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The Emergence and Future of Defence Technologies

from stirrups to satellites

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Abstract

An examination of several military technologies of the 20th century reveals that successful innovation arises from a combination of technology, doctrine and organization. Future military transformation will be marked by technological turbulence as rapid innovation decreases the longevity of any one technological innovation and the increasing diffusion of commercial technologies makes militarily significant technology more available. Open source analysis of some of the future science and technology areas that will be relevant to military transformation include: weapons of mass effect, information technology, the role of culture, strategic lift, footprint reduction, mobility, nanotechnology, uninhabited systems, countering the maritime mine threat, medicine in urban combat, protection, power systems, and the space environment. Success in the future will involve constant and rapid insertion of innovations combined with a disruptive technology watch.

Résumé

Un examen de plusieurs technologies militaires du XXe siècle démontre que les innovations s'avérant être une réussite sont le produit d'une combinaison de technologie, de doctrine et d'organisation. Les transformations militaires à venir seront ponctuées de perturbations technologiques; une innovation rapide réduit la longévité de toute invention technologique, et la diffusion accrue de technologies commerciales améliore la disponibilité de technologies militaires utiles. On a procédé à une analyse générale des secteurs scientifiques et technologiques d'avenir qui importeront à la transformation militaire, notamment les armes à effet de masse, la technologie de l'information, le rôle de la culture, le transport stratégique, la réduction de l'espace occupé, la mobilité, la nanotechnologie, les systèmes non habités, la défense contre la menace des mines marines, la médecine et le combat en milieu urbain, la protection, les systèmes d'alimentation et l'environnement spatial. Les succès futurs nécessiteront l'introduction rapide et constante d'innovations ainsi qu'une surveillance des technologies perturbatrices.

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Executive summary

An examination of several military technologies of the 20th century reveals that successful innovation arises from a combination of technology, doctrine and organization. One example of a disruptive technology was quick-firing artillery which greatly contributed to the defensive aspects of the First World War and epitomized the industrialized nature of that war. Conversely, tanks in the First World War did not prove to be disruptive due to technological and doctrinal problems. It was only when radios and tanks were combined that armoured forces became truly disruptive and altered the nature of warfare through mobility and shock action. Currently, precision-guided munitions are become more common and are a disruptive technology as they allow a change from attrition to precision warfare.

Open source analysis of some of the future science and technology areas that will be relevant to any military transformation include: weapons of mass effect, information technology, the role of culture, strategic lift, footprint reduction, mobility, nanotechnology, uninhabited systems, countering the maritime mine threat, medicine in urban combat, protection, power systems, and the space environment.

Future military transformation will be marked by technological turbulence as rapid innovation decreases the longevity of any one technological innovation and the increasing diffusion of commercial technologies makes militarily significant technology more available. Additionally, non-state actors will be better able to protect and arm themselves through commercial technologies. For state armed forces, there is a temptation to focus on technology-intensive solutions, but low-tech, legacy systems will continue to play a large role. Systems and platforms will be made more easily configurable and upgradeable. Surveillance and force protection will be driving forces in any transformation. Echoing previous DRDC research, it must be understood that culture and trust will have major roles to play in future military operations. Bridging the cultural divide between allied military forces and with local populations will be one of the most important challenges. The interdependence of defence and diplomacy will be evident in precision and stand-off engagements, fewer handling facilities being required, and less collateral damage. Two of the great future challenges will be providing suitable power sources as well as taking into account human capabilities and limitations during the introduction of new technologies. Success in the future will involve constant and rapid insertion of innovations combined with a disruptive technology watch.

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Sommaire

Un examen de plusieurs technologies militaires du XX^{e} siècle démontre que les innovations s'avérant être une réussite sont le produit d'une combinaison de technologie, de doctrine et d'organisation. La pièce à obturation par douille, qui a grandement contribué aux aspects défensifs de la Première Guerre mondiale et symbolisé la nature industrielle de cette guerre, est un exemple d'une technologie perturbatrice. Les chars d'assaut de la Première Guerre mondiale, par opposition, n'étaient pas des éléments perturbateurs à cause de problèmes technologiques et doctrinaux. Les forces blindées sont devenues perturbatrices seulement lorsqu'elles ont été combinées à la radio; elles ont changé la nature de la conduite de la guerre par le biais de la mobilité et des actions de choc. De nos jours, les munitions à guidage de précision sont plus communes et sont une technologie perturbatrice; en effet, elles permettent de passer d'une guerre d'usure à une guerre de précision.

On a procédé à une analyse générale des secteurs scientifiques et technologiques d'avenir qui importeront à la transformation militaire, notamment les armes à effet de masse, la technologie de l'information, le rôle de la culture, le transport stratégique, la réduction de l'espace occupé, la mobilité, la nanotechnologie, les systèmes non habités, la défense contre la menace des mines marines, la médecine et le combat en milieu urbain, la protection, les systèmes d'alimentation et l'environnement spatial.

Les transformations militaires à venir seront ponctuées de perturbations technologiques; une innovation rapide réduit la longévité de toute invention technologique, et la diffusion accrue de technologies commerciales améliore la disponibilité de technologies militaires utiles. En outre, les intérêts non étatiques pourront mieux se protéger et s'armer grâce aux technologies commerciales. Dans le cas des forces armées d'états, la tentation de se concentrer sur des solutions hautement technologiques demeure, mais les systèmes hérités et peu sophistiqués continueront de jouer un rôle important. Les systèmes et les plates-formes pourront être plus aisément configurés et mis à niveau. La surveillance et la protection des forces continueront d'être un élément moteur de toute transformation. Pour reprendre une étude antérieure de RDDC, il est manifeste que la culture et la confiance seront des facteurs importants des opérations militaires futures. Combler le gouffre culturel entre les forces militaires alliées et la population locale sera un des plus grands défis à affronter. L'interdépendance de la défense et de la diplomatie sera évidente lors d'affrontements de précision ou à distance, car moins d'installations de manutention seront nécessaires, et il y aura réduction des dégâts collatéraux. Entre autres, deux défis de taille se dessinent dans l'avenir, c'est-à-dire offrir des sources d'énergie adéquates et tenir compte des capacités et des limites humaines lors de l'introduction de nouvelles technologies. Les succès futurs nécessiteront l'introduction rapide et constante d'innovations ainsi qu'une surveillance des technologies perturbatrices.

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Introduction

> [T]here can be no doubt that with modern firearms the impression which battle makes on armies will be incomparably greater than before, while smokeless powder will change even the nature of these impressions. Infantry and artillery fire will have unprecedented force, while aid to the wounded will be made more difficult by the great range both of small-arms and of artillery. Smoke will no longer conceal from the survivors the terrible consequences of the battle, and every advance will be made with full appreciation of the probabilities of extermination. From this, and from the fact that the mass of soldiers will have but recently been called from the field, the factory, and the workshop, it will appear that even the psychical conditions of war have changed. Thus in the armies of Western states the agitation against war may extend even so far as the materialisation of socialistic theories subverting the bases of monarchies.[1]

Jean de Bloch, writing at the beginning of the twentieth century, argued that war was becoming impracticable. He was wrong that no one would attempt to use war to further their aims, yet he proved correct in his foresight of the character of the Great War, of the inability to achieve war aims, and of the social and political upheaval at the end of the war. It is difficult to be as visionary as Bloch; yet, starting with an examination of the historical importance of new technologies, it is possible to discern a number of areas where science and technology (S&T) will make significant contributions in the next two decades: weapons of mass effect, information technology, the role of culture, strategic lift, footprint reduction, mobility, nanotechnology, uninhabited systems, countering the maritime mine threat, medicine in urban combat, protection, power systems, and the space environment.

The stirrup originated with nomadic tribes in Central Asia and appeared in Europe between 500 and 1000 A.D. This innovation allowed armoured horsemen to brace themselves while using a lance or archers to stabilize themselves. The rapidity with which the use of stirrups spread is an indication of their usefulness. The ability for shock action meant the continued ascent of cavalry over infantry and resulted in the heavy armoured cavalry of Western Europe as a formidable force. Indeed, the stirrup, the high saddle, and the horseshoe resulted in the dominance of horsemen in European high Middle Ages society.[2] The stirrup is an excellent example to demonstrate how a simple tool can change the nature of warfare just as easily as the complex systems of nuclear weapons. Innovation need not arise through a technological tool alone; rather, new forms of organization or concepts also play a role. In the present, one of the most disruptive innovations is the suicide bomber, a ‘weapon’ that continues to defeat all technological measures meant to defend against it. It should be noted that there is a tendency in the present literature to emphasize the technological side of the equation over the science aspect; yet, an understanding of the future potential of both is critical. Warfare will

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[1] Jean de Bloch, The Future of War in is Technical, Economic and Political Relations, trans. R.C. Long (London: Garland Publishing, Inc., 1972), pp. lxx-lxxi.
[2] William McNeill, The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000 (Chicago: The University of Chicago Press, 1982), p. 20; Martin van Creveld, Technology and War: From 2000 B.C. to the Present (New York: The Free Press, 1989), p. 18.

increasingly become technology driven and interoperability issues among allies and the response to asymmetric threats will require solutions for which S&T are major drivers. New options are becoming available as S&T allows military objectives to be realized by non-traditional methods (e.g. uninhabited vehicles conducting reconnaissance normally provided by humans). It should also be noted that it is not really the technology itself, but rather the organization, doctrine, and tactics that embed themselves around the technology which lead to dramatic change. In the case of the stirrup, the shock effect from a charge was the deciding factor in cavalry's success, this tactic enabled by the use of the stirrup. Indeed, technology will not provide a magic bullet. A recent study of the Afghanistan campaign concluded that skilled and motivated ground forces will still bear the brunt of the fighting and that stand-off precision capability is no guarantee of success. The traditional wedding of fire and manoeuvre is still critical and one cannot succeed without the other.[3]

The increasingly rapid rate of growth in the military context is evident in the historical record. Examination of the past 1000 years, (beginning with the mounted archers of the Mongols), reveals that it is within the last 150 years that the greatest number of innovations have occurred ("steam and rapid mobilization; machine gun and trench warfare; internal combustion [engine], radio, and mobility; nuclear; and information"). Furthermore, any superiority garnered by technological innovation has been increasingly short lived.[4]

Today, military power depends more on the quality and usage of sensors, communication networks, and space-based assets than traditional combat platforms. Overarching concepts such as Network Enabled Operations and Effects Based Operations will set the tone for transformation. S&T alone will not enable transformation as doctrine and organization also need to change. The goal of Canadian research and development (R&D) must be to facilitate the regular and rapid migration of successful R&D products into operational systems. In conjunction with this technology insertion, a technology watch needs to be maintained in order to avoid being surprised by disruptive technologies.

