CONTINUOUSLY AVAILABLE BATTLEFIELD SURVEILLANCE

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Abstract

The question of what is necessary for the US to provide its fighting forces with continuously available surveillance of the battlefield is considered. The anticipated technological improvements forecasted to 2025 all support the conclusion that sufficient capabilities will exist should the US government choose to collect them into a single system. The resulting unmanned system will likely be a lighter-than-air vessel capable of operating for months or a stealthy derivative of the RQ-4 Global Hawk. The single largest hurdle for either system is the lack of political and military support for expanding existing unmanned systems. An Air Force sponsored survey conducted with several military, corporate and university experts which supports these conclusions is also presented.

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Acronyms

Above Ground Level (AGL)
Active Electronically Scanned Array (AESA)
Advanced Concept Technology Demonstration (ACTD)
Advanced Synthetic Aperture Radar Type 23 (ASARS-23)
Air Force Research Laboratory (AFRL)
Air Force Space Command (AFSPC)
Area of Operations (AO)
Area of Responsibility (AOR)
Artificial Intelligence (AI)
Battle Damage Assessment (BDA)
Close Air Support (CAS)
Combatant Commander (CCDR)
Combined Air Operations Center (CAOC)
Command, Control, Communication, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)
Common Data Link (CDL)
Common Operational Picture (COP)
Communications Intelligence (COMINT)
Concept of Operations (CONOPS)
Counter-insurgency (COIN)
Defense Advance Research Projects Agency (DARPA)
Demilitarized Zone (DMZ)
Democratic People's Republic of Korea (DPRK)
Department of Homeland Security (DHS)
Effects Based Operations (EBO)
Electronic Attack (EA)
Electronic Intelligence (ELINT)
Electronic Warfare (EW)
Electro-Optical/Infrared (EO/IR)
European Aeronautic Defence and Space Company (EADS)
European Space Agency (ESA)
Federal Aviation Administration (FAA)
Focus Long-Term Challenges (FLTCs)
Foreign Internal Defense (FID)
Forward Air Controller (Airborne) (FAC[A])
Full motion video (FMV)
Global Information Grid (GIG)
Global Persistent Attack (GPA)
Global Positioning System (GPS)
Ground Moving Target Indicator (GMTI)
High Altitude, Long Loiter (HALL)
High Altitude Airship (HAA)
Information Technology (IT)
Infrared (IR)
Integrated Air Defense System (IADS)

Integrated Defense Electronic Countermeasures (IDECM)
Integrated Sensor is Structure (ISIS)
Intelligence, Surveillance and Reconnaissance (ISR)
Integrated High Performance Turbine Engine Technologies (IHPTET)
International Atomic Energy Agency (IAEA)
International Civil Aviation Organization (ICAO)
Joint Broadcasting System (JBS)
Joint Surveillance and Target Attack Radar System (J-STARS)
Joint Warfighting Space (JWS)
Laser Infrared Counter Measure (LAIRCM)
Lighter Than Air ships (LTAs)
Live Fire Test and Evaluation (LFT&E)
Liaison Optique Laser Aéroportée (LOLA)
Low-Earth Orbiting (LEO)
Man portable air defense systems (MANPADS)
Missile Defense Agency (MDA)
Moving target indicator (MTI)
Multi-Mission Aircraft (MMA)
Multi-Platform Radar Technology Insertion Program (MP-RTIP)
Network-Centric Collaborative Targeting (NCCT)
Object-Orient-Decision-Action (OODA)
Operation Allied Force (OAF)
Operation Enduring Freedom (OEF)
Operation Iraqi Freedom (OIF)
Operational Test and Evaluation (OT&E)
People's Liberation Army (PLA)
Persistent Surveillance and Dissemination System of Systems (PSDS2)
Persistent Unmanned Maritime Airborne Surveillance (PUMAS)
Personal Digital Assistants (PDAs)
Quadrennial Defense Review Report (QDR)
Radar cross section (RCS)
Radio Frequency Countermeasure (RFCM)
Remotely Operated Video Enhanced Receiver (ROVER)
Semi Active Homing Radar (SAHR)
Semiconductor Intersatellite Link Experiment (SILEX)
Short Range Ballistic Missile (SRBM)
Small Diameter Bomb (SDB)
Space Based Radar (SBR)
Surface-to-Air Missile (SAM)
Suppression of Enemy Air Defense (SEAD)
Synthetic Aperture Radar (SAR)
Technology Readiness Level (TRL)
Time-sensitive-targets (TSTs)
Thrust Specific Fuel Consumption (TSFC)
Transformational Satellite Communications System (TSAT)
Unmanned Aerial System (UAS)

Unmanned Aerial Vehicle (UAV)
Unmanned Combat Aerial Vehicles (UCAV)
US Joint Forces Command (USJFCOM)
US Strategic Command (USSTRATCOM)
Versatile Affordable Advanced Technology Engines (VAATE)
Weapons of Mass Destruction (WMD)

CONTINUOUSLY AVAILABLE BATTLEFIELD SURVEILLANCE

"As commanders rely on more sophisticated and integrated ISR support, the [Strategic] command must supply unprecedented situational awareness for battlefield dominance." – James O. Ellis, Jr. Admiral, USN (Ret.)[1]

The Thesis of this Report:

What obstacles must be overcome to develop and field an Unmanned Aerial Vehicle (UAV) / Unmanned Aerial System (UAS) with multi-day endurance and all-weather sensors and weapons that can be controlled at the tactical level of combat? The first hurdle in the acquisition of any new system is justification. Why do we need it? This question is answered in Appendix B (The Past) of this document which provides evidence of surveillance aircraft successes and limitations. Current defense systems and aircraft attributes that increase their survivability are also discussed. The second hurdle for developing a new system is the mission. Can't what we already have do that? Examination of present US surveillance assets and the growing demand for their capabilities reveals an expanding battlefield surveillance deficit. This problem along with the inefficiency of space surveillance is discussed in Appendix C (The Present). The last hurdle is the uncertainty of the future. Will the technology provide an advantage worthy of its cost? This paper discusses the current and developing technologies that can be integrated into a survivable and enduring surveillance and strike asset. Technological advances before 2020 are emphasized due to the already long government procurement process which can take decades to evolve a new system from concept to fully operational. Further evidence supporting the rising need for these systems is given with examples of geographic coverage of specific nations. In summary, an aerial surveillance and strike asset capable of multi-day persistence is required to enhance current and future warfighter effectiveness.

The Future of Intelligence, Surveillance and Reconnaissance

"Timely and accurate information has become a decisive advantage in the shadowy global war on terrorism" – Admiral James. O. Ellis, Jr. USN (First Commander of U.S. Strategic Command)

Introduction

This paper provides a review of progressing technology which will support future military reconnaissance operations. In particular, near space aircraft and lighter than air vehicles are discussed. The reader is encouraged to first read Appendix B (page 41) which details the past operating environment and threats to surveillance aircraft. Appendix C (page 54) is also valuable in that present surveillance conditions are detailed which impact future designs. This paper will draw upon the conclusions presented in Appendices B and C.

Specific Operational Priorities for ISR and Communications

The 2006 QDR states: "The ability of the future force to establish an unblinking eye over the battle-space through persistent surveillance will be key to conducting effective joint operations."[2] The QDR goes on to state that this new capability will be integrated with operations all the way down to the tactical level of war.[3] These new systems must allow the warfighter to compete in the four defined priority areas of "defeating terrorist networks, defending the homeland in depth, shaping the choices of countries at strategic crossroads, and preventing hostile states and non-state actors from acquiring or using WMD."[4] As casualties mounted in Iraq of Oct 2006, the Pentagon re-emphasized the need for relevant research and development into new systems which could provide battlespace awareness and the ability to spot threats to ground forces early.[5]

To accomplish these goals, the QDR expands the challenges of US military forces from traditional warfare to now include irregular, catastrophic and disruptive challenges. As seen in

Figure 1, these new challenges enlarge upon the current mindset of military operations. The irregular challenge of defeating terrorist networks may be supported with current RQ-4 Global Hawk and RC-135 Rivet Joint aircraft. The catastrophic challenge of preventing acquisition or spread of Weapons of Mass Destruction (WMDs) and defending the homeland in depth requires much longer persistence so an unmanned near space airship is an ideal choice. The disruptive challenge of shaping choices of possible hostile countries requires persistence, stealth and possibly weapons so a low-observable, long-endurance UAV is required.

The agency responsible for developing the use of the near space environment is Air Force Space Command (AFSPC).[6] Since the near space regime is defined as altitudes between 65,000 and 325,000 feet, AFSPC was the logical choice. Interest in taking advantage of these extreme altitudes arose after combatant commanders (CCDRs) gave feedback that capabilities associated with space need to be more responsive and tailorable to the needs of the warfighter.[7] Once developed, the responsibility for coordinating these capabilities for the regional CCDRs would fall on US Strategic Command (USSTRATCOM).[8] USSTRATCOM also is the chief advocate for net-centricity, which requires an asset capable of providing high-bandwidth communications across the battlefield.

The battlefield communications requirement of high-bandwidth networks will continue to grow. This is a catalytic result of the transformation of older forces and systems into the new net-centric force envisioned by the Secretary of Defense.[9] The demand for secure communications is currently being met by government and civilian satellites, but as demand grows not even these systems will be able to keep up. One study has shown that airborne communication resources can reduce satellite communications by more than one third, making near space systems worth investigating.[10]

The systems acquired must be usable down to the tactical level of war and still be interoperable with the existing systems. Three combatant commands are already interested in exploiting near space possibilities: Central Command, Pacific Command and United States Force Korea (USFK).[11] A near space communications relay can solve one problem cited, which was the need for hand-held radios with greater range to allow Forward Air Controllers (FACs) to communicate directly with close air support (CAS) aircraft, allowing for more accurate support while minimizing aircraft exposure to enemy ground fire. Once fielded, more capabilities could be added as required whereas most satellites once launched, cannot be changed.

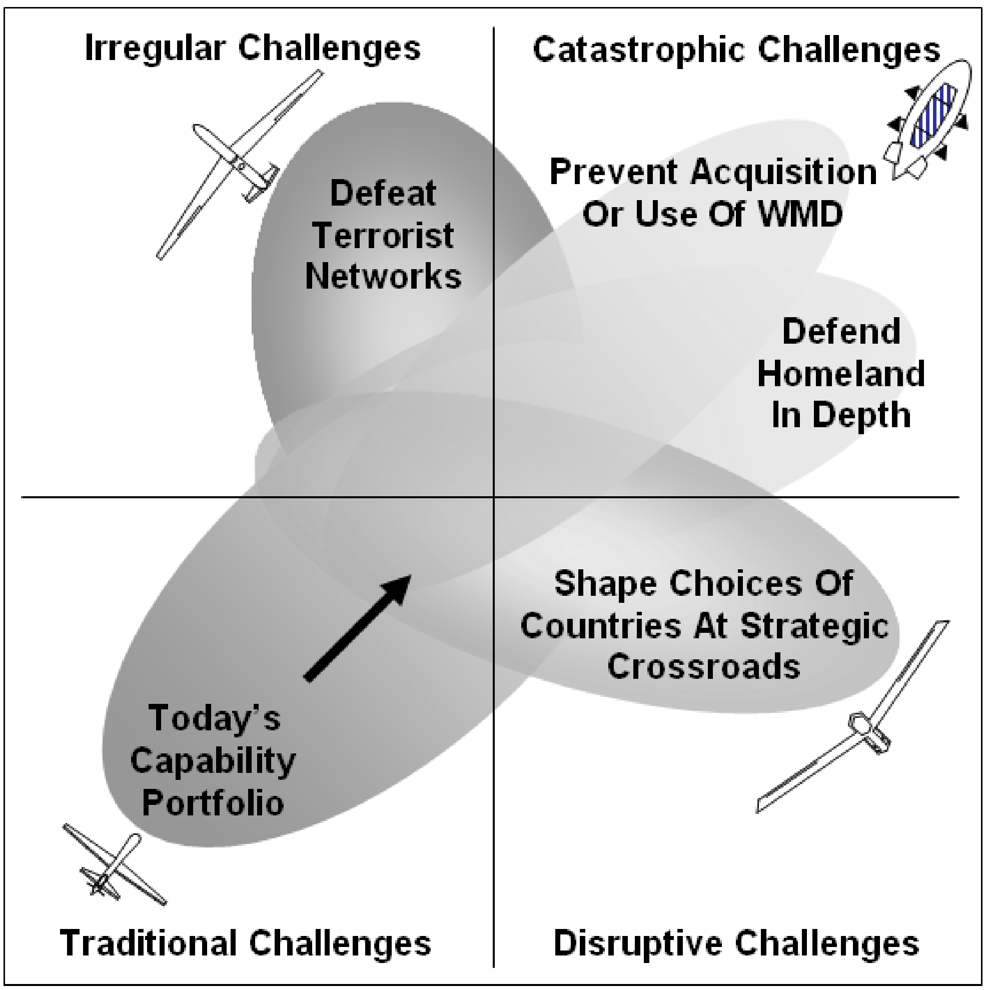


Figure 1. The Expanding Challenges for the US Military (adapted from the QDR Report)[12]

To determine which potential technologies are best suited for development for the warfighter, U.S. Joint Forces Command (USJFCOM) created Project Alpha. Part of the Joint Experimentation Directorate (J9), Project Alpha is examining balloons, high altitude UAVs and hybrid lighter than air (LTA) systems. With long sortie times in support of the QDR's transformation program, all of these systems are being grouped together under the High Altitude, Long Loiter (HALL) program. The goal of HALL is to provide "stay and stare" capabilities over the battlefield with continuous ISR support.[13]

The Advantage of Near Space

> *"We must determine what capabilities we can use in near space to improve the situational awareness of joint force commanders and leverage space power for all commanders in the field." – Gen. John Jumper, USAF Chief of Staff, 5 Oct 2004*[14]

By definition effects-based-operations (EBO) are focused on achieving desired effects instead of using specific systems or forces. This concept is also applicable to the sources that warfighters can draw on to achieve those effects – *ask not for a system, but for a system that can achieve your mission.* Placing assets in near space (65,000 to 325,000 ft) for extended durations can provide warfighters at the tactical level of combat with round-the-clock capabilities. Another positive attribute of this altitude band is the lack of other aircraft. FAA Order 7610.4 requires UAVs operating in the vicinity of other aircraft to provide "an equivalent level of safety, comparable to see-and-avoid requirements for manned aircraft."[15] Flight operations at high altitude will minimize the time where see-and-avoid concerns are a concern to other manned aircraft. The great coverage while operating at these extreme altitudes is detailed for specific locations in Appendix F (page 73).

Achieving continuously available surveillance is the goal of the recently formed Joint Warfighting Space (JWS) initiative.[16] The JWS budget for 2006 is $10.4M, much of which may go to near space programs.[17] One potential candidate capability is near space ISR imaging, which will provide much better images than satellites since they will be 20 times closer to the battlefield.[18] Communications payloads will allow information to reach pilots earlier in the kill chain further enhancing lethality and reducing enemy warfighter effectiveness.[19] The advantages and limitations for LTAs in this role while operating in the near space environment were summarized in a recent article and are presented in Table 1.[20]

Table 1. Advantages and Limitations of Near Space LTA Operations[21]

Advantages	*Limitations*
High altitude offers layer of defense	No existing platforms to build on
Enables net-centric operations	Sensors must be integrated in to a flexible surface
Enables continuous surveillance at better cost/benefit ratio than satellites or existing aircraft	Large quantities of power required for station keeping (nuclear power probably not an option)
Faster response to time-sensitive targets	Vehicle size grows significantly faster than payload size due to low density air for lift

The full potential for near space can only be realized in the hands of the warfighter. Lt. Col. Ed Herlik of AFSPC/JWS stated "With our current space capabilities, it's not that the information isn't available; it's just that relevant Battlespace Awareness doesn't always reach our forces" and "with near space, we believe we can provide persistence, payload and deterrence."[22] This capability is currently not achievable with periodic overflights of aircraft and satellites despite combatant commanders growing need for surveillance.[23] While the TacSat-1[24] experimental space satellite will attempt to lend control to the tactical user, many compelling arguments state this approach will not be cost effective compared to a single or few near space assets.[25] Former USAF Chief of Staff Gen. John Jumper wants to change the military focus to exploit near space, but recognizes it will be an uphill battle: “You never go to an air show to watch a balloon performance. They don’t put on a very good show and it’s just not very cool.”[26] To effect this change, *a significant rethinking of military operations and doctrine is necessary.*

Technological Advances in Aircraft Design: Lighter-Than-Air Ships

“With near space, we believe we can provide persistence, payload and deterrence” – Lt. Col. Ed Herlik, AFSPC Joint Warfighter Space Division[27]

Perhaps the most promising technology for meeting QDR goals of catastrophic challenges (Homeland Defense, Proliferation of WMD) is the Lighter-than-Air ship (LTA). Airships can be manned or unmanned, with reconnaissance or payload hauling their primary missions. US government interest is growing in these systems with a few planned for the prototype stage.[28] For this research, the primary benefit from this technology is the unique capability to place an ISR and strike payload over an area of interest for weeks or months at a time. The payload has the distinct advantage over space-based systems in that communications distances are shorter, sensors are closer to the action and power levels required for interaction with ground troops is reduced.[29] LTAs offer the advantage of continuous presence while operating above the Federal Aviation Administration / International Civil Aviation Organization (FAA / ICAO) controlled airspace (above 60,000 ft).[30]

The environmental conditions higher than 65,000 ft (above the jet stream and below the upper layers of the stratosphere) are relatively benign. Typical wind speeds between 65,000 and 85,000 ft are only 10 – 30 knots.[31] This condition is maintained throughout the year for many potential areas around the globe where an LTA might be used. Despite the mild conditions at altitude, the vehicle must still traverse the more turbulent weather below during launch and recovery. The time required for descent is estimated to be five hours with ascent estimated to be only one hour.[32] The difference between these is that descent requires far greater control to ensure landing at the correct location. Accounting for these extended periods of exposure to rough weather, planners may have to allow up to several days for the right environmental conditions.

Long endurance LTA designs must be capable of providing power for the entire duration of the mission. The long times involved (days or months) preclude the use of fossil fuels leaving only nuclear or solar power as options. Since nuclear power has many political and environmental restrictions, solar power is the only option currently under investigation. Sizing the solar panel area must take into account the power required for station keeping, battery charging for nighttime operations and the mission payload. Considering these criteria, an extensive analysis for different latitudes and seasons for a hypothetical design (10 kW payload power required, 22,000 pound payload at 70,500 ft) is presented by Coloza in NASA/CR-2003-212724.[33] Coloza's results showed that for US coastal observation all points along both east and west coasts were acceptable for this hypothetical LTA design except for one spot on the east coast between 40° and 44° latitude. The higher winds at altitude here would require a significantly larger power supply (1.8 MW) to perform the same mission.[34]

The results from this study also point to areas where improvement can provide the greatest advantages to LTA design. As shown in Table 2, specific advances in these areas can have a big impact. In designing an LTA, the energy balance for the entire system is the first critical step. The vehicle must be able to supply the power necessary to keep the ship on station while performing the mission even during periods of darkness.[35] Accounting for winds and sun angle at the intended station of use, the total power required can be estimated. The power required determines the fuel cell and motor size. With appropriate assumptions as to component mass and efficiency, a baseline design can be completed.

Table 2. Critical Technology Advancements for LTAs for 2010-2020[36]

Component	Future Advancement	Lessons Learned
Solar Cells	Increase efficiency by 50 percent and incorporate into outer skin structure	Engines may be largest consumer of power and they operate day and night
Drive Train (motor, prop)	Decrease weight by 25 percent	Induction motors don't require permanent magnet therefore lighter, induction motors can share common shaft, AC induction motors now heavily researched as part of auto industry, dual prop design with one for station keeping and a larger one for gusts,
Fuel Cell / Electrolyzer Specific Energy	Increase by 160 percent	Works best when kept cold, but lack of atmosphere may require liquid coolent, fuel cell design incorporating Hydrogen/Oxygen electrolyzer instead of atmospheric compressor wins in design trade off based on mass and energy required, fuel cell design using oxygen instead of air needs maturity
Fuel Cell Efficiency	Increase by 30 percent	Existing designs still capable of significant maturity
Electrolyzer Efficiency	Increase by 30 percent	Existing designs still capable of significant maturity
Lifting Gas	Switch from Helium to Hydrogen	Would allow for interoperability between fuel cell and lifting bag, air bag could be repressurized on station

Walrus, a maneuverable airship program initially funded by the Defense Advance Research Projects Agency (DARPA), was intended for the heavy transport role.[37] Designed for transfer of 500 to 1,000 tons (1-2 million pounds) up to 12,000 nautical miles, the system would have allowed for military forces to directly enter an AOR in less than seven days.[38] A civilian derivative (SkyCat-220) was also planned.[39] Despite growing US Army interest, Congress cancelled FY06 funding for the Walrus program.[40] Had the Walrus program continued, technology derived from it such as materials and controls could have been used as a baseline for continuous surveillance applications.

