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Industry Study

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Robotics and Autonomous Systems

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ROBOTICS AND AUTONOMOUS SYSTEMS 2015

ABSTRACT: The Robotics and Autonomous Systems (RAS) industry plays a critical role producing America's preferred means of global power projection: unmanned aircraft systems. But in a larger sense, RAS technology has also altered the defense industry's relationship with DoD, as the defense sector increasingly finds itself following commercial sector innovations. This report outlines the major issues affecting the defense sector of the RAS industry and DoD's ability to acquire and employ RAS. It then makes recommendations to enable DoD to better capitalize on the technology, strengthen its relationship with the industry and ultimately improve the nation's warfighting capability.

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PLACES VISITED

Domestic:
AlphaLab Gear, Pittsburg, PA
Carnegie Mellon University Robotics Institute, Pittsburg, PA
RedZone Robotics, Pittsburg, PA
Astrobotics, Inc., Pittsburg, PA
Re2, Pittsburg, PA
National Robotics Engineering Center, Pittsburg, PA
Human Engineering Research Center, Pittsburg, PA
AAI/Textron Unmanned Systems, Hunt Valley, MD
Federal Aviation Administration, Washington, DC
Office of Naval Research, Ballston, VA
Lockheed Martin Advanced Technology Laboratories, Crystal City, VA
Aurora Flight Sciences, Manassas, VA
Stark Aerospace Corp, Arlington, VA
Naval Air Station Patuxent River, NAVAIR UAS, NAS Pax River, MD
Intuitive Surgical, Sunnyvale, CA
Suitable Technologies, Palo Alto, CA
Institute For The Future, Palo Alto, CA
Stanford Research Institute, Menlo Park, CA
AeroVironment, Simi Valley, CA
Jet Propulsion Lab, Flintridge, CA
Northrop-Grumman, Palmdale, CA

International:
Israeli Ministry of Defense, Tel-Aviv, Israel
Roboteam, Tel-Aviv, Israel
Cogniteam, Tel-Aviv, Israel
G-Nius Unmanned Ground Systems, Nazareth, Israel
Rafael Advanced Defense Systems Ltd., Haifa, Israel
Amstaf on Guard/Automotive Robotic Industry Ltd., Nazareth, Israel
US Embassy, Tel-Aviv, Israel
Ben-Gurion University of Negev, Autonomous Robotics Lab, Beer Sheva, Israel
Aeronautics Defense Systems & Unmanned Systems Ltd., Yavne, Israel
SimLat Unmanned Vehicle Systems, Herzliya, Israel
Israel Aerospace Industry, Tel-Aviv, Israel

> In addition to new technologies, a third offset strategy will require innovative thinking, the development of new operational concepts, new ways of organizing, and long-term strategies. . . . [Y]ou need to ask how should we prepare for a future where new and disruptive technological developments are continuously occurring?[1]
>
> ―The Honorable Mr. Robert Work
> Deputy Secretary of Defense

> Destiny is no matter of chance. It is a matter of choice. It is not a thing to be waited for, it is a thing to be achieved.[2]
>
> ―William Jennings Bryan, *American's Mission*

INTRODUCTION

Over the course of the past fifty years, robots have sprung forth from the realm of science fiction to become essential, if still unintelligent, coworkers and comrades for industries and militaries worldwide. But the past fifty years will pale in comparison to what the next 50 hold in store not for just commercial and military endeavors, but for society and humanity. The confluence of revolutionary advancements in computing power, multispectral sensors, miniaturized inertial positioning systems, and lightweight materials is already altering the landscape of human technological achievement. Witness the rise of hardware/software integration giants like Google and Apple, the likes of which have greatly incentivized the application of software engineering to monetizable problems. Within this primordial mix of technology, societal demand and financial incentive, exist the building blocks of a true revolution in the application of robotics and autonomous systems (RAS) to the human endeavor.

While the RAS industry itself remains diffuse and vast, its impact on American society will be felt along two critical dimensions. First, the cost of robotic systems will continue to fall to the point where American industry, including manufacturing, may see a resurgence based on the use of highly automated robotic factories. While a potential boon for American firms seeking to "reshore" their previously offshored manufacturing activities, robotics will enable far more than just the resurgence of America's manufacturing sector. Robotic and autonomy technologies will usurp many jobs currently performed by unskilled, semi-skilled, and in some cases skilled laborers. The impacts on the US job market could be severe as thousands or millions of workers are gradually displaced and the very job market itself is redefined by new skills required to supervise robotic and autonomous systems. For the average person, the rapidly modernizing world is effectively getting easier and more difficult to live in simultaneously. (*See* Essay 1.)

The other dimension of the RAS industry is the development and employment of military power to ensure the nation's security. Since prehistoric men first picked up stones to hurl at their foes, competitive advantage in war has gone to the group most capable of using new technology.[3] The security environment of the 21st century is not so different. While the tools of war have changed drastically, the principle of using technology for efficiency in the exercise of national power remains essential. With funding for defense resources diminishing for the foreseeable future, the U.S. will need to develop increasingly efficient means by which to project force. The nascent RAS industry holds a key not only to greater efficiencies in force projection, but also to "offsetting" America's potential military rivals. The adoption of RAS is not simply the next evolutionary technological step, nor just the next trendy idea; it has the potential to support the transformation of how the U.S. achieves its national security objectives.

Forging the nation's third "offset" strategy depends not upon matching symmetrical force capabilities or increasing Department of Defense (DoD) resource levels to police the globe. Instead, the US military's ability to counter the conglomerate of disparate rivals rests—as it has since the end of WWII—on the abilities of its industrial base to deliver technological warfighting advantages. Even though America has achieved technological military superiority, the evolution of military power is dynamic, and its rivals continue to counter those advantages with tactics and technologies of their own. Thus, American's ability to deter, dissuade and otherwise influence nations and non-state actors in far-flung regions requires, above all else, the ability to leverage industry's ability to continuously innovate.

This seminar focused its study on the capability of the RAS industry to meet US national security objectives. To evaluate this industrial capability, we conducted academic industry research, field studies, interviews with subject matter experts, and focused analysis of the US unmanned systems defense sector. We began by engaging with recognized thinkers in robotic research and reviewing leading think tank reports and DoD's RAS-related plans in order to map the industry's conceptual space. We compared and contrasted strengths, weaknesses and linkages among academia, publicly funded research centers, and private industry—from small start-ups in the commercial sector to large defense corporations. To evaluate the US industry's status against the global market, we traveled throughout Israel and viewed an alternative model for employing RAS technology and leveraging an industrial base in pursuit of a nation's security objectives.

We assess the US military is acquiring a disparate portfolio of RAS-related systems with no unifying RAS vision and, consequently, the defense industry is coping with a high level of uncertainty. More importantly, however, the U.S. lacks a focus toward maximizing the use of autonomous systems to increase the nation's ability to project power. In the worst case scenario, the U.S. could find its current force structure increasingly contested by remotely operated and unmanned systems fielded by an adversary ready to capitalize on such opportunities. These challenges stem not from technological difficulty—although much remains there—but a lack of forward-looking doctrinal development. As a result, industry is uncertain about DoD's level of commitment to adopting RAS and unsure about what types of RAS investment will best advance national security interests.[4]

To support this assessment, this report first defines and assesses the defense sector of the RAS industry. Next, we explore the structural and institutional challenges facing the industry and the US military's efforts to adopt this technology. Finally, we provide a glimpse of a potential RAS innovation ecosystem that could bolster the nation's ability to quickly and efficiently harness cutting-edge RAS for the purpose of national defense. We conclude by offering a series of recommendations to achieve that vision.

INDUSTRY DEFINED

Just as the concept of "what is a robot" is broad and varied, so too is the loosely-defined RAS industry. The RAS market can be thought of as the group of firms that produce everything from unmanned military systems to intelligent software for use in "learning" capable industrial machines. (*See* Figure 1.) Its products are the synthesis of multiple engineering disciplines, including software, electronic and mechanical. The rate of advancement in the RAS industry is inextricably linked to advances in several related technologies, to include microprocessors, batteries, mechanical effectors, sensors, and composite materials.

