Global Horizons

United States Air Force
Global Science and Technology Vision

APPENDIX

AF/ST TR 13-01
3 July 2013

U.S. AIR FORCE

Table of Contents

Table of Figures

1. Introduction

Global Horizons provides the Air Force with a collaboratively derived, near-, medium- and far-term Science and Technology (S&T) vision for revolutionary capabilities that anticipate future threats and leverage global industrial sectors in an increasingly competitive, congested and contested future. *Global Horizons* aims to be a blueprint to sustain our strategic advantage and assure Global Vigilance, Global Reach and Global Power across air, space, and cyberspace. This volume contains more detailed motivation, justification, and articulation of key trends, threats, opportunities, game changers and recommendations in many of the areas addressed in the *Global Horizons* final report.

1.1 S&T Roles: Lead, Follow, Watch

Many of the sections include a technology roadmap that articulates Air Force focus in the near, mid, and far term. To clarify partnerships, roles, and responsibilities, *Global Horizons* articulates priority technology investment areas by distinguishing among three key roles: technology leader (L), fast follower (F), and technology watcher (W). In a *technology leader* role (e.g., trusted and resilient cyberspace, cold atom Position, Navigation and Timing (PNT), hypersonic and directed energy weapons), the Air Force is a lead investor and creates or invents novel technologies through research, development and demonstration in areas that are critical enablers of Air Force core functions and associated platforms. In a *fast follower* role, the Air Force rapidly adopts, adapts, and/or accelerates technologies originating from external organizations who are leaders and primary investors in focused S&T areas as part of their core functions (e.g., Department of Energy investments in power storage and management, commercial investments in high performance computing). In a *technology watcher* role, the Air Force uses and leverages others' S&T investments in areas that are not our primary or core functions (e.g., commercial commodity information technology, commercial communications, manufacturing technology, critical infrastructure such as power and water). Roles were assigned using the consensus of small groups of experts and stakeholders and could change depending upon resource, operational priority, or technology changes.

2. Future Environment

This section provides supplemental background on strategic trends and threats supporting the main document.

2.1 Strategic Trends

Figure 2.1 illustrates key demographic, economic, resource, technological, threat and investment trends that are shaping the future environment. By 2025, we forecast that 56% of the world's eight billion people will reside in Asia—making it an attractive commercial market for advanced information technologies. As is reflected in the comparative growth and national focus, by 2025 China will produce more than double the number of computer science doctorates as the US. By 2050, the world's population will grow to over nine billion and be increasingly urban (growing from 50% to 70%), middle class (from 50 to 65%), and older (from 31 to 41 years on average, but unevenly distributed with those over 60 years of age doubling from 10% in 2000 to 21.5% in 2050). Bulging population will place increased strain on limited resources. For example, at current production and consumption rates, the world supply of Indium (used in WWII to coat bearings in high-performance aircraft and now in liquid crystal displays and touchscreens) is expected to last only eight years. Limitations of some critical resources (e.g., water, energy, minerals) could drive future conflict. Combined temperature and humidity increases are expected to drive more frequent severe climate events. Explosive growth in communications and computing will accelerate progress in all sectors; however, exponential increases in malware will threaten increasingly dependent infrastructure, systems and services. A doubling of foreign satellites on orbit by 2033 will provide new challenges in space. However, there are positive aspects of this challenging future. For example, transportation costs, desire for local, rapid market access, and new technologies such as additive manufacturing will reverse some offshoring of manufacturing. Accelerating technology advances and adoption will create new wealth and the growing global middle class will demand higher quality education, housing, health care, environment, and governance, all of which will drive security, stability and prosperity. Moreover, as the public and private sector increase the current \$1.4 trillion investment in wealth- and security-producing research and development, there will be numerous opportunities to leverage multi-trillion dollar annual markets in industries such as automotive, pharmaceutical, communications and information technology (IT), financial services, and aerospace.

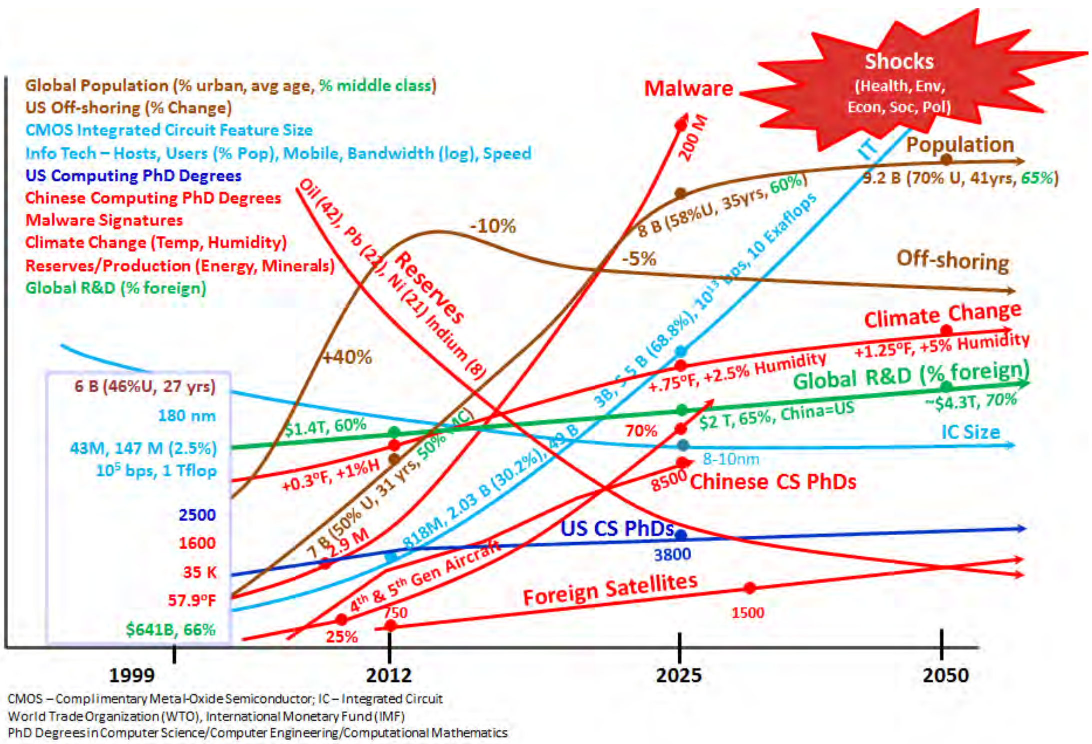

Figure 2.1: Strategic Trends through 2050

Economically, by 2025 China will rise to a close second behind the U.S. and India will rise to the number three position. The global population will grow by approximately two billion and put pressure on natural resources, becoming increasingly (60%) urban, and 13% older (See www.un.org/esa/population/publications/WUP2005/2005WUP_FS1.pdf). There will be seven trillion IP-enabled devices and 50 zetabytes (10^{21}) data (1.8 zetabytes in 2011 rising to 40 zetabytes by 2020). The role of organizations involved in global governance (e.g., World Bank, World Trade Organization, International Monetary Fund) is projected to increase.

Other increasing slopes in Figure 2.1 represent:

- Increasing internet users and hosts (1 more million in next 2 years alone) and exponential growth in mobile application downloads
- Alarming growth in malware threats
- A slight reduction off-shoring (re-shoring) of products and services (e.g., integrated circuits) given increase in foreign costs, transportation costs, and local market access (See January 2013 Economist special issue and IBM' www.smartplanet.com/blog/business-brains/offshoring-trend-set-to-reverse-study/23082)
- Increase in both temperature (National Climatic Data Center) and humidity (NOAA) increasing extreme weather events such as heatwaves and tornadoes (source: National Geography, September 2012). See also EPA climate indicators at www.epa.gov/climatechange/science/indicators/weather-climate.
- Faster growth in foreign PhDs increasing foreign/domestic gap (e.g., computing PhDs) (See NSF S&T Indicators)
- 70% more food required to support global population by 2050 (approximately 35% by 2025) (DNI Global Trends 2030 Study)
- Global Research from NSF S&T Indicators and Battelle global research report.
- Figure 2.1 also displays decreases:
- Reserves of energy and metal resources (e.g., R/P life-index in years is the reserve-to-production of resources. With 2500 metric tons of Indium used by .0000004 tons per person for LCD screens and semiconductors its life index is only 8 years; Nickel with 62M metric tons in reserve has .01 tons used per person for steel, superalloys, and batteries will run out in 22 years and oil which has 168.6B metric tons of proved reserves is used 25 tons per person leaving 42 years of it on the earth, assuming no further discoveries) Source: BP Statistical Review of World Energy 2008, www.bp.com/statisticalreview, British Geological Survey 2005, based on 6.8B population – 2010 UN Estimate
- Reductions in size Complimentary Metal-Oxide Semiconductor (CMOS) IC feature size – this will decrease gradually through 2025

Some additional trends that will influence global stability include:

- Rich/Poor Ratios – Gini Index (Corrado Gini, ran Mussolini's Central Institute of Statistics) measures income inequality (Davos severe income disparity is #1 threat to world risk) 0 =

perfect equality; 100 maximum inequality. Gini index is 70 globally. 1979 1% of households in US took 10% of pay. Today 1% takes 20%. US Gini index is 45 today (US Congressional Budget Office 1979-2007 US Gini index of PRETAX income rose 48-59.). Global Gini index is 70 – 11% world rich, 13% middle class, 76% poor (inconsistent with middle class #s?). Sweden is lowest at 23. Namibia Gini is 70.7. US Ranks 67th, behind Cameroon.

- Increased global education and literacy levels (www.wri.org/publication/content/8429, United Nations Educational, Scientific and Cultural Organization (UNESCO), Statistical Yearbook 1996)
- Change in corruption, instability, # or % of democracies
- Proliferation of nuclear, chemical and biological scientific knowledge will increase the possibility of proliferation of weapons of mass destruction.
- Growing middle class. The middle class is associated with greater political awareness, desire for more accountable and representative government (thus protests), and demand for free markets. Some evidence/sources include:
  - February 2009, *The Economist* reported over half the world's population in the middle class yet the US had only 45%. OECD estimates the middle class as 1.8B in 2010. The middle class in Asia became greater than that in the West in 2007 or 2008.
  - The middle class grew from .7B/3.3B in 1965 to 2B/6.8B in 2012 and is expected to grow to 4.9B/8B in 2030. By 2030, Asia will host 64% of the global middle class and account for over 40% of global middle-class consumption. [That would mean 21% in 1965, 29% in 2012, 61% in 2030] http://www.reuters.com/middle-class-infographic.
  - The World Bank defines the middle class as earning $10-$50/day with 369 million in developed countries; yet those who have cars (another measure) is 500-600 million. 12% of world makes > $85/day.
  - http://www.foreignpolicy.com/articles/2012/05/16/the_global_middle_class_is_bigger_than_we_thought?page=0,2
  - “The number of passenger vehicles per 1,000 people in India and China is just 10 and 27, respectively, compared with 502 in Germany and 451 in the United States. Even if the number of cars in circulation in China and India continues to grow rapidly -- near the 10 percent average annual growth rate recently projected by the International Energy Agency for these two countries - it would take about 25 years for China and more than 40 years for India to reach the current penetration rates in advanced countries”
  - General classes of trends include R&D, politics, demographics, resources, climate, technology, and military dimensions.

Some trends quoted here from the *Global Trends 2030* US Intelligence Community Report are notable:

- Population. Our demographic growth appears predictable. By 2050, it is projected that the World population will increase by 31% or from 7 billion currently to 9.2 billion. However, the urban component will nearly double from 3.5 to 6.4 billion, while the rural population will shrink from 3.5 to 2.8 billion. Population growth will be unevenly distributed and mainly concentrated in Third World countries. Many Third world cities will become gigantic. And, many of them will become unsustainable, chaotic, violent slums they already are today (example: Lagos in Nigeria projected to hold 16 million by 2025). Others may emerge as the next Singapore or Hong Kong.

- Economic growth is a huge multiplier of demographic growth in terms of resource consumption. The author mentions that if the entire developing world living standard rose to the West level material consumption would skyrocket. Let's say the US, EU, Canada, Australia, New Zealand, Japan, Singapore combined have a population of 900 million, and, that the average living standard of those countries is 10 x greater than the remainder of the World (6.1 billion). If the remainder of the World catches up to the developed group, it would cause overall material consumption to increase by 4.6 times! Where would all the oil, water, food, metals come from to support such a worldwide high living standard?
- Constrained resources. (The World in 2050: Four Forces Shaping Civilizations Northern Future, Laurence C. Smith) uses an interesting metric to capture that: Reserves of a given resources divided by yearly production or the R/P life index. For instance, oil has an R/P of only 42 years. That's why there is all the fuzz about Peak Oil. But, other critical resources have far shorter R/Ps. Those include many elements that are key to manufacturing our hi tech electronics (batteries, computers, screens, TVs, etc.). They include lead (R/P 22), nickel (21), silver (14), and indium only 8 years. Thus, how are we going to produce all our high tech gear 40 years from now for a potentially far larger customer base?

Global Trends 2030 also identifies potential *black swans* that would cause the greatest disruptive impact including severe pandemic, much more rapid climate change, Euro/EU collapse, a democratic or collapsed China, a reformed Iran, nuclear war or WMD/cyber attack, solar geomagnetic storms, and U.S. disengagement.

- By 2025, China is projected to have more than twice as many PhDs in computer science than the US. Domestic production of undergraduate computer science and computer engineering degrees is actually about half of what it was in 2004 (20k dropping to 11k in 2011).
- With an 11.5% annual R&D growth rate (versus US 4% (2.1% now, 6% in past)) China is projected (Battelle R&D Magazine) to surpass US in spending by 2023.
- By 2025, China will be a close second economically to the US, with India as #3 globally.
- The population will have increased another 2 billion and there will be 7T IP enabled devices processing around 50 zetabytes of data.
- The convergence of information technology, nano technology, and biotechnology will provide both new vectors of attack and unprecedented capabilities.
- The realization of quantum communications and the emergence of quantum computing will have significant impact on secure communications and computing.

Bottom line: The global air/space/cyber picture will be dramatically different in 2025, and there will be unexpected surprises along the way.

PhDs: "By 1970 America was producing just under a third of the world's university students and half of its science and technology PhDs (at that time it had only 6% of the global population). Since then America's annual output of PhDs has doubled, to 64,000.

Other countries are catching up. Between 1998 and 2006 the number of doctorates handed out in all OECD countries grew by 40%, compared with 22% for America. PhD production sped up most dramatically in Mexico, Portugal, Italy and Slovakia. Even Japan, where the number of young people is shrinking, churned out about 46% more PhDs. Part of that growth reflects the expansion of university education outside America. Richard Freeman, a labor economist at Harvard University, says that by 2006 America was enrolling just 12% of the world's students." – source: http://www.economist.com/node/17723223

Some recent energy remarks by Tom Donilon, National Security Advisor to the President at the Launch of Columbia University's Center on Global Energy Policy (April 24 2013):

"Total U.S. oil consumption peaked in 2005 and has been declining since—a trend the President's energy efficiency initiatives, including new fuel efficiency standards and investment in new energy sources, will only deepen. To understand just how significantly and quickly the landscape has shifted, consider a few statistics:

- Domestic oil and natural gas production has increased every year President Obama took office. We now produce seven million barrels of oil per day, the highest level in over two decades.
- The International Energy Agency has projected that the U.S. could be the world's largest oil producer by the end of the decade. Of course, we recognize that these are early days and prediction is a risky business.
- In 2005, sixty percent of U.S. oil was imported. Today the number is forty percent and falling—a dramatic move towards fulfilling the President's goal of cutting our oil imports in half by 2020.
- Today the United States is the top natural gas producer in the world. Our natural gas production has grown by one-third since 2005, driven by the increase in shale gas, which now accounts for forty percent of our natural gas output.
- The domestic price of natural gas has dropped from over $13 per million Btu in 2008 to around $4 today. Natural gas imports are down almost sixty percent since 2005, and we are exporting more natural gas by pipeline to Mexico and Canada.
- U.S. energy-related greenhouse gas emissions have fallen to 1994 levels due in large part to our success over the past four years in doubling electricity from renewables, switching from coal to natural gas in power generation, and improving energy efficiency.

Finally, "The Department of Defense's 2010 Quadrennial Defense Review, issued by Secretary Robert Gates, warned not only that climate change "may act as an accelerant of instability or conflict, placing a burden to respond on civilian institutions and militaries around the world" but also of the potential impacts of climate change on our operating environment, and on our military installations at home and around the world. A National Intelligence Assessment in 2008, multiple Worldwide Threat Assessments produced by the Director of National Intelligence, and numerous expert analyses have reached similar conclusions. This underscores the need – for the sake of our national security -- to reduce the greenhouse gas emissions that drive climate change and to ensure that we are as prepared as possible for the impacts of climate change. "

2.2 Strategic Threats

The increasing proliferation of technologies as well as the increasing availability of commercial components for innovative or traditional use in systems, will shorten the foreign research, development, acquisition, and deployment timelines, meaning advanced capabilities will be reaching military systems in a reduced time frame. In addition, low tier threat countries with access to proliferated technologies or low cost commercial off the shelf (COTS) components may develop capabilities in niche applications that will cause an increasing threat to the US.

The integration of technologies across the air, space, and cyber domains will yield unique capabilities and it is possible that the identified technology trends and threats may be used in an asymmetric manner. For example, consider the tweet that indicated President Obama was injured in two explosions that occurred at the White House (4/23/2013). The message panicked Wall Street with the result that the overall market value was reduced by nearly $200 billion. This is cyber technology used in a nefarious manner, resulting in an economic impact. Adversaries can use these asymmetric methods and technologies in attacks – that may be difficult to attribute to a source – against our economy, logistics pipelines, or other infrastructure while avoiding direct confrontation with our military.

The ability of our adversaries to integrate new capabilities – before the US – across the air, space, and cyber domains (and in some cases in the shortened time frame discussed) will negatively impact our ability to sustain our strategic advantage.

The information in Figure 2.1: "Threat Forecast" highlights specific threats that the USAF will face in the near, mid and far terms. They are sorted by domain to include air, space, and cyber threats and include threats that cross domains as well as supporting technologies that enable continued development of the future threats.

<u>Air Threats</u> – Foreign air threats continue to develop into more complicated and capable systems. UAVs will morph from single mission vehicles (i.e., supporting only ISR missions) in the near term to multi-mission vehicles supporting integrated strike, battle management, airlift, and counter-air support, in the far term. Detecting, tracking, and defeating single UAVs – let

alone a swarm of UCAVs – is a difficult issue made more challenging by the fact that the global UAV/UCAV market is expected to double by 2022 with one of the largest sales market to be in the Asia-Pacific area.

Fourth and fifth generation fighters will become more complex, utilizing advanced AESA, network data links, jammers, and detection and tracking algorithms, and long-range active radar missiles. By 2020, it is expected that 70% of fighters worldwide will be advanced fourth or fifth generation aircraft that can fill non-typical roles. Hypersonic vehicles and weapons will be difficult to counter because of their speed which reduces defensive reaction times.

Finally, munitions will stress US defense systems because they will be faster (hypersonic in some cases) and more accurate (employing improved navigation systems and sensors/seekers) while at the same time being capable of being launched from increasingly long ranges -- which places our air bases and logistics chains in jeopardy in theater, near theater, and even worldwide.

Space Threats – Superiority in the space domain can be affected in the near term by increasingly capable and widespread (i.e., available) SATCOM jamming. In terms of counterspace capabilities, by the 2030 time frame, multiple countries will have the ability to hold all US space services at risk via both physical and cyber attacks. Physical attacks via both direct-ascent interceptors and orbital anti-satellite systems can destroy our space assets. Foreign telemetry, tracking, and control (TT&C) and C2 threats can interfere with, disable, or destroy space assets that are vital to US space-based navigation, C2, and intelligence collection capabilities.

