA) International: History of Aerial Photography”, n.d. http://www.papainternational.org/history.asp.
“Raytheon Company: Multi-Spectral Targeting System (MTS)”, n.d. http://www.raytheon.com/capabilities/products/mts/.
“Raytheon Company: Special Mission Aircraft/ISR Story to Go with News Conference”, n.d. http://www.raytheon.com/newsroom/technology/rtn11_dubai/news22/index.html.
“Raytheon’s MALD Decoys Gaining Versatility.” *Defense Industry Daily*, December 1, 2011. http://www.defenseindustrydaily.com/Raytheons-MALD-Decoys-Gaining-Versatility-04844/.
Schanz, Marc. “The Reaper Harvest”, April 2011. http://www.airforce-magazine.com/MagazineArchive/Pages/2011/April%202011/0411reaper.aspx.
Shalai-Esa, Andrea. “Exclusive: U.S. Air Force Terminating Northrop Unmanned Plane | Reuters.” *Reuters News Service*, January 24, 2012. http://www.reuters.com/article/2012/01/24/us-northrop-globalhawk-idUSTRE80N2EM20120124.
“Short Wave Infrared (SWIR) Concepts of Operation (ConOps) - Goodrich ISR Systems (Sensors Unlimited)”, n.d. http://www.sensorsinc.com/swirconops.html.
“SignalExploitationBroch.pdf”, n.d.
“Signals Intelligence - NSA/CSS”, n.d. http://www.nsa.gov/sigint/.
“Small Power: The Role of Micro and Small UAVs in the Future”, n.d. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA463472.
“Small Unmanned Aerial Vehicles Advanced Concept Technology Demonstration(SUAV ACTD)”, n.d. http://www.natick.army.mil/soldier/media/fact/techprog/SUAVs.htm.
“Sniper Pod | Lockheed Martin”, n.d. http://www.lockheedmartin.com/products/Sniper/.
“Speeches : Transformation and Air Force Intelligence, Surveillance and Reconnaissance”, n.d. http://www.af.mil/information/speeches/speech.asp?id=321.
Staff, J. “Joint Operations in the Electromagnetic Battlespace.” *Washington: Joint Staff* 37 (2000): 68.
Stefanou, Marcus. “A Signal Processing Perspective of Hyperspectral Imagery Analysis Techniques”, June 1997. http://www.nps.edu/faculty/olsen/Student_theses/stefanou.pdf.
Streland, A.H. *Going Deep: a System Concept for Detecting Deeply Buried Facilities from Space*. DTIC Document, 2003. www.au.af.mil/au/awc/awcgate/awc/streland.pdf.
“Suicide Micro-Drones”, n.d. http://defense-update.com/features/2010/december/31122010_suicide_uavs_5.html.
Sukach, Chris. “SecAF, CSAF Provide FY12 Budget Details.” *U.S. Air Force Official Website*, February 17, 2011. http://www.af.mil/news/story.asp?id=123243261.
“Switchblade - Miniature Loitering Weapon”, n.d. http://defense-update.com/products/s/switchblade_31122010.html.
“TacTical iSR Technology.pdf”, n.d.
“Tags: Global ISR”, n.d. http://www.raytheon.com/media/parisair2011/tags/global-isr/.
“The Air Force in Facts and Figures 2011 USAF Almanac.pdf”. AIR FORCE Magazine, May 2011. http://www.airforce-magazine.com/MagazineArchive/Magazine%20Documents/2011/May%202011/0511facts_figs.pdf.

