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ADDRESSING FUTURE TECHNOLOGY CHALLENGES THROUGH INNOVATION AND INVESTMENT

By

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Table of Contents

Page

Figures

Abstract

America has enjoyed more than a half century as a superpower, much of which as the lone world superpower. For better or worse, this position has been underpinned by its technological superiority and ability to deter significant challenge.

In recent years, (potential) adversaries have eroded America's technological advantage through massive investment, while at the same time U.S. research and development (R&D) budgets have been shrinking. The necessity to maintain technological supremacy despite fiscal constraints requires the Department of Defense (DOD) to re-examine its policy and practices towards R&D. America can no longer afford to throw massive amounts of money at innovation, especially without some assurance of return on investment.

The Defense Advanced Research Projects Agency (DARPA) has, since its inception, made a science out of innovation and advancing the state-of-the-art. The DOD as a whole would greatly benefit from studying DARPA's best practices and motis operendai.

Preface

American warfare is often described in terms of weapons, systems and tactics, many of which are unique to the United States. Too often, however, the industry and methods that produce military technology and enable the American way-of-war are overshadowed by the materiel they produce. As I learned more about what the Defense Advanced Research Projects Agency (DARPA) does and how it does it, it became apparent that the defense industry itself is a weapon system that must be cultivated, and that DARPA's approach to doing so ensures the greatest potential for meaningful success.

I would like to thank the DARPA Director, Dr. Regina Dugan, for her continued support of the Air Force Fellows program at DARPA, and diligent outreach to the services through the Service Chiefs' Fellows program. I would like to thank LtCol Robert Winkler and Mr. "Boot" Hill for their guidance and mentorship during my time at DARPA. I would also like to thank and recognize Dr. Richard Bagnell, Mr. Steve Waller, Dr. Stephanie Thompkins, Dr. Arthur Mabbett, Maj Chris Schulz and Mr. Mitchel Burnside-Clapp for allowing me to shadow their programs and granting me access to their work. I would like to thank Mr. Greg Settles and Ms. Laura Gross for their gracious help in navigating the DARPA labyrinth over the course of this last year. Finally, I would thank my loving wife and children for their undying support during my fellowship and career to this point.

Chapter 1

Addressing Future Technology Challenges: Innovate or Die!

I thoroughly disapprove of duels. If a man should challenge me, I would take him kindly and forgivingly by the hand and lead him to a quiet place and kill him.

- Mark Twain

Duels are foolish. Mark Twain's approach to conflict resolution is much preferable to squaring off against an opponent with an equal arsenal and will to prevail. At best one guy gets out alive, but more likely both are bleeding from the belly. America has seen its fair share of pistol duels whether in open conflict, cold wars, or drawn out asymmetric fights. It's far better to avoid duels in the first place by not wooing the same maiden as your rival, but the fact of the matter is, there aren't that many pretty girls in the village.

The United States has four options when it comes to securing its future. One, stop wooing the pretty girls (oil, international influence, global trade, etc). Two, build bigger guns and hope that the wars remain cold. Three, keep inventing the new gun to bring to the knife fight. Four, perfect Mark Twain's form of diplomacy. Option one is unacceptable, option two has been tried before and proved very costly, and option four resides in the realm of statecraft. Option three depends on innovation; a precarious stone upon which to build a castle as there is no guarantee of success. This paper will demonstrate how the Defense Advanced Research Projects Agency (DARPA) accomplishes the goal of maintaining America's technological edge, and makes the case for

increased emphasis on Research & Development (R&D) in the national defense strategy.

American Way-of-War – Technological Supremacy

> An Englishman is a person who does things because they have been done before. An American is a person who does things because they haven't been done before.
>
> - Mark Twain

Since World War 2, the American way-of-war has relied heavily on machinery and technological solutions, but it hasn't always been so; earlier American conflicts saw victory at the expense of massive US casualties. The American affinity for technological warfare was fortified during the 20th century by victories that appeared to cost the US fewer soldiers[1]. This way-of-war was enabled, however, by the strength (and relative isolation from the ravages of war) of the American industrial complex multiplied by a surplus of American dollars to spend on defense. World War 2 leveraged the American manufacturing industry to build planes, tanks, and ships at astonishing rates. Arguably, it was the heavy industry itself that was the critical weapon system, not the weapons themselves. US planes were superior to German planes only in number and reserve[2]. Additionally, when faced with more heavily armored German Panther tanks, the US Army employed a tactic that involved overwhelming them with a superior number of inferior M-4 tanks.

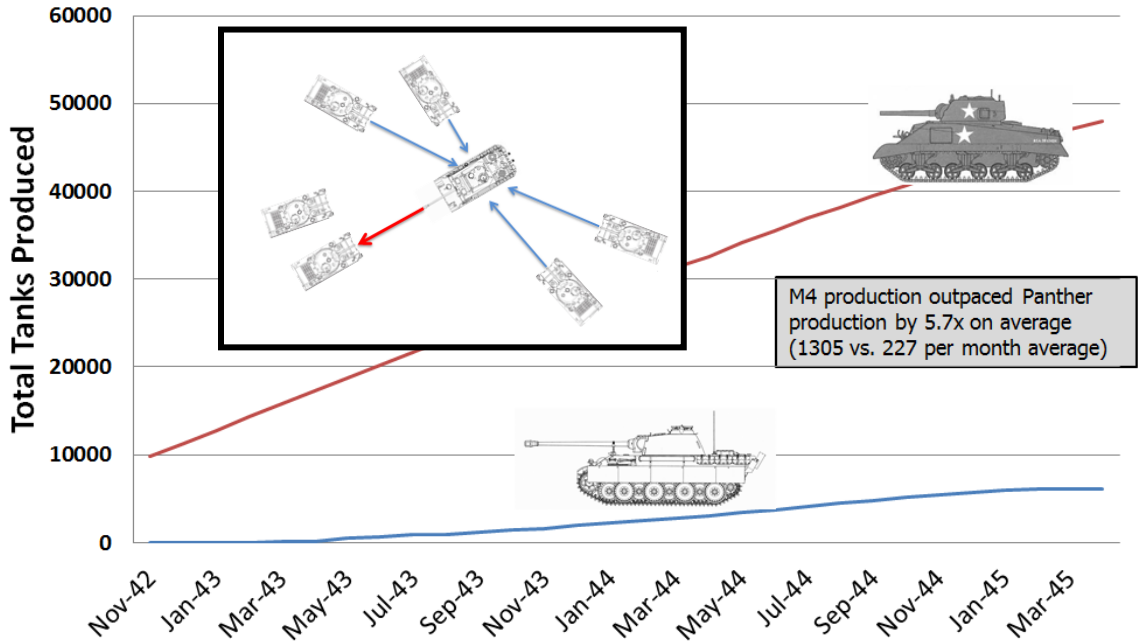

Figure 1: US vs German Tank Production and Tactical Impact[3]

At first this sounds like a victory won with superior tactics, but those tactics were only enabled by availability of *many more* US tanks. The US industrial base was inarguably superior to that of the Germans.