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Air Threats	UAV (primarily ISR) Multi-mode, imaging seekers	UAV (many UCAVs) 4th/5th gen aircraft (70% by 2020) Optic flow seekers Munitions (longer range, faster, more accurate) Advanced platforms (LO, Hypersonics)	UAV (multi-mission) Autonomous systems (cognitive enhancement)
Space Threats	Increased STACOM jamming capabilities SOSI improvements High altitude nuclear detonation (intentions)	Direct-ascent interceptors Orbital anti-satellite systems TT&C, C2 threats (interfere, disable, destroy) SOSI improvements	Number of satellites (from 750 to 1500 by 2033) SOSI improvements
Cyber Threats	Exploitation of mission vulnerabilities (embedded, targeted) Cyber extortion, espionage RF exploitation	Quantum communications Fusion of EW and cyber Autonomous cyber agents	200M new malware signatures per year in 2025

Cross Domain Threats	High power microwave weapons Lasers Foreign EM spectrum management GPS jamming/spoofing Data exfiltration/CNE Anti-access/area denial (basic) Robotics (remote piloting, logistics) Advanced ISR (Space, cyber, IO, wideband, low SNR signals, commercial systems) Active, passive, multi-static sensors	Lasers Particle beam weapons Mature anti-access/area denial threats Robotics (swarming) ISR (all weather, reconfigurable) Sensors (DRFM, anti-DRFM) Ionospheric modification (practical) Electronic Warfare Application of WMD	Autonomous decision support systems Ionospheric modification (large scale)
Supporting Technologies	Advanced materials Advanced manufacturing IT (hosts, bandwidth, processing speeds) Advanced algorithms (sensor fusion, DRFM)	Advanced materials Additive manufacturing Geomagnetic navigation Computer vision Optic flow IT (quantum information science, supercomputers, bioinformatics) Advanced algorithms (chaotic waveforms, computer vision)	Advanced materials Advanced manufacturing IT (distributed/local decision making) Advanced algorithms Autonomous systems Advanced power (reduction in fuel carrying percentages)

Figure 2.2: Threat Forecast

Cyber Threats – The future cyber threat is difficult to predict because of the rapid pace of change in this operational environment. For example, new types of computers may allow development of unique and unforeseen cyber threats – the digital world enables cyber attacks. However, it is clear that the cyber threat will manifest itself in a multitude of shapes and sizes and will be directed at both our military and our economy. Attacks against communication links (e.g., Link 11, Link 16, Link 22), especially crucial in operating UAVs/UCAVs, will disrupt our assessment of the tactical environment and may interfere with the distribution of command orders. Malware threats, increasing in complexity and number, can be embedded in an existing system until activated, can be totally autonomous (engage when ready, at predetermined time, etc.) or can be targeted against a specific system or capability. By their sheer numbers, malware is becoming more and more difficult to counter. And as software and weapon systems become increasingly connected, the cyber threat becomes even more serious – consider a weapon system that is "hacked" to target a civilian center in a domestic or foreign city. Furthermore, cyber attacks can be difficult to attribute to a source and may never be associated with a known assailant, group, or threat country.

Advanced technologies in the hands of our adversaries can be defensive in nature. For example, due to quantum mechanics, a foreign network incorporating quantum key distribution into its systems should enable positive detection of any attempt to eavesdrop on the foreign communications. These types of technologies will complicate our offensive missions and may deny access to our ISR assets.

The increased worldwide usage of the internet increases the vulnerability to cyber attack of individuals, groups, or countries. RF exploitation in terms of wireless hacking of our networks will be a continuing threat. The aforementioned hack into the AP twitter feed (identifying an explosion at the White House that injured the President) illustrates the effect a single tweet can have on the economy. A large scale hack of this sort may have entirely different and potentially devastating results.

The challenge for all future military forces (including the USAF) is to not only counter cyber threats in a timely manner but to also deter a cyber attack before it begins.

<u>Cross Domain Threats</u> – There are many threats that cross the air, space, and cyber domains. Directed energy weapons (DEWs) can be lethal/non-lethal and destructive/disruptive and can be used to affect all three domains via precise (and adjustable) targeting for surgical strikes (resulting in no collateral damage). In addition to their role as a weapon, DEWs can also serve as a sensing device and can include a diversity of deployment platform choices. Current threats such as high power microwave weapons can disrupt or destroy electronic systems used in communication networks and elsewhere. Lasers represent a current threat to pilots via induced temporary blindness but represent a future destructive threat to US ISR and other non-optical systems as the laser capabilities continue to develop. Particle beam weapons are examples of future destructive weapons.

Foreign offensive efforts in the electronic warfare area include threats from digital radio frequency memory (DRFM) jamming, GPS jamming, and spoofing; defensive efforts include reconfigurable jammers, low probability of intercept/detection signals, and counter-DRFM. The source of the jammer is often difficult to identify, and thus counter, making this a challenge for all future military forces. Furthermore, we currently operate under an antiquated industrial-age reprogramming process that affects our ability to quickly respond to EW threats. This is complicated by the number and disparate types of foreign EW techniques expected in the future.

Foreign exfiltration of data from US protected sites can give an adversary insight into our plans and capabilities. The impact of this is two-fold: they can develop defensive measures to our tactics and capabilities and, if the data is technical, they can use it to expedite their own capabilities, possibly bypassing intermediate and/or unnecessary steps, including “blind alleys”. Similarly, review and access to our research via conference and technical publications can also accelerate foreign research, development and acquisition (RDA) by identifying focus areas and key steps in technology and RDA.

Integrated use of air, space, and cyber capabilities can aid foreign efforts to deny the US access to the battlespace/theater. Foreign TBMs, cruise missiles, and cyber threats can augment their anti-access and area denial capabilities by impeding our ability to access the battlespace/ theater in a timely and efficient manner. We may be forced to operate from longer than expected distances, which will negatively affect operational plans, and ultimately our air and space forces' capabilities.

An autonomous system takes the human out of the loop, and all decisions and actions will then be determined by the system. The foreign ability to field systems that operate autonomously will increase as we traverse from the near to mid to far terms. Near term, there will be remotely piloted systems and robots present in logistics and manufacturing, i.e., automated systems and processes. Far term, systems that incorporate human cognitive behaviors will lead to truly autonomous decision making in an operational environment, i.e., the ability to act independently.

Multiple threats to our ISR capabilities continue to develop and will be available in the near, mid, and far term. These include wideband jammers, low probability of intercept/detection signals, and all weather sensors. The sensors will become more robust, resilient, and reconfigurable as we move forward. Non-traditional ISR threats include fifth generation fighters with AESA radars and advanced jammers.

<u>Supporting Technologies</u> – Underlying all of the threats above are various enabling technologies. These are the technologies that are necessary for our adversaries to continue improving and developing the various threats to our air, space, and cyber domain superiority.

2.3 Sources:

Sources for this section are expert opinions, both internal and external to the intelligence committee, to include SERG comments and *Global Horizons* section leads threat/comments. Additional sources include:

- http://www.rand.org/content/dam/rand/pubs/monographs/2011/RAND_MG1009.pdf
- China and India, 2025: A Comparative Assessment
- http://www.rand.org/content/dam/rand/pubs/.../RAND_MG1009.pdf
- http://www.nsf.gov/statistics/seind12/figures.htm#c2
- http://www.nsf.gov/statistics/seind04/

3. Air Domain

3.1 Vision

Over the next 15 years, the Air Domain will be increasingly contested, congested, and constrained. To maintain our edge over potential adversaries who have growing access to and ability to effectively employ new weapon systems and emerging technologies, we need to anticipate opportunities and challenges from global trends and scientific advances. Progress and breakthroughs in areas such as sensors, systems integration, secure communications, cybertrust, autonomous operations, precision, guidance, fuel efficiency, aerodynamic control, materials, munitions, and directed energy will contribute to the creation of an aerospace security complex that is self-forming, and if attacked, self-healing. This kind of a complex could be so difficult to disrupt that it would possess a conventional deterrent effect that would be stabilizing to whatever region it is deployed.

3.2 Trends, Threats, and Opportunities:

Contested: In the future, US air superiority will no longer be assured. Near-peer adversary area-denial strategies will increasingly involve capable integrated and networked air defense systems, long-range power projection systems, advanced strike platforms, sophisticated offensive and defensive capabilities across the electromagnetic spectrum. USAF platforms will likely experience an erosion of reduced-signature effectiveness. There will be a proliferation of 5^{th} generation fighters. Survivability involves more than just physical attributes of an aircraft; it will depend on a combination of speed, stealth, sensor-integration, connectivity to systems in other domains, numbers, and weapons. If game-changers allow our forces definitive success in such environments, nuclear-armed adversaries may then compel the Air Force to rapidly shift to operations in a nuclear environment, yet another contested challenge.

Congested: While the volume of the world air traffic doubles, the number of manned USAF platforms will slightly decrease. Although they will not enter the fleet during this period, we have the opportunity to shape and focus new concepts such as the Next Generation Bomber, the C-X, and KC-Y. The US will produce about 20,000 new RPA systems through 2020, while worldwide production will be almost double that. Challenges will continue to include a long time from program onset to IOC and the care and sustainment of large, legacy fleets.

Constrained: Constraints on the Air Domain will include increasing regulation and adjustment of operations by external forces. Requirements to invest in and improve fuel efficiency while simultaneously reducing emissions and noise will impact all air operations. The cost of new equipage can be daunting, but necessary to operate in certain airspaces. An intriguing opportunity exists in this space to focus on and adopt required technologies which will improve operational capability. For example, a robust, secure ADS-B improves surveillance and, potentially, situational awareness in austere areas or disaster/damaged regions. Its positioning capability could also enable efficient operations like formation flying for fuel efficiency across suitably equipped platforms.

3.3 Game Changing Themes

An order of magnitude (or more) improvements in key parameters can constitute a game changer. But one can also change the game by fundamentally altering operational methodology and paradigms. To address the challenges of being contested, congested, and constrained, and to aspire to the goal of a self-forming and self-healing aerospace complex, we will need advances in at least five broad technology themes: *high speed systems and directed energy; autonomy,* *distributed decision making, and fractionated systems; advanced aircraft adaptive architecture; weapons including small munitions and long-range missiles; and energy efficient aircraft and propulsion.* We should partner in development where there is overlap with commercial, joint, and coalition interests. Figure 3.1 describes these broad technology areas and where the AF should lead, follow, and watch. An asterisk means that the AF should generally follow industry, except where there is a specific AF application (e.g., certification of large airframe structures for military unique missions—such as unprepared strip operations, conformal antenna for military unique radios and communications, etc.).

High speed systems and Directed Energy:
Prompt global strike and our ability to project power erodes with improved anti-access capabilities. Swift, maneuverable and agile systems are more survivable due to reduced exposure time and aggressive threat response. Progress in hypersonic systems has been steady and hypersonic weapons should be ready in the near to mid-term. The next advance should focus on speedy ISR assets. Finally in the far term, we should strive for reusable and responsive platforms.

Directed Energy Weapons (DEW) use focused electromagnetic waves and represent a set of game-changing technologies. Attractive attributes include speed of light response, precision effects, low collateral damage, deep magazine, and low cost per kill. Directed Energy systems can augment and improve aircraft self-protect, theater base-defense, and suppression of enemy air defenses. Continued Development of compact, efficient High Energy Lasers and High Power Microwave systems will complement kinetic munitions and enable revolutionary advances in precision engagement, controlled lethality, speed of attack and range to effect.

Theme	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
High Speed Systems/ Directed Energy	Weapons (L) High Power Microwave missile (L) Target identification (pulsed lasers) (L)	***High Speed Systems*** ISR platforms (L) ***Directed Energy*** Mounted a/c self-protect (CW electric lasers) (L)	Reusable, responsive platforms (L) Integrated aircraft self-protect; speed-of-light strike (L)
Autonomy/ Distributed Decision Making/ Fractionated Systems	Distributed mission planning (L) Sense and avoid (F*) Automated/autonomous formation flight (L)	***C2 and Comm*** Automated terminal area operations (F*) ***Platform and Operations*** Cooperative and autonomous control (F*)	Human/machine cognitive communications (F*) Human/machine teaming (F*)
Advanced Aircraft Adaptive Architecture	Enhanced analysis for V&V (F*) Certification of composite structures (F*) Large composite structures (F*)	***Processes*** System-of-system certification (F*) ***Products*** Modular aircraft architectures (F*) Plug-and-play avionic interface (L)	Automated assembly and quality assurance (F*) Universal weapon system interface (L)
Small Munitions/ Long Range Missiles	Cooperative control and selectable effects (L) Self-realizing and adaptive guidance (L)	***Small munitions*** Multi-purpose, multi-mode effects packages (L) ***Long Range Missiles*** Sensor/seekers, apertures, controls, payload, guidance (L)	Optimized internal carry design (L) Real-time adaptive software (L)
Energy Efficient Aircraft and Propulsion Design	ADVENT/AETD/ESSP (L) Thermal management and adaptive cycles (F*) Laminar flow control (F*) Conformal antennae (F*)	***Propulsion and Power*** HEETE/ESSP (F*) On-demand integrated subsystems (L) ***Airframe/Aerodynamics*** Lightweight, unitized structure (F*) Adaptive structure and active flow control (F*)	Adaptive HEETE (L) Hybrid systems/distributed propulsion (F*) Supersonic tailless designs (L) N+1 generation efficient aircraft configurations (F*)

Figure 3.1: Air Domain Technology Roadmap

The two primary classes of DEW--lasers and microwaves--are based on different technologies, have different concepts of operation, and produce quite different effects. Lasers use thermal energy, or rapid thermal shock to defeat targets including imaging seekers, missile radomes and many other objects. A well designed laser system can accumulate sufficient energy against hard targets in less than 10 seconds and against soft targets in less than one second. High Power Microwave systems engage targets by creating large, non-lethal, electric fields for short periods of time. These large electric fields can interact with human skin to create a harmless, but painful effect in a few seconds or can disrupt and damage electrical components (e.g. cell phone systems or computer networks) within a microsecond or less. Additionally, the HPM electric field has a much wider beam which reduces high pointing accuracy requirements. Finally, HPM weapons create the desired effect with little to no collateral damage, greatly reducing or eliminating reconstruction costs. The evolution of DEW throughout this period will start with near-term efforts such as a HPM missile and laser enhancement of sensors. Development of mounted laser weapon systems should occur in the mid-term. Far-term applications will include aircraft-integrated systems.

Autonomy, Distributed Decision Making, and Fractionated Systems:
Our goal of an extended complex formed of multiple platforms which can absorb attacks and reconstitute functionality will rely on a number of key technology developments. The first is autonomy, much of which is being developed in the RPA community. The second is the ability to migrate decision making from centralized control to distributed operators. Guidance will likely still come from command centers, but information and ability to quickly fuse data and information will allow new paradigms in mission execution. Finally the concept of a fractionated or disaggregated system, in which functionality is split among several, perhaps smaller, cheaper, and potentially expendable, platforms will contribute to affordability, survivability and resilience. All of these will require secure and trusted hardware, software, processing, and communication.

Broadly we can break this down into command, control, and communications as well as platform and operations considerations. The C2 and communication developments should include technology advances which will enable planning, transfer of critical operational information, and human/machine interface. Platform and operations considerations include the progression of autonomy from simple sense and avoid capability to human/machine teaming.

Advanced Aircraft Adaptive Architecture:
A key trend is the drive to industry standards in hardware such as the Universal Serial Bus. This allows open architecture and the plug-and-play operation of a variety of modules. Open architectures and modular components (sensors, seekers, etc.) will allow weapons systems to rapidly adapt to changing missions. Instantaneous connectivity and recognition of attached armaments provide a plug-and-play approach. This allows easier system upgrades, mission-specific avionics and adaptable weapons system configurations, but could present new threat vectors. Processes in manufacture, certification, validation and verification, and, ultimately, automated manufacture will be key enablers.

Small munitions, long-range missiles:
Today we have 5th generation aircraft, but 3rd generation weapons. The emergence of area denial capabilities has significant, negative implications for current USAF air superiority and strike capabilities. Long range, networked, integrated air defense capabilities will threaten at greater range, and challenge our ability to gain and maintain air superiority; only the lowest signature platforms, employing internally carried weapons will be survivable in highly contested airspace. At the same time, capable point defense systems threaten the survivability of air-delivered precision guided munitions. An important consideration is the speed of target acquisition—technologies providing target location in a small number of minutes can be a game-changer over those having a 15-20 minute sensor to shooter timeline. These new technologies will likely drive new policy.

Currently, the US fields over 30 strike weapons for this target set. Many, if not all of these weapons are either too large for carriage in quantity, have inadequate standoff range, or are vulnerable to point defenses. Meeting the anti-access challenge requires a new family of weapons, matched to 5th/6th gen platform capabilities, weapon bay optimally sized, are survivable, and/or capable of employing cooperative attack strategies. In addition, fiscal realities mandate they be affordable in quantity, minimize certification (SEEK EAGLE) costs, and designed to enable rapid technology insertion, and provide competition at the component vs. end item level.

The adaptive architecture approach for aircraft can also apply to weapons. A modular, open systems architecture for a family of weapons, notionally based on three aeroshell form factors, to enable composable capabilities and facilitate technology refresh at the component level, in an affordable and sustainable design. Aeroshell designs will be optimized for maximum flexibility within weapons certification tolerances, provide standardized mechanical, electrical and computer bus interfaces to allow plug-n-play capabilities for a family of subcomponents (sensors/seekers, propulsion, effects packages). A key enabler will be a highly advanced mission computer with sufficient processing power and memory to allow for self-realizing aero, guidance, navigation and control algorithms, dependent on the specific configuration of the sensors, propulsion and effects package. The design will leverage industry open system architectures, advances in multi-function/band apertures and antennas, autonomy and cooperative control strategies to enable multi-system temporal and spatial coordination of attack, survivability and effect. Multi-purpose, multi-mode effects packages include kinetic, directed energy, and non-kinetic effects.

Energy Efficient Aircraft and Propulsion Design:
The fuel saved through energy efficiency can be exchanged for increased range, payload, endurance and overall combat capability. Two broad areas of improvement in efficiency are in the propulsion and power systems and in the airframe and aerodynamics.

The Adaptive Versatile Engine Technology (ADVENT) technology is targeted at the combat air fleet and provides high thrust for takeoff and maneuver, optimizes fuel efficiency for long range/loiter, and matches engine airflow to the inlet and exhaust across the flight envelope, resulting in reduced drag. Additionally the engine generates large quantities of cool air tailored for aircraft subsystems, exhaust cooling, and aircraft thermal management. The result is a potential energy savings of 25%.

The Highly Efficient Embedded Turbine Engine (HEETE) could offer as much as 35% improvements in Specific Fuel Consumption to mobility and other platforms. HEETE focuses on revolutionary technology advances in the core of the engine. One target is significantly increasing the Overall Pressure Ratio (OPR) of the engine, requiring a new generation of compressor design, high pressure seals, advanced materials and component cooling technologies. Additional technology solutions being pursued include adaptive core technologies; advanced efficient, low-emission combustion; advanced high temperature, high strength materials; and integrated power and thermal management concepts.

Materials improvements are also key to advances in airframe and aerodynamics. New lightweight materials and composites save fuel by reducing weight. Drag reduction through innovations like conformal antennas and laminar flow surfaces will improve efficiency. New methods of flight controls, through active flow control will be perfected during this period. Finally, ground-breaking body airframe configurations, such as highlighted in the N+1 and N+2 designs from far-sighted programs like NASA's Environmentally Responsible Aircraft and the FAA's Continuous Lower Energy, Emission, and Noise programs should be considered.

3.3 Recommendation

The Air Force should conduct a series of flight tests, experiments, and challenges to demonstrate an effective, robust, partnership of manned and unmanned air platforms—validating key concepts of autonomy, fractionated systems, and distributed decision making in realistic threat and permissive environments. (OPR: AFMC, OCR: ACC, AMC, AFGSC, AFSOC)

To accomplish this, AF leadership should create a stakeholder Integrated Process Team (IPT) which will:

- Define and validate methodology to measure key machine, human, and mission performance metrics
- Select representative technologies (e.g., human-machine cognitive communications, plug-and-play avionics and armaments interfaces, trust in cyber systems) and mission functions for consideration
- Generate integrated roadmap for development, test, and exercises to verify savings and improvements in operational capability.

Maturing affordable game changing S&T across the Air Domain will allow us to remain ahead of near-peer threats, operate with efficiency and impunity in A2AD environments, and evolve Air Doctrine with new technologies.

4. Space Domain

As noted in the *Global Horizons* main report, the world-wide proliferation of space launch and small satellites has caused the space environment to become increasingly congested, contested, and competitive. In this appendix, we will elaborate on a few of the main themes presented in the report to illustrate this set of claims.

4.1 Access to Space – Making the Space Environment More Competitive

A major trend for the space environment is that virtually any country can procure launch services and easily access space. As such, the United States freedom of action to operate at and beyond the global horizons will be severely challenged in the coming years. As world population and economic pressures grow, diplomatic and market boundaries blur. The information communities become conflict arenas, and non-national entities take on a growing role in the conflict environment. At this point we should understand that our current capabilities as a globally superior force will be challenged (OCS 2010). Future military space planning should recognize that access to space is rapidly proliferating and will be widespread. Adversaries will also use it for their purposes to mature their own space capabilities. As such, space accessibility is no longer a limit to carry out space missions. Figure 4.1 illustrates the explosive growth in access to space by numerous countries and also by government-sponsored consortia. In addition, nations can now utilize Internet Protocol (IP) enabled devices (smart devices) to virtually access space through a variety of different media including Radio Frequency (RF) ground channels. These advances require a real-time, predictive situational awareness of all of our space assets if they are to continue to serve as the force multipliers for our global capabilities.

