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Bolts from Orion: Destroying Mobile Surface–to-Air Missile Systems with Lethal Autonomous Aircraft

By

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Disclaimer

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PREFACE

One of the most interesting aspects of my job is participating in wargames, and sitting through many hours of wargame briefings provided the genesis for this research project. My primary concern at wargames is how to cope with anti-access/area denial (A2/AD) from a logistics and basing standpoint, because logistics is my profession. However, I am also fascinated by the overall challenge presented by A2/AD strategy.

When Air Command and Staff College put out a call for a focused research group concentrating on air superiority in an A2/AD environment, I jumped at the chance to dig further into topics that really peak my interest. My hope is that this paper, written from an outsider's view, will offer something of value to those that guide our Air Force's future. America's competitors are making serious inroads against our traditional technological advantages, and advanced mobile surface to air missile systems networked in a dense, integrated air defense system, present a huge challenge to even stealth aircraft with precision guided munitions. Autonomy offers an opportunity to stay a couple steps ahead of the competition in the dangerous world of suppressing or destroying enemy air defenses.

I would be remiss not to thank my classmates. Their peer reviews greatly enhanced this thesis, and reviewing their work provided ideas for my own. My advisors, Dr. Christopher Johnson and Dr. Heather Marshall have also been extraordinarily helpful. Dr. Marshall's constant barrage of pertinent news articles to read will be missed. I also want to thank my friend Dr. Robert Athay. Dr. Athay's background with the Navy's autonomous weapons programs and advice has been extremely helpful. Finally, I must thank my wife. Her support has been tremendous during the eight weeks of her thesis widowhood. I could not have done it without her.

ABSTRACT

Modern mobile surface-to-air missile (SAM) capabilities are far more lethal and sophisticated than the Iraqi integrated air defense system (IADS) the US demolished in 2003, and are being used by potential adversaries as one component of anti-access/area denial (A2/D) strategy. This research explored the possible advantages autonomous unmanned aircraft systems (UAS) could offer for the suppression of enemy air defenses (SEAD) mission. Research was conducted by surveying existing literature on advanced surface to air missile systems, SEAD, remotely piloted aircraft, and artificial intelligence. This was used to create four future scenarios envisioning how autonomous aircraft could be used for SEAD.

Lethal autonomous UAS are controversial and the concept of machines making lethal targeting decisions is not to be taken lightly. Arguments abound about the legality and morality of lethal autonomous engagement and the United Nations is actively debating the issue. Artificial intelligence (AI) needs to advance before machines can make lethal engagement decisions.

Fully autonomous UAS that execute SEAD without man-in-the-loop control are too much of technological and political risk, but the US should pursue developing flexible levels of autonomy to enable human-machine teaming followed by developing swarms to provide an advantage for SEAD. Increased investment in autonomous UAS is necessary to ensure the US maintains an edge over potential adversaries advanced SAMs in future A2/AD conflicts.

Introduction

For residents of London and other British cities, the summer and fall of 1944 were seasons of fear. The Germans had launched their campaign of terror using V1 and V2 rockets to rain sudden destruction from the sky. The V stood for vengeance, and the rockets exacted a price for the havoc wreaked on German cities by the Allies' strategic bombing campaign. In August of 1944, the Allies, in a desperate attempt to bring an end to that fearful summer, began Operation Aphrodite. They hoped to suppress and destroy launch sites and production facilities for the German V1 and V2 rockets that were terrorizing London.[1] Innovators added radio controls and television cameras to worn out B-17s to allow them to be flown by a companion aircraft, with 12,000 pounds of unnecessary gear replaced by explosives. The huge flying bombs could not reliably take off under remote control so they were flown to an altitude of 2,000 feet by a pilot and flight engineer. The crew parachuted to safety after reaching altitude while the command plane assumed flight control.[2]

Operation Aphrodite was spectacularly unsuccessful. Plagued with reliability issues, faulty B-17 radio controls failed to steer these new weapons to their intended targets. One devastated a two-acre swath of the bucolic English countryside after crashing. Only one remotely controlled B-17 did significant damage to its target, and the project was cancelled two months later.[3] The most notable piece of history connected to Project Aphrodite is that Navy Lt Joseph P. Kennedy, the older brother of President John F. Kennedy, died when his aircraft exploded as he and the flight engineer prepared to parachute to safety.[4]

Unlike the flying bombs of Project Aphrodite, modern RPA have made exponential progress since 1944. A human pilot can control an RPA from thousands of miles away and successfully find, fix, track, target and engage terrorist leaders or other adversaries. However, significant progress must be made in the areas of autonomous flight and autonomous target location and engagement. RPA performing these actions autonomously are the next technological hurdle to clear, and could provide an advantage for SEAD missions.

Autonomous and robotic weapons with advanced artificial intelligence (AI) represent a revolutionary path for developing weapons that exceed human endurance and increase kill chain speed. The US and competitor nations are currently developing and refining ever more autonomous weapons systems. US efforts include the Global Hawk, which is already capable of some autonomous flight functions including aerial refueling.[5] More recently, Russia set a goal to convert 30 percent of its military force to robots by 2025; China is also developing weapons with autonomous capabilities.[6] As Artificial Intelligence (AI) improves, there will be opportunities to use lethal autonomous aircraft in the extremely hostile environments being created by US competitors.

Many countries are developing, deploying, and proliferating weapons systems designed to keep the US Military from accessing or operating in a region. This strategy, called Anti-Access/Area Denial (A2/AD), extends through all domains and threatens freedom of physical movement and the command and control vital to successful military operations. The development of advanced mobile surface-to-air missile (SAM) systems is one of the most worrisome aspects of A2/AD, since these systems are specifically designed to counter the US military's technological advantages.[7] As autonomous aircraft progress, they could play a significant role in the suppression of enemy air defenses (SEAD), a key part of defeating A2/AD strategies and achieving air superiority. Advanced mobile SAM systems extended engagement ranges, coupled with their resiliency and ability to fire and move quickly, pose a huge challenge to air superiority. Airpower will have to continually evolve to stay ahead of these advanced threats. Autonomous aircraft should be examined as part of the needed evolution because they can perform high-risk missions without endangering pilots and present some advantages, like swarms, that cannot be affordably duplicated by manned aircraft. This paper proposes four possible future approaches for developing autonomous aircraft capable of employing lethal effects against advanced mobile SAMs.

Background

The Challenge of Advanced Mobile SAMs

Since the first Gulf War in 1991, US competitors and potential adversaries have developed military technology and political strategies designed to hamper or deny the US military's ability to project power into a region.[8] Because the US brought down Iraq air defenses so quickly during the Gulf War, it caused a worldwide revolution in SAM design and technology specifically aimed at nullifying US tactics and precision weapons.[9] Modern, sophisticated, mobile SAMs are not easy to suppress or destroy, and SEAD is a dangerous mission for even skilled, experienced pilots. As quickly as the United States develops new technology to defeat SAMs, adversaries will develop counter measures to keep their SAMs viable. Modern mobile SAMs can shoot and move in minutes, which makes pinpointing their location and destroying them an extreme challenge.[10]

Mobility is not a new concept for SAM launchers. During the Vietnam War, the North Vietnamese successfully used the SA-2, which operated from fixed sites, but had mobile elements that could be relocated to different locations. It is thought that the North Vietnamese rotated 50 SA-2 batteries between 150 fixed sites.[11] One of the primary differences between advanced mobile SAMs and their predecessors is that all system components are networked, and are mobile enough to re-deploy within in minutes of firing to another location.

Developing autonomous aircraft specialized for SEAD should be pursued as a primary approach to defeating modern SAMs. Published in 2012, Department of Defense Directive 3000.09 required military departments to develop doctrine for the use of autonomous weapons.[12] In 2014, the Air Force published the *United States Air Force RPA Vector: Vision and Enabling Concepts 2013-2038*, which calls for the next generation of RPAs to be capable of performing a broad range of missions.[13] The publication states that the Air Force must "address legal, moral, and ethical concerns" to enable lethal autonomous targeting.[14] Clearly autonomous aircraft are part of the Air Force's future vision. The rapid pace of technological advancement for integrated air defense systems (IADS), SAMs, and autonomous weapons demands the Air Force envision and examine how autonomous technology can be used to counter mobile SAMs and operate successfully in an intense A2/AD environment.

Throughout this paper, remotely piloted aircraft (RPA) will generally be used to refer to aircraft that rely on man-in-the-loop (MITL) piloting, unless historical or service specific context dictates a more appropriate label. RPA is the current preferred term in the *U.S. Air Force (USAF) Remotely Piloted Aircraft (RPA) Vector—Vision and Enabling Concepts: 2013–2038.* The *RPA Vector* uses the term unmanned aircraft (UAS) for entire control systems and aircraft with more autonomy, and thus this paper replicates current Air Force terminology to designate autonomous UAS.

Previous Thought on Employing RPA and UAS

Aircraft with limited autonomous functions already exist, and as their capabilities increase, there must be robust dialogue on their role and use, including the role of SEAD missions. Two Air University papers written in 2004 address using unmanned combat aerial vehicles (UCAVs) for SEAD. Major Brick Izzi suggested UCAVs could become global strike enablers penetrating air defenses early in a conflict to provide SEAD and envisioned UCAVs that could stimulate air defenses, thus revealing their positions and then suppressing the threat.[15] He also envisioned UCAVs that would act as super wingmen performing the more dangerous search role to find SAMs.[16] Since a mobile SAM can move quickly and frequently, locating them can be very challenging, especially if the SAM sits without emitting any radar signals until the last possible moment to engage strike aircraft. Major Izzi felt UCAV could be particularly effective in the search role and then passing the SAM locations to the SEAD commander for either kinetic destruction or electronic suppression.[17] Lt Col James C. Horton, also writing in 2004, argued that current airframes, sensor technology, weapons, and command and control capability would all have to be further developed before UCAVs could perform important SEAD missions.[18]

Given the time of writing, neither paper could explore how a fully autonomous UAS could execute the SEAD mission. In 2007 Major Julian C. Cheater addressed using autonomous aircraft to accelerate the kill chain, arguing that UAS could locate and rapidly validate targets increasing the speed of the human decision loop.[19] Major Cheater also briefly suggested that stealthy UAS fitted with next generation stand-off weapons could fill a SEAD role.[20] In 2014 Captain Michael W. Byrnes boldly proposed an autonomous tactical fighter called FQ-X in the *Air and Space Power Journal*.[21] Byrnes suggested a tactically autonomous, machine-piloted aircraft would bring new and unmatched lethality to air-to-air combat.[22] Byrnes argued artificially intelligent machine pilots could execute the mathematics underlying flight quicker than human pilots.[23] Byrnes focused on UAS for air-to-air combat rather than as a SAM hunter. However, Byrnes's ideas about highly maneuverable UAS can be extended and applied to the SEAD mission. In 2015 Lt Col Christopher Spinelli argued military professionals needed to explore fully the legal, ethical, and tactical/doctrinal implications of lethal UAS but did not suggest any specific doctrine urgently needed in the Air Force.[24] This paper will integrate arguments about UAS and SEAD to focus specifically on how UAS could locate and destroy advanced mobile SAMs to help achieve air superiority in an A2/AD environment.

Autonomous RPA Should be Developed for SEAD

The Air Force needs to develop technology and operating concepts incorporating lethal UAS into SEAD missions. This thesis explores how the Air Force should employ lethal autonomous UAS to defeat advanced mobile SAMs to help enable air superiority. Near-peer competitors' A2/AD strategies include advanced mobile SAMs that are difficult to locate and suppress or destroy, which threaten the United States' ability to project power into a region.[25] Mobile SAMs like the S-400 can engage aircraft out to 247 miles.[26] This places many of the US' current SEAD stand-off weapons inside the threat envelope. For example, one of the primary weapons specialized for SEAD is the AGM-88E Advanced Anti-Radiation Guided Missile (AARGM). It only has an estimated range of 60+ miles.[27] Russia has sold advanced mobile SAMs to China and other countries, including Iran. Both China and Russia can threaten US ability to command and control (C2) in A2/AD environment by using anti-satellite and cyber warfare capabilities. Therefore, if an adversary can successfully deny access and freedom of movement while degrading C2 it will jeopardize air superiority. UAS that can perform SEAD when C2 links to RPA are compromised is a strategy worth exploring.

Current SEAD approaches rely on electronic warfare platforms, high-speed anti-radiation missiles (HARMs), and stealth to defeat targeting radars so that SAMs can be engaged safely by manned aircraft. However, advanced SAMs can target aircraft before they reach the range necessary to employ many stand-off weapons, and SAMs are also built to defeat US countermeasures, including stealth technology. Therefore, SEAD remains a difficult and dangerous mission for manned aircraft.[28] To reduce risk to human pilots and more effectively defeat advanced mobile SAMs, autonomous UAS that are able to execute their mission in high threat areas, particularly when C2 is degraded, should be developed.

Research Framework and Methodology

This paper will use the scenario planning framework to consider the future development and employment of autonomous lethal aircraft for SEAD. The primary driving factors are technological feasibility, investment risk, and institutional and political friction. The four scenarios, which will be described in detail in the analysis section, include: *Singularity Rising*, *Killer Bees*, *Raging Centaur*, and *Erewhon.* Each will be rated along the axes of technological feasibility and investment risk. Technological feasibility is an estimate of how much current technology needs to progress to achieve each future scenario as well as how likely the US is to pursue a particular technological path. Investment risk refers to the trade-off between investing in autonomous technology versus manned technology. For Air Force senior leaders to invest enough funds to fully develop UAS technology they would have to embrace autonomy and accept the accompanying risk, as it would require an offset in manned technology investment.[29] The scenarios address distinct, potential future roles for UAS in Air Force SEAD operations, as partially pictured in Figure 1 below.