As the 20th century wore on, high technology replaced heavy industrial manufacturing as the unique American defense capability, spawning weapons and platforms that had no tactical nor strategic equal. American technological supremacy, coupled with heavy financial investment laid the groundwork for the US to become the lone superpower in the world. The US technological edge and large defense budget deterred war with near-peer adversaries such as the Soviet Union. It has also dissuaded smaller powers from attempting conventional confrontation, molding conflicts into much more palatable asymmetric wars[1]. America has enjoyed nearly 70 years as a military

superpower, but it has been underpinned by technological advantage and economic freedom of maneuver.

The 2010 Quadrennial Defense Review (QDR) Report sets out the way forward for US defense posture, acknowledging the role of technological superiority and the corresponding challenges[4]. The QDR emphasizes reliance on survivable *"5th gen* [stealth]*"* fighter aircraft to deter and defeat adversaries that have *"more potent anti-access capabilities"*. Systems will need greater range and flexibility with multi-mission versatility, and be supported by better enabling systems across the spectrum of warfare. This is an acknowledgement that military leadership sees *"possible shortfalls"* in current US forces when compared with emerging world powers, and contested battle-spaces. In some areas, the QDR admits that *"no readily available solutions are at hand"* warranting greater investments in research and development. The secretary of defense called upon the services to *"devote sustained efforts toward developing new… capabilities"*, and *"… meeting emerging challenges will call for the development of wholly new concepts of operation"*. In short, the US Defense Department acknowledges that technological superiority is the key to its success, and that continued investment its lifeblood. Unfortunately, technological superiority is not a prize that can be held forever once won; it is maintained by continuous investment; something the QDR recommends.

Lastly, Clausewitz contends that war belongs fundamentally to the social realm—rather than to the realms of art or science[5]. In America, the support of the people, or will of the people is closely tied to the belief that our

technological advantage guarantees relatively bloodless wars. The American freedom of political and military maneuver is irrevocably tied to a technological advantage. American will to exercise its military instrument of power is proportional to its technological advantage over its opponents (or perceived asymmetry in cost to friendly forces). Without technological superiority, America will not fail to succeed, but it will fail to try. ***The defense technology industry itself is the critical weapon system that ensures American security, freedom of political maneuver, and military superpower status.***

Problem: US Superpower Status is Waning

A poll taken in 2006 shows that Asians in the Pacific perceive the US as losing its *superpower status* to China[6]. Opinion polls have no real power except that they reflect perception, and the perception of weakness leads to challenge. In contrast, *superpower status* has no real power except to dissuade potential adversaries from challenging with direct force. As Clausewitz contends, war belongs to the social realm; therefore the perception that lofty national goals are achievable leads to attempting to achieve them, vice versa. Moammar Ghadafi gave up his nuclear weapons program based on the perceived threat to Libya after the invasion of Iraq in 2003[7]. Conversely, Japan perceived the US as weak and vulnerable to a decisive blow when it attacked Pearl Harbor[8]. Both perceptions were incorrect, but drove major national defense strategies. Furthermore, the success of one revolution in Tunisia arguably lead to the

Arab Spring as peoples oppressed for decades perceived that victory could be obtained. China has in effect begun an arms race with the United States, fueled by its perception of economic parity and means to achieve military parity. This is evident in the magnitude and nature of China's military spending and modernization efforts; directed primarily at US capabilities and interests in the Far East[9]. Subsequently, US perception of a rising Chinese military power and *near peer* rival has dominated US strategy and future procurement planning.

The technological advantage that underpins US industry and defense is also quickly eroding. The ocean that once isolated US industry effectively no longer exists in the information age. Asia has replaced America as the top manufacturer of high technology products, and subsequently, the capability gap between potential adversaries has diminished (figure 2 shows relative commitment to technology exports).

Figure 2: National High Technology Exports[10]

With technology gaps closing, all that is left is procurement and posture to separate foes. Though US defense dollars dwarf the nearest competitor, they are spread across many theatres and objectives, while an adversary can concentrate on a single theatre of interest to foil US objectives.

The Chinese perception of economic and military parity with the US is not without merit. The Chinese economy has been growing at a rate of nearly 10% a year for the last 20 years affording multi-billion dollar budget surpluses[11]. More compelling is the equally large 12.9% average annual increase in military spending since 1989 when Beijing launched an ambitious modernization program[12]. In contrast, the typical US annual economic growth is approximately 3%, when not in a recession, and defense spending has grown at an annual rate of approximately 4% over the past decade[13]. With the recent

but enduring budget cuts, US defense spending will continue this downward trend. Furthermore, Chinese military spending has concentrated on countering US capabilities in the Pacific, denying American military influence in the Taiwan Straight and other key trade routes and centers. American influence in major trading markets is being undermined, and the defense department no longer has the resources to simply match adversary capabilities by *buying more of the same weapons*.

Michael McConnell, the director of national intelligence acknowledged to the Senate Armed Services Committee in 2007 that China aims to reach *"some sort of state of parity with the United States"* and that *"they are a threat today, they will become an increasing threat over time"*[14]. To their advantage in this case, Chinese objectives are limited to regional defense and interests. This somewhat narrows the absolute defense dollars gap that exists between the US and China. It is far more expensive to project power across an ocean than a straight. Furthermore, the Chinese are far more cost effective in their efforts, investing in anti-ship missiles that can negate entire carrier strike groups, and mobile integrated air defense networks that diminish the effectiveness of costly US stealthy air assets. Relative technological parity has enabled the Chinese to deny the US access to certain domains for a fraction of the cost. American military supremacy through technological superiority has ceased to be a deterrent, and the closing technology gap threatens either an arms race or loss of US influence in the region. The DOD can ill afford a costly arms race; ***the technology gap must be reopened, and innovation is the key.***

Research & Development Further Threatened

The recent down trend in US Research and Development (R&D) investment is troubling, when compared with growth of near peer competitors. The FY 2012 Science and Technology (S&T) funding will take a proposed 11.8% cut, reversing the upward trend of increased investment peaking between 2005-7[15]. Contrast that with a steady increase in R&D investment in Asia. Between 1995 and 2008, China virtually tripled its R&D expenditures (as a function of GDP), while the US and Europe remained relatively flat. China's percent GDP R&D investment grew even faster than did its GDP over the last decade[12]. More troubling still is that a good portion of the defense R&D investment after 2003 concentrated on the wars in Iraq and Afghanistan, while US competitors have been focusing efforts towards countering US capabilities.

A 2011 Pentagon study explored the capability of the US military industrial base to continue to maintain its technological advantage post Joint Strike Fighter (JSF)[16]. It proposes that much of the foreign aerospace industry has reached relative parity with the US, and that "*If technologically advanced U.S. programs are not initiated relatively soon, the margin of competitive technological superiority is likely to shift against U.S. firms."* A *transition gap* is forming due to the lack of a program to follow the JSF; the industrial base has no program to transition to after developmental work completes on the JSF in 2014. The report proposes that the unique military aerospace industrial expertise will atrophy, if not die out completely, increasing the cost and risk to

"*restart the engine"*. It recommends several strategies to keep the industrial muscle exercised, but insists that a gap not be allowed to form. Specifically, the study recommends doubling current levels of spending on *basic/applied research*, *advanced technology development,* and significantly increasing spending on *advanced component development and prototypes.* In contrast, the DOD FY 2012 defense budget request shifts funding away from the more basic research and technology demonstration into advanced component/system development, resulting in the right relative proportions, but no net investment change[13]. The report discussed here focused on tactical fighter aircraft, but the principles apply across the board. As new systems take longer and cost more to produce, the frequency of new program initiation necessarily decreases. *Transition gaps* are a fact of life that must be dealt with to maintain the US technological edge.