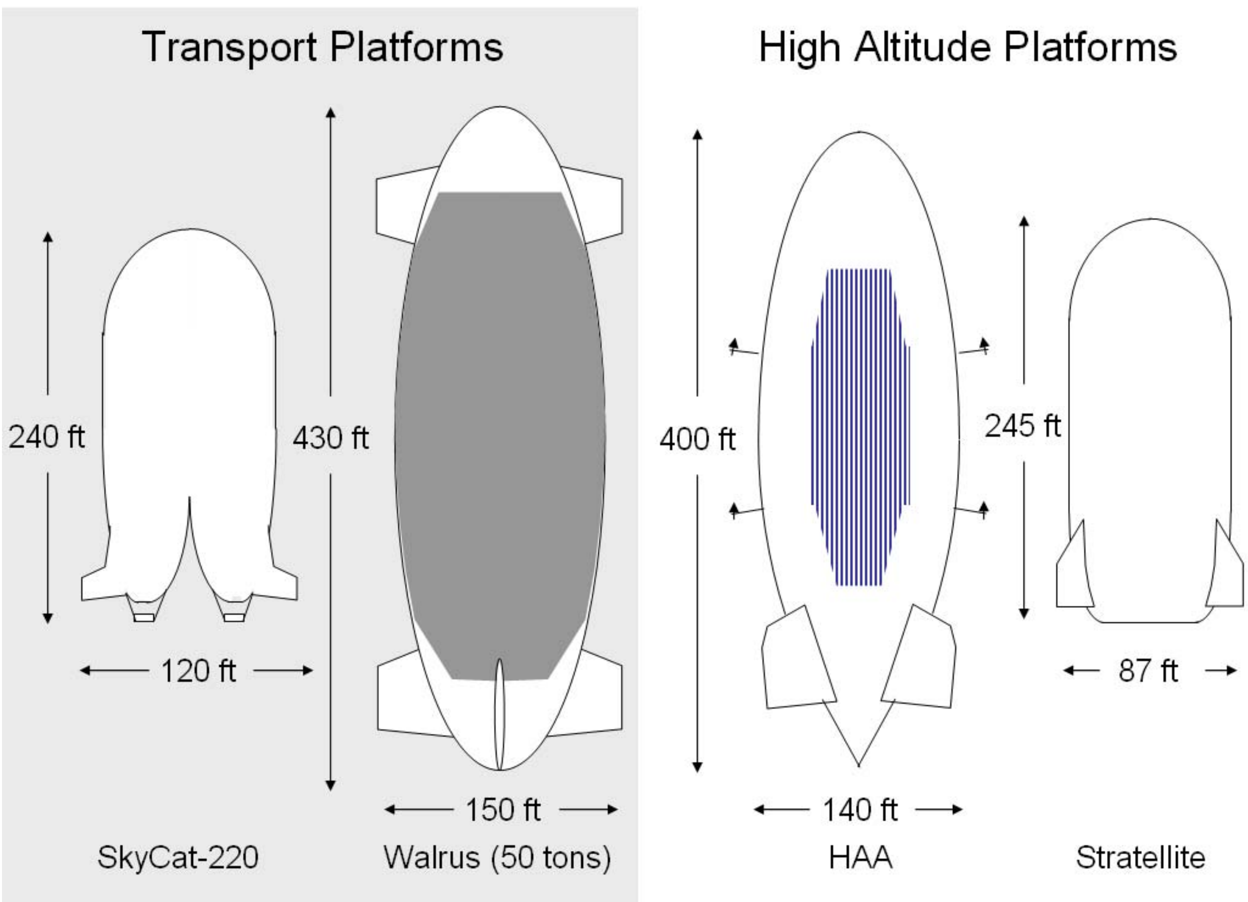


Figure 2. Comparison of Proposed Low and High Altitude Airships[41]

The most promising commercial attempts at producing a new LTA are the SkyCat 220 and Stratellite. The SkyCat-220 was envisioned as a broadband and mobile wireless provider. Operating at 10,000 ft and providing up to 1,600 cells (equivalent to 400 cell towers) the SkyCat 220 would have an endurance measured in days.[42] The portability of the system would have allowed its deployment for military use in AORs. The cancellation of its government predecessor however makes this program unlikely to see further development.

The hopes for an aerial based broadband communication system are not yet dead. The Stratellite is being developed by Sanswire Networks of Atlanta, GA for wireless broadband service. The vehicle is designed to operate at 65,000 ft with a 2,800 pound payload.[43] The military utility of such a design is appealing to many agencies, including the Missile Defense Agency (MDA) and the Department of Homeland Security (DHS). A single Stratellite is estimated to provide network coverage to 300,000 square miles at a cost of $25 - $30M per vehicle.[44] A military version would be capable of providing the required continuous EO/IR/SAR surveillance that CCDRs are requesting with negligible latency compared to the 0.25 second delay for signals traveling between the battlefield and geosynchronous orbiting satellites.[45]

The high altitude airship (HAA) prototype under development by Lockheed Martin for a $149M MDA contract is designed exclusively for homeland defense.[46] The prototype is part of the Advanced Concept Technology Demonstration (ACTD) program. The ACTD test article will operate initially for one month, with subsequent tests expanding this to one year. Internal payload capacity will be 4,000 lbs with a 10 kW power supply.[47] Envisioned as just one of ten eventual airships (production cost estimated at $50M each), the Lockheed Martin HAA will provide radar surveillance for detection of ballistic and low-flying cruise missiles. This network will operate continuously around the clock in a manner originally conceived by Gen. Billy Mitchell for homeland defense.[48] The detection diameter for the system is predicted to be 750 miles.

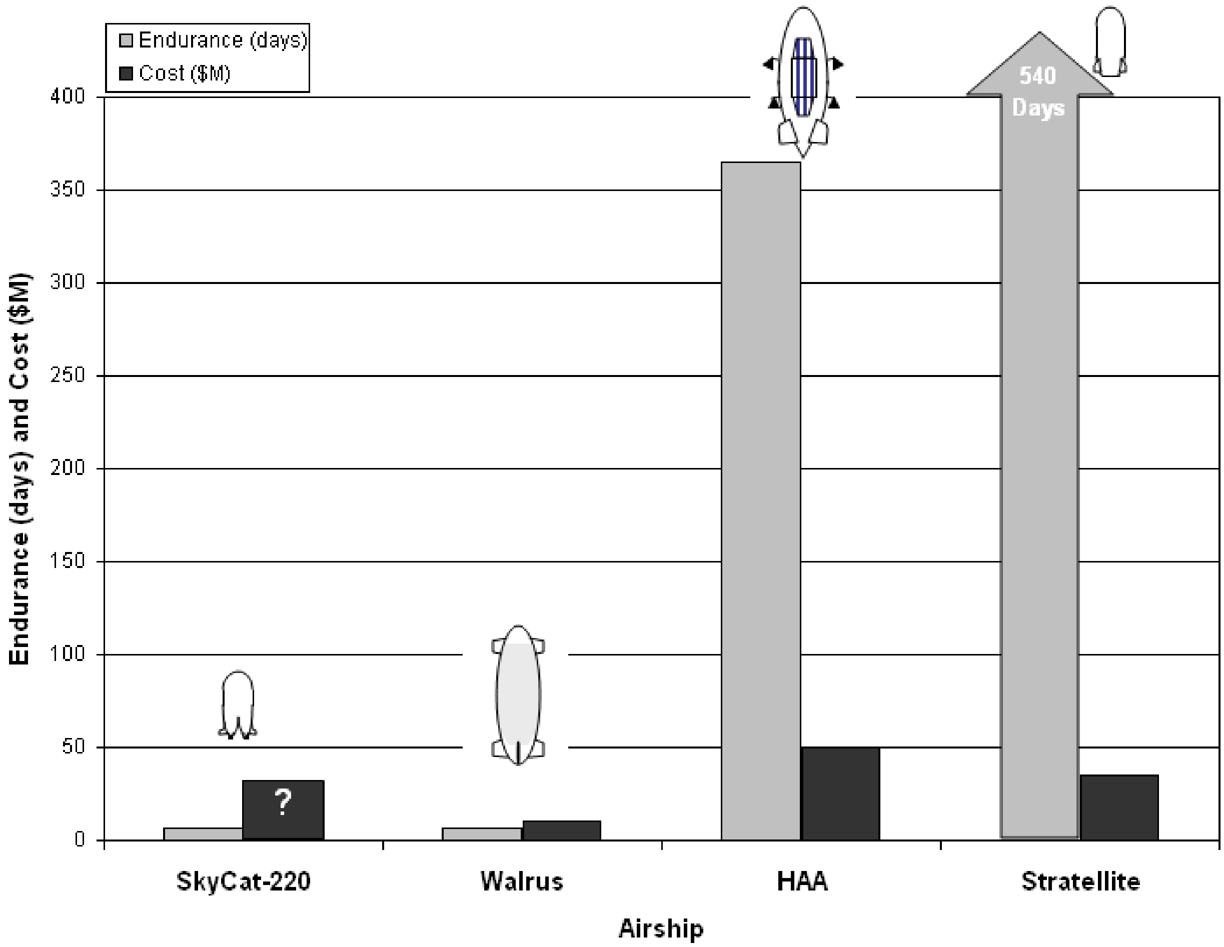


Figure 3. Comparison of Cost and Endurance for LTA Designs[49]

The Lockheed Martin HAA faces several design challenges. First, solar cells capable of providing the high power required for the system while surviving for years in the high ultra-violet environment must be developed. See *Technological Advances in Solar Cell Technology* on page 21 for more information. The current HAA design is for a constant volume where changes in temperature affect only the pressure of the lifting gas. This in turn alters the stress in the hull fabric. Materials capable of withstanding these stresses while exposed to ultraviolet radiation for extended periods are still in the experimental stage. If a constant pressure design were adopted, controls capable of overcoming the changes in buoyancy due to heating and cooling of the helium would have to be developed. The radar design must also be applicable to a flexible fabric-like skin. See page 25 for further information.

The MDA HAA project is scheduled for testing from 2007 to 2010. If successful, the design could serve as a baseline for future warfighter development. Should a combat version be procured, several risks requiring further study (see Table 3) were identified. In particular, lessons learned from past LTA programs recommended that immediately disposable ballast to recover from mishaps during ground handling be included. Also, the ability to drive the engines to much higher speeds is required when poor weather demands quick action.[50]

Table 3. Military High Altitude Airship Issues (adapted from Rand Study #TR-234)[51]

Issues	Risk Management Approach
Envelope material (strength and weight)	Restrict ascent / descent conditions
Thermal control (superheat)	Incorporate reflective material
Helium leakage	Limit endurance; use hydrogen from fuel cells
Photovoltaic cells	Limit endurance; operate in latitudes less than 38° for adequate solar power
Fuel cells	Use Li-polymer batteries as fallback
Weatherability	Restrict ascent / descent conditions; improve weather prediction; provide emergency ballast dump; add sprint engine(s)
Survivability	Operate within own air defense envelope; employ ALQ-214 IDECM RFCM suite to counter RF/IR/EO missiles

Figure 3 presents a comparison of the costs and endurance of the cargo and surveillance LTA designs. The cost and endurance for each system is speculative, as none are complete. Of special note, the high HAA cost includes the system payload, which the others do not. Breakdown of a separate HAA vehicle cost was not available. The important theme of Figure 3 is that when comparing system cost to endurance, the LTA designs offer one significant advantage over existing ISR aircraft (contrast with Figure 17 on page 57) – *endurance*. The endurance numbers on Figure 3 are *days* not hours representing more than an order of magnitude increase in mission presence. This capability is potentially the same cost as existing systems. Also, the risk of accident during take-off and landings is reduced for LTAs due to their long endurance. Additional information regarding limitations and survivability of LTAs is presented in Appendix D (page 63).

Technological Advances in Aircraft Design: High Altitude UAVs

The existing Helios UAV is solar powered, capable of flights up to 96,000 ft and can stay aloft for days.[52] While this may sound like a probable candidate for continuous battlefield surveillance, it has one great limitation – payload. The Helios is only capable of a 551 pound payload which must be distributed along its wingspan.[53] This design does not allow for the more substantial radars and weapons a battlefield asset requires. While future technological improvements will result in lower weight payloads, the Helios design limitations will not change. Other systems potentially capable of ISR payloads are illustrated in Figure 4.

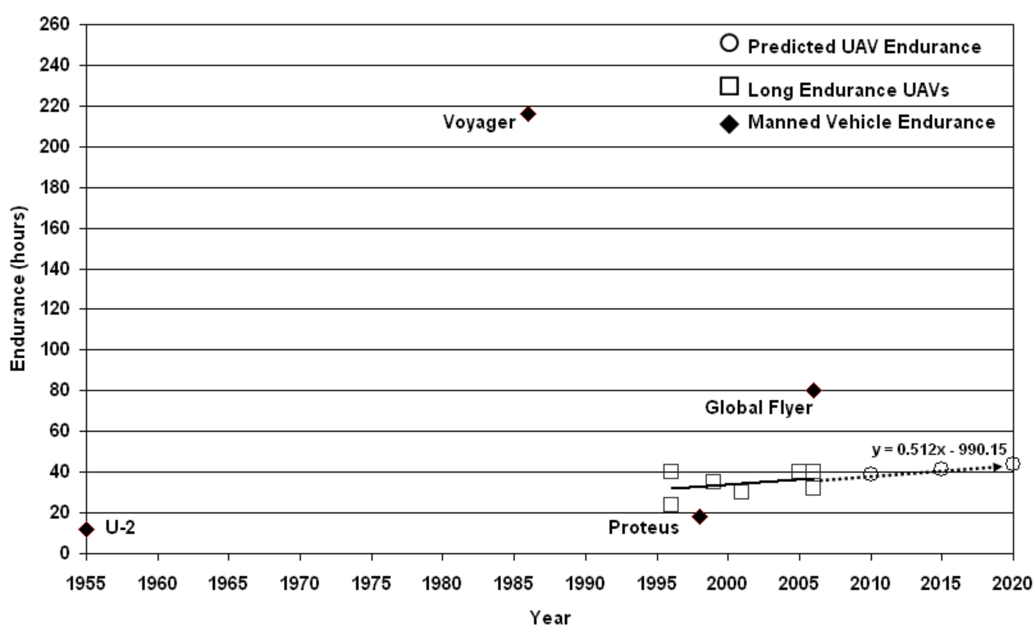
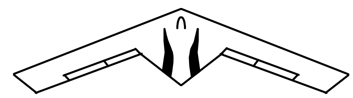


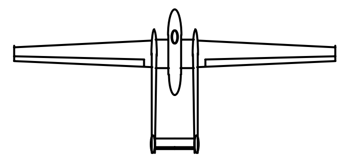
Figure 4. Endurance Trends for Manned and Unmanned Aircraft[54]

Figure 4 shows recent UAVs capable of transporting useful payloads (A-160 Hummingbird, RQ-1 Predator, RQ-4 Global Hawk, MQ-9 Reaper, Heron, Theseus, P-175 Polecat) over long distances.[55] Connecting these systems with an endurance trend line forecasts limited growth in average endurance until 2020. One reason for this is engine technology. Advances in engine technology, particularly increased thrust specific fuel consumption (TSFC) - which can be thought of as an equivalent to miles-per-gallon, is scheduled to be very limited. The AFRL Integrated High Performance Turbine Engine Technologies (IHPTET) program resulted in several advancements allowing a 2x increase in thrust to weight ratio. Long endurance aircraft however need improvements in fuel efficiency, not thrust. The current AFRL program – Versatile Affordable Advanced Technology Engines (VAATE) offered some hope in this area but funding has been cut by 50 percent.[56] Even if the VAATE program is cut, naturally evolving engine technologies will be sufficient for a 40+ hour endurance even when installed into a stealthy aircraft. Despite the uncertain results of VAATE, other research may result in higher engine efficiencies, including the use of dimples engraved into the surface of the low pressure turbine blades.[57]

The manned systems do not yield any statistical trend due to the one-of-a-kind nature of their designs. Also, the two manned systems with the greatest endurance, Voyager and Global Flyer, were designed for a payload of only one or two people requiring minimal electrical power and no redundant systems. A variant of these craft for ISR purposes would require significant rework and would result in significantly reduced endurance times. Endurance extension can be achieved through aerial refueling, which is currently under study for UAVs by both government[58] and contractor teams.[59]

Table 4. Two Possible Design Paths for Long Endurance UAVs and UCAVs[60]

	EO:	capable	***STEALTH***
	IR:	capable	
	SAR:	capable	
P-175	Endurance:	40 hours	
	Altitude:	65,000 ft	
	Cost:	$27 Million	
	Weapons:	none	Polecat

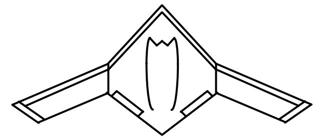
	EO:	MOSP (TV)	***TRADITIONAL***
	IR:	MOSP (IR)	
	SAR:	EL/M 2055	
Heron	Endurance:	40 hours	
	Altitude:	30,000 ft	
	Cost:	unknown	
	Weapons:	none	Heron

The future of unmanned aircraft surveillance will likely follow two paths: stealth and less expensive traditional designs (see Table 4). The stealth UAV trend recently started in the US with the development of the X-45 and X-47 Unmanned Combat Aerial Vehicles (UCAV). While the X-45 program has been cancelled, the X-47 continues in development for the US Navy. European designs include the British Corax, French nEUROn and EADS Barracuda. All of these UCAVs are low observable but their endurance is unacceptable for the persistent surveillance mission. Despite this limitation, the proliferation of low observable UCAV technology in Europe will give them an edge in developing future derivatives should they choose. A comparison of these is available in Table 5 (not shown are the Sky-X (Italy), FILUR (Sweden) and Raven (UK) low observable UAVs currently in development in Europe).

The first potential stealthy ISR unmanned platform is the P-175 Polecat developed by Lockheed Martin. While just a corporate prototype, the P-175 (see Table 4) was built to test three new features critical to future UAV success: new rapid prototyping techniques using composite materials, aerodynamic performance features required for sustained flight at 65,000 ft and autonomous flight control systems.[61]

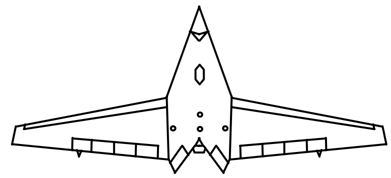
Table 5. Low Observable UCAVs Currently In Development (3 are European Designs)[62]

X-47B	EO/IR:	Capable
	SAR:	Capable
	First Flight	2007
	Endurance:	Unknown
	Altitude:	40,000 ft
	Cost:	Unknown
	Weapons:	Capable



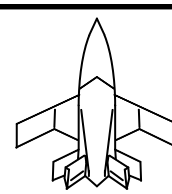
Pegasus

Corax (UK)	EO/IR:	Capable
	SAR:	Capable
	First Flight	2004
	Endurance:	Unknown
	Altitude:	40,000 ft
	Cost:	Unknown
	Weapons:	Capable



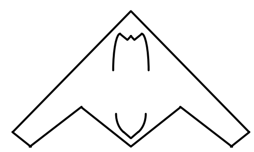
Corax

Barracuda (EADS)	EO/IR:	Capable
	SAR:	Capable
	First Flight	2006
	Endurance:	Unknown
	Altitude:	Unknown
	Cost:	Unknown
	Weapons:	Capable



Barracuda

nEUROn (France)	EO/IR:	Capable
	SAR:	Capable
	First Flight	2011
	Endurance:	Unknown
	Altitude:	Unknown
	Cost:	$480 M
	Weapons:	Capable



nEUROn

The low observable, long endurance UAV is the best candidate for persistent surveillance in an environment where air superiority either does not exist or is not yet desired. In the survey conducted by the USAF Air Command & Staff College, participants were asked what type of aerial platform would be most useful in detecting and tracking an enemy threat. Christopher Miller (Smart Information Flow Technologies) stated that:

> "reduced detectability, either through stealth, small size or high altitude, will become increasingly important for both survivability and for the ISR role (not giving away position/surveillance). Increased endurance will be important. Improved payload (especially for sensors, communication and computational processing)."[63]

The need for a long endurance, low observable platform was echoed by other survey responders including RADM Thomas J. Cassidy Jr. USN {Ret} (President/CEO, General Atomics Aeronautical Systems) and Bruce Carmichael (VP, L-3 Communications). Additional survey results are presented in Appendix A on page 32.

The traditional path to UAV development is typified by the Heron UAV. While not capable of operation at higher altitudes required for moderate survivability against man-made and environmental threats, the Heron is still a capable aircraft with a payload of 550 pounds featuring EO/IR/SAR payloads as well as additional space for mission specific sensors.[64] The configuration is a twin boom propeller driven design, allowing for easy configuration changes. Future UAV developments will likely fall into one of these two categories with less expensive systems developing on the RQ-1 and MQ-9 designs and the most expensive and survivable systems following the RQ-4 and P-175 designs.

Table 6. Listing of Potentially Beneficial Technologies

Section:	Useful For:	Page No.
Morphing Wings	UAVs	20
Weapon Systems	UAVs and HAAs	20
Solar Cells	HAAs	21
Fuel Cells	HAAs	23
Radio Relays	UAVs and HAAs	66
Data Integration and Management	UAVs and HAAs	66
Data Links	UAVs and HAAs	69
Traditional Radar Systems	UAVs and HAAs	23
Conformal Sensors	UAVs and HAAs	25

Another unique design still on the drawing board is the Pegasus. A European project, Pegasus will use solar or fuel cells on a traditional UAV design instead of fuel. The designer's goal is for sustained flight at 65,000 ft for several months.[65] The payload will initially consist of only 4.5 pounds of EO and IR sensors using 1 kW of electrical power. Scaling up the payload is difficult due to the electrical power requirements and volume constraint of the design. Specific technologies that may benefit UAV or HAA designs are discussed in the following sections. An overview is presented in Table 6.

Technological Advances in Aircraft Design: Morphing Wings

The concept of wing morphing refers to changes in the wing chord or aspect ratio while in flight. Also known as "adaptive compliant" structures, the shape of the wing can be changed without external hinge lines or structures which can disrupt airflow over the wing. Range or endurance can be improved by five to fifteen percent using this technology.[66] This is accomplished through micro-electromechanical mechanisms embedded inside the wing which change several times per second to achieve optimal flight performance. The first example flew 1 Aug 2006 in which a 100 pound UAV changed its wing area, chord, sweep and aspect ratio during flight.[67] Additional tests with a 200 pound UAV are planned for 2007. Another study using the US Marine Corps Dragon Eye UAV as a baseline (with multiple active winglets added) demonstrated a 30 percent increase in payload or a 40 percent increase in endurance can be achieved.[68] Morphing wing technology also provides an enhancement to survivability with the reduction or elimination of control surface gaps, allowing greater stealth.[69] Refinement of this technology will play a critical role for the designers of long endurance surveillance aircraft operating in the 2020 – 2030 timeframe.

Employment of Weapons in to a Continuous Surveillance Asset

The extremely high altitude of near space restricts the use of the AGM-114 Hellfire missile as previously proven on the MQ-1 Predator. Instead, the Small Diameter Bomb (SDB) may be used with its Global Positioning System (GPS) enhanced guidance system.[70] Another potential candidate system is the Top Cover missile. As designed, Top Cover can incorporate both munitions and surveillance payloads into the same missile. The missile's estimated cost is $200K and is capable of carrying a 44 pound payload for over 24 hours.[71]

Existing weapons which may be compatible include the selection of gravity and glide weapons. The range of gravity weapons such as the Guided Bomb Unit – 28 (GBU-28) and glide weapons such as the SDB is considerably enhanced when launched from a near space altitude. Powered weapons such as the Joint Air-to-Surface Standoff Missile (JASSM) will also benefit from the high altitude launch platform. The communications and computing capability of the near space system will provide any GPS or data link updates necessary for proper weapons function.