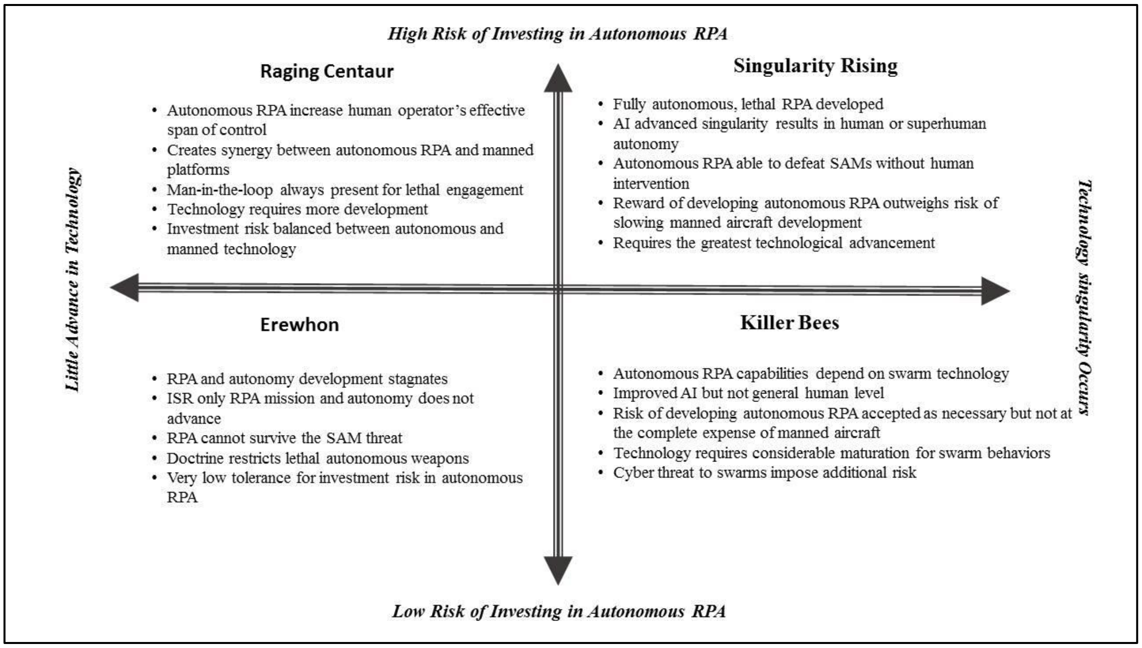

Figure 1. Scenario Planning Matrix

Select Current and Future Mobile SAM Threats

During the 1991 Gulf War the US' three-pronged advantage of precision guided munitions (PGMs), stealth technology, and superior intelligence, surveillance and reconnaissance (ISR), easily shattered the Iraqi air defense system that was based on Soviet technology and air defense doctrine.[30] It was a shocking wakeup call to the old Soviet arms industry, and a new arms race began to develop better air defense systems that could counter US air superiority. Currently competitor nations are producing SAMs that counter the US' traditional technological advantages.[31] The Russian arms industry leads this effort and has been very successful, producing SAMs such as the S-300VM (NATO nomenclature SA-23 Gladiator), or S-400 (NATO nomenclature SA-21 Growler), that are hard to locate and suppress or destroy.

To survive attacks by PGMs, advanced mobile SAMs include point defenses, which are weapons meant to defend the system from PGMs at close range. Point defenses are usually either anti-aircraft artillery or short-range SAMs such as the SA-22 Greyhound, designed to intercept and defeat PGMs in their terminal phase.[32] Increased SAM range can physically threaten ISR platforms out to 247 miles, and ground-based jamming technology has become much more effective at disrupting both C2 platforms like the Airborne Warning and Control System (AWACS) and ISR platforms like the Global Hawk.[33] Finally, the Russians have invested heavily in radar technology that can detect stealth aircraft. They focus on very high frequency (VHF) based radars as they use a longer wavelength that is better at detecting current stealth technology than radars emitting shorter wavelengths.[34]

Stealth relies on effectively shaping airframes and using absorbent materials to reduce radar signature.[35] The majority of signature reduction comes from shaping effects, and the shaping features must be longer than the radar waveform to be effective.[36] Large aircraft, such as the B-2, allow for longer shaping features and will retain much of their stealth against even VHF radars, but smaller aircraft such as the F-35 will be easier for VHF radar to see.[37] To add to the challenge, systems like Russian Nebo-M fuse data from three different radars, which increases the kill chain's ability to find, fix, track, target and engage stealth aircraft.[38] The Air Force's eventual fleet balance will have many more F-35s than B-2s or the new B-21. This will make aircraft with stealth that is effective against advanced mobile SAMs low density, high demand assets. The US will need to continue robust electronic counter measure development that outclasses adversaries' acquisition and engagement radars', jam resistance, and emitter locator systems to help F-35 SEAD aircraft make up for less effective stealth.

Russian arms makers have not been shy about exporting SAM technology, and even upgraded Cold War-era systems pose a nasty threat to US aircraft. Ironically, during their 2008 incursion against Georgia, the Russians lost several combat aircraft to their own Cold War-era SAMs that had been upgraded by Ukrainian contractors. During the operation, Russian aircraft's electronic countermeasures could not suppress the upgraded SAMs.[39] This is a lesson the US should pay attention to since all of its most likely competitors field credible mobile SAMs. China for example, is purchasing the current heavy weight champion of SAMs, the S-400 *Triumf*, or SA-21 Growler, from Russia.[40] If the Chinese placed the S-400 on one of their artificial reefs in the Spratly Islands, it would put real teeth in a South China Sea air defense identification zone. The below graphic displays how three S-400 SAMs could control a large portion of the South China Sea if placed on Woody Island, Mischief Reef, and Subi Reef.

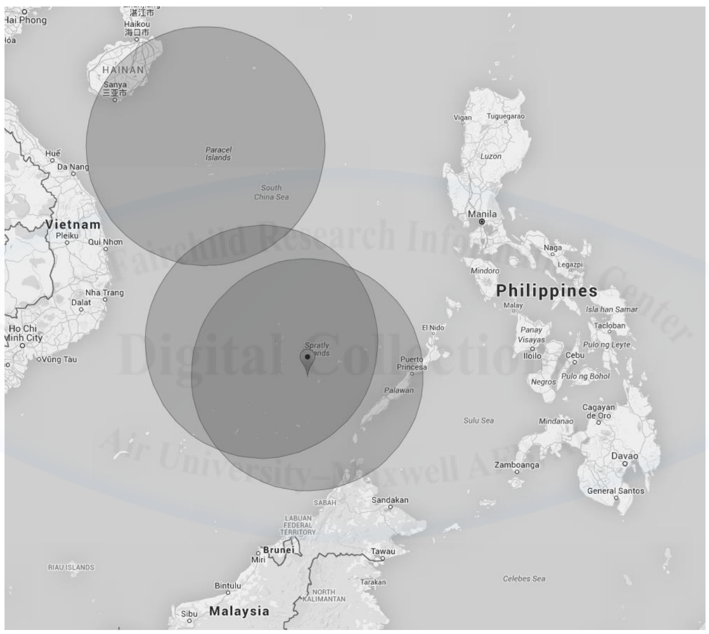

Figure 2. Possible S-400 threat rings in the South China Sea[41]

For comparison, an S-400 placed in Washington DC would have enough range to control air space over Baltimore, Philadelphia, and New York City to the north while stretching south to Raleigh, North Carolina, covering a circular area of 191,000 square miles.

The S-400 *Triumpf* was specifically designed to survive against PGMs by being highly mobile and integrating with point defenses. It was also developed to defeat opponents' jammers, stealth technology, and low-flying threats.[42] The S-400 has four primary mobile components mounted on a wheeled, all-terrain chassis. The battle management system includes the command post and acquisition radar, the fire units consisting of the transporter, erector, launcher (TELs) and "gravestone" engagement radars, extra SAM rounds, and the logistics support system. The "gravestone" engagement radar can track up to 100 targets and engage six targets simultaneously, making it a formidable system to locate and suppress or destroy.[43]

The S-400 will not keep its heavyweight title for much longer, with Almaz-Antey expected to field the next of generation mobile SAMs, the S-500, in 2017.[44] Little is known about the S-500, but it is believed to have the following capabilities: engage up to 10 targets at a range of 372 miles, provide ballistic missile defense, have a response time of three to four seconds, and carry two new missiles that can directly engage targets flying at hypersonic speeds.[45] The 372-mile engagement range will extend the threat against US C2 and ISR assets, electronic warfare platforms, and enablers such as tanker aircraft. Almaz-Antey is already working on an air-based replacement for the S-500.[46]

Advanced mobile SAMs have become a game-changing technology enabling A2/AD strategy and threatening US ability to gain and maintain air superiority. Stealth platforms like the B-2 Spirit and F-22 Raptor still present a challenge to SAMs like the S-400, but they are a costly, low density answer. The US will continue to advance stealth technology with platforms like the Long Range Strike Bomber (B-21) that will increase the ability of manned platforms to survive against advanced SAMs and penetrate air defenses. However, developing autonomous aircraft to hunt and destroy or suppress advanced mobile SAMs should be vigorously explored. Stealthy UAS would offer more loiter time to hunt SAMs while adding an extra layer of survivability since they can be built to maneuver at higher G-Forces than a manned platform.

US Forces have not faced a serious SAM threat for decades, and military aviators have been flying in a permissive environment since the invasion of Iraq in 2003. US aircraft last faced a SAM threat during Operation Unified Protector, but Libyan air defense operators never launched a SAM.[47] The US does have aircraft specifically tailored for SEAD and discussing their general capabilities will help envision the role UAS could play in SEAD.

SEAD Operations

Joint Publication 3-01, *Countering Air and Missile Threats*, outlines Joint SEAD doctrine as an "activity that neutralizes, destroys, or temporarily degrades surface-based enemy ADs by destructive or disruptive means."[48] As a doctrinal publication it does not give information about the tactics of engaging and suppressing or destroying SAMs, but it is useful for framing a general discussion of how SEAD works. One of the first things to understand is SEAD is more complex than firing high-speed anti-radiation missiles (HARMs) at active radars. In a 2011 article, Major Jeff Kassebaum argued that effective SEAD begins before the first sortie by thoroughly analyzing the command, control and communications (C3) used by an IADS. Kassebaum stated—"SEAD does not equal HARMs,"[49] and only by understanding how all IADS components communicate and share a common operating picture, can their C3 be disrupted and SAMs be fully suppressed.[50] The US did this effectively against Iraq's legacy SAMs and IADS, but the test against technologically advanced SAMs has never occurred. The US has not been resting entirely on their laurels, and there have been upgrades to primary SEAD aircraft since 2003, but over a decade of operating in permissive airspace has caused SEAD skills to erode.[51]

Planned SEAD is usually performed by a combination of platforms working together to suppress or destroy SAMs. The Air Force's main SEAD asset is the F-16 CJ equipped with the HARM targeting system (HTS). The HTS can autonomously locate and identify threat radars and pass targeting information to the HARMs before launch. The HTS can also provide targeting information to global positioning system (GPS) guided munitions.[52] The HTS was originally introduced in 1994 and has received several upgrades over the years. The last, which occurred in 2006, resulted in increased "frequency coverage, search speed, number of targets tracked and identification capabilities" and added precision targeting.[53] The problem is that the Russian S-500 will be fully operational in 2017, roughly 11 years after the last HTS update. That could mean the HTS technology will be dated compared to the most modern SAM.

The HTS represents a blending of man and machine since it autonomously locates, identifies, and ranges targets for the pilot to engage. This same technology could be applied to an UAS. The primary difference would be that an AI component would determine which threat was the priority to engage. Another option would be for a stealthy UAS to simply loiter and locate threatening air defense radars using HTS technology and then passing the information to manned aircraft so safe seams through IADS zones could be exploited. Air defense radars could be stimulated by unmanned decoy UAS to help map out SAM locations.

The Air Force is not alone when it comes to flying SEAD missions and the Navy provides significant capabilities. The premier airborne electronic attack aircraft used for SEAD is the EA-18G Growler which is replacing the old EA-6 Prowler. Based on the F/A-18 platform, it came into operational service in 2008. The Growler provides jamming of air defense radars to prevent SAMs from targeting friendly aircraft, and it also has powerful radar for locating air, sea-surface and ground targets. It carries the AGM-88E AARGM for destructive SEAD.[54] In contrast to the F-16 CJ, which only has electronic counter measures for self-defense, the Growler provides radar jamming and suppression for all friendly aircraft it is escorting. The F-16 CJ and EA-18G can combine to form an effective SEAD team. However, these assets have never faced S-300 or S-400 class SAMs designed to counter their advantages. Neither aircraft has stealth capability, so both would have to rely on their electronics being better than the adversarial SAMs to survive. It is a risky proposition for aircrew, and a well-planned role for UAS in SEAD could help reduce the risk.