With rapid innovation in civilian technologies and the convergence of technologies there will be much "technology turbulence"[5] in the future. Rapid obsolescence of equipment will mean that the military will have to choose wisely what investments it makes and ensure that upgrades occur regularly. To gain the military advantage, the appropriate S&T, doctrine, and organization will need to be forecast, united, and inserted in an organized, coherent process.

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[3] Stephen Biddle, "Afghanistan and the Future of Warfare: Implications for Army and Defense Policy," Strategic Studies Institute (November 2002), pp. 31, 49. Online at www.carlisle.army.mil/ssi/pdffiles/00106.pdf. Accessed 29 October, 2003.

[4] Lt. Col. Randolph Miller, "U.S. Military Transformation and Experimentation: Historical Perspectives, Prospects, and Prescription," (April 2002), p.2. Online at research.airuniv.edu/papers/ay2002/affp/miller.pdf. Accessed 29 October, 2003.

[5] Ministry of Defence, UK, "The Future Strategic Context for Defence," Online at www.mod.uk/issues/strategic_context/index.htm. Accessed 27 January, 2004.

Historical Background

The history of warfare is replete with examples of what would now be called disruptive technologies or systems. The fixation for discovering past revolutions in military affairs, establishing generations of war, or finding prior characteristics of transformations is indicative of the fascination with discovering what have been termed 'magic' bullets: those innovations which became 'war' winners by themselves. The truth is somewhat more complex. The following case studies illustrate how the current context attempts to differentiate between disruptive and battlefield ready technologies. Additionally, it must be noted that it is the doctrine (that guides the employment of new technology) that often decides success or failure as demonstrated by numerous victories won by forces with inferior technology. Technology is merely an enabler and victory stems from well thought out and realistic doctrine. The crucial key to success is the "development, institutionalization, and refinement of a doctrinal framework for war that reaches across forces."[6]

The years between the First World War and the Second World War are commonly mined for historical case studies relating to current military transformation. Like today, small military organizations had to adapt to political, strategic and financial uncertainties. It was in this period that many of the critical technologies developed in the First World War were refined: the tank, the aircraft carrier, the submarine, the airplane, etc. The following examples, from the First World War to today, illustrate the reasons why some technologies and concepts became disruptive.

Quick-firing (QF) artillery

Quick-firing artillery was a disruptive technology in that it its defensive strength turned the First World War into the first industrialized war. The characteristics of quick-firing artillery (volume of fire, range, accuracy) defined the nature of the fighting. As well, the logistics required to serve the guns put a huge strain on resources. This was an artillery war; for example, the ratio of British and German gunners to infantrymen doubled during the war while in the French case it tripled. Although Britain prided itself on its navy, by the end of the war, the Royal Artillery was larger than the Royal Navy.[7]

Technical Change

The new guns would not have been possible without new techniques of mass production and steel processes. The science of interior ballistics demonstrated what

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[6] Williamson Murray and Thomas O'Leary, "Military Transformation and Legacy Forces," Joint Force Quarterly 30 (Spring 2002), p. 21. Online at www.dtic.mil/doctrine/jel/jfq_pubs/0630.pdf. Accessed 14 November, 2003.

[7] Jonathan Bailey, "The First World War and the Birth of Modern Warfare," in The Dynamics of Military Revolution, 1300-2050, ed. Macgregor Knox and Williamson Murray (Cambridge: Cambridge University Press, 2001), p. 149.

improvements were required in order to evolve from cast iron, to wrought iron, to steel.[8]

A combination of pneumatic recoil, improved sights, new ammunition, and rifling allowed artillery guns to be deployed, sited, and fired quickly and accurately. The recoil system ensured that only the gun, not the carriage, leapt backward when fired. This meant that the weapon did not have to be moved back into position after each shot. Combined with breech loading this increased a gun's rate of fire. The QF system also meant that guns could be concealed. Previously they fought in the forward area with the infantry but this was now too dangerous with the advent of an enemy armed with its own QF guns and machine guns. The French 75 millimetre gun of 1897 exemplified the new technology. The gun was light, but stable, and could fire 20 rounds a minute up to six miles away. Other armies realized they needed to develop and adopt QF guns as soon as possible.

Disruption

Quick-firing artillery caused armies to disperse and camouflage their forces in order to avoid being caught in kill zones. The range at which artillery could now fire meant that indirect fire was possible (and necessary). Either ground or aerial observers could direct plunging fire onto enemy forces far from the actual gun battery. Improved ammunition, especially delayed-action fuses, rendered existing fortifications ineffective and increased the use of steel and concrete in fortification. The increased effectiveness of artillery in the First World War is demonstrated by the statistic that the majority of casualties were now caused by artillery fire. For instance the British in the First World War suffered 58% casualties from artillery, while in the Second World War the Germans lost 70% of theirs to artillery.[9]

Limitations

Doctrine held up the development of indirect fire and the armies of 1914 were still wedded to the weapons and tactics of direct fire artillery. There were few howitzers in the combatants' arsenals and the science of indirect fire (mapping, survey, ballistic calculation, etc.) were denigrated.[10] As the war progressed there was increased recognition that indirect fire and fire plans needed to become the norm. Artillery ammunition production also tied in to the growing concept of total war as the mass expenditure of ammunition created a strain on the Home Front. For instance, the British at Passchendaele in 1917 used 321 trainloads of ammunition, equalling a year's production for 55,000 workers.[11] Only through increased coordination and government control were ammunition shortfalls, such as occurred at the beginning of the war, avoided. While giving a huge advantage to the defence, quick-firing artillery

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[8] Bernard and Fawn Brodie, From Crossbow to H-Bomb: The Evolution of the Weapons and Tactics of Warfare. Rev. ed. (London: Indiana University Press, 1973), p. 140.
[9] Bailey, "First World War and the Birth of Modern Warfare," p. 150.
[10] *Ibid*., p. 138.
[11] Brodie and Brodie, From Crossbow to H-bomb, p. 192.

put a logistical burden on armies on the offensive. The weight of its own transport as well as the movement of its ammunition supplies was often too much for the available technology to move. Their destructive power was also a problem as the guns were difficult to move forward during an attack, the ground being so broken from the barrage.

Legacy

Even in the Second World War artillery remained the dominant arm. Over half the battle casualties were caused by artillery. The Russians were well known for their large number of artillery pieces and even the Allies used large artillery barrages on the scale of the First World War. In 1918 the Allies had 21,668 artillery guns to the Central Powers' 16,181 on the Western Front. By contrast, in the Second World War the Soviets had 7 million rounds of ammunition and 42,000 guns and mortars and 3,155 tanks and self-propelled guns for the attack on Berlin in 1945.[12]

Tanks in the First World War

In the First World War, tanks were a battlefield-ready technology in that they could break into a defensive system but not through it. They were too mechanically unreliable and too new for a coherent doctrine to be created around them. For these reasons tanks did not significantly alter the conduct of war during the First World War. For instance, the spectacular gains the Germans won in early 1918 were accomplished without the aid of tanks. In addition, the Allied tanks did not contribute much beyond the opening stages of a battle. For this case study the British tank experience will be the main focus.

Technical Change

It proved difficult to get the tank introduced into warfare even though the caterpillar track design on which it was based was already at the front in the form of tractors towing heavy artillery. It would be the British navy rather than the army that would develop the concept into a combat vehicle. The principle was simple and used existing technology. Basically, an armoured tractor with guns was created.

Limitations

When tanks went into action for the first time in 1916 it was hoped that they would provide fire support for the infantry, a task that the artillery could not do after the initial stage of an engagement. Unfortunately, none of the arms had developed the necessary doctrine of cooperation and mechanical failures further compounded the

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[12] By comparison, the maximum British expenditure of shells in a 24-hour period during the First World War was 943,847 rounds. John Terraine, "Indirect Fire as a Battle Winner/Loser," in Old Battles and New Defences: Can we Learn from Military History?, ed. Correlli Barnett (London: Brassey's Defence Publishers Ltd., 1986), p. 27; John Terraine, The Smoke and the Fire: Myths and Anti-Myths of War, 1861-1945 (London: Sidgwick & Jackson Limited, 1980), p. 127.

problem. The initial failures were the result of technology not keeping pace with changing conditions. When the request for tanks to be designed was first made, it was to break into linear German defensive positions. The tanks would be armoured machine gun platforms which would break the enemy front line, yet the Germans by 1916 were creating defensive networks that were discontinuous and in great depth.[13] Therefore tanks and infantry had to work closely together; otherwise, both were vulnerable. The impression was that while tanks were useful, their role was limited; they would not be a prime determinant in battle due to two factors: their tactics and their mechanical unreliability.