Technological Advances in Solar Cell Technology

Current state of the art solar cell technology provides 0.64 kW per pound.[72] Current solar cell efficiencies peak at 35 percent for laboratory tests, with commercial grade cells usually operating at half that value. Thomas Surek created a trend graph (see Figure 5) of solar cell efficiencies for the past thirty years.[73] Extrapolating these trends and assuming that production efficiencies can equal those in the laboratory, the maximum efficiency to be expected is approximately 50 percent. Assumptions in this estimate include all problems with manufacturing will be solved, flexible thin film array efficiency will rise to match rigid arrays, market share will grow to support additional research and materials availability issues will not be a concern.[74]

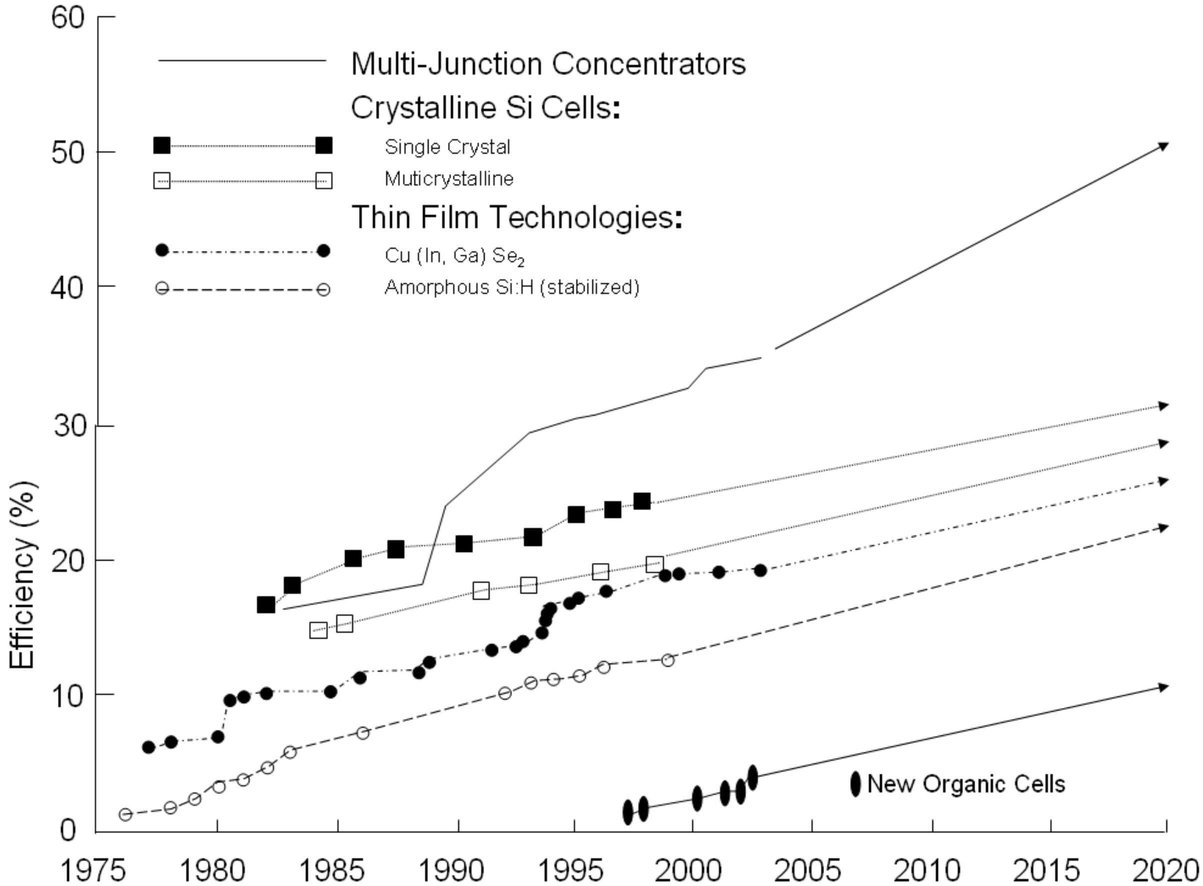


Figure 5. Solar Cell Trends for Past 30 Years and Extrapolation to 2020[75]

Despite the slow growth depicted in Figure 5, a leap in solar cell capability may be available in the next 10 years. Researchers at the University of New South Wales in Sydney, Australia, are working to double current solar cell efficiencies to 60 percent or higher. A new technique they are inventing involves using multiple layers of silicon to convert several wavelengths of light simultaneously. Before their research, this was only possible using different materials consisting of gallium, indium, phosphorous and arsenic which cost much more than silicon.[76] While a prototype will take at least two years to build, the potential increase in efficiency and reduction in cost make it a potential candidate for use on LTAs or UAVs operating for long durations.

Technological Advances in Fuel Cell Technology

The use of fuel cell technology in aviation is still in its infancy. Despite this, the potential for their use as a replacement for batteries in LTAs or power sources on standard aircraft is great. Fuel cells may also be an ideal method for powering LTAs during nighttime operations while solar cells recharge them during the day. Preliminary cost benefit ratios favor the use of fuel cells in long duration sortie aircraft. The current state-of-the-art automotive research into fuel cells has created compact, high power and durable designs.[77] However, these designs lack the energy to weight ratio required for optimum aviation use.

Miniaturization of fuel cells is also possible. EoPlex Technologies is creating a printing technique similar to that of electronic circuit boards. Their goal is to build a micro-reformer for fuel cells. The small size (approximately two dominoes) of the unit is capable of recharging the battery in a 20 watt radio.[78] Another approach is using the fuel cell to power a propulsion system. The 100 watt fuel cell built by Protonex Technology Corporation weighs less than 10 pounds and has already powered a small UAV for more than three hours.[79] While this endurance is not as good as a similar sized UAV using traditional liquid fuels, it is a considerable technological achievement. Future fuel cell development may provide sufficient power for greater endurance and altitudes enabling UAVs to operate for weeks instead of days at a time. A list of recommended fuel cell advancements is included in Table 2 on page 10.

Technological Advances in ISR and Communications: Traditional Radar Systems

Active Electronically Scanned Arrays (AESA) systems are currently in use in several aircraft, including the F-15C, F-16F, F/A-18G, F-22A and will be in the F-35. The F-15C's APG-63 radar is an X-band pulse-doppler system which features improved reliability over its predecessors.[80] This is achievable through its fixed antenna, which uses a 2-D array of transmit and receive modules eliminating the need for mechanical steering mechanisms.[81] After decades of development, the resulting system weighs less, has increased reliability and allows for performing multiple functions (air-to-air, air-to-ground) simultaneously.[82] For example, the F-15C can track multiple air-to-air targets while simultaneously creating a hi-resolution image of a ground moving target allowing for full 3-D situational awareness.[83] These existing systems may offer electronic warfare (EW) modes with only software changes.[84] Research into using small UAVs with electronic attack (EA) payloads operating at close distances to ground threat radars have shown positive results even at low power (100 W) outputs.[85] A high-altitude UAV could reserve some of its AESA capability for this jamming effect.

The Multi-Platform Radar Technology Insertion Program (MP-RTIP) was originally intended as an upgrade for the E-8 Joint-STARS system, but evolved into an aircraft system of its own – the E-10A Multisensor Command and Control Aircraft (MC2A). The MP-RTIP radar consists of an X-band AESA capable of tracking low-flying, stealthy cruise missiles at ranges of hundreds of miles in addition to the traditional role of low-speed ground targets.[86] The recently flight tested radar is 30 ft long and weighs 3,000 pounds.[87] Despite the cancelling of the E-10A MC2A, the MP-RTIP radar will continue in a smaller form as a radar upgrade to the RQ-4 Global Hawk.[88] The $2B MP-RTIP system or its derivatives *would be a likely candidate for a new all-weather continuous battlefield surveillance asset*.

Another airborne radar system is the Advanced Synthetic Aperture Radar Type 23 (ASARS-23) which has evolved from use on the U-2 to a modified British Bombardier Global Express business jet. The combination of aircraft and radar is now called the Airborne Stand Off Radar (ASTOR). ASTOR is being developed under a $1.3B contract to Raytheon, for use by the

British government.[89] The ASTOR system is a dual mode radar with an embedded moving target indicator (MTI).[90] Once operational, the system will use five aircraft to provide 24 hour surveillance linked to ground stations used at the tactical and operational level of war.[91] Miniaturization of ground support equipment and lessons learned from this system could be integrated into a higher endurance system capable of communicating the data directly to the warfighger.

Technological Advances in ISR and Communications: Conformal Sensors

One proposed method for increasing the situational awareness of the battlespace is the integration of an AESA radar onto a curved surface. Current AESAs are mounted to a flat panel behind a protective radome on the front of the aircraft. Creation of a conformal array would allow for direct mounting of the radar to the outer skin of the aircraft, potentially allowing much greater aperture sizes for better performance. The design must also be low observable to provide greater aircraft survivability.[92] Additional features enhancing this aspect is the growth of frequency-selective coverings designed to only let signals pass through that are in the same frequency as the radar and electronically agile arrays that can change frequency.[93]

Single curve dimensional arrays are currently under test by European Aeronautic Defence And Space Company (EADS) and Raytheon. This development will allow the AESA to be mounted to a simply curved surface by 2011. Two examples are an underside of a wing or the side of a fuselage.[94] These systems will be able to simultaneously track targets, create SAR images and act as high-bandwidth communications platforms.[95] While the first use of this technology is forecasted for the British Corax (see Table 5 on page 18), RQ-4 Global Hawk, MQ-9 Reaper and manned systems will eventually integrate this technology as well.[96]

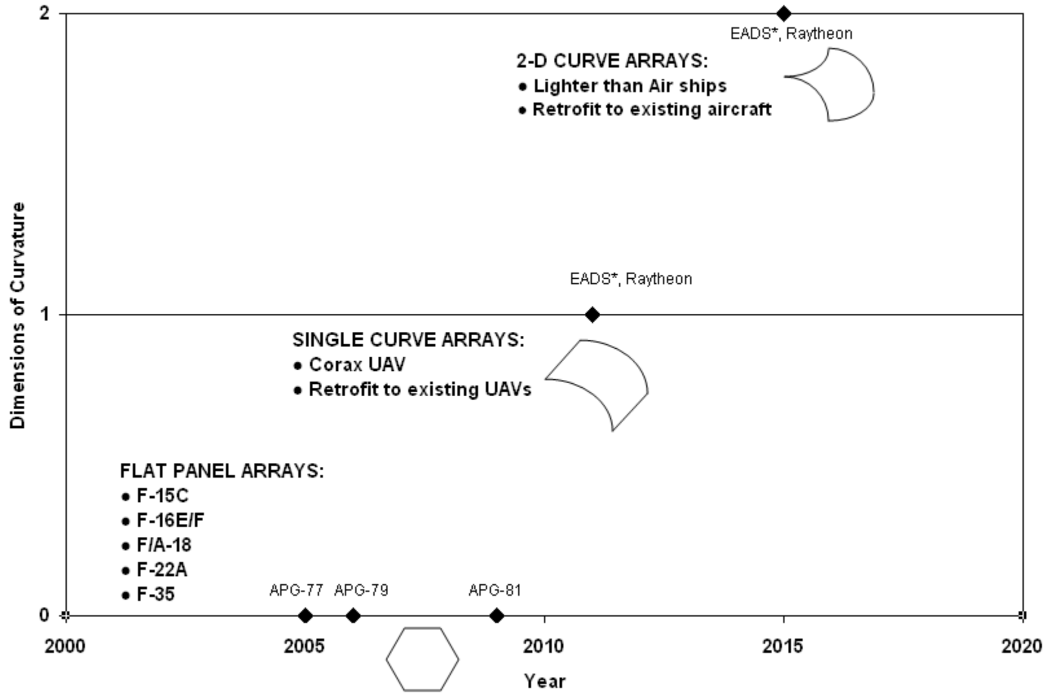


Figure 6. Evolutionary Forecast of Radar Technology[97]

The two-dimensional curved array is forecasted to be operational by 2015 (see Figure 6) and will allow for mounting to a fully curved surface, like the underside of a LTA. EADS researchers are currently considering use of gallium nitride (GaN) instead of the traditional gallium arsenide (GaAs) for their curved AESA project since it may enable the array to operate in different radio bands. For example, the array could use L-Band for long-range surveillance and X-Band for air-to-air surveillance while simultaneously operating in a third band for communications.[98] The merging of both surveillance and communications into the same antenna where the signal-to-noise ratios are so drastically different is one of the most significant challenges to the design and is currently being worked by several companies.[99]

The DARPA initiative to combine a two-dimensionally curved AESA system with the outer hull of an aircraft is called Integrated Sensor is Structure (ISIS).[100] Described by DARPA as the "ultimate persistent airborne platform for all radar missions," the effort is under development by Northrop Grumman for use by HAAs.[101] The final ISIS system, if completed, will be capable of dual air-to-air and air-to-ground surveillance simultaneously while possibly providing communications and large bandwidth options as well.[102] This dual-mode capability will greatly enhance net-centric operations which are detailed in Appendix E (page 66). It is ultimately hoped by the Air Force Research Laboratory (AFRL) that these technologies can be used to meet some Focus Long-Term Challenges (FLTCs). FLTC 2.2.1 is to have a survivable, high-altitude, long endurance UAV capable of multi-intelligence sensing for battlefield commanders in a medium threat environment.[103] Desired to demonstrate this capability by 2013, the system is also expected to use morphing wings in a low-observable structure similar to the P-175 Polecat (see page 17).

Summary of Future Developments to be Exploited:

1. Effects-based-operations (EBO) are focused *on achieving desired effects instead of planning for specific systems or forces.*
2. The tethered balloon approach is *not recommended due to vibration and scaling limitations.*
3. Lighter than air ships have little political support. To change this, *a significant rethinking of military operations and doctrine is necessary.*
4. LTA designs offer one significant advantage over existing ISR aircraft – *endurance*.
5. The risk to LTAs by SAMs is reduced by the *extreme altitude (65,000 ft), low radar cross section and negligible velocity.*
6. The low observable, long endurance UAV *is the best candidate for persistent surveillance in an environment where air superiority either does not exist or is not yet desired.*

7. Wing morphing or "adaptive compliant" structures, *can improve range or endurance by five to fifteen percent for traditional winged aircraft designs.*
8. ROVER technology *is an important baseline for the future of continuously available surveillance.*
9. A new technique may soon *double current solar cell efficiencies to 60 percent or higher*.
10. While commanders are forced to operate with fewer forces available to them, *additional situational awareness will be critical for efficient mission accomplishment.*
11. The TSAT laser communications system could allow high-resolution images and video to be *transmitted directly from aircraft operating at high altitudes over the battlefield to the tactical level of war*.
12. The MP-RTIP radar upgrade to the RQ-4 Global Hawk and its derivatives *would be a good candidate for a new all-weather continuous battlefield surveillance asset*.

Conclusions

"…clinging to the past will teach us nothing useful for the future, for that future will be radically different from anything that has gone before. The future must be approached from a new angle…" – General Giulio Douhet, The Command of the Air[104]

The need for continuously available surveillance for homeland defense, disaster relief and military operations is ever present and will not be going away. Just as GPS revolutionized existing military operations, continuous ISR will allow commanders greater assurance on enemy capabilities while allowing enhanced efficiency for friendly force allocations. Forces operating at the tactical level of war will be able to task a sensor in a Google-Earth fashion to discover what is over the next hill without requiring additional aircraft, pilots or personnel. The information they receive will simultaneously be viewable by everyone involved in their operation all the way up to the highest levels of government. The OODA and sensor-to-shooter loops will contract to a time span of seconds.

The system making this future possible is the continuously available surveillance system, consisting of lighter-than-air (LTA) or stealthy long-duration aircraft flying at near space altitudes of 65,000 ft. The stealthy ISR aircraft will provide information while operating over heavily defended regions where air superiority has yet to be achieved. Laser communications will allow unrestricted operations while not compromising stealth. When air superiority does occur, the LTA will provide continuous coverage for weeks or months at a time as the eye in the sky. These systems will not provide persistent coverage requiring terabytes of video and data to be continuously downloaded. Instead, their sensors will always be continuously available for the troops on the battlefield. As demand rises and falls, so will the output of the sensors.

The company and platoon commander will use a simple laptop-like device to point and click at a desired location on a map and choose the type of information desired: EO, IR or SAR and a tasking order will enter the Global Information Grid (GIG). This order will immediately enter the regional command office for uplink to the near space asset and one of the available sensors will immediately downlink, in real time, the requested information. The net-centric computers of the future battlefield will disperse the data to whomever is interested. Laser communications will negate any restrictions on radio frequency bandwidth.

The scenario described here will be capable of deployment between 2020 and 2030. Most of the technology required to make it happen exists already in commercial industry or in laboratory prototypes. Specific areas requiring additional research and development include solar array efficiencies, integration of sensors with curved external surfaces and fuel cells. Current industry growth in solar arrays will likely yield usable components by 2020. The integration of sensors into external surfaces will require continued government research support. The fuel cell technology will advance in industry, but government support will be required to yield a device applicable to the high altitude, low oxygen environment of near space.

For more information on the application of near space assets, the reader should see Dr. Ed Tomme's "The Paradigm Shift to Effects-Based Space: Near-Space as a Combat Space Effects Enabler"[105] and Anthony Colozza's "Initial Feasibility Assessment of a High Altitude Long Endurance Airship."[106] Each work provides background, detail and a sound report on the capabilities and limitations of the usefulness of near space systems. The important ideas captured in these two reports will not be contained by them. A third report authored by a panel of thirteen exports is "Future Air Force Needs for Survivability" which details the current and future technology base.[107] This report includes several recommendations for leaders and researchers in how to improve technology to meet the needs of the operational environment of 2020. One key element of this report is the statement that given past trends, current experimental technology must be at a Technology Readiness Level (TRL) of 6 by 2009 for it to be mature enough for operational use by 2018. The key obstacle in producing any of these systems may be the slow approval process of the FAA for approval of UAV flights in national airspace (see Appendix A, page 39). The inherent usefulness and exploitation of near space will come to mind for many people in the next ten years (it has already begun for the MDA and private industry) and the government will gradually embrace the technology that will eventually be indispensable to future military operations.

APPENDIX A: SURVEY RESPONSES

The Air Command & Staff College sponsored a survey to 73 leading industry, government and university experts in the field of UAVs. These experts were asked 16 questions relating to UAV development and use from now until the year 2025.[108] Questions focused on developing technology, government and civilian missions and systems integration issues. A selected review of their responses is included here. Forty-six people responded to this survey in January 2007.