"The Airborne ISR Market 2011-2021 by Visiongain in Technology, Military Aircraft, Surveillance", n.d. http://www.marketresearch.com/Visiongain-v1531/Airborne-ISR-6620692/.
"The Electromagnetic Spectrum." *Colour Therapy Healing*, n.d. http://www.colourtherapyhealing.com/colour/electromagnetic_spectrum.php.
"The EW World", n.d. http://www.tactical-isr-technology.com/tisr-home/354-tisr-2011-volume-1-issue-4-october/4792-the-ew-world.html.
"The Law of Accelerating Returns | KurzweilAI", n.d. http://www.kurzweilai.net/the-law-of-accelerating-returns.
"The Law of Air Mobility - the International Legal Principles Behind the U.S. Mobility Air Forces' Mission - Page 14 | Air Force Law Review", n.d. http://findarticles.com/p/articles/mi_m6007/is_66/ai_n56470571/pg_14/.
"Tomorrow's Spy Plane | Flight Today | Air & Space Magazine", n.d. http://www.airspacemag.com/flight-today/FEATURE-spyplane.html.
"Tough Cell - C4ISRJournal.com - Military Intelligence, Surveillance, Reconnaissance", n.d. http://www.c4isrjournal.com/story.php?F=5537004.
Trimble, Stephen. "Lockheed Seeks to Export Shadow Harvest Spy System for C-130s", October 9, 2009. http://www.flightglobal.com/news/articles/lockheed-seeks-to-export-shadow-harvest-spy-system-for-333319/.
"U-2 and Global Hawk Deployed to Survey Japanese Quake Damage | Defense Tech", n.d. http://defensetech.org/2011/03/15/u-2-and-global-hawk-deployed-to-survey-japanese-quake-damage/.
"U.S. Air Force Reveals Operational Stealth UAV", n.d. http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckBlogPage=BlogViewPost&newspaperUserId=27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog%3A27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3A649e3cf4-8c07-4739-82cf-322c6c56ccd5&plck.
"U.S. GAO - Intelligence, Surveillance, and Reconnaissance: DOD Can Better Assess and Integrate ISR Capabilities and Oversee Development of Future ISR Requirements", n.d. http://www.gao.gov/products/GAO-08-374.
"UAV Perspectives", n.d. http://www.tactical-isr-technology.com/tisr-home/328-tisr-2011-volume-1-issue-2-june/4375-uav-perspectives.html.
"UAV Sensors - Electro Optical, Infrared and SAR", n.d. http://www.uavm.com/uavsubsystems/imagingdatasensors.html.
"Uncooled Shortwave Infrared (SWIR) Cameras Open Up The Third and Final Window In The Infrared Spectrum - Goodrich ISR Systems (Sensors Unlimited)", n.d. http://www.sensorsinc.com/thirdwindow.html.
"Unmanned, Over Water, On Guard | Defense Media Network", n.d. http://www.defensemedianetwork.com/stories/unmanned-over-water-on-guard/.
"US Air Force to Develop Micro-UAV Killer Drones for the Special Operations Command Under LMAMS Program", n.d. http://defense-update.com/products/l/31122010_lmams.html.
"US Military Orders More King Air 350ER Aircraft [MC-12]", n.d. http://www.defenseindustrydaily.com/US-Military-Orders-More-King-Air-350ER-Aircraft-05165/.

“USAF Weighs Which ISR Programs To Cut | AVIATION WEEK”, n.d. http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/awst/2011/09/26/AW_09_26_2011_p30-373034.xml.
“Use of International Airspace by U.S. Military Aircraft”. Department of Defense, March 28, 2007. www.dtic.mil/whs/directives/corres/pdf/454001p.pdf.
“Warfighter’s Tactical SIGINT Resource (WTSR)”, n.d. http://www.es.northropgrumman.com/solutions/tacticalsigint/index.html.
Wilson, J.R. “Robo/Nano Spies and More | Defense Media Network.” *Defense Media Network*, April 20, 2011. http://www.defensemedianetwork.com/stories/robonano-spies-and-more/.
———. “Robo/Nano Spies and More | Defense Media Network.” *Defense Media Network*, April 20, 2011. http://www.defensemedianetwork.com/stories/robonano-spies-and-more/.
Wolfgang Wittenstein. *Survey of Hyperspectral and Multispectral Imaging Technologies.pdf*. RTO TECHNICAL REPORT. Neuilly-sur-Seine Cedex, France: NORTH ATLANTIC TREATY ORGANISATION, May 2007. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA473675.
“World’s Largest Digital Camera Receives Green Light from US Government”, n.d. http://www.petapixel.com/2011/11/09/worlds-largest-digital-camera-gets-green-light-from-us-government/.

Notes

[1] "AFDD1.pdf," 48.
[2] "Jp3_0.pdf," 37.
[3] "Meeting Our Fiscal and National Security Responsibility," Meeting our Fiscal and National Security Responsibility.
[4] "Department of Defense Instruction, Number 5000.02," 12–31.
[5] "Goodrich Wins U2 Multi Spectral Sensor Upgrade Contract," 2.
[6] "Factsheets : MC-12."
[7] Leverett, "MC-12 Reaches Major Milestones in Afghanistan," 2.
[8] "The Law of Accelerating Returns | KurzweilAI," The Exponential Growth of Computation Revisited.
[9] "1st Baron Rutherford of Nelson Ernest Rutherford Quotes - 29 Science Quotes - Dictionary of Science Quotations and Scientist Quotes," 19.
[10] "Jp1_02.pdf," 157.
[11] "Professional Aerial Photographers Association (PAPA) International: History of Aerial Photography," 1.
[12] "U-2 and Global Hawk Deployed to Survey Japanese Quake Damage | Defense Tech," 3.
[13] Majumdar, Dave, "The Story of the Optical Bar Camera - C4ISRJournal.com - Military Intelligence, Surveillance, Reconnaissance," 5.
[14] "Paris 26 Gigapixels - Interactive Virtual Tour of the Most Beautiful Monuments of Paris."
[15] Schanz, Marc, "The Reaper Harvest," 4.
[16] "Enhanced Full-Motion Video Advances Military UAS Surveillance," 4.
[17] "National Aeronautics and Space Administration," Glossary Section E.
[18] "Uncooled Shortwave Infrared (SWIR) Cameras Open Up The Third and Final Window In The Infrared Spectrum - Goodrich ISR Systems (Sensors Unlimited)," 3.
[19] Wolfgang Wittenstein, *Survey of Hyperspectral and Multispectral Imaging Technologies.pdf*, ES–1.
[20] "IMINT - Hyperspectral Imaging," 4.
[21] Ibid., 3.
[22] Gill, Victoria, "BBC News - Defence Lab Reveals Ultimate CCTV," Needle in a haystack.
[23] "Jp2_0.pdf," 122.
[24] "Airborne SIGINT Payloads for Manned and Unmanned Aircraft," 4–5.
[25] Ibid., 3.
[26] "Jp1_02.pdf," 217.
[27] "Jp2_0.pdf," 123.
[28] Streland, *Going Deep*, 21.
[29] "Factsheets : E-4B," 1.
[30] "Factsheets : RC-135V/W Rivet Joint," 2.
[31] "The Air Force in Facts and Figures 2011 USAF Almanac.pdf," 14.
[32] Trimble, Stephen, "Lockheed Seeks to Export Shadow Harvest Spy System for C-130s."
[33] "Factsheets : MC-12."
[34] "US Military Orders More King Air 350ER Aircraft [MC-12]," 6.
[35] Leverett, "MC-12 Reaches Major Milestones in Afghanistan."
[36] "Factsheets : U-2S/TU-2S," 2.