UAS could perform valuable SEAD functions because of their ability to loiter long periods of time. In a non-destructive, electronic-attack role, a stealthy, loitering UAS could continually jam radars over a designated area using the advanced electronic attack hardware and software fitted to the Growler. The same technology the HTS uses to passively detect active radar could be adapted to allow a UAS to monitor radar waves being emitted and adjust their jamming attack to the most effective modes. The Defense Advanced Research Project Agency (DARPA) believes electronic warfare is one of the most promising possibilities for AI because computers can analyze radio frequencies magnitudes faster than a human mind. DARPA envisions an aircraft recognizing strange radio frequencies and developing real-time counter measures to protect aircraft from hostile targeting.[55] It would be natural to develop this technology and fit it to a UAS. Such a RPA or UAS could provide constant jamming, gaining at least two advantages. First, constant jamming would help prevent the enemy IADS from building a clear common operating picture to coordinate air defense actions.[56] Second, it could also help camouflage strike aircraft as they made their attack approach since the constant jamming signal would not be an indicator that strike aircraft might be coming.

A UAS loitering stealthily above the battle field and monitoring for SAM radar emissions would be somewhat like the SEAD tactic known as "preemptive shots," which involves launching a HARM over a suspected SAM site before the SAM's targeting radar is active. This is meant to suppress the SAM by either engaging it immediately on radar activation, or by keeping the operator from turning on targeting radar altogether.[57] Loitering UAS could provide constant electronic suppression and be used repeatedly, unlike the single use HARM. To fully imagine all the possibilities presented by autonomous aircraft it will be helpful to understand their history and progression.

RPA History and Development

Innovation and pioneering technology is part of the RPA's heritage. Elmer Sperry, inventor of the gyroscope, became interested in the possibility of unmanned aircraft and convinced the Navy to fund experiments a decade after the Wright Brothers first took flight. In 1913 Sperry mated the gyroscope and radio controls to airframes to test the possibility of unmanned flight. Early projects were not very successful partly due to limitations with radio control technology.[58] Experiments continued through World War I and World War II with radio-controlled aircraft designed to be one-way flying bombs for attacking heavily defended targets, but technological deficiencies limited their success.[59] 20 years after the end of WWII RPA capability would radically change.

RPA demonstrated the ability to execute dangerous missions decades before Predators, Reapers, and Global Hawks became commonplace in the modern battlespace. During the Vietnam War, RPA shifted to an ISR role and flew 3,435 reconnaissance missions. RPA were especially useful in areas with heavy air defenses to avoid pilot casualties.[60] The primary drone used in Vietnam was the Ryan 147 Lighting Bug. This drone was small enough that it was carried and launched from the under the wing of a DC-130 that also served as the control plane for the drone.[61] The Ryan 147 was produced in many variations, including one that was fitted with AI that allowed it to evade threats. It actually out maneuvered nine SAM launches,[62] an early demonstration of AI's potential to improve RPA survivability.

Figure 3. DC-130 taking off on a mission in Southeast Asia, carrying two AQM-34s. (U.S. Air Force photo reprinted from: http://www.nationalmuseum.af.mil/[63])

After the Vietnam War, the Israeli Air Force used the versatile Lighting Bug as the basis to develop an RPA to help find and destroy Egyptian SAM sites during the 1973 Yom Kippur War, and the Israelis again used RPA in 1982 to enable SEAD against Syrian missile sites in the Bekaa Valley.[64]

RPAs' strength continues to be missions requiring long loiter times, but the natural evolution for the RPA is to increase their autonomy and enhance their capability to operate in dense SAM environments. *The United States Air Force RPA Vector: Vision and Enabling Concepts 2013-2038* sets forth an approach to increased autonomy starting with on-board data processing to reduce bandwidth and to help human analysts focus on key information.[65] *The RPA Vector* also states "autonomy should be applied in difficult, dangerous, and monotonous scenarios."[66] Hunting mobile SAMs definitely falls into the "difficult" and "dangerous" mission that an UAS should be developed to perform, and this fits in with the *RPA Vector's* loyal wingmen concept. Loyal wingmen are UAS that accompany manned aircraft to perform a variety of missions including SEAD.[67] The question is whether or not the Air Force will make the monetary investment necessary to achieve the vision. The *RPA Vector* shows many RPA and UAS programs are still unfunded.[68] The Air Force needs to come to terms with the investment risk if RPA and UAS are ever to be fully developed.

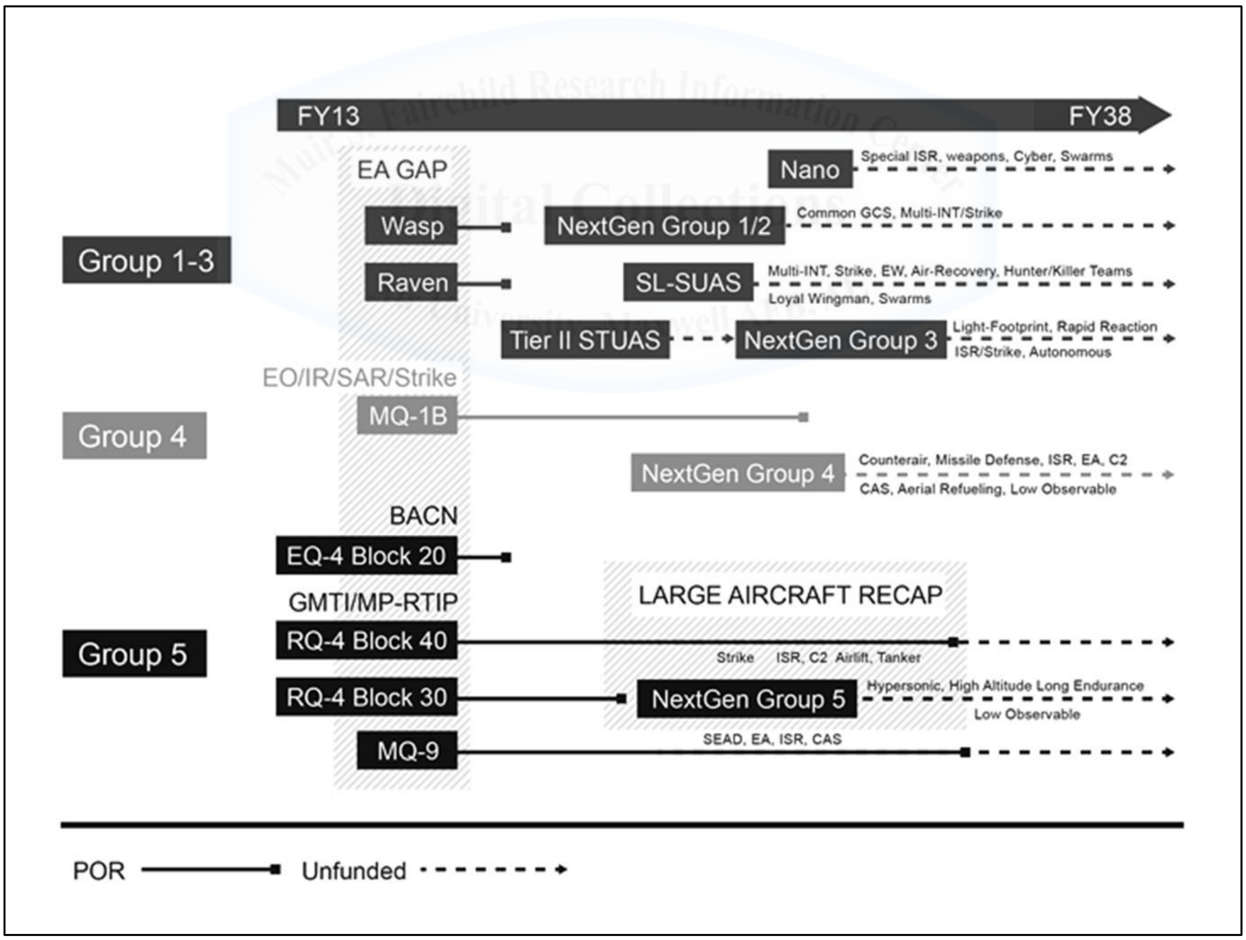

Figure 4. Future mission evolution by FoS. (Reprinted from, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 48)

The Navy is also pursuing autonomous flight capabilities designed to provide ISR and refueling support to carrier air wings with promising results. The Navy's test RPA, the X47-B, has landed on aircraft carriers and refueled autonomously in the air.[69] The Navy envisions using technology pioneered by the X-47B to develop the Carrier-Based Air Refueling System, (CBARS), also known as the "MQ-XX Stingray." The MQ-XX will serve as both an ISR platform and tanker with a future vision of teaming the unmanned aircraft with F-35Cs to extend the F-35s battlespace awareness.[70] This is a departure from the Navy's original vision for the Unmanned Carrier-Launched Aerial Surveillance and Strike (UCLASS) UAS that was meant to provide precision strike capability. The Navy's conversion from the UCLASS to the CBARS was a budgetary tradeoff to purchase more manned aircraft, primarily F-35Cs and variations of the F-18.[71]

The Navy's reason for this budgetary tradeoff is short sighted. Switching from the UCLASS program to the CBARS accomplishes three things: it allows the purchase of more F-35Cs to put stealth on aircraft carrier decks in the early 2020s, it frees more fighters since aerial refueling is currently done by FA-18s, and the refueling extends the range of a carrier's aircraft.[72] A fourth effect is it further delays strike UAS development. The Navy's decision is understandable because it avoids the risk of betting unproven technology will bear fruit and acquires a less uncertain (F-35Cs) capability instead. However, competitors are already fielding capability to counter the F-35, so short-term thinking may not even provide a short term advantage. The Navy's risk aversion will slow the progress of developing potentially game changing technology that could provide a decisive future advantage. The Air Force shares a similar risk aversion to the Navy, which slows overall advanced UAS development. An integrated joint approach to developing UAS might produce quicker technological advances.

Indeed, the Air Force's *RPA Vector* describes a path for joint cooperation between the Air Force and the Navy for RPA development. The focus is primarily on common control systems and a joint control architecture,[73] which will ensure common traits between both services' RPA. The *RPA Vector* also calls for the Air Force to become the RPA acquisition center of excellence for the DoD and participate in "appropriate joint acquisition with emphasis on innovation, rapid acquisition and fielding."[74] This idea has merit, especially if the Air Force and the Navy can agree on a joint path for channeling RPA or UAS research and development funds. Jeff Schogol suggested that more progress might be made if both services combined their efforts, with the Air Force taking the lead, to develop common UAS platforms instead of fragmented efforts.[75] A joint approach may actually be detrimental if a common vision cannot be established and each service keeps promoting competing interests. Schogol's approach with the Air Force acting as lead to channel all services efforts could be the most productive model. A common effort could increase research dollars in one concentrated direction without the services having to choose between current manned fighters (which killed the UCLASS) and UAS development.

In spite of often fragmented development efforts, RPA have made huge strides since 1913, but more work on autonomy is needed. One of the challenges for operating RPA in an A2/AD environment is the current remote split operations (RSO) model. RSO allows the Air Force to operate RPA from remote locations, sometimes thousands of miles from the physical operating location of the RPA using satellite communications.[76] However, serious rivals are all developing anti-satellite weapons or cyber capabilities to deny communication links. China, for example, has demonstrated the capacity to destroy satellites in orbit and has developed robust cyber weapons that can impact US forces' ability to command and control.[77] A resurgent Russia recently conducted a successful anti-satellite missile test,[78] and its cyber capabilities exceed China's[79], though their attacks are more subtle.[80] Iran and North Korea are also thought to be working on anti-satellite missiles.[81] Competitor nations' A2/AD capabilities could make RPA operations very difficult if they can deny communication links.

