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The Modern Face of Battle

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The Modern Face of Battle

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Abstract

New technology is entering the battlefield at a rapid pace, changing the way modern battle is conducted. This paper surveys the state of robotic systems, and identifies new technologies of war and the evolving military doctrine of the U.S. military. Our analysis is drawn from historical parallels and current publications. We conclude that the Department of Defense has adopted a high tempo, flexible doctrine that is capable of taking advantage of the evolving mission payloads of unmanned military systems.

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1 Introduction

The tactics and strategy of wars are largely defined by the technology of the era in which they were fought. Historically, dramatic advances in technology fundamentally changed battle doctrine. This paper examines the impact of modern technologies, especially robotics, on the battlefield. Thematically, it argues that: a revolution of warfare defined by modern technology is ongoing; and secondly, that historically air power and superior technology have not been enough to win a war by themselves. Our research suggests that this maxim holds true for 21st century warfare.

Section 2 of this paper outlines our research methods. Specifically, it addresses our primary sources of information and why we chose them. One goal of this project was to survey members of the robotics industry on the state and future of robotic systems. This section outlines our methodology for contacting professionals in industry and details our success.

Section 3 surveys the primary literature sources used in this paper. Before focusing on military robotics, we also explored medical and industrial robotic applications. We concluded that the majority of funding for robotics research is for military applications at this time. This research is presented here along with a brief survey of the capabilities of medical and industrial robots.

The fourth section begins by defining the *face of battle*[1] as it has been historically presented. It then progresses through the 20th century, setting the stage for a modern definition of the term. Section 4.1 presents historian John Keegan's analysis of the face of battle from 1415 through World War I, and his predictions in 1976 when his book was published, for the future trends of battle. Section 4.2 analyzes the asymmetrical ground war America fought in Korea. Finally Section 4.3 prepares the paper to enter the 21st century with a primer on the technology driving the NATO intervention into the Balkans in 1999.

Before addressing modern battlefield technology, we explored the history of air power. Historically strategic bombing campaigns have been advertised as a means by which an enemy force or country can be crippled and their ability to wage war devastated. Our examination of historical evidence shows that this is not the case. We believe that this analysis lends itself well to the drone warfare being presently conducted in the Middle East.

Section 6 is a survey of the modern battlefield as viewed by the United States. It begins by examining the traditional western and eastern fighting styles. Next it surveys the unmanned technology being deployed in battle on land and in the air. Finally, it examines the integration of human and machine on the battlefield. In Section 6.6 we propose a definition of the modern face of battle.

Finally, Section 7 outlines the future of unmanned warfare. The United States government has published specific goals for its unmanned programs over the next few decades. The capabilities and implications of these goals are analyzed.

Our conclusions review the proposed definition of the modern face of battle and the implications of current and near-future technology on it. Ultimately, this paper concludes that historically air power alone has not won wars. By extension our research concludes that modern and future conflicts will be difficult to win without the support of troops on the ground. The role of infantry is changing to reflect the kind of wars that America is now involved in. Infantry must be humanitarians as much as soldiers. Modern fighting is highly specialized. Rather than large-scale engagements, battles are now far more tactical in nature, requiring more specialized units fighting them. It is here that the integration of precision technology into the battlefield, and the logistical support provided by modern communications systems will have a transformational impact.

2 Research Methods

Our IQP examines the effect of technology on the battlefield from World War Two through today. This is a very broad topic, and we needed to focus in on key areas. Historically, we chose to focus on air power in World War II and the ground battles of Korea. World War II demonstrated among other things that air power can not win a war. Korea illustrated the limitations of technology and exemplified the decentralized style of warfare that America is encountering in the Middle East today.

Since we are focusing on historical and modern perspectives, our research had two main directions. For the historical perspective, we relied on history books and sources such as the historical *New York Times* for perspective. However, because we wanted this project to be more than a history paper, we also wanted to focus on the ongoing conflicts in Iraq and Afghanistan; namely the impact and future of technology on the battlefield. For this time period we took our information from journals, technical magazines, *The New York Times*, and various books published within the last decade.

Finally, since technology is playing such a pivotal role in the capabilities of the American army today, we wanted to interview industry representatives and get their opinions on the state of battlefield technologies - especially robotics. We contacted people from iRobot, Foster-Miller, Heartland Robotics, Onstott, and HP. Out of the approximately ten people we contacted, we were only able to personally interview two of them. Our success rate from contact to tangible response was 20%. We determined who to contact based on who we thought would be likely to respond. Some people are involved sponsoring various robotics competitions, others are contributers to technical blogs.

For a list of common interview questions, see Appendix C.

All transcripts of our interviews are available in the appendixes of this paper unless the interviewer requested they be kept private. They may be viewed upon request with permission from Professor W. Baller. Some interviews were conducted on the condition of anonymity and all interviews were conducted under the protocols set forth by WPI's IRB exemption, which we obtained.

3 Background / Literature Review

Before the modern face of battle can be explored, the historical progression of the battlefield to its present state must be established, and a survey of general robotics conducted. Robotic applications in medical and manufacturing technology have advanced significantly since the 1960's, however the amount of research and funding driving innovation in these sectors is dwarfed by military applications and research. Sources such as *The Face of Battle*, *The Coldest Winter*, and *Virtual War*, illustrate the battlefield in beginning with Agincourt in the 15th century, through the Balkan Conflict in the 1990s. Books such as *Tactics of the Crescent Moon, Wings of Judgment*, and *Rise of American Air Power* discuss the implications of irregular warfare and the effectiveness of air power. Current sources such as *New York Times, Washington Post, Wired for War*, and *Popular Science* discuss the emergence of robotics on the battlefield.

In *Robotics: A Reference Guide to New Technology* Joseph Angelo attempts to define a robotic system. This broad definition includes industrial machines used to automate manufacturing, missile guidance systems, autonomous robots, and human controlled robots, like UAVs. He presents many advantages to such robotic systems and attempts to tackle the moral and ethical dilemmas involved in replacing humans with robots in certain roles.

It became evident searching through the *New York Times Historical* archive between 1929 and 1985 that almost any automated device was called a robot, as seen by referring to a traffic sensor called the "automatic eye," as a robot[2]. The *New York Times Historical* search provided insight to the evolution of robots in the past century, going back to "Erik Robot", though Unimate, and first instances of autonomous and remotely controlled military robots.

Manufacturing has advanced greatly since the introduction of robots. Robots in manufacturing can decrease labor cost, increase efficiency, never tire, and can perform repetitive tasks with ease. In 1961, GM was the first company to use industrial robotics, this first generation was named Unimate. This 4,000 lb behemoth could maneuver 500 lb parts with ease[3]. Eight years later about 200 Unimate robots were in service with a prediction to grow to 5,000 in 5 years. At the time one of these robotic arms costs about $20,000[4], still out of the reach for mainstream production.

Though the initial investment costs of robotic manufacturing are high, in the long term, these systems are far cheaper than paying laborers. One brick making company found significant cost savings using robots, with the robots costing about $0.78/hr and humans costing $5/hr[5]. Robots were also thought of as human assistants, similar to an exo-skeleton; one example of this is the General Electric "Handyman" which can mimic the movements of an operator's arms and work safely on a hot engine, or scale down the force applied to work on very delicate parts[6]. Though robotic systems have proven to be extremely useful in manufacturing, the complexity of these systems is eclipsed by modern military applications

One use of robots in national defense is in the medical field, including but not limited to helping soldiers on the battlefield. Surgeons can perform operations from many miles away with possibly greater precision than if they were operating in person. Modern surgery is a very delicate and precise matter. Surgeons train for years before performing a live operation. Surgical difficulty is increased with the possibility of inducing trauma to a patient by incorrectly executed surgery. With the introduction of robotics controlled by a surgeon, precision can be increased allowing doctors to perform surgeries with minimal damage to the body. This is especially important in neurosurgery, where a slight mistake could have dire consequences. As early as the mid 1980's, surgeons used robotic arms to precisely sample areas of the brain where there were potential tumors[7]. By using a robot to perform the surgery, a computer could calculate the proper trajectory and distance to minimize brain tissue damage. Doctors also have the option of going back into the same incision with different instruments, a challenge without a robotic solution.

With such precision possible, surgery can now be performed across great distances. This suggests that patients can be operated on by the best surgeons for their respective malady without considering distance. A recent record for remote surgery was set when a man underwent a remote gallbladder operation in France. The operator of the robot was in the United States (over 3,000 miles away)[8]. Despite this success, this is not commonly performed. The latency involved when transmitting data across the world is still too much for precise operations to take place. As data rates and bandwidth become manageable or trivial with advanced communications systems, an increase of these remote surgeries taking place may be seen. This also has battlefield applications. Soldiers who require immediate attention to battle wounds could be operated on by top-class surgeons residing at remote location. Though international surgery is not currently possible, these surgeons might reside in a base-camp only a few kilometers away.

Though long distance surgery is possible, there are many innovations that must be made before it is practical. An important feature that surgeons have requested to further improve robotic surgery is a method for sensing touch. Dr. Robert Howe, a professor of engineering at Harvard University, thinks that "sensory feedback is the next generation of roboticized instruments that will, among other abilities, palpate internal tissues"[9]. Since current robotic assisted surgeries are done purely by visual information, surgeons feel disconnected from the patients. By adding in tactile feedback, Dr. Howe hopes to make the robots easier to use and increase the speed of surgical operations.

Another important division of medical robotics are artificial limbs. Advances have been made which elevate the prosthetic limb from a solid artificial arm to a more natural and functional arm. In recent studies, monkeys with sensors in their brains have been able to move mechanical arms with their thoughts. Scientists see this as a giant leap forward in treating patients with paralytic conditions. Dr. John Kalaska writes that such systems "would allow patients with severe motor deficits to interact and communicate with the world not only by the moment-to-moment control of the motion of robotic devices, but also in a more natural and intuitive manner that reflects their overall goals, needs and preferences"[10]. This is an important area of research for the military as well, as it would meet the needs of veterans coming home from areas of conflict with injuries to their head, spine, or appendages.

Nanotechnology is also an exciting technology for robots of the future. Scientists envision utilizing bacteria sized robots which could potentially deliver medicines directly to sick areas of the body, such as cancer tumors. Another potential development would be robots that interact with the machinery already existent inside cells to produce healing drugs, as a virus would do but in a beneficial way[11]. Such robotic devices are still far in the future; humanity has only recently been able to manufacture robots at such small scales. Where pacemakers were once miracles of modern medicine, we may see nanorobots which help cancer patients or completely automated surgeries as the next revolution in medicine. Though medicinal robotics might increase life expectancy and assist surgeons in their work, most of the money invested into robotics systems today is for purposes of national defense.

Traditionally, militaries have desired an advantage against their opponents; robotic systems represent this advantage in the 21st century. One of the earliest mentions of robotics in the military occurs with a navigation device on an airplane, this device was nothing more than a simple GPS[12]. Early artificial intelligence in a robot occurs nine years later in 1947, when a plane took off from Newfoundland and flew autonomously to Ireland where it picked up a frequency which guided the plane's landing. There was a crew on board but only to ensure the plane did not crash[13]. This plane demonstrated the modern equivalent of an autopilot at a time when the problem solving skills of modern computers had not yet been realized. The reliability of a military drone airplane comes into question, evident as early as 1956 with the downing of a drone. This was a remote controlled military drone, so not a true robot but nonetheless took 208 rockets to down the plane, of which was headed towards Los Angeles but fortunately was veered off into the desert[14].

The military has also experimented with autonomy in undersea applications. In 1985 the Navy tested a drone that could seek and destroy sea mines, saving lives and ships[15]. Currently these duties have to be performed by men expertly trained in explosive ordinance disposal (EOD). Use of these underwater drones is not restricted to military applications. A small civilian underwater ROV called Argos with another smaller ROV attached to the bottom called Jason, was used to explore the titanic in 1985. These small robots allowed explorers to observe the titanic for longer periods of time, in more detail, and more safely than diving down themselves[16]. The Navy also has a hand in the Argos/Jason ROV, financing up to $15 million to further research.

Land based autonomous vehicles are also being developed. In 1985 a six-wheeled vehicle called the Terregator was built by Carnegie Melon University. The vehicle weighs from 1,000 to 2,000 lbs and still is being worked on; most recently the device tried to climb a tree. This class of vehicle could be used to transport troops or civilians for the military as needed. Also, these machines can operate in hostile environments, such as clearing minefields. Carnegie Melon is not the only place to receive a grant for from the Pentagon, which also invested $600 million in a strategic computing program effort aimed at developing third generation robots, some within 5 years[17].

As technology advances, so do the capabilities of robotic systems. News sources such as *New York Times*, *Washington Post*, CNN, PBS and magazines such as *Popular Science*, *Wired*, *The New Yorker*, make the commercial and social impact of robotic technologies apparent to the consumer. All these sources have also noted that the battlefield is changing, becoming defined by network-centric warfare.

John Keegan defined the *The Face of Battle* by the technology and men who fight it. He explores its evolution throughout European warfare through WW1. The technology determines the means by which opponents have to destroy each other. The combatants thrive or perish as a result of their own personal motivations, training, and battlefield conditions. He examines Agincourt (1415), Waterloo (1815), and the Somme (1916)[18]. The technology present in a battle determines how infantry experience it.

Keegan predicted in 1976 that the nature of battle would become more brutal and inhumane. He predicted contrary to Poole that accurate weapons were outdated and that the future of war would be massive weapons of indiscriminate destruction. Instead, technology has enabled more accurate warfare. Weapons have become so precise the way we wage war is fundamentally changing. The most obvious new technology on the battlefield are the robotic systems developed by companies like Foster-Miller & iRobot. Though our research focuses heavily on this aspect of robotic technology, we also examined the history and evolution of robotics in different sectors.