In later years tank-infantry cooperation was stressed in theory but in practice proved to be a problem. Who supported whom? Was it an infantry advance with tanks or a tank advance with infantry? The problem was that early armoured commanders had no tactics on which to base their actions. These had to be developed through trial and error. Throughout the war the role of the tank varied from one of armoured cavalry, or armoured infantry, or self-propelled artillery. On the large battlefront of the war there was seldom the opportunity to concentrate enough tanks for them to be decisive; therefore, they were thought to be only useful for short, set-piece battles.

Further reinforcing the less than favourable impression that many commanders had of tanks was their mechanical unreliability. In 1916, at the first battle of the Somme, 49 tanks were used: 32 reached their start line; 9 of those promptly broke down; 5 ditched in trenches; 9 failed to rendezvous with their infantry support; and, the final nine actually reached their objectives. Although the tank's mechanical performance improved, so did the German anti-tank response. The British started the 1918 battle of Amiens with 414 tanks: 145 were running on the second day, 85 on the third, 38 on the fourth, and 6 on the fifth day. Not only was mechanical unreliability the problem, but also tank crews had to endure temperatures of over 100 degrees Fahrenheit and fumes from the engines and guns.[14]

Military planners were thinking innovatively by the later war years. The feasibility of amphibious tank landings was investigated and tanks for carrying infantry were constructed. Yet the problem was that the technology could not match their vision. In September of 1916, just four days after the tanks first abysmal start, the British military requested another 1000 tanks. Yet in six months only 60 tanks were ever made available, mostly repaired tanks from the Somme. Simply put, this new technology was an involved, complicated process. Production for the first nine months of 1917 was supposed to be 1460 tanks. Yet by November 1917 only 378 tanks were available for combat in France. Besides a difficult manufacturing process, inter-departmental rivalry was responsible for some of the hold-up. The Admiralty was keeping the supply of steel plate, so necessary for tank as well as ship armour, to itself. Yet tanks did make it to France in a variety of types. During the final hundred days of the war 2000 tanks of all types fought (supply tanks, gun-carriers, personnel-

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[13] Bill Rawling, Surviving Trench Warfare: Technology and the Canadian Corps, 1914-1918 (Toronto: University of Toronto Press, 1992), pp. 83-84.
[14] Shelford Bidwell and Dominick Graham, Fire-Power: British Army Weapons and Theories of War, 1904-1945 (London: George Allen & Unwin (Publishers) Ltd., 1982), pp. 135, 137.

carriers, armoured cars, etc.); yet, 887 were lost. By the last set-piece battle on the 4th of November, only 37 tanks were available for combat.[15]

Legacy

Whereas the Allies fielded thousands of tanks during the First World War, the Germans only put 45 into combat. The Allies did not expect Germany to collapse in 1918 and the Allied 'Plan 1919' was revolutionary compared to anything from the start of the war. The plan envisaged tank forces attacking German rear areas and disrupting their lines of communication and command. Of this force, 1600 tanks were to be the Medium D type, a tank not even in service in 1918.[16] Planners were no longer tied to their available technology but put their faith in the ability of new technology to successfully carry out their plans. Yet the war ended suddenly and the final open warfare campaigns of 1918 were forgotten. The lessons of the First World War for the Allies appeared to be that tanks were an auxiliary weapon to the infantry.

The tank remains as an example of a type of technology that promised a breakthrough, but when first put into battle no tactics accompanied it and it therefore failed. A series of trial and error battles followed, along with improvements in the design and by the end of the war it was an integral part of planning. What remained a problem was that ideas were outstripping the ability of the technology. One of the basic questions of the First World War was: what does one do when the older technology (for example the horse) is obviously outdated, but the new technology (the internal combustion engine) is still not sufficiently reliable? The potential for disruption was evident but in practice it failed.

The combination of Tanks and Radios

The combination of tanks and radios produced a disruptive technology in the Second World War. The grouping of mechanized ground forces with tactical airpower, linked by radio, proved to be a defining characteristic of the war. This style of war, termed *'blitzkrieg'*, was only possible through the combination of mobility and shock action provided by tanks, airplanes, and the instantaneous command and control provided by two-way radio. The German use of these three technologies granted them an early initiative in the war through some of the greatest operational victories in warfare, e.g., defeat of Poland, France, etc. The mechanized force was a small portion of the German army, less than 20%, but it achieved great aims.[17]

Technical Change

Technical change in this system did not rely so much on the Germans having better tanks (which they did not), airplanes, or the German lead in radios. Rather it was an

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[15] Terraine, Smoke and Fire, pp. 150, 152, 154.
[16] *Ibid*., pp. 155-156.
[17] Williamson Murray, "Armored Warfare: The British, French, and German experiences," in Military Innovation in the Interwar Period, ed. Williamson Murray and Allan R. Millet (Cambridge: Cambridge University Press, 1996), p. 46.

organizational change that successfully united these technologies. It must be acknowledged that while close air support was an important part of what came to be known as *blitzkrieg*, actual close air support played little role in the early battles of the Second World War. Radio controlled close air support was only experimented with by the Germans in April 1940 and the German air force provided little direct support during the Battle of France. Not until the invasion of Russia in 1941 were the procedures for radio controlled close air support in mobile operations established.[18] Meanwhile, tanks and radios had been in existence for several decades and it took innovators to see the potential provided by their combination. Superior radio command and control created doctrinal possibilities for armoured warfare which only the Germans made use of initially. Success did not only stem from new technology, it came from new doctrine (speed of operation and movement) and an innovative organization (the armoured division).

Disruption

From 1926 to 1931 and then again in 1934, a British experimental armoured unit participated in army exercises. It performed well but upper echelons preferred to dwell doctrinally and financially on the traditional arms (cavalry, artillery, infantry). Intellectually, the British army as a whole was not prepared for a rapid, mechanized war. In fact the strident criticism of some of the armoured innovators helped isolate their position from the rest of the army and ensured that those ideas were increasingly ignored. Even during the Second World War, no armoured innovator of the pre-war years reached a senior combat position in the British Army.[19]

The importance of a guiding hand from the top of an organization is illustrated by the difference in philosophy between the French and Germans. The French emphasized the defensive, embodied in the Maginot line, and had little tolerance for dissenting opinions. On the other hand, the Germans experimented with mechanized forces and allowed innovators into the decision-making process.

The French lessons from the First World War were that firepower and centralized control were what was important, not flexibility and mobility. In 1940 the French had more tanks than the Germans. Many of those tanks were superior in every fashion to the German tanks, but their strengths were negated. Both the French and the British would use their armoured forces in small detachments providing support to their infantry rather than in the mechanized concentrations of the Germans. By being constrained to a supporting role, Allied tanks were not able to exert a decisive role on the battlefield.

The Germans were the first to deeply study their efforts in the First World War. In 1921 the first part of their study appeared. It emphasized combined arms and manoeuvre. They also studied the experience of the British experimental armoured formation. For the next decade the Germans built up their armoured doctrine, resulting in the 1933 publication of *Die Truppenführung*, the German doctrine manual

[18] *Ibid.,* p. 43.
[19] *Ibid.*, pp. 25, 29.

which emphasized armoured operations. Oddly enough, they managed this without having any tanks on German territory. The Versailles Treaty forbade Germany to have tanks and Germany could only give select officers armoured experience by sending them to countries such as Sweden or Russia. Only in 1935 did the Germans authorize their first tank divisions.

The Allies frequently had better and more numerous tanks than the Germans. For example, during the invasions of both France and Russia, the bulk of the German tank force was composed of obsolete tanks inferior in almost every way to their opponents. The Western Allies' armoured force outnumbered that of the German. The former had an advantage of over a thousand tanks during the Battle of France, while the Soviet Union had an advantage of 17,000 armoured fighting vehicles during the 1941 invasion.[20] Additionally, the German armoured force was a very small percentage of their overall force (in the Western 1940 campaign, Panzer divisions accounted for only 8% of the total force).[21] This latter point illustrates that even a "relatively small number of transformed forces can greatly improve the entire force" although it must be noted that victory results from the proper combination of both transformed and legacy forces.[22] One of the major reasons for the German success therefore was the radio, which enabled the mobility and penetration aspects of *blitzkrieg*. The influence of German signal officers on the development of German armoured doctrine and the German analysis of the British armoured exercises meant that radio communication was emphasized. The Germans held their first radio-commanded exercise of an armoured division in 1935. While Allied tanks generally only had receiving sets, the Germans outfitted their tanks with two-way sets. They also established radio networks to ensure that units stayed linked together.[23] Greater communication gave the Germans greater flexibility, which is what the *blitzkrieg* style of warfare required.