If the security of the United States is underpinned by technological superiority, and by virtue, R&D and S&T, US investment cannot be allowed to wane. The inconvenient truth is that the US can no longer afford to invest what it needs to, and cannot afford not to. DARPA tackles these challenges head on, filling transition gaps and fostering US technological development.

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Chapter 2

Thesis: Change Lanes

Lynn Montross writing in War Through the Ages (1960) said; "… Jomini produced a system of war, Clausewitz a philosophy. The one has been outdated by new weapons, the other still influences the strategy behind those weapons." Technology is not a means of warfare, but a battlefield itself.

The *social art* of warfare is to mold your adversary's perception about the attainability of his goals through the application of real force or the threat thereof. A superpower is one whose opponents believe that there is no reasonable expectation of achieving their goals in a challenge. The strongest of wills can be changed by these means when even death will not; killing an enemy may not change his mind, but killing his aspirations will. The Japanese were (arguably) prepared to fight to the death to defend the homeland, but the atomic bomb made defense futile. Persuading the Japanese that their goals were unachievable was made possible by the technological advantage provided by atomic weapons. What is the next nuclear bomb or stealth technology that compels an adversary not to fight?

The American way-of-war has relied on technological superiority, but incremental advances in existing technologies will only feed arms races with *near peers*. Likening conflict to a busy highway, stealth technology and atomic weapons allowed America to *change lanes* to avoid the on-coming traffic, instead of simply bearing down to absorb the impact. America must once again *change lanes*, rendering adversary military options and investments

obsolete, deterring challenges in the first place. ***The major technological challenge that faces America in the future is developing that technology which will maintain American supremacy.***

To maintain the technological supremacy that underpins its security America must do the following:

- Develop *lane-changing* defense technology to render adversary investments obsolete (thus deterring the will to challenge the US)
- Cultivate the supporting industries for its exclusive use, while reducing the cost of development
- Remain relevant in a changing defense environment

There is no guarantee of discovering a breakthrough technology, but there are best practices that have been used successfully so far. The Defense Advanced Research Projects Agency (DARPA) was founded for this very purpose. *"[It] was established in 1958 to prevent strategic surprise from negatively impacting U.S. national security and create strategic surprise for U.S. adversaries by maintaining the technological superiority of the U.S. military. [DARPA] relies on diverse… multi-disciplinary approaches to both advance knowledge through basic research and create innovative technologies that address current practical problems through applied research… [spanning] the gamut from laboratory efforts to … full-scale technology"*[1]. The DARPA Director, Dr. Regina Dugan defined innovation in the following way; innovators are not oracles predicting the state of the future, but builders who know the future because they are making it[2]. DARPA embodies the principles in the list above

and does so through a number of deliberate practices that should be applied to the entire defense R&D and acquisitions system. This paper will illustrate these practices and provide contextual examples.

Changing Lanes the DARPA way

DARPA's charter declares that its mission is to create and prevent technological surprise, by virtue, enabling *lane-changing* technologies. To be considered for DARPA investment, a technology must create a strategic change in the conduct of warfare and have a lasting effect. Practically, this is accomplished by assessing the potential advantage or advancement any investment may yield. A nominal "10 times" (10x) improvement or advantage is used as an initial filter to determine where money should be spent. If a technology produces an incremental improvement over the existing state-of-the-art, it is not considered a "*DARPA-hard*" problem. DARPA reserves its money for revolutionary change, not incremental. Thus the state-of-the-art is constantly stressed and advanced; a specific DARPA program may never see the field, but the technology developed to meet its lofty goals often does. Setting high, sometimes very high goals is the only way to achieve great feats. Many DARPA programs fail. Many more than might be expected, but those that succeed far overshadow the failures along the way.

In 2011, DARPA director Dr. Regina Dugan describes (in an interview with the Wall St Journal) the *"nerve"* required for success: *"It's understood that for us to have those really big wins, we're going to have failures … you can't lose*

your nerve for the big failure, because the nerve you need for the big success is the exact same nerve—until the moment you know which one it's going to be. Not before."[3] This nerve is the same nerve a soldier requires when faced with setbacks in battle. It isn't a coincidence that DARPA's success comes from the same attitude that prevails in combat. Therefore it stands to reason that as perilous risk accompanies victory in battle, so it does in the defense industry. DARPA exists (in part) to assume that risk for the defense industry in the form of funding for research & development. Because as Dr. Dugan states *"Our singular mission is the prevention and the creation of strategic surprise"*[3], DARPA can afford to invest in risky technologies because the investment itself is the objective.

Admittedly, DARPA is in a unique position to assume risk that other agencies simply can't afford. The DOD acquisitions community has a different charter (to procure materiel), but the realities of diminishing budgets have created a crippling aversion to risk. Though all organizations cannot adopt DARPA's seemingly cavalier attitude toward failure, close partnerships and shared objectives can be mutually beneficial. In recent years DARPA has attempted to align its research into areas of shared interest with the services. Thus complimenting DARPA's inherent ability to accept risk with the services ability to identify critical capability gaps and transition technologies to the field.

DARPA attempts to be as agile as it is daring. When an R&D program teeters on the brink of failure, DARPA has the ability to make bold and radical

decisions about the future of the program. Every program at DARPA is closely managed by a program manager (PM) who is responsible for, among other things, setting objectives, monitoring progress, and making programmatic decisions. Because the PMs are experts in their fields of research, they effectively and honestly advise their office directors, and ultimately the DARPA director, as to the true state of their program(s). A brilliant absence of bureaucracy enables and empowers timely decisions to increase funding, re-scope/reshape a program, or cut it entirely. In this way DARPA ensures that every dollar it spends contributes to creating technological surprise (i.e. a *lane change*). For example, a jet engine program that started as a power plant for a hypersonic aircraft was recently re-scoped to a hybrid combustor technology demonstrator for ship-borne applications, as the parent aircraft program was scrapped. Then, in the span of a weekly staff meeting, became completely defunded past 2012. The residual program money was redirected to ancillary proof-of-concept demonstrators. This series of program decisions enabled DARPA to adjust to rapidly changing fiscal constraints while maintaining investments in more relevant research areas. Re-scoping the program prevented the valuable research that had already been completed, from *dying on the vine*. Much like a general maneuvering his forces to engage the adversary in battle, DARPA maneuvers its investment dollars to further its objectives in a constantly evolving battlefield.

Cultivating Industry and Reducing Cost the DARPA way

This paper contends that the defense industry itself is a weapon system or at least is a strategic core competency of the department of defense. DARPA does as well. The agency advances the industrial state-of-the-art and feeds it back into the acquisition machine. It does this in a number of ways: cost sharing, constructive contracting, seedling efforts (small investments) to name a few.