A secondary theme of this paper explores the development of war technology. Some of the most famous war scientists worked for Hitler and were chronicled by John Cornwell in his book *Hitler's Scientists*. John Cornwell discusses Fritz Haber in depth; Haber developed a process of taking two abundant gases and making ammonia which is useful as a fertilizer. While this arguably has helped feed many people, ammonia is also a component of explosives used by the Nazi Party. Haber advocated for the synthesis and use of poison gas against the allies calling it a "higher form of warfare"[19]. Poison gas is a particularly abhorrent weapon, causing burns, internal hemorrhaging of the lungs, and death. "These were the new German warriors: scientists who calculated injury and kill rates with graphs and equations, and employed toxic gases produced by their chemical formulae as weapons."[20]. Does this impart some responsibility to a scientist for what he creates and its applications? Poison gas also inspired an intense hatred for the Germans, directly resulting in poor treatment of prisoners[21], implying that some weapons are worse than others. This could be analogous to modern day UAV's and UGV's where an unconventional weapon can warrant an unfavorable response.

According to General Arnold "Careless inaccurate bombing, he explained, would spread and intensify feelings of hatred in the 'Victim populations,' poisoning relationships between countries after the fighting ended"[22]. Will the use of drones in the Middle East have similar consequences? *The Rise of American Air Power* by Michael Sherry establishes how air power became such a prominent part of American military doctrine. Sherry describes how airplanes were viewed in their infancy by military, and how they were used in the first real opportunity - World War I. In World War II, Sherry notes the shift from tactical to strategic priorities in air campaigns. He also points out after the bombing of Pearl Harbor, Americans felt that strengthening air power would be the most effective use of money. Another subject that Sherry brings up is the idea of using air power to terrorize an enemy populace, something which could be related to the War on Terror today, and the question of efficacy of American air power in the Middle East.

Another source used to analyze how drones might be interpreted by enemies is *Tactics of the Crescent Moon* by John Poole. He examines how the battlefield evolved after WWII. Since WWII, in Korea, Vietnam and today in the Middle East in Iraq, Afghanistan, and Pakistan, there has been a large shift in battle tactics. Large scale battles typical of World War I & II were gone. Middle Eastern fighters historically use guerrilla tactics to counter superior firepower or technology. Poole expounds on this fact, presenting a brief history of how guerrilla tactics became a staple of the Middle Eastern soldiers who have historically faced overwhelming odds. Poole also discusses how the United States (and any other contemporary military attempting to wage battle against so called "fourth generation fighters" must adjust their strategy to counter guerrilla tactics. More firepower isn't the answer. Small, specialized units which are trained for infantry combat are crucial in this new environment.

"Within a decade, machines will be able to perform many of the most dangerous, strenuous or boring tasks now assigned to people, military planners say, paving the way for a fundamental change in warfare"[23]. Attacking a target from a command center located thousands of miles away does not carry the same weight of war that being in the physical aircraft the carries out the attack has. Advanced robots threaten to remove this important bound of warfare. This sentiment is echoed my Michael Ignatieff in *Virtual Warfare*, his account of the NATO intervention in Yugoslavia in the 1990's.[24] Many stories surface in the news about U.S. air strikes accidently killing civilians in Iraq and Afghanistan. Stories that cover the opinion of people who are being attacked by the drones reveal thoughts such as America is lacking a 100% commitment to their country[25]. These opinions imply America may experience a backlash against the usage of drones and robots.

4 The Evolution of Battle Through the 1990's

When John Keegan published *The Face of Battle* in 1976, he challenged many popular conceptions of warfare and the way it was conducted. He drew out the realities of war and battle, filling in gaps in historical records with logical, often gritty, analysis. This practical analysis defined the atmosphere, logistics, tactics, and emotions of warfare, all of which define the face of battle. This section explores the historical definition of the face of battle and provides some background of America's historical encounters with asymmetrical warfare.

4.1 *The Face of Battle* according to Keegan

Published in 1976, *The Face of Battle* critically examines three historic battles: Agincourt (1415), Waterloo (1815), and the Somme (1916)[26]. Keegan discusses several aspects of warfare including infantry vs. infantry fighting, precision, range, communication, soldier's motivations, and psychological effects. He not only examines the battles but predicts how technology will define future wars.

The first battle discussed by Keegan is the battle of Agincourt which was fought in 1415 between the English (commanded by King Henry V) and the French (commanded by Charles D'Albert). Although the English were outnumbered by the French, their tactics resulted in a decisive victory. Occurring just before the advent of gunpowder, the troops of the era consisted of armored infantry, archers, and cavalry. Since the English were outnumbered, they needed to make judicious use of their troops. Keegan saw the cavalry in this battle as a morale breaker; cavalry horse bearing down would be quite terrifying to an infantryman. By instilling fear in the soldiers, holes in their lines would open, allowing the cavalry to exploit the weakness and wreak havoc. The English had no calvary here, but the French launched a charge against the English archers which proved disastrous. Stakes were driven into the ground at the archer's position at such an angle that the oncoming horse would be speared in the chest.

Here is where Keegan's analysis shines. The chroniclers of the time have conflicting accounts about how the stakes were arranged among the archers, the sizes of the armies, etc. Keegan breaks down the French calvary charge into its respective factors. First, the horses were carrying approximately 300lbs, to move at speeds between 10 and 15 miles per hour, they must have been big horses. Big horses have a lot of momentum - this means that once the charge has become, it would be very difficult to break off. The horses were being urged on by their riders, so that they would go against their animal instincts not to charge a man (or a stake). Thus, when the calvary charge collided with the archers and their thicket of stakes, the results were disastrous. Not only were several horses impaled and their riders set upon, but the horses who escaped this fate turned around in retreat. Behind the calvary charge, armored French infantry were advancing in long lines that were not conducive to panicked horses. When the panicked horses collided with the French infantry, they caused even more chaos[27]. Such physical analysis of the battlefield creates a lot of imagery and fleshes out what it might have been like there.

There were several factors motivating the soldier of Agincourt, including drink and religion. However, Keegan notes: "far more important for the common soldier was the prospect of enrichment"[28]. By capturing nobles during the battle, one could make a large sum of ransom money at the time. This characteristic of battle remains almost exclusive to battles before and around this time period. Religion and drink may have provided a reassurance to the soldiers before the battle, but in the heat of battle what prevented the vastly outnumbered English from fleeing in the face of the enemy? Battlefield triage was almost non-existent and a minor wound could result in death. Keegan suggests that in this specific battle, the presence of the King may have provided a prodigious morale boost to the soldiers who were faced with an intimidating enemy. It is also possible soldiers fought out of respect for their fellow soldiers.

The second battle Keegan examines is the battle of Waterloo. This was a battle between French forces, commanded by Napoleon, assaulting a position of "allied forces" commanded by the Duke of Wellington. Napoleon ultimately lost the battle once the Prussians arrived to reinforce the defenders. At Waterloo, artillery was used by both the attackers and defenders to attempt to break the enemy ranks. The French cannons were provided with optimal targets when the enemy infantry formed into the square formation used to repel cavalry attacks causing many casualties[29]. In addition the use of musket balls as well as cannon balls increased the likelihood of dying from a battlefield wound due to sepsis and lead poisoning. This battle was much less intimate than Agincourt because of gunpowder. A progression can be seen in the distance of the "killing zone;" at Agincourt this was maximized at 200 yards, at Waterloo it was over half a mile, and at the Somme, over five miles.[30].

Finally, Keegan examines The Somme (1916). The Somme was the first major British offensive of WWI. This battle is noteworthy because of the technology illustrated: aerial reconnaissance, artillery barrages (a new concept in WWI), wired communication, and machine guns. The Somme was fought geographically close to where Waterloo and Agincourt took place.

Since Waterloo, artillery had developed considerably. The maximum range of weapons had increased to approximately 10,000 yards[31], much farther than a cannons reach and significantly farther than an archer's range. The weapons here were designed to maximize inflicted damage. For example, the shrapnel round which was a shell filled with steel balls and other metal fragments designed to shred and inflict pain upon soldiers (as well as cut the wires between trenches). Weaponized gas rounds were used in the battle. Chlorine gas would infiltrate underground bunkers and caused soldier's lungs to hemorrhage while they attempted to escape. When used properly the machine gun would not allow soldiers to stand up in no man's land without being shot. High velocity rounds caused a great deal of damage, especially if the bullets ricocheted or tumbled through the body. If one was lucky the bullet would pass cleanly through. If you were hit by a shrapnel round one did not stand much of a chance, especially if caught out in no man's land.

British artillery fired around 1.5 million shells at the German position before the battle began[32]. This bombardment was supposed to annihilate the enemy defenses (trenches and barbed wire). The Germans had little chance to sleep because of the constant fear of attack and fear of the entrance to their dug-outs caving in[33]. Despite this, the German defenses remained largely intact. A lack of understanding of the capabilities and consequences of technologies such as the machine gun, high explosive shells, and shrapnel by the British generals had dire consequences. At the Somme, the British sustained over 57,000 casualties *on the first day.*[34]

Today, one missile can eliminate something which would have taken thousands of rounds to destroy in World War I. So while while the psychological effect of a seven day bombardment might be gone, the sense of security given by being underground is also gone. Like Waterloo, the commanders of The Somme were unable to determine how the battle was going on the front lines, being essentially blind and unable to make decisions -"for two hours after zero, no news whatsoever was received from the front, all communications, visual and telephonic having failed"[35]. The communication lines laid out before the battle only went as far as the British trenches. Any further lines laid during the assault were destroyed by enemy artillery.

Analyzing the evolution of technology from Agincourt through The Somme, Keegan makes several predictions about the future of warfare. He envisioned weapons evolving into larger wide-area weapons rather than smaller weapons focused on accuracy[36]. Soldier's skill sets are migrating towards specializations, technical and non-technical. With the need for soldiers to operate the machinery, maintain transmission equipment, the need for traditional infantry is diminished. Instead, warfare has become more precise. True, weapons of mass destruction exist, but they are hardly commonplace. The capabilities of a military are often assessed by the capabilities of its technology. Right now, that technology is precision technology: drones, smart bombs, satellite communications networks.

4.2 Korea

Sometimes called the "Forgotten War", Korea presented a markedly differently battlefield than Europe in World War II. Technology was difficult to bring into action and the type of warfare encountered was unique.[37] Veterans of the Pacific theater recalled how brutal the fighting could become against Japanese soldiers physically and psychologically entrenched into the land they were defending.[38] Korea represented much of the same kind of combat, but the American army fighting the war was very different than the one of 1945. The Americans did not have the heart of their country behind them.[39] Constantly short of ammunition and manpower they often felt overwhelmed by the clich "Asian hordes."[40]

Though outnumbered, the Americans did not face an organized enemy. The totalitarian nature of the North Korean regime meant that bad news did not filter up the chain of command.[41] What this meant was that Kim Il Sung's idealistic and unrealistic view of the battlefield was often reinforced. His Chinese and Soviet advisors often balked at his ignorance of the battlefield realities.[42] This deficit in command allowed the Americans to recover from the brink of defeat and prolonged the war by several years.

To summarize, the American forces in Korea were poorly supported logistically, often under questionable leadership, and were a far cry from the disciplined army they had been at the end of World War II.[43] When the war began, they were facing a very effective North Korean army that knew how to take full advantage of the local terrain. The North Koreans had numerical superiority on their side, but also had command issues. Kim Il Sung insisted on making strategic decisions and in doing so often crippled his army.

When North Korea crossed the 38th Parallel they pushed the Americans back to Pusin, where the Americans fought a desperate but effective defense on the Pusin Perimeter.[44] Once MacArthur landed at Inchon the tide turned dramatically against the North Koreans with American forces pushing them all the way back to the Chinese border.[45] Once the Chinese entered the war in November of 1950 the war again shifted against the Americans as the Communists made significant gains, once again crossing the 38th parallel. By 1951 the war had degenerated into a stalemate. The United Nations were slowly advancing, but President Eisenhower on a flying tour of the battlefield saw the futility of the fighting and became determined to end it.[46]

What characterizes the battlefield of a war defined by such dramatic power swings? The concept of a "front line" was hazily defined in Korea. Soldiers were fighting a war unlike any of them had fought before (except perhaps the Pacific Theater in WWII). Korea illustrated how much America relied upon its technology to win battles and provided a sharp contrast of eastern and western fighting styles.[47] These are the two ideas that are important to focus on to understand how the *face of battle* changed from World War II to Korea.

The battle of the Pusin Perimeter represented some of the fiercest fighting of the war. American soldiers were outnumbered, outgunned, and did not see surrender as an option (there were stories of prisoners being shot on sight).[48] Their only choice was to fight it out and hope that reinforcements would arrive in time. Failure meant being driven to the beaches of Pusan and forfeiture of South Korea. Survivors of the battle characterized it as a hectic series of small engagements constituting a larger front. Units were spread thousands of yards apart and as a consequence could not be of any mutual assistance to each other during the night, which was the North Korean's preferred time of attack.[49]

During these engagements Americans had little in the way of artillery support to call in. That which existed was of poor quality. One soldier recalls a time when he requested artillery support and a single shell landed several hundred yards away from the coordinates he had specified. When he asked for clarification the response he received was that the artilleryman were not trained on the equipment. Air support was also non-existent.[50] The American infantry were acting as best they could as independent infantry units. These independent units demonstrated strong small unit tactics and tremendous endurance at Pusan. Units fought until they were out of ammunition and then retreated as best they could. The American soldiers knew that failure was not an option and went to great lengths to remain in combat for as long as possible.[51]

Once MacArthur regained his bearings, he planned a daring strategic move at Inchon. His plan was to land an American force amphibiously behind the North Korea lines, recapture Seoul, and cut off the North Korean retreat. Though Chinese and Soviet advisors suspected exactly such a plan, Kim Il Sung ignored their advice and American troops landed unopposed at Inchon.[52] The landing at Inchon represented a turning point for American soldiers in the war. America was now fully committed to saving the Korean peninsula. Crushing pressure was removed from the Pusan line as North Korean troops began to retreat. American planes were now able to fly more sorties and soon a strategic bombing campaign began against the North.[53] The logistical support that the soldiers at Pusan had completely lacked was beginning to catch up with the war.