The British experimental force recognized the importance of radios in tanks. In 1931 they were the first to manoeuvre a brigade of tanks by radio commands. The French, being defensively minded, did not put great value on radio communications. Between 1923 and 1939 only 0.15% of their military budget was spent on communications equipment.[24] This meant that during the Battle of France of 1940 the majority of French tanks had to signal using flags and flares, an enormous disadvantage.[25]

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[20] Murray and O'Leary, "Military Transformation and Legacy Forces," p. 22.
[21] *Ibid.*
[22] *Ibid.*
[23] van Creveld, Technology and War, p. 180; Barry Watts and Williamson Murray, "Military Innovation in Peacetime," in Military Innovation in the Interwar Period, ed. Murray and Millet, p. 374.
[24] Robert Dougthy, "The French Armed Forces, 1918-40," in Military Effectiveness: Volume II The Interwar Period, ed. Allan Millett and Williamson Murray (Boston: Allen & Unwin Inc., 1988), pp. 57-58.
[25] James Corum, The Roots of Blitzkrieg (Lawrence, Kansas: University of Press of Kansas, 1992), pp. 107-108.

Limitations and Legacy

Radio control and coordination in armoured forces and tactical aviation is what allowed the cooperation that led to *blitzkrieg* offensives. The pace of these battles required instant communication. The Allies were quick to study German success and develop their own armoured forces. The aura of generals such as Montgomery and Patton would shine because of the doctrinal flexibility wrought by the tank and the radio.

The flexibility conferred by the two-way radio was expanded after the war through the replacement of vacuum tubes by transistors and the miniaturization of radios. For an American example, in 1943 there was 1 radio set for 38.6 men in a regiment while in 1971 the figure is 1 set for 4.5 men – a 857% increase.[26] The increasing requirement for information transmission was partly caused by the complex system that armoured formations became.

While the British and French initially used their tanks in small groups, mostly as infantry support, the Germans massed their tanks in order to gain the most shock action. As previously mentioned, the German tanks were often of inferior technology (minus their radios) demonstrating how doctrine is often the more important factor in success than is technology. It was recognized that the tanks still required infantry and artillery support. If all the arms were to stay together then the traditional arms would also have to be either motorized or mechanized. With ancillary services these three arms created the armoured division that was to symbolize conventional ground formation power throughout the Second World War and the Cold War.

Current Concepts: Precision guided munitions

Precision guided munitions (PGM) are now a disruptive weapon as they have moved the focus of aerial bombing from destruction through mass bombardment to precision targeting. The ability to use PGMs means that fewer planes and sorties are required to achieve the same objective. This not only frees assets for other missions but also reduces the potential losses. As targeting relies on precision, smaller amounts of explosives can be used which result in less collateral damage in the target area. While it took 240 tons of bombs to drop a bridge span in 1944, it only took 12.5 tons with PGMs in 1971. By 1990 that total was as low as 4 tons. Although Gulf War I is viewed as the war which showcased PGMs, only 10 % of the bombs dropped in that war were PGMs and these weapons have a much longer history.[27] While 9,300 PGMs were dropped in the Persian Gulf War, three times that number was dropped in Vietnam during the Linebacker campaigns of 1972.[28] In fact, the Germans and Americans in the Second World War used radio- and wire-controlled bombs and the

[26] Martin van Creveld, Command in War (Cambridge, Massachussetts: Harvard University Press, 1985), p. 238.
[27] Major John Malevich, "The Cult of Technology Laid Bare," The Army Doctrine and Training Bulletin 5 (Summer 2002), p. 45. Online at armyapp.dnd.ca/ael/adtb/vol_5/ADTB_vol5no2_e.pdf. Accessed 22 March, 2004.
[28] Murray and O'Leary, "Military Transformation and Legacy Forces," p. 24.

Americans had wire- and radar-guided bombs.[29] Demonstrating how doctrine can slow the adoption of a new technology, the United States did not actively pursue development of PGMs in the post-Second World War era. Rather the nuclear war paradigm shifted attention away from conventional munitions and the lack of interest in PGMs continued into the later years of the Vietnam War.[30]

There are three types of PGMs. The first is man-guided which requires someone to be sited in view of the target. Laser guided bombs and missiles of this type debuted during the later years of the Vietnam War. Their accuracy is limited by the ability of the person on the ground being able to keep the laser on target. The second type of PGM is seeker-guided which uses its own sensors. Acoustic torpedoes, developed during the Second World War, are an example. These weapons have the advantage of being able to be fired at a distance from the target, and thereby reducing possible casualties. A limitation of this type is their high cost. The final type is point-guided which is able to target a specific geographic location. Cruise missiles which use terrain following are an example. The largest disruption will probably come from less costly point-guided PGMs such as those weapons which use a Global Positioning System (GPS) satellite receiver to locate their targets. The Joint Direct Attack Munition (JDAM) is part of this wave.

Technical / Paradigm Change

Several developments were responsible for the increase in PGMs from the 1970s onwards. Some of the necessary criteria were new propulsion systems and explosives. As well, lasers improved guidance while accuracy was increased by the use of satellites.

PGMs were ideally suited to new perceptions. The Persian Gulf War changed public expectations about warfare. Massive casualties and collateral damage were no longer acceptable. This paradigm shift occurred even though only 10% of the munitions dropped were PGMs. The trend towards employment of PGMs only increased the perception that warfare was becoming 'bloodless'. During the 1999 Kosovo bombing 35% of munitions were PGMs. Afghanistan in 2001 had a rate of 60%, and the invasion of Iraq in 2003 saw 18,000 PGMs dropped in 3 weeks with a final total (between 19 March and 18 April) of roughly 68% of all munitions being PGM.[31]

Kosovo is a good example of the new type of war – low casualty and reduced collateral damage. One reason why the US decided on military action in Kosovo in 1999 was the belief that PGMs would make the campaign short and risk-free. In this campaign an American airplane, using a laser-guided bomb, destroyed a military communications tower located a mere 25 feet from civilian residences with no

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[29] Azriel Lorber, Misguided Weapons: Technological Failure and Surprise on the Battlefield (Washington, DC: Brassey's Inc., 2002), p. 108.
[30] *Ibid.*, pp. 109-110.
[31] "68% of Munitions used on Iraq were Guided, says US Air Force," Jane's Missiles and Rockets (1 July, 2003). Online at www.janes.com. Accessed 1 October, 2003; Michael Sirak, "Flexibility is Key to Weapon Mix," Jane's Defence Weekly (18 June, 2003). Online at www.janes.com. Accessed 1 October, 2003.

damage to the latter. In terms of cost, only two aircraft were lost during the whole operation.

The trend towards precision strikes and limiting collateral damage has led to detailed analysis of intended targets. A weapon is then chosen that will do the least damage to the civilian structures around the target. The US has developed the effects-based operations (EBO) concept in order to accomplish the goal of destroying an enemy's infrastructure with the minimum of collateral damage. PGMs play an integral role in EBO.

Disruption

The ability to accurately strike targets at long distances (e.g., cruise missile) means that dispersion and concealment have increased in importance. It also means that close contact with the enemy no longer has to occur. The ability for stand-off engagements means that air or naval elements can engage the enemy anywhere, obviating the requirement for negotiating land bases. As well, attrition warfare of the First World War or Vietnam has been fully replaced by precision attacks on an enemy's command and control networks.

Precision attacks mean that fewer aircraft are needed in order to accomplish the same mission. During the first Gulf War 3,000 missions were flown a day while in Afghanistan only 200 were needed to hit the same number of targets. In the first case 10 aircraft were assigned to each target, now two targets are assigned to each aircraft.[32]

An example of the new class of PGM is the US-built Joint Direct Attack Munition (JDAM). JDAM relies on GPS to guide its inertial navigation system (INS). Knowing its position and velocity, the system adjusts its tail fins in order to arrive at the target's coordinates. It is very cheap compared to other PGMs, a $20,000 (US) tail kit can attach to a normal 2 000, 1 000, or 500 pound bomb. Comparatively, other PGMs cost $70,000-100,000 (US). The need for a low-cost weapon was a major production incentive. The requirement was identified in the late 1980s with JDAM development starting in 1992 and first use occurring in Kosovo.

As it uses GPS, JDAM does not require good weather conditions or the absence of cloud cover in order to find the target. Cloud cover was a major factor in Kosovo where numerous laser guided bomb missions had to be cancelled because of it. The situation was much the same in Iraq where sandstorms and smoke impeded laser guided attacks. Unfortunately, as it attacks a specific geographic point, JDAM cannot attack moving targets. GPS jamming is not a concern as JDAM receives a number of signals, has anti-jamming software, and can guide itself on its INS alone (although with less accuracy).

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[32] "The Falling Price of Precision," Jane's International Defence Review (8 April, 2002), Online at www.janes.com/aerospace/military/news/idr/idr020408_1_n.shtml. Accessed 1 October, 2003.