Acquisition contracts are very rigid and single purposed, they need to be. They are designed to acquire a *thing* for the government, and that *thing* is rigorously defined in a requirements document. The interests of the government who needs the *thing* can be at odds with the contractor providing it. Deviation from the contract is discouraged and at times illegal. When dealing with the cutting edge of technology, it is ill advised to deal in *hard requirements*. The DARPA standard 10x improvement may not be achievable, but 8x may be. The initial objective may prove irrelevant, but pursuing it may reveal an equally beneficial alternative.

One of the unique strengths of DARPA is its ability to cut contracts that benefit both the government and industry. DARPA's relatively flat organizational structure (PMs have only an office director between themselves and the agency director) and access to a team of highly experienced contracting officers, enables a timely and efficient process of getting *performers* (contractors performing the work) on contract. Also, being an R&D organization, DARPA

programs do not *necessarily* fall under Federal Acquisition Regulation (FAR), freeing them to develop unique contracting vehicles with the *performers*. For some DARPA programs (Section 845 of Public Law 103-160) *Other Transaction Authority* (OTA) is used to create prototype systems, relieving much of the FAR burden. This allows maximum flexibility to use best practices in meeting program goals; including flexibility in the acquisition process, payment method, Intellectual Property (IP) rights, and cost share. As the program matures an OTA allows the PM and performer to rapidly and formally modify the contract/agreement to maintain progress toward overarching program goals[4].

Any cutting edge technology development is inherently costly and risky; two characteristics contrary to conservative business practices. However, the rewards may offset the risk if the company can capitalize later on. Contractor internally funded R&D (IRAD) tends to lean towards established markets and is inherently less risky, while government R&D rarely considers the commercial side of a business. A DARPA contract commonly involves cost sharing with a defense contractor, to entice more risk acceptance while still leveraging the benefits of a competitive free market; a 50/50 or 70/30 cost share is not uncommon. By cost sharing, DARPA accepts much of the financial risk during development, while maintaining performer's vital interests. After all, the industry itself is worth developing. In doing so, the symbiotic relationship between government and the defense industry is strengthened, and the state-of-the-art is advanced in a direction that benefits defense without compromising a performer's financial viability.

At DARPA, program managers are empowered to invest smaller amounts of money into ancillary yet related ventures under the umbrella of the greater program. These *seedling* efforts further advance the overall state-of-the-art related to a formal program. For example, the HELLADS laser weapon program invested in a seedling technology to increase the ability to correct atmospheric distortions in adaptive beam control algorithms. This technology may not be included in the HELLADS system itself, but greatly benefits the field of laser technology as a whole. A DARPA program is less an investment in one particular program, and more an investment in a particular kind of program.

Remaining Relevant the DARPA way

The 'D' in DARPA is for defense, a subtle but critical guiding principle. Maintaining relevance to the warfighter is how DARPA ensures that it is cultivating the American defense industry *weapon system*, and not just creating video games and gravity boots. DARPA ensures relevance systematically through a number of processes that maintain focus on the ever-changing defense landscape.

By policy, no DARPA program is designed to fulfill a stated DOD requirement. To remain relevant, however, *analytic frameworks* are used to guide the objectives of current programs and the initiation of new ones. An *analytic framework* is not a collection of requirements or capability gaps, but an overarching area of interest that has been identified to have *hard* technological

solutions beyond the current state-of-the-art and that would be of significant military utility. A framework attempts to characterize the *state-of-the-problem* in a particular defense area-of-interest by rigorously studying the applicable technologies, challenges to development, and existing/projected threats. When existing technologies/solutions are plotted against threats, the empty *white-space* is often where the analytic framework focuses, guiding program investment. The titles of the current frameworks (as of December 2011) are listed below:

Completed

- Intelligence Surveillance & Reconnaissance (ISR)
- Position Navigation and Timing (PNT)
- Cyber
- Electronic Warfare
- Energy
- Manufacturing
- Adaptive Vehicle Make (AVM)

Ongoing

- Tactical Communications
- Electromagnetic Warfare
- Human Element
- Robotics
- Lethal Effects in A2/AD (Anti Access / Area Denied)
- Space

Figure 3 is taken from the Space analytic framework comparing military utility to cost. DARPA programs are plotted in the white space as blue rectangles with white lettering.

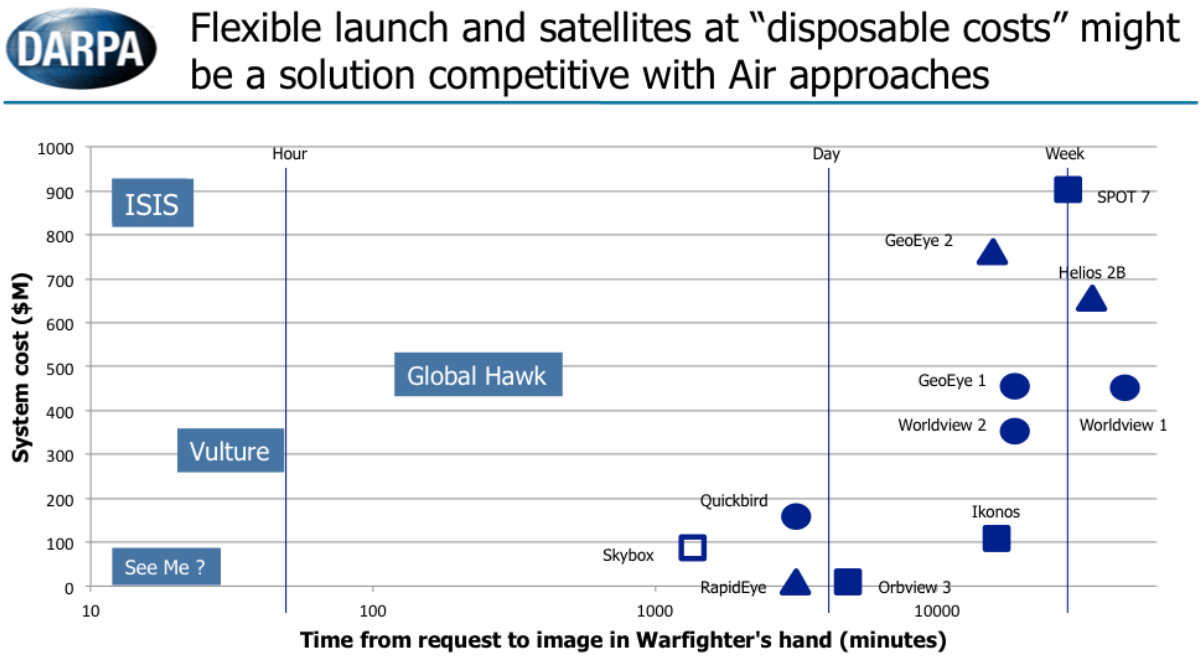

Figure 3: Space Analytic Frame Work Tradespace[5]

In order for a 'good idea' to become a DARPA program, it must fit into one of the analytic frameworks. Furthermore, the frameworks are periodically reassessed and matured. DARPA programs are in turn periodically reassessed against their parent framework to ensure that they are remaining relevant. Program objectives have been known to change, been re-scoped, or eliminated. In a recent case, the Energy framework was abandoned altogether due to budget cuts and overlap with ARPA-E efforts (Advanced Research Projects Agency – Energy). In doing so, all programs that fell under the Energy framework were discontinued. Rather than being a draconian measure, the cuts were strategically justified, aligned with evolving fiscal realities and agency posture, and focused specifically on the programs that no longer served the agency's greater purpose. Stewardship of public resources requires sound

decision making and organizational courage to follow through on tough choices. The analytic framework structure ensures that sound decision making is baked into the process from the beginning, achieving unity of effort from top to bottom.