The Americans also took full advantage of the technology they had available to them. "The speed of battle against an army with the technological advantages of the Americans was escalating all the time- more hardware coming into the country made the pace of battle ever faster."[54] Here the author is referring to communications. Americans took advantage of radio equipment and were very effective at breaking Korean codes. They often knew exactly where and when the Koreans were going to strike - they just lacked the manpower to do much about it.[55] This reflects the doctrine prevalent in the military today. Good information can be far more lethal than a carpet bombing campaign.[56]

The North Korean army was poorly commanded and ill-prepared for a sustained offensive.[57] Once the Americans began to push back, North Korean resistance quickly crumbled. The Americans were so successful that they pushed the NKPA to the Yalu river close to the Chinese border. Despite the fact that Americans were making use of the technology they had, like today in Afghanistan, they were not fighting a traditional enemy. The Americans advanced so quickly they outran their supply lines. Many of the more experienced veterans among the soldiers felt that they were advancing into a terrible trap.[58] Caught up in the moment, high ranking American officers were ordering swift advances with little logistical support as a harsh Korean winter approached. The end result was catastrophic. Practicing highly effective guerrilla techniques, Chinese forces launched a huge offensive against the Americans. The Americans were pushed back almost as quickly as the North Koreans had been - often losing contact with the Chinese forces.[59]

The Chinese practiced a method of combat foreign to the Americans. Having just emerged from their own civil war in 1949, the Chinese were well versed in guerrilla techniques. Their tactics were similar to the NKPA in nature, but they were far better organized and disciplined. They would attack in force and at many points. As soon as the battle turned against them they would split their attacking force into small units and strategically retreat. They would regroup and attack again.[60] These tactics made a front line difficult to define, as the Chinese were experts at slipping between gaps in a line. This degenerated Korea into a series of "hill battles."

What characterized a hill battle? First, the battle lines were circular. Flanking was a favored tactic of the Communists and the Americans soon learned to shape their battle lines to the contours of the terrain.[61] Once combat began, there were often so many Chinese soldiers that individual squads of Americans and ROK units were cut off and became independent units.[62] The attacks would come in waves, each one wearing down the Americans garrisoning the hill at a tremendous cost to the Chinese. Often, the Americans ran out of grenades and ammunition for their machine guns before they were overrun.[63] If a force was driven off of one hill, they would retreat to the next.[64] Such battles became characteristic of the war.

Fortunately for the Americans, when President Eisenhower toured Korea he recognized the futility of the war. He realized that no large victory could be extracted from these hill battles and returned from his tour determined to make peace.[65] When a cease-fire was declared and the battle lines were returned to the 38th parallel.

The Korean war emphasized how rugged terrain could nullify technology. Tanks had trouble navigating mountainous terrain. Aerial reconnaissance proved ineffective against the Chinese who actively tried to avoid it with camouflage. Today, military robotic systems are limited by how rugged they need to be. Industrial robots are capable of up to 18 independent axis of movement; the reason that such capabilities have not made it into Iraq and Afghanistan is that these advanced components are not rugged enough to survive a hostile environment.

More than anything, Korea was defined by the soldiers who fought it, not their technology. The Korean war drew out the face of battle as few other combat experiences have. It emphasized fear, courage, and brotherhood.

Large American units withstood assault on a unit-by-unit basis. The camaraderie was strong and so was the will to survive. The reason many such units held out to the last man was the belief that they were buying more time for their compatriots to retreat.[66] The Korean war brought out the best and worst of many men; in the words of Bruce Ritter "combat stripped men down to their essentials. Some men looked strong and tough...Some of them wouldn't be very tough at all, and by contrast, someone who was skinny and mild would turn out to be a very good soldier, strong inside instead of outside."[67]

What words can better describe the core of what the "face of battle" means? Many battles of the Korean war elicited this kind of tough self-examination from soldiers. Technological doctrine employed was often more primitive than that of the second world war. Limiting terrain and a mobile, untraditional enemy, made many tactics and technologies developed to fight in Europe during World War II obsolete or unpractical. This is not to say that technology was not effective in some areas - radio communications and code breaking techniques proved valuable.[68] What compounded the difficulties of the Americans were high ranking officers that had little clue how to command infantry units - especially when things went poorly.

This combination of technological impotence and deficiencies in leadership created an environment that made it very difficult for American forces to be effective in Korea. Though they eventually adapted to their situation[69], the fierce combat that marked the Pusan Perimeter and Chosin Reservoir would characterize the combat of Korea as unforgiving and exhausting. Today in Iraq and Afghanistan, the American military once again face unconventional enemies.[70] Though perhaps we are becoming unconventional ourselves. Robotic systems in the military must present unique challenges to an insurgent enemy. We are taking a different approach than the Soviets took in Afghanistan in the 1980's. In Korea, Americans fought against overwhelming numbers of enemies using unconventional tactics. It took the Americans a significant amount of time before they were able to effectively hold their own, but even then, they never developed a truly groundbreaking offensive strategy. In the Middle East, we are forcing insurgents to fight an enemy at least a full generation ahead of them in technology. By redefining what unconventional warfare is through technology, we may be putting them in a comparable situation to the soldiers at Pusin who fought valiantly, but were ultimately facing defeat by a numerically superior and tactically unfamiliar enemy.

4.3 The Balkan Conflict

While the Operation Desert Storm in 1991 was the first war to realize the potential of digital computing[71], it still possessed a significant infantry element. The NATO intervention into the Balkans represents a shift from this doctrine of mobilizing infantry. In 1999, Serbians began an ethnic cleansing of Albanians in Yugoslavia. Already under scrutiny by NATO and the UN, this caused the U.S. to spearhead a military intervention into the region.[72] From March 24th, 1999 to June 11th 1999, NATO waged a new and sophisticated type of war waged by proxy through technology, and not boots on the ground.[73] Though the bombing campaign made war unsustainable for Yugoslavia, it did not immediately stop the ethnic cleansing.[74]

Throughout the Gulf War, the American media hyped up smart bomb technology and the decisive advantage it gave America.[75] This led to a perception of warfare as a form of precision surgery.[76] Throughout the NATO intervention, zero casualties were incurred by the United States.[77] To prepare for the Gulf War, thousands of troops were mobilized. Saddam Hussein had built up the image of the Iraqi Republican Guard as an elite force, and it was portrayed as such by the media.[78] In the Balkans, no such troop mobilization took place. The war was fought by approximately 1,500 NATO pilots and their logistical support.[79]

The air campaign waged over the Balkans represented an unprecedented integration of command and control. Since there was no infantry on the ground, reconnaissance pilots needed to develop and relay targets of opportunity to bombers fast enough to allow an effective response to time-sensitive intelligence.[80] The commander of the NATO air campaign, General Wesley Clark, emphasized to his pilots that it was their responsibility to determine valid targets.[81] Since there were no ground troops, targets were classified by aerial photographs, assessed for their collateral damage potential and military value, then filed away for possible use at a later date. It was often difficult to verify the original intelligence on a target weeks or even months after it had been gathered. This led to several accidents, including the bombing of the Chinese Embassy.[82]

In May, 1999, NATO began targeting vital Serbian infrastructure. The grid supplying power to Belgrade was repeatedly targeted, leading to continuous power outages.[83] Though it directly targeted civilian infrastructure, this was the most effective way of winning the war.[84] It made the war real to the Serbian middle/upper class.

Michael Ignatieff, author of *Virtual War*, calls this evolution of technology a revolution of military affairs (RMA). The RMA emphasized technology, especially precision technology. Up until this point in history, warfare had been about attrition: strategic bombing, heavy artillery, and massive land armies. The new RMA states that *the carnage of modern wars will be directed towards nervous systems of enemy activity.* Attacked by precision weapons systems, targets will be identified by small, independent units that serve as the eyes and ears of a sophisticated technical backbone.[85] This shift implies that radical changes will be necessary in traditional the military structure to take full advantage of new technology.

Virtual warfare also promises to redefine the moral and ethical lines of warfare. If weapons are precise in nature, civilian casualties become amplified. Historically, strategic bombing has been seen as a crude, but necessary part of warfare by the United States.[86] Now that unmanned aerial vehicles (UAV) can guide a missile to within inches of its intended target, the indiscriminate nature of strategic bombing cannot be justified. During the height of the Balkan conflict, civilian protesters of the war stood on bridges in Belgrade wearing large, red, circles. Their message was clear: Although NATO says it is not at war with the Serbian people, *we suffer the consequences of war*.[87]

> More Kosovos, less Iraqs.[88]
>
> –Lawrence Korb

This sentiment emphasizes an important consequence of precision technology. In the 2001 quadrennial defense report, the DoD emphasizes the desirability of being able to resolve threats from a long distance.[89] For America, Kosovo was a bloodless war. However, there was no follow up. After the intervention, there was still some semblance of intact government that did not require nation building (or re-building). In Iraq and Afghanistan, the United States toppled the governing regimes and set out to implement a new government - a fundamental difference between the two conflicts.

Despite this difference, Kosovo showcased the potential of precision warfare. The air campaign in Kosovo represents an evolutionary step from the "dumb" bombs dropped through Desert Storm. The next section analyzes this evolution and implications of modern air power on the battlefield.

5 Implications of Air Power

Since World War I air superiority has been sought in wars. Air superiority offers logistical, intelligence, morale, and combat advantages. How has the concept of air superiority changed since its inception? Strategic bombing has historically been a cornerstone of American air doctrine, however contemporary air doctrine has evolved past this. In this section, a historical survey of air power is presented to support the conclusion that it is difficult to win wars through air power alone. A broad history of air power and its use in World War II is established. Then presented are several specific examples of air operations from World War II and Vietnam which support the idea of air power's historical impotence when used on its own, in an attempt to reduce the means or will of the enemy to fight.

5.1 History of Air Power

When the airplane was in its infant stages, and even before the Wright brothers had managed to make a successful flight, military and social commentators were making predictions about how the aircraft might change the face of battle. Some envisioned fleets of bombers completely preventing war, in the same way that people thought the machine gun or heavy artillery might prevent war - by making war so costly and deadly that rational civilizations would abstain. Others thought that bombers would be able to completely destroy a civilization, by ravaging the cities and destroying the economic and political fabric causing the civilization to collapse. H. G. Wells echoed this sentiment, but he also noted that bombing a city might rile up the masses, causing the war to escalate and become more savage. We could compare this to today's world, when the United States united and mobilized against terrorists after the attacks on the World Trade Center. In the current wars in Afghanistan and Iraq, accidental or collateral damage, resulting in the deaths of non combatants, provides terrorists a way to turn local people against the United States.

Early on in the development of air power, not everyone thought air power would become a dominant force. Some still maintained the belief that warplanes "could inflict immense damage but they could not disarm, much less could they occupy, the surrendered areas below."[90]. In this sense, critics were arguing that infantry would continue to be necessary even with an advanced air force (an opinion still carried today by many in the military). Even the United States Army was skeptical about the use of airplanes in combat, seen by their reluctance to fund aviation at all. Beyond the technical limitations of airplanes, military leaders had very little idea of how to use them in war.

After WWI, debate shifted from whether to use air power to how to use air power. There is a separation of the use of air power into two distinct categories, tactical and strategic use. Tactical use is directly related to battlefield operations. In WWI, for example, tactical use of aircraft involved reconnaissance, observation, artillery spotting, and strafing enemy positions. We define strategic operations as "aerial attack on an enemy's capacity and will to sustain military operations, rather than on those operations themselves."[91]. During WWI, air power was generally used in tactical operations; however strategic campaigns against enemy cities did occur from both sides of the war. By the end of the war, bombs had hit almost every capital city (except Rome) of the warring nations. After WWI, a lot of misconceptions still existed about air power. People still made exaggerated scenarios where airplanes would win wars within 48 hours simply by dropping bombs on enemy cities. It would take another world war to fully flesh out military aviation.

World War II was the first war where strategists were free to experiment with their theories about how to bring about surrender with bombers. United States bombers played similar roles in both theaters of the war. In Germany, daytime raids were conducted against industrial hubs, with the hope that the bombing would cripple the factories and scare factory workers into staying home. British use of air power was more controversial. They sought to utilize air power against cities in order to terrorize the enemy populace into submission in addition to hitting industrial strong points. This dream was not realized however, as Michael Sherry notes, "If the object had been to stimulate the German war economy and to encourage the Germans to fight, no better technique than the clumsy air offensive of 1940-1943 could have been devised."[92].

Albert Speer, Hitler's minister of arms and munitions had this to say about the effect of strategic bombing on German cities:

> These air raids carried the war into our midst. In the burning and devastated cities we daily experienced the direct impact of the war. And it spurred us to do our utmost. Neither did the bombings and the hardships that resulted from them weaken the morale of the populace. On the contrary, from my visits to armaments plants and my contacts with the man in the street I carried away the impression of growing toughness. It may well be that the estimated loss of 9 percent of our production capacity was amply balanced out by our increased efforts[93].

There is also an interesting sociological impact of the weapons and strategic development. There was a rise to seemingly immoral or ultimately useless tactics employed by the United States because of the competitiveness and structure of the military. Because of the military structure, men were rewarded by maximizing "the number of trained crews, bombers in the air, targets hit."[94] while the actual results of the bombing operations has little impact.

The role of scientists in weapons development prior to and during WWII also plays a part. Scientists were given freedom and resources which they had probably never seen before, and all they needed to do was develop weaponry for the military. As seen with the atomic bomb project, many scientists were thrilled to be solving wartime problems, albeit cautious about the potential ramifications. Speer's personal reflections about his personal accountability are revealed in his memoirs.

> During the twenty years I spent in Spandau prison I often asked myself what I would have done if I had recognized Hitler's real face and the true nature of the regime he had established. The answer was banal and dispiriting: My position as Hitler's architect had soon become indispensable to me. Not yet thirty, I saw before me the most exciting prospects an architect can dream of.[95]

His perception of boundless opportunity were shared by scientists on both sides of the war.