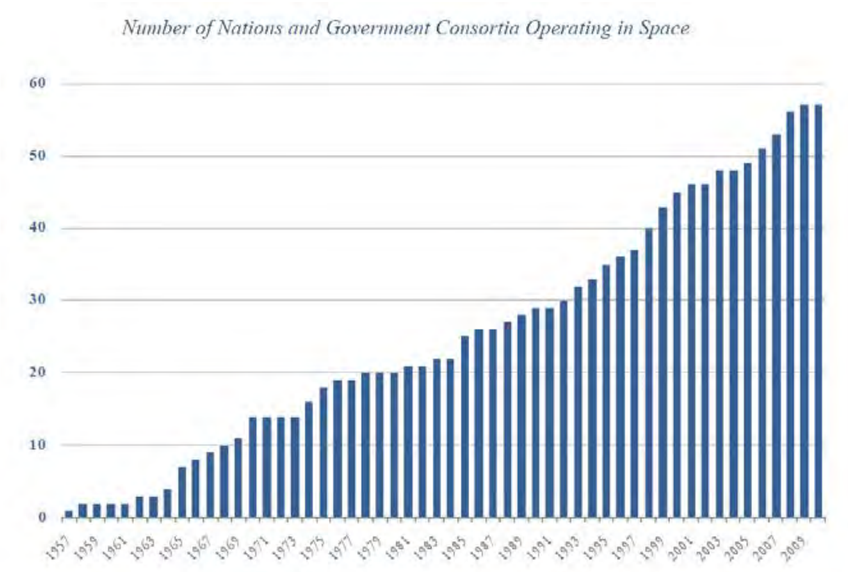

Figure 2. Source: National Air and Space Intelligence Center

Figure 4.1: Rapid Growth of Space Access Since about 1965

The rapidly evolving capabilities of these countries and consortia have led to an extremely dangerous space environment, over and above the usual hazards due to strong radiation. For example, Figure 4.2 shows both the linearly increasing number of catalogued space objects, including debris, and also the current overloaded US frequency allocations for communications. The debris field presents a formidable hazard to (mainly) Low-Earth Orbit (LEO) satellites, but the contested and competitive nature of the frequency allocations makes operating in space a much more difficult proposition for US military services.

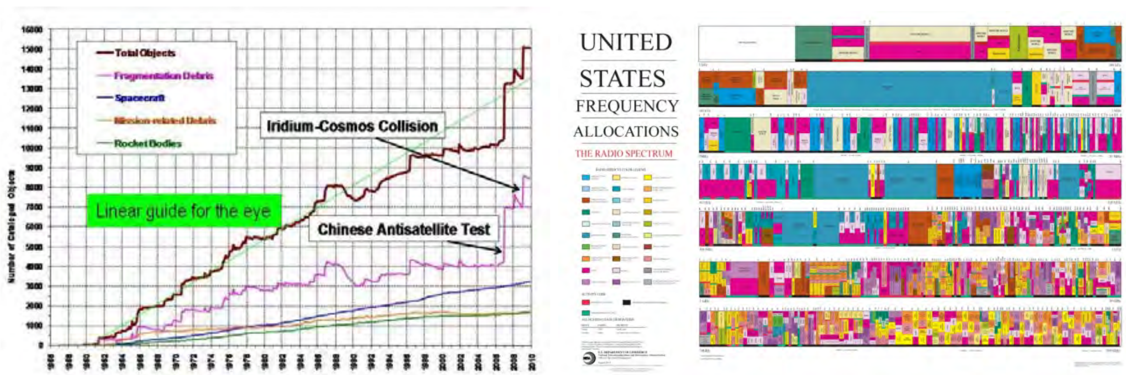

Figure 4.2: The congested and competitive nature of space:

(a) Left hand plot of linearly increasing number of space objects and
(b) Right hand plot of US frequency allocations

A paradigm shift towards interconnected and distributed space frameworks is necessary, as documented in recent publications by US space leaders (Pawlikowski et al. 2012). We need a "system of systems" approach, rather than "stove pipe" single mission approaches of the past. This overarching system of systems must include future dedicated military space capabilities and civil, commercial, national and international assets in a complementary way. Extremely capable space systems and their products, until recently protected by strict security and trade restrictions, will now be available to many buyers on a commercial market. The producers, owners and operators of these systems will include domestic and foreign governments and corporations as well as alliances and multi-national consortia. This diversity complicates the process of deriving the *Global Horizons* vision, and makes a far richer opportunity for the diplomatic, industrial, military and economic systems to be interwoven.

4.2 Distributed Architectures

Space technology of the future will need to be more cost effective and reliable to deliver accelerating space access, agility and responsiveness. This would require advanced capabilities in distributed but well integrated space assets. This technology family could be supported by a flexible array of inexpensive, agile, short notice, flexible, easy to launch variants. These initiatives would highly rely upon related Cyber technology, software technology, radiation and engineered resilient capabilities.

Advances in computers, sensors, and materials permit establishment of large constellations of interlinked satellites, whose integrated output will give global, real-time coverage. The advantages of such systems have already been embraced by the commercial space industry as a way ahead. We recommend several specific approaches:

- The Air Force should create a developmental road map which recognizes the twin realities of fielding inexpensive, single-sensor, small satellites and distributed processing and communications, enabling a significant advance in navigation, weather, reconnaissance, surveillance and battle awareness with agility.
- The Air Force should begin development and deployment of a suite of small satellites and also small launch capabilities to complement both legacy and evolving national sensors for timely capability delivery.
- Published standards should be established for future information intensive architectures to be distributed, flexible, open, scalable, fault-tolerant, reconfigurable, and transparent to the users.

To accomplish these initiatives the industrial base still needs to be maintained to vibrantly deliver innovative technology proposals. Technology resources such as Small Business Innovative Research (SBIR), Rapid Innovation Fund (RIF), Independent Research and Development (IR&D), and University Multidisciplinary University Research Initiative (MURI) DoD initiatives can help further solidify these efforts.

4.3 Debris Modeling and Space Situational Awareness

In addition to leveraging disparate data sources, real-time, predictive Space Situational Awareness (SSA) requires identification and location of a rapidly growing and potentially disruptive space debris population (Jenkin, et. al. 2012). In this constantly changing space environment it is imperative that our space assets come equipped with advanced operating systems, rapid response, diverse waveband star catalogs and sophisticated spectral and spatial resolvers. This SSA and debris management task helps static navigation and collision-avoidance as well as provides superior freedom-of-space defensive and offensive mobility. These capabilities enhance observation and avoidance as well as orbit clearing, parking and station keeping activities, ensuring an environment analogous to the United States Navy "Freedom of the Seas."

It is of great importance to control the environment of our space assets wherever possible. As shown in Jenkin (2010), space debris is becoming a major hazard to active space assets and poses an increased and additional risk to upcoming missions (see Figure 4.2). The Air Force should continue to study the potential threat posed by space debris and implement necessary surveillance techniques to advance rapid identification tracking accuracy and observe potential collision(s) and cascading debris effects. Better analytical models of cascading should be developed to address the main uncertainty concerning the number of pieces produced per collision. Increased situational awareness and surveillance can determine how cascading affects operational capability.

The launch rates and staging events to create the constellations of the future will likely drive up the debris population to the point that the probability of physical collision may exceed the probability of a mechanical or electronic failure on a spacecraft. Advanced real time algorithm(s) and IP-enabled tracking devices can be implemented on upcoming missions to study the debris situation and increase global awareness, while improving space environment stewardship for our world as a whole and the future generations. Furthermore, technology-performance enhanced versions and derivatives of the space fence are obligatory for complete space situational awareness.

4.4 Technology Options for Future Space

Figure 4.3 illustrates the road map of the space domain for near-, mid-, and far-term technologies for space domain solutions.

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Disaggregation	Demonstrate Disaggregation (L)	Demo Fractionation (L) NavSat (L)	Microsatellites (F) as canonical architecture Persistent SSA (L)
Inexpensive Launch	100-kg to LEO for $1-3M (W)	GEO and LEO commodity launch (L)	Launch raw materials (L) Launch deployables (L)
Space Cyber	Testbeds (L)	Space-HAIPE (F)	Agile and Resilient by Design (W)
Architectures	Deployable antennas (L) Open standards (L)	Synthetic apertures (F) Open Architecture (L)	Composable constellations (L) Quantum computing (F)
Communications	AEHF (L), V/W band (L)	Laser communications (L)	
Manufacturing	Radiation-hard (L)	Additive manufacturing (F)	Build in space (L)

Figure 4.3: Space Technology Roadmap

4.5 References

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5. Cyberspace Domain

5.1 Trends and Threats

Key trends contouring the future cyber environment include the increased government use of COTS, explosion of malware, use of cloud computing and increased complexity of systems.

As of May 2013, there are over 120 million recorded pieces of malware with more than 200,000 new malicious programs being recorded daily. Estimates indicate that by 2025 that number will more than double to over 547,000 pieces recorded daily. The advent of the Stuxnet virus in June of 2010 ushered in a new generation of sophisticated malware. Stuxnet targeted SCADA software and equipment with the purpose of shutting down systems. The fact that Stuxnet was digitally signed by two legitimate companies with stolen private certificates made the malware even more dangerous. Being signed by multiple legitimate companies gave the malware credibility and trust so systems automatically installed it. The Flame virus discovered 2012 was considered the most advanced piece of malware ever created, being 20X more sophisticated than Stuxnet. The Shamoon virus that attacked the Saudi Aramco Oil Company in 2012 caused 30,000 machines to go offline and physically destroyed some of them. Data from Mandiant shows that the frequency of attacks from advanced persistent threat one (APT1) has been increasing since 2006 and are against many technology fields (see figure 5.1). Trends of increasing prevalence and sophistication of malware and attacks are expected to rise in the future.

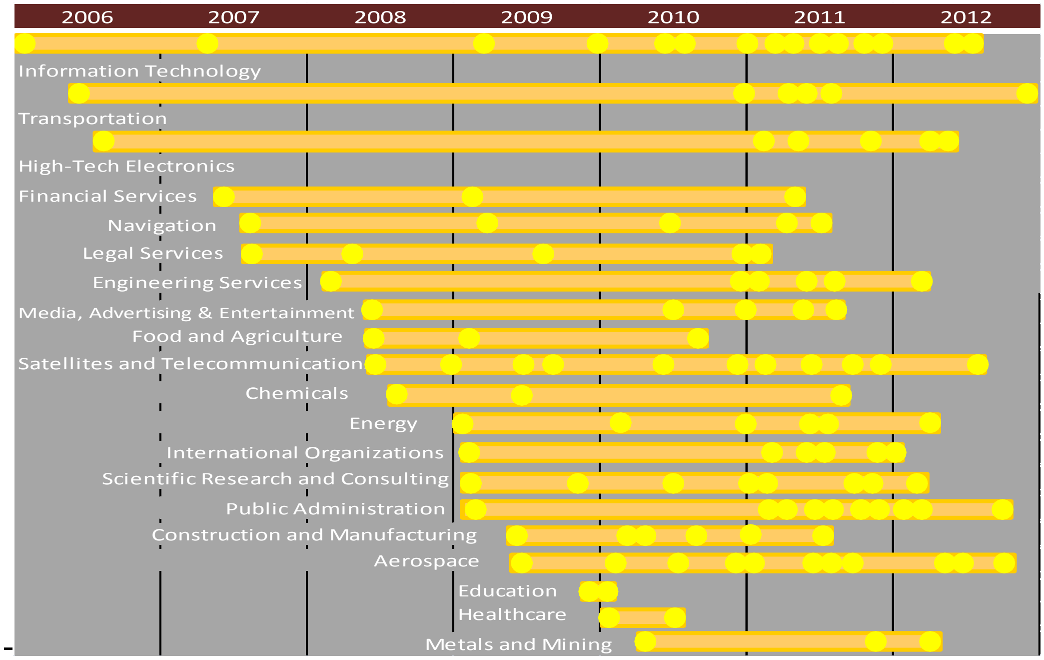


Figure 5.1: Timeline of APT1 Compromises by Industry Sector (Mandiant APT1 Report)

The prevalence of cloud computing assets has grown in recent years. Cloud vendors provide cost effective computing power, storage and software. As the AF looks to cloud technology for low cost alternatives for mission operations, the main security challenge they will need to address is how to store and operate in an inherently untrusted environment. While US policy may dictate that the cloud provider hosts the services domestically, the cloud service may also host foreign commercial and military data in its environment. The technology trend toward ubiquitous encryption and research in fully homomorphic encryption may lead to the ability to perform sensitive operations in an untrusted cloud computing environment.

AF system capabilities are increasingly complex and dependent on software. The F-4 was designed with less than 5% of its capabilities implemented in software, which increased to over 90% in the F-35. In commercial and military environments, large software integration systems often require software reuse and architecture optimizations. As software complexity and size increases the verification and validation (V&V) processes become exponentially more difficult. In software, one of the major threats is the system V&V difficulties caused by software complexity and size. For the Air Force, this challenge requires the speedy adoption of commercial integrated software practices. An important technological solution is scalable formal verification methods to achieve correct-and-secure-by-design systems. Methods based on open standards, accessible environments can provide techniques for synthesis and composition to ease validation and verification. To achieve software V&V and complexity control, it is important for the Air Force to follow and adopt best commercial practices and technologies in open standards, software reuse, and large integrated system for software development and verification. We expect this to happen in both the near term and mid term. For the far term, the DARPA crowd sourced formal verification (CSFV) program seeks to make formal program verification more cost-effective by reducing the skill set required for verification. We recommend following this technology development.

5.2 Opportunities

In 2005 the AF added cyber to its mission statement. USAF capabilities in air, space, cyber and intelligence, surveillance and reconnaissance (ISR) are inextricably integrated with, and enabled by an intricate communications network infrastructure that is a part of the global cyberspace. With global cyber threat sophistication and activity growing at an alarming rate, the development of cyber-based capabilities for an assured, resilient cyber infrastructure that enables the AF to execute its mission in contested cyberspace is imperative. AF cyber architectures are static and fragile threatening the ability of the AF to assure its missions and protect critical information from cyber attacks. Adversaries rely on the static nature of our networks to engage a slow stealthy reconnaissance, exploitation and attack methodology. Cyber defense is like maneuver warfare, in that speed and agility are important. Transforming the Air Force cyber infrastructure from static configurations to a dynamic environment will raise the level of difficulty for our adversaries to conduct attacks as well as make the infrastructure more adaptive and resilient. The AF cyber infrastructure is a composite of hardware and software that includes specialized embedded systems, custom and militarized commercial systems and commercial off the shelf (COTS). Much of the commercial hardware and software is of unknown pedigree, developed outside the United States. This introduces risk that somewhere in the supply chain, which often stretches around the world, backdoors and malware have been implanted. Supply chain includes purchasing, manufacturing, warehousing, transportation, customer service, end of life, demand and supply planning, and supply chain management.

Counterfeit electronics have been introduced into the commercial, Government and DoD supply chain for many years. In 2008, counterfeit Cisco Networking equipment was introduced into DoD networks. The counterfeit products were purchased by the government through the sub-contracting process. The cost of the counterfeit equipment should have been an indication of a substandard product, as one of the routers normally priced at $1,375 was sold for $234. A recent Senate report stated that over 1 million counterfeit electronic components are estimated to be in use on US military aircraft. The parts are usually substandard and fail more often when compared to original equipment. These counterfeits can lead to security issues including backdoors and malware. As offshore manufacturing continues to rise, and fiscal constraints force equipment to be purchased by the lowest qualified bidder, the possibility of malicious or counterfeit products entering the US Government and DoD supply chain will continue to rise. Mounting security concerns throughout the government and private sectors has caused increased pressure on vendors to innovate and deliver more trustworthy hardware and software. Commercial firms are concerned with supply chain threats; however, their main priority is price and time to market. The AF must be able to assure its missions and protect critical information in contested environments from cyber attacks. Creation of affordable trusted hardware, software, and protocols, can strengthen cyber defense and support unique “out of band” capabilities. Survivability in a contested cyberspace will demand an effective mix of resilience, redundancy, diversity, and distributed functionality. System risk can be minimized by reduction of attack surfaces, segregation of critical mission systems, and attack containment. Enhanced resiliency of cyber elements will improve the ability to fight through, survive, and rapidly recover from cyber attack. This can be enhanced by autonomous compromise detection and repair (self-healing) and real-time response to threats. Advancing from signature based cyber sensors to behavior based detection will enhance attack detection. Active defense demands rapid cyber maneuver enabled by dynamic, reconfigurable architectures (e.g., polymorphic instruction sets). Security can be improved by advancing formal V&V of complex, large scale, interdependent systems as well as advancing vulnerability analysis, automated reverse engineering, and real-time forensics tools. High speed encryption, quantum communication and, eventually, quantum encryption will further increase the confidentiality and integrity of supporting infrastructure. Hardware and software foundations of trust require advances in reverse engineering and anti-tamper, V&V to ensure integrity, quantum methods and provable assurance to provide trust and mitigate contested environments. Recommend development of trusted hardware, software, supply chain, out of band C2 and cloud services to improve security, agility, resilience and trust for AF networks and systems to achieve mission assurance in contested environments. (OPR: AF, MAJCOMs, AFRL, AFLCMC, 24AF).

Integrated Cyber Operations: The USAF’s capacity for Global Vigilance, Reach and Power is enabled by a global networked information infrastructure known as cyberspace. Cyberspace provides unique global reach and access, unconstrained by distance, time, terrain and borders and has the potential to deliver a full range of effects from the tactical to the strategic. Cyber operations have become an integral part of AF missions across the air, space and cyber domains. More than any other technology, cyber technology and our adversaries' nefarious use of it, evolves rapidly in unpredictable and complex ways. Freedom of action in air, space and cyber is dependent on an assured cyber infrastructure. To achieve the AF mission to fly, fight and win in air, space and cyberspace, the AF must have superior capabilities in all areas of the cyber mission set. The AF requires a balanced and synchronized cyber offensive and defensive capability across the full spectrum of AF missions. Trusted, validated, verified capabilities able to deliver a full range of cyber effects and a means to measure and assess the effectiveness and degree of assurance of a delivered cyber effect prior to usage are required. Currently the lack of persistent access limits the operational utility of full spectrum cyber capabilities. Integration of capabilities across Cyber, SIGINT, Electronic Warfare and Communications will provide the greatest access and effects capabilities for the USAF and ensure operations in contested and denied environments. Recommend the AF develop offensive cyber capabilities to augment kinetic operations during wartime scenarios to affect strategic, operational and tactical missions. Develop capabilities for persistent and/or dynamic access capabilities for collaborative missions across Cyber, SIGINT, EW/EP, Space, and Communications to obtain a flexible full spectrum ISR capability in contested and A2AD environments (OPRs: ACC, AFSPACE, AFRISA, 24AF, AFRL)

AF commanders often lack real-time situational awareness of the mission impact of cyber events. Mission awareness, synchronizing cyber operations and maintaining real-time situational awareness are prerequisites for shaping cyberspace to support mission-essential functions in and across the air, space, and cyber domains for effective full-spectrum operations. To assure AF missions in contested environments the AF must perform dynamic, real-time mapping and analysis of critical mission functions onto cyberspace. This encompasses the cyber situational awareness functions of monitoring the health and status of various traditional entities (e.g., desktops, servers) in cyberspace, and extends to capture how missions flow through cyberspace. Situational awareness of our own and our adversaries defensive and offensive cyber capabilities is necessary to project the threats they may present, predict the impacts to AF missions and allow commanders to plan appropriate courses of action. Enhanced cyber situational awareness is required to ensure survivability and freedom of action in contested and denied air, space, and cyber domains. Recommend development of comprehensive cyber situational awareness capabilities for cyber superiority across blue and against red missions. (OPR: AFSPACE, 24AF, AFRL) Figure 5.2 illustrates the Cyberspace Technology Roadmap, added cyber recommendations are in *Cyber Vision 2025*.

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Mission Assurance	Mission awareness through managed information objects (L) Cloud based cyber operations (L)	Mission aware cyber C2 (L) Trusted cloud based cyber operations (L)	Autonomous cyber collectives (L)
Offensive Cyber	Integrated offensive cyber capabilities with SIGINT, EW/EP, and Communications (L)	Persistent access ISR capabilities for collaborative missions across Cyber, SIGINT, EW/EP, and Communications (L)	Autonomous offensive cyber operations (L)
Root of Trust	Quantum encryption (W)	Real-time cyber SA (L)	Dynamic S/W (F)
	Root of trust H/W & S/W (F)	Trusted embedded systems (L)	Trusted Automation (F)

Figure 5.2: Cyberspace Technology Roadmap

6. Global C2 and ISR

6.1 Trends

USAF C2 and ISR are vital military capabilities, leveraged to confront an ever-increasing array of threats across the spectrum of conflict and across all environments (permissive, contested, and highly contested). Global trends and associated economic, demographic, and social-media pressures are narrowing our dominance in vital national security capabilities. We have outlined five major C2 and ISR global trends that will impact our ability to dominate the air, space, and cyber domains.

1) **National Fiscal Challenge:** The AF has already seen a $500M reduction in the AF RDT&E top line in just a year ($17.9B FY12 Enacted Budget to $17.4B in FY13 President's Budget). The sheer size of the CY13 Sequestration decision requires additional cuts to the AF ten year RDT&E investment plan. Both the SECDEF and DNI have characterized the US Budget Deficit as our most significant threat and shaping influencer of future S&T trends.

2) **Contested and Highly Contested:** Another major trend influencer is the need to focus a greater fraction of the AF S&T investments to support increased freedom of operations in contested or denied environments. The aim of emerging Anti Access/Area Denial (A2/AD) systems is to deny US access to global domains (Air, Space, and Cyberspace).

3) **WMD proliferation is a special trend case:** Chemical, Biological, Radiological, Nuclear, and High Yield Explosives (CBRNE) capabilities are in a class by themselves in terms of potential for damage, disruption, and devastation. These types of capabilities are sought by adversaries who desire an offset strategy to US hegemony in world affairs. Sensing and controlling these will be challenging.

4) **Global Network Integration:** Network integration capitalizes on the growing, adaptive air/space network layer opportunities which support cutting edge services to generate local applications based on a commercial infrastructure of varying IP services, 4G wireless devices, social media, and affordable storage capabilities. These communication and network services are becoming ubiquitous, yet operationally transparent, enabling users with power of control from edge to edge, not center to center. In the future, these global, resilient network services, supported by regional teleports, will create interference, cyber, and mission management challenges along with organizational and integration issues.