While experiments were conducted in order to combine laser and GPS guidance it was found that the low cost benefit of JDAM was lost. The marriage of the two may still come as users of weapons are reported to want the flexibility provided by laser-guidance.[33] Experiments to combine GPS and an imaging infrared (IIR) focal plane-array seeker were successful. The combination allows greater accuracy as the GPS guides the weapon close to the target where the IIR takes over. The IIR then compares its view with a stored target picture and guides the weapon the remaining distance to the target. Normal JDAM has a 13m circular error of probability. This decreases to 3m with IIR. Best of all, there is little additional cost as the IIR system was already in use in civilian industry, in Cadillac cars as a night-vision aid, of all places.[34] Developments were also undertaken to increase JDAM's range from 24km to 96km.[35]

There are many benefits to the use of low-cost PGMs like JDAM. JDAM offers an excellent stand-off attack capability. Pilots do not have to verify the target or remain behind after launch in order to guide it to target. The target's coordinates are simply programmed before launch. As the aircraft can theoretically stay out the heavily defended target zone this decreases the potential losses during a campaign. Shorter target identification to shooting loops are possible with JDAM. In Afghanistan, Forward Air Controllers on the ground were able to directly contact patrolling B-52s. Target coordinates were then programmed into the plane's JDAMs and strikes launched. Quick reaction strikes can also be conducted. JDAM can be reprogrammed in flight, meaning that opportunity targets can still be precisely struck. During Operation Iraqi Freedom the JDAMs on an in-flight B-1 were reprogrammed in twelve minutes in order to strike an important command bunker.[36] Another flexibility characteristic of the weapon is that it can be individually programmed to strike different targets. For example, it is expected that a B-2 bomber will be able to drop eighty 500 pound JDAM bombs, each striking a separate target.[37]

The US Air Force has such faith in (and propensity to use) JDAM that in 2002 it increased the original number of JDAMs it was to purchase by 2007 from 88,000 to 236,000.[38] Fortunately, JDAMs are easily manufactured. During Kososo, monthly

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[33] Robert Wall and Douglas Barrie, "Better Bullets: War planners want cruise missiles and bombs to become more flexible," Aviation Week & Space Technology 160 (April 26, 2004), p. 26.
[34] Nick Cook, "Affordable JDAM add-on Boosts Targeting Precision," Jane's (3 October, 2000). Online at www.janes.com/regional_news/americas/news/jdw/jdw001003_1_n.shtml. Accessed 1 October, 2003.
[35] "Joint Direct Attack Munition (JDAM)," Jane's Air-Launched Weapons. Online at www.janes.com . Accessed 1 October, 2003.
[36] David Isby, "Coalition Makes Massive Use of Guided Munitions," Jane's Missiles and Rockets (1 May, 2003). Online at www.janes.com. Accessed 1 October, 2003.
[37] "B-2 Drops 80 Test Bombs," Jane's Missiles and Rockets (1 September, 2003). Online at www.janes.com. Accessed 1 October, 2003.
[38] "US Air Force Boosts Proposed JDAM Buy," Jane's Defence Weekly (18 April, 2002), Online at www.janes.com/regional_news/americas/news_briefs/jdw020418_11.shtml. Accessed 1 October, 2003.

weapon production was doubled with the addition of four people to the production line.[39] In fact, the entire JDAM assembly workforce in 2002 was only 17 people.[40]

Limitations

Striking at enemy command and infrastructure systems creates moral dilemmas. For example, disrupting enemy power systems means that the military cannot exercise command and control but it also affects the civilian population.

The cost of PGMs, even JDAMs, can pose a problem for countries with tight defence budgets. During the bombing of Kososo in 1999, the Americans were the only country with a large supply of them. The use of PGMs was critical in order to reduce the possibility of collateral damage and therefore maintain political support for the operation. The result was that the Americans flew more missions than the other countries and therefore dominated the entire mission politically, strategically, etc. This was a cause for concern for the Europeans who immediately after the operation sought their own PGMs.[41]

The fact that GPS guided weapons requires outside interaction is also a limitation. The bombing of the Chinese embassy during the Kosovo operation had a significant negative political impact. This mistake resulted from outdated maps and poor intelligence.[42] When JDAMs hit the wrong targets in Afghanistan the error was due to incorrect coordinates being programmed on the weapon.[43]

Legacy

Public belief in the technology to provide pinpoint accuracy has become a problem. Minor collateral damage is now evidence of military ineptitude. In order to continue to satisfy the requirement for low collateral damage through the use of PGMs, tests are undergoing for the production of a 250 pound PGM whose limited effect will provide greater precision.

The invention of further low cost and stand-off PGMs is critical. As campaigns become shorter and the cost and complexity of weapons increase, only stockpiled munitions will be readily available. Wars are becoming 'come-as-you-are' and the Americans will not be able to provide all of their Allies' missing capabilities. In addition, the revolution where almost all bombs dropped are PGMs rather than

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[39] Cook, "War of Extremes."
[40] "The Falling Price of Precision."
[41] John Peters et. al., European Contributions to Operation Allied Force: Implications for Transatlantic Cooperation (RAND, 2001), p. 55. Online at www.rand.org/publications/MR/MR1391. Accessed 1 October, 2003.
[42] Nick Cook, "War of Extremes," Jane's Defence Weekly (7 June, 1999). Online at www.janes.com/regional_news/europe/news/kosovo/jdw990707_01_n.shtml. Accessed 1 October, 2003.
[43] Nick Cook, "The Air Campaign," Jane's Defence Weekly (26 March, 2003). Online at www.janes.com. Accessed 1 October, 2003.

‘dumb’ is linked to the increased use of lowered cost PGMs such as JDAM and the trend towards limiting collateral damage. Further innovation with PGMs will occur as they are linked to uninhabited aerial vehicles (UAV) and thereby give those vehicles enhanced destructive power.

Emerging Concepts

The future science and technology environment will be characterized by the diffusion of advanced military technologies to a wider number of state and non-state actors. Additionally, the commercial market will increasingly drive the R&D effort and compound the diffusion dilemma.[44] Possible problems stemming from the increased use of commercial off the shelf products may prove to be a security and interoperability challenge as the rate of obsolescence increases and upgrading is required, or the difficulty of integration of secure military systems (e.g. information systems) with commercial systems occurs.

Weapons of Mass Effect

Weapons of Mass Effect will continue to hold attraction to countries seeking an asymmetric response against the West or to increase their own influence. The United Kingdom's Joint Doctrine and Concepts Centre identified biological weapons as the most probable trend in this area with India, Pakistan, Israel, Iran, Libya, and Syria having weaponised capability for these weapons by 2015 and thereby joining the existing club of China, Russia, North Korea, and Iraq. Weapons of Mass Effect will also be more available to non-state actors, even without state support.[45]

There will be a wider means of delivery of Weapons of Mass Effect in the future. Current missile technologies will proliferate and asymmetric delivery through such means as civilian ships is highly possible. The construction of ballistic missile defences may in fact spur asymmetric delivery experimentation, as traditional delivery systems are rendered ineffective.[46]

Information Technology

Information technology will continue to expand as silicon based computers are replaced by nanotechnology and biological processing systems offer increased space and speed respectively. With current quantum computing technology at the experimental stage one estimate is that it will take until 2030 for a quantum computer to exist.[47] On the other hand, the technologies for quantum cryptography are already available. Text can be transmitted over an unsecured channel once a secure key has been transmitted using the quantum nature of the photon. Eavesdropping without being detected is unlikely due to the necessary

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[44] Joint Doctrine and Concepts Centre, "The Science & Technology Dimension," Strategic Trends (UK Ministry of Defence, March 2003) Online at www.jdcc-strategictrends.org. Accessed 30 October, 2003.
[45] Joint Doctrine and Concepts Centre, "The Military Dimension," Strategic Trends (UK Ministry of Defence, March 2003) Online at www.jdcc-strategictrends.org. Accessed 30 October, 2003.
[46] *Ibid.*
[47] Joint Doctrine and Concepts Centre, "The Science & Technology Dimension."

disruption of the photons.[48] Although advances in source and detector capabilities are required, it is envisioned that quantum cryptography systems could be miniaturized to the extent that they would be man-portable and thereby used by the military in the field. For communication at distances greater than 100km there would be a requirement for global satellite systems or fibre links with quantum repeaters.[49] In addition to its defence benefits are its challenges as the spread of civilian quantum cryptography will allow non-state actors to tell if they are being monitored.

Quantum computing will itself have a disruptive effect on the future defence environment. The real-time processing speed of quantum computers will aid battlefield decision-making; they will help with logistical and operational planning; and they will aid the design of new materials at the atomic level thereby leading to new defence technologies. In order for these benefits to appear the current limitations of quantum bits (i.e., their fragility) must be overcome and it is not foreseen that a battlefield role will be filled in the next two decades.[50]

Culture

Lt. Gen. William Wallace, V Corps commander in Operation Iraqi Freedom, noted that one of his lessons learned was the value of cultural intelligence and understanding the impact one's own forces would have on the local population. In his words, "[t]he more distant a culture is from our own, the more difficult it is to put ourselves in that position, in that mindset."[51] In addition, he stated that human intelligence had an important role as "[a]lthough there's a lot of really cool technical things out there, the technical things and electronic things can be spoofed, where humans, if they're properly trained, cannot."[52] Part of the understanding cultures emphasis of the future environment will involve technologies that aid Human Intelligence (HUMINT) and Civil-Military Cooperation (CIMIC) activities. Automatic translation would be one means towards this end. The US Department of Defense Advanced Research Projects Agency (DARPA) is creating technology that recognizes and interprets key elements of a foreign language. By 2030 real time automatic translation itself might be enabled through natural language algorithms and speech recognition.[53] DARPA has already provided the "Phraselator" for current operations. This handheld device, originally intended for the medical field, translates either spoken or predetermined English phrases into foreign languages.[54] For cultural understanding between allies or with local populations an efficient