During World War II, bomber pilots faced enormous psychological stresses. Faced with below average survival rates and the inability to improve their chances through experience or control, missions only became more nerve wrecking as crews completed more of them (this opposed to fighter pilots, who were given full control over their vehicle and whose survival rates generally increased with experience). Today, drone pilots experience their own psychological stress when viewing battles they cannot assist in. Colonel Michael Downs is the director of operations at Beale Air Force Base and notes:

> [Recalling the instance in which the crew of an unarmed Predator done could only watch from above as insurgents killed a team of U.S. Special Forces operators]
> It was tough on the young kids...I worry about the young airmen. They don't have the same life experience and support systems, they just go home and internalize it.[96]

Similar bombing campaigns were employed with little success in Korea and Vietnam. Desert Storm saw the first use of "smart bombs" in a war environment, however precision bombing truly came about in the NATO intervention of 1999. With precision bombing came expanded operational capabilities, making possible the close, real-time support roles that drones play today in the Middle East.

5.2 Strategic and Tactical Air Power

During World War II, the predominant method of destroying military-infrastructure was through strategic bombing. By destroying the enemy's factories and the cities that supported these factories, it was hoped that the enemy's ability to wage war would be much diminished. The effectiveness of the bombing campaigns in World War II are often called into question. Because of the limits of technology at the time, large fleets of bombers would often completely miss their intended targets, sometimes hitting the cities near industrial centers (this is especially true of the British nighttime bombing campaigns[97]). The damage done to the actual industrial facilities was minimal, and could often be repaired quickly with little effect on the total output of the facilities. Damage done to civilian centers near the industrial areas often ended up building support for and encouraging German production. Whereas air operations in close support of ground operations can usually have some measure of failure or success (depending on the whether or not the ground mission was successful), the effect of air interdiction operations is harder to measure. The consistent bombing of industrial points in Germany and Japan and its effect on the war is debatable, and the benefits to the ground forces in the eventual invasion of Nazi occupied Europe is hard to measure.

Allied forces attempted air interdiction campaigns which were complemented by aggressive ground actions as well. Operation Strangle, conducted from March through May of 1944, is one such mission. The primary objective of Operation Strangle was to hinder the supply of German forces in Italy by the destruction of vital transportation systems. It was hoped that the operation would lead to a loss of the German will to fight in Italy, and to cause a withdrawal. However, the German withdrawal would only come once Allied ground forces arrived in Operation Diadem. Operation Strangle failed in its primary goal of supply denial of the German forces for several reasons, including the low supply consumption of the Germans, the buildup of their existing supplies, and their quick switch to other means of supply transportation[98].

Because the Germans were so frugal in their use of supplies, even the reduced flow of supplies was enough to sustain their efforts in Italy. During Operation Strangle, the overall level of important supplies (fuel and ammunition) actually *increased*[99]. Only when the ground offensive began did the German consumption increase, but not to the point of shortages in any area. Even though railroad yards did sustain heavy damage at the hands of allied air forces, the Germans made quick and adequate repairs during night time and during bad weather to ensure that at least the most basic of supplies could be transported. The redundancy of the German supply system also played an important role in their ability to maintain supply quotas. In cases where rail transportation was not possible, road transportation proved adequate enough supplement the rail system in transportation of supplies.

Operation Strangle proved that air power couldn't be used with the objective of reducing the enemy's supplies and denying future supplies from being transported. Measured in terms of this objective, Sallager notes that "Strangle would have to be adjudged a failure. Even when German consumption rose steeply during Diadem and when their supply system was exposed to both air and ground action, the German armies did not lack essential supplies"[100]. Strangle, however, did have an unintended effect which would prove useful for the ground operation. This crippled the German's troop mobility. Sallager again notes:

> The attacks on vital communication links which were intended to throttle German supplies had other effects as well: they severely curtailed the tactical mobility of the German armies, imposed costly delays on the movement of troops and supplies, played havoc with the enemy's plans and timetables, forced the diversion of scarce military personnel to a vast repair effort, and created such disorganization in the combat area that only German military discipline could prevent it from becoming utter chaos[101].

The effect of Strangle on German decision making during Diadem here was very real, and proved that a more tactical use of aircraft could be valuable. Because the Germans relied heavily on mobility in order to strengthen weak points, there is a good chance that Strangle was a key factor in the German retreat. Unfortunately, these lessons would only be learned in retrospect by American air forces.

The same lessons learned in Germany and Italy were relearned in Korea. Special purpose missions were designed to attack railroad yards and transportation systems in order to deny supplies to forward troops, however these missions were once again proven ineffective. The North Korean army, similar to the German army, had the flexibility and low consumption rate of supplies that the attacks played very little effect on their overall supply level[102].

The conflict in Southeast Asia proved to be much different than previous wars simply due to the geographic and climate differences present. Operations needed to be planned ahead taking into consideration the monsoon seasons of North Vietnam and Laos. During the wet season, overcast clouds, rain, and fog would hinder any air operations planned for the area. The enemy would take advantage of this shifting seasons when moving men and supplies, which needed to be taken into account for air operation planners[103]. The tropical forests also provided the enemy very adequate concealment from aircraft. Because of all of the geographic and climatic concerns, the air war in Vietnam proved challenging to carry out and challenging to measure the effectiveness.

Vietnam proved to be another conflict in which air power was used with the hope of reducing the means for an enemy to fight. Strategic bombing missions were carried out with similar objectives to the World War II operations, but these proved highly controversial and ineffective. The most notable mission of the war was the Linebacker II mission, in which fleets of B-52 bombers and various support aircraft were used in an attempt to destroy major targets near Hanoi and Haiphong. Among the targets of these missions were railroad yards, supply centers, radio communications facilities, power facilities, airfields, surface to air missile sites, and bridges[104]. While large amounts of destruction was obtained during this air mission, it did not significantly alter the enemy's ability or willingness to wage war. This is because the North Vietnamese fighters had a very flexible supply and transportation system, and the man power to effectively repair any damage done before it became a factor. The Vietnamese army was also frugal, even more so than the German army seen in Italy during Operation Strangle. The fact that much of the Vietnamese army was supplied from outside sources also meant that the damage to the industrial base near Hanoi meant very little to those fighting on the front lines. The air campaigns in Vietnam were however useful in proving the efficacy of precision weapons.[105]

In the Linebacker missions in Vietnam, in addition to the standard bombs used by the B-52 bombers, newer "smart" weapons were used. While primitive, the laser guided weapons did prove to be extremely effective in damaging targets requiring precision, such as power plants, radio communications centers, and bridges.[106] It is precisely these targets that we would later target with even more precise weapons in the Gulf War. A natural evolution of strategic bombing, the purpose of precision bombing is again to reduce the ability and willingness of the enemy to fight. By destroying radio communications centers, air fields, and supply centers, the operational ability of the enemy may become diminished. However, once the enemy has set up temporary solutions to the problems created by bombing these tactical targets, then the desired effects are reduced. By adapting to the strategic bombing, they also learn important lessons in "unconventional" tactics that become useful later.

During the Korean war, the conflict in Vietnam, and now in the United States' war in Iraq and Afghanistan, our policy towards the use of air power has shifted from strategic use (for example by destroying industrial centers) to more tactical use. This evolution is a result of fighting unconventional armies that don't have large industrial centers where weapons are produced (and ironically, whose unconventionality is a result of facing technologically superior enemies). With the first Gulf War, the lines began to blur significantly on the difference between tactical and strategic use of air power. Lieutenant General Charles A. Horner was the Central Air Force commander during Operation Desert Storm. He was critical of the distinction between the tactical and strategic levels of war, calling the words "meaningless and dysfunctional"[107]. Ultimately, the advancement of aircraft technology resulted in aircraft which could hit targets close to home or very far away.

5.3 Conclusions on the Historical Use of Air Power

Although air power has traditionally played a large part in the United States military, historical evidence suggests that it is difficult to win wars with air power alone. World War II was the first war that saw wide use of strategic bombing. It was this strategic bombing that many critics point to as the ultimate evidence that air power is ineffective. Air interdiction campaigns were carried out, such as Operation Strangle, which were a benefit to the ground forces (although not in the intended manner). The loss of mobility the Germans incurred in Italy by this air operation hindered their performance, but it is important to note that it was ultimately the ground forces that pushed the Germans out of Italy.

In Vietnam, once again, the United States used strategic boming missions in order to hinder the means and will of the enemy to fight. The Linebacker air operations were carried out with the intention of hindering the flow of supplies to the ground forces at the front lines. Once again, it proved ineffective in completing its objective; enemy forces were still equipped well enough to combat the American ground forces. These historical operations suggest that only in conjunction with ground troops can the full potential of air power be realized. Air operations on their own have rarely caused an enemy to lose the will to fight. Ultimately, only ground forces been capable to defeat enemy forces and to bring about a victory. The rise of UAVs which directly support infantry operations may be a result of this line of thought. By helping infantry, air power will maintain its status as an integral part any new military doctine. These fundamental changes concerning the role of air power have affected the evolution of the modern face of battle.

> Gentlemen, we need to understand the implications of what we are doing, he said. Air power contains the seeds of our own destruction. A guy with a long-barrel rifle runs into a compound, and we drop a 500-pound bomb on it? Civilian casualties are not just some reality with the Washington press. They are a reality for the Afghan people. If we use airpower irresponsibly, we can lose this fight.[108]
>
> –Stanley McChrystal

6 The Modern Face of Battle

Throughout history there have been examples of "unconventional" warfare being used effectively against more sophisticated forces. Asymmetrical warfare is a necessary tactic for those who lack the technological sophistication of an enemy. John Poole, in his book *Tactics of the Crescent Moon* notes the tradition of unconventional response to invading forces by middle eastern warriors in Gallilopi, and draws parallels to the modern day conflict in Afghanistan and Iraq.

6.1 Western & Eastern War Styles

The modern battlefield is more complex than a typical World War II battle fought in Europe. World War II was defined by large scale battles controlled by generals; now America's enemies in the Middle East use guerrilla tactics to counter superior firepower and technology - tactics which demand a unique response. Poole suggests that any contemporary military attempting to wage battle against "fourth generation fighters" must adapt their strategy to guerrilla warfare. More firepower isn't the answer; rather small units which specialize in light infantry combat.

John Poole, in his book, *Tactics of the Crescent Moon*, examines the fighting between the Turks and the Allied forces at Gallipoli in 1915. The campaign at Gallipoli was staged by the Allies in an attempt to capture the Ottoman capital of Constantinople, and to create a supply line to the Russians. During this campaign, the traditional Western method of fighting was tested by guerrilla tactics. The Turks utilized loose, independent groups of fighters to lure the attacking Allies into isolated pockets and ambush them. Poole calls this tactic the "inverted U," noting that it is still used today by insurgent forces. The Turkish defenders also used the terrain to their advantage, ambushing enemy troops by hiding in thick brush. Snipers would camouflage themselves with green paint and hide in trees. The Turks used female soldiers as well, to assist against the enemy. The ability of the Turkish army to repel the Allied invasion by using guerrilla tactics is important to note in the development of battle.

Though the Turkish army used guerrilla tactics effectively at Gallipoli, this fighting style did not originate there. It had been used for centuries with great success in the Middle East to repel invading forces. The tradition of guerrilla tactics in the Middle East possibly originated in the 11th century, when Hasan bin Sabbah created a small army for "defensive purposes" who "adopted an upheaval method of guerrilla warfare"[109]. He also created a school for assassins, where he trained men to be unafraid of death. This method of training can be related to the way terrorist organizations might train suicide bombers to be martyrs for their cause. The Mongol invasion of the Middle East also exposed Middle Eastern people to the Far East methods of warfare. The Turks showed in the late 11th century that "they could withdraw just as expertly as their Mongol in-laws."[110] This tradition of unconventional warfare would influence the tactics of the indigenous people for generations.

The influence of Far Eastern military doctrine continued into the 20th century. In 1979, Iran established the Iranian Revolutionary Guard, which adopted the "people's army" style of organization seen in China where "every member's allegiance was owed not to his commander, but to the Islamic state."[111] This style of organization emphasized infantry tactics rather than firepower. Iran also adopted certain styles that the Chinese found effective as well, such as using a human wave as a feint for a smaller operation from a different direction. Doing this could cause the enemy to drop its guard on a certain front, allowing a penetration from the flank. Islamic leaders found they could accomplish missions successfully without risking so much by using small unit, with guerrilla style tactics.

In the early 1980's, the efficacy of guerrilla warfare was seen again in Lebanon against Israeli forces. Throughout Israel's campaign in southern Lebanon, Hezbollah used unconventional tactics to destabilize the area and to demoralize Israeli forces. Because Hezbollah had a decentralized command structure, Israeli leadership had a hard time dealing with the insurgents. They also found that all of their heavier firepower was useless against infantry hidden among unarmed civilians: “In this struggle, 95 percent of the firepower was irrelevant; neither the fighter-bombers nor the tanks nor the heavy artillery were of any use”[112]. Because of this, Israeli troops found it “very demoralizing” to serve in occupied territories. Poole points out another Far Eastern influence on the guerrilla warfare used by Hezbollah with the “haichi-shiki” ambush, essentially a standard roadside ambush wherein the enemy is surrounded and attacked from all sides. Israeli Defense Forces also noticed the similarities between the Hezbollah defense of Lebanese villages to the Vietcong's defense in Vietnam. By allowing the enemy to penetrate into the villages, fighters are then able to fire on intruders from all directions, leading to a situation in which “the IDF is often pinned down in fixed positions, and no amount of air superiority can compensate”[113]. In such a case, improved light-infantry training would be invaluable.

Examining the recent military history of Afghanistan is important when reflecting on the tactics employed by the United States today. Afghanistan's natural geography makes it easy to defend, especially with guerrilla tactics. The Soviets learned this when they decided to support the formation of the Democratic Republic of Afghanistan. Naturally opposed to foreign influence over their nation, many Afghans joined the Mujahideen in jihad against the Soviet forces. Although the Soviets had a clear technological and firepower advantage with tanks and aircraft supporting them, the Mujahideen resisted them long enough to cause them to abort their operations. Using the terrain of the country, they established bases in narrow canyons, where air strikes and artillery were ineffective. Canyons and steep-sloped valleys were also ideal locations to ambush enemy troops.