Graphs and titles are all well and good, but to be useful a framework must produce guidance. An example outcome from the Space analytic framework is listed below. It narrows the focus of DARPA programs into efforts that have been vetted during the framework development.

Invest in new technologies to break the habit:[5]

- *Pursue technologies that sponsor commercial capabilities, responsiveness, and creativity*
- *Develop on-orbit servicing to leverage the sunk costs of existing and future on-orbit hardware.*
- *Partner with non-traditional providers (commercial, academic, international) for hosted payloads and integrated services to deliver more robust, less expensive, capabilities directly to users.*
- *Take advantage of cost reductions and unimagined techniques that inherently come with widespread commercial activities*

Closing the Loop

"God created men…Colt made them equal"

– *Old West saying*

A technology or system on a shelf is of no use to anyone; it must be put in the hands of a soldier. For this reason, DARPA aims to *transition* some of its technology into defense acquisition programs of record. DARPA does not do acquisitions, but it is uniquely positioned to identify technologies for future procurement. To these ends DARPA does two things of interest: transition technology, and manage the Adaptive Execution Office (AEO). Transitioning technology to end product is not unique to DARPA, but it is necessary to maximize the impact of R&D dollars spent. DARPA PMs aid in this effort by identifying transition partners early in the R&D effort, and developing memorandums of agreement (MOA) among other things. The basic idea is to have a partner ready to take over a technology (and the program funding) as it matures out of the *DARPA-hard* state and into a more practical system. The perfect transition has DARPA funding running out just as a transition partner's funding matches the program's requirements (with necessary overlap in between)… and no unnecessary delay. DARPA also has a transition office whose job it is to identify programs that are ready and suited to make a transition and then develop the partnership with the DOD customers.

Another novel approach to transition is the Adaptive Execution Office (AEO). AEO takes select technologies and prototypes that have utility in their

current form and brings them to the warfighter for use. This aids transition in two ways; brings a limited capability to the field immediately while the program undergoes a full transition, and rigorously evaluates the technology in an operational environment. A perfect example of AEO success was the deployment of the High Altitude LIDAR Operations Experiment (HALOE) system to Operation Enduring Freedom (OEF). DARPA took a prototype sensor and put it in the hands of a combatant commander to use while the groundwork was being laid to produce a more permanent sensor pod for future procurement. Warfighters got the benefit of, albeit, just a single sensor, but operational use vetted the technology for the ongoing system design. In the end, capability was brought to the war fighter sooner, and the end product refined.

DARPA purposefully and systematically takes on the challenges that face the US defense industry. Through a series of best practices outlined above, DARPA is developing lane-changing technologies that are relevant, advancing the state-of-the-art and getting them to the end user faster and cheaper. The entire acquisition community could benefit from DARPAs example.

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Chapter 3

Examples: Changing Lanes

The preceding discussion outlined the methodology DARPA uses to achieve *lane-changing* results, but theory is nothing without practice. The following examples serve to validate their approach.

A Case For Lasers: HELLADS/ORCA/HALOE

Until recently, laser weapons were the stuff of science fiction. One doesn't have to be from the 24th century to understand the benefits of a laser gun, but directed energy has many more advantages that span the spectrum of military operations. In the present threat environment, adversary kinetic weapons are reaching parity with American systems. Russian and Chinese missiles put our aircraft and ships at risk (Russian/Chinese missiles risk our ships aircraft n.d.), denying access to strategic regions of the world. Adversary electronic attack capabilities can also degrade or render useless many American radar and communications systems. Faster, longer range missiles and more robust electronic protection would merely feed an arms race, and hardly present a lane change. Lasers have unique characteristics that render useless the large investments America's adversaries have already spent to achieve this relative military parity.

Lasers by virtue are fast, the speed of light to be precise. No missile can outrun a laser. Laser kinetic effects can be achieved the instant the decision is

made to do so. The problem has always been size, weight and power (SWAP). The DARPA High Energy Liquid Laser Area Defense System (HELLADS) program aims to achieve a 150 kiloWatt offensive and defensive weapon system, capable of being carried on a B-1 aircraft.

Figure 4: HELLADS concept drawing [6]

The power and duty cycle are sized to provide tactically significant effects against a variety of air, ground, and missile type targets. The specific details are classified, but in a defensive role, such a system could significantly degrade multi-billion dollar Integrated Air Defense Networks (IADS) and anti-ship missile systems. In an offensive role, such a laser could theoretically

immobilize ground targets with no collateral damage or shoot down aircraft. Not to mention that the HELLADS system is rechargeable, providing an (effectively) unlimited magazine. A viable laser's impact to military tactics and doctrine would be akin to the introduction of military aviation itself. Many R&D programs have tried and failed to achieve the practical-tactical laser holy grail. Programs such as the Airborne Laser (ABL), have had great successes as of late, but only the DARPA HELLADS program has made the practical problem of size, weight and power a program objective.

In a radio frequency (RF) jamming environment, a jamming-angle radar track would be sufficient to cue a laser, which could in turn disable the jammer. The effects could be achieved immediately, something that can't be done with missiles, especially those susceptible to jamming themselves. In an integrated sense, the HELLADS laser could serve to negate airborne electronic platforms, restoring radar system effectiveness.

Alternately, laser sensors are immune to existing RF electronic attack systems altogether. To jam a laser, a jammer would have to be in the path of the laser, and therefore vulnerable to attack. The DARPA High Altitude LIDAR Operations Experiment (HALOE) program built and fielded a laser radar (LIDAR) system that provided ultra-high resolution 3-D ground maps to war fighters engaged in Operation Enduring Freedom. The HALOE project is transitioning to a podded version for UAVs, and could be adapted to an air intercept application with modest additional investment. An airborne LIDAR

sensor would provide precision greater than any existing radar system and be immune to all existing electronic attack systems.