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[48] G. Austing, P. Hawrylak, A. Sachrajda and R.L. Williams, Technology Foresight on Quantum Information Processing (Ottawa: National Research Council Canada, 2003), pp. 7-8.
[49] *Ibid*., p. 46.
[50] *Ibid*., pp. 47-48.
[51] Joy Pariante, "Leaders Assess Role of Intelligence in Iraq War," Army News Service (February 9, 2004). Online at www4.army.mil/ocpa/read.php?story_id_key=5656. Accessed 9 February, 2004.
[52] *Ibid*.
[53] Joint Doctrine and Concepts Centre, "The Science & Technology Dimension."
[54] Gerry Gilmore, "DARPA-Developed Device Bridges Language Divides," American Armed Forces Information Service (April 25, 2003). Online at www.defenselink.mil/news/Apr2003/n04252003_200304254.html. Accessed 6 April, 2004.

way to communicate medical diagnoses or give large-scale medical support requires efficient, trusted communication which the limited skills of interpreters may not be able to provide.[55]

During the war in Iraq an American soldier was televised placing an American flag on the statue of Saddam Hussein, unleashing a torrent of criticism and symbolizing for many the real intentions of the United States. More recently the inappropriate actions of a few soldiers at Abu Ghraib created numerous problems for the American leadership. The decisions of soldiers, far from leadership oversight, will be subjected to instant media and public scrutiny and their actions will be taken as representative of their country's policies. Junior soldiers will affect their own tactical situation, but also possibly the operational and strategic levels. As the fate of entire operations can rest with them, individual soldiers have become the "strategic corporal".[56] If all soldiers, regardless of rank, are to be culturally aware of their actions then cultural translation devices, which allow them to interact more fully with the local population, are required. More than just translation of language is necessary, as the nuances of tone and meaning are also needed. It is not always safe to rely on the ability to find locals who can provide the required level of service as the recent difficulties in finding French interpreters for the 3rd Battalion Royal 22e Régiment in Afghanistan proved.[57]

Strategic Lift

One of the problems for future campaigns is how to mobilize quickly and deploy large formations. During Operation Iraqi Freedom, Turkey's refusal to allow an American division to deploy through its territory demonstrated how military forces cannot always acquire passage rights through even a friendly country. Deployment by traditional aircraft or through sea-basing is not always an option. Therefore one of the ideas being floated is to bring back a legacy capability. The capability of lighter-than-air craft to provide higher speed and long-range heavy lift is making airships attractive. Airship technology is part of the wider movement towards reducing the logistical tail within the theatre of operations and thereby reducing risk. Such airships would not require airfields, could move over difficult terrain, and could even operate from sea bases. It is estimated that airships "could move tons of materiel at approximately five times the typical speeds attained today," principally through sealift.[58] At present there is no requirement for significant technical breakthroughs in order to build

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55 Lester Grau and Charles Gbur Jr., "Mars and Hippocrates in Megapolis: Urban Combat and Medical Support," US Army Medical Department Journal (January-March 2003). Online at fmso.leavenworth.army.mil/FMSOPUBS/ISSUES/hippocrates.htm. Accessed 30 January, 2004.

56 Gen. Charles Krulak, "The Strategic Corporal: Leadership in the Three Block War," Marines Magazine (January 1999) Online at www.usmc.mil/cmcarticles.nsf/0/2d9790f3fe41087d8525670f0059b50d?OpenDocument. Accessed 15 January, 2004.

57 Les Perreaux, "French Translators Tough to Find in Afghanistan," Globe and Mail (February 2, 2004). Online at www.globeandmail.com/servlet/ArticleNews/TPStory/LAC/20040202/AFGHAN02/TPInternational/Asia. Accessed 8 April, 2004.

58 Rick Barnard, "Iraqi Conflict Brings Increased Interest in Military Airships," Sea Power (July 2003). Online at www.navyleague.org/sea_power/jul_03_01.php. Accessed 18 January, 2004.

craft with a payload 200 tons.[59] The American military vision is to have a commercial lighter-than-air industry into which the military could tap. In Canada the use of an airship to resupply remote northern communities will be tested in the near future with a flight to a First Nations community in Manitoba. It has also been proposed that airships could provide a useful means to assert Canadian sovereignty over the Arctic regions.[60]

Reflecting on Canada's problems in positioning its forces into Afghanistan, two authors suggested that airships would have helped alleviate the problem. While airships would not have had the same speed as traditional air strategic lift they would have been cheaper, would have increased payload capacity (both volume and lift), and would have required fewer handling facilities (point-to-point delivery also means cutting out excess transport by rail, road, etc.). In a military sense, airships can be designed to have low infrared and radar signatures and loss of helium due to enemy action could be reduced through new materials and structural designs.[61]

Another use of lighter-than-air craft is in surveillance. DARPA is investigating a 150m long airship whose structure would also act as a radar array creating a 580km radar horizon. As well, the US Missile Defense Agency is producing an airship that will stay at 70,000 feet for up to a year.[62] Israel is also constructing an uninhabited airship to operate at the same height for a period of three years, thereby capable of surveillance to 600 miles away. The craft will also have commercial uses such as civilian communications, weather forecasting, etc. Lightweight materials and solar power would be key to the airship's performance.[63]

Footprint Reduction

One of the most important concepts in the future will be footprint reduction. This means reducing both the demand for an item in the supply chain and enhancing the item's potency. These measures should reduce the mass and length of the supply chain and increase the value of the item relative to its size and weight. Reduction of the supply chain will result in fewer facilities and fewer troops tasked to handling the logistics of an operation. Some of the technologies that may lead to a reduction in the demand for resource intensive commodities include: petroleum, oil, and lubricants reduction technologies; hydrogen extraction and

[59] LTC Michael Woodgerd, "The Mobilus Initiative: Creating a New Component of the US Aerospace Industry Centered Upon Transport Airships," Office of Force Transformation (22 July 2004). Online at www.oft.osd.mil/initiatives/mobilus/mobilus.cfm. Accessed 3 August, 2004.
[60] Bruce Garvey, "Blimps 'Perfect' for Arctic Sovereignty," Ottawa Citizen (August 15, 2004). Online at www.canada.com. Accessed 16 August, 2004.
[61] Lt-Col. Christopher Thurrot and Major Shane Jennings, "The Dirigible – A Phoenix Rising from the Ashes," The Army Doctrine and Training Bulletin 5 (Fall 2002), pp. 55-56, 58-59. Online at armyapp.dnd.ca/ael/adtb/vol_5/ADTB_vol5no3_e.pdf. Accessed 5 March, 2004.
[62] Patricia Parmalee, ed., "No Hot Air," Aviation Week & Space Technology 159 (December 15, 2003), p.13.
[63] Abraham Rabinovich, "Airship to Keep Eye on Mideast," The Washington Times (March 4, 2004). Online at www.washtimes.com/world/20040303-094723-7239r.htm. Accessed 4 March, 2004.

storage technologies; ammunition reduction technologies; and self-diagnostic, self-maintaining equipment.[64]

One current example of reduction technology is a pump that recovers water from vehicle fuel. The US Army in Iraq is using 40% of its supply chain capacity to distribute water, a statistic sufficient to demonstrate the possibilities of this technology. The pump cools the vehicle exhaust, causing water in the exhaust to condense. The final step is to make the water potable by treating it with a mixed oxidation generator (using salt, water, and electricity). In one hour of operation, the pump can produce one gallon of water for each two gallons of fuel used. This system would initially be aimed at helping units be more self-sustaining, a prime requirement of special forces.[65] At an individual soldier level, water purification pens issued to US soldiers can purify two litres of water at a time with a total use of 300 litres.[66] A portable osmosis bag can remove 99.9% of all bacteria and viruses from contaminated water. The bag can be used three times a day for up to 10 days. It works by having an electrolyte powder draw water through a membrane that viruses and bacteria cannot pass through.[67] The bags can even clean urine, a feature shared by a new ration package. By using dehydrated rations one day's supply of food (3.5 kg) can be reduced to 0.4 kg. The dehydrated food is then rehydrated when required. Extended use of urine for rehydration is not recommended as the membrane cannot filter out urea.[68] Without a doubt the reduced footprint of the future soldier will continue to of prime interest in the future S&T environment.

Supply chain and weight reduction technology can also be applied to foodstuffs. Techniques are being sought to actually avoid food consumption for up to 5 days by tricking the body's metabolism into burning fat rather than carbohydrates, without any adverse side effects. Other 'metabolic dominance' areas involve investigating how mitochondria (the powerhouse of the cell) supply energy, lowering body temperature to reduce production of certain proteins, and controlling lactic acid production. There are related investigations into nutritional supplements through transdermal patches and alertness through caffeinated gum.[69]

Mobility

A problem identified in operations in Afghanistan was the increased loads carried by infantry soldiers. A study released by the US Army found that the weights carried were in excess of

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[64] Neal Porter, Jim Kennedy, Bert Bridgewater, et al., "Transformation Concepts and Technologies: DRDC Tiger Team analysis of Transformation implications," (DRDC 2004-003). Defence R&D Canada, p. 39. Online at Defence Research Reports - pubs.drdc.gc.ca. Accessed 24 March, 2004.

[65] Bill Putnam, "Army Testing Pump that Makes Water from Exhaust," Army News Service (October 14, 2003). Online at www4.army.mil/ocpa/read.php?story_id_key=5311. Accessed 14 October, 2003.

[66] Paul Stone, "New Technologies Make Life Easier, Safer for Troops on the Battlefield," American Forces Press Service (December 17, 2003). Online at www.defenselink.mil/news/Dec2003/n12172003_200312171.html. 17 December, 2003.

[67] Lisa Burgess, "System Cleans up Almost any Water," Stars and Stripes, (22 June, 2004). Online at www.stripesonline.com/article.asp?section=104&article=22022&archive=true. Accessed 19 August, 2004.