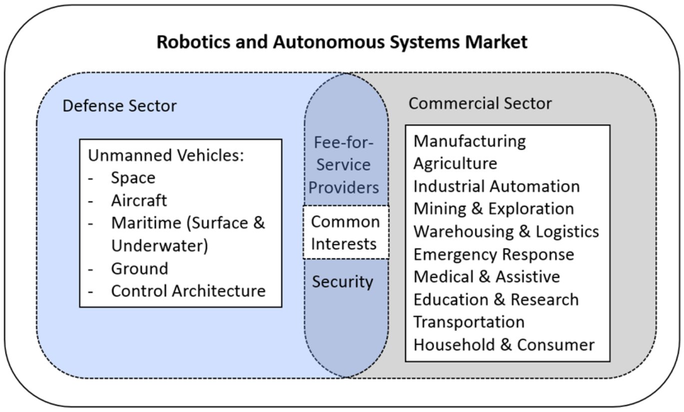

Figure 1: Robotics and Autonomous Systems Market

In the commercial sector, the majority of robotic systems are used in industrial manufacturing, though the past few years have seen a rapid expansion in robotic applications, to include entry into the medical device, food processing, and electronics manufacturing spaces. US manufacturing firms now use an estimated 230,000 robots, second only to Japan with 300,000 industrial robots.[5] Other segments are slowly taking shape and are becoming increasingly lucrative enterprises. The household and consumer segment aims to transform everyday lives through the application of autonomy technology applied to home use such as vacuum cleaners, lawn mowers, pool cleaners, personal assistants, etc.[6]

The defense sector is more tightly focused on the development and manufacturing of unmanned or remotely operated vehicles of varying levels of autonomy that operate in the air, land, sea, and undersea domains. This sector is characterized by a mix of large, established defense industrial firms, as well as a smattering of small-to-medium sized firms that entered the market by fielding small robotic systems developed for use in Afghanistan and Iraq.

As RAS technology is a relatively recent addition to military operations, the industry's lifecycle dynamics are best explained through the concepts of *disruptive* and *sustaining* technologies.[7] (*See* Figure 2.)[8] Disruptive technologies tend to upset the established order of an organization when introduced. For example, the unique capability of the RQ-1 Predator to provide senior commanders full-motion video in real-time changed the nature of battlefield command and control when it was fielded in the mid-1990s. Sustaining technologies, on the other hand, tend to fit in the shakeout or production portion of the curve. The follow-on to the Predator system, General Atomics' MQ-9 Reaper, is an example of a sustaining system and is essentially a bigger, better version of the Predator.

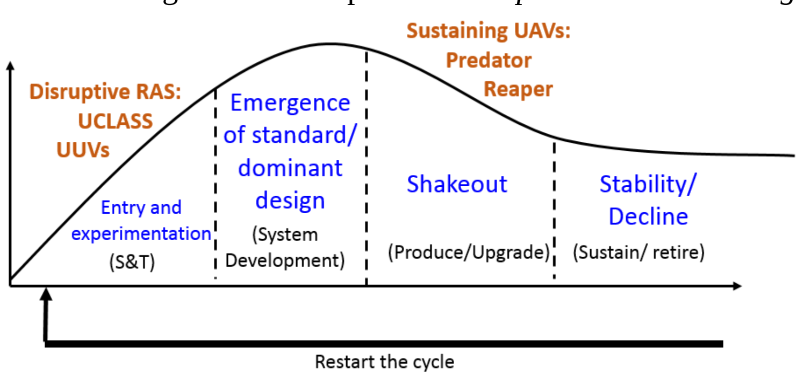

Figure 2: Industry Lifecycle Curve

Conversely, doctrinally upsetting systems like the Navy's UCLASS (Unmanned Carrier-Launched Airborne Surveillance and Strike) prototypes tend to remain in the entry and experimentation phase while the sponsoring service determines what capabilities the system should ultimately possess. As disruptive capabilities proliferate and become the industry norm, firms are faced with the strategic dilemma of either refining previous products or developing new market segments through product differentiation. This tension has become the defining characteristic of the defense unmanned systems market space.

CURRENT INDUSTRY CONDITIONS

Industry Segment Analysis. Due to the immaturity of the majority of the national security RAS industry, our analysis of defense industrial firms focuses primarily (but not exclusively) on those competing in the unmanned air vehicle (UAV) sector. UAVs represent the most mature market and provide insight into likely future trends as the DoD fields larger numbers of unmanned systems in the maritime and ground domains.[9] While some public financial data exists on the UAV sector, analysis is challenging as the UAV manufacturing sector possesses no North American Industry Classification System identifier and few large defense companies distinguish these systems within their military sales figures. The large number of competitors within the UAV segment presents the best data from which to assess its likely future. Existing since the late 1970s, the maturation process of the UAV segment is instructive for divining future trends for other unmanned system segments.

Within the UAV segment, DoD categorizes systems by weight and operating altitude, known as groups 1-5.[10] (*See* Figure 3.) Each category poses distinct challenges in terms of complexity, technology, payload, capability, and price differences. The past decade has been marked by a relative oligopoly in each of the group sizes. AeroVironment and Boeing's Insitu dominated Group 1 and 2 (small UAS or SUAS), respectively. AAI Corporation's Hunter and Shadow platforms controlled the Group 3 market. General Atomics' Predator and Reaper systems were almost exclusive in the Medium Altitude, Long Endurance (MALE) Group 4 into Group 5 category. Finally, Northrop Grumman's Global Hawk system makes up the High Altitude, Long Endurance (HALE) Group 5 market.

UAV Category	Max Takeoff Weight (Lbs)	Normal Operating Altitude (ft)
Group 1	0-20	<1,200 AGL
Group 2	21-55	<3,500 AGL
Group 3	<1320	<18,000 MSL
Group 4	>1320	
Group 5		>18,000MSL

Figure 3: Joint UAV Group Classifications

In sum, the UAV segment is characterized by one to two companies dominating a given group market and facing limited competition as a reward for being the first to market to provide intelligence, surveillance, and reconnaissance (ISR) solutions for combat operations. With two simultaneous long-term combat operations (Enduring Freedom and Iraqi Freedom), the proliferation of Overseas Contingency Operations (OCO) funding allowed quick fielding of these systems and created above average returns on investment (ROI) with an 11.5% growth in revenues from 2007 to 2012 for the few companies involved across the defense industry.[11] Recently, the federal government's reduction in purchases, combined with delays in expanding into the commercial market, has altered the structure and strategy of the UAV firms as detailed below.

Market Structure (Porter's Five Forces Model). Porter's Five Forces model demonstrates the highly competitive nature of the RAS market and explains why firms in this industry seek to create new markets through niche strategies to secure a competitive advantage.[12]

Bargaining Power of Buyer: High. The most significant factor facing the industry is the buyer's bargaining power. (*See* Figure 4.) The US government has a relative monopsony on the UAV market with 90% of the sales revenue.[13] The monopsony impact is magnified by: 1) reduction in market sales due to decreased DoD budgets, 2) inhibition of UAV commercial market by Federal Aviation Administration (FAA) delays with opening the National Air Space (NAS) to UAVs and 3) highly controlled international sales under the International Traffic in Arms Regulations (ITAR) and the Missile Technology Control Regime (MTCR).

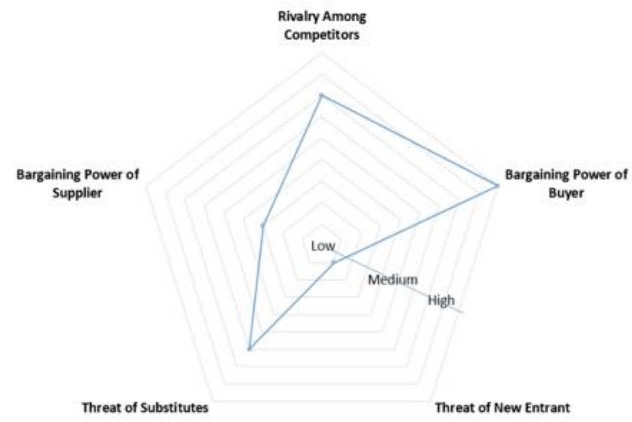

Figure 4: Porter's Five Forces Model

Rivalry Among Competitors: Medium. In 2012, the concentration ratio was 59.1% for the industry overall.[14] The competition between rivals still resembles an oligopoly in the group 3, 4, and 5 categories as a few large companies vie for a limited number of large dollar US government procurements. In groups 1 and 2, the expansion of competitors for each program makes the market more reflective of monopolistic competition.

Threat of New Entrant: Low. The challenges of government acquisition, delayed opening of the commercial UAV market and the costs of remaining technologically ahead of the field combine to keep the threat of new entrants low.