Tactics were different in urban areas than in the country. In cities, guerrilla groups were smaller, and lacked the organization of their rural counterparts. They were careful not to engage in open combat with enemy troops in urban environments in order to gain the support of the civilian population, which was “crucial if the Communist power structure was to cave in.”[114] By "discouraging occupation", the Mujahideen eventually caused the Soviets to give up in Afghanistan. The United States is facing a very similar style of opposition in Afghanistan today, with guerrilla operations designed to put the U.S. military on the defensive, and make long term occupation difficult. "While Western soldiers were evolving technologically, Eastern soldiers may have been compensating tactically Not lost to the third world is how the superpowers fared in Korea, Vietnam, and Afghanistan."[115]

In Iraq, American forces are facing many of the same problems they encountered in Afghanistan. There is a strong insurgent presence in Iraq, fighting to destabilize the country and force foreign forces out by attrition. These insurgents are replicating the tactics employed by the Mujahideen against the Soviets in Afghanistan, and by Hezbollah against Israel. The mobile nature of guerrilla soldiers makes urban air strikes dangerous; they might hit civilians. This collateral damage furthers the agenda of the insurgents, who seek to undermine the U.S. influence with locals. Though urban environments constitute a typical Iraqi battlefield, and the heavy-handed tactics traditionally employed by the United States are ineffective, this does not mean that the U.S. military has not adapted accordingly.

> Joint ground forces will continue to take on more of the tasks performed by today's special operations forces...Future warriors will be as proficient in irregular operations, including counter insurgency and stabilization operations, as they are today in high-intensity combat. They will be modular in structure at all levels...and capable of operating both in traditional formations as well as disaggregating into smaller, autonomous units.
>
> DoD - Quadrennial Defense Report, 2006

The Marine Corps has increased its infantry capacity 12%, its light armor units by 25%, and reconaissance capacity 50% since 2001.[116] Clearly, Poole is not alone in his conclusions that flexible light infantry units will decide asymmetric battles. The U.S. DoD has stated the goal of creating modular soldiers. Driven by the Future Combat Systems (FCS), such modularity is possible. FCS are designed to provide "Full spectrum, joint operations with networked battle command[117]" This means that a soldier could interface seamlessly with his command and control logistical support and act as an extension of their capabilities (Predators, MILSTAR, etc.).

Such soldiers, capable of fulfilling roles traditionally reserved for special forces, dramatically expand the operational flexibility of the U.S. military. Poole's book was published in 2004, closely following the beginning of the Iraq war. His conclusion that America must take an asymmetrical approach to combat operations in Iraq and Afghanistan is in line with current DoD policy. In addition to training soldiers for irregular warfare, the DoD is integrating modern technology into their capabilities, creating a new kind of soldier trained in traditional and irregular tactics, with the logistical support of a powerful computing network integrated into their capabilities.

6.2 Unmanned Aerial Systems

As stated in section 5, air superiority has always been desirable. It provides a tactical advantage in firepower, intelligence, and mission payload. Strategically, air power denies the enemy these advantages. Since the Cold War, the U.S. has invested heavily in aviation technology. In the early days of unmanned systems, the line was blurred between intelligent missiles and pilotless aircraft.[118] The first remote control planes were actually targets for piloted aircraft or missiles.[119]

The Cold War stimulated the development of UAS in the United States. Never wanting to be behind the Soviets in information, drones started to be used as reconnaissance platforms; however manned aircraft such as the SR-71 Blackbird were still the reconnaissance aircraft of choice. Not until the mid 1980's would unmanned aerial vehicle (UAV) technology start developing at a pace suitable for deployment.[120]

The acknowledgment that UAVs could be a valuable battlefield asset for tactical reconnaissance was necessary to pique the U.S. military's interest in the technology. The first "battlefield" UAV was the Pioneer system, used by the Navy, Marines, and Army. The first Gulf War, and later the Iraq war proved to be an excellent testing ground for the UAV systems.[121] The Pioneer illustrated the potential of a drone platform for battlefield intelligence; after 2002 every branch of the military started to seek more capable drones.[122]

The first generation Predator drone, which evolved into quite a capable and dynamic combat system started in the late 1990's. Three were flown over the Balkans with lackluster results. Since they were unarmed, they needed to coordinate with piloted aircraft. This coordination was a difficult process for the untrained operators of '95 and '99.[123] In 2003, Predators were experimentally armed with Hellfire missiles. The expected outcome was unknown, however a desired one existed. The Air Force sought a fast response strike vehicle and the Predator appeared to fit the M.O. The tests were a success, and this led to the next generation of the Predator, the MQ-9 Reaper (Predator B).[124]

The development of the Predator B was privately funded in 2000, by General Atomics, who anticipated a strong demand in the near future from the USAF. As the USAF realized their need for drone designed for "seek and destroy" missions, they began ordering them.[125] The Reaper brings a deadly persistence capability to the battlefield. It is specced endurance time (time in the air) is over 30 hours. Capable of continuously observing susipcious targets, the Reaper reduces the "sensor to target" time to almost nothing.

A third UAS worth mentioning is the RQ-4 Global Hawk built by Northrop Grumman. The Global Hawk's explicit purpose is intelligence and surveillence. Flying at extremely high altitudes they are capable providing high resolution images over vast distances. Mission payloads include sensory and observational packages, as well as proposed information warfare (IW) packages.[126] IW packages refer to disrupting enemy communications, eavesdropping on data, etc.

The evolution of UAS is perhaps a generation ahead of UGVs. During the Cold War, there was a lot of interest and investment in UAS, but little comparable interest in UGVs. This has led to a collection of proven aviation systems and a retinue of experimental ground systems. However, most military missions occur on the ground. Near-earth missions also have far more diverse payload requirements. Once near-earth robotic systems are proven, many diverse platforms supporting numerous mission payloads will emerge. UAS will continue to evolve and take on additional levels of autonomy. Presently, they fill an important role in

Iraq and Afghanistan as support vehicles for troops on the ground.

6.3 Unmanned Ground Vehicles

Many battles use ground support vehicles of some sort. In Roman times there was the Chariot, at Agincourt, cavalry, in WWI and WWII, tanks. Ground vehicles transport troops and supplies alike as well as engage in combat. In warfare, an attack vehicle provides a tactical advantage to the operator. The capabilities of such vehicles can intimidate opponents similar to the cavalry's effects in the 15th century. However as a reaction to fear, weaknesses of this new technology will be eventually exploited and newer competing tech must emerge to maintain the upper hand. In Agincourt the cavalry proved damaging to infantry, this was countered by driving pikes into the ground to deter their charge. In the Somme, WWI, and WWII there were tanks, countered by improved tanks and artillery. While ground vehicles will eventually become automated, there are still many obstacles to overcome.

While large vehicles such as tanks and troop transports continue to advance, robots have also begun to infiltrate the battlefield. Robots such as TALON, MAARS, SWORDS, etc. are the first incarnations of robots on the battlefield. These are not fully autonomous robots however; they require a human operator to give instructions. While a tank's armor can continue to improve to protect occupants, if there is no operator inside the vehicle there is one less life at stake. Robots have to prove they are as fearsome as modern day tanks such as the Abrams, which dominates the battlefield. Sophisticated technology in vehicles such as the Abrams tank that can hit a moving target, while the tank is moving intimidates foes. Robot's fearsomeness is currently being tested and will continue to be tested as they continue to invade the battlefield.

TALON started as a bomb disposal robot in 2000 in Bosnia and was more notably used during the World Trade Center cleanup[127]. Currently these robots are used as EOD robots, mainly helping disarm explosive devices. Along with usage in Bosnia, TALON was used by US Special Forces in Afghanistan as well as Iraq and continues to be used in the Iraq theater with 30,000 accomplished missions in 2006, neutralizing about 11,000 IEDs[128]. While there is a large market for military applications there are also TALON Responder units available for public safety, fire, and rescue missions as well[129]. Thus technological developments in the military sector tend to trickle down into the civil sector as well.

One innovation of TALON was SWORDS, a weaponized version, capable of wielding a M249 SAW, M16, or a 40mm grenade launcher among other weapons[130]. The controls and aiming systems are designed to be learned quickly, akin to using a video game controller. Some aiming systems use computer assisted aiming while another uses a military scope similar to what a soldier would use in the field, in order to decrease the learning curve. Robots like TALON and SWORDS can enter a hostile environment, being a house filled with enemies or challenging terrain, without any harm to the operator.

Currently in development, are vehicles which could assist the wounded on the battlefield without a person physically retrieving the injured soldier. These Robotic Extraction Vehicles or REV, a "10-foot-long, 3,500-pound robot that can tuck a pair of stretchers - and life-support systems - beneath its armored skin", would act as a transport for wounded soldiers. The device could be controlled by a joystick or drive along pre-determined routes. The developers of this machine hope to reduce the number of soldiers needed to assist the wounded by half[131]. Such advances could reduce excess casualties on the battlefield in retrieving the wounded.

If not transporting soldiers or moving wounded ones, robots could be used to move heavy equipment. Projects such as Big dog and M-gator are delving into solving this problem. Big dog is a quadruped robot that looks similiar to a dog, and is capable of bearing 340lb loads. This is a hydraulically driven robot in development by Boston Dynamics and funded by DARPA. Big dog is set apart from other robots by its four legs instead of treads or wheels. This allows it to traverse difficult terrain including snow, sand, and rocky terrain[132]. M-gator is a six-wheeled mini-jeep that can theoretically carry 1,400 lbs of equipment[133]. In its current state M-gator is driven by a human operator, but can be adapted for remote controls. Another contender in the robotics field, iRobot hopes to have a 250lb Warrior robot, capable of carrying ammunition and supplies into battle ready for sale in the next few years[134]. While supplies and troops can be transported on trucks and similiar vehicles in moderate terrain, advanced robots could navigate difficult terrain, reducing the weight the soldier has to carry.

UGVs aim to assist soldiers in their duties, reducing if not removing the risk, if a soldier can accomplish their task quicker, then the military can accomplish their mission at an increased rate. Robots such as SWORDS and TALON do not fire or execute commands autonomously, they simply act as extensions of the soldier's capabilities[135]. UAVs, UGVs, and similar technology exist to assist the soldier on the battlefield, acting as additional tools in the modern soldier's growing arsenal.

6.4 Robotic Assisted Warfare

Soldiers today are becoming increasingly specialized. With precision weapons becoming the weapon of choice, large infantry groups (armies, divisions, etc.) characteristic of a WWII army model are becoming obsolete. Trained pilots are used by the US Air Force to pilot drones instead of planes. Technology can now track the sound of a bullet as it travels through the air and identify the origin of the shot and the type of weapon that shot it. Such precise technology implies that a revolution of military affairs is ongoing.

One of the tools in the soldier's arsenal is an enemy position location device. Devices such as Boomerang, EARS, and WeaponWatch can extract the shooter's position as soon as shots are fired. After finding the shooter's position, Boomerang can immediately aim a machine gun at the location, ready to fire at a soldier's discretion. Boomerang can be mounted on a permanent structure or a vehicle. This device has already been proven in battle, "Incoming fire detection and shooter position are determined and reported in less than 2 seconds, and the system is accurate for shots taken up to 1/4 mile away - a range that covers almost all urban combat situations. False shot detections are less that 1 per 1,000 hours of system operation at vehicle speeds under 50 miles per hour"[136]. As of September 8th, 2009 BBN Technologies who manufactures the Boomerang systems has received a contract for $22,460,000 to deliver 1,095 Boomerang Shooter Detection Systems and 2,195 vehicle installation kits, in addition to the already 6,000 units deployed in Iraq and Afghanistan[137].

QinetiQ builds a similar product: EARS, a 6.4oz portable device that can locate sniper fire within 1/10 of a second while moving at speeds up to 50 mph. This device informs the soldier of where the shooter is hidden with respect to the soldier's current location[138]. EARS is equipable, Boomerang is not. A similar device WeaponWatch, uses light to locate a discharged weapon, then compares the infrared signature of the weapon to a database of thousands of weapons, providing weapon type and location, enabling soldiers to return fire rapidly. Since this system uses light instead of sound, the enemy's location can be calculated before the shots are heard. In one instance, upon implementation in Iraq, a noticeable drop in enemy attacks occurred shortly after using the system.[139]. Documented benefits like these have encouraged further development of such systems by the US military. As of November 2005 the U.S. government invested $15 million over five years into WeaponWatch; besides the four test units in Iraq, another twenty were ordered[140]. Devices are in development by Torrey Pines Logic that locate a sniper's scope by finding the reflective lens on the scope.[141] Though it is possible to counter such systems by using silencers and firing through heavy cloth, these methods can lower the penetrating power of the rifle[142]. These devices cause the enemy to carefully consider opening fire on soldiers, thus saving lives and reducing casualties. Enemies will learn to adapt to new battlefield technologies given enough time, therefore it is imperative to continually advance battlefield tech. in order to stay one step ahead and keep soldiers safe.

Sending a robot into a battlefield instead of a soldier offers several advantages. Robotic systems significantly reduce the threat to a soldier. Robots such as TALON are designed to be extremely durable. One reported incident documented a TALON being blown off the back of a Humvee, over a bridge, and into a river. The robot was later recovered by simply turning on the remote and driving the robot out[143]. Another robot was repaired thirteen times at a repair facility in Iraq before the fourteenth explosion finally destroyed it. One way these units remain durable is the modular construction, which increases the possibility of field repairs and upgrades[144].

In the case of explosive ordinance disposal (EOD), deploying a robot can be faster. A TALON can be deployed in less than a half hour, where it can take several times longer to obtain and put on an 80lb, self-cooled, bomb disposal suit and helmet[145]. Sgt. 1st Class Gregory Carroll stated "These robots are a human cost-saving mechanism."[146], referring to the EOD casualties suffered by IED devices. At a cost of approximately $230,000[147] this can be cheaper than a soldier, considering the education, training, food, housing, and insurance provided to a soldier. With the cost of a single soldier per year in Iraq valued at $775,000[148], platforms such as TALON and SWORDS are not a poor investment.

Weaponized robotics undergo rigorous safety testing. The SWORDS platform went through many years of safety certification. This machine was tested as both a weapon and a vehicle. While these vehicles have weapons attached they are designed with safety in mind, for instance the MAARS unit has a separate weapons channel that if communication is lost the unit will shut down. The commander overseeing operations also has an emergency override switch that can shut down the robot if deemed necessary. The MAARS unit can also be programmed to have a fire and no fire zone, and as an additional safety will not fire in the direction of the controller[149].