SURVEY: Top 3 Enabling Technologies

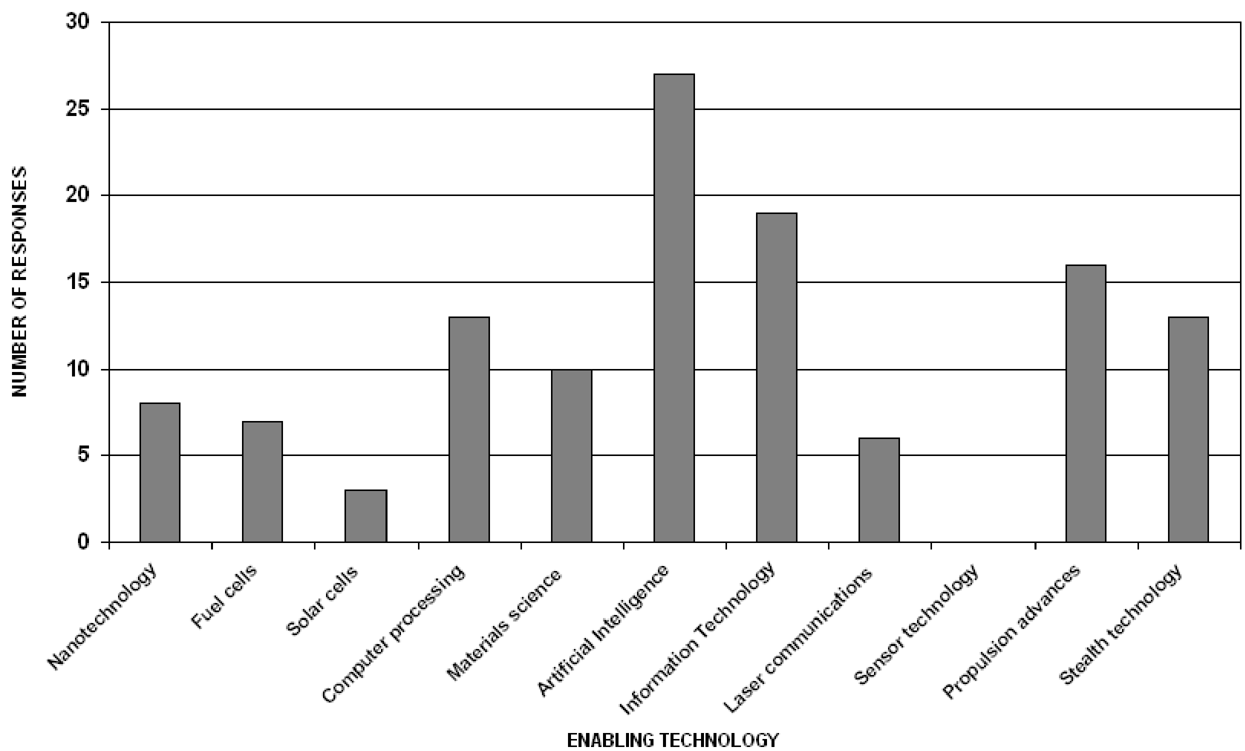


Figure 7. Survey Response for Top 3 Enabling Technologies for UAVs in 2025

Survey recipients were asked to pick three enabling technologies that will have the greatest impact on the future of UAVs in the year 2025. As seen in Figure 7, the clear winner amongst the experts was Artificial Intelligence (AI). Information technology (IT), propulsion, stealth and computer processing follow. This response clearly indicates how dependent aircraft operations will be on computer processing capabilities and speed. The current military and civilian reliance on net-centric operations supports this prediction, with perceived military capabilities evolving to capitalize on commercial technological developments. One critical obstacle this technology must solve is the ability for UAVs to sense and avoid other aircraft. Mr. Dyke Weatherington, Deputy of the OSD UAV Planning Task Force noted that solving this "challenge is one of the most pressing current challenges which will require sensors" in the near future.[109]

SURVEY: Level of Autonomy

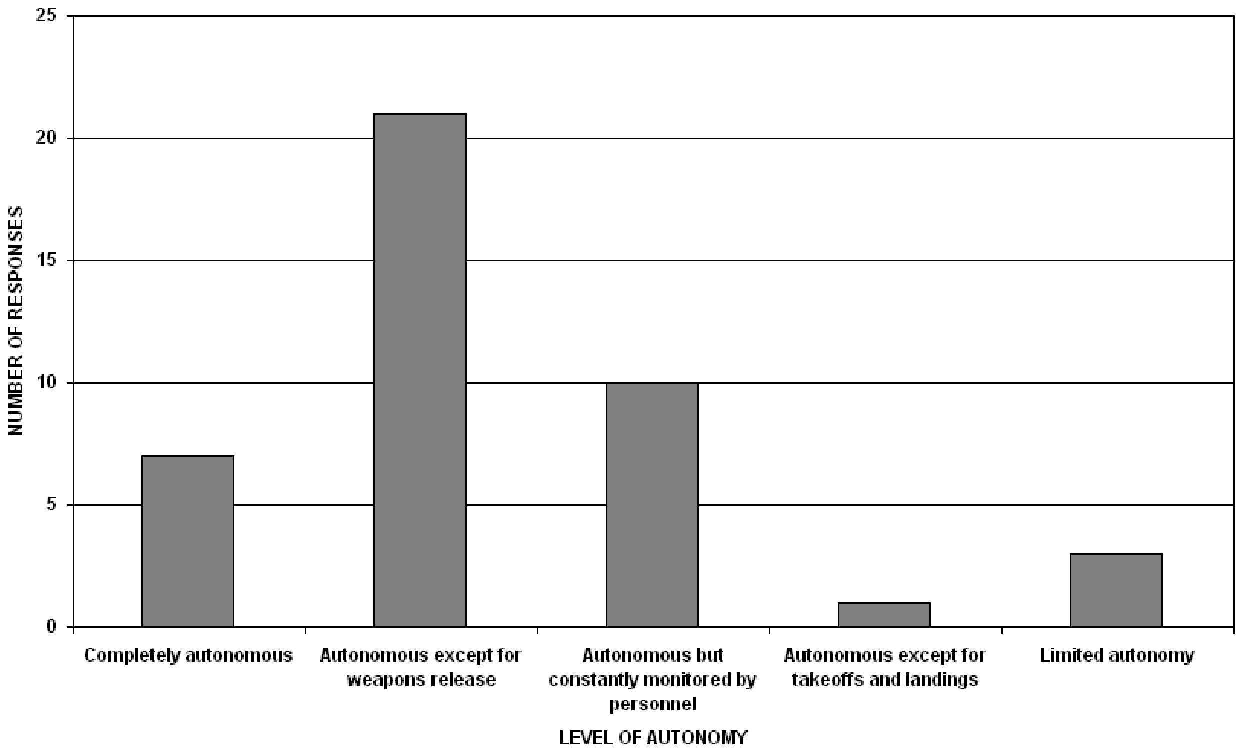


Figure 8. The level of Autonomy Expected for UAVs in 2025

Survey responders predicted the level of autonomy expected for UAVs operating in 2025. As UAV capabilities increase, their autonomy is expected to grow in accordance with it. The greatest anticipated exception to this is the release of weapons, which is still expected to require interaction from human operators or observers (see Figure 8). A special case was noted by Dr. Steven Rasmussen of General Dynamics Advanced Information Systems who stated that "for missions that do not require lethal force, the UAVs could be completely autonomous."[110]

SURVEY: Likely Targets

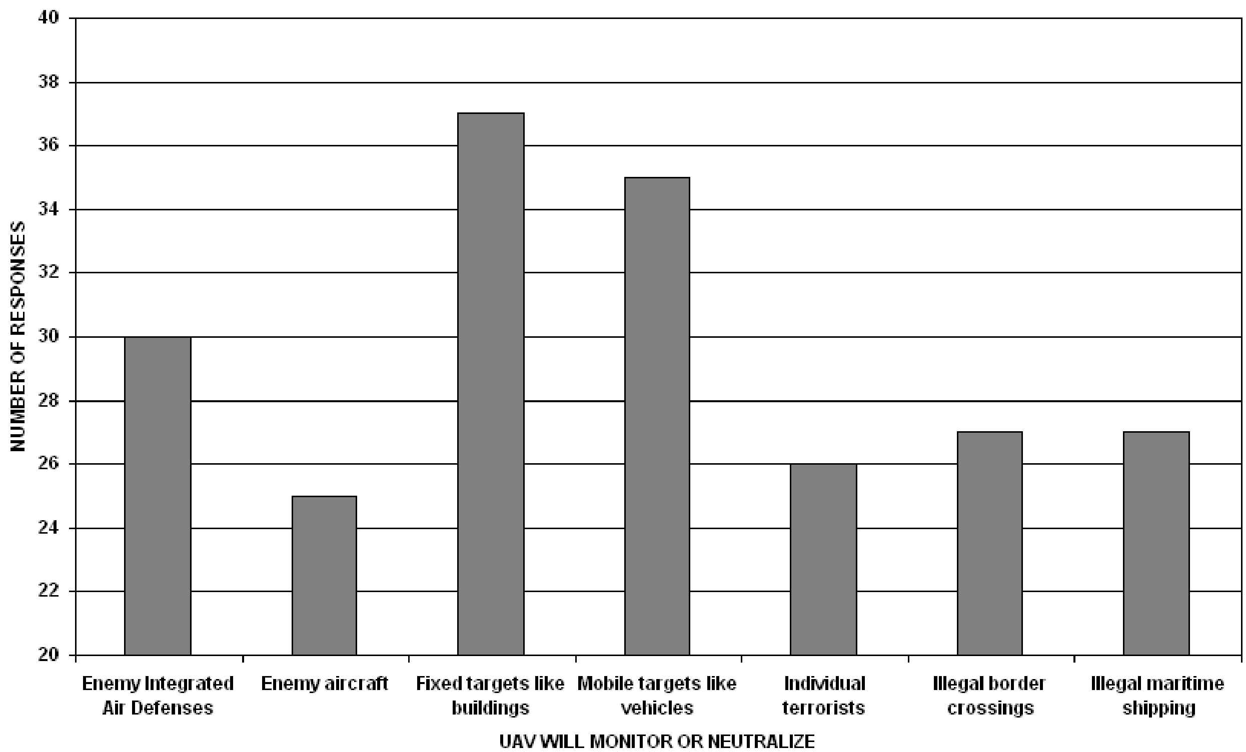


Figure 9. Most Likely Targets for UAVs to Monitor or Neutralize in the Year 2025

Survey recipients were asked to select the most likely targets for UAVs to monitor or neutralize. There were seven categories to choose from, and responders selected as many as they thought were applicable. No rank ordering was given for the responses shown in Figure 9. The top two choices were fixed and mobile targets like buildings and vehicles, respectively. Current hopes for UAV technology such as tracking and identifying individual terrorists or criminals are predicted to be less likely. Dr. Michael Francis, former J-UCAS Director of DARPA, stated that these “answers depend on countermeasures developed and the airborne threat environment” since “ISEAD is the most difficult mission.” Francis also noted that “cancellation of J-UCAS limits time to mature this most technologically complex capability” placing doubts on the ability of future UAVs to survive in complex threat environments.[111]

SURVEY: Reason to Invest in UAVs

While mission endurance for future UAVs is a primary concern for providing continuously available surveillance capabilities, it is not perceived as the best reason to invest in UAVs. The 73 experts in the survey were asked to select one of five different reasons as the best for future investing in UAVs. Shown in Figure 10, their best answers are almost tied between directing UAVs on missions too risky for manned aircraft and performing routine missions where repetition allows for automation. The comments of Mr. Jeremiah Madigan (VP for High-Altitude, Long-Endurance Systems, Northrop-Grumman Corporation) reflected those of most recipients when he stated: “If there is a single answer then it is to reduce the risk to a human operator. However, there a many reasons and include the fact that they are a cheaper way to solve the "Dull, Dirty, and Dangerous" problems while reducing human risk and improving efficiency.”[112]

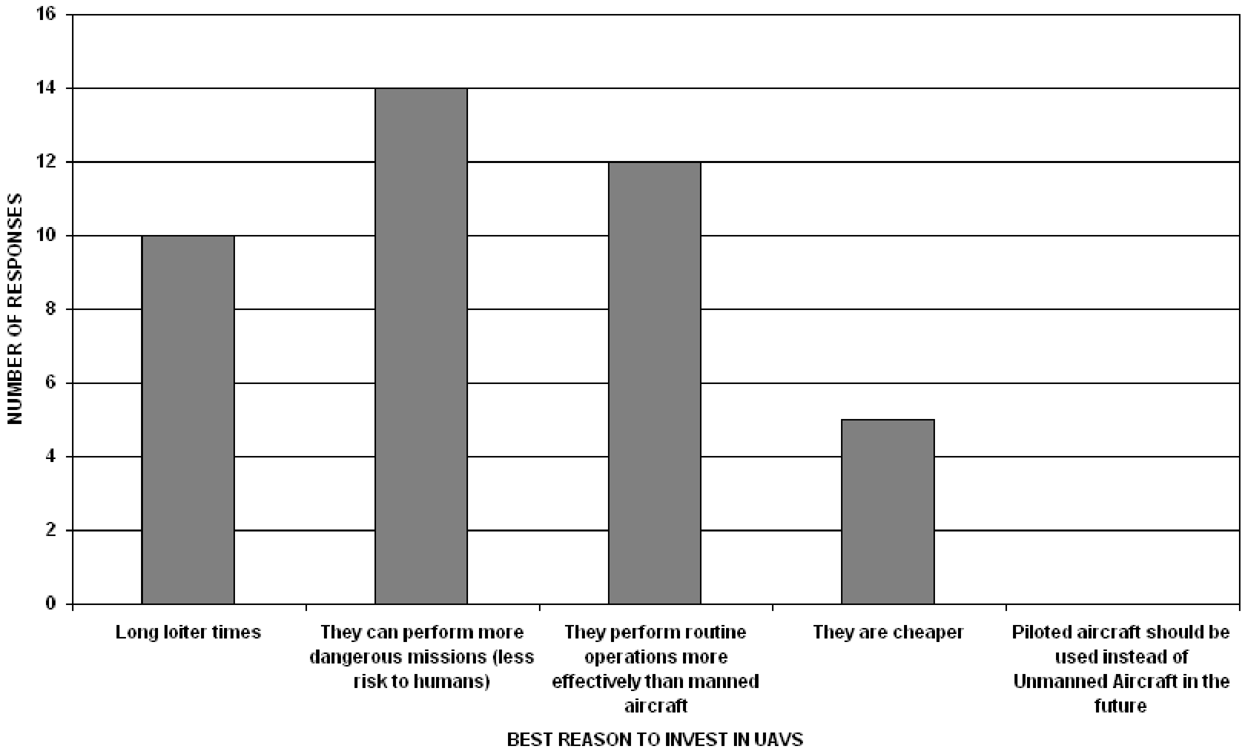


Figure 10. Best Reason to Invest in UAVs Instead of Manned Aircraft

SURVEY: UAV Roles

The premise of this paper is that present and soon to be available technology can be combined to create a system capable providing continuously available battlefield surveillance for weeks or months at a time. Research revealed many articles with a preference for civilian uses for the same technology. Others stated that the military capability was unlikely to be developed until it a commercial equivalent was successful. The leading experts disagree with these sentiments. When asked which role UAVs will be best suited for in 2025, their overwhelming response was for wartime operations. As shown in Figure 11, homeland defense placed second. Civilian and scientific missions received only 2 votes. Arun Ayyagari (Technical Fellow, The Boeing Company) explained the close relationship between the top two choices by stating that "while I have selected wartime operation since the intent is to limit the human operator to be in harm's way, once this is achieved it can also be applied to border monitoring for homeland defense purposes."[113]

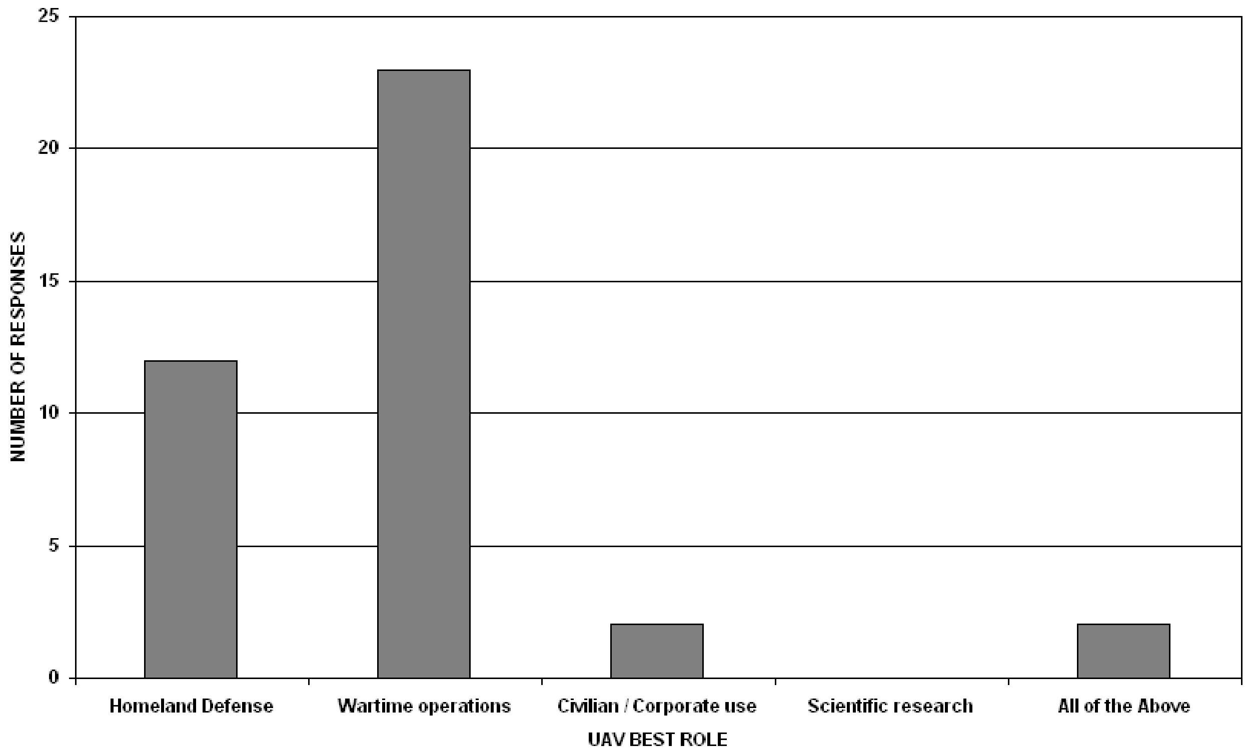


Figure 11. The Role UAVs Will be Best Suited for in 2025

SURVEY: UAV Missions

The results of Figure 11 were reinforced by the survey respondents when asked which UAV mission government users will demand the most of in 2025. Their responses (shown in Figure 12) were strongly indicative of the ISR role currently filled by Predator, Global Hawk and other systems. Other potential roles such as communications, weather, or even weapons delivery received very little support. Cory Dixon of the University of Colorado stated that as UAVs grow in capability that "we will see a trend to widen their use spectrum and will see strong demand in all of the categories listed above."[114]

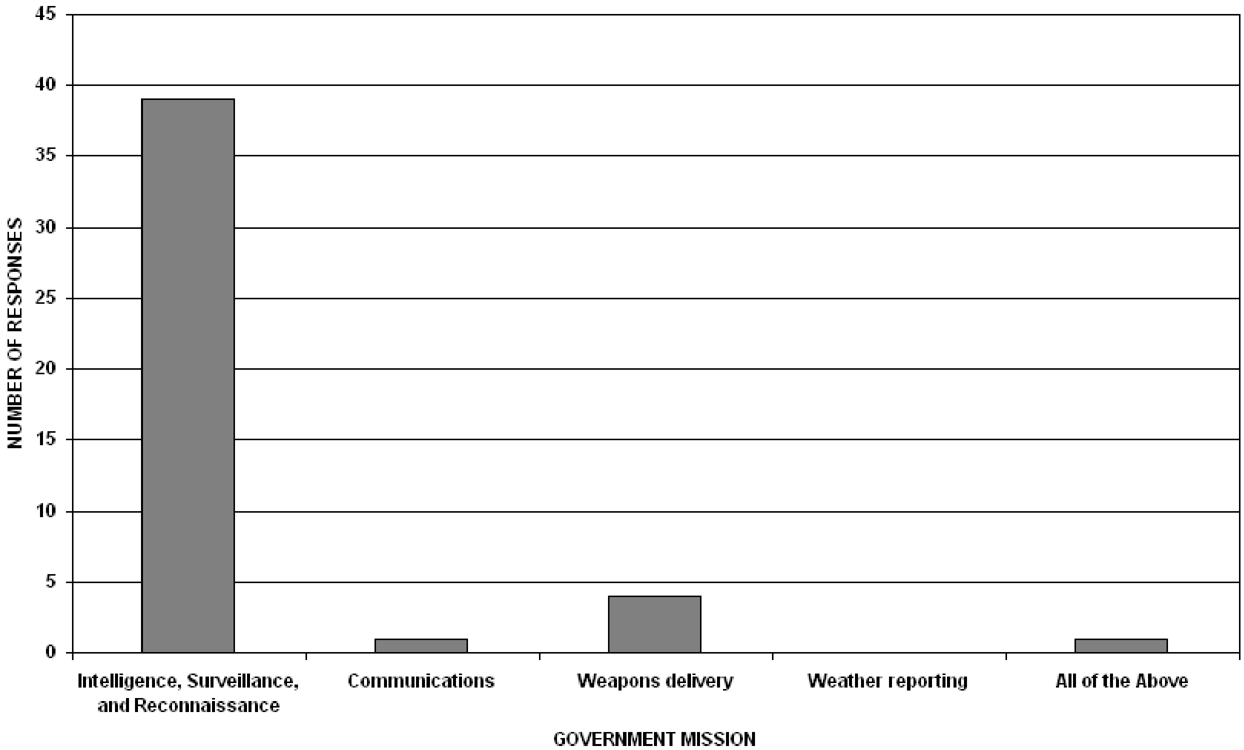


Figure 12. UAV Mission Most in Demand From Government Users in 2025

SURVEY: Supporting UAV Development

Considering the strong indications that government users and missions will lead the development of UAV technology to 2025, the question arises as to how the government should sponsor further research and development. The survey provided recipients with five choices including university research grants, contracts, competitions, law reform and international partnerships. Figure 13 shows that most prefer corporate development contracts. Todd Bruner's statement integrates the possible answers into a combined proposal: "Top three: University for 6.2 & 6.3 research dollars and STTRs, corporate development both under DOD contract (SBIR, and directed) 6.3 & 6.4 R&D funds. Design competitions? Sure via competitive proposals."[115] Bruner's response highlights many of the comments made by survey participants who stated that no particular method should be singled out as best, but a combination of the methods should be employed as the situation requires it.