[68] Duncan Graham-Rowe, "Army Rations Rehydrated by Urine," NewScientist (21 July, 2004). Online at www.newscientist.com/news/print.jsp?id=ns99996185. Accessed 19 August, 2004.

[69] Noah Shachtman, "Darpa Offers No Food for Thought," Wired (Feb 17, 2004). Online at www.wired.com/news/medtech/0,1286,62297,00.html. Accessed 1 March, 2004.

Army doctrine and affected combat performance. For instance, nearly all soldiers had a combat load of 60-70 pounds, this being the minimum load that did not include their rucksacks. Technologies that would help in weight reduction and therefore improve the combat effectiveness of soldiers include: lighter and more flexible body armour systems; advanced miniaturized equipment (such as GPS systems); using more off-the-shelf load carriage equipment (e.g., in order to address the needs of specialists like radio operators); and multi-functional items (e.g. a helmet with built-in night vision capability). The report also noted that "drastic action" would be required to meet the goal of cutting the approach march load in half to 50 pounds by 2010.[70]

One means of accomplishing the weight reduction goal could be in the introduction of unmanned ground vehicles to follow behind dismounted troops with extra equipment. Another could be providing soldiers with exoskeletons. The Berkeley Lower Extremities Exoskeleton (BLEEX) straps onto a soldier's legs and uses sensors and hydraulic mechanisms in order to move with the soldier and carry the load. In experiments, "testers have walked around in the 45-kilogram exoskeleton plus a 32-kilogram backpack and felt as if they were carrying just 2.25 kilograms."[71] As warfare becomes more urbanized, exoskeletons have the potential of carrying an individual soldier's armour, heavy weapons, and sensors and giving increased speed and strength. Full exoskeletons, rather than extremity enhancers like the BLEEX, await resolution of problems with "framework materials, actuators, and sensors, plus the heat, noise, and weight of each of these components." The biggest challenge will be finding a "compact, portable, and ample source of power."[72] There is even some thought about the potential of making invasive exoskeletons that would be "partially implanted within a person's musculature and nervous system" or of having intelligent exoskeletons which would leave the battle if their human was injured.[73]

The trend towards integration of components will also apply to soldiers' helmets. The Canadian Forces are spending $5.8 million on the Soldier Integrated Headwear System Technology Demonstration Program. The helmets will weigh approximately 3 kg and offer ballistic protection. They could potentially be equipped with computer screens, video cameras, thermal night-vision, a gas mask, anti-laser properties on the visor, radio, and GPS. Many of these capabilities would be able to transmit to and receive data from other forces.[74]

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[70] "Combat Load Study Shows Soldier's Burden," ISN News (February 2004), p. 6. Online at web.mit.edu/isn/newsandevents/isnnews/isnnews204.pdf. Accessed 21 February, 2004; "Study Says Combat Load too Heavy," RDECOM Magazine (March 2004). Online at www.rdecom.army.mil/rdemagazine/200403/itl_nsc_combat.html. Accessed 7 September, 2004; Lisa Burgess, "Army to Lighten 'Monster Ruck," Stars and Stripes (February 21, 2004). Online at www.estripes.com/article.asp?section=104&article=19825&archive=true. Accessed 21 February, 2004.

[71] Michelle Locke, "Terminator Togs for Anyone," The Ottawa Citizen (March 11, 2004); See www.me.berkeley.edu/hel/bleex.htm.

[72] Peter Weiss, "Dances with Robots," Science News 159 (June 30, 2001), pp. 407-408. Online at www.sciencenews.org/articles/20010630/bob8.asp. Accessed 11 March, 2004.

[73] *Ibid.*

[74] Chris Lambie, "High-tech Helmets Cost Forces $5.8M," National Post (March 29, 2004). Online at www.canada.com. Accessed 29 March, 2004.

Nanotechnology

One of nanotechnology's most promising applications is in individual soldier protection. At one level, water-repellent and anti-microbial nano-coatings are being produced at the Institute for Soldier Nanotechnologies (ISN). For sensors, the ISN is investigating chips of less than one square centimetre with nano-engineered surfaces.[75] At the ballistic protection level, ISN is working with magnetorheological fluids in order to create flexible armour that would become rigid on command. Extremely small iron particles mixed in silicon oil or corn syrup will stack on top of each other when a magnetic field is applied. This change only takes 0.02 seconds and is reversible. The challenge is to create a flexible fabric that will stiffen into armour using electric current wired into a soldier's uniform.[76] Another approach is to coat Kevlar fabric with a fluid of hard silica nano-particles suspended in polyethylene glycol. The fabric will become rigid if a projectile strikes it. The fabric can be sewn in a normal fashion and used to make sleeves and pants, normally not protected by body armour, thereby allowing flexibility, but also protection.[77]

Another line of analysis is towards strengthening fabrics, for example through the use of spider silk. Fabrics made of this material would already be lightweight, flexible, and waterproof. The ISN is attempting to make silk from polyurethane stronger by adding nanoscale particles.[78] In Canada, a transgenic goat technology, partially funded by the Defence Industry Research Program at DRDC, has already permitted the production of spider silk fibres and may point the way towards soft body armour.[79]

Increased armour will not be the only new addition to future uniforms as microtechnology will make heat-actuated pumps man-portable. A cooling vest using ammonia and powered by burning hydrocarbon fuel is being developed. The vest's water passes microscopic tubes of liquid ammonia whose evaporation and condensation cycle cools the water. Not only will this allow soldiers to cool themselves while wearing nuclear, biological, and chemical (NBC)

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[75] "Team Combines Modeling and Experimentation to Improve Microfluidics," ISN News (February 2004), p 4.

[76] Mitch Jacoby, "Science Transforms the Battlefield," Chemical & Engineering News 81 (August 11, 2003). Online at pubs.acs.org/cen/coverstory/8132/8132science.html. Accessed 14 January, 2004; "Instant Armor," ScienCentralNews (4 December, 2003). Online at www.sciencentral.com/articles/view.php3?article_id=218392121&language=english. Accessed 23 February, 2004.

[77] "Liquid Armour Increases Effectiveness of Kevlar," Jane's International Defence Review (June 2004), p. 23; Tonya Johnson, "Army Scientists, Engineers Develop Liquid Body Armor," Army News Service (April 21, 2004). Online at www4.army.mil/news/article.php?story=5872. Accessed 26 April, 2004.

[78] "Spider Silk Wear," ScienCentralNews (5 February, 2004). Online at www.sciencentral.com/articles/view.php3?article_id=218392167&language=english. Accessed 23 February, 2004.

[79] "Nexia and US Army Spin the World's First Man-made Spider Silk Performance Fibers," EurekAlert! (January 17, 2002). Online at www.eurekalert.org/pub_releases/2002-01/nbi-nau011102.php. Accessed 2 March, 2004; See Nexia Biotechnologies www.nexiabiotech.com/en/00_home/index.php.

suits, but it also has potential applications for astronauts or others who wear thick protective clothing.[80]

A goal, which nanotechnology seems ideally suited for, is to create a 'smart' uniform only a few millimetres thick that will have sensors to monitor the soldier's body, exterior sensors for threats, and actuators that would change the properties of the material to deal with injuries by contracting to form tourniquets or casts. In dealing with the challenges, biomimetics (i.e. reproducing the structure of biological materials) may be ideally suited to help as it is already providing clues in other areas of nanotechnology such as nanowires.[81]

One key ingredient in any future nanotechnology initiative is to gain the public trust and avoid any backlash such as occurred with genetically engineered foods. Already popular literature is painting an unflattering light of nanotechnology and the possibility of a public relations nightmare is ever present. Many questions remain about the health hazards and environmental effects of nanoparticles and there is the additional question of what disposal policies are in place for "nanolitter".[82] One paradigm shift will involve viewing the toxicology of a substance not in relation to its composition but rather its particle size and surface chemistry. For instance, gold is inert but nanoparticles of gold "are extremely chemically reactive, with the potential to disrupt biological pathways."[83] Government, industry, and the military will have to assess the societal and environmental impacts of nanotechnology as it is introduced.