Threat of Substitutes: Medium. The US military's advocacy for the primacy of manned systems over unmanned drives the availability of substitutes. Additionally, the supporting architecture (e.g., data-link satellites) that enables long-distance remote UAV operations is constrained. This limitation has created a substitute marketplace for both leased and purchased manned ISR capabilities.

Bargaining Power of Supplier: Low. The increased obtainability of miniaturized technologies needed for UAV production renders the supplier's bargaining power low. This bargaining power may alter in the coming years, however, as large civilian corporations purchase small firms with emerging UAV component technologies. Additionally, the advancement of open architecture will allow suppliers with sensor, communication, or manipulator systems to contract directly with the government thus increasing their power as the platform commoditizes.

Firms' Conduct (Strategic Gameboard Analysis). Though intended for individual firm analysis, the lens of the strategic gameboard provides insight into where the majority of firms are targeting their strategy.[15] (*See* Figure 5.) In support of combat operations over the last decade, most UAV companies created new markets with their products as the military quickly fielded this new technology. Once the immediate requirement was met and sales leveled off, companies sought to further segment the market and create niche capabilities

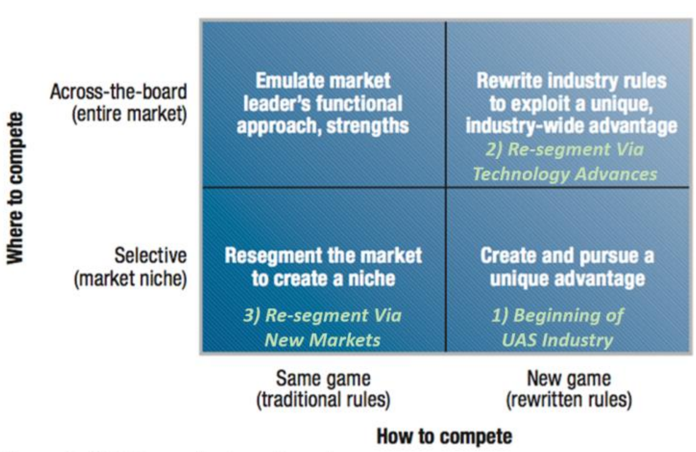

Figure 5: UAV Strategic Gameboard

through focused research and development (R&D). During the OCO funding years, profit margins and gross sales created value and supported these competitive strategies. The reductions in defense funding and limitations on OCO have changed the market strategy across the industry.[16] Most companies are seeking new markets in the commercial and international markets arena and life cycle support of existing products to create long-term profits.[17] This may be the only viable strategy for the smaller companies that are largely dependent on UAV sales. Larger defense companies appear to be weathering this fiscally constrained storm through reduced R&D, cost-cutting moves, and buyback of stocks with excess cash reserves to create necessary dividends for their stockholders.

Industry Performance. The domestic UAV industry has demonstrated a slow-down in revenue growth that mirrors the reduction in defense spending over the last four years. The overall spending within the UAV industry has declined 6.2% annually from 2010 to 2015.[18] Despite this recent defense spending recession, The Teal Group continues to estimate that worldwide UAV industry sales will grow from $6.4 billion to $11.5 billion in the next ten years.[19] Their forecast is based on growth in the commercial and international sectors, which are delayed. The small companies in the UAV market are producing an ROI well below the ten percent value accepted as the cutoff for creating value. For example, since the market decline, AAI Textron reported a 5.4% ROI in 2013 while AeroVironment had a 5% ROI in 2014.

In order to create value going forward, these companies must continue to support the R&D required to capture new programs. In addition, they must adjust their strategy to diversify their market to international sales or capture the opening of the commercial market. The large defense contractors continue to deliver strong ROI through their diverse portfolios. Over the past few years, Northrop Grumman had an ROI of 12.4% and Lockheed Martin had an ROI of 29.8% across their range of business sectors. These large firms' continued interest in the UAV industry depends upon a sufficient market existing to justify their R&D investment. The limited number of DoD programs of record (POR) will result in heated competition for the decreased availability of defense market share. The required commitment in independent research and development (IR&D) funding to compete for large programs, like the UCLASS, will have negative consequences for those companies not selected. Potential growth areas for profitability within the UAV market are fee-for-service and performance-based logistics (PBL) contracts that could provide additional revenue streams to the contractors above profits gained from system sales.

International Market Forces. The global market for UAV is extremely competitive as foreign companies increase their presence in this sector.[20] Israel and China lead these efforts with aggressive sales of multiple platforms that exceed or have near equivalent capabilities to available US defense products. Without public data, it is almost impossible to determine the exact market share that they command; however, it is clear that these international competitors have surpassed US defense industry sales. For the years 2005-2012, Israel exported $4.6 billion in UAVs—close to twice that of the U.S.[21] Israel's compelling innovation model and export emphasis provides strong evidence for their continued market strength. (*See* Essay 2.) The persistent challenges of ITAR and MTCR limit US companies from fully realizing the benefits from overseas sales and the support that these sales would bring to the domestic defense industrial base.

Outside Influences on the UAV Market. Outside influencers and stakeholders continue to shape the UAV domestic industrial base. Congress has sought to support the industry through legislation directing the DoD to detail specific actions with regards to the procurement strategy. Congress has also served as the forcing function to spur the FAA to shorten timelines to open the NAS for commercial UAV use. Finally, trade groups in support of the industry expansion have lobbied Congress to put pressure on DoD and DoS to change policies currently impacting domestic and overseas sales of UAV.

CHALLENGES: INDUSTRY AND DOD OBSTACLES LIMITING POTENTIAL BENEFITS OF RAS

The nascent RAS industry faces significant challenges in gaining both acceptance and adoption into the US military's way of war, though the reluctance of the US military to accept new technologies is not a new phenomenon. Militaries have historically rejected groundbreaking technology. Such new technologies are best described as disruptive innovations—improvements in performance "along a war fighting trajectory that traditionally has not been valued."[22] The difficulty in understanding the particular barriers to adoption of robotic and autonomous systems is compounded by the diffuse nature of the technology. While the services are procuring individual weapons systems that can be variously described as either "robotic" and/or "autonomous," the underlying technology—increasingly powerful microprocessors, miniaturized inertial systems and sensors—is increasingly employed on weapons systems not ordinarily considered as either robotic or autonomous.[23] With technology advancing along multiple simultaneous dimensions, the central challenge is not the identification of promising new technology, but rather divining future warfighting concepts that can capitalize on that technology. Without a deliberate and iterative effort to develop such concepts, industry will continue to receive mixed demand signals and guess about where to focus its R&D efforts.

Challenge 1: Lack of Coherent, Integrated Warfighting Vision. Autonomy technology holds the potential to fundamentally alter the US's military advantage over its future adversaries. However, the individual military services' approach to RAS reflects the historical pattern of procuring and prioritizing weapons systems that advance well-established means of warfighting, but are also heavily anchored in the past decade of conflict. Consequently, few forward-looking concepts of operations (CONOPS) exist for exploiting RAS's potential advantages in the context of joint warfighting. Instead of becoming a force-wide attribute, autonomy (or the degree thereof) has become a means to accomplish undesirable missions.[24,25]

Ultimately, individual military services decide which systems and capabilities align with their core interests, resulting in the funding of a disparate and parochial set of capabilities. As such, the services' requirements for future unmanned systems tend to shift frequently as debates about roles and missions occur within the services.[26] Industry's response has been to take a conservative approach toward developing new concepts while DoD figures out what roles its future unmanned platforms will perform. Combined with DoD's declining R&D budget, even the larger defense conglomerates are unsure to what degree the DoD is willing to invest in RAS.[27]

Challenge 2: Culture and the Disutility of the "3D" Paradigm. The services also face internal challenges in terms of the degree of autonomy disrupting their established systems of domain–centric warfare. The predominant attitude is one of grudging acceptance when it has come time to replace humans with mechanical and robotic systems, with three notable exceptions: missions and tasks that are either too dangerous, too dirty, or ultimately too dull for humans to do.[28] This "3D" mentality has long been the mantra guiding the adoption of RAS technology, but limits critical thought about its applicability to DoD opportunities. Furthermore, some military communities (i.e., pilots, ship drivers, logisticians, etc.) view RAS systems as a direct threat to their core skill sets and tasks—not to mention manpower authorizations—that form the very identity of their military services.