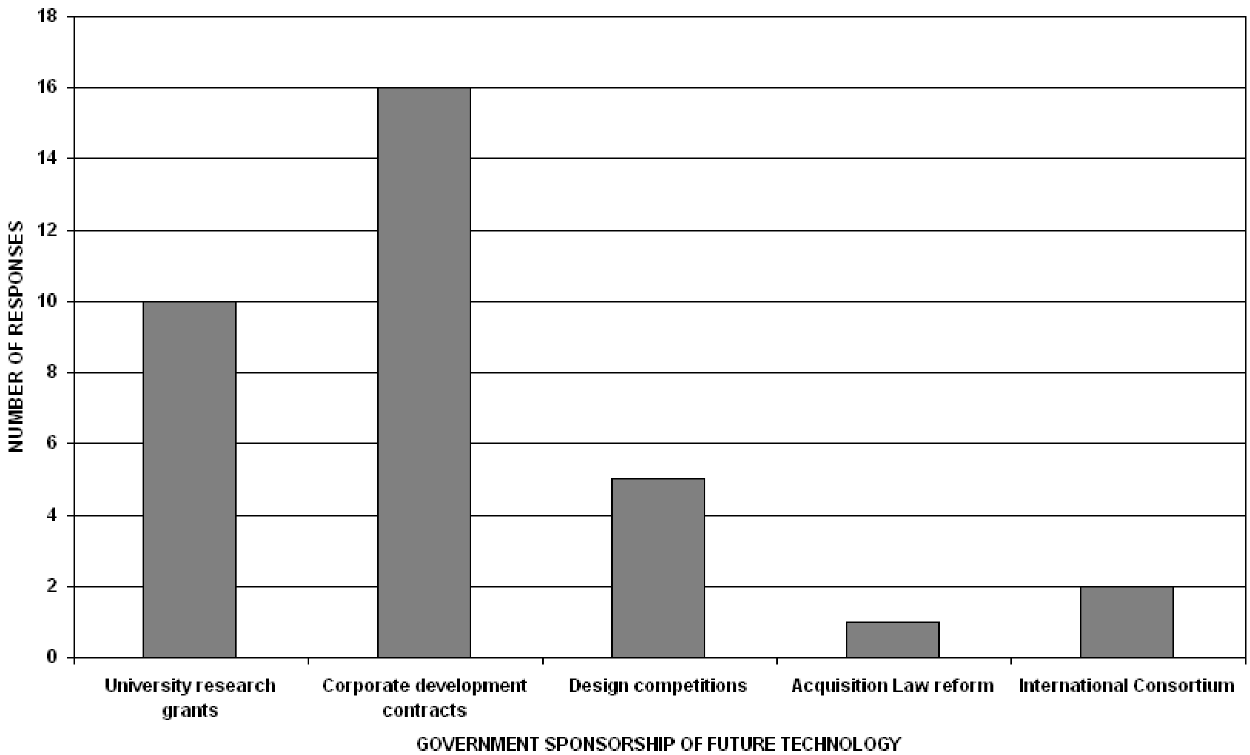


Figure 13. The Best Method for the US Government to Sponsor Future UAV Technologies

SURVEY: Government Policy

Perhaps the most important question posed to the survey recipients was what government policies exist or need to exist to maximize the role of UAVs at home and abroad in the year 2025. The overwhelming response was the need for simplified FAA guidance on approving UAV flights for test and operations. Specific comments included:

> "There is a need to simplify the procedures for obtaining FAA approval for flight testing these technologies. Rules must be established to protect the public while giving researchers/developers enough latitude to try out designs without having to spend time and money traveling to areas with restricted air space." - Steven Rasmussen[116]

> "While the FAA is developing methods and regulations for UA, there is little talk on how to properly regulate the development and testing of the smaller university

sized vehicles while still allowing them to fly under a COA. Restated, once a COA is certified for an aircraft any modification to the system hardware or software a new COA will need to be filed for. At the university level a single aircraft will have many modifications to hardware and especially software for testing different theories/algorithms which happens on the order of days to weeks, not months. Thus the FAA will need a way to certify a UA system and not the aircraft itself." – Cory Dixon[117]

"First and foremost is a rational way to integrate them into the national airspace structure. Current limitations on UAV flights in the US are seriously stifling development of hardware and conops." – Dr. Ed "Mel" Tomme, LtCol, USAF (ret) [118]

"Acceptance of UAVs as a normal part of civilian (US and international) airspace operations through more automated air traffic control concepts and specific UAV "see and avoid" technologies. Development in the military of UAV-only pilots and support crews (to develop internal constituencies for follow-on systems)" - Tom Ehrhard, Ph.D., Colonel, USAF (ret.)[119]

These comments all illustrate the red tape confronting anyone attempting to perform research and development in support of UAVs. A more well-defined, simple and most of all fast system for coordinating UAV flights over US airspace must be developed. Current flight operations suffer under the current system, which also acts as a barrier to potentially additional participants. Most corporations and universities simply don't want to be involved in a program with so many government hassles. Perhaps solving this problem is of greater importance than overcoming any technological obstacle for the future development of UAVs.

APPENDIX B: THE PAST

Surface-To-Air Missile Systems

Throughout history accurate and timely information on enemy location, strength and capability has proved crucial to battlefield success at all levels of conflict. At the strategic level, U-2 spyplanes flew missions over the former Soviet Union during the Cold War until the famous shoot down of Francis Gary Powers by an SA-2 Guideline missile.[120] At the operational level, the RQ-4 Global Hawk provides the Central Command staff with near real time information on possible insurgent activity in the Middle East.[121] At the tactical level, the RQ-1 Predator provides laser designation of targets for other manned aircraft with bombs.[122]

All of these aircraft are very similar in appearance. Each aircraft has a high-aspect ratio wing (long wingspan but a short chord length) for long endurance missions and a single engine to maximize fuel economy. The U-2[123] and Global Hawk[124] were designed to overfly possibly hostile environments so each is capable of operating at altitudes of greater than 65,000 feet. This extreme altitude requirement provides a margin of survivability against most Surface-to-Air Missile (SAM) systems.

Russian SAM systems have proliferated throughout the world. These systems now account for the majority of aircraft losses in modern conflicts, with the former Soviet Union producing roughly three-quarters of the world's supply.[125] The willingness of the Russian government to sell older but refurbished systems to the smallest of third-world governments creates a potentially deadly predicament for mission planners. The SAM systems track their targets through radar or optical means (visual or infrared). National control of the systems is maintained through an Integrated Air Defense System (IADS) which allows for a centralized command and control authority. Therefore, detailed knowledge of the SAMs is required to maximize survivability of aircraft when operating over much of the world. A brief overview of SAM systems is presented in Table 7, which includes whether or not the system is transportable and what type of guidance is used.

Table 7. Summary of Russian Surface-To-Air Missile Systems (SAMs)[126]

System	Code Name	Tracking
Fixed Ground		
SA-1	Guild	Radio Command
SA-2	Guideline	Radio Command
SA-3	Goa	Radio Command
SA-5	Gammon	Radio Command, Active Radar Terminal Homing
Man Portable		
SA-7	Grail	IR
SA-14	Gremlin	IR
SA-16	Gimlet	IR
SA-18	Grouse	IR
Ground Portable		
SA-4	Ganef	Command, Semi-Active Terminal Homing
SA-6	Gainful	Radio Command, Semi-Active Terminal Homing
SA-8	Gecko	Radio Command
SA-9	Gaskin	IR
SA-10	Grumble	Radar
SA-11	Gadfly	Command, Semi-Active Radar Homing (SAHR)
SA-12	Gladiator/Giant	Command, Semi-Active Radar Homing (SAHR)
SA-13	Gopher	IR
SA-15	Gauntlet	Command, Radio & TV Tracking
SA-17	Grumble	Semi Active Homing Radar (SAHR)
SA-19	Grisom	Command
SA-20	Gargoyle	Semi Active Homing Radar (SAHR)

The most capable SAM systems are the SA-1 and SA-5 but both are limited to fixed installations requiring significant preparation before use. More modern systems, such as the SA-10 and SA-20, use wheels or tracks to simultaneously increase mobility and to defeat detection.[127] Perhaps the most significant proliferation threat comes from the use of man portable air defense systems (MANPADS). MANPADS are easily concealed and moved and pose the greatest threat to aircraft operating low to the ground. For example, two SA-7 Grail rockets were fired at an Israeli airliner during take off from Mombasa, Kenya in November of 2002.[128] The aircraft was fitted with a countermeasure system which defeated the warheads. A comprehensive picture of range and altitude capabilities of these systems is in Figure 14. Information on the SA-21 Triumph is not included in Figure 14 due to the systems lack of public specifications.

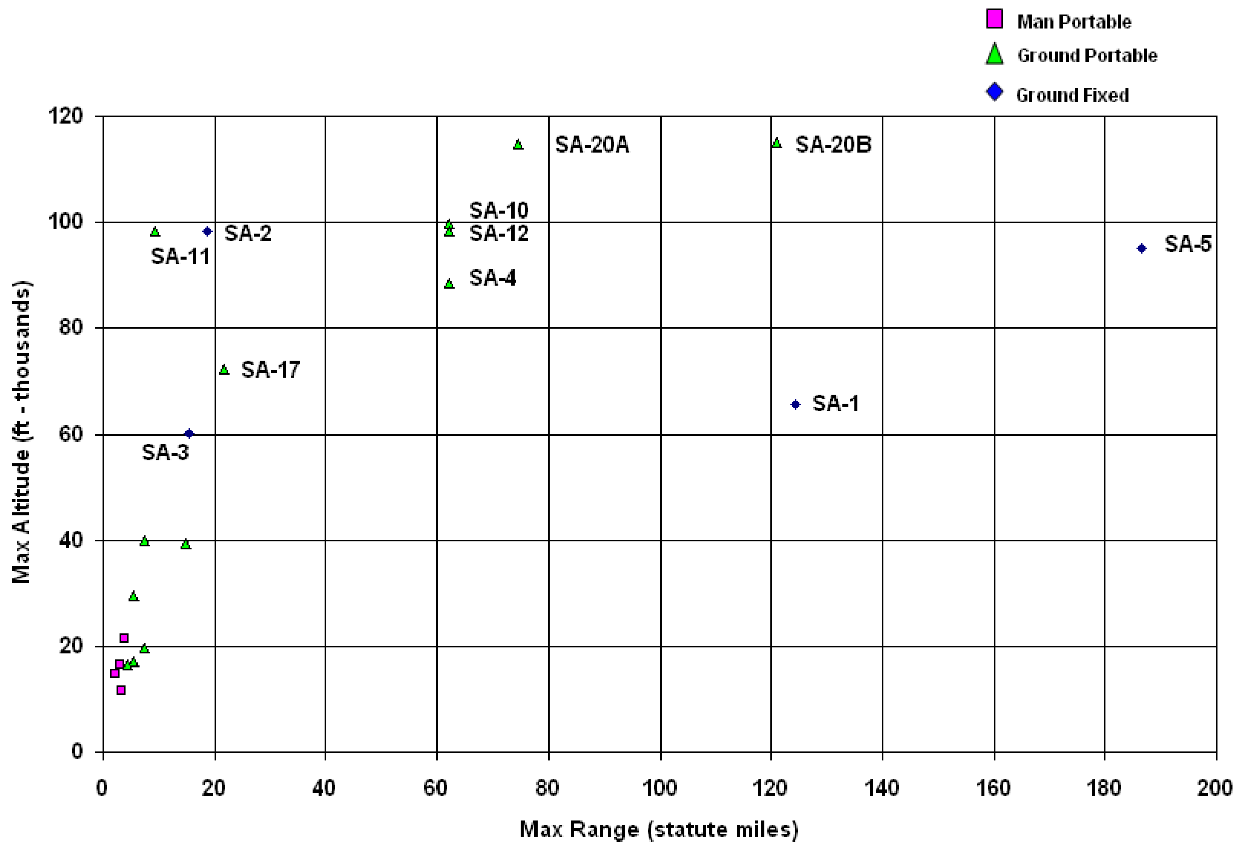


Figure 14. Surface-to-Air Missile System Capabilities[129]

As can be seen in Figure 14, flying at high altitudes is not a guarantee of safety. Complete safety requires the elimination of the SAM threat altogether (a form of Offensive Counter Air operations) and is a basis of USAF doctrine.[130] This necessitates the establishment of air superiority as the first goal of the battlefield plan.[131] Attaining air superiority involves a serious effort of persistent and high risk attacks to destroy both the SAMs and their IADS. This research does not seek to provide additional insight into achieving air superiority, but what aircraft designs will survive in environments where attaining it may not be desirable or possible.

Survivability in the SAM Environment

How do you design an aircraft to survive the SAM threat environment? This question is extremely difficult to answer and even more difficult to prove once you've answered it. The idea of survivability is first broken down into two major concepts. Susceptibility[132] is defined as how likely is the aircraft to get hit? Vulnerability[133] is defined as when the aircraft does get hit, will it survive? Addressing these concerns is best looked at in the context of the specific adversarial kill chains the aircraft system is likely to encounter. A graph comparing aircraft altitude capabilities to Russian SAM systems is in Figure 15.

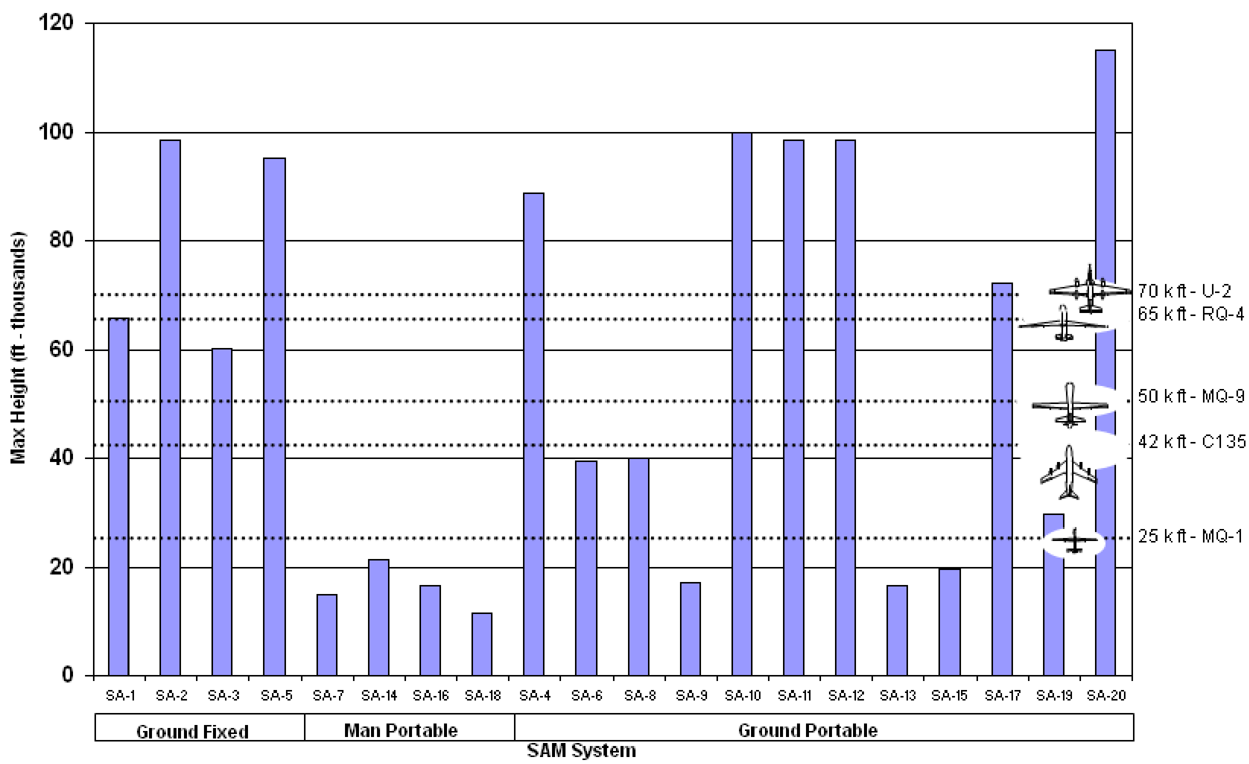


Figure 15. Maximum Aircraft Altitude Compared to Russian SAM capabilities[134]

The kill chain is the system of systems that form an Integrated Air Defense System (IADS) chain of knowledge and actions. This gives the air defense commander the knowledge and capability to destroy the invading aircraft. Breaking any link (see Figure 16) will increase the survivability of the aircraft. Breaking the surveillance link (search, detect, track and classify) means designing low-observable or stealth features into the aircraft. Breaking the fire control link (extract targets, develop fire-control solution and launch missile) emphasizes Suppression of Enemy Air Defense (SEAD) tactics which includes jamming and decoys. Breaking the guidance link (air vehicle kinematics, midcourse guidance, target acquisition and terminal homing) leads to aircraft with greater speed and maneuverability. Finally, the end game link (fuze detection and detonation) can be defeated through aircraft deployed countermeasures.

Figure 16. The Adversarial Kill Chain[135]

Designing for survivability involves attacking one or more of the kill chain links. Speed and altitude were the first critical design features for survivability, most notably in the SR-71 and U-2.[136] Despite the success of the U-2 and SR-71, these design techniques were not applicable to combat aircraft operating at lower altitudes. Those early attempts meant the use of chaff (ribbons of wire released from the aircraft) for radar guided missiles and flares for infrared guided missiles. Chaff and flare dispensers were added to existing airframes such as the C-130 with the next step in evolution fielding the Laser Infra-Red Counter-Measure (LAIRCM) system. In-depth study of SAM systems led to Wild Weasel (F-4G, F-16CJ) aircraft capable of jamming the guidance radar (Suppression of Enemy Air Defense – SEAD) diminishing the capable range of the threat. The final evolution in aircraft design is stealth (F-117A, B-2A), which minimizes the radar cross section (RCS) and infrared signature; thereby making the initial detection extremely difficult. New combat fighters typically employ several of these schemes into a single design. For example, the F-22 combines speed, maneuverability, stealth, chaff and flares and will probably fly with some SEAD aircraft as well.

Table 8. US Aircraft Design Features to Defeat Kill Chain

Link	**Countermeasure**	**Aircraft Example**
Surveillance	Stealth	F-117A, B-2A F-22, F-35
Fire Control	SEAD / Altitude	EA-6B, F-16CJ / SR-71, U-2
Guidance	Speed / Maneuverability	SR-71 / F-22, F-35
End Game	LAIRCM / Chaff, Flares	C-17 / C-130, F-15, F-16, F-18

Which links in the kill chain will be defeated in the aircraft design depends on the aircraft mission and the threat environments that will be faced. A complex trade study will evaluate which design features best ensure survivability while keeping costs on budget. Once a specific aircraft design is complete, the system must undergo Operational Test and Evaluation (OT&E).[137] Part of this testing includes flying against simulated SAM threat environments at the China Lake Test Center.[138] Results of OT&E determine the actual susceptibility of the system.

Vulnerability is determined through Live Fire Test and Evaluation (LFT&E) testing.[139] LFT&E uses components or entire systems (airframes) in which they are subjected to enemy fire typical to that which the system will likely encounter. The resulting damage to the aircraft is studied to determine if the aircrew or aircraft could have survived. These results are then combined with the susceptibility results for overall aircraft survivability.[140] Tactics for using the system to maximize this survivability are then created.

Survivability and Surveillance Aircraft Design

Surveillance aircraft missions are defined by their persistence. The longer the aircraft can perform the mission, the more useful it is to the warfighter. This simple fact dictates that the aircraft will be exposed to enemy air defenses for an extended period of time which means greater risk. Speed, maneuverability, chaff and flares will not be able to protect the aircraft for multi-day missions of continuous susceptibility.[141] Instead; stealth, altitude, SEAD and laser infrared countermeasures (LAIRCM) are the best options for aircraft designers. Specific examples have focused on either altitude (U-2,[142] RQ-4[143]) or stealth (P-175[144]) to provide a measure of survivability. As with manned systems, the more means designed into the aircraft system to defeat the kill chain, the more survivable the system will be.

Thirteen experts addressed future reconnaissance and strike aircraft survivability and design in a study looking at the world environment of 2018 and beyond.[145] The first finding of the report was that the Global Strike Concept of Operations (CONOPS) for Global Persistent Attack (GPA) requires round-the-clock reconnaissance of areas with significant SAM capability. This will include areas where major combat operations have not yet started so the adversaries SAMs and IADS will still be intact. The Intelligence, Surveillance and Reconnaissance (ISR) CONOPS stress range, endurance and persistence, requiring the aircraft to operate for days or longer. This finding is consistent with the latest Quadrennial Defense Review (QDR)[146] guidance for persistent surveillance. Considering risk, survivability and the need for aircrew rest, *an unmanned system provides the best solution for persistent surveillance*. This enables the US to develop global situational awareness to support the Combatant Commanders (CCDRs) decision making within the adversaries Object-Orient-Decision-Action (OODA) loop cycle.

The last recommendation from the report is to not rely on countermeasures for survivability, but instead focus on an inherently survivable design.[147] Countermeasures are to be used in contingencies only, *which leaves only stealth and altitude as the primary design considerations for persistent ISR aircraft survivability*. To summarize, an unmanned, stealthy, high-altitude aircraft is the best choice for providing ISR capabilities to the warfighter while surviving in a hostile threat environment. The success and limitations of these ISR aircraft are now examined.

Unmanned Surveillance Aircraft Used in Recent US Conflicts

> *"The big thing we're finding out in Afghanistan is that ISR is all about targeting." – Kevin Meiners, ISR Director, Pentagon*[148]

Airpower used in Operation Allied Force (OAF) were deconflicted using a 15,000 Above Ground Level (AGL) flight restriction. Manned aircraft were to stay above this line for better protection from SAMs while unmanned systems flew below it. The Unmanned Aerial Vehicles / Unmanned Aerial Systems (UAVs/UASs) were controlled from the Combined Air Operations Center (CAOC) in Italy, and were tasked target verification, battle damage assessment (BDA) and time-critical targeting. The RQ-1 Predator and RQ-5 Hunter UAVs provided this information without the need for ground troops in the vicinity of the enemy. This capability was provided below the cloud formations which prevented the use of higher altitude aircraft and satellites. The most significant impact made by the UAVs was the real-time video feed into the CAOC made possible by using the Joint Broadcasting System (JBS) and Ku-band satellite communications which also made the video available to other users, including the Pentagon.[149]

The role of unmanned systems expanded from OAF to Operation Enduring Freedom (OEF). The RQ-1 Predator was fitted with a laser-designator for target acquisition by other weapon systems. Joining the Predator for its first time use was the RQ-4 Global Hawk which provided all-weather Electro-Optical/Infrared (EO/IR) and Synthetic Aperture Radar (SAR) capabilities. The combination of Global Hawk, Predator, U-2 and other manned system operations provided for nearly continuous coverage of the battlespace.[150] The combined sensor inputs from these systems fed into the Common Operating Picture (COP). This capability is being further expanded upon by the Network-Centric Collaborative Targeting (NCCT) program, which will build networks linking surveillance to shooter systems to minimize the sensor to shooter timeline.

Operators of the MQ-1 Predator along with its AGM-114 Hellfire missiles combined for the first time persistent surveillance and strike capabilities. The on station endurance enabled operators to view targets from a standoff distance until the optimum moment to strike. The Hellfire missiles allowed for the capturing of that moment. The sensor to shooter decision cycle was now reduced to a matter of minutes.[151] This capability continues to grow in US Iraqi operations.

Operation Iraqi Freedom (OIF) is the largest example of ISR sorties to date. According to a USAF general officer tasked with supporting ISR requirements for US Central Command, during one twelve month period from October 2005 to September 2006, OIF forces called upon 8,100 ISR sorties. These missions consisted of both manned and unmanned systems. In comparison, OEF forces in Afghanistan used 3,589 ISR sorties during the same time period. While the importance of these sorties is likely to grow as force strength is reduced, a more persistent system could provide the same effectiveness at less cost with fewer sorties.

The Marine Corps in OIF used the RQ-2 Pioneer UAV. USMC operators credit the Pioneer's EO and IR sensors with making the difference between tactical success and failure.[152]

The Pioneer flew more than 4,500 flight hours during the initial phase of OIF. These sorties supported troops on the ground which used the sensors to visually observe their combat areas before starting out. Once on the move, the Pioneer's imaging continued to be downlinked to the unit during the conflict.