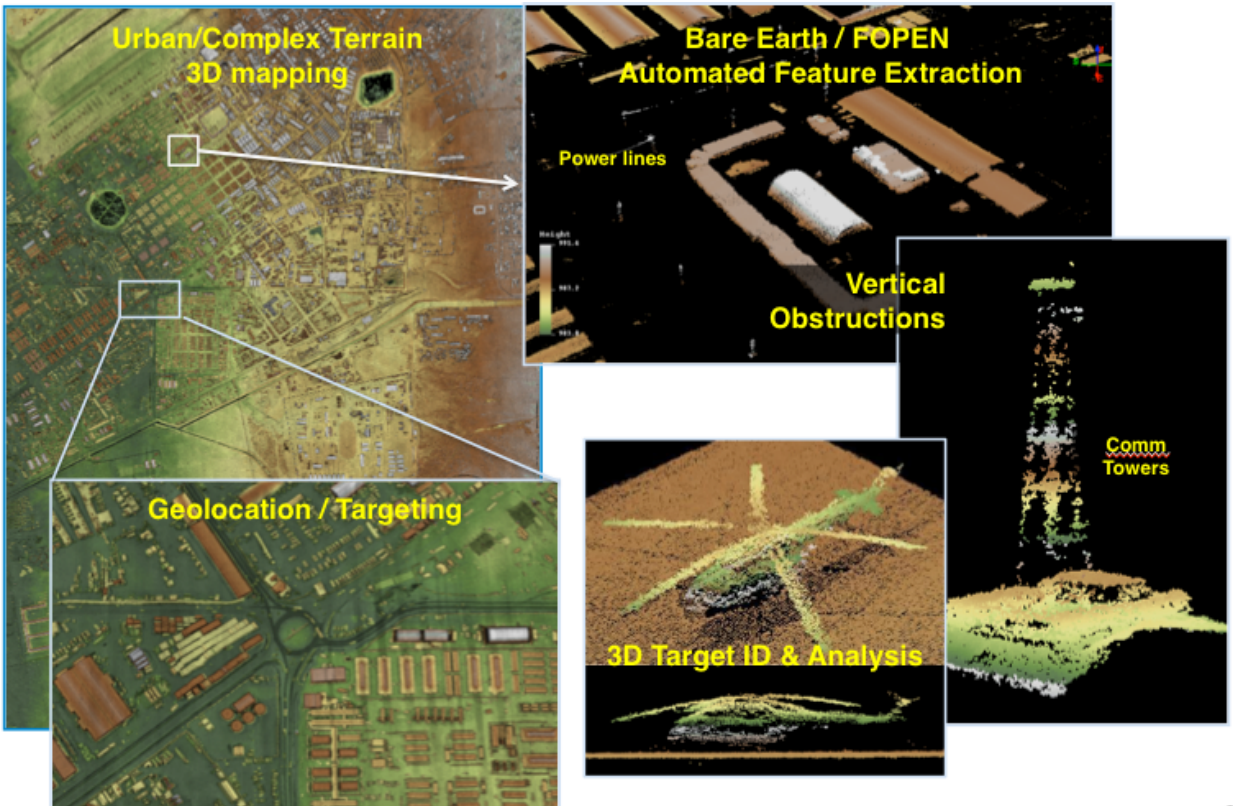

Figure 5: High Altitude LIDAR Operations Equipment (HALOE) 3D Imagery[7]

Furthermore, the DARPA Optical RF Communications Adjunct (ORCA) program is developing a hybrid Radio Frequency (RF) and Laser Communications data link system. It enables secure, high bandwidth communication over laser a connection, and resorts to a baseline RF connection when the weather doesn't allow a clear line of sight. Though weather is a degrading factor, the system would perform no worse than existing radios (in the worst case), and limits the vulnerability to RF jamming to only

those nodes that cannot acquire a laser link. Deliberate network design and tactics could be developed to overcome this apparent weakness.

Critics will inevitably point out the inherent limitations of lasers, but that misses the point. The strengths of laser technology serve to render useless billions of dollars worth of adversary investments. Weaknesses could be minimized by integrating with existing technologies, multiplying their strengths symbiotically. DARPA's holistic approach to investment in laser technology has opened up a broad spectrum of realistic choices for military acquisitions. *Changing lanes* across the operational panorama not only degrades expensive adversary defense systems (without firing a shot), it provides unrivaled capability and freedom of maneuver.

A Step Back is a Step Forward: PINS/HiDRA

The Global Position System (GPS) revolutionized the way America approaches warfare, arguably, unlike any technology in its history. Precision guidance and navigation not only made the US more effective at prosecuting targets, achieving tactical and strategic effects at a lower cost (lives, equipment, collateral damage), but it changed the public's perception and expectations for military operations. The public has always expected the US military to succeed, but the advent of precision GPS weapons meant that it could attain the same military objectives without causing undue collateral damage. Precision strike has always existed in the US arsenal in one form or another, but the low cost and availability of GPS systems has spread to all spectrums, changing the expectations for all forms of operations. Many technologies have contributed to reduction in collateral damage, but for the most part, they have all been underpinned by GPS precision guidance and navigation. Like many luxuries long enjoyed, this appetite for 'humane' warfare is here to stay. And so, America's adversaries have positioned themselves to deny GPS on the battlefield. Arguably, the main objective is not to deny America the ability to strike a target, but to deny the ability to strike it cleanly and surgically without undue collateral damage. Thus attacking America's critical center-of-gravity, public support.

Through the Precision Navigation and Timing (PNT) analytic framework, DARPA is investing in a suite of technologies focused on improving or at least

maintaining GPS quality precision and universal availability. Most notably are the Precision Inertial Navigation Systems (PINS) High Dynamic Range Atom (HiDRA) and Micro Precision Navigation and Timing (Micro-PNT) programs. Both attempt to mitigate GPS vulnerabilities by returning to physics based inertial navigation systems, which cannot be jammed or denied. The DARPA hard portion of these programs is to achieve GPS precision at a low cost, and make it available to every warfighter. Highly precise inertial navigation systems are nothing new, but have been prohibitively expensive for vast proliferation or disposable systems like weapons. PINS HiDRA uses atomic physics to achieve better than GPS precision for platforms like fighter jets, submarines, and some weapons; enabling unmolested operations in jamming environments and/or allowing submarines to stay submerged significantly longer. Micro-PNT developed a corn-kernel-sized inertial navigation sensor, enabling GPS precision in nearly any application imaginable.

Inertial navigation has always been superior to vulnerable beacon based systems like GPS, but material science lagged satellite advancements. DARPA's portfolio investments in inertial navigation technologies will allow the US military to change lanes *back* into inertial navigation, weaning it from the stopgap GPS technology without compromising the capability it provided.

Family of Long Range Precision Strike Technologies: HTV-2/T3/EXACTO

Precision and reach are core competencies of US military power, but the measure of precision and range is contextual. DARPA's has aimed to develop a family of technologies to this end. Warfare has generally involved nations, but always involved battlefields and people. Precision and reach are as beneficial to any one area as all three; ignoring one area entices an adversary to attack it, finding the kink in the armor. Three programs in particular illustrate how DARPA has explored this trade space, and leveraged cutting edge technology to give the US a significant advantage.

The Hypersonic Test Vehicle 2 (HTV-2) program developed a Mach 20 delivery system that can reach any point on the globe in under an hour. To put Mach 20 in perspective, the Russian SA-10 surface to air missile employs a Mach 6 missile and the SR-71 was a Mach 3+ aircraft[8]. Along with being unmatched in speed, it has the ability to navigate and change course inflight. Survivability through speed and inflight maneuver make the HTV-2 potentially the most strategically significant delivery platform in the US arsenal. Initiative, tactical surprise, global reach, and the ability to mission abort in real time will enable the commander-in-chief to hold any target on the planet at risk without the political implications of nuclear weapons. This set of capabilities is only possible due to the high-risk hypersonic technology development under the HTV-2 program. No other US agency is investing in this regime of flight.