Also if a robot falls into enemy hands, no information is compromised - they are not programmed with their mission. Robots such as the TALON are controlled by a unique controller, thus the robot cannot be used without an appropriate remote[150]. If a robot is expendable then nobody needs to risk their life to recover the device if an operation goes awry.

Currently soldiers on the battlefield can call in an air strike using via UAV or a traditional aircraft. While the ability exists for soldiers on the battlefield to fly the UAV themselves this typically happens in a central command center. The ability to call in an air strike has existed since WWI; the difference now is the usage of drones rather than manned aircraft. Drones offer exceptional support without risking a pilot's life and at a fraction of the cost of a manned plane.

Soldiers on today's battlefield have access to increasingly diverse weapons and advanced technology than ever before. Much of this technology focuses on removing the soldier from danger. Systems such as Boomerang and EARS, help soldiers pinpoint enemy fire and in turn deterring the enemy from opening fire. Drones are already prevalent on the battlefield and their capabilities will continue to evolve. Most of these tools the soldiers have are "dumb" in the sense they cannot perform their given task without an operator. Automation will most likely be the next step in the evolution of these robots.

6.5 Autonomous Warfare

Though robotic systems have recently been introduced into the battlefield, none of these are fully autonomous. Robots such as the TALON, SWORDS, Reaper, Predator, etc. are simply large remotely controlled vehicles. Take the Reaper for example; there is a person to control the flight and weapons of the aircraft and another to control the sensors. As it is there are several steps to go through to make the decision to attack an enemy position. The TALON is mainly remote controlled with little to none autonomy, which indicates there will be a long period of time before ground based robots are autonomous.

The next step towards autonomy is robots that can act on their own in certain situations; for example a TALON robot that knows to turn around if it moves out of signal range or knows to return to base while the remote is being packed away. It would not be unlikely to see some level of autonomy within 50 years in ground-based robots. The aerial vehicles will most likely evolve to have this technology before ground vehicles, however it is unlikely there will be 100 per cent autonomy since there are many safeties in place as it is. To remove these safeties and place all of the decision making on the robot requires a tremendous amount of trust, of which there is very little of.

Autonomy requires a significant level of trust by the operator. There can be no doubt the robot's behavior will deviate from a predictable pattern, or fire on the wrong target. The SWORDS went through arduous military testing for safety certification before it could be used in the field. During testing, a mishap occurred where the device turned when it was not supposed to, this event almost destroyed the notion of using these devices on the battlefield[151]. Though the device did turn at the wrong time, the weapon would not fire as these controls had not been engaged. The SWORDS units currently deployed in Iraq (equipped with M249 machine guns) have not fired yet[152]. No matter how many safeties are put in place, the question remains: what if the robot goes rogue? While the company manufacturing the robot can continue to assure safety the doubt will most likely be there.

One of the biggest obstacles with TALON was persuading EOD personnel to accept the machine. Many people preferred to put on a bomb suit and perform the task themselves, not trusting the robot. Now the TALON is quite popular, with some units going so far as naming their TALONs. This is a major obstacle the robotics industry will have to overcome if it hopes to ever see fully autonomous robots on the battlefield, gaining people's trust. When difficulties occur in marketing a bomb disposal robot which does not carry a weapon, how does one market a robot that carries a weapon? This ground will have to be tread carefully as it is difficult to gain trust since it is easily lost.

Autonomy among unmanned aircraft is also of interest to the USAF. The advantages of autonomy are obvious; by having autonomous capabilities, aircraft will more efficiently carry out their missions, training for using these aircraft will be less expensive, and it will allow for capabilities that are currently impossible with human control. The USAF sees automation as something that will "reshape the battlefield of tomorrow."[153] In the UAS flight plan, it is hypothesized that automation will start small. Initially, simple but tedious tasks will be automated such as takeoff and landing of the aircraft or automatic flight path transit. These are meant to simply reduce the operator workload, increasing efficiency and effectiveness.

The flight plan makes note of the initial low level autonomy it desires:

> It differs from full autonomy in that the system will follow preprogrammed decision logic. It will however be more dynamic than simple preprogrammed flight in that the aircraft will alter its course automatically based on internal sensors and inputs from external sources to include traffic and weather avoidance. This will mature to conduct benign mission operations in the near future.[154]

In the future, the USAF anticipates that more autonomous functions will become available. On top of basic functions such as takeoff and landing autonomously, there is also a desire for more complicated capabilities such as automated repair and maintenance, automatic air refueling, and automatic target engagement. The final step in their flight plan includes full autonomous capabilities from their UAS. Swarming is one function that they are especially interested in. As automation increases, it will be possible for one operator to direct the actions of many different aircraft, creating a "focused, relentless, and scaled attack."[155]

These tools in a soldier's arsenal are reshaping the way battles are fought. Robots will continue to increase in technical capabilities, slowly gaining autonomous abilities, and eventually becoming fully autonomous. These robots and new battlefield technologies are redefining the face of battle in the modern era.

6.6 Defining the Modern Face of Battle

Now that a survey of the technologies emerging in warfare has been conducted, we propose the following definition of the modern face of battle. Earlier, the face of battle was defined as the atmosphere, logistics, tactics, motivations, and emotions of warfare. Today's Warfighter has an unprecedented amount of technology at his disposal. This technology is becoming more than a simple tool; it is becoming integrated into his equipment in every respect: radio, uniform, helmet, and weapon. We assert that precision warfare is defining the battles of today. Additionally, the responsibilities of infantry have shifted. Not only are they required to be more specialized by the nature of their equipment, but in order to win asymmetrical conflicts like those in Iraq and Afghanistan, they must be humanitarians as much as soldiers.

Since 1997, the United States Department of Defense has published a Quadrennial Defense Review Report. This report assesses the direction of DoD policy and attempts to validate its strategy. It also sets forth a roadmap for the next four years, defining policy and doctrine that will shape DoD actions. The last QDR was published in 2006, the next one will be published in 2010. Some of the stated goals in the 2006 report are worth reproducing[156] here:

This roadmap acknowledges the asymmetrical approach to warfare identified as necessary

Single focused threats	→ Multiple, complex challenges
Nation state threats	→ Decentralized network threats from non-state enemies
Conducting wars against nations	→ Conducting wars in countries we are not at war with
"One size fits all" deterrence	→ Tailored deterrence for rogue powers & terror networks
Focus on kinetics	→ Focus on effects
20th century processes	→ 21st century approaches
Static defense, garrison forces	→ Mobile, expeditionary operations
Conventional combat operations	→ Multiple, irregular, asymmetric operations
Emphasis on ships, tanks, guns	→ Actionable intelligence
Moving user to the data	→ Moving data to the user
Predetermined force packages	→ Tailored, flexible forces

Table 1: DoD QDR Stated Goals

in this paper[157]. Present technology is already capable of achieving many of these goals. The MILSTAR satilite communications network is capable of the high data rate communications necessary for secure real-time battlefield interaction with infantry. These communications networks are truly generations ahead of the capabilities of an insurgent group. This implies that they are jam proof, secure, and fast, which means that infantry are capable of interacting with UAVs and other support craft in real time - truly integrating their capabilities into their mission payload.

In preparation for the 2010 QDR, the DoD has released a factsheet that outlines continuing goals for the next four years including:[158]

- Further institutionalizing irregular warfare and civil support abroad capabilities and capacities, to include building partnership capacity
- Addressing threats posed from the use of advanced technology and WMD

In 2005 an earthquake registering a magnitude of 7.6 occurred in Pakistan. The United States military responded immediately and without condition with tremendous aid, giving over $106 million for relief operations, donating equipment, clearing debris, and offloading over 18 million pounds of humanitarian aid.[159] After two months, the number of Pakistanis with favorable opinions of the U.S. doubled to 46% from 23% 4 months prior to the earthquake.[160]

Indeed, humanitarian efforts have been identified by the Department of Defense as an important policy going forward. Not only do they prevent natural disasters or other crises from escalating into broader conflicts with regional consequences, but they demonstrate the good will of America and leave an impression of kindness.[161] By involving the U.S. military in events such as the Kashmir earthquake, the and the 2005 tsunami, the DoD not only accomplished significant humanitarian achievements, but increased goodwill toward America from the regional and international community.

This directly undermines the stated goals of insurgents[162], especially in Afghanistan.

> Victory...will not be accomplished by the mujahed movement while it is cut off from public support...In the absence of popular support the...mujahed movement would be crushed in the shadows, far from the masses...The Muslim masses...do not rally except against an outside occupying enemy...Therefore, the mujahed movement must avoid any action that the masses do not understand or approve.
>
> –Ayman al-Zawahiri, July 2005

The Taliban in Afghanistan operate a shadow government, which is a direct challenge to the national Afghan government. This shadow government operates at a local and tribal level, imposing justice and order. This governance is quite sophisticated; the Taliban send out ombudsmen to self-assess their representation in each locality.[163] Both McChrystal (Commander of U.S. & NATO forces in Afghanistan) and the Taliban recognize that a strategic victory is not possible without the population of Afghanistan.

The modern face of battle is being defined by precision technology and a new flexible military doctrine. Soldiers are now required to engage in full spectrum operations, including combat, developing relationships with local populations, and humanitarian aid. The challenges in Iraq and Afghanistan are irregular in nature and demand an irregular response. The Department of Defense has recognized this is is working to decentralize and expand the mission capabilities of the American army.[164]

7 The Future of War Technology

In 2009 the United States Department of Defense published a report titled *FY2009-2034 Unmanned Systems Integrated Roadmap.*[165] Its stated purpose is to:

> propose a feasible vision for capitalizing on unmanned systems technologies so that the Warfighter can conduct missions more effectively with less risk.

The report evaluates the state of unmanned maritime, ground, and air systems, proposes a tentative schedule to implement unmanned systems in the military, acknowledges the strengths and limitations of unmanned systems, and addresses the technological challenges of building an unmanned fighting force. Two key items to note in the report are the proposed statistics that by 2010 one third of all deep strike aircraft should be unmanned and by 2015, one third of the Army's operational ground combat vehicles should be unmanned.[166]

From 2008 through 2010 the Air Force is slated to order 40 F-22 Raptors.[167] Over the same time period, they have ordered 15 Global Hawks[168] and over 60 predator drones.[169] The following table reflects the trends of the near-future of aircraft procurement by the U.S. Air Force.

Table (2) shows that the desired ratio of unmanned to manned systems is being respected.

	Unit Cost ($M)	FY08	FY09	FY10
Predator Drones	5.0	24	38	no data
Global Hawks	80.0	5	5	5
F-22 Raptor	132.0	20	20	no data

Table 2: U.S. Air Force Aircraft Procurement FY08-FY10

It is important to note that the unit cost in this table reflects the cost of the aircraft itself and does not account for the logistical support the aircraft must receive. It is also worth mentioning that in the case of unmanned systems, the cost of this logistical support is spread over many aircraft. One control station can control several aircraft. The command and control infrastructure is often interoperable and dynamic in nature.

Perhaps the largest recurring cost of manned aircraft are the pilots themselves. They must be supported with the plane, and are certainly not expendable. Drone pilots on the other hand may be housed in the United States while operating equipment across the world. Operating an unmanned platform is far simpler than flying an aircraft. Drone pilots require less training than fighter/bomber pilots since software handles most of the flying for them.

In addition to the obvious fiscal benefits of adopting an unmanned Air Force, the Department of Defense is investing heavily into all classes of unmanned platforms. The following table has been reproduced from the DoD's roadmap.[170] The dollar amounts are in millions.

	Funding Source	FY09	FY10	FY11	FY12	FY13	Total
UGV	RDT&E*	$1291.2	$747.5	$136.2	$108.7	$68.9	2,353.0
	PROC*	$33.4	$42.3	$53.5	$59.5	$21.1	$210.0
	O&M*	$2.9	$3.9	$3.0	$12.8	$10.1	$33.0
UAS	RDT&E	$1347.0	$1305.1	$1076.4	$984.0	$719.5	$5,342.0
	PROC	$1875.5	$2006.1	$1704.7	$1734.3	$1576.2	$8,897.0
	O&M	$154.3	$251.7	$249.0	$274.9	$320.2	$1,250
UMS	RDT&E	$57.3	$73.8	$63.2	$70.1	$76.9	$341.0
	PROC	$56.7	$78.4	$95.9	$91.6	$103.7	$426.0
	O&M	$5.0	$4.5	$11.3	$13.5	$13.9	$48.0
Total		$4,823.0	$4,513.0	$3,393.0	$3260.0	$2911.0	$18,900.0

Table 3: FY2009-2013 President's Budget for Unmanned Systems

"Clearly space is the high ground, and we need to capture that high ground and exploit it." Spoken in 2003 by the Undersecretary of the Air Force, Peter Teets[171], this statement, by extension reflects the DoD's sentiment on technology. With over $3.0 trillion dollars earmarked for the research and development of unmanned systems in FY09 alone, the DoD is utilizing the largest defense budget in the world to gain an important headstart in the realm of unmanned technologies.

The United States has established itself as the leader in unmanned battlefield technologies, for now. However China and India are quickly making up lost ground. The American education system is not producing enough technical people. Nor is the American economy as conducive as it once was to innovation and business, with many companies paying more in Healthcare costs than in production costs.[172] Three out of every four research facilities scheduled to be built are being built in China and India.[173] *Unrestricted Warfare*, published by two Chinese colonels, agrees with Ignatieff that an RMA is coming. They predict that China will out-innovate and supersede America's technological edge in the near future.[174] The world agrees that unmanned and high-technology systems are on the cusp of revolutionizing warfare. While America has an early lead in the deployment and use of this technology, its lead is not assured.