The RPA Vector states increased autonomy for RPA and UAS is a part of the solution to overcome loss of communications in an A2/AD environment.[82] It also suggests other alternatives besides autonomy to control RPA. The Air Force vision includes airborne control where manned aircraft control RPA, or even large RPA control smaller RPA and UAS. The *RPA Vector* points out that control does not equate to flying the aircraft, which the RPA or UAS can do autonomously, but rather directing actions for the RPA or UAS to complete. The loyal wingman concept with one manned aircraft controlling up to four RPA or UAS could replace RSO, and would rely heavily on autonomous flight capability so the controlling pilot is not overtasked.[83] The pertinent fact is the Air Force recognizes the need for autonomy to operate in A2/AD environments as well as for alternatives to the RSO control model. Autonomy for controlling aircraft flight is not very controversial, but using autonomy to find, fix, track and engage targets is, even though weapons such as the AGM-88E AARGM can find their targets autonomously.[84]

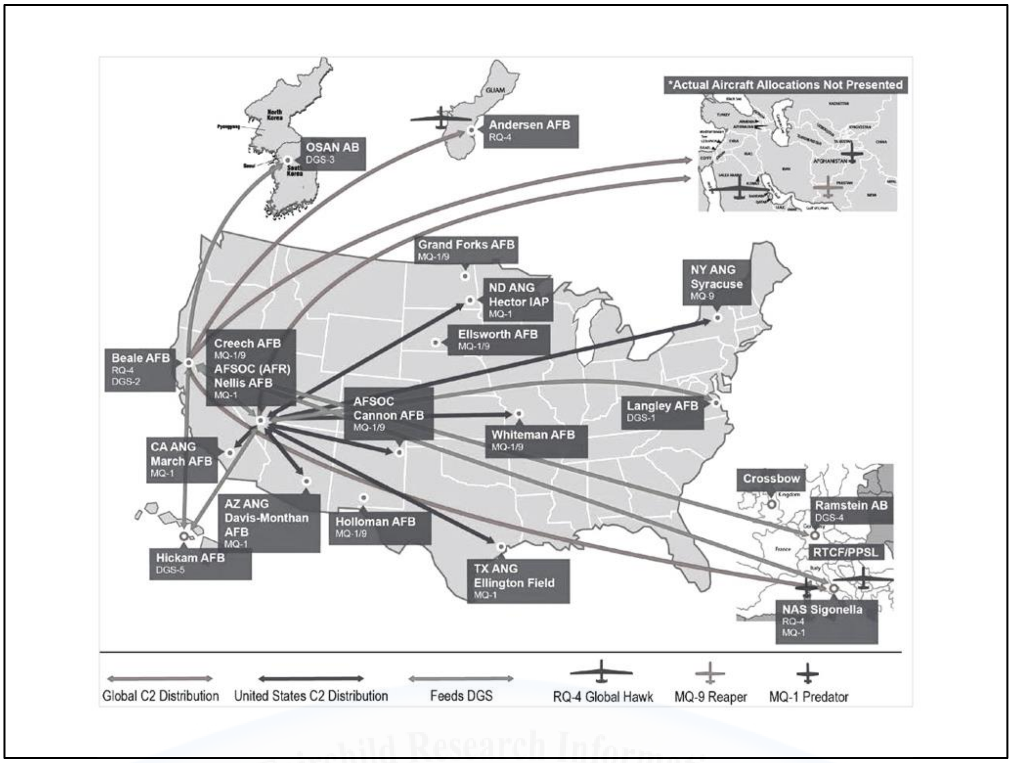

Figure 5. RSO Diagram. **(**Reprinted from, RPA Vector: *Vision and Enabling Concepts 2013–2038*, 21)

Lethal Autonomous UAS Concerns

Autonomous weapons are already in common use, but there are important distinctions between autonomous weapons like cruise missiles or homing acoustic torpedoes and a UAS that can target and fire weapons independent of human control. Cruise missiles are preprogrammed to fly autonomously to a predetermined target location, or in the case of an anti-ship cruise missile (ASM), the weapon autonomously searches a "box" with a known enemy presence after launch. The same is true of a homing acoustic torpedo like the Raytheon Mark 54, which is launched from an aircraft or surface ship when the operators have located an enemy submarine. The Mark 54 torpedo will autonomously find, fix, track, target, and engage the submarine without further human intervention. These and other autonomous weapons are all fired by a human operator that has identified a possible target, but the weapon can locate the target independent of human control. The real distinction is the weapon does not make a launch decision.

A lethal autonomous UAS would locate the probable target, and the on-board AI would validate the target and make the decision to engage with weapons. There is no human in the final decision chain. This key distinction is the cause of much legal, moral, and ethical debate. The Mark 50 torpedo is an example of a "fire and forget" weapon that finds, fixes, tracks targets and engages the target after launch.[85] The launch platform does not control the torpedo once it is released, but there is still a conscious decision by a human to engage the target. Thus, there is someone to hold accountable if things go wrong. There is no way to hold a UAS responsible for an erroneous engagement decision.

Determining who is responsible if a UAS engages an illegal target is somewhat controversial. It is a difficult question that has been debated for years, but this does not mean autonomous UAS should be strictly forbidden from engaging targets. In 2014, experts met to debate the question of accountability and to discuss growing concerns about the development of autonomous weapons at an international Red Cross conference.[86] Some committee members asserted there could be an "accountability gap" between the weapon's manufacturer, software programmer, individual, or state.[87] Most attending the conference felt the state employing the weapon could be held responsible.[88] In 2011, Lt Col Michael Contratto concluded the primary responsibility would fall on the commander, but legal review would determine if some diminished responsibility also belonged to the weapon engineers, manufacturer, and programmer.[89] Contratto's opinion that the employing commander would bear the most responsibility for an autonomous weapon that commits Law of Armed Conflict (LOAC) violations, is consistent with the Red Cross expert meeting report since most attendees felt the state should be held responsible. The employing commander is the most logical representative of the state. The argument about accountability can quickly become complex, but it is not unsolvable nor is it a roadblock to using UAS. There has been enough debate to lay the groundwork for a legal opinion should the need arise to hold a human accountable for a lethal UAS's actions.

In addition to accountability, the inability of AI to match human capacity for decision making and subjective reasoning is a concern, and opinions are divided over how well AI will ever match human capabilities.[90] However, some researchers believe one day there will be machines more capable of complex reasoning tasks than humans.[91] The relevant question is, how advanced must AI be for a UAS to validate targets as well as a human? The answer to this question could be well short of human-level intelligence, but an autonomous UAS's ability to discriminate between valid and non-valid targets, and potential levels of collateral damage, has direct LOAC implications.

Arguments about autonomous weapons complying with LOAC usually center on the concepts of distinction and proportionality.[92] Distinction is the capability to distinguish between civilian and military targets.[93] Opponents claim autonomous weapons will never truly have this ability due to sensor limitations and because current AI cannot reason subjectively. In certain scenarios, for example, distinguishing between civilians and combatants in some urban settings would be difficult if not impossible, but in other applications, like the anti-armor Brimstone missile, distinction is already possible.[94] Distinction should not be a problem for UAS performing SEAD. Weapons like HARMs are specifically targeted at threat radar emissions and do not rely on a pilot's visual verification of the radar system on the ground. Likewise, imaging matching technology is good enough to pick out the silhouettes of mobile SAM vehicles. If

SAMs are suspected in an area with high potential for collateral damage, then the decision whether or not to allow SEAD with autonomous UAS will have to be made at the appropriate command level.

Proportionality refers to ensuring collateral damage from attacks on legitimate military targets does not outweigh the concrete military gain.[95] Subjective reasoning plays a role here. For a UAS to satisfy proportionality it would have to recognize whether or not destroying a legitimate target would cause unacceptable collateral damage, which could limit target sets engaged by autonomous RPA. However, this does not logically negate their use altogether.

As discussed earlier, there are already autonomous weapons in use that can find, fix, track, target and engage enemy assets without human intervention after launch. Therefore, AI advanced enough for autonomous targeting already exists. The previously mentioned Brimstone anti-armor missile—used by British forces to destroy armored vehicles in Libya[96]—uses a millimeter wave radar seeker to distinguish between valid and non-valid target signatures and has direct and indirect targeting modes.[97] In direct mode, the pilot selects the target using a semi-active laser seeker, but in indirect mode the pilot fires at non-visible targets and the Brimstone's radar finds valid targets.[98] It can be programmed to search for targets only in a defined box to help protect friendly forces.[99] Similarly, Major Robert Trsek argued that manned aircraft routinely engage beyond visual range targets, and a UAS could use the same on-board and off-board data inputs to perform beyond visual range targeting and engagement.[100] Captain Michael Byrnes recently pointed out that commercial computer vision and recognition software provides feasible targeting capability for air-to-air engagements.[101] The concepts the Brimstone uses to find and identify targets could be used by autonomous UAS. Also, Byrnes suggested use of computer vision detection and recognition algorithms, could certainly discriminate the distinct shape of mobile SAMs' TELs, radar, logistics, and command vehicles. The AGM-88E AAGRM already does this after being launched using a millimeter wave seeker to match signatures to a threat library.[102] In short, discreet autonomous targeting is already possible without human level AI.

Current autonomous targeting capabilities, however, do not resolve proportionality issues in complex environments. Target discrimination becomes more difficult when the desired point of impact is in an urban area, instead of remote buildings, aircraft in contested airspace, or a ship out at sea.[103] UAS should be limited to distinct engagement areas and target sets until they can discriminate target validity, and make subjective reasoning calls about proportionality at a human level, which does not imply perfection. Collateral damage is an ugly reality of war even with humans making all of the targeting decisions. Therefore, perfect target discrimination is not a reasonable standard to demand of autonomous UAS. This is not to say the bar should not be raised before lethal autonomous engagement is allowed. Improving on human performance should be the goal of autonomous operations. In the present, proportionality could be satisfied by graduated levels of autonomy and restricting the search box where an autonomous aircraft can make the decision to engage without man-in-the-loop (MITL) control to areas where the chance of collateral damage is small or more acceptable to the military objective.[104] Unintended collateral damage by lethal autonomous UAS leads to the concern they may breed more wars.

The fear that autonomous weapons will encourage war is difficult to prove. It is a theory, and, unlike AI limitations, there is no reliable way to measure the truth of this argument. America's current use of lethal RPA strikes receives heavy domestic and international criticism, which generates political pressure against using current RPA for lethal strikes.[105] The same political pressures associated with drone warfare will likely restrain war with autonomous systems.[106] While UAS could limit the amount of blood a nation invests in a war, it would not limit the amount of national treasure war costs. A 2013 GAO report estimated that a RQ-4 *Global Hawk* cost $88 million in 2001. That cost grew by 152 percent to $222 million per unit by 2012, mostly due to development costs for block 20, 30 and 40 aircraft.[107] By contrast, the same report put the 2012 per unit cost of the F-35 at $136 million,[108] which is somewhat deceiving since the greater quantity F-35s being purchased divides the total program costs included over more airframes. Still, this demonstrates that advanced RPA are not cheap. The Global Hawk, moreover, is a better predictor of autonomous UAS cost than the much cheaper Predator or Reaper; since it is already semi-autonomous, its cost better reflects the expense of a highly autonomous UAS. Certainly autonomous UAS capable of making a useful lethal attack will be too costly to drive indiscriminant wars just because less human life will be lost.

Autonomous UAS taking human life has serious moral implications. Many argue that an act as serious as taking a human life should always be a human decision.[109] There may not be an answer to this concern that will satisfy critics. War drives actions that fall outside the bounds of civilized, moral behavior, and the concept of killer robots seems to make immorality of war that much worse. Lt Col Contratto raised the morality argument another level claiming the use of lethal autonomous platforms would "chip away at the profession of arms' moral foundation."[110] Contratto argues a key moral aspect of the profession of arms is a willingness to sacrifice one's life for the greater good of the nation, and using machines for the most dangerous or difficult missions erodes the military's moral responsibility because accepting danger is part of the role and purpose of a soldier.[111] It is true that service members accept personal danger as part of their profession, but a nation also has a moral responsibility to not waste the lives of its sons and daughters that have sworn to protect it. Therefore, their lives should not be forfeit if an autonomous UAS can perform the same mission. UAS that independently kill humans are frightening, so all the more reason to make sure their use is carefully considered and limited to situations where potential benefits outweigh potential costs.

Artificial Intelligence

The final piece of imagining what an UAS could bring to the battlefield is an understanding of what artificial intelligence is, what its current limitations are, and what it could become. For the purpose of this thesis AI is defined as the ability of a machine to perform specialized functions as well as or better than a human. This definition reflects the current reality that AI does not match general human intelligence, but in specialized roles AI does match, or even surpass human capabilities.

Murray Shanahan, professor of cognitive robotics at Imperial College London, addresses the current difference between human intelligence and AI by comparing the IBM Deep Blue chess computer that defeated world chess champion Gary Kasparov in 1997 to the general intelligence possessed by a human being. Deep Blue was highly specialized to do one thing: play chess. Gary Kasparov, on the other hand, could perform many tasks besides playing chess, such as composing a letter to a friend, or learning to play poker instead of chess.[112] Shanahan uses this example to highlight how AI's strengths are currently applicable to specialized tasks versus general versatility.

Shanahan also states the other advantages of human intelligence are creativity and common sense. Which he defines as the ability to formulate solutions to an unfamiliar situation and anticipate probable out comes from different actions.[113] For example, a person stranded on a tropical island trying to open a coconut could use creativity to improvise tools and apply common sense to understand a sharp edged rock offers a better chance of success than a smoothly rounded rock. AI does not exist that can match the creativity and common sense of human, or even higher animal intelligence. Until AI reaches a level of intelligence that matches human generalist capabilities (if that ever occurs), UAS will have to be more like Deep Blue and built to perform specialized missions.

This is what makes UAS attractive for dangerous mission like SEAD. AI can react much quicker than humans to detected threats. If the HTS senses a threat it would directly feed an AI module that could recognize and respond to the threat almost instantly. Also AI does not get tired; it is always "mentally" sharp. As previously suggested UAS could be restricted to prosecute lethal action in specific geographic boundaries where the SAM threat is dense and the collateral damage risk is lower or more acceptable to military goals, while reducing the risk to human pilots.

The most likely application of AI to UAS is to use them as greatly expanded expert systems. Dr. George Zarkadakis explained that expert systems are built by studying how human experts process information and make decisions, and then using logic to encode this to develop an AI-driven, analytical, decision-making tool. Dr. Zarkadakis used this technique to build an expert system that worked very well for recommending medical treatments based on a patient's vital signs, medical history and various test results. Dr. Zarkadakis posits that while his expert system was very competent at recommending treatments, it had no sense of consciousness like a human doctor would have about their self, or about the patient being treated as a person, meaning it lacked true intelligence.[114] Therefore, an expert system is a form of AI, but it is not human level AI. However, this does not restrict its usefulness for application in a UAS.