The result is that within the services (particular the aviation-oriented communities) unmanned systems duty is a lesser professional occupation than operating manned platforms. Despite the fact unmanned systems have been in use for decades, their operators have not risen to the highest ranks of their respective services. Without senior officers who understand the unique opportunities unmanned and remotely operated systems offer, few requirements for new, revolutionary systems are likely to survive against the entrenched way of conducting business.

Challenge 3: Lack of Trust in RAS Technology. The cutting-edge RAS technology this group observed, while impressive, still trails by a wide margin the cultural perception of what robotics ought to be able to do. The fragile and essentially disposable nature of the first generation of RAS also contributes to a lack of trust in the overall technology, even though early systems generally performed as designed. As a result, the services are hesitant to build future concepts of operation that rely on unproven and yet-to-be-developed military for mission sets outside the "3D" paradigm.

The task of identifying and developing promising RAS technology falls primarily to the individual services' research labs and the Defense Advanced Research Projects Agency (DARPA).[29] Many times the successful adoption of technology hinges on its inherent demonstrability. RAS demonstrations tend to include large numbers of operators and support, which gives the impression of little to no savings in manpower cost. Demonstrations also often make public exhibitions of system failures and limited successes, which can lead to lack of confidence in not just the individual system, but the state of the underlying technology.[30]

Challenge 4: The Defense Acquisition System. Failures of the acquisition system to deliver advanced technological programs on time, on budget and performing up to specifications are not new. The timeline from idea and requirements development to fielding a fully operational system almost guarantees that the acquired system will have been technologically surpassed by the time it reaches a warfighting unit. This elongated process does not mean that the technology won't be useful, but it does pose problems. Identifying future state-of-the-art RAS capabilities is difficult; codifying them into meaningful performance parameters is an exercise in hedging for uncertainty.

Challenge 5: Budgetary Uncertainty. One of the most significant challenges facing the near-term development and fielding of RAS are the individual service's existing weapons system programs. The uncertainty as to future funding levels has caused the services to rally in defense of large spending programs that sustain their most cherished platforms. This squeezing effect limits the services' ability to invest in future programs that require the development of unproven and immature technology, but could ultimately address key security challenges. Additionally, the ad hoc nature and rapid acquisitions authority under which some of the urgent wartime systems (primarily the thousands of explosive ordinance devise (EOD) robots currently fielded in Afghanistan) were procured means there is no long-term POR, and therefore no sustainment funding for future use and improvement.[31] Corralling these systems into a consolidated program now competes directly with funding for other, more forward-looking service programs.

Challenge 6: Private Sector Competition. As a corollary to the defense industry, the commercial sector increasingly rewards the development of software as opposed to robotic hardware. As a result, commercial firms offer higher-paying positions to professionals in the robotics field and are viewed as more attractive than defense industry positions.[32] Google, for example, employs at least one former DARPA director and has recently purchased eight robotics firms, two of which are DARPA Robotics Challenge winners.[33]

The software and applications market also represents a far more lucrative endeavor for individual firms, particularly when viewed against the current defense budget environment. Firms like Google, Amazon, and Apple are not currently investing R&D in military-ready technologies. More importantly, the potential profits from DoD projects do not come close to the profits such firms can earn in the commercial market. The private sector—once a follower of DoD technology—has become a market-driven leader in many RAS-related technologies.

OUTLOOK: CHARACTERISTICS OF AN IMPROVED RAS INNOVATION ECOSYSTEM

When considering the future outlook of RAS outside of the defense context, it is clear that the civilian sector will see explosive growth in RAS as the technology matures and becomes cheaper. With the benefit of a profit motive, the commercial sector will continue to outpace the defense industry in researching and developing RAS applications. The commercial RAS sector will make these technological leaps out of sight of DoD, as the norm for the larger innovating firms is to keep products wrapped in secrecy until ready for launch. In light of this unfamiliar dynamic, DoD needs to adjust its view of how to work with commercial RAS firms and learn to leverage the inherent creativity and speed with which the commercial sector can match technological solutions to seemingly unsolvable problem sets.

Given this outlook, this seminar sought to better understand and define an ecosystem with the characteristics necessary to promote rapid RAS innovation within the defense industrial sector. To further our understanding, we visited and studied both domestic and international innovation models and gained a new perspective for an innovation ecosystem that could better harness and integrate RAS technology. This section outlines the lessons we took from these engagements and describes the key attributes of a system that will allow DoD to not only move past its current challenges, but to take the lead in developing military robotics and fielding useful capabilities in a timely fashion.

During our field studies to Pittsburg, Pennsylvania, we saw first-hand the use of a commercial "accelerator" model. These firms provide startup companies with training, mentorship and office space as well as a quick infusion of seed funding; in exchange, accelerators receive a small share of equity in these companies.[34] Besides providing a quick boost of capital and mentoring to a cohort of startup companies, the networks of learning within accelerators provide the keystone of the innovation model.[35] Accelerators typically surge development on a fixed timeline, taking products from concept to product in a matter of months.

We also examined an alternative paradigm for interactions between the military and defense industrial base through extensive field studies in Israel. The close working relationship between Israel's Ministry of Defense (MoD), Israeli Defense Forces (IDF) and its defense industrial base provided a unique perspective on harnessing technology quickly to solve real-world battlefield problems. While Israel's strategic focus and geographic position are drastically different than that of the U.S., some of the lessons in promoting innovation in the RAS industry are highly applicable. (*See* Essay 2.)

Based on our studies, this seminar believes the nature of DoD and RAS industry interactions ought to possess four key characteristics. First, the development and idea generation process needs to feature a close working relationship between the developers and the end users. This relationship is symbiotic in that the developer gains insight into potential military utility while the operator gains a reciprocal understanding of the art of the possible. Operators and developers working together provide a greater chance of maturing an idea that can be written into both a useful operational concept and a realistic set of requirements. Second, DoD needs a bridging function to shepherd promising systems from the idea stage through the requirements-generation stage. Third, the ecosystem must emphasize demonstrations of RAS technology to the services' senior leadership. Demonstrations for senior civilians, congress, and others are useful, but historically none of those are as effective as gaining the advocacy of a service's chief for a particular idea. Lastly, the ecosystem must feature more flexible funding mechanisms that will enable rapid technology procurement and encourage small firm participation in the defense sector of the RAS ecosystem.

RECOMMENDATIONS

To overcome these challenges in the RAS industry and ensure that the U.S. obtains the full value of RAS contributions to national security, both DoD and industry must improve how they think about, plan for, develop, and utilize robotic and autonomous systems. Based upon our study, we offer the following recommendations to further that effort:

Recommendation 1: Develop and Manage an Evolutionary RAS Strategy. First and foremost, DoD must intentionally develop and manage an evolutionary strategy toward RAS in order to lead to revolutionary results. While this seminar is convinced that autonomous military systems will one day lead to a revolution in military affairs, such results will not be achieved in the next five to ten years. To encourage progress toward such an outcome, DoD should target areas where RAS integration into the military will not collide with institutional resistance and focus on uses of RAS that will build trust and acceptance of the end-users and military leadership. Using the advice from Terry Pierce, author of *Warfighting and Disruptive Technologies*, RAS product champions should "disguise or shape the disruptive innovation as a sustaining innovation" to improve the likelihood of gaining acceptance within DoD.[36] To that end, DoD should focus upon:

Logistics: RAS has great potential to increase logistics productivity in everything from warehouse management to resupply routes. The logistics arena also allows for quick, easy wins by adopting robotic and autonomous systems that have been proven to work in the commercial sector (e.g., Amazon robot-assisted warehousing). An iterative approach to integrating RAS into logistics is required to gain user confidence and promote innovation gains. (*See* Essay 3.)

Manned-Unmanned Teaming (MUM-T): DoD should develop CONOPs and then seek to procure systems that focus on collaboration and synergy between manned and unmanned systems. Instead of perfecting a robotic system that can "do it all", services should focus on a "system-of-systems" approach that enables humans and robots to perform functions for which they are best designed. Systems such as leader-follower convoys or unmanned-wingman concepts will provide effects unobtainable by current systems and such an approach will also improve trust and acceptance of RAS within the defense community. (*See* Essay 4.)

Leverage commercial RAS Technology: DoD can speed implementation of fielding systems by leveraged commercial capabilities with a high technology readiness level. One clear area to capitalize on synergies between the military and commercial sectors involves autonomous cars and corresponding application to military convoys.