5) **Urbanization/Youth Growth:** In 1950 only six cities had populations over five million. Today over 60 cities have populations in excess of five million inhabitants. Tokyo has more citizens than Canada. At present trends, China and India alone may have 60 cities with over five million inhabitants by 2030. Detecting, tracking, and forecasting human threats in increasingly dense urban environments will challenge global ISR.

6.2 Threats and Opportunities

National fiscal challenges pose a near-to-mid-term threat to development of future USAF C2 and ISR capability to counter predicted gains of near peer, 2nd, and 3rd tier adversaries. The fusion of EW and cyber techniques in the mid-term as well as long-term proliferation of LO air platforms will stress our ability to provide situational awareness of the tactical battle space and ultimately degrade trust in our C2 and ISR. Extremely widespread usage of UAVs for a variety of missions, including attack, will challenge our ability to detect, track, identify, and mitigate.

Global connectivity, the use of non-traditional, non-dedicated ISR, and commercially available ISR by low tier adversaries will lessen our strategic information superiority. Significant advances in directed energy weapons pose likely mid and far term threats to both air and space-based ISR. The ever increasing reliance of our C2 and ISR systems on the cyber domain poses new avenues for exploitation, specifically as data is pushed to more widespread and vulnerable networks. We also face an increasing likelihood of adversaries having access to and willing to employ WMD, particularly nuclear, possibly with non-traditional delivery. If unaltered, the USAF will see its advantage of superior strategic knowledge and timely (anticipatory) capability to command and control operational forces for precise, synergistic effect degrade.

6.3 Recommendations

Our C2 and ISR game changer recommendations are focused on providing policy makers, military users and commanders, coalition partners, and intelligence community professionals with timely, accurate, and operational relevant information services. Operationally and strategically, there is no substitute for responsive, global situational awareness and understanding. By strategically combining the power of our networks in a way that simultaneously increases the combat capability of every platform, every sensor, every weapon, and every decision maker they connect, we will enable anticipatory C2 and retain our unchallengeable military leadership in both current and future threat environments. The three recommendation areas, described in detail below, are: Innovative C2 and Analysis, Battlespace Networking, and Integration across Missions and Domains. Figure 6.1 illustrates three C2 and ISR game changing themes with these recommendations:

"Analyze, Act" **"Communicate, Collaborate"** **"Integrate"**

Figure 6.1: C2 and ISR Game Changing Themes

6.3.1 Innovative C2 and Analysis

Vision: "Ensure the speed of information exceeds the speed of engagement"

The challenge of operating in tomorrow's highly contested environment will require partnering with autonomous systems to operate with increasing speed and efficiency despite the growing complexity and uncertainty of the evolving battlespace. The USAF's need to remain ever vigilant and maintain a global presence in the face of shrinking budgets is the basis of the Innovative C2 and Analysis game-changer. It combines data analytics, neuromorphic computing, cognitive modeling, and autonomy through collaborative foresight to make USAF analysts deeper, broader, and more synchronized with warfighter operations. Better sensors will drive better data, better data will drive better automation and autonomy, better automation/autonomy will drive better analysis and the product will be faster delivery of time critical information to the user.

Data analytics have already shown significant success by reducing the search area for targets of interest. In some cases, these efforts have reduced the workload by almost two orders of magnitude. When combined with collaborative foresight, operator speed/knowledge improves by another tenfold. The real game-changing benefit is integrating these technologies with neuromorphic computing and cognitive modeling in a wrapper of autonomy. This integration will deliver enhanced decision-making such that 5X more targets can be found and tracked while consuming one-fifth the resources of today's C2 and ISR missions. These capabilities must be fully developed and integrated to process the volume of data available in a globally networked environment that leverages the speed of social networks and the breadth of open source data.

Intelligent platforms that collaborate with their operators will complement and enhance human capability while increasing the resiliency and adaptability of current systems. The analyst must be able to dedicate greater focus on threat characterization and defeat instead of searching for targets. As target identification and tracking improves, decision timelines will be decreased from hours to seconds due to mining of social networks, open sources, and ISR data through innovative collaboration and autonomy technologies. In addition, these technologies must also be used for individualized real-time training to improve analysts' performance for more effective and adaptive threat tracking and decision-making. To globally maximize these effects, it is important to extend these capabilities to our allied partners through cooperative developmental efforts along with the necessary technology and data sharing agreements.

6.3.2 Battlespace Networking

Vision: "To connect any information source to any consumer for any mission, anytime, anywhere"

An affordable, high-speed, battlespace internet that connects all sensors, command nodes, analysts, and combatants together into distributed mission teams is critical. Fielding the agile, resilient, and high capacity Beyond Line-of-Sight Command and Control (BLOS-C2) Quick Reaction Capability (QRC) and Tactical Datalink Gateways and using their fielding as an on-ramp to the build out of the Joint Aerial Layer Network (JALN) using JALN CONOPS and technology plan capabilities will tie together assets on the ground, in the air, and in space. Network and information management techniques that understand the dynamic, real-time needs of AF missions and their dependencies on connectivity and spectrum will use context and content awareness to efficiently route and transmit data, assuring highest priority missions are serviced by the available collaboration infrastructure. This enables new concepts like sensors as a service and collaborative mission teams spanning continents while breathing new life into long sought after capabilities in non-traditional Intelligence, Surveillance and Reconnaissance (NTISR) and Universal Battlespace Awareness. “Enhanced Battlespace Awareness (EBA)" is a new term for the broader NTISR term and OpsRecce refers to the airborne portion.

Sensors as a service exploit modern sensors that provide incredible persistent wide area coverage such as GMTI, SIGINT, wide-area motion imagery, overhead persistent infrared satellites, cyber, and sensors on the 5th generation fighters and bombers. These sensors can bring tremendous efficiencies by simultaneously serving analysts, mission planners, and active combatants for disparate purposes with little or no interference. Not everyone can have their own sensor platform, but everyone can have their own sensor service. An open-architecture, pod-based acquisition strategy that leverages existing CDL infrastructure will make this affordable and available in the near term.

In addition to the AF and sister services, the national Intelligence Community is also collecting, publishing, and analyzing data to produce actionable information. However, that information is not easily discoverable or accessible by AF warfighters or analysts through machine-to-machine interfaces. Common protocols and information metadata standards must be developed and enforced. We also postulate that the AF's tenants of Global Reach, Global Power, and Global Vigilance will only be sustained through Global Partnerships. Therefore, mission accomplishment by Joint forces in coalition environments, including leveraging commercial partners, requires advances in scalable multiple classification-level domain data messaging in ways that authoritatively preserve end-user context, present transactions via shared services, protect data transparency through application of enterprise business rules, ensure integrity through single-source-of-truth data quality methodologies, and maintain high assurance while acting as aggregated, independently provided, systems of services.

6.3.3 Integration across Missions and Domains

Vision: “Shared understanding of the battlespace enables anticipatory C2 and drives situational-aware monitoring, collection, assessment, planning, tasking, and executing”

Command and Control and Intelligence, Surveillance, and Reconnaissance (C2 and ISR) are most effective when decision-makers, at all levels, have the right information at the right time to make decisions. Given the Air Force’s responsibility to fly, fight, and win in air, space, and cyber - this game changer is focused on developing leadership, funding, and technologies that integrate and enhance C2 & ISR capabilities within and among those three domains.

The interrelationship of the Air Force’s C2 and ISR needs requires new technologies to deliver capabilities to fuse information and integrate C2 in the three domains with dramatically different characteristics of speed, time, and distance while also being able to fully leverage land and maritime C2 and ISR capabilities of US and coalition forces. Moreover, to have the agility to meet decision support needs across the spectrum of conflict, future C2I&SR systems will require high levels of synchronization, humans aided by machines with autonomous capabilities, and a pervasive ability to constantly assess if we're doing the right things and if we are doing those things right.

This can be accomplished by fully integrating across air, space, and cyber and enabling both traditional and "non-traditional (air, space, and cyber systems)" capabilities in adopting 21st century operational concepts that focus on combined effects. Making the investment to enable resilient space through small satellites, fully exploiting OPIR data as an intelligence source, and enabling 5th generation aircraft to collect, process, and disseminate "targeted" ISR data are examples of ways in which to significantly address shortfalls in intelligence collection within contested and highly contested environments. Cross-domain collection from non-traditional sensors can provide exceptional and often unattainable intelligence data to other tactical (traditional and 4th generation), operational (CAOC/DCGS/Distributed C2 Nodes) and strategic (NASIC/NSA/NGA) consumers in a speed and manner that is revolutionary. In addition, application of advancements in machine learning, electronic warfare (EW) and signature development offer considerable leverage to improve the speed and methods of combat ID and targeting. As the number and capability of threats increases, current methods supporting the development of intelligence for mission data (IMD) are not sustainable. EW Integrated Reprogramming (EWIR), Enemy Order of Battle (EOB), Signatures, Characteristics and Performance (C&P), and geospatial intelligence (GEOINT) represent five major IMD functional areas. Advances in Cognitive EW and Signatures Saliency offer the potential to greatly reduce the intelligence required for CID and targeting, enabling sustainability, while greatly enhancing capability. Closely related is the need to develop the capability to rapidly test and evaluate communication systems in ever increasingly complex electromagnetic environments. Development of a Threat Modeling and Analysis Program (TMAP) -like capability for communications signals modeling is a requirement. Finally, development of a resilient C2 infrastructure combined with automated decision aiding and autonomous information systems will ensure distributed planning and synchronization of global forces across domains using all available assets can be done quickly and affecting more targets, with the same resources, with clear understanding of cost/benefit in achievement of mission success. Thus we are recommending developing cross-domain C2 CONOPS in parallel with R&D and experimentation to clearly demonstrate military utility that C2ISR integration of air, space, and cyber forces will create desired effects at an affordable cost.

6.4 C2 and ISR Knowledge Gap and Game-Changer Mission Impacts

The entire C2 and ISR observation space continues to grow exponentially while our ability to reason about that data ("sensemaking") is growing very slowly. The difference between the two is what we are calling the "C2 and ISR Knowledge Gap". The goal of our game-changers is to help to close that gap as illustrated in Figure 6.2.

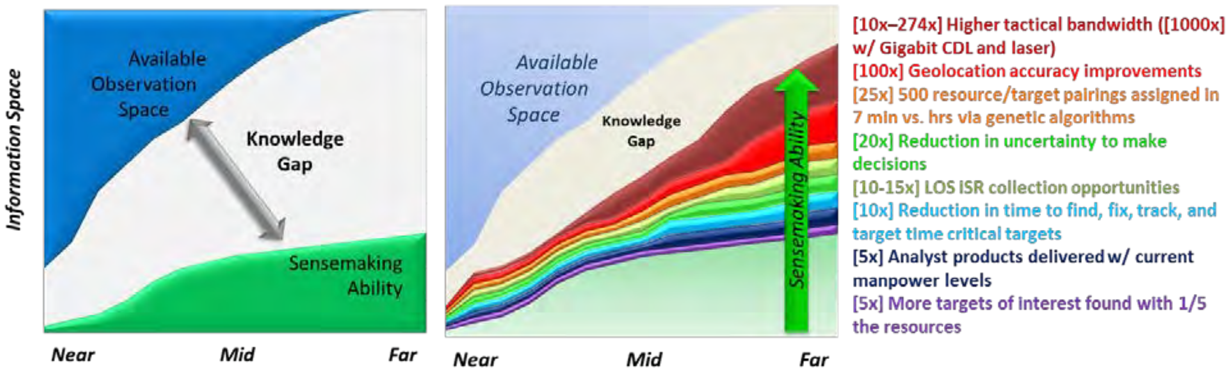


Figure 6.2: C2 and ISR Knowledge Gap and Game-Changer Mission Impacts

6.5 Recommendations

In this dynamic world where the United States continues to be challenged by near peer states, the enduring specter of terrorist related activities and the potential proliferation of weapons of mass destruction require that we bring all of our strategic and tactical C2ISR resources to bear, including those of our allies. The ultimate goal is to establish information dominance which increases the combat capability of every platform, every sensor, every weapon and every decision maker it connects in our evolving air, space and cyber domains. To meet this goal, the following game changing recommendations are offered for the C2 & ISR mission areas.

Develop flexible autonomy and all-source intelligence fusion technologies for enhanced analysis and planning capabilities for C2 and ISR (OPRs: SAF/AQR, AFMC (AFRL & AFLCMC); OCRs: AF/A2, NASIC, MAJCOMS)

- Establish requirements and funding to fully incorporate analysis and exploitation tools to support emerging trends in data management and enhanced battlespace awareness for A/S/C asset intelligence analysis.
- Establish requirements and funding to increase ops tempo in denied environments via most efficient use of A/S/C resources

Field a secure, resilient, agile, and high capacity air-space-and-surface network to enable joint and multinational global C2 and ISR. (OPRs: ACC A5/8/9, AFSPC; OCRs: SAF/CIO A6, HAF/A2, SAF/AQ, MAJCOMs, AFRL)

- Field a secure, self-forming, resilient, and agile IP network using existing infrastructure and advanced data link gateways enabled high capacity global C2 and tactical datalinks with mission-aware networking.

- Leverage this to support the build out of Joint Aerial Layer Network using the JALN CONOPS and technology plan.
- Ensure C2 in a satellite-communications-denied environment, including support of the POTUS mission essential tasks.
- Develop AntiJam CDL Waveform for highly contested environment.
- Develop communication signals modeling (TMAP-like) T&E capability.
- Develop mission-based on-demand routing, network and information management.
- Leverage coalition partnership capabilities with integrated multi-level security enabled networks.

Fully integrate weapon systems and PCPAD across air, space, and cyberspace to achieve synchronized effects (OPRs: ACC, HAF/A2; OCRs: AFMC (AFRL & AFLCMC), SAF/CIO A6, SAF/AQ, MAJCOMs, HAF/A10)

- Enable 5th generation aircraft and resilient space collection of intelligence in highly contested environments.
- Provide "Mission Command" C2 capabilities to Wing and Unit Level Commanders through S&T efforts extending JFACC Air Operations Directive level guidance through Autonomic Control, Big Data/Cloud and Data Mining.
- Enable cross domain A/S/C MAPE operations by combining CONOPS and R&D development with experimentation to establish quantifiable MOEs/MOPs. Technically focus on distributed C2 collaborative planning and execution tools, seamless integration of C2ISR processes, and near real-time world state knowledge.
- Initiate S&T effort on theory of integration
- Develop capabilities to reduce dependency on IMD, such as cognitive-based reprogramming (CEW) and signature saliency. CEW, or behavior-based EW, supplemented with machine learning, will be required to defeat functionally agile adversary EW system. Signature Saliency (signature develop from salient features analysis integrated with systems theory) techniques are required to replace unsustainable methods for CID and targeting from unintended emissions.
- Develop MLS, message, and data formats to fully integrate service and coalition forces.

Figure 6.3 illustrates the C2 and ISR Technology Roadmap.

Innovative C2 & Exploitation: Each segment (human and machine) understands mission context, sharing common-base data and situation awareness, while continually bi-directionally adapting a common set of needs and capabilities. The keys to maximizing the human-machine interaction are: instilling confidence and trust among the team members (humans and machines); understanding each member's tasks, intentions, capabilities and progress; and ensuring effective and timely communication. All of these assumptions rely upon a flexible architecture for autonomy, facilitating different levels of authority, control, and collaboration.

As the ultimate decision authority, the human must adjust the authority and decision-making provided to the machine based on the mission situation (speed and accuracy required) and comfort-level for such control delegation. Foundational to airmen-machine team systems is an intelligent machine which can coordinate location, status, mission intent, intelligence, and surveillance data.

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Innovative C2 and Analysis	Bi-directional human-machine info flow for effective decision-making (F)	Adjustable human-machine teaming for real-time shared learning/exploitation/decision-making (F)	Flexible, collaborative human-machine teaming for exploitation & shared decision-making (L)
Battlespace Networking	Field BLOS C2 QRC (L) Multi-Datalink Gateways (L)	Net-Enabled Weapons (L) Mission-Aware Networking (L) Joint Aerial Layer Network(L) Comm Signals Modeling (L)	Autonomous & Cognitive Networks (L)
Integration across Missions and Domains	ISR Enterprise for 4-5th gen fighter aircraft (F) Integrated C2 and ISR A/S/C Plans (L)	Dynamic Reallocation of Resources (F) Cognitive EW (L) Autonomous mission assembly and optimization (L)	Automated A/S/C Sensor Tasking (F) Fully integrated A/S/C dynamic planning and execution (L)

Figure 6.3: C2 and ISR Roadmap

Battlespace Networking: A new technology called NET-T () changes the DoD standard CDL point-to-point datalink into an interlinked network providing an incredible 10-44 Mbs to the tactical user. In the near term, this allows us to link together and extend the various datalinks such as CDL, Link-16, SADL, and the IFDL and MADL on 5th generation assets. The BLOS-C2 QRC developed and tested the relay and gateway technologies and the advanced CDL waveforms for the IP backbone. These gateways are available as upgrades to the existing and highly valued BACN program and in pods such as the Smart Node Pod, TACPOD, and JetPack. In the mid term, the next step of the LPI Anti-jam waveform is needed for the highly contested environment. NET-T technology should be proliferated across the Services, sound net-management CONOPS developed including mission aware networking, and integrated with space and cyberspace systems. In the long term, R&D efforts should focus on increasingly intelligent and autonomous networking to ensure secure, cross-domain access.

Integrated C2ISR: In this near term, emphasis should be to provide enterprise-wide access to 5th generation aircraft state of the art multi-INT sensing capabilities by maximizing their ability to collect, store, and transmit mission data. Enabling threat handoff warnings to other 4th and 5th generation strike packages will support integrated mission operations. And developing collaborative services and applications will enable machine to machine cross-domain (air, space cyber) monitoring, planning, execution, and assessment. In the mid-term this should be augmented with hybrid algorithmic approaches to prioritize and optimize tasking and automation to monitor executing operations and dynamically adapt tasking based on available resources and plausible adversary threats. CEW, or behavior-based EW, supplemented with machine learning, will be required to defeat functionally agile adversary EW system. Signature Saliency techniques are required to replace unsustainable methods for CID and targeting from unintended emissions. Triggers from technologies like intelligent agents and machine learning will alert planners to changes in critical conditions that warrant a re-plan supporting dynamic sensor tasking, planning, and execution. In the long term fully integrated and automated sensor tasking and dynamic planning and execution will ensure secure, survivable operations.

7. Mission Support

Current acquisition methods emphasize vertical integration of systems or platforms. To achieve the objective of rapid fielding, integration across platforms and modular upgrades, the acquisition process should be refocused on acquiring system components that align with mission and system architectures. This approach would result in the funding and development of portfolios of capabilities that align with mission-needs roadmaps and approved architectures that can be rapidly composed, tested, fielded, and upgraded as technology advancements are achieved and mission requirements evolve.

The development, employment, and integration of digital design tools across the acquisition lifecycle - the Digital Thread – will help to enable such an approach. Digital Thread is the creation and use of a digital surrogate of a material system that allows dynamic, real-time assessment of the system's current and future capabilities to inform decisions in the Capability Planning and Analysis, Preliminary Design, and Detailed Design, Manufacturing and Sustainment acquisition phases. The digital surrogate is a physics-based technical description of the weapon system resulting from the generation, management, and application of data, models, and information from authoritative sources across the system's life cycle. A Digital Thread capability is enabled through technical advances in modeling, data storage and analytics, computation and networks. The Digital Thread concept creates informed decision making at key leverage points in the development process that have the largest impact on acquisition programs. This would lead to earlier identification and a broader range of feasible solutions; a structured assessment of cost, schedule, and performance risk; and accelerated analysis, development, test, and fielding.

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Digital Design Tools	Optimized digital design tools (L) Engage industry (F)	System of System trades (L) Open architecture w/built-in trust (F) Digital Thread expanded to exercises, CONOPS, training environment (L)	Tightly integrated digital thread and prototyping process to enable agile development and quickly field scalable capabilities (L)
Prototyping	Prototype program demonstration (L) Open challenges (F)	End-to-end prototype centers w/joint user & industry experimentation (L)	
Agile Workforce	Expand flexible hiring & management practices – Lab Demo (F)	Develop workforce skills through prototyping (F)	Agile workforce to respond to rapidly emerging technical challenges (L)

Figure 7.1: Mission Support Roadmap

Figure 7.1 illustrates the Mission Support Roadmap. In the near-term, the Air Force should continue development of computational and probabilistic high performance computing in the areas of materials development, system design, manufacturing, and sustainment in order to: decrease time-to-market for next-generation materials; enable efficient exploration of the resilient design space; streamline testing; predict manufacturing yields, defects, and supply chain issues; and provide maintenance feedback to inform next generation design. During near-term model and tool development, the Air Force should engage industry to establish a common set of industry and government standards that would enable integration across the acquisition domains and communities.