Current expert systems are primarily decision making tools. If the concept could be expanded by melding the expert system with AI learning models, such as genetic algorithms,[115] it could possibly be used for advanced autonomous flight control. AI learning models attempt to mimic biological learning patterns.[116] Genetic algorithms are a very complex subject. The basics of the approach is to allow the computer to "evolve" generations of algorithms and select the solutions that work best against a defined set of criteria; Ray Kurzweil used this process to develop speech recognition algorithms.[117] If a genetic algorithm could take the pre-coded logic of an expert system and evolve it, perhaps it could form the basis for AI systems capable of enabling autonomous UAS for SEAD. This thesis will refer to this concept as expanded expert systems.

The flight computers of aircraft like the F-16s and F-22s could potentially be evolved and form the basis for AI capable of high performance autonomous flight. These aircraft's designs sacrifice flight stability for maneuverability and the flight computers make constant adjustments to flight surfaces so the human pilot can control the aircraft. It is not implausible that the concept used by current flight computers could be expanded into true autonomous flight. It would require providing interfaces with sensors for situational awareness beyond the aircraft's stability, but the F-16s' Automatic Ground Collision Avoidance System demonstrates this potential. It continuously monitors the aircraft's altitude and autonomously takes over the aircraft at the last second to avoid ground impact.[118] Attempting to evolve these systems with genetic algorithms could help lead to advanced, autonomous flight.

Two authors already mentioned in this paper, Captain Michael Byrnes and Major Robert Trsek, both theorize an AI fueled machine pilot could outfly a human pilot. Byrnes' assertion has already been covered, but Trsek's is worth considering in greater detail. First, Trsek points out that a manned aircraft's maneuverability is limited by the pilot's ability to withstand increased G-forces, roughly 10G's, and an UAS's ability to execute high G maneuvers is only limited by the airframe. More germane to AI and an expanded expert system, Trsek states that during basic fighter maneuver training, pilots essentially learn checklists and priorities to build a decision matrix to guide split second reactions during combat that could easily be automated. He even uses the chess playing Deep Blue as an example of how an UAS could look moves ahead to anticipate an adversary's possible moves much deeper and quicker than humans.[119]

If we apply the above line of reasoning to a UAS specifically built for SEAD it could have several strengths. First, the airframe could be optimized for high-speed maneuverability to provide a last layer of defense if a SAM is locked on and closing. Since the AI would receive input directly from on-board radar tracking the SAM, it would be able to calculate flight paths and evasive maneuver far quicker than a human. Second, it could be a more survivable decoy, trolling through IADS at high-speed to lure SAM targeting radars into activity so UAS optimized for stealth and loiter could acquire targeting information and launch HARMS to destroy the threat—all without risking a human pilot in a high threat, A2/AD environment.

The logical question to conclude AI discussion with is: will AI ever reach or surpass human level intelligence? George Zarkadakis feels it is not possible with current computer technology. The basic problem is software and hardware are separate pieces that don't interact the way a human brain does with a human body, and human sensorimotor skills are a key part of how humans develop self-awareness and intelligence.[120] Computers simply lack the ability to explore the world around them and learn through experimentation like a human. Experts systems can be programed to perform at human or superhuman levels but, as mentioned, they still lack a human's versatility and adaptability.

On the other hand, Ray Kurzweil, who leads Google's AI efforts, believes an AI singularity can be achieved. The AI singularity can be roughly defined as the point where AI not only matches but exceeds human intelligence.[121] Shanahan further explains Kurzweil bases his belief on *exponential technological trends* and what he calls the *law of accelerating returns* (LOAR). For example, Moore's law states the number of transistors that can be fit on a silicon chip approximately doubles every 18 months. Moore's law has held true since the 1960s, and even if it slows down other exponential progress has held true for other computer related technology. Kurzweil's LOAR states that technological development is similar to compound interest on money: "The more you have, the faster it grows."[122] Even if an AI singularity is never achieved, the growth in computing power will enable ever more powerful AI applications, such as expanded expert systems, that would enable UAS to perform roles like SEAD at human levels.

SCENARIO PRESENTATION

The point of scenario planning is to examine alternate futures based on how a defined set of driving forces will affect the future. The following scenarios will predict how UAS could be used for SEAD in future wars. Sydney J. Freedberg Jr. describes three broad scenarios for using autonomous technology, Skynet, Swarms, and Centaurs. Skynet refers to an army of autonomous drones controlled by a central AI directing the robotic army. Swarms, as the name implies, involves masses of UAS working as a coordinated group. Centaurs refer to a symbiotic human/machine relationship where the UAS are used to enhance human action resulting in devastating synergy.[123] These concepts will help frame the first three scenarios and examine how they can be applied to SEAD. The fourth scenario will examine a future where UAS development has atrophied.

Scenario planning works best when three factors are woven into each scenario: the long view, outside-in thinking, and multiple perspectives. The long view is basically looking past immediate needs to anticipate investments or changes that need to occur near term to prepare for the future. Outside-in thinking involves evaluating what factors outside on an organization will influence its path or change its circumstances. Multiple perspectives is the purposeful inclusion of diverse viewpoints, which will provide unexpected insights and innovative thinking.[124] Long view and outside-in thinking are not foreign to military planning. Wargames look at future scenarios and red teams (the team that simulates what an adversary might do) provide an outside-in perspective. Wargames are also useful to provide multiple perspectives since they bring together a diverse team of subject matter experts and may include participants from allied nations. The scenarios attempt to provide diverse perspectives on UAS use by looking at various opinions on technological feasibility and legal or moral concerns.

Technological feasibility is a prime axis that will be used to help frame each scenario. A basic assumption is the proposed future scenario is technological feasible. However, it must be understood that the further to the right a scenario occurs on the axis, the further technology has to progress.

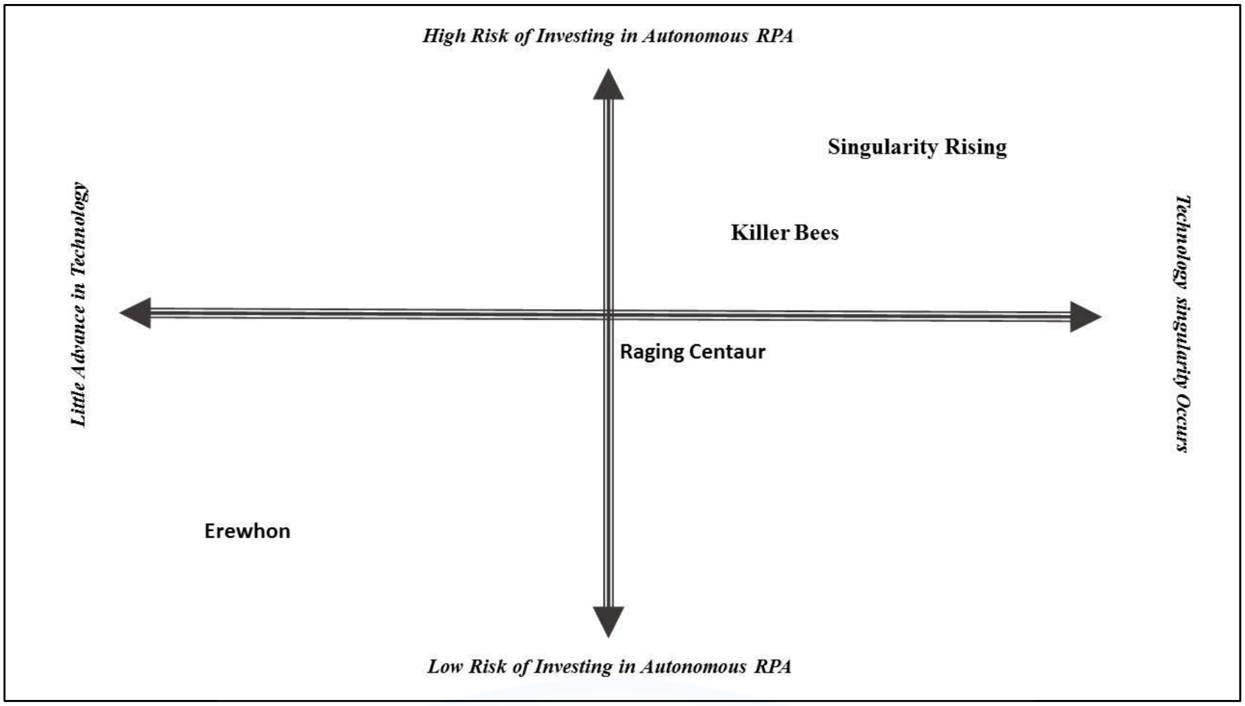

Figure 6. Scenario axis plot.

The other axis is risk tolerance for investment in UAS technology. This represents the overall risk to military readiness since, if the investment in autonomous technology does not pay off, the military will be less ready to protect national interest. Therefore, the primary measurement is the trade-off of investment in manned aircraft versus UAS. The final analysis will be an assessment of the risk involved with pursuing each future scenario.

The scenarios will also analyze the institutional and political friction the proposed future may generate. Both are a risk factor that must be considered. For example, in the *Singularity Rising* scenario, which presents the most technological advanced future, friction in the form of institutional barriers that work against increasing the use of fully autonomous UAS over manned aircraft, compounds the investment risk. A key component of institutional friction is trust. The Air Force's *Autonomous Horizons: System Autonomy in the Air Force–A Path to the Future* emphasizes Airmen must know how much they can trust autonomous systems to function correctly, in a given environment, to properly employ them.[125] Developing autonomous UAS that can be trusted will be a process that steps through varying, flexible levels of autonomy, as systems prove their reliability. This process will reduce institutional friction. Political friction represents the risk of both an institutional bias against UAS use and the possibility of political priorities shifting funding before research bares fruit. It also addresses pushback by domestic and international organizations against UAS use. The very active role of lethal RPA on the battlefield is a relatively new development. It is largely out of sight and out of mind for the American public, but that could change as domestic groups work to raise the public's awareness about RPA use.

James Carafano offers a contrasting point of view postulating that as autonomous robotic technology becomes more common in everyday life (such as self-driving cars) the general public will be more accepting of the military using lethal UAS.[126] This could counter balance the efforts by groups that are currently opposed to RPA, let alone lethal, autonomous UAS. Public acceptance of lethal UAS is critical to their development because a general public outcry could generate enough political friction to severely limit UAS development and use.

Historically, RPA or UAS development has always been obscured in the long view. War tends to drive RPA and UAS research, and it tends to drop off once the need has passed. During WWI both the Army and the Navy experimented with RPA and UAS, but research slowed when the war ended. This pattern also held true during WWII and Vietnam.[127] The scenarios envision futures where investment in UAS either grows or once again tapers off. To reflect this each scenario will have the following sections:

1. Proposed future

2. Technological feasibility

3. Investment risk

4. Institutional and political friction

5. Scenario analysis, effect on SEAD.

Scenario 1, *Singularity Rising*:

Proposed Future

The autonomous UAS know as SLAM-01 loiters at 60,000 feet, passively collecting signals and checking terrain features to map search routes for the fast flying UAS it will direct to sniff out mobile SAMs in a few hours. SLAM-01 has uploaded terra-bytes of diverse data to aid analysis of possible enemy IADS' C3 nodes that coordinate the mobile SAMs into a nearly impregnable air defense shield. SLAM-01 fuses disparate data into a cohesive prediction of IADS behavior. The analysis includes social media feeds for known human IADS commanders, cell phone signals, their financial and family data, and even their driving records to build a profile of the human commanders' behaviors that can be used to predict how they would direct the overall IADS operations. SLAM-01 fuses this data with all available ISR, signals intelligence, known utilities maps, mobile SAM capabilities, enemy air defense doctrine, and military installation locations. SLAM-01 refines the information and builds an optimized IADS layout and SAM placement map around probable centers of gravity (COGs). SLAM-01 priority ranks the probable IADS C3 nodes and SAM battery placements in order of precedent, then transmits the target list, and directs the attack.

The careful circle SLAM-01 flies around the circumference of its assigned suppression area is to confirm what SLAM-01 considered a certainty. SLAM 01 checks with its autonomous partners sending finalized search patterns and attack phasing. Multi-mission, modular UAS (MMUAS),[128] Air Launch Small UAS (AL-SUAS),[129] and autonomous decoy UAS, are SLAM-

01's primary SEAD assets. The MMUAS are versatile UAS that can be configured with different modules to optimize them for a variety of missions. A typical SEAD package will include MMUAS configured for electronic attack, kinetic attack, and C2 networking. They are highly maneuverable and smaller than SLAM-01. The AL-SUAS are even smaller and launched from standoff distance. The AL-SUAS' primary role is to extend SLAM-01's situational awareness of the battlespace and one-way kinetic attack. The decoy UAS are for stimulating IADS radars, and are reused if they survive. When SLAM-01 receives the engage signal from the air operations center (AOC) the UAS begin to pour into the suppression area. The cat and mouse game between SLAM-01, the hunting MMUAS, AL-SUAS, decoy UAS, and the SAM operators begins.

SLAM-01 will approach its task with absolute focus, no fatigue, no emotion, and with a decision and kill chain speed far beyond human ability. The decoy UAS will tease the SAM radars into life, and SLAM-01 will mark the radar positions to compare to pre-estimated locations and improve its predictive capability. When the radars become active, the MMUAS will unleash kinetic attack to back up their already active electronic attack modules. The AL-SUAS will spread out to search for mobile SAMs along the routes identified by SLAM-01 and perform ISR. SLAM-01 remains at 60,000 feet orchestrating the suppression and destruction of C-3 nodes and mobile SAMs, clearing the way for the day's massive strikes on the unlucky enemy's COGs. Go time arrives and SLAM-01 acknowledges the "execute" signal from the AOC and switches from ISR/planning mode to autonomous attack direction. It is time for the machine versus missile carnage to start.