After the end of major combat operations, counter-insurgency (COIN) or Phase IV Stability Operations efforts began. Urban warfare in the Iraqi town of Fallujah consisted of house-to-house fighting. The first round of effort in Fallujah (March through November 2004) consisted mostly of USMC ground troops drawing out insurgents with little coordinated air support. This changed with the use of persistent surveillance to map out the city for both visual targets and electronic signals.[153] Constant round-the-clock collection was required for accuracy. The resulting information was used to create a list of pre-planned targets for the second round. Starting on November 7th 2004, the second round lasted eight days resulting in a Fallujah which was passable by US and coalition forces.[154] The big lesson taken from this is that preplanning shortens the kill chain, allowing immediate and accurate response from air support. Target accuracy was ensured by ground troops using laptops with links to the same downloaded Predator video footage the CCDR was seeing. *The Fallujah model allows for the accurate destruction of ground troop selected targets through persistent surveillance combined with strike capabilities.*[155]

The MQ-1 Predator performed so well in the close air support (CAS) role during OEF and OIF that it is now also being considered for future use as a Forward Air Controller (Airborne) asset. With an endurance of 20 hours, the Predator FAC(A) would allow for fewer transfers of authority between air controllers, which can cause severe reductions in situational awareness.[156] With higher situational awareness, the capability to exploit time-sensitive-targets

(TSTs) and overall tactical efficiency is increased. The growth of UAVs in supporting the warfighter continues to grow, albeit at a limited pace.

Shortcomings of Unmanned Surveillance in Recent US Conflicts

Even with all these success stories, several examples of surveillance deficiencies can be drawn from OAF, OEF and OIF. During OAF, there were times that more than 300 allied aircraft were in the air, but the four UAVs flying could not provide enough reconnaissance to support the planned strike missions.[157] The slow speed of the RQ-1 Predator and RQ-5 Hunter also allowed for several potential targets to escape before it could reach viewing range.

In addition to these problems, the RQ-5 Hunter UAV had a maximum altitude of 15,000 ft. This limitation and the direction to fly below 15,000 ft AGL forced the aircraft into poor weather and made it vulnerable to enemy ground and helicopter fire. Eight Hunter UAVs were lost, five of them from enemy fire.[158] Two additional Predators were also shot down. The poor survivability of the UAVs was exacerbated by the requirement for them to operate over hostile areas for prolonged periods. The mountainous terrain further complicated matters requiring additional UAVs to act as communication relays and limited ingress and egress routes over targets. Time to travel to the target was extremely slow for the UAVs with icing conditions preventing some taskings from being accomplished altogether.

Predators again suffered from bad weather problems in OEF. The high altitudes of the Afghanistan mountains led to three RQ-1 Predator crashes from winds and icing.[159] At least one of the two RQ-4 Global Hawks lost in OEF was due to icing. Several more UAVs were lost to anti-aircraft artillery and SAMs. UAV use in Iraq revealed different problems.

During the opening days of OIF and before the land attack started, a former Iraqi colonel informed coalition forces that as many as 180 T-72 tanks had been shipped south to defend the Iraqi border.[160] Although all previous intelligence contradicted this claim, commanders still had to consider it. Poor weather made verification difficult, and a Harrier equipped with a LITENING targeting pod revealed nothing. Deciding to use caution, the commanders chose to completely change their attack strategy with only hours left before they were to depart. The report of T-72 tanks turned out to be wrong. Available ISR support was still insufficient.

On 23 March 2002, AH-64 Apache helicopters from the 11th Attack Helicopter Regiment launched to attack Iraqi T-72 tanks of the Medina Division. The attack was initiated without any reconnaissance of the flight routes or target sites.[161] The result was damage from enemy fire to almost all the helicopters, several wounded crewmembers, two taken prisoner and minimal mission accomplishment. In retrospect, the aircrews realized that the Iraqi forces had practiced for this type of attack with asymmetric warfare (using small arms fire directed by spotters with cell-phones). Aerial reconnaissance may have alerted the mission planners to the concentration of Iraqi ground forces along the intended flight routes, resulting in different strategies for success.

Despite the success of the Dragon Eye and Predator drones used in OIF, commanders still lamented over the lack of situational awareness. During the drive north to Hantush by the 3rd Battalion, 5th Marines on March 24th, the Fedayeen surrounded the troops on Highway 1. While commanders had information on the Marines movements via Blue Force Tracker, the unexpected fight with the Fedayeen led to the question “When do we get Red Force Trackers?”[162]

The lack of a Joint persistent surveillance was again highlighted when the Marines reached Diwaniyah on March 27th. A captured Iraqi officer indicated that a building in town was being used as a staging area. The Marines flew an RQ-2 Pioneer drone over the area and verified the intelligence. However, the Army V Corps would not authorize an air strike until one of their own Hunter UAVs separately verified the information.[163] Even though the building was eventually destroyed by Air Force A-10s, CENTCOM commanders had trouble verifying any mission success due to untimely and inaccurate BDA.[164]

These examples all point to the need for more capable and persistent battlefield surveillance. Lessons learned from OIF indicate the need for greater Joint interoperability and persistence. The capability to strike targets as they are observed is also desirable. *But, the most important capability battlefield surveillance must have is round-the-clock availability.*

Summary of Past Lessons Learned:

1. Aircraft operating *above 65,000 ft will be immune from IR seeking and some simpler SAM systems, but stealth is still required for direct overflight of adversarial locations.*
2. Considering the need for aircrew rest, *an unmanned system provides the best solution for persistent surveillance*.
3. Countermeasures are to be used in contingencies only, *which leaves only stealth and altitude as the primary design considerations for persistent ISR aircraft survivability*.
4. The Fallujah model allows for the *accurate destruction of ground troop selected targets through persistent surveillance combined with strike capabilities.*
5. *The most important capability battlefield surveillance must have is round-the-clock availability*.

APPENDIX C: THE PRESENT

Proliferation of the SAM Threat

Surface to Air Missiles (SAMs) are being sold across the world. Many of the nations purchasing these have either histories of poor relations with the US and its allies or may soon with the war on terror (e.g., Iran and North Korea). While exact numbers of functional air defense systems in these nations are not known, the number and types can be estimated. Additional information indicates Iran has purchased unknown quantities of SA-6, SA-7 and SA-16 missiles.[165] While not complete, Table 9 illustrates the magnitude of the known SAM threat.

Table 9. Proliferation of Russian SAM Systems as of 1989[166]

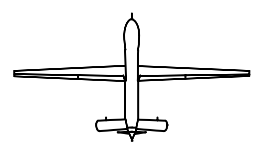
	System											
	Fixed Ground			Man Portable		Ground Portable						
Nation	SA-2	SA-3	SA-5	SA-7	SA-14	SA-6	SA-8	SA-9	SA-11	SA-13	SA-15	SA-16+
Afghanistan	120	115		*							NO DATA	
Algeria	44	28		*		60	20	36				
Angola	12	33		*	*	72	20	20		*		
China	750			*	*	*		50		*		
Cuba	140	48		*	*	12		*		*		
Egypt	360	200		*		72						
Ethiopa	36	8		*								
India	66	20		*	*	24	48	50		*		
Indonesia	6											
Iraq	120	100		*	*	100	20	*		*		
Iran	60		10	*		*					29	*
Jordan				*			20					
North Korea	270	30	24	*								
Kuwait				*		*	*					
Libya	60	80	36	*	*	150	72	70		*		
Mauritania				*								
Nicaragua				*								
Nigeria	*	*		*								
Pakistan	6			*								
Somalia	36	12		*		10						
Sudan	18											
Syria	300	160		*	*	160	40	*	*	*		
Tanzania	*	12		*								
Uganda		?		*								
Vietnam	200	180		*			*					
* Numbers uncertain or on order as of 1989												

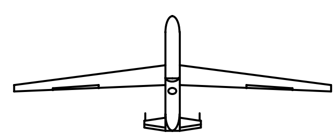
The information in Figure 14 and Table 9 is limited to Russian made equipment due to the lack of unclassified information. US, European and Chinese systems complement the IADS of many of the nations listed. For example, information collected on Iranian defensive systems suggests that in addition to the SAMs in Table 9, they also have 150 I Hawk, 30 Rapier, 15 Tigercat and 45 HQ-2J missiles[167] which have similar performance to Russian systems.[168]

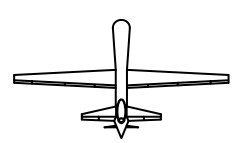
Current Surveillance Aircraft

Surveillance aircraft assets fall into two basic categories: manned and unmanned. Manned aircraft have the advantage of expert personnel co-located with the sensor to maximize responsiveness and minimize downtime when problems occur. On the other hand, unmanned systems have the advantage of endurance and commanders will be more willing to send them into higher risk areas. The mission capabilities of each aircraft system varies widely, so a short review is presented in Table 10 and Table 11.

Table 10. Unmanned ISR System Capabilities[169]

MQ-1	EO:	FMV: day variable-aperture TV camera	
	IR:	FMV: variable-aperture infrared camera	
	SAR:	still-frame images: 1 ft resolution	
	Endurance:	40 hours	
	Altitude:	25,000 ft	
	Cost:	$10 Million each (1997 dollars)	
	Weapons:	AGM-114 Hellfire missile / laser designator	Predator

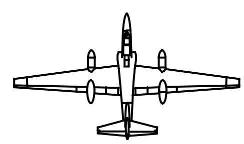
RQ-4	EO:	NIIRS 6	
	IR:	NIIRS 5	
	SAR:	Strip @ 3 ft, Spot @ 1 ft and GMTI	
	Endurance:	35 hours	
	Altitude:	65,000 ft	
	Cost:	$48 Million	
	Weapons:	none	Global Hawk

MQ-9	EO:	capable	
	IR:	capable	
	SAR:	still-frame images: 4 inch resolution	
	Endurance:	30 hours	
	Altitude:	50,000 ft	
	Cost:	$8 Million	Reaper
	Weapons:	AIM-92 Stinger, GBU-38 JDAM, AGM-114 Hellfire missile / laser designator	

The three systems highlighted in Table 10 represent the most capable unmanned US ISR systems currently in use. The comparatively low-altitude MQ-1 Predator provides near-real time images to the CCDRs.[170] The long loiter time of the MQ-1 coupled with the AGM-114 Hellfire presents commanders with the capability of striking targets of opportunity as they arise. The RQ-4 Global Hawk provides near-real time day and night imagery valuable to the CCDRs in all weather for up to 35 hours.[171] The Global Hawk also flies at a much higher altitude of 65,000 feet, allowing for overflight of possibly hostile areas while still giving a margin of survivability. The MQ-9 Reaper (formerly Predator B) is the next generation Predator, with improved altitude, sensors and weapons.[172] Not depicted in Table 10 is the low observable Excalibur UCAV which is designed for use at the tactical level and will be compatible with the AGM-114 Hell Fire missile and other small munitions.[173] First flight for the Excalibur is scheduled for 2007, with initial operational capability in 2010.

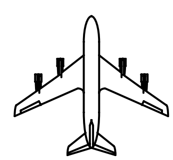
Table 11. Manned ISR System Capabilities[174]

U-2	EO:	capable
	IR:	capable
	SAR:	MTI with 100 mile range
	Endurance:	6+ hours
	Altitude:	70,000 ft
	Cost:	classified
	Weapons:	none



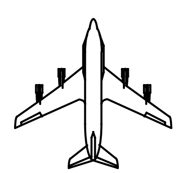
Dragon Lady

E-8C	EO:	none
	IR:	none
	SAR:	120° field of view with 155 mile range
	Endurance:	12 hours
	Altitude:	42,000 ft
	Cost:	$244.4 Million
	Weapons:	none



Joint-STARS

RC-135	EO:	none
	IR:	none
	SAR:	ELINT and COMINT only
	Endurance:	12 hours
	Altitude:	42,000 ft
	Cost:	$130 Million
	Weapons:	none



Rivet Joint

The best known manned ISR system is the U-2 Dragon Lady. Made famous by Francis Gary Powers and the shoot-down of his U-2 over the former Soviet Union, the U-2 is capable of a wide variety of data collection, depending on the systems installed for each flight. However, recent budget cuts have limited the U-2's life span to retirement before 2012.[175] The E-8C Joint-STARS contains a very powerful Synthetic Aperture Radar (SAR) capable of detecting moving ground vehicles.[176] The RC-135 Rivet Joint does not provide imaging but instead collects Electronic Intelligence (ELINT) and Communications Intelligence (COMINT) data valuable to the CCDR.[177]

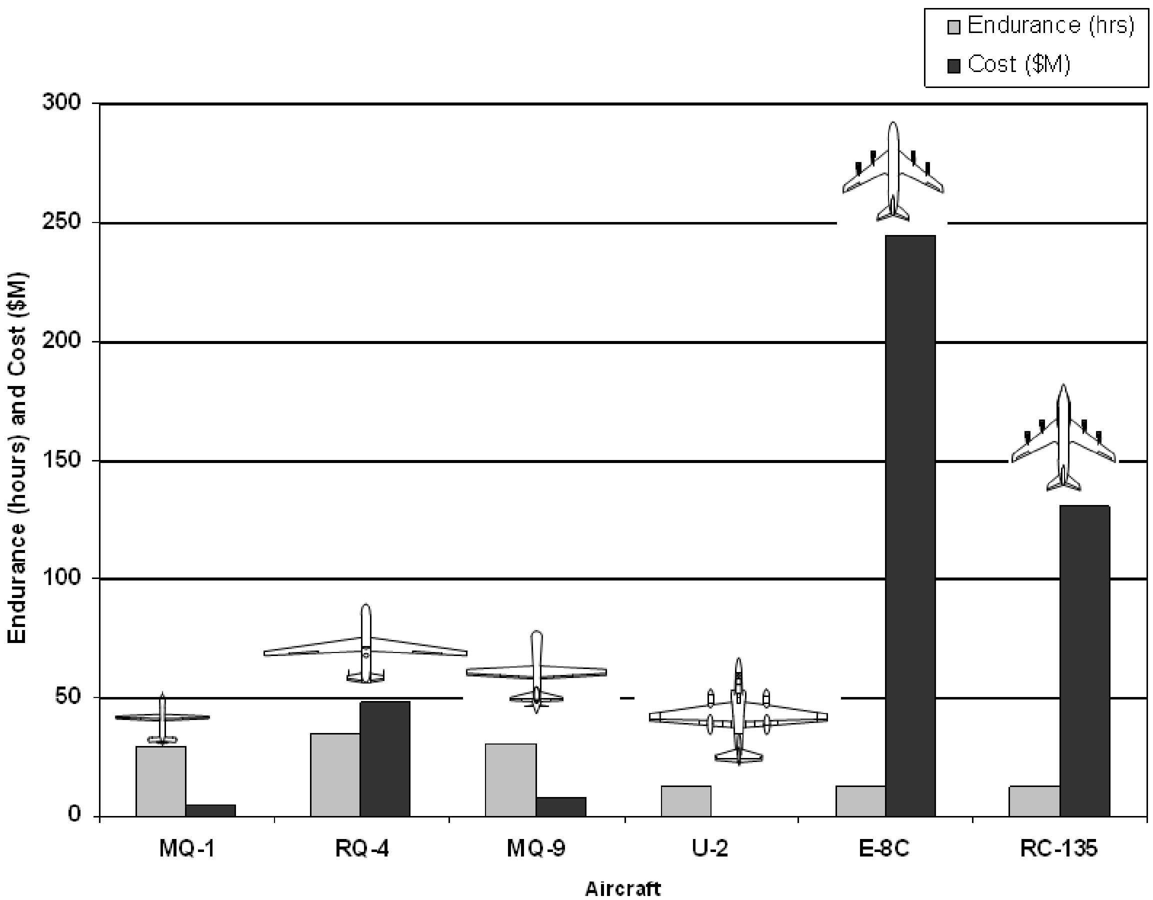


Figure 17. Comparison of Endurance and Cost for Surveillance Aircraft (U-2 cost classified)

While all surveillance aircraft provide a view of the battlefield, not all systems are created equally. As seen in Figure 17, the cost for a long-endurance system can vary wildly. The key factor to gain from Figure 17 is that manned systems cost much more than the unmanned systems, while unmanned systems are not restricted to 12 hour missions because of crew rest obligations. For continuous battlefield surveillance availability, *the preferred design choice is an unmanned system*. An unmanned system also provides the CCDR with the additional capability of sending the system into higher risk environments. The need for persistent ISR is known in the highest levels of the US military. The 2006 QDR captures this need, stating a requirement for "persistent surveillance, including systems that can penetrate and loiter in denied or contested areas."[178]

The Usefulness of ISR in the War on Terror

"If you take your eye off the target for a minute, you might miss something." –
Lt. Gen. Michael Wooley, AFSOC Commander[179]

Two basic strategies exist for using ISR on the war on terror. First, the surveillance assets are tasked by and for US forces in roles targeting other states (see page 73). Second, the assets are supplied as part of a greater strategy for foreign internal defense (FID) improvements to a weaker state.[180] The second strategy benefits both the host nation and the US by strengthening indigenous forces while simultaneously minimizing US military presence. The use of airborne collection systems enables the FID strategy with a minimal additional burden to space assets.

These techniques prove useful in the daily war on terror operations. In 2002, an MQ-1 Predator drone equipped with AGM-114 Hellfire missiles tracked and destroyed a vehicle in

Yemen containing six suspected Al Qaeda members wanted for the bombing of the USS Cole. Among those killed in the attack was Qaed Senyan al-Harthi (also known as Abu Ali).[181] In Pakistan in 2005, another Al Qaeda operative was killed while traveling in a car. Haitham al-Yemeni was with a local warlord, Samiullah Khan, who was also killed.[182] In 2006, an MQ-1 Predator operating in Iraq directed two F-16 fighters to bomb a house containing Abu Musab al-Zarqawi, a suspected Al Qaeda leader.[183] These strikes would not have been possible were it not for the four unique capabilities of persistent surveillance and strike aircraft*: long loiter times, immediate strike capability, instant battle damage assessment and feeding real-time video to ground forces*.[184]

High Demand, Low Density Assets

Access to the information from Predator and Global Hawk is demanded by every US Army battalion commander, USAF targeting cell and special operations team around the clock.[185] The demand for data from airborne ISR assets far outweighs current US capability. A Joint Force Component Commander recently stated that ISR planners can only meet 50 percent of the requests for visual and synthetic aperture radar images. The capability to meet the needs of moving target indicator (MTI) and full motion video (FMV) requirements is even less. With user demands increasing exponentially, the already saturated ISR capability requires immediate enhancement. Both space and atmospheric based ISR programs are continually being upgraded by the US Government. But which offers the greatest potential?

The Inefficiency of Space

The great advantage to space satellite reconnaissance is that international treaties allow for the unmolested use of space assets for ISR data collection. However, several disadvantages in using the space-based systems still exist for the Combatant Commander. First, space-based ISR systems require years of development and billions of dollars. Even with that significant investment, Low-Earth Orbiting (LEO) satellites provide only a stroboscopic view of the battlefield. The relatively low satellite altitude (100-150 miles) is required to maximize the performance of the sensor package. This low orbit dictates a fast pass over the ground. Placing the satellite in a higher orbit will result in longer pass times (the longest being for satellites in geostationary orbit where the satellite is fixed over a specific ground location) but results in greatly degraded performance, with imaging sensors almost useless for CCDRs. Therefore, dwell time over a specific Area of Operational Responsibility (AOR) is measured in minutes (33 seconds to 4 minutes, 29 seconds depending on the mission) requiring several satellites just for daily coverage.[186] During the limited pass time over the target area, the fixed capabilities of the aging satellite systems may not be able to keep up with advances in enemy strategy. For example, the use of distributed systems and seldom-used cloned phones.[187] The products of imaging satellites are still subject to poor weather conditions which may obscure the desired area altogether resulting in a useless image.[188] A third disadvantage is the inherently strategic nature of the satellite which delays delivery of the data to the warfighter and makes it almost impossible for the end-user to control them. Diminishing budgets for space-based surveillance continues to delay providing space-based capabilities like Space Based Radar (SBR) which could be performed by a near space asset and at a higher relative resolution due to its decreased distance to the battlefield.[189] To overcome the limitations of satellites, many capabilities traditionally associated with space could be relocated to airborne assets. The direct tasking of these systems from the battlefield provides a great capability worth considering.

Perhaps the greatest risk is the US dependence on its satellite systems. Should these systems become disabled or destroyed in any way, current CONOPS will be difficult to cope. Predicted threats for the 2010 to 2025 timeframe consist of high-altitude nuclear bursts, anti-satellite kinetic vehicles and lasers (see page 80).[190] The high-altitude nuclear burst would create an electromagnetic pulse disabling or disrupting satellites for a radius of thousands of miles. Re-creating the current on-orbit capability would take several years and trillions of dollars. An alternative would be fielding these same capabilities on a near space asset for a fraction of the cost with no space launch risks.

Dr. Ed Tomme (retired USAF Lt. Col., Sci-Ops Consulting, Inc) summarized this argument in a 2007 USAF Air Command & Staff College survey when he stated that:

> "The layered approach is the one that will work. Space, the strategic layer, has the advantages of freedom of global overflight and, for the time being, relative immunity to threats. The drawbacks are distance (limits resolution and/or requires high power for communications). Complementing space, near-space gives persistence, lower cost, and responsiveness over theater- to region-sized AORs. Its limitations are lack of speed and perhaps lack of resolution. The tactical layer, air breathing UAVs, need to have speed and resolution (and weapons in some cases) to respond to cues received from space and near-space. This layered approach makes the air-breathers much more effective since they don't spend time searching through a soda straw, only responding to potential threats already tagged by the wider area searches performed by space and near-space assets. This set-up is much like what is used by surface to air missiles, where a target tracking radar with a large beamwidth and rapid scan finds the target and hands them off to a very narrow beamwidth target tracking radar."[191]

Tomme's comments were supported by Bruce Carmichael (VP, L-3 Communications), Cory Dixon (University of Colorado) and Dr. Brent Marley (USAF Air War College). Additional survey results are presented in Appendix A starting on page 32.