One of the most significant technologies currently being used and actively developed by the United States military is in the area of unmanned aerial systems (UAS). The United States Air Force (USAF) published a "flight plan" for unmanned aerial systems, laying out the technologies they hope to be developed and improved upon over the next 38 years. In this flight plan, they outline the necessary doctrine, organization, training, material, leadership and education, personnel, facilities, and policy recommendations in order to sustain one of the most "in demand capabilities the USAF provides the Joint Force" (page 3). They anticipate the development of an array of technologies, ranging from micro and nano-sized vehicles, medium "fighter sized" vehicles, to large "tanker sized" vehicles. On top of this, they call for better engineering methodology in regards to modular, interoperable, and open architecture design. They also outline some of the challenges the USAF might face with more technologically advanced systems. The flight plan lays out a very optimistic view of what the USAF wants with its UAS by the year 2047:

> Future UAS should be multi-mission, all-weather, net-centric, modular, open architecture and employ leveraging appropriate levels of autonomy. They should also carry any standard payload within in its performance envelope, with dial-a-yield, dial-an-effect and be multi-mode capable. Additionally, some platforms may consider optionally manned capability.[175]

Modularity is an important design consideration in engineering which the USAF wants to ensure is included in future UAS. A top priority of new military technology is the cost. The Air Force's premier fighter plane, the F-22 costs $137,000,000 + pilot[176]. At $4.5

million, a remote controlled Predator drone is much cheaper, and safer. For $30.5 million, the U.S. Air Force gets four drones, a ground station, and a satellite link. In 2009, Congress cut funding for additional F-22 planes When developing future UAS like the Predator drone, it is hoped that by having modular components, upgrades and augmentations can be made to the technology without redesigning the fundamental components. It also helps to leverage discoveries and developments made in other fields beyond the DoD's research and development. Another benefit of modularity within a system is that it allows for a single system to be tailored to many different mission profiles. By having a single aircraft capable of multi-mission and multi-payload flexibility, the cost-effectiveness and capability of the aircraft are increased. Open architecture is another methodology which needs to be included in future UAS development, for similar reasons to that of modularity. Cost effectiveness, time to deployment, and capabilities of aircraft systems can all be increased by utilizing open architecture design. Ultimately though, it is the development of autonomy that will "be a revolution in the roles of humans in air warfare."[177]

The most significant challenge facing the Air Force as it develops new technologies is financial in nature. While some savings can be realized by building unmanned systems instead of manned systems, no system is cheap. Operating costs, personnel costs, and acquisition costs are all of concern to the USAF. Newer, more complicated equipment means better trained, and more capable operators. Part of the reason why autonomy is so appealing to the USAF is because autonomous aircraft will need less input from the pilot, which means the pilot does not need to be trained as strictly. Currently, UAS training is difficult because the development is different from classical aircraft development, meaning simulators and training programs fall behind in development. Of the five USAF UAS programs operationally deployed, only one has a full scale simulator for initial and mission qualification training.[178] If the United States hopes to see more UAS and UGV systems in deployment over the coming years, it must not be afraid to spend the resources to do so.

8 Conclusions

> Finally, as much as operational success depends on training and doctrine and weaponry, it also depends on a deep knowledge of the campaigns of the past. It would be the highest imaginable folly for the present-day U.S. Army to believe that its technology (which in some cases has yet to be invented) has somehow invalidated all the lessons of past wars.[179]

Military doctrines have changed dramatically in the past as a consequence of technology. In World War I technological advances such as the machine gun, planes, tanks, and artillery redefined tactical possibilities. In World War II mobile warfare, and strategic bombing developed and evolved. The Atomic bomb ushered in a new era of deterrence based doctrine. However, historically, technology has not won wars by itself. There is nothing to suggest that this historical trend will not continue. It is still true today in Iraq and Afghanistan. Classical counter insurgency doctrine - take, hold, build - requires boots on the ground to be successful.

The DoD's 2006 quadrennial defense report emphasized a shift toward a more flexible doctrine. In their outline for the 2010 review, they reacknowledge it. This transformation from a fighting force accustomed to fighting wars against nations into a decentralized, mobile force trained for irregular challenges represents a shift in fundamentals. An ongoing effort is underway to make infantry more specialized and flexible in their operational capabilities.

This flexibility is encouraged and enabled by new battlefield technologies. Unmanned air platforms have established themselves as an integral part of the U.S. military. Unmanned ground platforms are just coming into their own on the battlefield. Before such systems become ubiquitous, they need to prove themselves to the soldiers who will be using them. Breaking through this barrier is non-trivial; however as EOD teams in Iraq demonstrate, once done, these systems become indispensable to the units they are assigned to.

The capabilities of new battlefield technologies are impressive. The new XM-25 rifle scheduled for 2012 deployment fires "smart bullets" that communicate wirelessly with the rifle as they travel to their target. Once they travel a certain distance, they detonate, rendering cover useless.[180] Systems such as EARS and Boomerang can locate attackers in real time as they discharge their weapons. The deadly persistence offered by Reapers allows for patient, methodical warfare against insurgents.

Network-centric and informatic warfare are more elegant solutions to conflict than strategic bombing campaigns. However, this does not mean that all conflicts can be completely resolved by them. Collateral damage caused by a drone strikes alienate many locals. Counter-insurgencies demand boots on the ground.[181] Impressive technology will not convince local populations that one side is more right than the other. Their needs are far more practical.

In Afghanistan, McChrystal is not advocating more drone strikes. He is pressing for more foot patrols - for soldiers to get out of their Humvee, take off their sunglasses, and engage the local population across a formidable language barrier.[182] This fundamental shift in doctrine is reflected in the 2006 and 2010 QDR. As next-generation technology proves it is ready for battlefield deployment, it will be integrated into America's evolving combat doctrine focused on individually tailored force responses.

This technology is especially suited to this sort of dynamic mission. The TALON and SWORDS systems are modular in nature, allowing their mission payloads to be dynamic. Integrating the evolving capabilities of this technology into FCS will produce a technically superior army trained in asymmetrical tactics. Such flexibility will expand the operational capabilities of the American military to include numerous irregular challenges. This new doctrine is being empirically tested in Iraq and Afghanistan.

Though the final outcomes in Iraq and Afghanistan are still ambiguous and depend largely upon the actions or inactions of their respective local governments,[183] the shift to a flexible military doctrine from a one size fits all approach will be a positive, if abstract, outcome from these wars. This integration of technology and doctrine represents a revolution of military affairs; transforming America's military into a dynamic force capable of achieving operational success in a wide spectrum of operations.

Appendices

A Acronyms

- COIN - Counter Insurgency
- EOD - Explosives Ordinance Disposal
- FCS - Future Combat Systems
- MAARS - Modular Advanced Armed Robotic System
- O&M - Operations & Maintenance
- PROC - Procurement
- QDR - Quadrennial Defense Report
- RDT&E - Research, Development, Test, and Evaluation
- SWORDS - Special Weapons Observation Reconnaissance Detection System
- TALON - Tactical Air-Land Operations
- UAS - Unmanned Aircraft System
- UAV - Unmanned Aerial Vehicle
- UGV - Unmanned Ground Vehicle
- UMV - Unmanned Maritime Vehicle
- USAF - United States Air Force

B Consequences of an Inflexible Doctrine

> Myself, I'm a wimp on Iraq: I'm in favor of invading, but only if we can win easily. So can we?[184]
>
> –General Van Riper, Op For commander, 2002 Millienium games

Van Riper is acknowledging that hubris that is associated with technological superiority. In the Millienium Games, utilizing asymmetrical tactics, he soundly defeated the American fleet using low-tech tactics. He anticipated that the Americans would be able to eavesdrop on his communications - so he used motorcycle couriers. He knew the American navy would dominate another "big fleet" so he used swarm tactics to overwhelm them. The result? The Americans reset the war game, this time imposing artificial restrictions on Van Riper preventing him from effectively fighting back. They won the second time.[185]

That is not to say that American doctrine has not matured considerably since 2002. Stanley McChrystal has recommended a classic counter insurgent strategy in line with many of Pooles conclusions.[186] His doctrine emphasizes winning the population and trading tactical military success for strategic domestic success.

However, the 2002 Millienium games and the early years of Iraq and Afghanistan reflected the consequences of a different kind of doctrine and perhaps foreshadowed an even deeper quagmire had U.S. military doctrine failed to evolve. Though the Department of Defense is taking an aggressive, proactive, and self-critical approach to its policy, considering the alternative is just as important.

C Common Interview Questions

1. Participation in this interview is voluntary. You may end the interview at any time, and you may refuse to answer any or all questions in the interview.
2. We plan to include answers obtained in this interview in our IQP report. You may refuse to have your name associated with your responses.
3. You may also choose to review the recorded material prior to being included in our report.
4. If you do not wish to be included in our report, all answers will be made confidential.

After consent is obtained, we will ask the following interview questions:

1. What is your occupation?
2. What is your general experience in the field of robotics?
3. Are you most interested in robotics development in the military, medical, or commercial field?
4. (Students only) Would you have any ethical concerns about designing robots to be used in the military?
5. How large a part of robotics is funded by government for military purposes?
6. (Professors only) As a professor, do you teach students about the ethical concerns related to defense development with regards to robots?
   a. If so: What do you think these concerns are?
   b. If not: Do you think students should be made aware of any concerns?
7. Is the development of robotics in the medical or commercial fields as rapid as in the military?
8. In general, what do you think is in store for the future of robotics?

D Transcripts

D.1 QinetiQ North America

Who are you and what is your role in the robotics industry?
My name is Jake Warren, I am a staff engineer in the unmanned systems group in QinetiQ North America's Technology Solutions Group. I work on our family of unmanned systems ranging from the small 15 lb dragon runner to 9,000lb TAGS vehicle.

Where does QinetiQ North America get its research funding from?
Our funding comes from both internal and external sources. We do front a lot of internal R&D money for projects we feel are important. We also make internal contributions to core robot competencies that we see could be used on our entire family of robots. Some government contracts stipulate that the company match a certain amount of money, or sometimes partner with smaller companies or universities.

QinetiQ North America designs and builds primarily robots purposed for national defense?
Right now our biggest customer is the US government, that includes DoD, Homeland Security, as well as local law enforcement and first responder agencies. Our robots are also used by our allies around the world.

The reason you develop products such as TALON / Last armor is because that's where the money is?
No, we build life saving equipment; the business grew around our products of value. The money right now is with the Government because of the war funding. It's been that way for several years. Before robots were big, say pre-1998 or so, Foster-Miller was really big in commercial industries. Before the acquisition by QinetiQ, Foster-Miller was a go-to engineering consulting firm. If you had a problem, you came to us and we would solve it. The government offers Small Business Innovative Research (SBIR) contracts for all kinds of engineering challenges. Foster-Miller won more SBIR contracts than any other company in the country. When Fig Newton came out with the low-fat cookie, we invented the machinery that cut them (previously, the cutting machine relied on the fat in the cookie to lubricate itself as soon as you took the fat out, all the cookies got stuck). We've worked with Velcro America to design a machine that continuously extrudes Velcro. We now license to Velcro what we call heavy-duty Velcro which we use to apply our LAST Armor products.

We are the largest manufacturer of armor appliqu kits for fixed-wing aircraft. We also do things like invented the machine that put the gush in gushers. We have a contract to test and validate vending machines - we're not just a robotics company.

What are the biggest technical & non-technical challenges facing robotic systems today?

The technical side is pretty easy for me - being a mechanical engineer. We see a lot of desire for very light, very low-cost, very rugged systems. Those three things don't mix very well. We often find ourselves buying a commercial off-the-shelf widget, putting it inside a box and putting it on a robot. It's because most of the time the commercial market doesn't really care how rugged it is. If you buy an x-box controller, and it breaks, you just go to Radioshack and buy another one. In a war environment, if your controller breaks, it means you're putting on a bomb suit and putting yourself in danger.

So making things rugged and reliable is the biggest technical constraint right now. That is putting a limit on degrees of freedom - often industrial robots have 17-18 degrees of freedom - to reach a level of that complexity is cost prohibitive on a platform our size with its expected life-time.

From the non-technical side, we have seen a lot of push back from the government regarding the use of robots. In about '98 we were asked to make a robot to do explosives ordnance disposal in Bosnia. We sent 2 of the first gen TALON systems to Bosnia where we cleared out arms caches next to schools and other soft targets. At that time, there were no "small" robots fielded. This was the first successful demonstration of a small, man-portable robot for explosive ordnance disposal. Then we decided to invest in making a real product to address this unmet user need.

The first challenge we had to overcome were EOD guys who said "I've always put on the suit, that's always how I've done it, now you're telling me to do my job differently." It's difficult to get people to adjust their life styles to use these new tools even though it's safer for them

Have you found people more receptive to new technologies once they have been proven?
Absolutely, we've broken into EOD successfully - all of the robot companies have - we have made it safer for them to carry out their missions. In fact to be recognized as a level 1 bomb squad by Homeland Security, you must have a robotic asset on your team. A lot of first responder bomb squads are getting their robots through Homeland Security grants.

The next first responder branch we're trying to break into is firefighters. Firefighters have HAZMAT teams and we make HAZMAT robots that have sensors on them. We are showing them that this is a useful tool for them and that you can save lives with it - a TALON can drag fully equipped firefighters or soldiers across the ground. Their response is that they don't want to have to trust a robot to save them. It's the same stage we were at several years ago with EOD. Every market we try to break into, there are several people who don't want to see the way they do things change or that believe using a robot might make their job harder. There is also the concern of cost among other barriers to entering the world of robotics.

They don't trust robots like they would trust a human?
Right, but once they've proven themselves, they become a part of their team. For example, everyone names their rifle, now people are naming their TALONS. You have to prove yourself.

Could you discuss some of the modular attachments that go on the TALON?
The TALON was designed to be a modular system for repairability. We have trained Joint Services technicians in field level replacement of parts. We support a "robot hospital" in Baghdad. The procedure is: if a robot gets damaged, you take it to the hospital, if it can be repaired in less than 4 hours, they repair it there and it gets sent back out, if not due to severe damage, a robot is issued from reserve and the damaged robot is eventually rebuilt and returned to the fight.

The robot is divided into different modules: a battery bay, a communications module, a power distribution module, an arm module, all the cameras are modular, etc. It's built like this because it's easy to repair. This also allows us to expand the TALON's capabilities. The TALON GenIV which is our current widely distributed system, is USB and Ethernet capable. We have several different data and video radio options. Our communications are all modular so that you can swap out the standard radios to operate with Electronic Warfare Equipment, or on fiber optic tethers. Those are the first expansions of the GenIV. Now we are seeing things like CBRNE which has an expansion box that can accommodate 8 different sensors.