Technological Feasibility

Singularity Rising represents a future where the AI singularity predicted by Ray Kurzweil's law of accelerating returns (LOAR) has occurred.[130] This is the riskiest future because it requires the most technological development. Kurzweil makes a compelling argument for the validity of the LOAR. He shows how the exponential growth of computing power, in terms of calculations per second, has grown at a predictable rate since 1900. Kurzweil applied his LOAR in the 1990s to make 147 predictions about technological growth by 2009. Kurzweil claims 127 of those predictions were correct, or essentially correct, including growth in supercomputing power, which he predicts will be powerful enough for human brain neural simulation by 2020.[131] Kurzweil's claims are counterbalanced by the issues noted earlier in this paper, such as Zarkadakis' belief that true human level AI cannot be reached under the current model of separate hardware and software. Zarkadakis believes human level AI requires a new approach and refers to the promise of infant technologies called "neuristors" that act like a neuron and offer the possibility of "neuromorphic" computers that closely mimic the human brain.[132] This does not invalidate Kurzweil's LOAR. The base assumption for this scenario is the LOAR holds true and advancement in AI and autonomous capability continue with an exponential rate with heavy investment. Hypothetically, the F-35 would become the last manned fighter the US ever buys.

Imagine an UAS called the Cognitive Reasoning Autonomous Machine Piloted Unmanned System (CRAMPUS). CRAMPUS is a fully autonomous, high-altitude, long-endurance, low-observable, UAS optimized to direct SEAD by other UAS. CRAMPUS's AI is capable of human level reasoning even as it performs analysis on data and reaches decisions at a speed no human brain could hope to match.

Networked with MMUAS and AL-SUAS, CRAMPUS directs them to provide effective SEAD. The MMUAS can perform ISR, signals intelligence, electronic warfare, and strike missions to locate and suppress SAMs. These UAS are optimized for speed and maneuverability since they routinely penetrate the SAM threat envelope to gather either intelligence and conduct electronic or kinetic attack. MMUAS are smaller and less expensive than CRAMPUS to minimize the fiscal risk of operating in high-threat environments. The AL-SUAS act as off board sensors,[133] extending CRAMPUS' "eyes" and "ears" over the battlespace.

CRAMPUS's AI uses several different methods to locate the highly mobile SAMs that challenge US air superiority. CRAMPUS fuses known SAM capabilities with terrain mapping and center of gravity analysis to determine the optimal placement for SAMs within an IADS, and it then directs the MMUAS and AL-SUAS to deliberately search for mobile SAM components and attack C3 nodes. CRAMPUS designs the search pattern based on the most likely terrain for the mobile SAMs to traverse if they are employing shoot and scoot tactics. CRAMPUS also strategically calls in decoy UAS to entice the air defense radar to emit so the MMUAS can engage. CRAMPUS uses signals intelligence to understand the make-up of the IADS by analyzing the most likely networking capabilities and communication nodes needed to link SAMs and form an effective IADS. CRAMPUS then directs the MMUAS to disable IADS command and control. CRAMPUS also fuses Big Data to anticipate human SAM operators' behavior. The combination of autonomous aircraft directed by the central CRAMPUS AI provides effective SEAD in highly contested airspace without endangering human pilots.

Investment Risk

CRAMPUS became reality because Air Force leaders looked into the future and saw threats that would be beyond the capabilities of human pilots. This vision is captured in the *RPA Vector* that states: "Some combat decision cycles occur at speeds that are many orders of magnitude faster than human reaction time. Systems will need to automatically respond, nearly instantaneously or at a very precise time, to achieve a desired effect."[134] Air Force leaders also realized that the rapidly closing technology gap between the US and other nations would continue to narrow.[135] This long view of a future where human pilots have to compete with highly autonomous systems fielded by competitor nations increased the tolerance for risk and an all-out research and development effort. The focus was developing highly autonomous UAS that could compete with SAMs controlled by highly autonomous engagement systems.

The investment risk for this scenario is very high. Even if Kurzweil is correct that supercomputers fast enough to simulate human brain neural networks are available by 2020,[136] there would be a great deal of research required to apply this computing power to autonomous flight. It would require trade-off between UAS development and manned aircraft development, which usually makes Air Force leaders hesitate.[137] This risk is compounded because the US still has a good lead in fighter technology as the F-22 is still the only fully operational 5th generation fighter in the world.[138] The US has proven its ability to produce advanced manned aircraft and would likely produce a 6th generation fighter well ahead of competitor nations. China is close to bringing their 5th generation fighter, the J-20, into service possibly as early as 2017.[139] They may also have another 5th generation fighter, the J-31 ready by 2024. The J-31 is thought to be based on plans for the F-35 stolen from the US in 2009.[140] The J-31 highlights the risk that the US technological lead is just one good hacker away from shrinking even further. Russia, Iran, Turkey, India, South Korea, and Japan are also working on 5th generation fighters.[141] It is probable that technology like stealth will proliferate. Therefore, if the US concentrates research and development on autonomous UAS, and it does not deliver results, the technology gap with rising adversaries will quickly close—a very risky possibility.

Institutional and Political Friction

Singularity Rising is the scenario furthest from the vision articulated by the Air Force in the *RPA Vector.* While autonomy is certainly a part of the Air Force's vision for RPA, nothing in current Air Force literature suggests developing autonomous UAS at the expense of manned aircraft. The Air Force's *Air Superiority Flight Plan 2030* does call for continuing to pursue potential game-changing technologies, such as autonomy, but only as the technology matures.[142] The *RPA Vector* does foresee a role for UAS in SEAD, but it is considered to be "far term" potential and discussions about UAS and SEAD usually include a teaming component with manned aircraft.[143] Finally, the *RPA Vector* states the use of UAS in any role is at the discretion of the Core Function Lead Integrator (CFLI).[144] ACC is the CFLI for SEAD and there may be strong bias against aggressively developing UAS over manned aircraft. Thus there would be significant institutional friction against this scenario.

Political friction would likely be high against this scenario. Similar to institutional friction, investing heavily to rapidly develop autonomous technology may be perceived as too risky by Congress, especially if US manned aircraft maintain a leading edge. This could impact defense appropriations to support rapid autonomous UAS development. The other issue that would generate political friction is a whole-sale push to develop lethal autonomy. It may eventually become more palatable, but the current international political climate is not favorable.

In September 2015, protestors marched at Ramstein AB to demand its drone control relay station be shutdown.[145] In 2015 the United States' permanent mission to the United Nations addressed the committee that recommends restrictions on certain conventional weapons (CCW) that was specifically held to examine lethal autonomous weapons. The US statement favored exploring issues with future autonomous weapons but stopped short of either endorsing or banning lethal autonomous weapons.[146] The US' stance in its UN statement shows domestic political friction about the legality of lethal autonomous weapons would be present, but not a complete roadblock.

Scenario Analysis: effect on SEAD

The *RPA Vector* acknowledges RPA and SUAS have the potential to enhance SEAD.[147] The main advantages offered by *Singularity Rising* are the reduced risk to manned aircraft and pilots flying SEAD missions, the speed at which autonomous aircraft can react and maneuver, and the speed at which ISR data can be fused and acted on by autonomous UAS. The fact that modern mobile SAMs can fire and move quickly is a problem for SEAD approaches that rely on stand-off weapons that can be launched from outside the threat envelope. By the time an S-400 TEL is located and targeted it may have simply moved out of the desired impact point, and there are also point defenses to contend with. This may be one of the reasons the *Air Superiority 2030 Flight Plan* calls for a Penetrating Counterair (PCA) analysis of alternatives in 2017. PCA is expected to be a key enabler for standoff weapons by supplying targeting data.[148] Autonomous UAS are a logical choice for a PCA mission since they can be built to maneuver at much higher G-Forces than manned aircraft, which increases survivability. Still, the overall speed of the kill chain is vital to suppress highly mobile SAMs and autonomous UAS could provide an edge.

That being said, the risk of this scenario is very high. Kurzweil's LOAR provides an argument that AI advanced enough to provide the levels of autonomy needed for *Singularity Rising* could begin to be available by 2020, but it would still require significant investment to mature the technology. The *Air Superiority 2030 Flight Plan* warns that using a formal program to push technological boundaries can result in delivering weapon systems that are decades late to need and instead recommends that technologies be harvested as they mature.[149] This is an important point. It took 14 years from the joint strike fighter's conception until its actual delivery to the Air Force.[150] With the technology gap rapidly closing, 14 years is too long to develop new weapons system and stay ahead of adversaries. Therefore, even though fully autonomous UAS could provide decisive advantages for SEAD, the risk of this scenario outweighs potential benefits.

Scenario 2, *Killer Bees*:

Proposed Future

HIVE-10, a large carrier aircraft, opens its rear cargo ramp and discharges its payload of a 100 AL-SUAS. To save fuel, the AL-SUAS extend their wings and glide from 40,000 feet into the engagement envelope before releasing their individual payload of 10 micro SUAS,[151] placing 1000 eyes over the battlefield. Simultaneously four more High-altitude Insertion Vehicles (HIVE) missions launch the same payload with the same purpose. In all 500 AL-SUAS and 5000 micro SUAS form an ISR network scanning and transmitting images or detecting radar emissions to pinpoint the location of mobile SAMs. The micro UAS do not use powered flight. Rather they control their drift using sensors to lock onto radar and other electronic emission and guide their descent to allow them to perch un-detected on radar and control vehicles. They unite their tiny voices into a tremendous roar of static, deafening the target vehicle radars, and then emit the location of possible SAM vehicles.

The AL-SUAS receive the micro UAS location signals and cross check throughout the swarm to validate targets and form assault groups. The sheer number of sensors allows the swarm to correlate suspected enemy emissions and overcome the effect of enemy jammers. All of the AL-SUAS carry lethal kinetic warheads, and once mobile SAM vehicles are identified, the assault groups coordinate a mass-attack to overwhelm SAM point defenses, destroy SAM vehicles, and cripple the enemy's IADS. With the IADS down and SAMs suppressed, the enemy COGs lay open to attack. Swarms of inexpensive, highly specialized UAS, have revolutionized SEAD, and enabled the US to overcome this troubling part of the A2/AD equation.

Technological Feasibility

In 2014 the Navy demonstrated how one person could control a swarm of 13 unmanned boats. After spotting a potentially hostile vessel, the boats autonomously surrounded and interdicted the hostile vessel.[152] This demonstration points to the viability of groups of autonomous vehicles cooperating to achieve a common goal. Paul Scharre points out that swarming vehicles need not be exquisite technology, thus reducing the amount of technological development required.[153] The ability to create AI that supports swarms of specialized UAS is likely much closer than creating human level AI. The *RPA Vector* sees great value in AL-SUAS used in swarming applications to provide ISR and even kinetic strike.[154] However, the Air Force is reluctant to fund the necessary research. The RPA Vector shows three of four near-term projects for AL-SUAS development are unfunded.[155]

The academic world has made interesting progress in creating micro UAVs. Researchers at Harvard University developed a method to three-dimensional print a micro UAS called the "Mobee."[156] The Mobee is about the size of a quarter and must be tethered to a power source, so it is a long way from practical military use. However, this is an area where Kurzweil's LOAR applies. As microprocessors continue to reduce in scale and power requirements, a micro UAS for military use is conceivable. Micro UAS would not have to stay airborne for long period of times, and they could be released at a sufficient altitude to allow them to make a controlled, unpowered descent while searching for targets. This would be similar to BLU-108 sub-munitions that have infrared seekers and self-guide to attack armored vehicles after being ejected from the BLU-108 canister.[157] The *RPA Vector* describes a role for "perching" micro UAS that could be inserted and sit unnoticed until needed to neutralize enemy IADS by attacking communication networks.[158] The *Air Superiority 2030 Flight Plan* calls for increasing collaboration with industry to develop science and technology, which will increase the likelihood of developing viable swarming technology for military use. The *Flight Plan's* point that acquisition must be agile will be important, not just for quickly developing technology, [159] but also to keep industry engaged with the government. The swarm approach focuses on more cost effective, disposable systems, so it has less investment risk.

Investment Risk

Swarms have the potential to pay large dividends for smaller investment amounts. Paul Scharre notes that Augustine's Law is an observation that the rising cost of military aircraft will eventually push the number of aircraft procured so low that US defense will be in jeopardy. Scharre supported this point with a 2009 RAND study detailing the US versus China fighting over Taiwan. The study showed that even though an F-22 was considered to be 27 times more capable than any Chinese aircraft, the Chinese still won because they could launch far more sorties.[160] There is a point where quality will no longer overcome quantity. This raises the question of how much risk is there investing in ever more exquisite manned systems over a cheaper, specialized, autonomous UAS? Augustine's Law has held true over the last five decades, which suggests solely investing in ever more advanced manned platforms is as risky as investing solely in unproven UAS technology, because the US will not be able to purchase all the aircraft needed. As Scharre argues, there needs to be a mix of investment along both lines to achieve the combat power the US will need in future conflicts, since neither cheaper swarms, nor larger exquisite manned systems, will be the sole the answer.[161]

Achieving a future with swarms of autonomous UAS requires a shift in the balance of investment between manned and unmanned aircraft. In the Department of Defense Fiscal Year 2017 budget the Air Force's air superiority answer for countering potential adversaries' continued technological sophistication is upgrading legacy aircraft, further investment in F-22 modifications, B-21 development, and further F-35 acquisition and development.[162] Unmanned platforms are only mentioned as ISR assets, [163] which indicates the Air Force is not making serious investment to develop UAS capable of providing strike capability in an A2/AD environment.