Recommendation 2: Complete the Joint Unifying Vision for RAS. To guide this evolutionary path, DoD senior leaders must commit to and promote the possibilities afforded by RAS. To that end, we encourage the Joint Staff to complete and publish a comprehensive and unifying vision of RAS that will provide direction and focus areas of joint development for the services across all domains. Additionally, service leaders must do more than just tout their approval of unmanned systems through notional roadmaps; they must demonstrate that support by drafting CONOPs that identify how RAS can advance each warfighting domain, develop and promotes personnel expertise to utilize RAS systems, and budget funds in the POM (Program

Objective Memorandum) to create actual RAS programs of record vice reliance on OCO expenditures.

Recommendation 3: Establish a RAS-specific Board Under the DoD Innovation Initiative. To underscore commitment to and obtain the most value out of robotics, the Deputy Secretary of Defense should chair a RAS-specific board under the new DoD Innovation Initiative.[37] This board would be chartered to capitalize on RAS technology identified in the Long-Range Research and Development Program Plan due to be completed in summer 2015.[38] This board would also be charged to implement a common vision across services; find, sponsor, and execute testing of early stage technology in an operational environment; and synchronize efforts and collaboration across warfighting domains. The creation of such a board also enables flag-level champions to emerge from the services and to promote RAS resource allocation.

Recommendation 4: Adopt a Fast-Follower Approach. Though countless critics have bemoaned the lengthy procurement process for traditional systems, a protracted timeline for RAS undermines—and potentially undercuts—the very value of obtaining a high-tech, innovative robotic systems. While we witnessed amazing technological advances and ideas at the concept or demonstrator level, moving those ideas across the "valley of death" to development and procurement has proved challenging. Based on fundamental differences in business models and motivations, the DIB is simply not structured to innovate with cycle times comparable to the commercial RAS technology sector. In order to best capture promising RAS commercial technology for small scale application and develop paths to a traditional programs of record, the US government can enable the DIB to be a more effective fast follower:

Understand Distinctions between DIB and Commercial Sector: The President should direct an industry study under his Title III Defense Production Act authority to understand the robotic industry capabilities, assess any personnel or talent shortages, and clarify which companies are capable of developing autonomous systems for future defense use. In particular, this study should determine how the defense industrial base can leverage innovations within the commercial robotics sector and target R&D allocation based on determined gaps between civilian and defense priorities. Based on this study, the U.S. should then promulgate a national RAS strategy that encompasses and promotes development of economic growth and defense strategy resourcing. (*See* Essay 5.)

Focus R&D that Leverages Commercial Sector Advances: With the decline of research dollars in the traditional DIB and the growth of powerful commercial companies like Google overtaking new tech areas like autonomy, DoD must critically examine how it fosters R&D in RAS. DoD's current ambiguous commitment to RAS does little to encourage industry innovation and expenditure of IR&D by the defense firms.[39] As one industry representative noted, "Why should we invest our dollars when you don't know what you [DoD] want?" A better articulation of RAS requirements and DoD RAS vision will provide industry assurance and direction for expenditure of IR&D on autonomous systems. This is especially critical in the "valley of death" period between science and technology R&D and pre-program of record R&D. Simply relying on the DIB to provide innovation in this field, however, is not enough; DoD must improve its ability to leverage commercial markets. By identifying those areas that are of shared interest between the commercial and military sectors, DoD can prioritize government R&D funds appropriately to either stimulate a joint effort to develop a RAS capability faster, or to efficiently assign funds in areas specific relative to DoD interests, leaving other areas that are commercially viable to internal R&D funding without augmentation. (*See* Essay 5.)

Create opportunities for DIB and Commercial Collaboration: DoD should adopt a variety of commercial innovation models such as accelerators, technology sprints, "maker" spaces, and crowd-sourcing initiatives. The commercial sector has found these approaches result in more rapid generation of ideas, reduction of risk, and greater speed of technology to market. Additionally, DoD, in consultation with industry, should identify areas where standardization can occur. For example, the UGV community identified interoperability—enabled through video, audio, and electrical communications—as a standard.[40] Similarly, the cyber community realized the benefits of standardization through the Joint Open Architecture Spectrum Infrastructure effort by bringing together industry experts on communication and electronic warfare systems and RF spectrum standards.[41] The key component for RAS will not be the platform technology itself, but the ability for industry to develop new "apps" and plug-and-play systems to augment the platform. Thus, the more DoD embraces standardization and common control architecture the greater flexibility it will have to decouple hardware from software on autonomous systems.

Incorporate Israel's Building-Block Approach: Israel views unmanned systems not as a UAV or USV but as a UXV.[42] As one Israeli robotics researcher explained, "Only 5-10% of an unmanned system is unique to a particular domain…so a generic approach is best."[43] This building-block approach enables more rapid development and eases the test burden by relying on already validated sub-systems. Adoption a UXV methodology in both procurement and testing would allow DoD to acquire upgraded RAS technology rapidly and promote interoperability across the services. (*See* Essay 2.)

Create Opportunities for Experimentation: DoD should develop a National Autonomous Test Range that includes robust modeling and simulation tools RAS and physical range space for MUM-T test and evaluation (T&E). Creating a space that both the DIB and commercial sectors can utilize would encourage additional collaboration between the sectors, speed technical improvements in RAS, advance technical understanding of autonomy through a centralized testing databank, and reduce the overall cost of T&E for RAS. (*See* Essay 6.) DoD should also require RAS participation in joint force and service-specific exercises. A combination of operational experimentation and realistic modeling and simulation tools will have the added benefit of promoting user trust of RAS.

Recommendation 5: Development of Trust in RAS Users. As with any nascent technology, industry must avoid overselling technological capabilities—especially early in the development phase in front of potential operators. Until users begin to trust RAS capabilities, premature integration or overinflated expectations can actually set back operational acceptance.[44] To that end, DoD and industry should replace the "dull, dirty, and dangerous" mantra long used to describe traditional robotics applications with a new phrase: "efficient, effective, and economical." By emphasizing how robotics *adds* to DoD capabilities vice *replaces* personnel or missions, industry can promote a wider array of RAS capabilities and potentials for the warfighter. Finally, DoD should also look for opportunities to promote talent and robotics capabilities within its ranks and develop a core of professionals whose in-depth understanding of autonomy naturally leads to greater trust in the systems. One such way to imbed such talent in through integration of robotics into the military service academies' curricula, to include specific concentrations in the study of robotics. The United States has only begun to start down this evolutionary path, and it needs talent to propel and guide it toward a robotics revolution.

CONCLUSIONS

To be clear, the U.S. has not lost the robotics revolution. The RAS industry is expanding, and set to truly transform the nature of society's use of technology. The DoD remains technologically ahead of its competitors in many respects. In truth, DoD—largely through the innovative work of DARPA—has done more for commercial robotics around the world than perhaps any other single entity. But the days of DoD leading industry and dictating terms to a wide field of capable, defense-focused firms are over. Today's environment is one characterized by widespread diffusion of RAS's underlying technology and the lucrative prospect of its commercial utility. Just as with GPS and the Internet, many successful robotics firms owe their good fortunes in some capacity to a previous DARPA-funded research initiative.

For all the collective technical brilliance located there, Silicon Valley, Boston, and Pittsburgh—collectively America's RAS center of gravity—will not of their own accord develop militarily-useful technologies, nor seek to do large-scale business with DoD. For its part, the DoD may not entirely drive technological innovation within the industry, but it must be capable of understanding the state of technology for the purpose of assessing its potential defense applications. To that end, warfighters must be not only capable of developing visionary ways of warfare, but also articulating the performance attributes of the RAS that will enable them. Until that happens, the defense industry will continue to be both fractious and focused at the same time: fractious as it searches for diverse product portfolios with which to assure income, and focused on incremental improvements to the systems it already produces. The defense industry will persist in this condition until DoD and the services come together on a collective vision and organizing construct.

APPENDIX: ESSAYS

ESSAY 1: COMMERCIAL ROBOTICS AND THE US ECONOMY

Robotic and autonomous systems hold the potential to revolutionize American productivity, create new product markets, and ultimately boost US economic growth—but only if Americans are willing to go "all in" on the technology. In order for this benefit to materialize, American firms will have to make difficult investment decisions about technology that is sure to displace large portions of their human workforces. Additionally, the nation will need to adopt policies that transform it into the world's leading adopter of robotic technology.