We also make quick and agile field upgradable parts. You have a gripper on the TALON which you can take off and replace with a heavy duty gripper, a wire cutter, scraper, cameras, visible cameras, visible IR cameras, auto-illuminating cameras, night vision, thermals, range finders, etc.

Can you put a weapon on it?
Yep. We were asked in about 2003 by the military ARDEC to weaponize a TALON, and see if a remotely operated vehicle could be utilized as a remote weapons platform. We paired with a company that specializes in weapons platforms and we added a platform to TALON.

We learned a lot from that. The government came to us and asked can you arm a TALON? We said what do you want to put on it? We then developed and tested the Barrett .50 caliber M82A1, LAW rocket launchers, flash launchers, and several machine guns as payloads on the TALON robot. It came down to: yes we can safely and effectively use weapons on our platform.

SWORDS came out of that. It was decided that the M249 squad automatic weapon would be the primary weapon of choice. That vehicle went through several years of development, mostly focusing on making the TALON platform safe. It was built off the TALON 3-A which was one of the older platforms. Through our testing, we upgraded the 3-A platform to a 3-B to incorporate safety features.

The system was safety certified for use by soldiers. The SWORDS platform was the first ever weaponized ground robotic platform by the US military. Through that safety testing we learned a lot. One challenge was defining what a safe weaponized robot was. Were you going to classify it as a weapon, a vehicle, or as something a soldier would hold, and what specs would you settle on to determine it's safe?

We were tested in some areas up to ammunition standards. Our robot had to survive the same tests that ammunition is subjected to. We were also tested as vehicles. Whatever made a military vehicle safe made a TALON safe. In some areas we were pushed hard - some of our electronic systems, especially the software were pushed hard.

There were some findings through safety testing - you probably have read the Popular Mechanics article that said our robot pointed a weapon at people. Events like this happen during testing - that's why it's testing, and why it wasn't safety certified at the time. We identified the root cause of these problems as loose wires on joysticks or components that didn't meet the strenuous requirements. Some of our failures were designed to test the system identify known but undesirable actions. An example of that is on a slope test - a test where you need to drive up a slope and need to stay there for some extended amount of time - we stayed up there and our brakes were holding the robot in place, the brakes overheated and released, and the robot rolled down the hill. That's an example of a known but undesirable outcome. These types of failure could be prevented through training and procedures like, "don't park on a hill with the brakes on for more than X hours." It is important to mention that at no time during testing did any system directly related to the firing or safety of the weapon fail.

3 SWORDS units were deployed to IRAQ, and they are still there. We don't have information about what they are doing or how often, or if, they are being used. We know they are still there and we have issued spare parts for them.

One thing that is interesting to us is the hearsay posted on the internet - from the blogosphere for example: "Oh my god, the robots are going crazy!" People actually thought that in positions of power, and positions where the funding was. We had to go through a lot of sources and figure out what people were actually saying, where they were hearing this information and whether the information was true. Through all those lessons learned we developed MAARS - the 2nd generation armed unmanned ground platform.

What kind of combat situations are these robots tested in?

We participate in war games with live and blank fire. There are several different war game type experiments where our platforms integrate with real soldiers and various new technologies. We've integrated with Battlefield Networks, among other technologies. We support user experimentation often.

Do you send engineers with SWORDS to support them in the field?

Part of the purchasing agreement involved training the military on how to maintain these robots. They are very similar to the TALON in every way, except that the top of it is a weapon instead of an arm. They are capable of being supported at the government repair depot in theatre.

How much do they cost?

It's like a car. It's definitively cheaper than a tank or a person. I don't know the numbers exactly, but if I had to guess, I would say $100k for the inexpensive version, up to $350k with all the bells and whistles. They avoid all of the logistical costs associated with a soldier.

Do you have any statistics on how many soldiers these robots have saved?

There are some stats that go around, I don't know them off the top of my head, but I can give you some ballparks. There have been nearly 3000 TALON Robots produced in 8 years and used by the US Army, US Marine Corps, US Navy, US Air Force, International Customers, and US First Responders. TALON has completed over 120,000 combat missions and has defeated over 11,000 Improvised Explosive Devices (IEDs) since 2002.

So they are used a lot?
They are used a lot. They are on the ground much more than you hear about on the news. They are very reliable and designed to be replaced and repaired very easily. The one statistic I do know is that they typically survive on average 13 explosions before they come back to us as scrap. If the arm gets blown off or a couple of cameras get damaged it can all be repaired in a few hours. The guys get quite attached to their talons, we had 1 come back with the pennant of a unit wrapped around the video antenna - we sent it back to that unit once it was repaired.

All the major robotics companies will tell you stories about guys who have written back about their robots. We have a few on our website. Robots have been named; I've heard some units issue purple hearts to robots. My favorite letter from a unit dealt with an IED explosion. A secondary blast had damaged their TALON's control station. They are on their way back to their base, going over a bridge, and they got hit by an IED. Their TALON was blown off the back of their truck and landed in the river. It was going to take them several days to recover or replace it so a few guys went back there later that day. One of the guys opened up the damaged control unit and saw he had a video link. He drove the robot that had just been blown off the truck out of the river and brought it back to the robot hospital for repair.

Right now these robots are fighting against a low-tech opponent?
The enemy is not stupid. We do something, the enemy counters, we get a request to counter the counter, and it goes back and forth like this often. At the beginning of the war the IEDS were being detonated by wires, or close proximity. So at the beginning of the war the TALON would go out, find a wire, and cut the wire. Then they started using radio signals. So our side started using jammers, but you still deal with IEDS, and now our robots need to operate in jam fields.

Now the enemy uses sensors, which we need to find - it goes back and forth like that a lot. Our systems are secure. They use frequency hopping and operate in military bands; they are as secure as military assets, but they are also stupid. They don't know where they are, they don't know their mission. Even if they are captured and compromised, they don't give the enemy any intelligence. They are for lack of a better word: expensive RC cars. All of the robots are uniquely keyed; each robot has its own controller, so you need to capture the pair to operate it.

If you had to design a robot that would fight against a country with the resources of a

government backing its technology what would you do differently?
No matter who you are fighting the EOD robots are useful for their mission. If it's an ambush situation, and the shooter fires at the robot, they've revealed their location for return fire. With the MAARS platform, a lot of the war games scenarios are played against a well equipped Op-force. So every tool is useful, but none are perfect for every mission.

You mentioned iRobot - are you competitive with them?
A lot of people think we are big rivals. But what it comes down to is that we are all different tools in the same toolbox. In the MTRS (Manned Transportable Robotics System) program, there were two awards given at the dawn of the program. One was to the iRobot Packbot and the other was for TALON. The two most widely procured systems through the MTRS program are the TALON and the Packbot. MTRS is essentially the program that buys all the EOD robots and distributes them to the EOD teams. Everyone has their favorites, you like the way the system interacts with you. The Packbot is light and small, but its more integrated, not always easy to repair, etc. Ours is big, powerful, and easier to repair. The control schemes are totally different, some people like the high-tech feel of a pack-bot. Some people like the user-friendly TALON interface. The objective is to use a robotic system to save your life. With that said, the TALON is the preferred MTRS platform. Apart from the MTRS program, we are the only small robotic system procured by the US Army Engineer Corps.

In 5-10 years what will the TALON look like?
The robot companies will look about the same. Robots will be cheaper, more rugged, and you will be able to add more things onto them. I think the future of robotics is in the mission payloads that get put into the systems. There may be some autonomy coming out soon, but it won't involve robots completing missions on their own. It will be like: "You've traveled outside of radio contact, back up a bit", or "Okay, the mission is over, return to base while I pack up your controller." Once those functions can be proven to work every time - which is quite difficult - robots will start to become more autonomous. Ultimately, they will support more diverse mission payloads. We will also see better robot-to-robot interoperability as well as more operator-to-many robot control with smaller, easier to use operator controllers. Along with those improvements, we are also expecting longer battery life, or different power sources all together, with better communications ranges.

Have you looked into extremely small robots?
The smallest thing we have right now is the Dragon Runner - a recon scout. Even those are modular for mission payloads. We call it the DR-20, it's a 15lb system, designed in its smallest package to be thrown through windows, down stairs, etc. On top of it has some expansion rails to accommodate arms, sensors, or whatever else the mission dictates. Everyone in the industry has pursued smaller systems but there's not really an understanding in the government of what these systems are capable of.

For example, one competition that industry had was to make a 5lb robot that could form an intelligent mesh network, go up stairs, I.D. targets, move to waypoints in a GPS denied environment, and accommodate expansions. What do you mean by stairs? How do you get a 5lb robot to get up there? Climb, hop? The GPS navigation problem is in itself a huge challenge. There needs to be more of an understanding between the technical capabilities of a robotic system and the budgetary side of things. We are also looking into smaller systems, but I am not at liberty to discuss those systems in detail.

When you have a good idea, how do you get funding for it?
DARPA is really good for those types of things that are really out there, you can pitch to DARPA every year, they also release requests for contracts. They have ideas that they are willing to pay you to research. There are also lots of different independent robot organizations. One is called the Robotics Technology Consortium. Sometimes industry will issue challenges. Sometimes a customer with funding will ask us to solve X problems. Funding for projects like these will typically be between \$50 thousand to \$3 million. We also undertake internally funded projects if we believe the technology can serve a function that is not currently being met.

Are you allowed to accept funding from other governments?
TALON is controlled through ITAR - international traffic arms regulations. We are free to operate within these restrictions. If a foreign company wanted to acquire TALON technology, we must go through the State Dept. to work out what they can see and have. We do have international sales. Our parent company is based out of the UK. We have sales all over the world.

Do you see robots replacing soldiers on the battlefield?
The objective is to have a robot operate fully autonomously. Go out on missions, make its own decisions, and then come back. Everyone wants that. When is it going to happen? Probably not within the next 50 years. It will happen when all of the sensors, intelligence, materials, and purchased parts prove beyond a shadow of a doubt that it can complete those missions. Today's battlefield robots can help keep soldiers out of harms way for many of the most high risk tactical duties like building entry or crossing urban intersections - let the robot make first contact with the enemy so that our soldiers can quickly and effectively respond.

The example I give with SWORDS is that we went through 3.5 years of certification testing to prove that this system is safe. It doesn't do anything by itself; it doesn't even know where it is. It doesn't know what type of weapon it's carrying, or even how much ammunition it has. If the weapon jams, it can't fix the weapon. If it runs out of ammo, it can't reload, if it gets stuck on a rock, it can't get itself off. Those aren't the mission parameters of the SWORDS platform. The mission parameters are that it is a remote weapons platform. It can do that. Someone is driving it, puts it where it is, authorizes it to fire, and then fires it; it does that really well, it can't do anything else. I don't even see it happening within 50 years - the proof of these systems being able to take on that type of responsibility by themselves. We get asked these questions all the time: "You're putting a weapon on a robot how is that safe?" We spent 3.5 years proving it was safe.

Do you deal with the ethics of surrounding weaponizing robotics?
At this stage all we've made is a gun that moves around by itself. We've made a taxi cab for our soldiers capabilities, or an invisibility cloak for the soldier. We've taken the soldier off the front line and put him back a kilometer. It is not a weaponized artificial intelligence. The biggest problem that people see with the ethics of a robotic system doesn't have to do the ethics of being a robot - it has to do with the ethics of war. When they see a weapon in front of them, they ask: "How is that ethical?" Ours happens to be one that is easy for Hollywood to pick on. Recall that the V2 rocket, the Goliath tank, the ICBM, the cruise missile, predators, smart bombs, were/are all unmanned kill vehicles. We're no different from those systems in that we always have a human-in-the-loop for target acquisition and firing.

In the future, do you see land, air, or sea robotics systems most prevalent in the military?
Right now it's the air side. They are about 30 years ahead of the ground robots because the Air Force had a lot of money during the cold war. In about 20 years, you will see as many if not more, ground robots as air vehicles. The most prevalent robots will probably be ground or near-earth robots. This includes anything that drives on the ground or flies at extremely low altitudes (such as around a building). This is because there are more missions here and this is where the technical challenges are.

Does QinetiQ invest in fundamental robotics technologies, for example: mobility? We are always looking into mobility improvements. We do pair with other companies that are interested in similar things. There was a video released of a robot that can jump over a 20-something-ft wall. QinetiQ North America was involved in the early stages of developing that system. Mobility is a core robot competency; yes we do invest in the fundamentals.

There is a lot of collaboration within the robotics industry?
Yes - it's a small community and it is not uncommon to find companies teaming up to best address opportunities. I believe it is better to get some of the work versus none of the work! We partner with many small businesses on an ongoing basis. If one company is downsizing, another company will pick you up. There are lots of startups and lots of new small businesses. Before we were acquired by QinetiQ, we were classified as a small business and took advantage of small business innovation grants and funded ourselves through these. We are always looking for mobility improvements - sometimes we work with universities. On this class of vehicle, we're seeing that different kinds of mobility are good for different classes of vehicles. On the TALON for example treads are the preferred method of mobility. Treads handle sand quite well because of the weight distribution.

Funding for Robotics: Does it go towards medical, manufacturing, or military sectors? Right now government funding is in all areas, but the military receives most of it. But that's the way technology advances usually happen. The military will push the technology, the technology will be developed, and then it becomes cheaper and moves over to commercial applications. The medical market is also beginning to fund more research in robotics through the National Institute of Health (NIH).

If you go to shows open to the public - the most popular questions are: "When can I buy one that can mow my lawn, or clean my house?" Right now the focus is on autonomy and battlefield interoperability, but eventually these technologies will make it possible to have several robots working together in your home to accomplish these tasks without operator intervention. If that's where the market is, it's very easy to transfer the technology over there. Most companies do this. TALON started from LEMMINGS - a submersible system. We were able to apply certain technology from that program to the TALON.

D.2 Additional Transcripts

Due to the sensitive nature of these interviews, the transcripts are witheld from this paper.

E Notes

Notes

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