In the mid and long-term, the Air Force should pursue a "modeling commons" architecture that integrates the disparate domains of capability planning, materials performance, component and system design, test, manufacturing and sustainment. These integrated tools and processes would substantially enhance trade space exploration (system-of-system concepts, design and manufacturing), quantification of risk at critical decision points, identification and management of technology maturation risks, and the reduction in late discovery of system performance deficiencies. A Digital Thread during Capability Planning and Analysis would enable feasibility, affordability, interoperability, and producibility assessments by tying physics-based models with wargames, campaign, and operational models to assess military utility and interoperability. During preliminary design, the Digital Thread could provide preliminary probability based assessments to enable early looks at material selections, manufacturing, and even logistics modeling to assess producibility. A Digital Thread during detailed design, manufacturing, and sustainment would enable optimized and adaptable approaches in tailored material properties, structural analyses, testing, and agile manufacturing. The Digital Thread concept leads to an airframe digital twin which provides actionable and decisionable output on a fleet-wide and tail-number unique basis regarding the structural response, performance, failure models, and reliability now (diagnosis) and in the future (prognosis). Finally, using the Digital Thread to support Training enables full embodiment of live-virtual-constructive modeling for training at any stage of the life cycle; operational assessments through active operator engagement in simulators during earliest trade studies as well as virtual simulations for maintenance and sustainment.

Prototyping has historically been of great benefit to the AF and DoD in terms of risk reduction and concept demonstration prior to system development, advancing new technologies, workforce enhancement and skills continuity between major acquisitions, dissuasion of adversaries by demonstrating capabilities, maintaining technological surprise through classified technologies, and an overarching strategy of overall risk reduction during austere budget environments. Given the reduction in DoD modernization budgets over the FYDP and possibly beyond, and the new defense strategy shifting focus to the air-sea strategy in the Pacific, renewing a prototyping program would serve as a means to encourage innovation in new concepts and approaches, and provide a means to assess and reduce risk before commitment to major new programs. The creation of prototyping centers consisting of laboratory, joint operational users, academia, and industry would enable rapid discovery, a culture of risk tolerance, and multi-disciplinary workforce skills. In addition, Open Innovation and Grand Challenges are opportunities to leverage the $1.4 trillion global R&D investment and knowledge and also offers a broader set of possible solution providers, provides better opportunity for cross-domain solutions, and is potentially much faster and less expensive than traditional sourcing.

An agile Air Force workforce is foundational to maximizing revolutionary technology, tools, and practices. The Air Force needs new innovative ideas to attract and energize top global talent. Some opportunities include creating “hands on” rapid prototyping environments that would create high value, multi-disciplinary STEM skill capabilities and 10-week software programming training courses to expand the number of personnel that can write code. A near-term opportunity is to expand flexible hiring and management authorities that have been successful in the Air Force Research Laboratory’s Personnel Demonstration program. Providing these authorities to the larger Air Force acquisition workforce would enable advanced degree scientists and engineers to be hired 60 days faster than typical processes and also the opportunity for technical and management career tracks. An agile workforce will enable the Air Force to quickly respond to rapidly emerging technical challenges and opportunities.

8. Enabling Technology

Based on assessment of opportunities, threats, and identifiable trends, we recommended targeted investments in the following five areas of enabling technology: (1) materials sciences, (2) biotechnologies, (3) autonomous/robotic systems and platforms, (4) knowledge discovery and decision-making tools, and (5) social forecasting and influence. We identified subsets of each area and recommended for timeframes out to 2027 whether the Air Force should lead (L), follow (F), or watch (W) the development of each technology. See Figure 8.1.

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Materials Sciences	Flexible electronics available for military use (F) Metamaterial-based antennas, detectors, coatings (F)	Molecular-engineered materials and devices (F) Metamaterial-based optical detectors and filters (F) Large-airplane cold-atom navigation (L)	Chip-based cold-atom navigation (L) Tunable metamaterial devices (F) Plasmonic-based high-speed/ low-power photonics (F)
Biotechnologies	Biosensors (F) Human-machine interface: control of biotic/abiotic interfaces (F) Synthetic biology and Epigenetic control (F)	Bioelectronic devices (F) Computer-enhanced human sensing (F) Large-scale neuromorphic computer (W)	Synthetic bio for adaptable devices, meterials, fuels, electronics (F) Computer enhanced human cognition (F) General-purpose neuromorphic computer (W)
Autonomous and Robotic Systems and Platforms	Human-on-the-loop air vehicles (F) Information visualization & understanding tools (F)	Trusted, robust human-machine teams (F) Collective performance in adversarial environments (F)	Self-learning collective performance, with minimal human supervision, in adversarial environments (F)
Knowledge Discovery and Decision-making Tools	Crowdsourcing (W) Prize competitions (W) Data collection / transmission algorithms (F) Knowledge discovery tools (F)	Integration with planning (L) Knowledge discovery from exabyte-sized data sets (F)	Real-time data-to-decision tools under adversarial conditions (L)
Social Forecasting and Effects Influence	Actionable foreign culture insight and tools (L) Actionable insight for trust in automation (F) Cognitive-effects modeling (F)	Actionable prediction of weapons effects on behavior (F) Influence tool suite for AF effects (L) Trusted foreign-use autonomous sys (F)	Influence tools integrated into mission planning (L) Cyber tools for influence (L) Trusted domestic-use autonomous systems (F)

Figure 8.1: Enabling Technologies Roadmap

The input into the assessment came from data-mining of published technical literature and reports, discussions with program officers at the Air Force Office of Scientific Research and scientists and engineers at the Air Force Research Laboratory, discussions with various experts from academia and the military, responses to the *Global Horizons* RFI, reports from the other Global Horizons teams, and a host of previous studies, including the Air Force's *Technology Horizons*, *Energy Horizons*, and *Cyber Vision 2025*.

Dozens of technologies were examined. Those that could yield orders of magnitude improvements in performance and cut across multiple domains fit readily into the five categories. For each key technology, we answered as quantitatively as we could:

- Why is this a key enabling technology?
- How can this technology be used to make a significant impact?
- What devices/systems will be impacted by this technology?
- How much improvement (looking for a factor of 10 or more)?
- Which nations are the significant players?
- What funding amounts are the nations contributing (past, current, planned future)?
- In which specific centers of mass are the technologies being developed?
- When might the technology be available for use in devices/systems?
- What were the sources of the answers?
- Should we lead the world in the overall technology development, follow what the world is doing, but make targeted investments into subsets of the technology area, or watch and wait?

The two principal findings from our studies were: (1) there are a great many technological opportunities offering huge improvements over current performance and (2) most of the technologies of interest have use beyond military systems, and the world as a whole is investing significantly in developing them.

Materials science provides the foundation for all Air Force physical systems. Significant improvements can be expected from all classes of structural materials, but factors of ten or more improvement do not seem likely. For electronic, optical, and magnetic materials, orders of magnitude improvements are possible. For example, in comparison to current semiconductor-based electronics, plasmonics coupled with nanophotonics can lead to equivalent device density and processing speeds a few orders of magnitude faster, and quantum computers, whatever material they are based on, can perform some calculations many orders of magnitude faster than can digital supercomputers. Cold atoms can produce inertial navigation systems that significantly outperform other systems when the global positioning system cannot be accessed.

Trends in materials sciences over the next 15 years include further miniaturization and reduced cost; increased sophistication in design and fabrication of metamaterials, which will include new functionality; tapping the unique transport properties of graphene and carbon nanotubes for new classes of electronics; and realizing the immense potential of plasmonic-optical systems to replace current electronics. As to the effort worldwide, since the mid-1990s, Asia has been the overall leader in materials sciences, Europe has been second, and the US a distant third. In 2010, Web of Science data showed Asia publishing ≈30,000 research papers (≈14,000 from China and ≈5000 from Japan), the EU-15 publishing ≈15,000 papers, and the US publishing ≈7000 papers. The trends indicate expanding foreign dominance. Over the last decade, Asian publications doubled and EU-15 publications increased by 50%, while the US's total was approximately the same as it was in the mid-1990s.

One material, graphene (single-layer carbon) offers a compelling example of how the world can respond to a perceived technological opportunity. The US, once the leader in graphene research papers, has seen its share decline each year. China now leads. In an attempt to shore up its position, in 2013 the European Commission announced graphene R&D would be one of two winners of the Future and Emerging Technologies competition: garnering one billion euros in investment over the next ten years. This amount will be the largest government investment in the world for years to come.

The second field of technology we recommended for investment, biotechnology, offers promise of new bioelectronic devices, human-machine interfaces (including direct coupling through implant technology), and very-low-power but high-speed computational neuromorphic architectures. The trends over the next 15 years are expected to include substantial increases in basic research to understand the fundamentals and capabilities of bioelectronics, including biosensors, and then to understand and apply the underlying principles of their systems. Robust, highly functional devices that consume low power and are resistant to damage from electromagnetic pulses should result. Self-assembly through biological synthesis will expand. Harnessing the processes within the cell for direct synthesis of useful product should be one result. Enhanced human performance was called out in Technology Horizons as a main enabling technology for the Air Force. Much success has already been achieved in coupling machines to human beings. Research should lead to hybrid systems capable of performance far superior to that of today's human-machine partners. The organ capturing most attention is the human brain. Its network of neurons can carry out approximately 10^{15} logical operations per second (a petaflop). The world's faster supercomputer is for some calculations more than ten times faster, but a brain consumes about 15 watts of power versus 15 million watts for the supercomputer. Research now will guide design and materials-science solutions to achieve the breakthrough of low-power neuromorphic computing.

There is considerable activity worldwide in these fields, but total funding in non-medical fields remains comparatively modest at present. One exception to this statement is the remarkable increase in funding in brain sciences. In 2013, President Obama announced $100M of new investment in brain research. In 2006, Korea launched a 7 year, $1.75B national brain engineering program, and Japan's investments are on the same order as those of the United States. In 2013, the European Commission announced the Human Brain Initiative is set to receive one billion euros ($1.35B) over ten years, with a goal of delivering "world-beating science at the crossroads of science and technology." History suggests the significantly increased investment by other countries will yield significant advances across many fields of technology.

Data-mining revealed in biotechnology a trend seen in many fields of R&D: among countries, the US is in the lead, Europe is in aggregate approximately equal or larger, and China is closing the gap quickly:

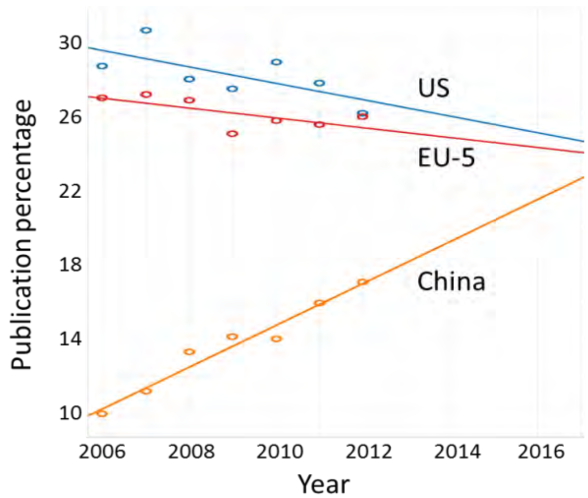


Figure 8.2: Web of Science Data for Biomaterials and Bioelectronics Papers

Autonomous and robotic systems are fielded widely and their use will continue to expand. These systems were the second main enabling technology cited in Technology Horizons. Ability to deploy vehicles from large-insect size upward, often at low cost, allows broad coverage of terrain, including battlespaces, while keeping airmen from harm's way. Future developments will include further miniaturization, increased mission lifetimes, further improvements in information capture, transmission, and processing, cooperative control within squadrons and swarms, group robustness so that missions can be completed, despite significant loss and degradation of individual units, and self-learning and reliably increased autonomy with minimal human oversight. The Air Force already fields many capable autonomous and robotic systems. So do other public and private entities, including examples such as NASA's Curiosity Mars rover, the autonomous Google car, and the global shipping system at the Brisbane Terminal in Australia. Our allies all have active development programs in unmanned systems. World leaders in the field outside the US include Japan, Europe, and Australia.

Information storage and processing, and proceeding from knowledge discovery to informed decision, are at the heart of Air Force operations. There is a compelling need to make sense of huge amounts of data, in some scenarios in real time. Advances in algorithms and computer hardware, fueled by basic research, will allow for extracting knowledge from data sets substantially more diverse and orders of magnitude larger than can now be exploited. The challenges of so-called big data are ubiquitous. In addition to the US, several countries in Asia and Europe, notably the UK, Germany, and Spain, have significant expertise and strongly funded R&D efforts.

Crowdsourcing and prize competitions are venerable means to create knowledge and drive innovation. Their use should expand for the Air Force, once obstacles related to publicly releasing relevant data have been overcome. Recent successful challenges include the Ansari X Prize for lower-cost access to space and DARPA's robotic vehicle. One can envision prizes being used for technological needs such as smaller and more-capable unmanned air vehicles.

The final category of recommended enabling technologies is social forecasting and influence. These subjects are obviously of central concern to marketers everywhere and virtually any organization that focuses on public concerns. The Air Force should focus the bulk of its R&D on Air Force-specific considerations, such as the ramifications of the use of weapons. Currently available forecasting tools have some utility, but they are hindered by limitations in amount of relevant data and understanding of human cognition. Near-term targeted data collection and cognition research should progress through modeling and experimentation to development of course-of-action tools available to commanders. This progress from knowledge to prediction to influencing outcomes requires developments in social science, psychology, network analysis, and means of information dissemination. There is now a dearth of empirical studies and of capturing and assessing the rapidly expanding body of web-based information (including to the level of the individual) on which to base modeling. Much basic research is needed. It is especially important to ensure research concentrates on all relevant cultural and societal groups, not just on Americans.

The United States' percentage of the overall global S&T investments continues to shrink because other nations are investing at a more rapid rate that the US. In particular, the US military's S&T budget represents about 4% of the world's total S&T budget. Therefore, it is critical for the US to keep abreast of the S&T being developed around the world and exploit/leverage it to the greatest extent possible. There are certain areas, such as hypersonics, where the US is clearly the leader in S&T, and should remain so due to its technological superiority and its requirements. In other areas such as autonomy, the US has specific military needs that can greatly leverage global investments with targeted S&T in militarily-relevant applications.

There are a number of ways for the US to tap into the global S&T community to leverage their investments. The easiest way is for interested organizations to identify and attend international conferences, especially those held overseas. The international attendance at conferences held outside the United States is much more diverse and substantial than for US-hosted international conferences. Conferences contain a wealth of S&T information from basic research to developmental engineering.

A second way to access global S&T investments, that is relatively straightforward, is to partner with military basic research organizations: Air Force Office of Scientific Research (AFOSR), Office of Naval Research (ONR), and Army Research Office (ARO). They have the ability to form partnerships with international organizations for joint research projects, information exchanges, and more, without the necessity of country-to-country agreements. More specifically, AFOSR has offices in London, Tokyo, and Santiago, and is the most active in the US government at identifying and supporting foreign research. They have existing partnerships that can be leveraged and can expand them as needed. New programs can be created and new projects can be funded anywhere within months. For example, in the early 2000s, a study by the Air Force Research Laboratory (AFRL) indicated a shortfall in the amount of funds it thought were needed for investment in nanotechnology. Shortly after the study, Taiwan and Korea announced national nanotechnology initiatives. AFOSR partnered with both countries, managing to bring many of the top researchers in those countries into collaborations with AFRL. Similar programs have been launched within a year of identifying a need with India in micro air vehicles, Korea in brain science, Singapore in non-GPS navigation, Mexico in advanced materials, and Russia in hypersonics. These initiatives feature huge leverage in expertise, capabilities, and funding from the partners. New topics and countries for international initiatives include Australia and ubiquitous sensing and South Africa and advanced materials.

Applied research and developmental engineering partnerships with international organizations can be accomplished through the military laboratories: AFRL, Naval Research Laboratory, and the Army Research Laboratory. They each have decades of experience establishing and exploiting such partnerships. Country-to-country agreements are required for non-basic-research partnerships, and can take a year or more to establish; however, there are many existing agreements that may be broad enough to be used for new partnerships. Agreements totaling $420M of in-kind effort from AFRL are now distributed among 20 partner countries, and more are being developed. The Technical Cooperation Program (TTCP), which links the militaries of the US, the United Kingdom, Canada, Australia, and New Zealand, provides an ideal forum for collaboration from applied research through technology demonstration. Materials science, social forecasting, and human-centered biotechnologies offer promise for cooperative development through TTCP. NATO's Science and Technology Office (STO) links applied military research across the alliance. Social forecasting and some information technologies offer promise for joint development through the STO.

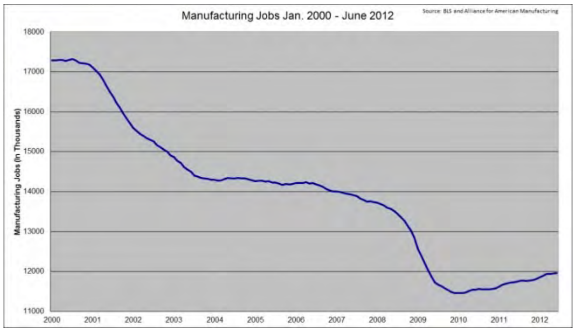
Industry carries on the bulk of applied research and technology development in the US and in most developed countries. AFRL funds considerable industrial R&D. It should continue to do so, and incorporate into its new systems as many as it can of the products that domestic and foreign industry develops. Many, especially new materials and advanced telecommunication equipment, are likely come from foreign sources.

9. Manufacturing and Materials

9.1 Trends

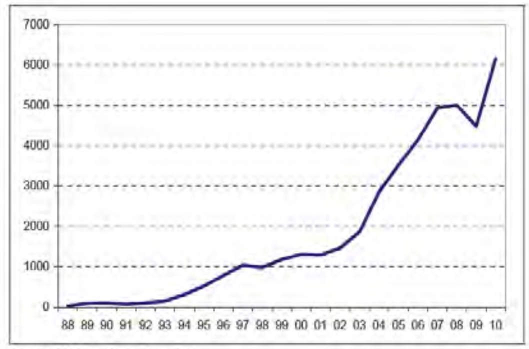
Some key trends in manufacturing and materials include the reduction in manufacturing employment and increases in additive manufacturing, as illustrated in Figure 9.1 Addition facts are detailed below.

U.S. Manufacturing Employment Decreasing



Source: Manufacturing & Technology News, April 17, 2009

Increasing Sales of Additive Machines



Source: Wohlers Associates, Inc.

Figure 9.1: Trends in Manufacturing Employment and Machining

Factoids from *Rising Above the Gathering Storm, Revisited*

- Hon Hai Precision Industry Co. (computer manufacturing) employs more people than the worldwide employment of Apple, Dell, Microsoft, Intel and Sony combined.
- Eight of the ten global companies with the largest R&D budgets have established R&D facilities in China, India or both.
- In 2009, 51 percent of United States patents were awarded to non-United States companies.
- Manufacturing employment in the US is lower now than when the first personal computer was built in 1975.
- The legendary Bell Laboratories is now owned by a French company.
- IBM's once promising PC business is now owned by a Chinese company
- In a survey of global firms planning to build new R&D facilities, 77 percent say they will build in China or India.
- GE has now located the majority of its R&D personnel outside the United States.
- An American company recently opened the world's largest private solar R&D facility . . . in Xian, China.

Quotes from *Rising Above the Gathering Storm, Revisited*

- ". . . in today's integrated and digitized global market, where knowledge and innovation tools are so widely distributed. . . . : Whatever can be done, will be done. The only question is will it be done by you or to you." Thomas L. Friedman, Author, "The World Is Flat"
- "Will America lead . . . and reap the rewards? Or will we surrender that advantage to other countries with clearer vision?" Susan Hockfield, President, MIT
- "The fate of empires depends on how they educate their children." Aristotle
- "The history of modernization is in essence a history of scientific and technological progress. Scientific discovery and technological inventions have brought about new

civilizations, modern industries, and the rise and fall of nations . . . I firmly believe that science is the ultimate revolution." Wen Jiabao, Premier, People's Republic of China

- "The 19th century belonged to England, the 20th century belonged to the United States, and the 21st century belongs to China. Invest accordingly." Warren Buffett

From Technology Horizons, AF/ST-TR-10-01, 15 May 2010

- " 'flattening' of the world is making it increasingly challenging for the U.S. to maintain technology superiority over potential adversaries. A growing number of nations will soon have the ability to transform science and technology advances into militarily significant capabilities. Over the next decades, we will increasingly face potential adversaries having peer or near-peer capabilities." - Michael B. Donley, SECAF and General Norton A. Schwartz, USAF Chief of Staff
- "Potential adversaries, however, may be willing to field systems with far higher levels of autonomy without any need for certifiable V&V, and could gain significant capability advantages over the Air Force by doing so. Countering this asymmetric advantage will require as-yet undeveloped methods for achieving certifiably reliable V&V."

9.2 Game Changers

Historical trends in the U.S. industrial base, expected to continue, bode ominously for the ability of the AF to design, develop, manufacture, and deploy trusted advanced technologies on a time scale consistent with the emergence of new threats. Global trends toward more agile and distributed manufacturing will only exacerbate the challenges, especially as regards trusted sourcing, perhaps even lowering the bar to "nuclear club membership".