The stakes for America's economy are high. Post-2008 financial crisis growth has been lackluster, and after multiple rounds of debt relief and taxpayer-funded "quantitative easing," the U.S. is more than $13 *trillion* dollars in debt.[45] By 2024, servicing just the *interest* on that debt will require 3.3% of US GDP, meaning the U.S. will spend more on interest than the nation's defense.[46] Put simply, the nation's ability to provide all the things expected of it far exceeds the US historical 2% GDP growth average. The central question, however, remains: Will the adoption of commercial robotics be sufficient to lift the US economy out of its stunted growth condition, or is the idea of a "reshoring" revolution just a hopeful idea?

The rapidly decreasing costs of industrial robots have provided an increasingly suitable substitute for expensive US human labor, sparking optimism in what has become known variously as the "reshoring," "onshoring," or "insourcing" movement. Bringing back previously outsourced manufacturing capacity is a promising trend for the economic outlook.[47] Having steadily declined from its peak in 1979, the US manufacturing sector lost more than a 5.8 million jobs (33.6%) between 2000-2009.[48] While a reshoring movement marks the bottom of that curve, the degree to which more American firms will reshore and its ultimate effect on the economy is a topic of dispute.

What is clear, however, is that the declining costs of autonomous systems and a corresponding decrease in manufacturing costs is propelling offshored manufacturing capacity back to US soil.[49] The automobile industry led the way in robotics adoption in an effort to drive down labor costs.[50] But the automobile industry cannot carry the weight of the manufacturing sector in this adoption effort, much less spur the rest of the economy. In the next ten years, the pharmaceutical, medical devices, electronics and food and beverage industries are all expected to invest heavily in automated manufacturing infrastructure, but the forecasts for just how much are imprecise and a matter of speculation.[51] Industry optimists at Robotics Industry Association (RIA) estimate that only 10% of US firms that could benefit from manufacturing automation have adopted it so far—the implication being manufacturing automation represents a vast opportunity for American firms to both boost productivity and reduce costs.[52]

The US economy has shifted since the heyday of manufacturing. American firms increasingly provide services instead of physical products, and manufacturing now only comprises 12% of US GDP.[53] Meanwhile, the types of reliable, precision systems required to suitably replace humans in the services sector are still one-of-a-kind or hand-assembled units that remain cost prohibitive. Compared to the manufacturing and industrial robot segments, service sector applications—including both robotics and the application of sophisticated artificial intelligence to replace human analysis—still represents a niche market in its infancy.[54] By most accounts, the US services sector—responsible for nearly 80% of nation's GDP—will be unlikely to reap the benefits from robotics-augmented productivity before the 2020 timeframe.[55]

The downside to an increasingly automated global economy is and will continue to be the elimination of human jobs that accompanies the technological progress. While study data is sparse, anecdotal evidence is mounting of an oft-repeated pattern where unskilled and semi-skilled labor is replaced by technology.[56] The prospect of losing thousands of jobs to increasingly automated factories is likely to generate political repercussions designed to slow the inevitable shedding of unskilled and semi-skilled labor positions. What is less clear is just how much the effects of the recent US recession will dampen the fervor with which unions move to preserve status quo jobs and by extension, erode the cost saving potential of autonomous systems. Again, hard data is elusive, but anecdotal evidence indicates labor unions are increasingly willing to make concessions in the hopes of saving at least *some* manufacturing jobs instead of losing them *all* to offshoring.[57]

On the other side, robotics proponents forecast aggregate job gains from the expected increase in productivity and the accompanying growth in "downstream activities," such as supply chain activities, shipping, storage, and other supporting services.[58] One study observed a set of 76 companies adopting industrial robotic technology, which resulted in the creation of 294,000 US jobs over the course of a three year period.[59] Robotics analysts currently estimate at least two million aggregate jobs will be created worldwide by the year 2020 due to such activities.[60] While such an assessment sounds like cause for celebration, a bit of perspective is required. As the US manufacturing sector alone lost two million jobs in a single year between 2008-2009, the aggregate jobs forecast—if accurate—will not be the sole economic savior many are making it out to be.[61] A secondary benefit may come from a renewed focus on engineering and production teaming, which will strengthen the US historical core competency of product innovation, but the economics of this shift are difficult to predict as well.[62]

While many factors make predicting the future effects on the US economy problematic, one conclusion is certain. The potential productivity gains American industry—and later services firms—could reap is not only open to American firms. Despite the onshoring movement and increasing adoption of commercial robotics, the U.S. trails three other nations in robotic usage. South Korea, Japan, and Germany all employ more robots per human worker than does the U.S.[63] And the trend amongst US competitors is set to follow the path that killed the American manufacturing industry in the first place: the world's low-cost labor leaders, not content to lose manufacturing dominance, are increasingly adopting robotic manufacturing techniques to continue competing on cost. Proof? In 2013, China became the world's leading importer of industrial robots, purchasing one of every five produced worldwide.[64]

Even as American firms increasingly automate production, those same labor cost savings will remain available to any firm—American or otherwise—willing and able to invest in the technology. In other words, American firms will have to remain competitive through the use of automated manufacturing, but its global use means robotic systems will become a minimum requirement as opposed to a source of unique competitive advantage. This environment is hardly a recipe for rescuing the US economy from its compounding national debt trap.

In order to ensure America's industrial base is doing all it can to remain competitive on a global scale, the US government needs to take proactive measures. First, the US government should incentivize the adoption of robotic and autonomous systems in order to boost aggregate worker productivity. Second, the U.S. must face head-on the pending shock to the jobs market caused by robotics displacing human workers. While no single, easy solution exists, predicting the types of jobs that will be displaced is straightforward. Thus, the government and industry should team to make adjustments to the education and vocational training systems necessary to provide the types of skills displaced workers will need to reenter their industries. It will not be an easy transition for individuals or for the nation, but it is an entirely necessary one for the sake of the US economy—and by extension, the future of America. (Lt Col Rob Masaitis, USAF)

ESSAY 2: ISRAELI LEADERSHIP IN ROBOTICS AND AUTONOMOUS SYSTEMS

Over the past decade, Israel's successful integration of unmanned systems into its armed forces helped the country become the planet's leading exporter of unmanned air systems (UAS). Israel's success is firmly rooted in unique factors directly related to the country's foundation, historical experience and a hostile regional environment. These forces and the country's small size have endowed its people with a sense of urgency, common cause, and closeness—amplified by the relationships forged through compulsory service in the IDF—that result in the pragmatic approach to innovation that has yielded such outstanding results.

A young democracy founded after the trauma of the Holocaust and thrust immediately into almost constant conflict with its Arab neighbors, Israel has felt the pressure of a constant existential threat for much of its history. The challenge of creating a new state in a politically hostile environment with scarce natural resources forced Israelis to find new, creative and innovative solutions to the challenges they faced. From the outset, Israel has depended on and consistently invested in the one strength that it had: its people. Succeeding waves of immigration brought diversity and critical human capital that bolstered the nation's considerable investment in education, science, and technology and buttressed an entrepreneurial spirit unrivaled in the region. This well-tended human capital enabled Israel to develop and maintain a qualitative edge that allowed it to face numerically superior foes without exposing the Israel Defense Forces (IDF) to the high casualties that would have devastated its small population.

Compulsory military service by all men and women over the age of eighteen is a shared reality for most Israelis that gives the IDF tremendous influence in shaping the nation's culture and education. Soldiers acquire technical skills and a personal understanding of the military's needs before pursuing college degrees or entering the workforce. This experience is reinforced and kept current by the continued obligation to serve in the IDF reserves. Compulsory service and the prioritization of Israel's security underpin a tight working relationship between the IDF and the defense industry that enables innovation and rapid adoption of new defense products. Specialized agencies and operational units collaborate with defense companies during all stages of development and testing. The resulting shorter feedback loops and constant learning produce an optimized development cycle for cutting edge technologies.

The Israeli acquisition system mirrors the pragmatism and collaboration evident in product development. With persistent security challenges, rapid fielding of the latest systems is a shared priority of the IDF and industry. The closeness of Israeli society allows field commanders to request solutions to operational needs and to push hard for rapid acquisition. Sharing a high tolerance for risk and improvisation characteristic of Israeli culture, commanders and developers frequently collaborate on field-testing by deploying innovative products into operational use before the end of the development cycle. Greater risk tolerance and a willingness to accept an "80% solution" in order to get system into the soldiers' hands dramatically speed the transition time from prototype to program of record and accelerate the rate of adoption of new products.