The shortcomings of current US surveillance are explicitly mentioned in the 2006 Quadrennial Defense Review Report (QDR). The QDR is the key document which discusses the current and future focus of the US military, including: shortcomings, capabilities, missions and probable future threats it will face. Repeated throughout the QDR is the transformational requirement that new systems must provide "better fusion of intelligence and operations to produce action plans that can be executed in real time."[192] A stated key component of this capability is the doubling of current unmanned airborne surveillance systems, allowing more continuous coverage.[193] These new systems will provide the US with the QDR required capability of "long-term, low-visibility presence in many areas of the world where US forces do not traditionally operate."[194]

Summary of Present Lessons Learned:

1. For continuous battlefield surveillance availability, *the preferred design choice is an unmanned system*.
2. The 2006 QDR states a *requirement for "persistent surveillance, including systems that can penetrate and loiter in denied or contested areas."*
3. Strikes against time-sensitive-targets would not have been possible were it not for the *four unique capabilities of persistent surveillance and strike aircraft: long loiter times, immediate strike capability, instant battle damage assessment and feeding real-time video to ground forces.*
4. Satellites are *limited because of their short pass time over target areas, high cost, fixed capabilities and their inherently strategic nature which makes initial tasking and final data delivery to CCDRs very difficult.*

APPENDIX D: LIMITATIONS AND SURVIVABILITY OF LTA'S

Technological Advances in Aircraft Design: Balloons

The simple balloon concept is well understood and may still provide tactical and operational advantages. Called free-floaters due to their lack of station-keeping ability, the potential for communications and surveillance support is still substantial.[195] Released upwind, the balloons provide coverage while over the AOR and then are commanded to release the payload using a parachute or gliding wings for terrestrial recovery. Collection over friendly territory is a must. The incorporation of a glider into the system payload can allow for easier recovery of the more expensive components.[196] The one clear advantage to this method is that space qualified hardware is not required which minimizes costs.[197] The disadvantage is the periodic replenishment needed as the balloons drift out of range.

Connecting a cable from the balloon to the ground fixing it in place changes the name to aerostat. Current use of aerostats includes Homeland Defense and support for personnel in Baghdad, Iraq.[198] The Baghdad aerostats carry a 300 pound payload at altitudes up to 56,000 ft. The aerostats alert ground forces to shoulder-fired missile launches.[199] The US Army chose this system deliberately for its low cost and minimal logistical requirements.[200] Despite this successful use, scaling up is not possible with current balloon designs to larger payloads at higher altitudes. The weight of the cable and stresses placed upon it are too great. However, breakthroughs in carbon nano-tube wires may again make this a viable alternative.[201] Other limitations include the requirement for a ground tower or naval vessel for attachment of the tether and the camera shake caused by the vibration of the balloon-tether system. *Because of these limitations the tethered balloon approach is not recommended.*

LTA Limitations

Perhaps the greatest limitation to LTAs is the weather. Transiting the troposphere for raising or lowering operations places the system at risk to the jet stream, lightning and windstorms. Detailed weather forecasts will be required since jet stream velocities of up to 250 knots would easily overpower the station-keeping propulsion system of the proposed LTA designs.[202] While current meteorological forecasting methods may be sufficient for the lower altitudes of LTA transits, the near space weather environment is not as well defined. To predict weather at the operational altitudes of these systems, Air Force Space Command (AFSPC) is developing a new software package called Talon SHU.[203] This program is scheduled to be available to the operators of the near space assets.

LTA Survivability

The survivability of LTAs in a foreign threat environment must be considered before deployment. At first glance, the risk to LTAs by SAMs (SA-2, 4, 5, 10, 11, 12, 17 from Figure 14 on page 43) seems credible. However, *the extreme altitude (65,000 ft), low radar cross section and negligible velocity all make targeting an LTA extremely difficult task*.[204] Considering all the systems with enough reach, of these only the SA-2 and SA-5 have been exported in any great number.[205] Should an attack occur, the LTAs inherent ability to endure several small punctures from an exploding SAM warhead will allow for a gradual and controlled descent. Specific survivability will be dependent on the final design and its systems. Incorporation of an AN/ALQ-214 Integrated Defense Electronic Countermeasures (IDECM) or similar system would also greatly enhance survivability.[206] Despite these means to increase survivability, air superiority is the preferred means for survivability.

A USAF Air Command & Staff College survey submitted to 73 leading industry, government and university experts in the field of UAVs considered which type of aerial platform would be the most useful in detecting and tracking an enemy threat. Dr. John Baker (Professor, Mechanical Engineering, University of Alabama) stated that:

> "I believe near space systems will be the most useful in detecting and tracking enemy threats because such systems would typically be out of the range of enemy fire. They will be more responsive and have superior imaging capabilities relative to satellites. Near space systems will also have superior loitering capabilities compared to UAVs."[207]

Dr. Brent Marley and Dr. Ed Tomme responded with similar comments. Mr. Dyke Weatherington (Deputy, UAV Planning Task Force, Office of the Under Secretary of Defense) added that it:

> "Depends on the threat, large airships will have advantages for large area surveillance from static locations (Missile defense, Homeland defense, Maritime defense awareness) for individual human targets, a combination of large and small technologies will likely provide the most robust capability."[208]

Further survey results are presented in Appendix A on page 32.

APPENDIX E: ENABLING NET-CENTRIC OPERATIONS

Technological Advances in ISR and Communications: Radio Relay

Communications across the battlefield require immediate improvement for current and future operations. Present methods of passing CAS information from one to operator to the next increases the odds of getting poor support or creating a fratricide event. A high-altitude repeater for existing radios can expand the troops on the ground radios from 10 to 400 miles allowing direct contact with CAS pilots preventing possible fratricide.[209] The AF Space Battlelab demonstrated a prototype system, Combat SkySat, using PRC-148 two-way radios in March 2005.[210] Upon the successful conclusion of the test, the USAF awarded a $49M contract to Space Data Corporation to build more of them for use in Iraq, each of which will provide approximately eight hours of coverage before the payload will have to be recovered.[211]

An LTA or UAV can also be used as a GPS pseudo satellite. The proliferation of Russian made GPS jammers provide their users with the capability to potentially prevent satellite guided bombs from impacting their targets and increasing the risk of collateral damage to civilians.[212] A near space asset provides the perfect platform for broadcasting an additional GPS signal, either as a differential signal for improved accuracy or as an additional pseudo-satellite.[213]

Technological Advances in Data Integration and Management

The Common Operational Picture (COP) is a new system for providing Joint commanders with mission data and near real-time ISR updates.[214] These updates increase or create situational awareness across the battlefield, allowing commanders to bring together the various elements of the Joint force in the most powerful way possible. The COP consists of "a single identical display of relevant information shared by more than one command."[215] However, studies of the new system have revealed a shortcoming. The user is not able to tailor the system for their specific needs, thus limiting effects-based sequencing of operations across the battlespace. Despite this, at the tactical level in the field a new system is spreading situational awareness in near real time. The Remotely Operated Video Enhanced Receiver (ROVER) is a 15 pound laptop and radio receiver carried by units in Iraq to observe video footage collected by other ISR collectors. ROVER is capable of receiving video from more than 100 different sources including Predator UAVs.[216] The principle shortcoming of ROVER is that it is currently a one-way system. The units receiving the data can not control the sensor sending them the video. Air Combat Command is planning on adding a simple uplink capability to allow ground users to highlight targets on the video footage to indicate preferred targets to the Predator operators. *ROVER technology is an important baseline for the future of continuously available surveillance.*

Just deployed for the US Army is the Persistent Surveillance and Dissemination System of Systems (PSDS2).[217] PSDS2 integrates video, radio and acoustic sensors into a three-dimensional map for continuous surveillance of a specific area. The data can come from UAVs, LTAs, ground vehicles, buildings or individuals. PSDS2 users can set alerts to changes in activity to focus their attention on specific events. The system can also record all information for the past 20 days, allowing users to "rewind" and observe actions leading up to an event.[218] An even greater feature is the ability to transmit the data to hand-held Personal Digital Assistants (PDAs) which are being distributed to commanders and combat patrols in the field. This system can be expanded on as technology continues to improve to the point where the field users are tasking the sensors directly.

A similar system is under development for the US Navy, called Persistent Unmanned Maritime Airborne Surveillance (PUMAS).[219] PUMAS will integrate manned and unmanned sensors into a single system. To be ready by 2013, PUMAS will integrate the still experimental X-47B and Mariner UAVs with existing systems and be fully operational by the time the new P-8A Multi-Mission Aircraft (MMA) is ready.[220] Incorporation of a high-altitude UAV or LTA with PUMAS would provide continuous surveillance for US naval fleet protection.

The COP, PSDS2 and PUMAS all heavily rely on net-centric capabilities. The USAF is looking ahead at what it will take to support them in the year 2020. Commanders and warfighters will take the capabilities offered by these systems for granted, even as bandwidth and surveillance demands continue to grow. Shown in Table 12, the USAF study revealed four key enablers to ensure their effectiveness. The goal is to have a system by 2020 that can use a publish-and-subscribe capability.[221] This system will share all the data, but users will only be alerted to the new information based on their defined alert settings.

Table 12. Enablers for Persistent Connectivity and Surveillance in 2020[222]

Enabler	*Description*
Net-Centric Warfare	Already in use, but system capability must continue to grow and be made more robust to failures and attacks in order to allow for more rapid target acquisition, identification and engagement and post-strike assessment
UAVs	Increasing use will flood network unless capabilities are directed for specific uses
Persistent Area Dominance	Maintain 24 hour surveillance and strike capability over a target
Directed Energy Weapons	Possibly placed on an LTA, used for both lethal/non-lethal ops

To supplement the COP and current ISR assets, additional surveillance is required. While commanders are forced to operate with fewer forces available to them, *additional situational awareness will be critical for efficient mission accomplishment.* The investment of one or more additional Joint systems capable of reducing the fog and friction of war are critical.[223]

Technological Advances in ISR and Communications: Data Links

The data collected by the flying system does no good if it can not be relayed instantly to those who need it. Technology trends favor the continued development for UAVs, since miniaturization makes individual components smaller and easier to integrate into the payload. Electrical power required continues to drop while capabilities increase. This trend when applied to computers is called Moore's law. As seen in Figure 18, the calculations computers are capable of are increasing not at a linear rate, but an exponential one.[224] In words, this trend can be described as computers will double in capability approximately every two years. In addition to the ever increasing capabilities of traditional silicon chips, quantum computing may emerge by 2020.[225] Initial uses for quantum computers include image processing and UAV control.

A simple example of this trend is the $11.7M government contract given to AAI Corporation to build a new miniature Common Data Link (CDL).[226] The new CDL will require less power and payload than existing CDLs, and allow UAVs as small as the RQ-7B Shadow (12.75 ft wingspan, 328 pounds take off weight) to interact and share data with existing ground systems.[227]

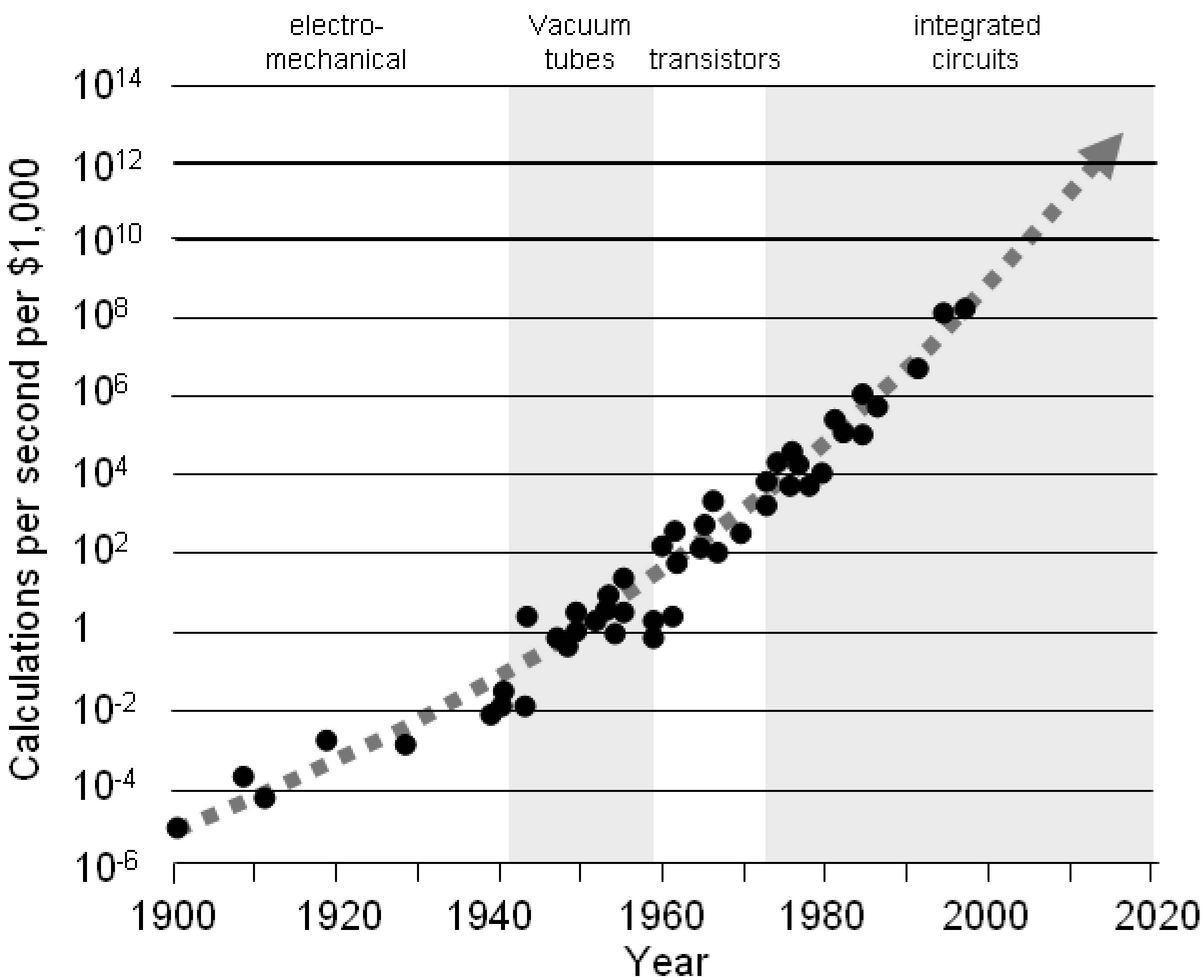


Figure 18. Moore's Law: The Exponential Growth of Computing (adapted from Kurzweil)[228]

Growing computational power is the key enabler for the "power to the edge" concept. This concept uses a wideband data network populated with high quality information to share situational awareness at all levels of combat.[229] The authors of the concept state that through the use of a single network (similar to the Global Information Grid), operators at the tactical level of war orient themselves without additional instruction from their superiors, thereby shortening the traditional Observe, Orient, Decide and Act (OODA) loop decision model (see Figure 19).[230] The authors estimated that the power to the edge concept would not be possible until 2050 due to the current lack of computational power and bandwidth. However, as seen in Figure 18, computational power is increasing at an exponential rate. The rise in computer capability coupled with laser communications (see below) indicate this capability may be possible much sooner.

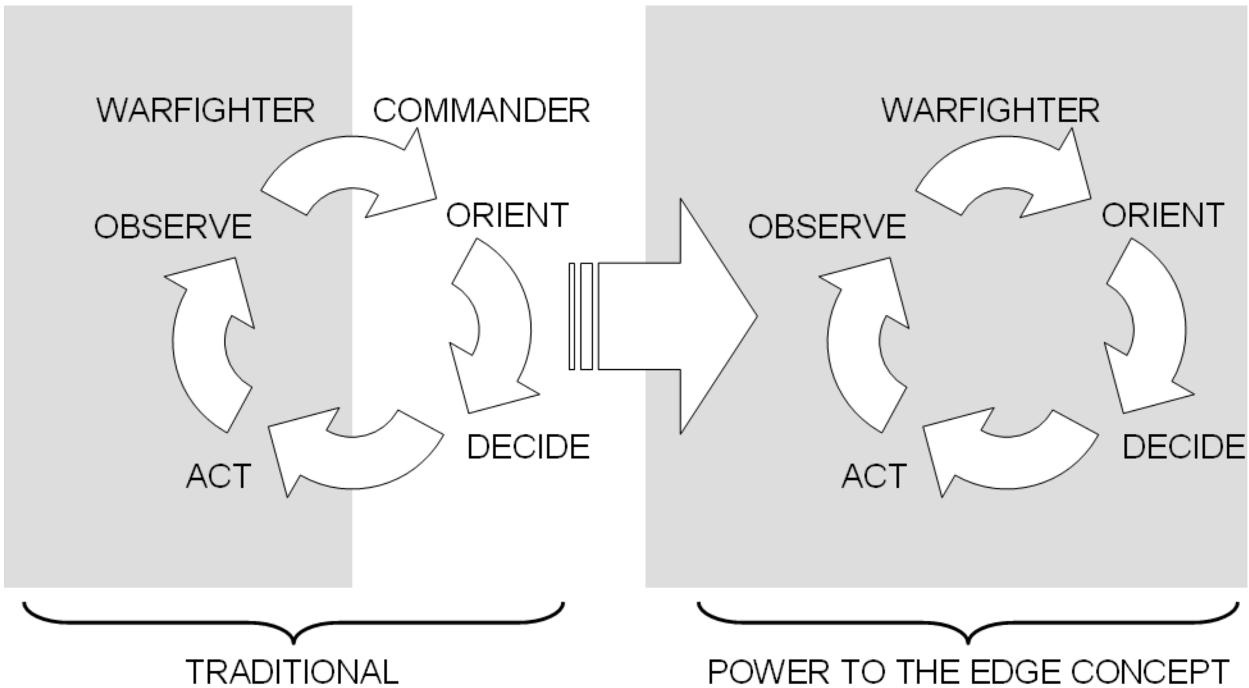


Figure 19. Computer and Communications Technology will Shorten OODA Loop[231]

Secure and high-bandwidth communications can be achieved through the use of lasers. Laser communication offers the possibility of bandwidth as high as fiber optic lines, but without the physical medium connecting the transmitter and receiver. Currently under development for the new USAF Transformational Satellite Communications System (TSAT), a satellite based laser communication system could be fielded as soon as 2013.[232] Data transfer rate for this system is specified at 40 Gbps, or the equivalent of sending the entire Encyclopedia Britannica (including all graphics) 40 times per second.[233] This system is being considered for integration into existing ISR platforms such as the RQ-4 Global Hawk. The designers of the TSAT laser communications system have suggested that sensor to shooter links using this technology are possible, allowing high-resolution images and video to be transmitted directly to the tactical level of war.[234] This system could easily be integrated into an airship or aircraft operating at high altitudes over the battlefield. Another benefit of using lasers is the independence from the radio spectrum, allowing frequencies to be assigned to other projects.[235] But the US has already lost the edge in this race.

The US must develop this technology immediately. The European Space Agency (ESA) satellite Artemis successfully tested laser communications between an aircraft and space in December 2006. A French Mystère 20 aircraft using the LOLA (Liaison Optique Laser Aéroportée) airborne laser optical link established six two-way communication links with the SILEX (Semiconductor Intersatellite Link Experiment) payload on the Artemis satellite.[236] The altitude difference between these two crafts is substantial – 22,370 miles for Artemis, 20,000 ft for the Mystère 20 aircraft. The SILEX payload is capable of transmitting data only at 50 Mbs, significantly less than the still experimental TSAT system currently under development in the US but it still clearly demonstrates the feasibility of the system.[237]

APPENDIX F: GEOGRAPHIC USES FOR CONTINUOUS SURVEILLANCE

Geographic Uses for Continuous Surveillance

"What we have seen [in Afghanistan and Iraq] is a change in doctrine from overwhelming force to overwhelming ISR." – David Stafford, Northrop Grumman Information Systems[238]

Prevention of another catastrophe like September 11, 2001 is the most important reason to pursue continuous surveillance of a potential threat. No other unnatural disaster has struck the people of the US to a greater degree. To protect the US people in the continental US (CONUS), the department of Homeland Defense (DHS) was created. The first of five key objectives in combating terrorism of "timely and actionable intelligence, together with early warning, is the most critical enabler to protecting the United States at a safe distance."[239]

Table 13. The Shift from Reconnaissance to Persistence (Pendall, US Army)[240]

Reconnaissance	*Persistence*
Periodic, "snapshots in time"	Continuous, enduring contact and "dwell"
Stovepiped, hierarchical collection	Multimode collection with broad access
A few sensors support a few missions	Sensors support entire enterprise
Analysts see data first then pass it on	Data available across network to all
Target-centric collection and analytic focus	Deep systemic and relationship focus
Analytic templates and assessment	Patterns, inference, case-based models
Data sets remain within stovepipes	Data integration – horizontal and vertical
Driven by predetermined requirements	Data and analysis on demand

Once threats are detected, the second key objective is "to intercept and defeat threats at a safe distance from the United States."[241] An enabling technology for this mission is persistent surveillance – constant and enduring contact with the target (as opposed to reconnaissance – see Table 13) combined with weapons capable of intercepting the threat immediately upon detection. This responsibility falls to the Air Force development and fielding.

The current US inventory of reconnaissance aircraft is insufficient to meet this requirement. Current ISR assets with their limited endurance require hand-offs to a succession of follow-on aircraft every few hours. Complex schedules coordinating several different aircraft types for continuous coverage of the battlefield result in difficult tactical operations when the procedures, communications, and equipment required for working with the overhead ISR asset continually changes. This problem is highlighted by US Army Lt. Col. John Nagl, Ph.D. who stated that the fifth priority for Air Force support of the Global War on Terror (GWOT) should be providing an "unblinking eye" over the battlefield.[242] Nagl supported this claim with personal experiences in OEF and OIF where finding particular individuals responsible for planting explosives and committing other acts of violence was hampered by a lack of continuously available surveillance. This requirement is not one of the top five designated by Air Force Secretary Michael Wynne and AF Chief of Staff Gen. T. Michael "Buzz" Moseley.[243] The AF instead will focus on recapitalizing its core mission aircraft (see Figure 20). The replenishment of satellites will not provide the persistent surveillance required in the protracted war on terror.