- **Advanced Manufacturing**, including additive (See Figure 9.3), 3-D, and direct digital printing, will enable open architectures that permit rapid prototyping, mission specific reconfigurability; material tailoring for specific applications (See sidebar); efficient small lot productions; better systems, faster and cheaper. Advanced manufacturing technologies will deliver products when and where needed and will facilitate multi-functionality, with manufacturing cycle time improvements from 60% in design phase to 30% in automated assembly. On-site Advanced manufacturing could allow for instant part replacement for battle damage repair.
- **Redefined Qualification and Certification Paradigm** will allow rapid utilization of products from Advanced Manufacturing (efficiently from prototype to practice). The new paradigm will eliminate the excessive development times for complex capability systems (15-20 years) by inclusion of concepts such as defined and finite system life, qualification and certification as "adequate" for this application for this length of time, and process qualification and certification vice component qualification and certification.
- **Digital Thread and Digital Twin** comprise advanced modeling and simulation tools that link materials-design-processing-manufacturing (Digital Thread) will be the game-changer that provides the agility and tailorability needed for rapid development and deployment,

while also reducing risk. State Awareness and System Prognosis advantages will be achieved through the Digital Twin, a virtual representation of the system as an integrated system of data, models, and analysis tools applied over the entire life cycle on a tail-number unique and operator–by-name basis. M&S tools will optimize manufacturability, inspectability, and sustainability from the outset. Data captured from legacy and future systems will provide the basis for refined models that enable component and system-level prognostics. Archived digital descriptions of new systems would greatly facilitate any subsequent re-engineering required in the future. Human performance monitoring will enable adaptation of systems to the "mission capable" state of the operator.

Taken together, these three game changers will dramatically improve the ability of the AF to consistently bring its best technology to the fight, affordably, reliably, and more rapidly. However, there is value to be had with each step and in each separately. Advances in materials and processes have been the foundation of the computer and information revolutions; we now must bring the power of these Digital Revolutions to improve our materials and manufacturing technologies. To escape the 15-20 year time it takes to get advanced materials into AF systems, we need to be able to design the material and the component iteratively to take full advantage of the material properties; to manufacture, singly or in quantity, the component as-designed; to verify that we have done so; and to verify that the component meets specifications.

Doing these more rapidly will mean little if the qualification process continues to move at a snail's pace. Revised policies to get these technologies into the acquisition process more rapidly (when safe and possible) are essential. This Digital Revolution of the M&M processes also leads to technologies to escape the ever-rising cost of sustainment. The Digital Twin paradigm (wherein the digital, virtual representation of the components or systems can be subjected to the conditions seen by their physical counterparts) addresses the need to be able to detect the current state of a system and its components, down to the material level where failure will eventually occur – *and* to be able to predict both expected life and remaining life. CREATE, a conceptual framework through which to implement, coordinate, and utilize these M&S tools and data, is being developed in coordination between AFLCMC, AEDC, AFRL, and SAF/AQR.

As we drive toward faster/better/cheaper, we can use physics based M&S at the start of the Digital Thread to verify that the design will actually be mission effective before it is produced. Additive manufacturing will require that digital thread to produce it, and will allow rapid prototyping if shortcomings are identified. That rolls into our required policy changes to ensure that we can go to print sooner. The digital thread and prognostics then support sustainment through spare part replacement and P3I.

9.3 Recommendations

To Increase Life Cycle Affordability and Rapid Development:

1. Define pilot programs to instantiate the Digital Thread/Twin (DT/T) from Concept Development though Disposal (OPR: AEDC/CZ)

- Identify resources and create a roadmap to implement DT/T (OCRs: SAF/AQRE, AFRL/RX, AFLCMC/EN/XZ, Industry/SME)
- Support the development of Modeling and Simulation tools to address every phase of a system life cycle (OCRs: AFMC/EN, AFLCMC/EN/XZ, SAF/AQ, AFTC, SAF/CIO A6, WFI GOSG, AF/A9)
- Identify key data to support DT/T M&S tool validation and Identify resources to initiate data capture (OCRs: AFMC/EN and EN/XZ AFRL/RX and RQ, SAF/AQ, AFTC, SAF/CIO A6, WFI GOSG, AF/A9)

The CREATE framework, already under development, would provide a cost effective approach within which to define the pilot programs and to integrate modular M&S tools into the DT/T concept.

2. To more rapidly provide the AF with the advantages of the latest materials & manufacturing advances, establish a working group to (OPR: AFRL/RX):

- Identify and eliminate obstacles that limit AF exploitation of the benefits of Additive and other Agile Manufacturing (AM) methods. (OCRs: SAF/AQ, AFMC/EN/A2/5, AFLCMC/EZP)
- Identify AF specific requirements and research needed to enable AM to meet them (OCRs: AFLCMC/XZI, SAF/AQR, AFMC/A2/5)

9.4 Technology Enablers

The Key Technology Enablers (shown in the Figure 9.2) required to achieve these Game Changers include Advanced Materials (rapid development via M&S tools), Advanced Manufacturing & Design Tools, A Skilled Manufacturing Workforce, Human Performance Monitoring and Augmentation (HPMA), Advanced Sensors for NDE and HPMA, and Data Capture and Management. Lastly, the way basic research is executed in the U.S. should perhaps be scrutinized.

Advanced Materials (rapidly developed via M&S tools): The Materials Genome Initiative, led by the White House Office of Science and Technology Policy, embraces Integrated Computational Materials Engineering to optimize material and component design iteratively and synergistically and build in manufacturability, inspectability, and sustainability from the outset. The Modeling and Simulation tools will provide the ability to tailor the material for the application (location specific, if necessary) and design systems to take advantage of this capability.

Advanced Manufacturing & Design Tools: The Digital Thread runs from the discovery and development of materials, though the design of components, to the end of the manufacturing line that produces hardware for the AF. The M&S tools that yield advanced materials more rapidly must interface with a suite of digital M&S tools that describe and drive every step of the manufacturing process. A key aspect is that the tools that are used to design a component are cognizant of and incorporate limitations (or advantages) of the various manufacturing processes that can be used to produce that component with the desired properties.

A Skilled Manufacturing Workforce: STEM issues are well known. A particular aspect of this for the AF is in producing a skilled workforce in areas that are no longer among the hot topics pursued by the funders of basic or academic research. We can get all the PhDs in nanoscience we want, but where do we go to get a process metallurgist or NDE expert or manufacturing expert – or the research needed to advance these areas? The "bygone" fields are still critically important to military (and industrial) research and development. The message from the Persh Conference on DoD, Government, and Industrial Manpower was that the universities are generally not producing graduates that meet the needs of the defense industry.

Human Performance Monitoring and Augmentation (HPMA): The operator is a key element of any AF system. Understanding the operator's capabilities and cognitive/mental acuity under specific environmental, work-load, duration, etc. are critical to obtaining maximum, optimum performance from the warfighter. Monitoring the operator's physiology may provide ways to ascertain his current capabilities and (eventually) offer means to augment those abilities in real time (e.g. providing a small dose of caffeine when the operator's sweat physiology says his attention to task is waning.) Materials for appropriate sensors and manufacturing for wearable, non-intrusive monitoring and reporting devices (smart bandage) are some of the products needed from the M&M Sector.

Advanced Sensors for NDE and HPMA: Broad M&M Sector needs are for multispectral sensors, low power computer chip, battery technologies, and Plug & Play modularity. More specifically, sensors for specific bio-markers for HMPA are needed (see above) as are sensors for Non-Destructive Evaluation/Inspection. The latter will provide for more sensitive, reliable, more rapid inspections, either *in situ* or with less disassembly of the system or component. These in turn will mitigate sustainment costs by extending or eliminating inspection intervals, and coupled to Digital Twin concepts and Prognostics, will allow safe utilization of a greater fraction of a components life.

Technology	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Advanced* Materials Rapidly Developed	M&S tools (L, F) Flexible Electronics (L)	M&S-aided design (L,F) Hybrid structures (F)	M&S-aided Qual (L) Energetic materials (L) Meta-materials (L)
Advanced* Manufacturing & Design Tools	M&S tools (L, F) Reduced part variability, reduced qual. testing (L, F)	M&S-aided design (L,F) Open architecture reconfigurable systems (L)	M&S-aided Qual (L) Small lot production of Quick Reaction Systems (L)
Advanced* Sensors	Multi-Spectral (L)	Low Power Computer Chips (W)	Plug & Play modularity (L)
Data Capture & Management	Continuous process improvement (L)	Digital Thread (L)	Prognostics (L)
Materials State Awareness	Advanced Non-Destructive Evaluation (L, F)	Prognostics tools (L)	Digital Twin (L)
Human Perform. Monitoring & Augmentation	Biosensor markers (L) Lab-in-a-Bandage (L,F)	Performance Therapeutics (W)	Remote activation of therapeutics (W)

Figure 9.2: Manufacturing and Materials Roadmap

Advanced* => beyond the current state of the art; M&S => Modeling and Simulation; Qual => Qualification

Lead (L) is a primary investor, Follow (F) an area where the AF should rapidly adopt, adapt or augment another organization's lead investment, and Watch (W) is an area we might be dependent upon but is not a primary, core AF function.

Data Capture and Management: Modeling and Simulation Tools are only as good as the verification, and validation underlying their results. Uncertainty quantification is a key factor needed to enable full utilization (and acceptance) of Digital Thread abilities. Capturing and managing data is of paramount importance. Data from every step of the Digital Thread (materials-design-processing-manufacturing) and data from the maintenance and performance of the operational fleet must be captured and archived in order to bring the Digital Twin concept to reality and allow Prognosis from the material, thorough the component, and to the subsystem and system level.

U.S. Research Enterprise: Until now we have invested as a nation in unclassified academic research and development (NSF, NIST, DARPA, etc.) to serve military needs largely because we were the only nation capable of manufacturing the results. Small nations are now launching satellites, building advanced aeronautics, venturing into space, establishing auto industries, and manufacturing integrated circuits. Should the AF (and DoD) define areas of unclassified S&T that it wants to control and advance far in excess of adversary expectations? Those areas require in-house S&T investments hidden from (international) public view. It also requires attracting some of the best and brightest. Do the advantages of keeping S&T research hidden in select areas outweigh the advantages of having a broad technical community addressing the problem from wide and diverse perspectives? Perhaps globalization warrants a new assessment of these long-standing issues.

10. Logistics and Transportation

10.1 Vision

A core mission of the Air Force is to hold any target on the globe at risk. That could require a very long distance and flight time, with potentially several enroute stops and/or refuelings to reach the target. Mission success is vitally dependent on logistics and agile combat support throughout. Logistics breeds logistics and the amount of personnel, energy, equipment, and infrastructure can have huge operational overhead. The expeditionary focus of operations has allowed us to refine logistical processes and increase efficiency. However, emerging technologies offer opportunities to improve further. Our vision is to define a new measure, the fully burdened cost of logistics and combat support, and exploit advances in several technologies and processes—secure and trusted cyber, automation, additive manufacturing, industry best practices, and direct delivery—to drive that cost down.

10.2 Trends, Threats, and Opportunities

During Operations Iraqi and Enduring Freedom (OIF and OEF), the start-up process for each forward operating location (FOL) airbase required approximately 50 C-17 load equivalents and 44 days, plus 1 C-17 load per day for sustainment. In the future we may be called upon to establish our operations at remote locations with minimal awaiting infrastructure. We may contend with the added complexity of a robust and growing A2AD threat environment which will certainly attempt to actively disrupt and challenge our combat support logistics. For example, Futures Game 13 proved the need for an effective base defense to provide persistent and effective air power and validated the need for promising technologies that offer protection for USAF and DoD combat capability and critical infrastructure.

Since FOL set-up and operating footprint is driven by the physical preparation required for aircraft hosted there along with housing and security for the staff which provide it, an integrated, layered approach to technology strategy is required to minimize the logistics and combat support footprint. Each aspect of FOL operation as well as the aircraft bed-down requirements must be addressed for an effective, systemic change of state in time, mass and energy needed to establish and maintain warfighting capability.

A "case study" of getting 2 JSTARS, tankers, fighters, and personnel to a 30 day deployment from the US to an established base in the Western Pacific revealed a deployment energy cost of nearly $12M and a 30-day employment cost of $25M to secure, operate and sustain deployment operations. Standing up a bare base would require an energy bill of over $50M.

Several technologies of interest could provide capabilities to attack logistics cost at an enterprise level as illustrated in the roadmap in Figure 10.1:

Automation: The 2013 Robotic Roadmap predicts the rise of autonomous vehicles capable of operating in any environments in which humans currently drive or pilot during the next 15 years. These vehicles learn and adapt to changing or novel scenarios. Current automated ports, like the wharves in Brisbane, Australia, experienced a 27% reduction in labor, savings in maintenance, and dramatic (18 fold) drop in injury rates.

On-site production and manufacture: Advances in new manufacturing paradigms, like 3-D printing and additive processes would allow rapid generation of needed devices and parts. Use of indigenous resources and assets, including recycled materials, offer procurement options which eliminate transportation overhead costs, shipment energy expense and time delays affecting combat readiness and mission capable rates for deployed forces.

Logistics Efficiency: Transportation of energy and equipment for power production consumes much of the supply chain, so better energy efficiency from platforms to infrastructure to personnel will have a compounding benefit. Advances in computer processing and algorithms will provide more optimal routing, scheduling, and tracking. Adopting commercial best practices to exploit technologies like RFID will improve in-transit visibility and customer confidence to avoid over-stocking and multiple requisitions of critical equipment.

10.3 Game Changing Theme

The driver in our approach to reduce the fully burdened cost of logistics and combat support is to reduce the mass flow. Ultimately—can we achieve the logistical effects we need, but move less "stuff"? Critical technology areas of emphasis include *automation; on-site production and manufacturing capability; logistical efficiency; and precision delivery to austere/remote bases.*

Automation

Home station logistics and operations will be enhanced with increased use of robotic or remotely operated systems, but there is huge payoff in using these systems to reduce the forward footprint at the FOLs. Material processing and handling (armaments and cargo), servicing, maintenance, emergency response, protection and base surveillance are all potential mission targets. By example, a standard BEAR (Base Expeditionary Airfield Resources) set for 550 people requires 28 C-17 loads of equipment to set up housekeeping and flight-line facilities (AFPAM 10-219V6). Automation technologies applied at the same scale as Brisbane could drop this requirement by up to 8 C-17 loads.

Theme	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Automation	Robotic warehousing (F) Automation integration into aerial ports and flight line servicing (L)	Robotic shipping/handling (F) Integrated automated shipping (F) Automated sensors and base protection (L)	Aircrew optional airlift and refueling (F*)
On-Site Production and Manufacturing	Additive manufacturing (W) 3D Printing (W) Multi-material recycling (F)	Certification of parts produced by additive manufacturing (F*)	On-Site manufacturing for deployed sites (L)
Logistics Efficiency	Compatibility with Next Gen ATC (F*) Logistics Situational Awareness (F*)	Energy efficient aircraft and propulsion (L) Cognitively-enabled Logistics Alerting, Awareness, and Optimization (L)	Self-aware, autonomous Logistics Management (F*)
Precision Delivery to Austere/Remote Bases	Precision airdrop (L)	Efficient high power lift (L) Ground-based laser for base defense (L)	Autonomous ground delivery systems (F*) Airships (F) Cargo UAS (F*)

Figure 10.1: Technology Roadmap

On-site production and manufacturing

In OEF, the average delivery time for spare parts warehoused in CONUS to end user in Afghanistan was approximately 15 days, which typically included several intermediate distribution centers. Onsite manufacturing, with effective quality control could reduce the wait time to only what is required to fabricate the part. A benefit of additive manufacturing is reduced waste. Raw materials for production could be brought in as part of the supply chain, but we gain efficiency by exploiting indigenous materials or targeted recycling.

Logistics efficiency

In OEF and OIF, fuel for aviation operations was by far the largest commodity consumed. In the first 100 days of OEF approximately 800,000 tons of avgas fuel (nearly 18,000 C-17 load equivalents) was consumed and in the first 30 days of OIF approximately 945,000 tons of fuel (21,000 C-17 load equivalents) was consumed. Improving aircraft fuel efficiency by 30 percent with advanced designs featuring improved engines, aerodynamics and structural technologies would save as much as 270,000 tons (6,000 C-17 sortie equivalents) in the same time frames.

Improving aircraft operations, for example through better mission planning and routing, can reduce fuel costs further. Use of smart systems and tagging options can create a responsive and agile supply chain. New computational and visualization tools can be used to optimize logistics at every stage.

Precision delivery to remote/austere locations

Precision airdrop technology will enable reliable, single-pass delivery of guided and unguided payloads from high altitude, minimizing threat exposure and maximizing OPSEC. This will involve exploitation of on-board or off-board sensors and modeling algorithms for wind profiling augmented with more precise release systems. Once released, RFID tracking systems will enable real-time situational awareness of overall drop effectiveness and enable ground forces to quickly locate and prioritize specific bundles in event of a widely dispersed drop or changing threat environment during recovery. Far-term focus is on achieving accuracy from greater standoff distances to shift the operational concept from multiple-pass (current operations) to no-pass options (future). For example, extended-range gliding concepts and/or unmanned cargo systems may offer very efficient, precision delivery of time-critical materiel with no risk to a manned aircraft.

During the period through 2027, we can start planning next-generation tactical airlift and tankers. These new systems can provide runway-independent access to short, improvised airfields to allow direct delivery to the point of need, eliminating the need for FOLs dedicated to supporting ground forces as supply distribution nodes. Critical technologies of viable fixed-wing systems include performance flexibility that enables routine short takeoff and landing (STOL) for global access as well as efficient high speed cruise for effective flexibility in day-to-day operations as a utility airlifter or tactical tanker. These features enable the aircraft to produce nearly double the ton-mile per day throughput of a C-130 with only half the effective fuel burn.

Aerial refueling within contested airspace presented by A2AD environments will be critical to supporting our strike aircraft. KC-Z is conceptually being explored as a tactical complement to KC-46 that would combine the range, speed, and survivability technologies lower infrastructure requirements to support strike missions. The “strike tanker” concept, if feasible, could have a major impact on operational flexibility and end-to-end fuel efficiency on multiple levels. For example, a tanker capable of dispersed basing could drastically reduce operations fuel consumption by having lower drag and basic fuel burn of its own, while also saving trip fuel to/from the tracks by flying less distance to them. Roll-on/ roll-off cargo carriage would enable it to support theater airlift operations when not employed as a tanker. We need to couple tanker size with projected range requirements.

Far-term options for direct access could include hybrid airship platforms. Recent technology development activities have focused on ISR applications for airships due to their low fuel consumption providing cost-effective endurance relative to fixed wing aircraft. However, this same attribute may have payoff for effective cargo carrying capacity, especially when coupled with STOL or VTOL capability to reach isolated landing zones and/or perform effective seabasing operations for a fully joint mobility system. Critical-path technologies needed to make operationally viable cargo airships include ballast-free buoyancy control systems, precision flight path and hover control in terminal areas to be safely interactive with other MAF systems in controlled airspace, and weight-efficient rigid-hull designs to maximize useful load and avoid ground handling issues while parked and empty. If the commercial sector builds and develops these systems, airships might be a good candidate for Civil Reserve Air Fleet operations.

10.4 Recommendation

The Air Force should conduct a series of field tests, experiments, and challenges to reduce the logistics footprint of the Air Force by 50% (over current costs) by 2025. (OPR: AFMC, OCR: ACC, AMC, AFGSC, AFSOC)

To accomplish this, AF leadership should create a stakeholder Integrated Process Team (IPT) which will:

- Define and validate methodology to measure "fully-burdened cost of logistics" against current baselines
- Select representative technologies (e.g., autonomous warehouse robots, remote-sited 3-D printing capability, secure supply chain sourcing) and mission functions for consideration, test, and evaluation
- Generate an integrated roadmap for development and test, and conduct exercises to verify savings and improvements in operational capability as a result of logistics footprints

Reducing the fully burdened cost of logistics through improved efficiency, on-site production capability, and human-machine partnership will result in increased availability to assets, personnel, and resources; improved resilience; and a lower target "cross section" of our deployed operations

11. Energy

The *Global Horizons* energy appendix provides information on the *Energy Horizons* (2011) study which preceded *Global Horizons*, as well as documentary information for the trends and threats compiled in the study.

11.1 *Energy Horizons* Background

The Energy chapter in the Global Horizons reports leans heavily on the extensive work accomplished for the January 2012 *Energy Horizons* project. *Energy Horizons* is similar to *Global Horizons* in seeking pervasive S&T opportunities which could impact the Air Force mission in the near, mid, and far terms. *Energy Horizons* is the Air Force vision for Energy Science and Technology (S&T) focusing on core Air Force missions in air, space, cyberspace and infrastructure. Created in partnership with subject matter experts, it articulates where the Air Force needs to lead, follow, and watch in S&T to advance operational energy.

The Office of the Chief Scientist also led the *Energy Horizons* effort in partnership with the Deputy Assistant Secretary of the Air Force for Energy, the Deputy Assistant Secretary of the Air Force for Science, Technology and Engineering, the Air Force Research Laboratory, and the MAJCOMs. *Energy Horizons* incorporates the best ideas originating not only from across our Air Force but from other Services, Agencies and Departments as well as National Laboratories, Federally Funded Research and Development Centers, industry, academia and partner nations. With the partnership of relevant stakeholders, the Air Force will realize and refine this vision over time with evolving threats, operational needs, and technology advances. Properly realized, it will help save lives and treasure through the advancement of readiness, robustness, and resilience.