For autonomous systems, the IDF has coupled the advantages detailed above with a building block approach to development and testing. Unmanned system innovations in one domain are leveraged to advance research in another. For example, a successfully tested and fielded control algorithm is the natural starting point for the next unmanned platform. This "Lego" or building block approach enables more rapid development and eases the test burden by relying on already validated sub-systems. This methodology has allowed the IDF to acquire and upgrade unmanned systems rapidly while promoting interoperability across its forces.

(BG Mordechay Baruch, Israeli Defense Force and Mr. David Mico, Department of State)

ESSAY 3: RAS INTEGRATION INTO LOGISTICS

While DoD logistics demands are complex and variable, projected and commercially-proven RAS technology has the potential to deliver enormous labor and capital productivity improvements. An analysis of common DoD logistics processes shows substantial overlap and opportunity for integration of commercially available industrial robots. In short, it's time for the DoD logistics to embrace RAS.

Commercial trends in industrial robot development improve their utility for DoD logistics application. Such commercial trends include: improved human-robot collaboration, greater robot flexibility and user-friendliness, uncomplicated configuration, and low price points.[65] State of the art software graphical interfaces and intuitive reconfiguration and programming tools have lowered user skill requirements and increased the flexibility of robotic applications. For example, the Baxter robot simplifies programming by recording its physical movements as the user guides the product's arms and manipulators through the desired work steps.[66]

Many RAS technologies for DoD logistics application exist or are in development today:

Logistics Unmanned aerial vehicles (UAVs): The Marine Corps pioneered the use of UAVs in tactical lift with its application of the remotely operated K-MAX helicopter in Afghanistan.[67] A more ambitious project by DARPA, the Areal Reconfigurable Embedded System, aims to create a tactical resupply UAV.[68] While the use of UAV technology in strategic lift applications may not remove humans from cargo aircraft in the near future, the potential to reduce flight crews below two is a soon-to-be-realized objective.

Autonomous Ground Vehicles (AGVs): AGVs offer obvious logistics utility for mail delivery, material handling in depots and distribution centers and cargo handling. AGV designs can operate under remote user control, in "follow-me" modes, or using *a priori* user-specified route plans. For example, the Autonomous Mobility Appliqué System can transform an existing cargo truck into an AGV to minimize risks to supply convoys.[69] An AGV model to watch for DoD strategic airlift is Frankfort International Airport's implementation of pilot-controlled AGVs to support heavy aircraft taxi from parking to point-of-takeoff to reap fuel cost savings.[70]

Warehouses: Commercial firms like Amazon and Diafuku already capitalize on AGVs to dramatically improve productivity in factories, warehouses and distribution centers.[71] The use of autonomous material handling equipment also enables firms to capitalize on big data applications through interfaces with warehouse, logistics and transportation management systems.[72]

Remote Presence Technology: When combined with precise manipulators, 3-D imaging, and high bandwidth networks, remote presence technology allows high skilled maintenance artisans to execute complex tasks on work pieces at remote distances. SRI International has adapted this technology with light-weight, dual-arm actuators mounted on unmanned ground robots to permit explosives experts to disarm bombs remotely.[73] Such capability would allow the DoD to affect depot-level repair in remote locations using artisans working in DoD facilities on the other side of the globe.

Exoskeletons: Operational logistics personnel can reduce fatigue associated with repetitive lift-and-carry tasks and amplify human strength through the use of exoskeletons. Lockheed Martin has even developed logistics specific exoskeleton that lightens user loads and reduces fatigue with an unpowered design.[74]

Adoption of robotics technology by the DoD logistics community will yield productivity improvements. Over the long-term, such improvements will enable DoD to invest scarce budgetary resources in warfighting technology and personnel thereby placing greater emphasis on the tooth rather than on the tail. (Mr. Terence Emmert, Department of Defense)

ESSAY 4: OPPORTUNITIES FOR MANNED-UNMANNED TEAMING (MUM-T)

Today the U.S. faces growing, multi-axis threats and the need for presence in more places than ever before. Given declining defense budgets, the U.S. must find an economical approach to sustained conflict against global extremism and simultaneously prevent the overuse of high-end capabilities designed to deter near-peer threats.[75] Much like the previous offset strategy's focus on technology, the development of RAS may serve as a cornerstone of the next offset strategy. RAS can provide both an economical means to address the low-end spectrum of military operations and an effective means to mass against a high-end peer threat.[76] To reap the full benefits of RAS, DoD should employ the concept of Manned-Unmanned Teaming (MUM-T).

For MUM-T to cornerstone a truly effective strategy, the U.S. must develop Concepts of Operations (CONOPS) in each domain that capture the true value RAS can provide the joint force. In his book, *Warfighting and Disruptive Technologies*, Terry Pierce stated, "A study of modern warfare suggests that whoever is first to combine new technologies with disruptive doctrine can gain a decisive advantage. Conversely, a military that is slow to adapt new ways of fighting to technological advance opens itself to catastrophic defeat."[77] Thus, the challenge remains: can DoD describe the realm of the possible with RAS?

To meet this challenge, DoD should envision how MUM-T will benefit the force across every discipline and in every regime. DoD should first analyze the portfolio of manned platforms and then leverage RAS to increase effectiveness or to fill gaps in critical vulnerabilities. Instead of perfecting a robotic system that can "do it all," services should focus on a "system-of-systems" approach that enables humans and robots to perform functions for which they are best designed. Examples of such teaming approach exist on land, in the air, and in the sea:

Ground: Through a MUM-T focus, manpower intensive convoy operations can be transitioned to a "pack" of manned platforms with unmanned follower ground vehicles.[78] Israel operationally employed this very concept in their latest conflict in Gaza. What used to take scores of personnel could be accomplish with a mere handful, plus be exponentially safer in the face of Improvised Explosive Device (IED) tactics.

Sea: The Office of Naval Research (ONR) is currently developing Unmanned Surface Vehicles (USVs) that defend larger manned assets, such as destroyers and carriers.[79] USV arsenal ships, sailing in formation with their manned counterparts, would increase the overall lethality and effectiveness of destroyers and provide a critical defensive edge against advanced enemy missile systems. Likewise, future Unmanned Undersea Vehicles will be capable of autonomously tracking enemy submarines and ships, creating "hunter-killer" teams between the manned and unmanned subsurface force.

Air: Opportunities for MUM-T abound in supporting both our legacy aircraft and the newer F-35 Joint Strike fighter (JSF). From unmanned refueling aircraft to Electronic Warfare, teaming UAVs with manned aviation will improve effectiveness and efficiency while significantly enhancing survivability through digital networking and shared sensor data.

Plentiful opportunities for effective teaming of manned and unmanned platforms exist. To exploit the full potential of RAS, DoD must create opportunities for successful integration of MUM-T into military operations and develop CONOPs that support and embrace RAS as a critical enabler. Through the adoption of MUM-T, DoD can expand security and cooperative defense initiatives around the world while preserving the US ability to provide suitable offset against near-pear aggression. In short, MUM-T can enable RAS to serve as an effective and economical component of the next off-set strategy. (LTC Kevin Murray, USMC)

ESSAY 5: DIB, GOOGLE, AND THE NEED TO STRENGTHEN THE DEFENSE PRODUCTION ACT

US national security depends upon DoD's ability to field innovation and cutting edge technologies into our defense portfolio. With the decline of research dollars in the traditional Defense Industrial Base (DIB) and the growth of powerful commercial companies like Google overtaking new tech areas like autonomy, the US government must critically look at its approach to engaging, leveraging and—at times—directing commercial markets. By updating our historical and present day tools to meet tomorrow's future challenges in developing and fielding robotics and autonomous systems (RAS), the U.S. can be armed once again to bring the entire arsenal of democracy to bear in furtherance of our national security objectives.