The Triple Target Terminator (T3) program incorporates an air-breathing ram-jet engine into a rocket boosted missile. This hybrid mode propulsion system multiplies the effective range and lethality of this conventional missile against three types of targets. Though the technology involved isn't as high risk as that of HTV-2, the DARPA-hard problem lies in making it fit into an existing missile form factor. To ensure that this technology was relevant to the warfighter and would see the field before it was obsolete, a key design trait was chosen to make it fit on all existing fighter aircraft with no modifications. This practical design trait ensures proliferation, decreases time-to-field, and enables a seamless transition to procurement. Such practical design traits are as essential to system effectiveness as the technological traits.

Foot soldiers are often left out of consideration when money is spent on precision weapons. The DARPA Extreme Accuracy Tasked Ordnance (EXACTO) is a command-guided .50 Cal sniper round designed to put long range, pinpoint precision in the hands of a common soldier. The system works by tracking a target with an infrared spotter's scope that doubles as a command-guidance tracker. The .50 Cal bullet is fired and responds to trajectory commands sent by the scope (which tracks the target and bullet). The system accounts for wind, moving targets, and provides accuracy at range that normally requires years of sniper training to achieve. The EXACTO program not only gives sniper capabilities to common foot soldiers, it ensures a kill on the first shot, and enables moving target capabilities that have until now only been available to tactical aircraft and UAVs. In this case, the range is far

shorter than HTV-2 or T3, but the strategic implications of super-sniper-battalions may prove even more deterring to an enemy force. For years, the real practical advantage US soldiers held over adversary soldiers came in the form of the air power watching over. EXACTO aims to enable America's soldiers to enjoy technological advantages its airmen have enjoyed for decades.

Omnipresence on a Dime: ISIS

Information about the strategic and tactical battlefield is invaluable. America enjoys relative freedom-of-movement in the tactical information spectrum. From ISR satellites to AWACS and JSTARS, US commanders have had information superiority over adversaries for decades, but it has come with a high price tag. The DARPA Integrated Structure Is Sensor (ISIS) program is building a massive, 300 meter long, unmanned airship with a massive radar inside. Furthermore, it is designed to stay aloft for a decade. The 6000 m^2 (1600 m^2 looking in any direction) X-band and UHF radar has nearly triple the range of an AWACS and/or JSTARS across every mission they can perform. It can theoretically track individual people at 300 km, and *small* radar cross-section (RCS) airborne targets at 600 km. Larger tactical fighter aircraft can be tracked and targeted as far as 1000 km.

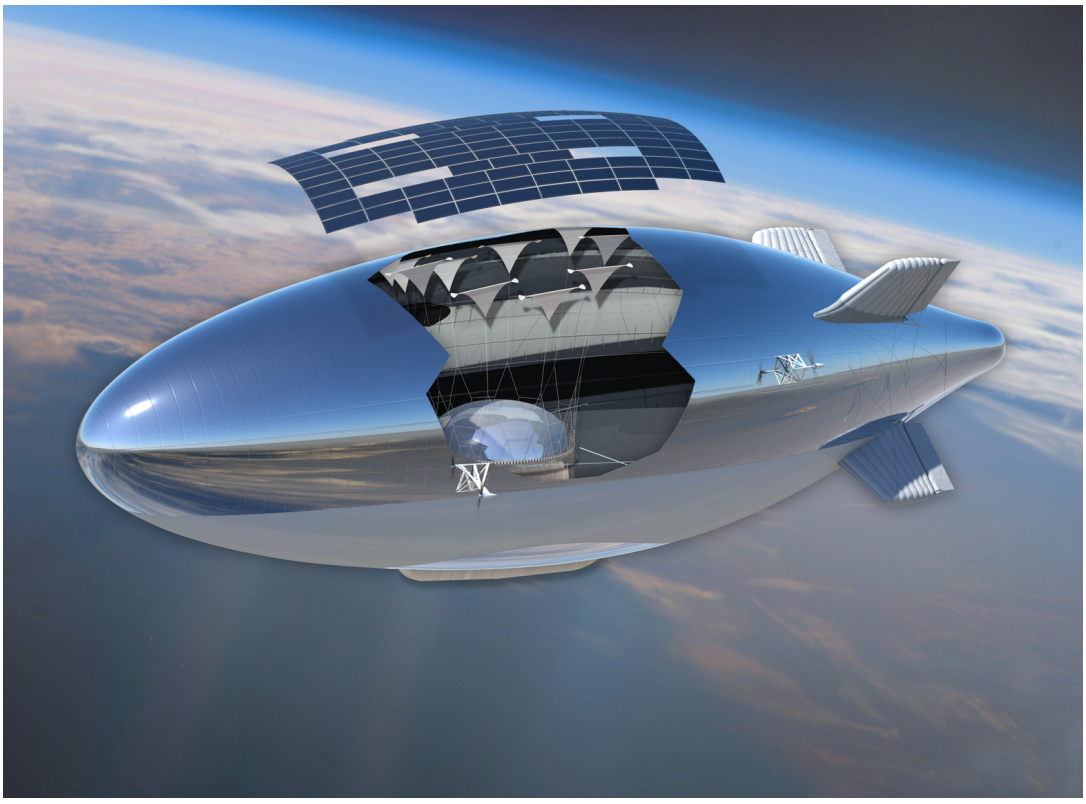

Figure 6: Integrated Structure Is Sensor (ISIS)[9]

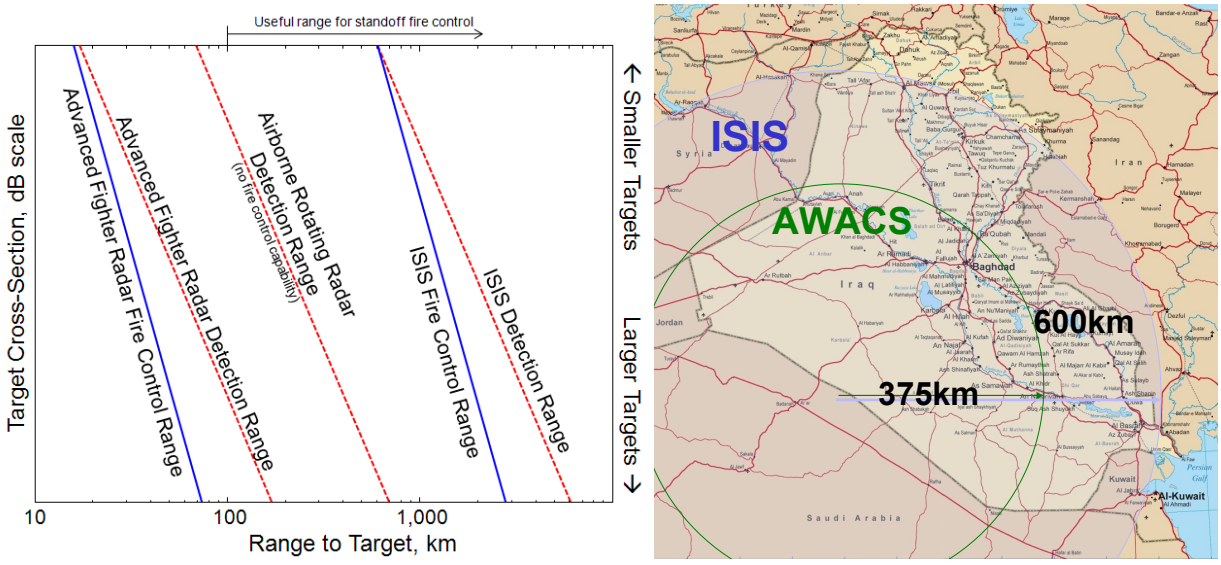

Figure 7: Integrated Structure Is Sensor (ISIS) Tracking Capability[9]

Practically speaking, a single ISIS could have performed the entire JSTARS/AWACS mission in Operations Iraqi Freedom or Enduring Freedom (providing an order of magnitude higher fidelity) for 1 year at a cost of around $30M. In contrast JSTARS and AWACS operating costs for the same mission costs nearly $5B; an order of magnitude better quality for an order of magnitude less cost. Additionally, ISIS could support non-permissive battle spaces such as the Korean peninsula or the Taiwan straits by virtue of its 600 km tracking range of the smallest (adversary) airborne threats. Though it is slow, standoff distance is its defense.