11.2 *Energy Horizons* Summary

Energy is essential to all Air Force (AF) missions. The *Energy Horizons* Science and Technology (S&T) vision provides the Air Force a vector to increase energy supply, reduce demand, and change our culture as articulated in our *Air Force Energy Plan*. Figure 11.1 exemplifies some of the elements from Energy Horizons in the near-, mid-, and far-term. *Energy Horizons* delineates S&T areas where the Air Force should lead (L), follow (F), or watch (W) in order to advance operational readiness, resiliency, and robustness while at the same time supporting national objectives of economic development, environmental stewardship, and supply independence.

Energy Horizons provides the Air Force vision and blueprint for energy S&T spanning the domains of air, space, cyber, and infrastructure. *Energy Horizons* focuses on S&T in the near (1-5 years), mid (6-10 years), and far (11-15 years) term that hold the most promise to revolutionize AF operations, efficiency, and effectiveness. In partnership with operators and technologists from across the Air Force, the Office of the Chief Scientist engaged experts across government, industry, academia, National Laboratories, and Federally Funded Research and Development Centers to identify the most promising energy S&T.

In the air domain, for example, advanced engines, fuels, structures, and operations were identified that promise to achieve single and double digit improvements in efficiencies promising increases in loiter/ranges and/or enhanced missions. Also in the air domain, replacing kinetic anti-missile weapons with high power and high energy lasers substantially reduces the logistical tail required to maintain replacement missiles, as directed energy weapons can recharge and fire effectively with the equivalent of 1-2 gallons of fuel. High power and high energy lasers will be employed to upset sensors in the mid-term, and to defeat hard bodies in the far-term.

In the space domain, highly efficient photovoltaics, Hall and electric thrusters, and new battery technologies promise more efficient and resilient space operations and revolutionary new services such as in-space power beaming and on-orbit refueling. In the cyber domain, efficient algorithms and processors and cloud computing promise not only energy savings but also enhanced cyber resiliency. Finally, in infrastructure, advances in renewables, smart grids, and Solar-to-Petrol plants promise to increase energy resilience and independence for both fixed and expeditionary bases.

Theme	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Reduce Demand / Increase Efficiency	Propulsion: ADVENT (L) Aero: Blended Wing (F), Lifting Body, Laminar Flow Optimization Thermal Management Cycles (F) M&S: Systems of Systems (L)	Propulsion: HEETE (L) Energy Harvesting for RPAs (L) Energy Harvesting: Thermoelec/ pyroelectric Development (F) Cyber Energy Efficiency (F)	Propulsion: Adaptive HEETE (L) Hybrid Sys/Distributed Propulsion (F) N+1 Gen Efficient Aircraft Config (F)
Increase Supply / Storage	Alternative Fuels (F) Adaptable Storage/Emerging Battery Technologies (F)	Inverted Meta-Morphic Space Photovoltaic Array Storage: Nano Materials (L)	Superconducting Magnetic Storage (W)
Energy Resiliency	Micro Grid (F) Alternative Fuels (F)	Alternative Fuels (F)	Compact Self Contained Nuclear Reactor (W)
Directed Energy (DE)		• DE Power Beaming (L) • DE Kinetic Weapon Alternative (L)	• DE Power Beaming (L) • DE Kinetic Weapon Alternative (L)

Figure 11.1: Energy Roadmap

Across all Air Force domains of operation, *Energy Horizons* identifies game changing technologies in energy generation, storage and use. Advances in energy generation include ultra-efficient, flexible photovoltaics; small, auto-safing modular nuclear reactors; and efficient and abundant non-food source biofuels. Advances in energy storage (advanced batteries, ultra- capacitors, high power fly wheels, and superconducting magnetic energy storage) promise significant improvements in power and energy density and with increased flexibility in charge/discharge cycles. Finally, nanomaterials (e.g., carbon-carbon nanotubes, memristers), cloud computing, efficient supercomputing, and energy micromonitoring promise multiplicative efficiencies from energy efficient structures and microelectronics, efficient and resilient computing architectures, energy optimized platform designs, and enhanced energy situational awareness and management. While not exhaustive, *Energy Horizons* provides essential focus.

Extracting value from *Energy Horizons* will require adoption and sustained effort across the RDT&E, energy, acquisition, and operational communities.

11.3 Trend Data

The trends section highlights world energy consumption increasing from 553 quadrillion Btu in in 2013 to 721 quadrillion Btu in 2030. This information was obtained from the U.S. Energy Information Administration International Energy Outlook 2011. (www.eia.gov)

The trends section also highlights global oil price projections ranging from $130 to $200 in 2030. This information was obtained from the U.S. Energy Information Administration Annual Energy Outlook 2013 Early Release. (www.eia.gov)

Recent shale gas production information was obtained from the U.S. Energy Information Administration International Energy Outlook 2011. (www.eia.gov). The exact long term impact of United States production increases in shale gas is yet to be fully understood.

11.4 Threat Data

Data from Iraq and Afghanistan show that fuel convoys account for a significant number of casualties. Information was obtained from the September 2009 Army Environmental Policy Institute technical report titled "Sustain the Mission Project: Casualty Factors for fuel and Water Resupply Convoys." (www.aepi.army.mil)

In FY12 alone the Air Force reprogramed $500M from the MQ-9, C-17, GPS III, and F-22 programs to pay higher fuel costs. Fuel price increases in mid-2013 from $3.72 to $4.72 per gallon could drive a $1B bill for the Air Force based on projected pre-sequestration flying hour programs. The information was obtained from SAF/FM, AF/A9, and the Defense Logistics Agency.

11.5 Ongoing Initiatives

The *Global Horizons* Energy chapter focuses on future science and technological solutions which could become game changers with the requisite level of investment. However significant energy innovation efforts are ongoing by organizations including the Air Force Research Lab and the Air Mobility Command Fuel Efficiency Office to reduce energy demand, increase supply, improve resiliency, and create an energy aware culture.

11.6 References

Energy Horizons: United States Air Force Energy S&T Vision 2011-2026. United States Air Force Chief Scientist (AF/ST) Report. AF/ST-TR-11-01-PR, 31 December 2011.

12. Communications, Information Technology and Financial Services

12.1 Information Technology

The population gap between USA and China will continue to increase through 2050. Among the world's 500 fastest supercomputers, the US has a dominant lead over China with a total computing power of over 17 Peta-FLOPS, or 17 quadrillion (10^{15}) operations per second, a 6X capability over China.

Technology is moving toward the computation capacity of Peta-FLOPS in a single computer, but advances in computational intelligence software are necessary to achieve close-to-human-level intelligence. The research and engineering focus is shifting from automation to autonomy. Modern automobiles provide automation capabilities such as active steering, automatic transmission and navigation. The Google self-driving car targets human-level capability of driving by autonomous steering, speed regulation, navigation, etc. IBM's Watson computer is an example of a research endeavor in human cognitive functions through big data analytics and data-driven intelligence.

New advances in system integration and nanotechnologies are delivering cost reductions and computing density improvements. Without three-dimensional (3-D) integration, the computing density improvement is decelerating due to the power density constraint which limits the maximum number of transistors in a given chip area, and this limits the maximum speed the computer can run. With 3D integration, computing density can be accelerated again by stacking many layers of computer chips vertically. We project the acceleration trend will continue through the next fifteen years. At the same time, we project that computing cost will rapidly decrease. For a supercomputer with one Peta-FLOPS of computing power, the cost was approximately $4,000,000 in 2010 and $1,000,000 in 2013. By 2026 we anticipate the cost of a computer with human-level computing power will approach $2,500. Emerging nano/bio materials and devices such as memristors, spin-torque-transfer memory and graphene are capable of maintaining this trend beyond 2026.

Countries with significantly higher populations could convert their enormous labor power into global competitive advantages by achieving higher Gross National Product (GNP). To turn population disparity into opportunities, the US must develop the ability to do more with autonomous intelligent computing. This will be achieved by developing the advanced science and technology to enable computational intelligence and autonomous systems that can augment human performance and productivity.

Big data poses an immediate threat to system computational complexity, real-time processing and analytics which can be developed using large disparate data sources. As human capacity to process data becomes overwhelmed, the quality and speed of information analysis becomes limited, and the big data problem causes adverse impact to human effectiveness in analysis and decision making. Many opportunities exist for developing capabilities of high-performance technologies for massive analytics to automatically extract information and knowledge from big data.

Despite decades of efforts, there remain significant challenges to achieving close-to-human-level intelligent and self-conscious systems that can perform many tasks autonomously. Attaining close-to-human-level intelligence remains one of the most difficult technological problems for scientists and engineers. Opportunities exist for discovering theories, models, algorithms and architectures for trusted autonomous systems that are capable of learning from data, reasoning over outcomes, inferring events and interacting with humans.

Very-Large-Scale Integration (VLSI) circuit technology is the hardware foundation for electronic technology developments. Computing hardware technology is facing performance threats due to the fact that manufacturing (a.k.a., CMOS) technology is approaching the physical limits in area, power and speed. To achieve computing capacity that matches the human brain, one of the promising solutions is 3-D integrated circuits and systems, which is stacking thin silicon chips vertically to achieve optimized performance under size, weight and power (SWaP) constraints. Technologies in nano/quantum/neuro devices, circuits and systems are the future of hardware beyond the CMOS era.

In the area of hardware, software and computational intelligence, we have identified a few critical technologies that may greatly enhance the capabilities of the AF and civilian enterprises to achieve global competitive advantages.

Speedy development and adoption of 3-D integrated circuits and systems is the game changer to achieve computing advantages in both the data center environment and SWaP constrained contested domains. In the near term we expect matured multi-layer 3-D integrated CPU-memory systems. In the mid term, hardware innovations are focused on many-layer 3-D integrated systems leading to high-performance computing capabilities in a single processor-memory-networking cube. In the far term, a 3-D integrated computer will provide a computing capability of Peta-FLOPS in a single computer with a small SWaP footprint. Since the industry has been spending tremendous amount of resources in developing this and related technology areas, we recommend that the AF follow these technologies with in-house research and development for speedy adoption, application and transition to AF systems and capabilities.

For future computing technologies beyond the CMOS era, game-changing components will be based on nanotechnology, quantum computing, neuro/bio and graphene technologies. Emerging research and developments at nanometer dimensions promise revolutionary technological changes for a wide range of AF applications and platforms. Nanotechnologies to be incorporated within the platforms which are directly relevant to the AF include the areas of aerodynamics, mobility, stealth, sensing, power generation and management, smart structures and materials, resilience and robustness, and augmented human performance. In addition, nanotechnologies will impact battle space systems concerned with information and signal processing, autonomy and intelligence. With regards to information technology, substantial advantages are expected to be gained from nanotechnologies enabling new capabilities that include threat detection, novel electronic displays and interface systems. Finally, nanotechnology will enable the development of novel materials providing the basis for the design and development of new properties and structures which will result in increased performance (for example through nanoenergetics and new types of catalysts), reduced cost of maintenance (for example through wear reduction, self-healing and self-repair), enhanced functionality (for example through adaptive materials), and new types of electronic/opto-electronic/magnetic material properties.

Near-term innovations may come from nanotechnology devices such as memristors and spin-torque transfer devices. Emerging quantum computers will bring unprecedented computing power for some specific computing problems. In the mid term some of these nanotechnology devices will reach manufacturing maturity, thus the research will focus on new system components that can replace some of the CMOS-based modules such as the memory and special computation units. In the long-term, graphene-based circuits may emerge to compete with CMOS technology. It is not cost efficient for the AF to lead this research category. However, the AF can benefit greatly when these technologies are matured and available for applied research. We recommend the AF follow nanotechnology and quantum computing augmented with in-house applied research, while watching graphene technology developments.

Computational intelligence (CI) technology is application and data specific. There are significant differences between military applications/data and civilian applications/data. We recommend the AF lead or closely follow the mission-oriented computational intelligence research related to human performance augmentation, human-system interface, and trusted autonomous systems. In the near term, human performance augmenting CI can largely enhance the warfighter’s information processing and decision making capabilities with enhanced perception, pattern recognition, intelligent data filtering, event prediction, etc. The AF should follow the technology development in deep learning and natural language. These are general CI technologies that are applicable to both military and civilian applications. However, some of the outcomes will positively impact our mission-specific research. The next step in the mid term is to lead the research for human-in-the-loop autonomy for control and data-to-decision processes. The goal is to develop computing capabilities that can perform a few autonomous tasks for the warfighter while leaving the critical control and decision making functions to the human. The key CI technologies include adaptive learning, human-system interaction, reasoning, inferencing, cognitive processing, etc. We recommend following the research in expanded symbolic knowledge base and inference, which is being widely studied and adopted in commercial applications and highly related to the autonomous data-to-decision process. In the far term, we recommend following the development of human-friendly trusted autonomous systems. Although it is difficult to define the “human friendly” and “trusted” properties for an autonomous system, we expect research in this area will improve the AF’s confidence and capabilities toward fully autonomous systems. As the enabling technology for trusted autonomy, we recommend following the research in close-to-human-level general intelligence, which is targeted at technologies for a computer to take on different tasks with human-level performance.

In software, game changers in the areas of augmented reality (AR), large and open-standard software development, reuse, verification and validation (V&V), and software for service robotics. With the help of advanced AR technology (e.g. adding computer vision and object recognition) the information about the surrounding real world of the user becomes interactive and digitally adaptable. In combat, AR can serve as a networked communication system that renders useful battlefield data onto the warfighter's goggles in real time. This is a near-term technology that we recommend the AF watch. Robotics is one of the most pervasive technologies for the future and robotic software is a complex technology challenge. For the far term we recommend to watch the pervasive service robotics that can operate semi- or fully autonomously to perform service useful to humans and AF warfighters. To achieve software V&V and complexity control, it is important for the AF to follow and adopt best commercial practices and technologies in open standards, software reuse, and large integrated systems for software development and verification. We expect this to happen in both the near- and mid-term.

12.2 Communications/Financial Services

Trends in communications indicate that the percentage of the World population that will use the internet will approach 100% by 2030. In 2012, 38% of the global population used the internet. It is predicted that by 2030, this figure will increase to 94%. Global mobile data communication trends indicate that traffic will increase from 900 petabytes per month in 2012 to greater than 10 exabytes per month in 2018, approximately a 10X increase in total network traffic. Cyber-attacks against the financial industry have been increasing in frequency over the past year, and the trend is expected to continue.

Algorithmic trading is the use of computers to input trade orders, frequently without human intervention, based upon variables such as stock price and timing in the financial markets. One type of algorithmic trading firm is High-frequency Traders (HFT), which are proprietary trading companies that rely upon completely automated computer algorithms to trade. In terms of US total trade volume, HFT represented 21% of shares traded in 2005, steadily increased annually to over 60% in 2009, but declined to 51% by 2012. HFT firms typically hold only short lived investment positions in order to minimize their capital volatility and instead trade in high volumes and buy and sell in the form of many small orders to make fractions of a cent per share. The 2007-2008 Global Financial Crisis created a perfect storm for HFT, which capitalizes on high market volatility to make large profits in the shortest amount of time. HFT firms were earning between $0.001 and $0.0015 per share during this period. However in 2012, with improved market stability and HFT technology usage becoming more saturated, total annual earnings from HFT firms was estimated to be down about 25%, with per share earnings ranging from \$0.0005 to \$0.00075. New potential governance that proposes to submit incoming orders in a batch mode further threatens HFT firms.

Big data predictive analytics has now become the new norm for financial services. Sophisticated data mining algorithms look for anomalies in known trends and innovative big data analytics identify new trends and opportunities in the market data. Financial services employ the latest data mining techniques and were among the first to adopt complex event processing algorithms. The individual analytical techniques are largely proprietary, and now utilize the latest in big data computing infrastructures. These deeper dive analytical techniques use in some cases hundreds of thousands of commodity computers while employing open standards for collecting, storing and managing their data. Big data represents both a threat and opportunity, and the utilization of data analytics is the driving force behind most long-term investments in the financial sector.

The financial sector has shifted away from expensive, internally developed proprietary data management approaches as they can no longer gain a competitive edge due to open-source frameworks like Apache Hadoop. Open-source also provides greater interoperability and agility with technology refresh, reduces dependency on specific vendor systems, is more affordable to deploy, and is more reliable due to better code quality gained from extensive breadth and depth of users. Better code quality translates to better processing efficiency. The financial sector is reliant on making the best decisions in a short period of time to gain an advantage over competing firms. Software engineers are more inclined to work for companies that use open-source products, since proprietary software developments hinder an engineer's future employment options.

Financial services are driving low latency network connections between markets, such as between the New York Stock Exchange (NYSE) and the Chicago Board Options Exchange (CBOE). The fastest current round trip time (RTT) connection between New York City and Chicago is 12.98 milliseconds, and the company which built the state-of-the-art dark fiber route plowed through mountains to create a connection as straight and direct as feasible. The one-inch fiber cable shaved 100 miles and a mere three one-thousandths of a second off the previous fastest RTT connection. Illustrating the demand for low latency connections, it is estimated that the company recouped their initial \$300 million dollar construction costs in six months. High-frequency trading firms that operate between these markets must use this connection to remain competitive, particularly HFT that trade via arbitrage which profit from millisecond differences in stock prices between two or more markets.

Area		Near (FY13-17)	• Mid (FY18-22)	Far (FY23-27)
Communications		Adaptive Waveform Reasoning (L) Near-Field Comm (W)	Joint Comm, EW, SIGINT, Cyber(L)	Quantum Comm (F) RFID Internet of Things Sensor Mesh Network
IT	Hardware	Multi-layer 3-D integrated CPU-memory system (F) Quantum Comp for C2 (W)	Many-layer 3-D integrated embedded HPC (L) Nano components (F)	Graphene circuits (W)
IT	Software	Augmented reality (W) Open standards for S/W reuse (F)	Large system S/W development and V&V (F)	Widespread service robotics (W)
IT	Computational Intelligence	Human performance augmented w/ computational intelligence (L) Deep learning and natural language Q & A (F)	Human-in-the-loop autonomy C2 and data-to-decision (L) Expanded machine learning for data analytics (F)	Human-friendly, trusted autonomous systems (F) Close-to-human-level general intelligence (F)
Finance		Predictive analytics for Activity Based Intel (F,W)	Terascale In-Memory Database Management (F)	Real-time Intelligent Analytics (F)

Figure 12.1: Communications, IT, and Financial Services Roadmap

Game changers in the communications and financial sector involve technologies focused on reducing network latency to zero; or the speed of light. These may include microwave communication technology that has a lower latency as it uses air rather than fiber optic glass to connect. Microwave technology has existed for decades, but the utility of microwaves was small due to overall throughput being minute. Advances to gigabit microwave connectivity for live market data updates could be the new competitive advantage for HFT. We recommend the AF watch growth in microwave high bandwidth communications technologies. A bandwidth game changer in this sector could be realized by utilizing space-based laser communications which could offer terabit per second data rates and scalable uplinks and downlinks. S&T in this area will need to address site diversity and other means of countering propagation and weather effects inherent to space-based communication.

In big data analytics, a key limiting factor is the speed of data access, especially input and output (I/O) speed to disk storage. With 64-bit machines, the theoretical limit of random access memory (RAM) addressing is 16 exabytes. There are a number of power and system design issues that must also be addressed beyond increasing memory density to approach this limit. 3-D chip processor integration, incorporating layers of both memory and logic units, is a potential game changing technology in this area. Current state-of-the-art systems capable of storing RAM fast approaching the terabyte scale present game changing technologies such as terascale database management and data file system in-memory analytics, which would overcome normally induced I/O latencies. State of the art co-processors, such as graphical processing units

(GPUs) and many-core architectures like the Intel Phi present possible game changing technologies for big data analytics by decreasing processing time, increasing power efficiency, and decreasing overall infrastructure size. We recommend the AF follow these current big data architectures and integrate with AF lead in Activity Based Intelligence (ABI) data analytics technologies, while following with applied research for 3-D chip integration and high performance co-processor analytics due to the AF need for low size, weight and power (SWaP) information architectures. The AF has been a leader in the movement of services to the cloud. Recommend the AF continue to lead movement toward cloud based IT services as a way to mitigate Distributed Denial-of-Service (DDoS) and other cyber-attacks. We recommend the AF lead information systems and data cyber security initiatives in collaboration with industry to improve cyber defense.

13. Pharmaceutical and Health Care

13.1 Trends

The global cost growth of the Pharmaceutical and Healthcare Sector is unsustainable (Ernst & Young 2012). The US spends $2.8 trillion dollars or approximately 20% of GDP in healthcare annually, more than the next 10 big healthcare spending countries combined, equating to 27% more per capita than other developed countries (Brill 2013). Additionally, the cost and time required for the Pharmaceutical Industry to bring new drugs to market is unsustainable (See Figure 13.1). For example, between 2002 and 2011 the Industry spent $1.2 trillion on R&D at an average cost per approved molecule of $2.2-$4.9 billion (Pricewaterhouse Coopers 2012), and time to market of 8-12 years (Lesko 2007). Despite these alarming costs, most prescribed drugs in the US are effective in less than 60% of treated patients, unnecessarily costing billions to the healthcare system (Aspinal and Hamermesh 2007). Additionally, the global population is increasing, aging, and becoming more overweight or obese, resulting in a rise in both age-related diseases and preventable, chronic diseases and which poses a significant burden to health care systems (UN 2004, NIA/NIH 2007, WHO 2010). The aggregation of these trends results in the vicious cycle of ever-increasing and unsustainable healthcare spending in the US, underscoring the need to revolutionize the Pharmaceutical and Healthcare Sector. Fortuitously, unprecedented advances in, and the global proliferation of mobile, sensing and data technology has established the necessary infrastructure for four critical drivers that are transforming the Sector, including: 1) mobile health and the Quantified Self, 2) nanomedicine, 3) genomic sequencing and the 'omics', and 4) Big 'My' Data (See Figure 13.2).