It is outside the scope of this paper to treat the many criticisms of the F-35 program, but a significant amount of national treasure is being spent on a system that may already be outdated against rising threats. As stated earlier, Russia has focused on developing VHF radars and networking sensors to more effectively detect stealth aircraft, and the F-35 is projected by some to be much easier for Russian VHF radar to locate than B-2s or F-22s.[164] This could make a

SEAD role for F-35s very risky, thus swarming UAS could help mitigate that risk. The heavy ratio of investment in manned systems versus autonomous systems runs the risk of investing too little in autonomous technologies.

Institutional and Political Friction

Institutional friction for this scenario is very similar to *Singularity Rising.* There is reluctance in the Air Force as an institution to embrace autonomous UAS. In the case of swarms, Scharre points out that the Air Force is stuck in a "one pilot controls one aircraft" paradigm.[165] This paradigm works directly against adopting technology like autonomous UAS swarms. However, the future for swarming UAS is not all bleak, since the *RPA Vector* at least acknowledges the advantages of swarms. The problem is the *RPA Vector* also insists multiple SUAS (swarms) require human control.[166] This greatly increases the complexity of fielding swarms since it requires a control mechanism that would allow one human a very large span of control, perhaps more than a human can effectively exercise. Greater autonomy is the obvious answer and the *RPA Vector* acknowledges this.[167]

Political friction would also be very similar to the first scenario. Swarms of autonomous UAS performing SEAD incur legitimate concern, as do autonomous weapons in general. Paul Scharre discusses the potential of "flash wars," or wars that start extremely quickly if autonomous systems behave in unpredictable manners, or prove too tempting to use. Scharre acknowledges there will have to be very judicial use of autonomous weapons that include appropriate man-in-the-loop controls. It is fine balance because autonomy offers game changing decision speed, and where the human is the weak link in the decision chain, it will be tempting to let the autonomous system do all the targeting. However, what makes sense in a tactical situation could lead to strategic disaster if it led to a flash war.[168] International and domestic political friction against using fully autonomous systems is likely to be high. This will mandate that levels of autonomy are discreet and allow for man-in-the-loop control at critical decision points.

Scenario Analysis: Effect on SEAD

The *RPA Vector* envisions a definite role for swarming SUAS to overwhelm enemy air defenses.[169] Paul Scharre believes that intelligent swarms that coordinate decoys, electronic attack, jamming, and kinetic attack, offer a significant advantage for overwhelming enemy defenses.[170] Major Jeff Kassebaum promotes the same conclusion that the best approach to SEAD is to simply saturate the IADS and SAMs with inexpensive systems, rather than constantly trying to technologically outclass adversaries.[171] The concept appears to be a promising course of action.

As discussed earlier, modern SAMs are equipped with point defenses meant to counter PGMs. A swarm would be able to simply overwhelm point defenses negating this advantage. A swarm that included ISR would also have advantages for locating mobile SAMs quickly.

One issue is the possibility of adversary counter measures hijacking control of the swarm. Scharre discusses this possibility and suggests counter-counter measures like the swarming UAVs voting on actions to weed out rogue instructions.[172] Additionally the Air Force's *Autonomous Horizons* document insists cyber security must be part of the initial design for any autonomous system, and it suggest solutions such as self-health monitoring and the ability to detect and repel cyber-attacks.[173] However resistance to cyberattack is accomplished, it must be a key part of swarm, or any autonomy development. Russia and China have aggressive cyber warfare programs, and Iraqi insurgents used cheap, commercial software to hack predator video feeds.[174] Even with cyber threats, swarms offer a promising future state for autonomous UAS to conduct SEAD, if they receive enough investment.

Scenario 3, *Raging Centaur*:

Proposed Future

The Pilot's Autonomous Loyal Wingman (PALW) and human teaming begins in specialized undergraduate pilot training. The basic AI that would be a new pilot's PALW learns how to fly with the pilot. It repeatedly teams with a new pilot in flight simulators and live exercises to learn the pilot's flight tendencies and how the pilot reacts to threats. This allows a PALW to anticipate a pilot's maneuvers during flight and the pilot's response to threats. PALW uses this knowledge to autonomously present the best tactical picture for the pilot. The other advantage of this process is the pilot learns to trust PALW. The PALW AI can be loaded to multiple aircraft preserving the "knowledge" of how a pilot operates in threat situations, and how to best work as a team with the human pilot. PALWs are designed to minimize the need for pilot control and create synergy between man and machine. The other advantage is the AI is not lost when a PALW is destroyed; the backup can be loaded in a new airframe with no loss of experience. PALWs multiply combat power and save lives. Their autonomous flight ability enables the human pilot to direct their actions with minimal effort. The blending of man and machine gives the US a distinct advantage for counterair operations.

PALW-1 keeps pace off of the lead F-35s starboard wing while a second, PALW-2, flies to the portside. PALW-3 and PALW-4 fly in front, searching for threats. The PALWs collect ISR through an array of sensors that PALW-1 fuses and feeds to the F-35 pilot. The PALWs fly autonomously but are linked to F-35 for C2 and lethal engagement directions. The PALWs are

UAS optimized for SEAD missions. They carry potent electronic attack and jamming packages to neutralize SAMs and stand-off weapons to destroy them. The PALWs also receive ISR from AL-SUAS launched by high-altitude carrier aircraft. PALW-1 melds this information with the fused data and relays it to the F-35. The human pilot uses the fused data to build a tactical picture for SEAD actions and then instructs the PALWs to autonomously engage validated targets. As the flight reaches the projected SAM engagement envelope, the PALWs surge ahead of the F-35 to perform their assigned tasks. Not all will return, but the loss of human life will be limited and the ability of single human pilot is multiplied to a level that overwhelms enemy IADS and SAMs.

Technological Feasibility

The *RPA Vector* describes the loyal wingman concept as a way of leveraging autonomy to enhance the effectiveness of manned aircraft. It also states that SEAD is a potential mission for the loyal wingman family of systems.[175] The technology to enable this is feasible. Mike Fowler stated the technology to allow a single person to control multiple UAS is in reach.[176] This was also demonstrated in the previously mentioned Navy experiment where one person controlled 13 surface vessels. Current autopilot technologies can fly aircraft to and from locations and control them in loiter orbits.[177] This technology needs to expand significantly to enable autonomous flight that is useful in an A2/AD environment, but this is an area where Kurzweil's LOAR could quickly pay dividends with enough research and development investment. The Air Force's preference for manned platforms is probably the greatest roadblock to the needed technological development. However, the PALW approach retains significant man-in-the-loop control, which is more in line with the RPA vector and more palatable to the Air Force.

Investment Risk

As with the two previous scenarios there is investment risk. However, this scenario could pay dividends much quicker. It would be easier to implement loyal wingmen for SEAD if the first phase focused on disposable, semi-autonomous UAS. This would roughly harken back to the one-way flying bomb B-17s from WWII except the UAS would reach their intended targets engagement zones. The semi-autonomous UAS would act as weapons truck loaded with stand-off weapons or HARMS. The controlling pilot, likely in an F-35, would direct targeting and weapons release. Although not capable of human level autonomous flight, these UAS would be competent enough to reach engagement zones and avoid other aircraft. This would require less investment upfront and be more in-line with the *Air Superiority 2030 Flight Plan's* direction of harvesting technologies as they mature.[178]

Institutional and Political Friction

Similar to either of the first two future scenarios, Raging Centaur faces a fair amount of institutional friction. Paul Scharre points out that in 2010, then Secretary of the Air Force, Robert Gates, allocated $50 million to fund multi-aircraft control. Air Force senior leaders never developed the technology because they felt multi-aircraft control needed more conceptual development. They also felt it was a decade-after next technology. Scharre disputes this stating that multi-aircraft control is already being demonstrated in its basic form by several companies.[179] The Air Force recognizes the one pilot controlling one aircraft paradigm needs to change, and the *RPA Vector* repeatedly discusses multi-aircraft control, but it needs to start being viewed as a this decade technology. Captain Michael Byrnes predicted the Navy would lead the Air Force in UAS development because the Navy's ego is centered on ships.[180] Two Navy projects mentioned in this thesis point to this. First, the Navy's demonstration of one person controlling 13 boats, shows multi-vehicle control can be developed this decade. Second, even the CBARS to provide aerial refueling and ISR is more ambitious than any public Air Force UAS program of record. Viewing multi-aircraft control as a far-term technology constitutes institutional friction that remains one of the strongest barriers to autonomous UAS development.

Since *Ranging Centaur* inherently keeps man-in-the-loop control it is more politically acceptable. As stated earlier in this thesis, there are already weapon systems that can find both the target and the engagement path autonomously (homing torpedoes and AGM-88E AARGM). The philosophical gap between these weapons and autonomous UAS that are first pointed at valid targets by human operators is not very large. Scharre sees this line blurring in the future,[181] which should reduce political friction.

This does not mean there will not be political pushback. The current use of RPA for lethal attack receives heavy criticism. Websites like *KnowDrones.com*, *ProjectRedHand.org,* and *No Drones Network* on *Blogspot.com* abound, and share a common theme protesting against the use of RPA in warfare. Project Red Hand was founded by an ex-USAF RPA sensor operator who now actively opposes drone strikes.[182] *KnowDrones* recently published a letter signed by 45 retired and former service members calling on RPA operators not to fly and released graphic television advertisements showing the aftermath of drone strikes as part of their "refuse to fly" campaign.[183] There is potential for these movements to gain momentum that could expand to protests against lethal autonomy. The Obama administration has actively defended drone strikes, indicating recognition of both domestic and international criticisms. Observers fear that drone strikes cause destabilization, and deteriorating relations with Islamabad changed drone operations in Pakistan allowing for more State Department involvement and notification to Pakistani officials for certain strikes. Despite this, the Pakistani parliament voted unanimously to end drone strikes on Pakistani soil in April of 2012.[184] However, this has not stopped the use of RPA or practices like signature killings where unknown persons are killed by RPA attacks because their activities bear the signature of extremists.[185] If public resistance has not stopped this practice then it will not likely stop teams of manned aircraft and autonomous UAS.

Scenario Analysis: effect on SEAD

Raging Centaur offers a future where humans retain far more control over UAS but leverage their autonomous capabilities to achieve synergistic effects. Relying solely on manned platforms is a risky course. Russia and China both present SAM threats unlike any the US has faced before. Trying to suppress modern SAMs could take a heavy toll on aircraft and trained pilots. This thesis has discussed the difficulties presented by modern mobile SAMs at length. The bottom line is the US cannot afford to merely refresh or upgrade the same tactics; adversaries will just continue to upgrade their counter measures.[186] Employing new approaches to SEAD, such as multiple UAS controlled by a single pilot, will provide new advantages, including the ability to saturate IADS and mobile SAMs. Similar to the *Killer Bees* swarming concept, teams of manned aircraft and autonomous UAS would bring more firepower to the battlefield and have a better chance to locate SAMs and overwhelm their defenses to suppress or destroy them.

Scenario 4, "Erewhon":

Proposed Future

Only brave, dedicated, F-16CJ pilots would continually risk their lives on SEAD missions against top-flight S-400 and S-500 SAMs. Even the older S-300s networked into the IADS with the more advanced SAMs presented a huge challenge. The F-35 SEAD pilots faired a little better since their stealth afforded more protection, but that also meant they fought closer in to the SAMs and took greater risks since they were not totally invisible to the adversary's networked VHF radars and emitter locator systems. Aggressive electronic warfare and stand-off weapons helped lesson the odds, but the opponents' own jammers, jam-resistant technology, point defenses, and shoot and scoot tactics decreased the advantages the US forces once held. Gaining even temporary air superiority came with a high cost in blood and treasure, one the US could ill afford given an F-35's high replacement cost. The pilots did their heritage of manned aviation proud, but training their replacements was a lengthy process and personnel losses were becoming unsustainable. However, the battle still called, and America's brave pilots answered the call despite the odds.

"Erewhon" represents a future where research and development of RPA and autonomous UAS has followed historical precedent and atrophied. The name "Erewhon" is the title of a book written by Samuel Butler and published in 1872. The book describes a society that has utterly rejected the use of machines in the fear they would one day develop consciousness and the ability to reproduce.[187] This is an extreme example but the name fits this scenario. This thesis has already stated that investment in RPA dries up after wars. For example, drone technology advanced rapidly during the Vietnam War. In December 1971 Teledyne Ryan delivered a drone that could fire a Maverick missile. The Air Force wanted to use drones to soften up air defenses so manned aircraft could finish them off. However, the SAM sites were so well camouflaged that drone pilots could not locate them using the drone's television optics, and neither could human F-4 pilots. Because the drones could not outperform humans they were not used for this role. The solution was to be an infrared sensor to locate the SAM sites, but the development of an infrared sensor was never finished.[188] Probably because time simply ran out as the January 1973 Paris peace accords put an end to US military combat in Vietnam. After Vietnam, investment in drone technology stopped for a decade in favor of other weapons platforms.[189] The Teledyne Ryan drones had made tremendous progress during the Vietnam War. Continued investment may have led to much more capable RPA and UAS today.