USAF: *Recapitalization*

Priority	Gen. T. Michael Moseley
1	New Tanker to Replace KC-135
2	Combat Search and Rescue Helo (HH-47)
3	Early Warning & Communication Satellites
4	F-35
5	Long Range Strike Aircraft (B-3)

USA: *AF Support for Counter-Insurgency Operations*

Priority	Lt. Col. Nagl, Ph.D.
1	Air Supremacy
2	Precision Strike
3	Transportation
4	Training Host Nation Forces (for CAS)
5	"Unblinking Eye" – Persistent Surveillance

Figure 20. Different Priorities for Future of AF Support of War on Terror[244]

Persistent surveillance can not be achieved through existing aircraft or satellites. Current aircraft have endurance limitations, requiring frequent rotations between platforms for the desired coverage area. Satellites offer only stroboscopic coverage at a high cost (see page 60).

A near space system could offer the advantage of a high cost, orbital unblinking eye for the cost of an aircraft. Placement of a high-altitude airship or UAV at 65,000 ft provides ISR coverage for a radius of 310 miles (see equation 1 where r is the radius of the Earth and h is the airship altitude).[245]

$$S = \cos^{-1}\left(\frac{r}{r+h}\right)r \qquad [1]$$

This is a total of 305,000 square miles, roughly the same size as Texas. A higher altitude of 120,000 ft gives a radius of 420 miles. The range of this capability allows stationing of a high altitude asset outside international borders of the target nation while still providing significant ISR data. But where should the government focus this technology?

Five nations have been identified as the largest state-sponsors of terrorism: Iran, Syria, Sudan, North Korea and Cuba.[246] Monitoring of the activities of these states is critical. Weapons of Mass Destruction (WMD) development, technology transfers, training and other forms of support may be monitored to provide US leaders with a real-time assessment of threat growth. Compliance with possible UN sanctions or other agreements can also be accomplished. Regardless of the source of the mission, the capability is enabling.

Another key use of persistent surveillance is supporting existing operations. US forces operating in Iraq (see page 51) already need this capability. The utility is apparent for operations in Afghanistan as well.

Geographic Uses for Continuous Surveillance: Afghanistan

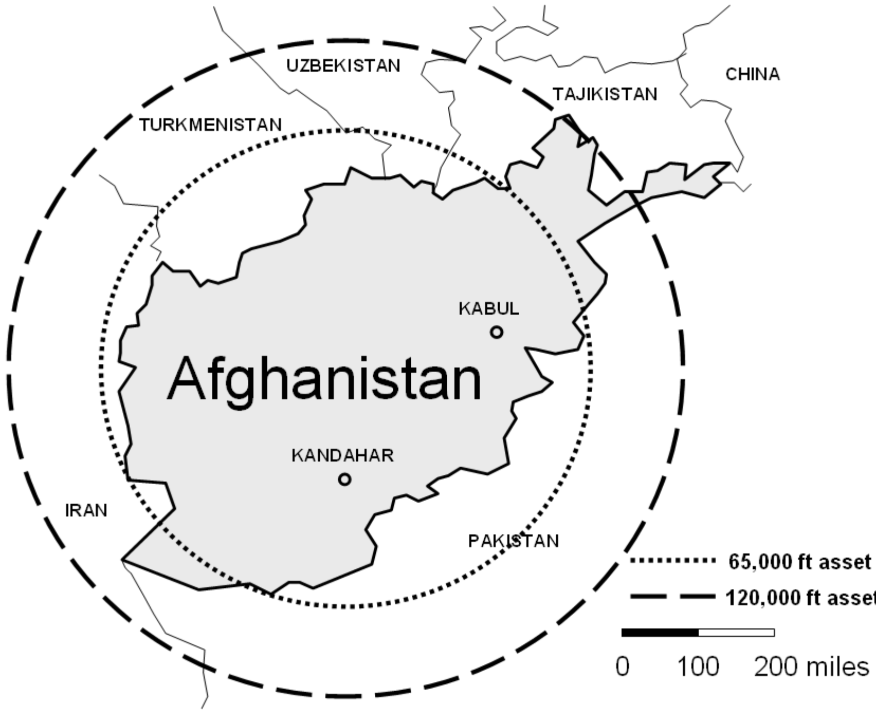


Figure 21. Coverage of Afghanistan from a Single Near Space Location

The struggles of the new democracy in Afghanistan may require long-term commitment to the region by US or NATO forces. Current problems include the rising organization of Taliban fighters, mass-production of Opium and poor staffing by NATO forces inside the country. Exacerbating these problems is an indigenous Afghan army that is grossly under funded and a government image of corruption.[247] Allied support of the Afghan army relies heavily on UAV operations which fill a vital ISR role of monitoring Taliban cell phone and mobile radio communications. Despite the successes with data collection, the need for combined surveillance and strike capabilities persists with opportunities and time-sensitive targets (TSTs) arising and disappearing.[248]

Geographic Uses for Continuous Surveillance: Iran

"We may face no greater challenge from a single country than from Iran" – National Security Strategy of the United States of America[249]

The poor state of relations between the Islamic Republic of Iran and the US makes it a highly interesting target for information collection by US assets. One motivation for the US to pursue intelligence collection of Iran is the revelation that Iran conducted undeclared nuclear research activities, including Uranium enrichment.[250] Different expert scenarios predict it will be at least 2009 before Iran could have enough enriched Uranium to produce a nuclear weapon.[251]

Experts also suggest that Iran has exported eight Mheger 4 UAVs for Hezbollah forces in Lebanon, along with the technical advisors to make them work.[252] Iranian military UAV development and integration continues to grow with their monitoring of US naval forces in the Sea of Oman as part of their exercises conducted in November, 2006.[253] These actions continue to highlight the labeling of Iran as the largest promoter of state-sponsored terrorism in 2000.[254]

In addition to their clandestine activities, Iran is failing to follow the provisions of the Additional Protocol.[255] The Additional Protocol was established to allow International Atomic Energy Agency (IAEA) inspectors to information and locations where nuclear technology is being developed, including nuclear weapons.[256] A key concern with the detection of Iranian Uranium enrichment is the lack of "direct surveillance other than unreliable satellite monitoring," which supports the need for a persistent surveillance asset.[257] This is exacerbated by the dispersal of the nuclear facilities to at least eight different locations across their country.[258] The QDR takes on this mission stating that the US needs the capability for "persistent surveillance over wide areas to locate WMD capabilities or hostile forces."[259] The available coverage of proposed near space systems over Iran are depicted in Figure 22. Note that each system is stationed outside of Iran's legal borders. If Turkmenistan were to allow a fifth asset to be stationed there, complete coverage of Iran is possible.

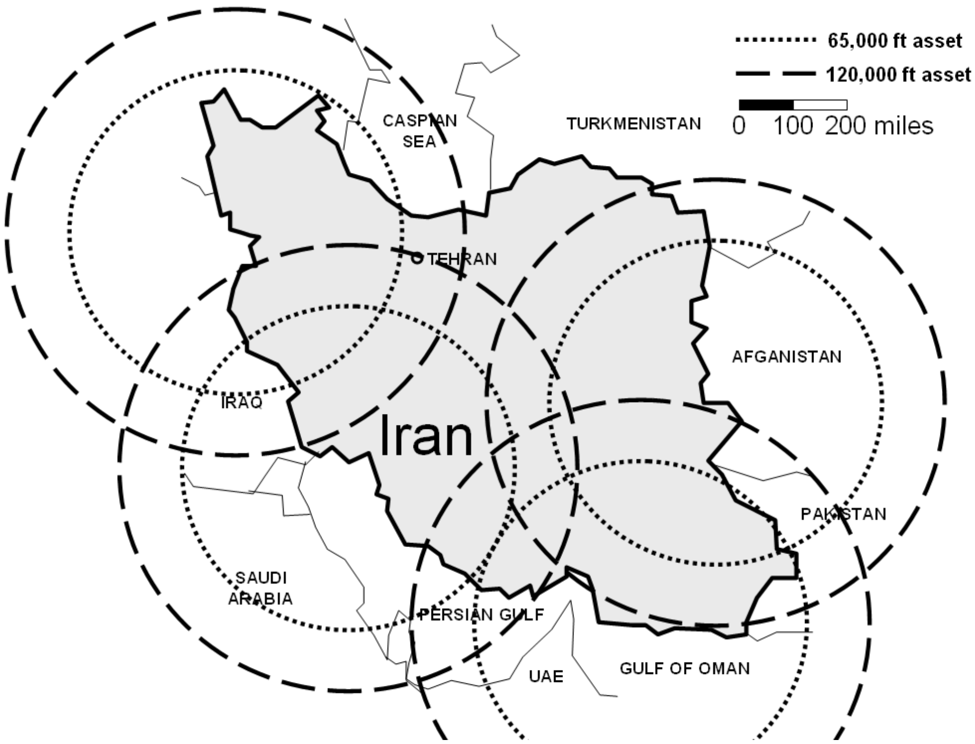


Figure 22. Coverage of Iran from Four Different Near Space Locations

Should the US decide military actions are required, full knowledge of the Iranian IADS is required. Current estimates of Iranian air defense capability is rated to be comparatively poor, with defense preference given to large cities and the sites of the indigenous Uranium program, which is the most likely target for US or allied air strikes. The current Iranian IADS lacks the ability to create a real-time comprehensive early warning picture and can not act as a fully integrated system.[260] However, this is changing with the importation of TOR M-1 SAMs and the possible purchase of Almaz S-300PMU SAMs. Indigenous upgrades include the Sayyad-1 and Feiming 80 SAMs. Iran is also soliciting help from the China National Electronics Import-Export Corporation to extend their radar detection capability up to 1,000 miles.[261] The simultaneous improvement of the Iranian IADs and decaying relations with western powers provides a strong argument for persistent surveillance.

Geographic Uses for Continuous Surveillance: Iraq

The occupation of Iraq will continue for the foreseeable future. Current OIF surveillance requirements provide a good example of how near space ISR could support the US warfighter today with planning and battlefield damage assessment. The US situation in Iraq is characterized by uncertain allied force levels and congressional support while the new government falters.[262] Should the US cease its stabilization operations in Iraq, continuous surveillance will become even more critical to monitor the potential rise of terrorist support networks.

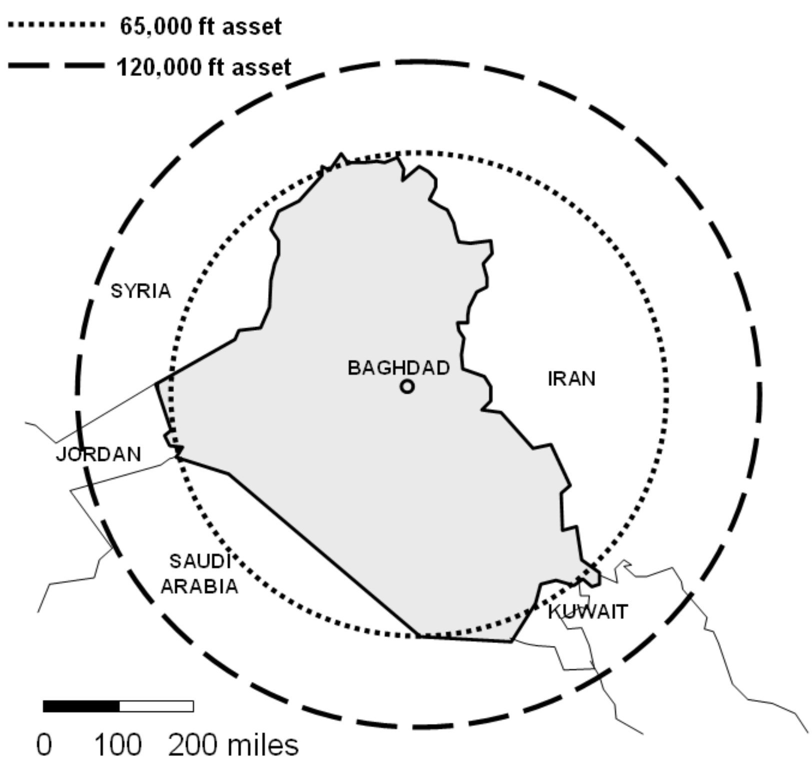


Figure 23. Coverage of Iraq by a Near Space Asset

Geographic Uses for Continuous Surveillance: People's Republic of China

> *"There is a great tradition that The Inferior Defeats the Superior. We need some Assassin's Mace weapons that the enemy will fear." – General Liu Jingsong, PLA*[263]

China observed the defeat of Iraqi forces during Desert Storm and Operation Iraqi Freedom, taking many lessons learned from the conflicts. Due to the commonality of many People's Liberation Army (PLA) systems with those of Iraq and ever growing capabilities of US military technology, China embarked on an incredible modernization program. The central theme guiding this development is modernizing all services for improved joint operational capabilities.[264] Particular system improvement efforts are being made in command, control, communication, computers, intelligence, surveillance and reconnaissance (C4ISR) for potentially hemispheric coverage.[265] The PLA's training upgraded after Operation Allied Force to counter the US use of stealth aircraft, cruise missiles and helicopters. Specifically, the Chinese were concerned with the US precision strike capability, electronic warfare and reconnaissance platforms.[266]

US reconnaissance satellites have already seen this threat. China used a ground based laser to "dazzle" the optical imaging system of a US satellite as it passed over their territory. It is not known if the intent was to blind the imaging system of the satellite, or merely to track it.[267] Whatever the intent, this prevented the satellite from collecting useful imagery as it passed overhead.[268] The potential for permanent damage to the satellite is further complicated by the fact that the satellite can not be repaired once in orbit. This technology can also be used to blind US pilots causing temporary or permanent eye damage.[269] In addition to the anti-satellite laser, China demonstrated the successful testing of an anti-satellite kinetic kill vehicle on 11 Jan 2007.[270] China's subsequent reluctance to engage in space treaty negotiations foreshadows their future development.[271] A near space asset could provide substitute capabilities for damaged satellites while still allowing for repairs should the need arise.

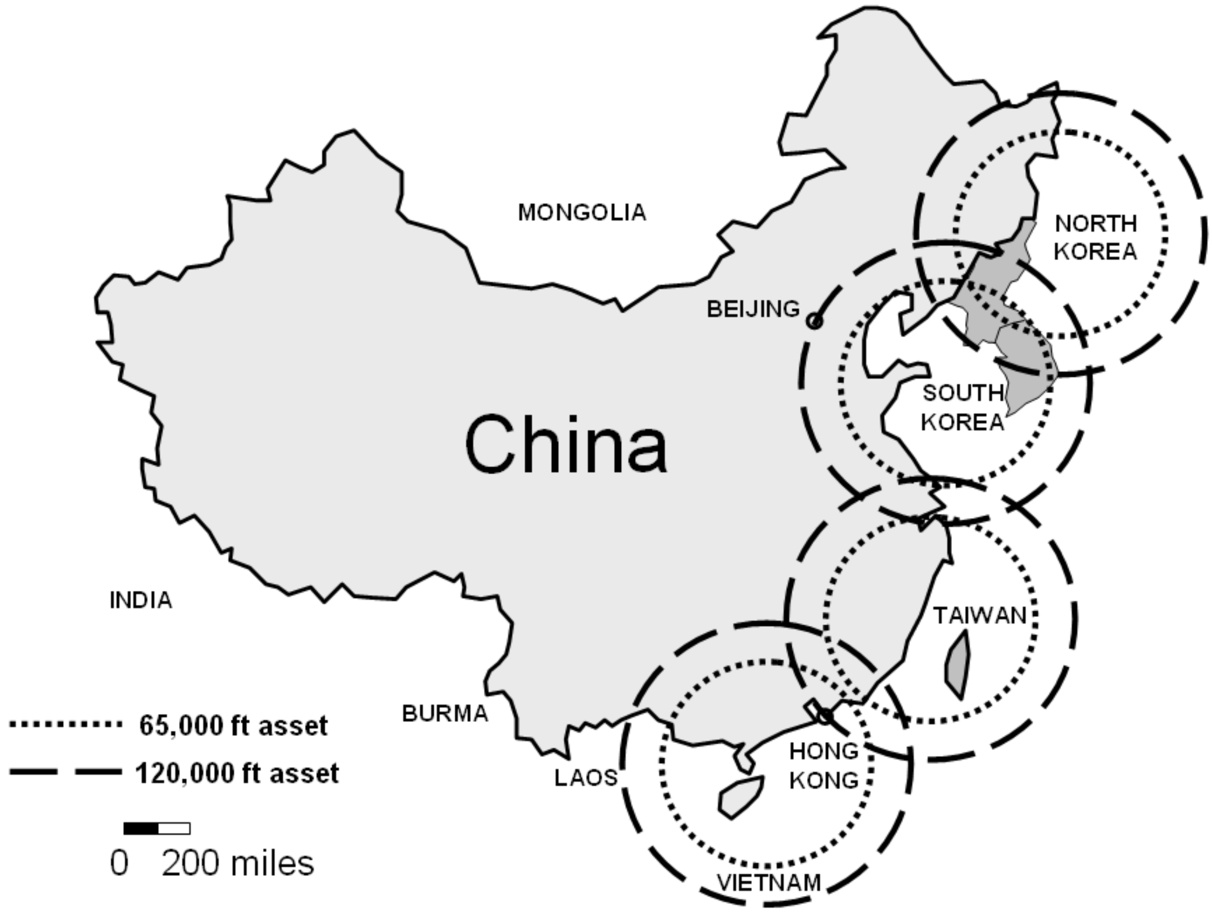


Figure 24. Coverage of the People's Republic of China from Four Near Space Locations

China's goal for developing advanced technology is not limited to blinding and destroying satellites. Rather, a series of capabilities are seen as necessary to counter and prevent US military forces from intervening should the Chinese PLA take control of Taiwan.[272] This policy has been given the broader name of "The Inferior Defeats the Superior," which is an intentionally asymmetric doctrine.[273] Systems procured under this policy are called "Assassin's Mace weapons" and are to strike at the opponents largest vulnerabilities. While many experts state that China's technology base is twenty to twenty-five years behind western systems, active research is underway. Short range ballistic missiles (SRBMs) are in production and as many as 800 may be deployed near the Taiwan Strait.[274] A "Giant Leap" in technology aimed at quickly surpassing US dominance includes the use of non-nuclear electromagnetic weapons to negate US naval command, communications and information systems followed by shore-based anti-shipping missiles.[275]

The use of these weapons in a first-strike scenario is legitimized since China considers diplomatic, information, economic and military operations as part of a gradual escalation of conflict.[276] Other Assassin's Mace weapons include air defense missiles, joint information warfare, anti-satellite weapons and information security protection systems. Another asymmetrical approach currently in development is the indigenous production of a variant of the Russian Kh-31P anti-radiation missile. Designated in the west as the Yingji-9, it is to specifically target the Patriot's MPQ-53 and AEGIS SPY-1D radars. The range of this system is estimated at 1,300 miles.[277]

These factors make China a good candidate for protracted surveillance, which will become a requirement should any military invention become necessary. As seen in Figure 24, only the eastern seaboard of the nation can be observed by near space systems. Despite this limitation, the areas covered consist of the preponderance of PLA forces which would most likely be used in a confrontation involving Taiwanese separation. The reconnaissance area could be improved if overflight of surrounding nations were to be performed.

Geographic Uses for Continuous Surveillance: Democratic People's Republic of Korea

The Democratic People's Republic of Korea (DPRK) has not entered the global community with openness or cooperation. The North Koreans have also engaged in potentially inflammatory actions by kidnapping Japanese civilians[278] and more recently by shining lasers at

US AH-64 Apache helicopters flying south of the Demilitarized Zone (DMZ) in March 2003. The device used against the Apache helicopter crew was most likely a Chinese ZM-87 laser blinder.[279] The Apache's on-board laser detectors confirmed the use of the weapon. Specifically, the ZM-87 is the world's only known laser-based anti-personnel weapon and can cause damage to human eyes at up to 3 miles.[280] Also in March 2003 four North Korean fighters (MiG-23s and MiG-29s) attempted to force a US RC-135 Rivet Joint to land, despite the fact that it was operating 150 miles over international waters.[281] The DPRK is also identified as one of the leading proliferators of missile technology with Iran (No-Dong 2 missile technology) and Syria as customers.[282] North Korean actions since then have continued to degrade culminating in their first testing of a nuclear weapon despite international pleas not to.[283] To make matters worse, North Korea's poor economy and unemployment rate are making the disintegration of its government a distinct possibility.[284] All of these actions support the need for continuous monitoring of North Korea by a low observable, unmanned system operating at a high altitude (see Figure 25) incapable of being shot down for the foreseeable future.[285]

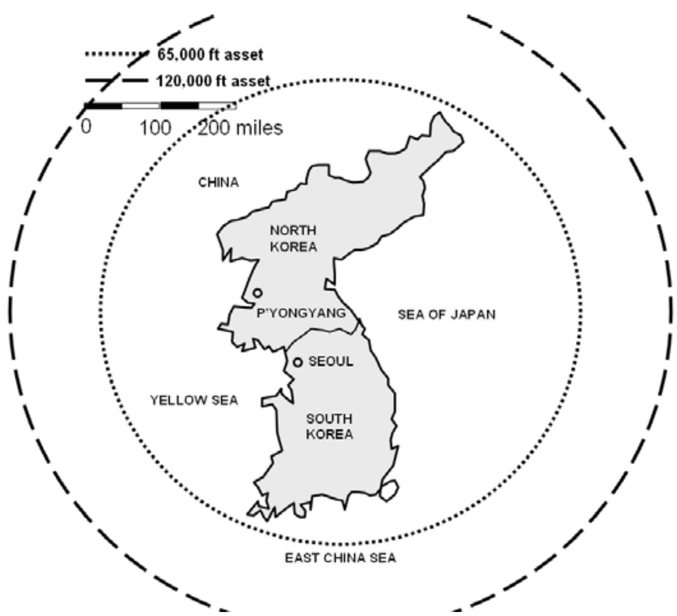


Figure 25. Coverage of North Korea by a Near Space Asset

Geographic Uses for Continuous Surveillance: Triborder Area of South America

The triborder region of South America, where Paraguay, Brazil and Argentina meet is rural and undeveloped with out the presence of sufficient law enforcement. Recently, several terrorist groups including Marxists Colombian rebels, Hamas, Hezbollah and others have started using this area to trade ideas and supplies.[286] The combination of so many groups and established smuggling routes from South to North America provide the US with a rising problem of potentially catastrophic proportions. Observation of this remote area is increasing in importance and could be accomplished with a single near space asset (see Figure 26).

Figure 26. Coverage of South-American Triborder Area by Near Space Asset

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