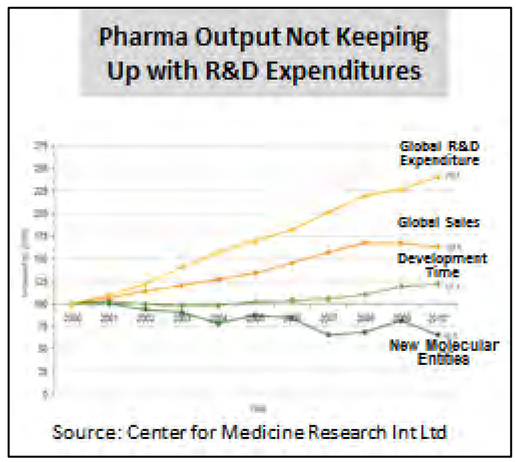
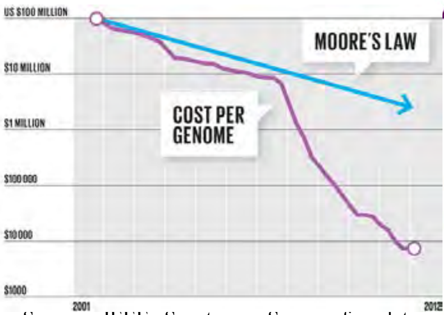
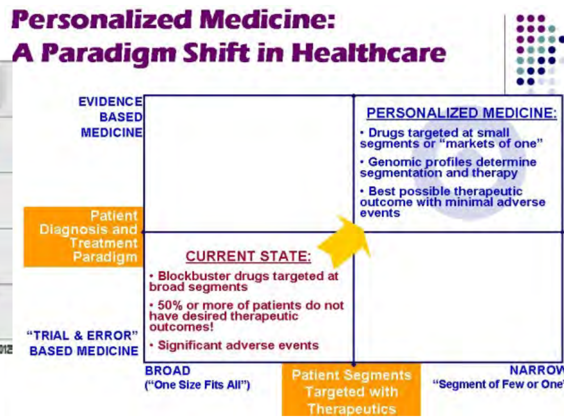


Figure 13.1: Cost Trends



Source: IEEE Spectrum; Source for data: National Human Genome Research Institute.



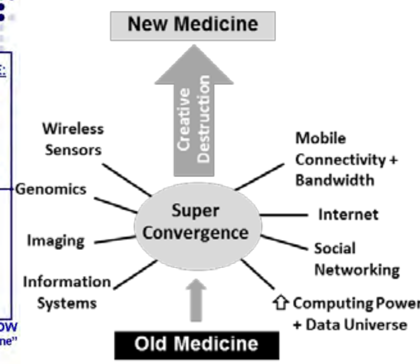


Figure 13.2: Pharmaceutical and Health Care Trends

Mobile Health, or mHealth, is the utilization of emerging mobile communications, apps, network technologies and remote sensing devices for healthcare systems (See Figure 13.3). mHealth is gaining in popularity by both the practitioner and the general consumer and across developed and developing countries. Medical and healthcare is the third fastest growing app category for smartphones (Float 2012). In 2012, 247 million people had downloaded a health app as compared to 127 million in 2011 (BCG 2012). Purported cost savings associated with mHealth include a 25% reduction in the cost of elderly care, a 30% reduction in maternal and prenatal mortality rate, a doubling of rural patients that can be reached per doctor, and a 24% reduction in the cost of medical data collection (BCG 2012). Additionally, there is a growth in technologies centered on the Quantified Self, focused on empowering the consumer to monitor, regulate, and participate in their healthcare (Economist 2012). These technologies include wearable biomonitoring devices, ingestible microchips, and health and fitness apps. Combined, mHealth and technologies for the Quantified Self offer 'care anywhere' solutions for: patient monitoring and compliance, health surveillance, remote diagnostics, remote data access, and telemedicine (BCG 2012).

Area	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Mobile Health & the Quantified Self	Medical & Performance Apps on Smart Devices ("Dry" data: HR, BP, Respiration, Temp, etc.) (F) Wireless Biosensors (F)	Expansion of Apps/Sensors to integrate "dry" and "wet" data (Biochemical/Volatile Organic Compounds) (F) Adaptable & personalized performance training regimens (L)	Adaptable systems (adapting to the human's physical and cognitive performance) (L)
Nanomedicine	Nanoparticle based diagnostics (W)	Therapeutics (Nucleic Acid delivery vehicles) (W)	Remote activation and external control of ingested nanoparticles (W)
"omics"	Diversity in biomarkers & indications (base pair changes associated w/ certain proteomic expressions connected to specific metabolic defects) (W)	Increased knowledge of interdependencies, in the context of specific missions/ tasks, in growing suites of biomarkers (W) Pharmacogenomics: drug response due to genetic makeup (W)	Mission Selection – Match the Operator to the Environment (Epigenetics) (F)
Big 'My' Data	Electronic Health Records (F) Digital Dog Tag: medical history always carried (F)	Intelligent Information carried at all times: medical history, training history, omic data and the idata interrelationships (F)	Increasing predictive power using real-time, dynamic data analytics, over longer time horizons (F)
Personalized Health & Performance	Battlefield point-of-care advancements: internal hemorrhage diagnosis & control (F), shunts/ aortic balloon occlusion (L), customized limb restoration (F) Individualized fitness & performance: disparate biosensors/apps, performance tracking by individual (W)	Care Anywhere: telemedicine remote care/diagnosis (F), robotic surgery (F), 3D Bioprinting (W), high altitude closed loop O2 controller (L) Personalized dashboard: aggregate biosensing & whole-body/mind performance tracking at the individual level (F)	Continuous quantification of health: from virtual behavior coaching for prevention (F) to remote, quantifiable triaging (L) Commander's mission dashboard: Remote tracking and adaptation based on collective 'Fitness to Fight' for the system and environment in the mission (L)

Figure 13.3: Technology Roadmap

Nanomedicine is an application of nanotechnology that focuses on enabling earlier and personalized diagnostics and therapy, enhancing efficacy, and minimizing side effects associated with standard drug treatments (Ventola 2012). The National Science Foundation predicts that by 2020 one third of patents and start-up companies in nanotechnology will have biomedical applications and half of all future pharmaceuticals will have nanotechnology components (Roco 2011). The nano-scale drug delivery systems (DDS) segment of the global nanomedicine market is expected to grow from a current value of $2.3 billion to $136 billion by 2021 (Cientfica 2012). The utility of nano-scale DDS is targeted delivery of drugs to the diseased sites without impacting healthy cells, triggering immune system responses, or introducing toxic side effects. In addition, advances in 3D molecule printing allow drugs to be specifically designed and printed to bind to receptors of targeted diseased cells (Ricciardi M. 2012). Nanotechnology also offers in vitro sensing for diagnostics or lab-on-a-chip capabilities which enables testing of candidate therapeutic molecule effects (Cohen-Karni et al. 2012) and will significantly impact the development of point of care diagnostics (Ventola 2012).

The cost of sequencing an entire human genome has dropped from $100 million in 2001 to $5000 in 2013 (Wetterstrand 2013). The sequencing trend followed Moore's Law until 2008, when it dropped precipitously due to the proliferation of next-generation sequencing platforms (Wetterstrand 2013). China's BGI-Shenzhen Corporation leads in genomic sequencing, with an output twice that of the US and UK combined (Topol 2011). However, sequencing output is only part of the equation to fully realize the potential afforded by increased genomic understanding. An outgrowth of these genomic discoveries is advancement in the 'omics' to include proteomics, metabolomics, and transcriptomics (Battelle 2011). Discovery of the links between genetic and other 'omics' variations for disease susceptibility, detection, and treatment response is critical. This is evidenced by the growth of pharmacogenomics applications and the increase of personalized drugs, treatments and diagnostics products from 13 in 2006 to 72 in 2011 for such diseases as arthritis, breast cancer, colon cancer, leukemia, lymphoma, cardiovascular disease, diabetes, lung cancer, and melanoma, etc. (Personalized 2011, Pearson 2009). These discoveries enable patient-specific treatments, reduction of trial-and-error prescribing, diagnostic accuracy, and patient adherence to treatment programs.

The impact of Big Data is pervasive. However for Healthcare, the push is from Big Data to 'My' Data (Snyder 2013). Though still 'big', 'My' Data focuses on individual-level data – such as genomic sequencing, patient health records, health feedback on social media, and the aforementioned Quantified Self data – that when combined informs population-level decision making as well as targeted drug development. Physicians' use of electronic medical records has increased from 18% in 2001 to 51% in 2011 (Hsiao et al 2011) and patients prefer physicians who offer access to medical records (Deloitte 2011). Additionally, social media has enabled a platform for health consumers to share response feedback on medical treatments, drug effects, and fitness device and health monitoring technology efficacy. The availability, accessibility and variability of the data has the potential to revolutionize the full spectrum of the Sector by enabling pharmaceutical companies to develop more targeted drugs, allowing the physician to make more proactive evidence-based decisions, and empowering the consumer to positively influence their own health and wellness behavior.

13.2 Threats and Opportunities

Identification of the aforementioned trends, and the potential afforded by the aggregation of the trends, allows exploration of associated threats and opportunities of relevance to the US Air Force (USAF). The threats fall into two major categories: privacy/security in the near term and precise biological weapons in the far term. For privacy and security, the continuous, accessible, networked volume of individualized data coupled with imbedded biosensing devices poses threats for malicious biohacking and external control and manipulation by adversaries, a new form of genetic and medical health identity theft, and an increasing difficulty to keep secrets and avoid detection. For biological weapons, the availability of population-wide data with specificity down to the individual-level along with advances in ingestible nanotechnologies yields the potential for a new class of Weapons of Mass Destruction – intelligent, precise bio-terror weaponry (Toffler 2008), including counterproductive genomic therapies, remote activation of nanoparticles, bioregulation to incapacitate, control, or kill, two-step biological attacks via activation of disease precursors previously exposed to, and engineered biomass with destructive effects (Waller 2009).

Along with threats, the trends also implicate the potential for new opportunities for the USAF. For the En Route Care-Aeromedical Evacuation mission, the opportunity exists or will exist to remotely assess medical conditions, conduct point-of-care triage, monitor and assess in real-time and provide care and treatment in near real-time from the point of injury, through air transportation, to the definitive medical care center. This opportunity has the potential to defragment the delivery of healthcare from monitoring, to diagnosis, to therapy and from the first responder to the caregiver at home (Schachter 2009). Aspects of this opportunity are realizable today, but it will be in the far term when the confluence of the technology will revolutionize Care Anywhere for the USAF. The trends also point to opportunities for augmenting performance for Special Operators, Pilots, Aircrew and Critical Care Air Transport Teams who face extreme physical and cognitive demands, to the ISR, Cyber, and RPA Operator challenged with an extreme cognitive burden. Performance augmentation opportunities include: in the near term, convenient, continuous physical performance monitoring and feedback for self-improvement and self-selected nutritional supplements; in the mid term, individualized performance training regimens; and in the far term, human-machine teams equipped with the capability to adapt to the operator's physical and cognitive abilities. Additionally, the evolution of 'My' Data and the opportunities afforded by the 'omics' indicate a potential for empirical selection and matching of the right person for the mission, having AF-wide implications.

13.3 Game Changer

The game changer for the USAF is Personalized Health and Performance. It is the result of the superconvergence of the trends identified above. It is consistent with the conclusions drawn by thought leaders (Topol 2011, Hood 2009) and extends the results from major studies showing that Personalized Medicine has the potential to make a disruptive and revolutionary impact on the Pharmaceutical and Healthcare Sector (Pricewaterhouse 2012, Personalized 2011). Moreover, the motivation for this game changer for the Military, as in the private sector, is to confront the unsustainable cost of Military Healthcare, which has grown from $19 billion in 2001 to $53 billion in 2012, and expected to escalate to $95 billion in 2030.[30] To put this in perspective, the Department of Defense currently spends almost twice on healthcare than the total budget of the Marine Corps. Personalized Health and Performance compliments and expands the strategic vision postulated by the Military Health System (MHS) and the AF

Medical Service (AFMS) (Military Health 2012, AF Medical Service 2013). The MHS is embracing personalization via advancements in genomics, as well as Patient-Centered Medical Homes (PCMH), both of which are critical to Personalized Health and Performance, but fall short of closing the critical loop in the health and wellness control system.

Fully realized, Personalized Health and Performance closes this loop, by optimizing the health, wellness and performance of an individual through the networking of nano, 'omics,'and mobile and sensing technologies that provide an unprecedented level of real-time continuous feedback and results in the right diagnosis, care, prevention and intervention for the right person at the right time, which is expected to save billions for the USAF. The potential return on investment (ROI) for the USAF is derived from cost savings the private Pharmaceutical and Healthcare Sector has seen by employing components of Personalized Health and Performance. For example, the use of personalized remote monitoring for managing chronic disease has the potential to prevent up to 627,000 hospital readmissions for congestive heart failure resulting in an estimated annual savings of $6.4 billion, to reduce readmissions by 50% and hospital costs by 17% for chronic obstructive pulmonary disease, and to decrease the use of healthcare services by diabetics by 20% (Qualcomm 2012). Additionally, personalization via pharmacogenomics-based approaches to Warfarin dosing (anticoagulant) is estimated to save the US health care system $1.1 billion annually (Deloitte 2009), and targeted prescription of drugs for colorectal cancer is estimated to save $604 million annually (Personalized 2011). From a wellness perspective, health programs implemented at the workplace incorporating personalized wellness coaching showed a ROI of $5.50 for every dollar invested (Eckes 2011).

The potential for Personalized Health and Performance to make an immediate impact to military healthcare costs may be via targeting type 2 diabetes. For the USAF, personnel with type 2 diabetes make up 11.5% of the total TRICARE-enrolled population (Lott 2009). PCMHs and pharmacogenomics-based approaches have shown promise for diabetes care (Pearson 2009, Bojadzievski and Gabbay 2011, Reid et al. 2010). However, little evidence exists in the Sector for the ROI of mobile apps and wireless devices for closing the feedback loop in diabetes care. A 2012 actuarial report found that better diabetes control that focuses on lowering A1C, blood pressure, and LDL cholesterol levels, results in substantial potential savings (Fitch et al., 2012). Apps and mobile systems for diabetes control specifically aimed at lowering these levels and providing critical real-time feedback is an area ready for further analysis.

13.4 Recommendations

In order to determine the utility of mobile technology advancements for closing the health and wellness loop for the USAF, the following recommendations are proposed. Analyze the ROI for type 2 diabetes control via personalized health and wellness apps and self-tracking devices (OPR: A9) and conduct a demonstration program to validate the ROI specific to TRICARE-enrolled beneficiaries (OPR: AF SG). For performance optimization, conduct a pilot project to empirically determine the ROI for self-selected fitness and health management apps and biomonitoring devices used by the AF Special Forces (OPR: AF SG).

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14. Education and Training

In lean fiscal times, resources risk being diverted to address today's priorities and away from investment areas whose paybacks are so immediate. For the Air Force, the need to meet operational requirements risks abandoning investments in training and education endeavors, resulting in an inability to catch up--it takes years to 'grow' Airmen with advanced academic degrees, leaders educated in the profession of arms, and experts who are skilled in their profession. The cost of in-resident college education continues to rise, but the ability for families to pay those costs has not (Figure 14.1, left figure). America faces increasing competition from international growth of science degrees, particularly in China (Figure 14.1, right figure). And as the American economy stays flat, an increasing number of foreign graduates in STEM programs—nearly half now—find it more lucrative to return to their home countries to work. This not only reduces the domestic supply impeding our national ability to conduct and sponsor research for domestic priorities, it also moves those resources to countries that compete with the United States.

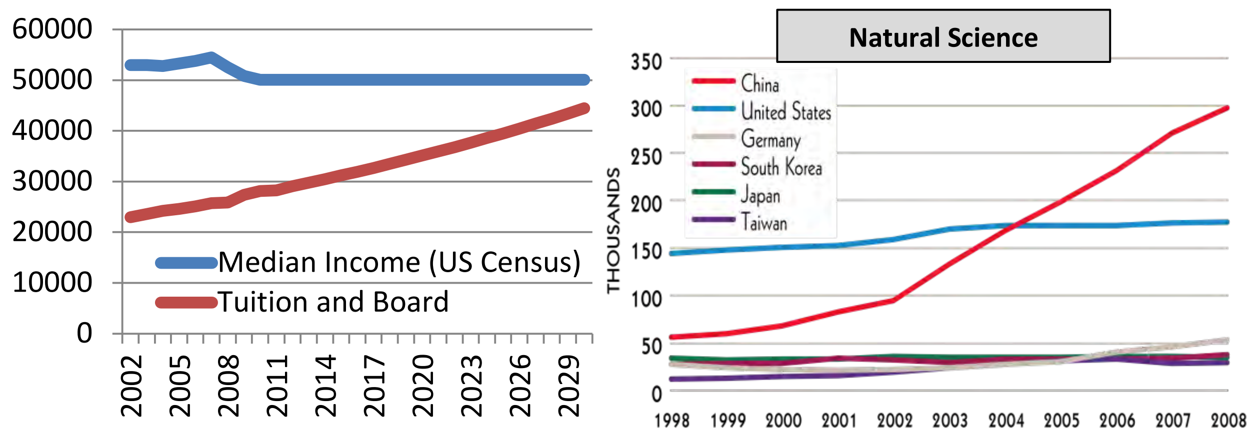

Figure 14.1: Cost and Competition Trends for Graduate Degrees

Several trends could offset the relative cost of education and improve learning effectiveness. These are shown in the table in Figure 14.2, depicted as a high level road map that shows the main theme areas and some milestones for future growth in the near, mid and far term. As the roadmap indicates parenthetically across capabilities, the Air Force will be principally a follower in education and training technology and associated networking/communications infrastructure. Appropriate leveraging of educational technologies and trends enable one of the most important ingredients for success in education: facilitating collaboration for learning. The goal is to have a structure where students can learn whatever subject(s) they need when they need them. To do this, learners need access to instructors/experts in the topic of choice, they need access to supporting materials with which to study, manipulate, and practice, and they need access to teammates and peers for collaboration and professional networking. Computer trends in immersive environments make it easier to create a synthetic/virtual classroom, and can make it seem as realistic as needed for the lesson at hand. It can add people that are computer-created images with actions and features that are indistinguishable from the avatars of real participants. Developments in expert systems make it possible to capture and replicate human knowledge on various subjects, and improvements in human-computer interfaces will make interactions as natural as talking with a real person. Mobile devices make these technologies available when and where we humans desire it, and miniaturization trends are enabling both wearable devices and those that enhance natural human ability through cybernetics.

Theme	Near (FY13-17)	Mid (FY18-22)	Far (FY23-27)
Immersive Env/ Visualization	Avatars (W) Multi-user gaming (F) Social Networking (F)	3D worlds (F) MOOCS (F)	"Holodeck" (F)
Expert Systems/ AI/HCI	Synthetic Teammates (L) Desktop Trainers (F)	Intelligent Tutors (F)	Mixed Initiative Dialog (F)
Networking/ Bandwidth	5G (F)	6G (F)	7G (F)
Mobility	Smart Devices (W)	Wearable Devices (F)	Cybernetics (F)

Figure 14.2: Education and Training Roadmap

In summary, the advancement of avatars, multiuser gaming, and social networking in the near term will precede increasing multiuser, three dimensional environments leading up to the employment of "holodeck"-like virtual learning environments in the far term. Increasingly intelligence in synthetic teammates and desktop trainers in the near term will be replaced by truly intelligent tutors which will become increasingly realistic including supporting mixed initiative dialogue in the longer term. Increasing networking and bandwidth will be augmented by intelligent mobile devices that will become increasingly wearable and embedded in humans in the medium to far term. With this kind of technology in place, education will be more available and accessible in ways that help deflect the cost and inconvenience of traditional brick-and-mortar programs. It provides the structure to sidestep geographical competition for degree-holders and subject matter experts through virtual connections and collaborations, depicted in examples in Figure 14.3.

Figure 14.3: Synthetic Classrooms and On-line Collaborative Learning

15. Conclusion

Global Horizons is an S&T vision and blueprint to help the *Air Force* achieve the "assured global advantage" across core AF functions. *Global Horizons* recognizes that all our core functions depend on global domains and that our warfighting mission systems are both threatened and enabled by global industrial sectors. Furthermore, these global domains are increasingly contested and/or denied from increasingly capable adversaries. Our current environment is characterized by constrained resources (e.g., financial, human, time) derived from federal deficits, limited production of U.S. STEM graduates, and increasing threats in the commons. Yet global industrial sectors present important opportunities. This appendix details the specifics of where those opportunities should be leveraged.