Technological Feasibility

This future is certainly feasible. The US has proven its ability to produce advanced manned platforms. The upcoming B-21 is projected to have better stealth performance against sophisticated IADS and SAMs allowing the aircraft to penetrate enemy defenses. With a projected $564 million price tag (in FY16 dollars), however, the Air Force likely cannot afford many more than the 21, B-21s ordered under the original contract.[190] Also, the world is catching up with US technology. As more 5th generation fighters become operational, the US loses the advantage provided by F-22s and F-35s. This thesis has focused on SEAD in relation to SAMs, but an IADS that is networked with 5th generation fighters would be very difficult to suppress. The US still has a large lead over other nations in RPA and UAS development,[191] and it should not allow this gap to close because UAS may provide a crucial advantage in future conflicts.

Investment Risk

The primary investment risk of this scenario is the skyrocketing cost of manned aircraft. The previously discussed Augustine's law can be seen in the estimated price for the B-21. Paul Scharre highlights the escalating cost issue with the following statistic: from 2001 to 2008 the Air Force's base budget increased 27 percent even as the number of combat aircraft decreased 20 percent.[192] This is not a sustainable trajectory. On one hand, investing in manned aircraft is a safe strategy because it has been a proven approach against historical adversaries; however, it carries the risk of not being able to afford enough aircraft for a conflict with near-peer enemies. Better acquisition practices might help ease costs, but as started early, much of the cost increase for Global Hawks is due to technology development. Any time the Air Force develops new technology it is expensive, but switching to open architectures that allow easy technology sharing across airframes could also reduce costs.

Institutional and Political Friction

This scenario is the path of least of resistance when it comes to institutional and political friction. A 1981 GAO audit found the Remotely Piloted Vehicles (RPVs) program suffered more from apathy and attitude than from technological drawbacks, and in the same year Benjamin F. Schemmer wrote that RPVs suffered because they competed with pilots for jobs.[193] The long standing bias against RPA and UAS continues as investment in these systems pales in comparison to manned systems. As of Fiscal Year 2013 nearly every RPA and UAS family of systems required for advanced applications like SEAD were unfunded.[194] The bias may have eased some, but as the director of Duke University's Humans and Automation laboratory (a former Navy fighter pilot) pointed out in 2014, there are still people in the Air Force that are fighting against UAS programs.[195] Until the funding is there, documents like the RPA Vector articulate good ideas but will not drive real change in RPA and UAS technology. As long as institutional friction favors heavy investment in manned aircraft then the research and development money, like water, will follow the path of least resistance.

It is hard to project a great deal of political friction for this scenario. Programs like the F-35 have received substantial critique due to cost overruns and program delays. This may be one reason the *Air Superiority 2030 Flight Plan* insists that money cannot be invested in fixed programs meant to bring about cutting edge technology.[196] The role of political friction in this scenario would be more focused on a cheaper, faster acquisitions process, than on pressure to invest in RPA and autonomous UAS.

Scenario Analysis and effect on SEAD

Historical precedent points to this scenario being a real possibility. RPA have enjoyed a golden age because they are suited to fighting the war on terror. Current RPA technology is not survivable in a heavy A2/AD environment, and there appears to be little push to fund the technologies that could prepare RPA and UAS for an A2/AD war. There is some development of stealthy RPA, the secretive RQ-170 and RQ-180 appear to be primarily ISR aircraft, though it is thought the RQ-180 will have some electronic attack capability giving it a role in SEAD.[197] The Air Force is making a step in the right direction if it truly is giving the RQ-180 electronic attack capability, but strike capability for UAS conducting SEAD should still be explored. In this future, SEAD remains a dangerous activity for pilots. Air Force leaders have predicted that even the B-2 is losing its stealth advantage against advanced SAM radars.[198] Projected B-21 acquisition costs are too high to assume many of these aircraft will be available for SEAD. This will leave the SEAD mission to aging F-16s and F-35s. Concurrently competitors will continue to develop SAM capabilities to counter these aircraft, leaving SEAD a dangerous mission.

Overall Scenario Analysis

The four scenarios present possible future states the Air Force could pursue towards future development of RPA and autonomous UAS for SEAD operations. The battlefield of the future will require autonomous UAS operating at greater tactical speeds to successfully counter advanced mobile SAMs. *Raging Centaur* provides the earliest viable future state and could be the most feasible future. Technology still needs to be developed, but the ability to control multiple aircraft has been demonstrated and a phased approach with less expensive, more disposable systems is possible. Both the *RPA Vector* and *Autonomous Horizons* consistently emphasize the need for man-in-the-loop control, indicating this scenario would receive the least institutional and political friction of any of the proposed futures that include autonomous RPA. However, inertia against fully funding RPA research remains an issue.

Singularity Rising carries the highest risk both in terms of the required technological advances and the required investment, which would severely curtail investment in manned technology. It would also encounter the most institutional and political friction. For these reasons it makes little sense to pursue this future. *Killer Bees* is also on the edge of technological feasibility, and it would involve more technological development and investment risk. Some of the technologies, such as micro drones, are still more concept than reality. However, the loyal wingman concept and multi-aircraft control would develop precursor technologies to swarms. "*Erewhon*" is a possible future state, but not a desirable one. RPA technology has too many fertile possibilities to allow it to become sterile again. As SAMs grow ever more sophisticated and deadly, the man and machine partnership proposed by *Raging Centaur* is a reasonable path forward to counter the threat and reduce risk to pilots. As such, the following recommendations are offered:

1. Aggressively develop autonomous flight capability to enable UAS to fly without human supervision. Some consider this the easiest form of autonomy to develop because aircraft usually have more space to correct errors before colliding with other aircraft or objects.[199] A human operator simply cannot fly more than one aircraft at once. Much of the *RPA Vector's* vision for swarms or loyal wingmen will require aircraft that can autonomously fly to the area of operations and execute the maneuvers required for their designated mission. This frees human operators for tasks that require human reasoning, such as directing the overall attack or making proportionality decisions about engaging targets. This is a key partner technology for multi-aircraft control.

2. Fund multi-aircraft control research and development sufficiently to rapidly mature the technology. This means, at a minimum, restoring the $50 million provided by Secretary Gates in 2010 to fund multi-aircraft control development.[200] Like autonomous flight, multi aircraft control sits at the heart of achieving swarms or loyal wingmen. These two technologies will build synergies with human operators to maximum the capabilities RPA or UAS can provide. Multi-aircraft control will enable the human teaming element to control when a UAS may exercise autonomous engagement. This consideration needs to be a key part of multi-aircraft control interfaces. The human operator has to have enough situational awareness to know when UAS can be allowed to switch autonomous lethal engagement modes. This is in-line with the recommendations made in *Autonomous Horizons* to implement gradual and flexible levels of autonomy that allow humans to delegate how much autonomy a system can exercise appropriate

to the situation.[201] Until autonomous flight and multi-aircraft control are matured RPA and UAS will not realize their full potential for missions such as SEAD.

3. Develop autonomous UAS that can contribute to SEAD as part of a man-machine team. SEAD is and will remain a dangerous mission. Developing UAS that can effectively engage IADS and suppress or destroy SAMS are the advantage the US needs as SAMs continue to evolve in lethality and survivability. UAS' long loiter times could enable continuous standoff jamming and electronic attack. UAS built to optimize speed and maneuverability can turn at higher Gs than manned aircraft and could provide more survivable penetrating counterair. UAS could speed up the kill chain for SEAD missions and be programed similar AGM-88E AARGM to autonomously attack mobile SAM signatures once the human commander authorizes autonomous engagement. SEAD is an essential counterair mission required to establish even temporary, localized air superiority, and it is one of the first mission the air campaign must undertake. As autonomous flight and multi-aircraft control progress, applying this technology to loyal wingmen and swarms in a SEAD role will give the US an advantage against advanced IADS and mobile SAMs, since it will put more fire power in the battle space and provide the possibility of overwhelming IADS with sheer numbers. Developing AL-SUAS for SEAD should be a priority to maximize the amount of airframes that can be leveraged against and IADS and mobile SAMs. These three recommendations will work together to counter advanced mobile SAM threats and enable air superiority.

Conclusion

SEAD is a complex part of counterair operations. Modern mobile SAMs have been created specifically to counter US technologies such as precision guided munitions, electronic counter measures, and stealth. Current and projected mobile SAM capabilities present a much more sophisticated threat than the Iraqi IADS the US smashed in 2003. As the US develops new methods for executing SEAD, the advantages of autonomous UAS should be fully developed to aid the SEAD mission. Modern RPA and UAS far exceed the capabilities of their forerunners and, with more autonomous development, they could keep the scales tipped in the US' favor for SEAD operations. Autonomy also presents a potential solution to RPA command and control in an A2/AD environment that degrades overall command and control links.

Lethal autonomous UAS are controversial. Many people oppose the concept of machines making lethal targeting decisions and argue it is neither legal nor moral. The United Nations is actively debating the issue. There are standoff weapons, such as AGM-88E AARGM that can autonomously find their target, but a human always makes the firing decision. This is a small but important distinction, and there needs to be advances in AI before a machine can make a lethal engagement decisions.

The probability of AI reaching human level performance is debatable, but expanded expert systems evolved to become advanced AI can potentially match or exceed human performance in specialized applications. This level of AI may be all that is needed for a machine pilot to fly an aircraft or conduct SEAD as part of UAS and manned aircraft team. As AI improves so will autonomous capabilities, but there will always be a need for flexible levels of autonomy that keep human control in the loop.

The US cannot continue on the same technological development path and remain the world's leading military power. Competitor nations are closing the technology gap, and the US should pursue technologies like autonomous flight and multi-aircraft control that can provide an advantage for SEAD missions. Given China's aggressive land reclamation projects in the South China Sea, and Russia's 2014 annexation of the Crimea and recent combat deployment to Syria, the US cannot assume close military peers have purely benign intentions. Accelerating investment in autonomous UAS to conduct SEAD missions is needed to ensure the US maintains a combat edge over competitors.

This thesis examined four possible futures for RPA and autonomous UAS executing SEAD operations. Trying to pursue a future where fully autonomous UAS prosecute SEAD with little to no human control is on the far edge of technological feasibility and presents unacceptable investment risks. Swarms of autonomous UAS are already being tested, and can become a viable SEAD option. Semi-autonomous swarms limited to primarily ISR and threat and target detection may be achieved in the near future,[202] but highly autonomous swarms conducting SEAD and employing thousands of micro-UAS are a longer term prospect. This path presents heavy investment risk and should be allowed to mature through government and private partnerships instead of being pursued as an immediate course of development. Humans and autonomous UAS teaming presents possibilities for SEAD that are potentially effective. It allows for the greatest ability to implement flexible levels of autonomy that can be changed as the situation demands. This can be viewed as an evolution of current SEAD tactics that rely on automated sensors like the HTS to find targets and stand-off weapons like HARMS that can autonomously engage targets after launch. Integrating these technologies with advanced autonomous flight and multi-aircraft control into an UAS built specifically to penetrate IADS and locate mobile SAMs will add a new level of lethality to SEAD assets. It prepares a future that transfers greater autonomy to UAS that are meant to return from the mission. Autonomous flight and multi-aircraft control still require significant development but represent the best near-term solution to fully capitalizing on autonomy and employing it for SEAD. Teaming also falls more in line with the *Autonomous Horizons'* recommendation for flexible autonomy. The Air Force cannot afford a future where manned aircraft are left alone to face ever evolving SAMs and IADS that are increasingly lethal.

Major David J. Blair and Captain Nick Helms correctly assess that for UAS and RPA to reach their full potential, the Air Force needs to develop a culture of air-mindedness specific to unmanned technology.[203] One approach to this would be looking at what advanced technologies are being developed for manned aircraft could be applied to RPA or UAS. For example, Major Robert Trsek demonstrated UAS air-mindedness when he suggested the distributed aperture system (DAS) cameras and software that provide 365-degree awareness and target tracking to an F-35 pilot could be fitted to a UAS to increase its dynamic target identification ability.[204] DAS technology integrated with autonomous flight systems would give a machine pilot the situational awareness to track, avoid, or pursue targets. It would also provide greater situational awareness for multi-aircraft control.

The last decade of RPA operations has shown the importance of unmanned aircraft in the battlespace. Blair and Helms correctly note that the toll Predators and Reapers have taken on terrorist leadership has established a proud legacy for RPA operations.[205] Recognizing the RPA's contributions will help establish a culture that values RPA and UAS development equally with manned aircraft development. Secretary of Defense Ashton Carter's Third Offset Strategy is a positive step forward for the DoD as a whole. The Third Offset focuses on creating advantages for the US over other great powers. One of the primary focuses areas in human-machine combat teaming that pulls RPA and UAS into operational teams with manned platforms. The Army's Apache-Gray Eagle RPA, and the Navy's P-8-Triton RPA teaming projects are good examples.[206] The Air Force is painfully absent from the list of combat teaming examples. The Air Force must not just follow the other services' lead for RPA or UAS combat teaming, they should lead the way.

The *RPA Vector* outlines a vision that should be realized, but will not until Air Force senior leadership commits to leading development of RPA and autonomous UAS for the DoD. The Air Force has proven they can build exquisite aircraft; the F-35 will wrap the pilot in a stealthy cocoon of incredible technology. However, as peer adversaries' field their own 5th generation fighters, teamed with advanced mobile SAMs, the Air Force will begin to lose their technological advantage. The Air Force must develop autonomous UAS to dominate the battlespace of the future.

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