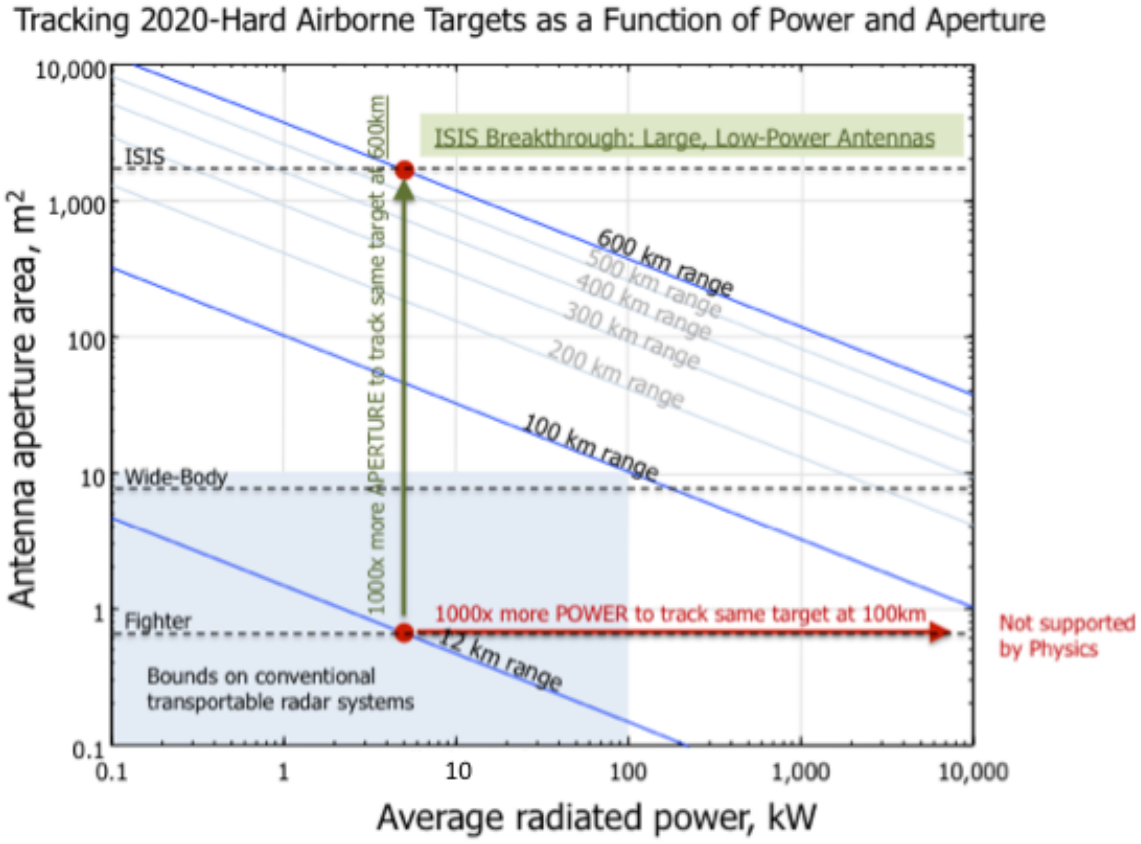

Figure 8: Antenna Size vs Power Trade Study[9]

Detractors readily point out the (supposedly) apparent vulnerabilities of airships. However, several classified doctrines have already been developed to provide integrated defense and symbiotic operations with existing weapon systems, which in turn are greatly enhanced by such a massive sensor. Furthermore, once air dominance is established, ISIS could move into the theatre to support low intensity operations, drastically reducing the cost of peace keeping and rebuilding efforts, not to mention intelligence gathering building up to a conflict or support of military operations other than war (MOOTW). It is for these reasons that multiple Combatant Commanders have requested this capability in virtually every theatre. ISIS is not a single weapon system that will lumber into a hostile adversary's airspace and establish air dominance on its own, bringing an end to hostilities with no other help. It will provide long range, persistent, precise, real-time tracking for combatant commanders, at a bargain price (not to mention, no people will have to forward deploy to operate it). Through a novel approach, DARPA/ISIS has broken the paradigm that precision ISR and Command and Control (C2) is necessarily expensive.

The examples given here demonstrate that DARPA is using a systematic and comprehensive approach to solving the problems that face the defense industry. Through deliberate and focused investment, DARPA is advancing the state-of-the art in many technological areas and achieving significant and relevant effects across the full spectrum of warfare. Through continuous investment, it also fills transition gaps before they form.

Chapter 4

Conclusion

For better or worse, the American way of war will most assuredly continue to rely on technology. The peace, freedom, and influence it enjoys will inevitably depend on its ability to maintain technological supremacy. This paper contends that the defense industry itself is a weapon system and/or core competency that the department of defense (DOD) must exercise and cultivate in order to maintain America's superpower status. The reality is, however, that potential adversaries and international rivals are encroaching on America's top spot, threatening its political freedom of maneuver. Declining budgets and national resources create a significant challenge for the DOD as it can no longer simply outspend an adversary. More striking is the disparity in R&D investments; potential adversaries are beginning to adopt the American way of war. In order to prevail, America must innovate and change lanes as it has done so many times in the past. But past performance does not guarantee future success, so deliberate action must be taken to maximize potential for success.

The Defense Advanced Research Projects Agency has a proven record of innovation, which is by no accident. Its deliberate policies, practices, and organization are as important as the brilliant minds within its walls. The entire DOD acquisition system should adapt a more DARPA-like attitude as adversaries get smarter and budgets get smaller. In determining future requirements, the DOD should accept more risk and demand more

revolutionary advances over incremental change. Requirements must be developed such that capabilities change lanes to avoid the oncoming traffic, not simply bearing down to take absorb impact. The DOD should eliminate layers of bureaucracy that add no significant value, namely redundant headquarter staffs, and empower lower level decision makers to make significant change. Similarly, decision makers must be selected based on expertise in the subject matter, not on archaic measures of promote-ability. The DOD should cultivate the defense industry, treating it more as a partner than as a merchant, and do so holistically, including performers at every level from requirements development to end user deployment. Lastly, the DOD acquisitions system must remain relevant to the warfighter. DARPA does this by deliberately steering investments to real needs and remaining flexible as the environment changes. Requirements creep is the bane of an acquisitions program, but DARPA's ability to react in meaningful ways turns requirements creep into relevant change.

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