Historically, the U.S. has relied on a combination of patriotism and statutes to ensure access to the manufacturing capability necessary to preserve national security. From Henry Ford's voluntary conversion of his factory capability to the war effort to the best physicists in the country joining the Manhattan Project, the U.S. has effectively used patriotic calls to preserve national security.[80] Today, presidents enjoy a range of statutory tools to compel US companies to support national security priorities.[81] For example, Title I of Defense Production Act (DPA) allows the president to impose priority contracts on domestic companies or individuals for goods and services "necessary for national defense."[82] Thus, the government can trump other contracts through the use of DPA prioritization, like it did when purchasing Mine Resistant Ambush Protected (MRAP) vehicles for use in Afghanistan.[83] Title III of DPA provides tools for the government to ascertain the health and capability of a particular industry and take steps to ensure the country has the ability to produce critical defense materials and goods.[84]

In his farewell address, President Eisenhower made the case for a vast, permanent armament industry as to "no longer risk emergency improvisation of national defense."[85] While America's approach toward building a robust DIB has worked well historically, in recent years the DIB has failed to keep pace with the commercial sector in RAS. In Ike's day, the U.S. spent more on military security than the income of all other US corporations combined.[86] Today, Google's net worth is over *twice* the sum of the entire DIB; indeed Google could purchase any defense firm simply with on-hand cash.[87] Most troubling is how the commercial sector has outpaced the DIB in terms of R&D. The combined R&D expenditures for the top five defense companies is less than half of Google's annual R&D.[88] This disparity has grown more apparent with Google's procurement of top robotics firms. Within the last two years, Google has gobbled up eight of the US top RAS firms.[89] Google also possesses a seeming magnetic-pull on software engineering talent. Both government research laboratory and industry officials lament the difficulty in retaining talent in the face of Google job offers…especially in the autonomy area.[90]

What makes Google's recent robotics purchases most troubling is that no one seems to know what innovative breakthrough or robotics market the company is trying to pursue. Google's corporate values make clear that it seeks to provide "a great service to the world," to "do things that matter," and above all "don't do evil."[91] Recently, the chief of Google X—the main innovation powerhouse within Google—reinforced the "don't do evil" informal mantra and stated the company's desire to "actively make the world…a radically better place" even if that forsakes opportunities for profit.[92] While some are comforted by these grandiose visions of goodness, DoD should be concerned if it fails to understand either Google's innovation intentions or its capabilities. In short, Google is not Ford and may not help the U.S. develop autonomous robotic systems solely out of a sense of patriotic duty.[93]

Given the great number of unknowns about Google coupled with the declining R&D

investment by the DIB into RAS, the U.S. should take a serious look at a range of approaches—from engagement to statutory compulsion—to ensure the nation can maintain its national security edge in RAS. On the engagement front, the US government should appeal to a common set of shared values with Google regarding autonomy. In the cybersecurity realm, Google has indicated a willingness to collaborate with the government on "the defensive side of things."[94] In that same vein, DoD should promote engagement through events such as DARPA challenges designed to demonstrate RAS in natural and man-made disasters. Furthermore, DoD should recognize Google's leadership in autonomy and include Google in discussions about ethical and legal implications of autonomous systems in warfare.

DoD should also encourage DIB companies to engage and partner with high-tech commercial firms across a range of RAS projects. Even if a commercial firm like Google voluntarily assisted DoD in furthering RAS technology during a national security crisis, they would need DIB partners skilled in manufacturing, testing and deploying weapon systems in order to bring systems to production. Through dialogue and joint partnerships in RAS, these firms may find synergies in research endeavors—such as how to test autonomous systems cheaply and effectively. While DoD has limited authority to compel DIB firms and pure commercial firms to partner, DoD can facilitate interfaces and collaboration.

In addition to engagement, the president should assert his existing DPA authorities to understand industry capabilities in RAS and to leverage Google personnel for national security purposes. First, the president should direct an industry study under his Title III DPA authority to understand the robotic industry capabilities and clarify which companies are capable of developing autonomous systems for future defense use. In particular, this study should seek to understand how the DIB can leverage innovations within the commercial robotics sector and determine whether enough R&D dollars (between defense and civil companies) are being invested in autonomy research. By identifying areas of overlap between the commercial and military sectors and ascertaining gaps, DoD can better target limited R&D funds.

While Title III of the DPA can be applied to better our national security posture with respect to RAS, Congress should also clarify Title I in the unfortunate event the president must compel Google, or similar company, to assist in manufacturing RAS systems.[95] It remains unclear whether the government can force a company like Google, which does not make any goods, to produce a product just because the firm possesses the know-how. While the statutory language implies that the president can require performance under contracts for any entity he "finds capable" of such performance, the statute expressly denies the president the ability to require purely employment contracts.[96] Thus, the question becomes whether the president could find a company legitimately "capable" of producing a product when it currently sells no product nor accepts contracts for production of goods.[97] Enforcement becomes more problematic because the DPA is premised on reassignment of contract "priorities" by jumping in the front of the production line.[98] In Google's case, they do not currently accept production contracts for robotics nor service contracts to develop software for other companies. In all, the ability for the government to exercise the Title I power of the DPA toward Google remains unclear.

The U.S. should not play a passive role in understanding the deltas between commercial and DIB capability. In light of lagging R&D investment in RAS by DIB and absorption of the best robotics minds into commercial firms like Google, the US government should maximize engagement opportunities and clarify applicability of the DPA to companies clearly capable of RAS production, but who have yet to produce products or accept contracts. The U.S. can ill-afford to start asking the tough questions about leveraging commercial RAS capabilities once on the receiving end of an autonomous weapon strike. (Lt Col Linell Letendre, USAF)

ESSAY 6: RECOMMENDATIONS TO IMPROVE RAS TESTING

While RAS procurement poses unique challenges with requirements development and lengthy acquisition processes, test and evaluation (T&E) may prove the most challenging aspect to rapid RAS fielding. As one RAS program manager put it, "the testers may price autonomy out of business."[99] To overcome this looming predicament, DoD must proactively develop and resource a strategy that acquires the tools and technology necessary to test autonomous systems.

Why is T&E so challenging for RAS? First, contrary to normal T&E, testers are not comparing the system's actions against predicted actions but instead judging the *decisions* made by the system.[100] Evaluators must collect data to determine whether the system made a good choice to accomplish a particular outcome and also understand why it made that decision and what its degree of confidence was when making the decision.[101] These testing difficulties are compounded when placing a single autonomous system into an environment with multiple manned and unmanned platforms. The resulting emergent behavior presents nearly an infinite amount of non-deterministic responses to a given mission set.[102] Additionally, when evaluating an autonomous system during operational T&E, testers must assess the collaboration between the RAS and human operator in order to determine if the system as a whole accomplishes the desired effects.[103] Finally, beyond just the testing of reliability and safety, T&E must yield trust in the warfighters, both those operating RAS and those sharing the same battlespace.[104] This last aspect—essentially testing RAS for trust—greatly compounds testing difficulty.

While DoD has recognized these complexities, insufficient investment has been made and numerous shortcomings exist in RAS testing.[105] DoD has neither standardized testing framework nor design of experiment methodology for RAS.[106] DoD lacks a uniform modeling and simulation (M&S) approach and does not possess a centralized database for comparing RAS performance. Further, DoD has no standard way to judge a system's level of autonomy nor has it adopted a specific model for evaluating human-machine interaction or metrics for measuring human "trust" in a system. Most troubling, however, is the lack of a consistent DoD strategy to enable the development of the technology and tools necessary to validate autonomous systems.[107]

DoD should take a proactive, intentional approach to autonomous testing by:

Adopting a RAS T&E Strategy: Currently, DoD is developing RAS testing technology and tools in an uncoordinated fashion. To correct this, DoD should assign an office of primary responsibility, draft an overarching strategy for development of RAS T&E tools and technology and then link resources to it. Within this strategy, DoD should establish target dates and requirements for the development of: 1) standards for RAS testing frameworks, 2) a RAS M&S approach, 3) metrics to evaluate human-machine interfaces, 4) measurements of human trust of the unmanned system, and 5) a uniform method of determining levels of autonomy.

Creating a National Autonomous Testing Range: To propel such a strategy forward, DoD should develop an autonomous test range with both robust M&S capability and physical test range space. Such a test range would encourage standardization of testing frameworks and enable centralized collection of data, which in turn would allow developers of autonomous systems to learn and capitalize on unmanned platform testing from across multiple domains.

Almost three years have passed since the Defense Science Board laid out a series of recommendations for the T&E community regarding autonomous systems, yet DoD has made limited progress on developing the tools and techniques necessary to test RAS effectively.[108] With a unified RAS testing strategy and a national autonomy testing range, RAS can be rapidly tested…and placed in the warfighter’s hands, where they belong. (Lt Col Linell Letendre, USAF)

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