[37] Shalai-Esa, Andrea, “Exclusive: U.S. Air Force Terminating Northrop Unmanned Plane | Reuters,” 1.
[38] Church, Aaron, “RPA Ramp Up,” A Corps of Professionals.
[39] “Airborne SIGINT Payloads for Manned and Unmanned Aircraft,” 2.
[40] Dudley, Richard, “USAF Cancels Block 30 RQ-4 Global Hawk | Defense Update,” 2.
[41] “Factsheets : Wasp III”; “Factsheets : RQ-11B Raven”; “Factsheets : Scan Eagle.”
[42] “U.S. Air Force Reveals Operational Stealth UAV.”
[43] “Factsheets : RQ-170 Sentinel.”
[44] “Obama Asks Iran for RQ-170 Sentinel Drone Back - ABC News,” 1.
[45] “Airpower Stats Through September 2011.”
[46] “The Air Force in Facts and Figures 2011 USAF Almanac.pdf,” 14.
[47] “Use of International Airspace by U.S. Military Aircraft,” 4.
[48] “DoD Electronic Foreign Clearance Guide.”
[49] “The Air Force in Facts and Figures 2011 USAF Almanac.pdf,” 14.
[50] “Sniper Pod | Lockheed Martin.”
[51] Batey, Angus, “ISR Needs Put Fighters in Surveillance Role,” 21.
[52] “The Air Force in Facts and Figures 2011 USAF Almanac.pdf,” 14.
[53] “Raytheon’s MALD Decoys Gaining Versatility,” MALD and Its Variants.
[54] Majumdar, “Long-range Bomber Will Be 1 Aircraft, Not Many - Air Force News | News from Afghanistan & Iraq - Air Force Times,” 3.
[55] Carlisle, Herbert, “Fiscal Year 2012 Combat Aviation Programs Update,” 14.
[56] Wilson, “Robo/Nano Spies and More | Defense Media Network.”
[57] Carlisle, Herbert, “Fiscal Year 2012 Combat Aviation Programs Update,” 1–14.
[58] Kopp Carlo, “Evolving Technological Strategy In Advanced Air Defense Systems,” 93.
[59] Sukach, Chris, “SecAF, CSAF Provide FY12 Budget Details.”
[60] Majumdar, “Long-range Bomber Will Be 1 Aircraft, Not Many - Air Force News | News from Afghanistan & Iraq - Air Force Times,” 3.
[61] Geis, John et al., “Future Capabilities and Technologies for the Air Force in 2030, Executive Summary,” xv.
[62] Carlisle, Herbert, “Fiscal Year 2012 Combat Aviation Programs Update,” 14.
[63] “B-17 Flying Fortress : Definition of B-17 Flying Fortress and Synonym of B-17 Flying Fortress (English).”
[64] “Factsheets : F-15E Strike Eagle.”
[65] Davis, *Nano Air Vehicles*.
[66] Hylton, Todd, “Defense Science Offices, Nano Air Vehicle (NAV),” 1.
[67] Wilson, J.R., “Robo/Nano Spies and More | Defense Media Network,” 13.
[68] Peck, Michael, “Nanoprocessor Challenge - C4ISRJournal.com - Military Intelligence, Surveillance, Reconnaissance,” 1.
[69] “Low Cost Autonomous Attack System (LOCAAS),” 1.
[70] News Desk, “Insect Sized UAV in Defense Labs :: Weekly Blitz,” 19.