Uninhabited Systems

Semi and autonomous intelligent systems will proliferate with the "rising cost of manned systems, the continuing cost reduction in computer systems and the digitisation of the battlespace."[84] Due to legal and ethical restraints humans are likely to continue to stay in the decision making loop when weapon systems are involved. This is not to say that systems with fully autonomous capabilities would not be possible.[85] Possible roles of unmanned ground vehicles (UGVs) include reconnaissance, surveillance, application of effects (door breaching, smoke generation, delivery of concussion grenades), logistic transport (including unmanned

[80] Will Knight, "Hi-tech Vest Could Cool Heat of Battle," NewScientist (17 February, 2004). Online at www.newscientist.com/news/print.jsp?id=ns99994687. Accessed 1 March, 2004; Mark Horstman, "Aircon Backpack Helps Soldiers Chill," News in Science (16 February, 2004). Online at abc.net.au/science/news/stories/s1045830.htm. Accessed 6 April, 2004.
[81] Chappell Brown, "Nanotech Goes to War," EE Times, (August 25, 2003). Online at www.eetimes.com/story/OEG20030825S0017. Accessed 4 April, 2004.
[82] Rick Weiss, "For Science, Nanotech Poses Big Unknowns," Washington Post (February 1, 2004). Online at www.washingtonpost.com/wp-dyn/articles/A1487-2004Jan31.html. Accessed 2 February, 2004.
[83] *Ibid.*
[84] Joint Doctrine and Concepts Centre, "The Science & Technology Dimension."
[85] *Ibid.*

follower vehicles), mine detection, etc. Their size will vary from man-portable systems to several tons.[86]

Interesting developments could occur with naval systems. Recently the US Seaglider, an autonomous underwater vehicle, set a record by staying at sea for 5 months and travelling 1,677 miles. The craft's thrust is gained by creating changes in its buoyancy that result in a forward glide.[87] Another American unmanned underwater glider being planned is a flying wing that could travel thousands of miles underwater over extended periods. The wing would have a speed 10 times greater than existing gliders but its 20-foot wingspan would cause it problems in shallow waters. Initially the sensors on the glider could aid in homeland security but future applications could include payload delivery. The wing's effective design would give it superior lift and reduce the need for using its batteries.[88] Other naval capabilities for unmanned vehicles include "maritime reconnaissance, undersea search and survey, communication and navigation aid, and submarine track and trail".[89] DRDC is presently experimenting with instrumentation onboard gliders at DRDC Atlantic. The SLOCUM Glider is a self-propelled gliding vehicle that can carry out volume surveillance in littoral waters for up to two months between battery changes; during this period it can travel up to 2000 km. Current activity is centred on incorporating both active and passive acoustics sensors. Among other missions, the SLOCUM glider is well suited to act as a 'gateway' between submerged surveillance systems and a satellite link to a distant controller, to carry out reconnaissance in advance of fleet operations or, as a 'pack' of gliders, to conduct long term area surveillance, such as might be needed on one of the fishing banks.[90] A similar device for maritime surveillance would lie with the stealth buoy produced by DRDC. These devices would rest on the seafloor until activated by a specific occurrence. Each buoy could monitor 2 km and would present a good solution to the monitoring of ports and coastlines.[91]

The potential in the air is perhaps greatest. In Operation Iraqi Freedom a single uninhabited aerial vehicle (UAV) provided the intelligence that led to the "destruction of 13 air defense missile batteries, 50 [surface-to-air missile] launchers and 300 tanks."[92] Tactical and endurance UAVs will continue to improve in performance and unmanned combat air vehicles (UCAVs) are envisioned that rival manned strike platforms. This is not say that manned platforms will disappear, as UCAVs will have to prove that they are durable and financially

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[86] Terry Griffin, "Ummanned [sic] Ground Vehicles," Army AL&T (January-February 2004). Online at asc.army.mil/docs/pubs/alt/2004/1_JanFeb/articles/42_Unmanned_Ground_Vehicles_200401.pdf. Accessed 28 May, 2004.

[87] "Seaglider," University of Washington. Online at www.apl.washington.edu/projects/seaglider/summary.html. Accessed 1 June, 2004; Noah Shachtman, "Navy Floats High-Tech Arsenal," Wired (28 May, 2004). Online at www.wired.com/news/technology/0,1282,63633,00.html. Accessed 1 June, 2004.

[88] David Snow, "Underwater Travel Takes Wing," Wired (3 March, 2004). Online at www.wired.com/news/technology/0,1282,62435,00.html. Accessed 4 March, 2004.

[89] "Autonomous Operations FNC – Introduction," Office of Naval Research. Online at www.onr.navy.mil/fncs/auto_ops/default.asp. Accessed 1 June, 2004.

[90] See DRDC Atlantic "Sensors and Actuators Goup" fact sheet, www.atlantic.drdc-rddc.gc.ca/factsheets/03_sensors_actuators_e.shtml. Accessed 14 September, 2004.

[91] Randy Boswell, "'Stealth buoy' Stands on Guard for Thee," The Ottawa Citizen (3 April, 2004), p. A1.

[92] Steven Zaloga, "UAVs Increase in Importance," Aviation Week & Space Technology 160 (January 19, 2004), p. 105.

competitive in comparison to missiles and manned aircraft.[93] New capabilities for UAVs such as formation flying (to enable larger strike densities), air refuelling, and self-defence are also envisaged. With the increased cost of such systems, they may no longer be expendable. However, their design flexibility and lower operating costs (e.g. higher ratio of operational to training flights) will make them attractive. Once again, it needs to be emphasized that the use of armed uninhabited vehicles creates problems in applying the law of armed conflict. With autonomous systems it would be difficult to determine accountability and responsibility for violations of the laws of armed conflict. Would it be the developers, the vehicle commander, or the combatant commander who would be responsible for violations? In addition, how would the right of self-defence apply to an uninhabited vehicle?[94]

Countering the Maritime Mine Threat

The future challenge in the maritime sphere has been identified as projecting power from the sea through littoral waters. Asymmetric attacks in this area are as likely as are attacks by "air defenses, advanced quiet submarines, anti-ship missiles, modern torpedoes and mobile mines."[95] One of the most worrisome of these anti-access weapons is the sea mine. The mine has the potential to block areas such as ports with ease while requiring a disproportionate amount of activity to clear them. This threat will increase with the availability of inexpensive advanced electronics and nanotechnology. They are also being proliferated by countries such as Italy, Sweden and Russia. The low cost of mines make them available to a wider number of countries than do other naval threats such as submarines. At present, at least 50 countries have a mining capability.[96]

As an example of their danger, during the Cold War, mines were more of a threat than missiles and aircraft to the US Navy which lost or had damaged 14 ships by mines while only two were damaged by missile or air attack.[97] One US Navy ship cost $52.1 million dollars to repair while the mine that did the damage only cost $1,500.[98] Offensively, mines are also much deadlier than the common perception of them. During the Second World War the British air force sank 638 ships (at a loss of 450 aircraft) after flying 20,000 mine-laying sorties, while only 366 ships were sunk by air force torpedoes or bombs (at a loss of 857 aircraft).[99] During the same war the ability to damage the shipping capability of a nation was

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[93] *Ibid*., p. 110.
[94] John Klein, "The Problematic Nexus: Where Unmanned Combat Air Vehicles and the Law of Armed Conflict Meet," Air & Space Power Chronicles (July 22, 2003). Online at www.airpower.maxwell.af.mil/airchronicles/cc/klein.html. Accessed 13 February, 2004.
[95] Don Babcock, "Maritime Vision for the Future," DARPATech 2004 (March 9-11, 2004). Online at www.darpa.mil/DARPAtech2004/proceedings.html. Accessed 22 March, 2004.
[96] Committee for Mine Warfare Assessment, "Naval Mine Warfare: Operational and Technical Challenges for Naval Forces," (Washington, D.C.: National Academy Press, 2001), pp. 1-2, 18-19. Online at www.nap.edu/books/0309075785/html. Accessed 18 March, 2004.
[97] *Ibid*.
[98] David Morris, "The Mine Warfare Cycle: History, Indications, and Future," Marine Corps University Command and Staff College (1997). Online at globalsecurity.org/military/library/report/1997/Morris.htm. Accessed 18 March, 2004.
[99] Committee for Mine Warfare Assessment, "Naval Mine Warfare," pp. 1-2, 18-19.

demonstrated by the losses suffered by Japanese shipping through mine action. For instance, in 5 months, 1.25 million tons of Japanese shipping was sunk by mines.[100]

Modern mines include "crawling mines, burying mines, mines with noise reduction coatings and composite materials, and mines that can sense MCM [mine countermeasures] activity to deactivate and then reactivate after the minesweeper has left the area."[101] One suggestion for dealing with the mine question is, instead of searching for them by their shape, another characteristic be used to locate them and neutralize them.[102] Another is to use unmanned undersea vehicles, each with a speciality such as detection, discrimination, classification or identification. A swarm could locate and then either tag or identify a mine with greater speed and precision than current systems. Countermine measures will be an increasingly important aspect of naval warfare as the strategic importance of easily mined sea-lanes such as the Persian Gulf, the Strait of Hormuz, the Taiwan Strait, etc., will not likely diminish. Littoral areas are also prime areas for debris such as old cars. The amount of metal garbage on the sea floor is problematic as the signature of the mines is hidden and it increases the length of sweeps as false positives need to be checked. In 1984 a task force had to clear mines in the Red Sea. One part of the force investigated 480 contacts, all of which were metallic debris.[103]

In addition, the blockading of ports or attacks on shipping are a possibility. In order to be most effective, minefields will be composed of different types of mines and be integrated with shore systems and submarines. Mines will present an inexpensive form of asymmetric response to Western naval power and improved intelligence, surveillance, and reconnaissance of their diffusion, properties, and emplacement will be required.[104] They will also have a lasting influence. In 1971 it was estimated that 2000 influence mines remained in Japan's coastal waters even though clearing operations began in 1945.[105]

In the Canadian context, solutions to the sea mine challenge are being developed in the Remote Minehunting System Technology Demonstration Program (TDP).[106] This TDP will attempt to end the need for expensive single mission ships for minehunting, an idea that is becoming favourable in the transforming navies. A US high-speed vessel has already been used in MCM operations, but it is intended to play a much larger role and is part of a wider naval transformation. It will support mine, surface, and antisubmarine warfare, special forces, helicopters, etc.[107] The crew will be small and the ship will accept interchangeable modules so that mission configuration can occur in the smallest amount of time possible. The ship will

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[100] Morris, "The Mine Warfare Cycle."
[101] *Ibid*.
[102] Babcock, "Maritime Vision for the Future."
[103] Morris, "The Mine Warfare Cycle."
[104] Committee for Mine Warfare Assessment, "Naval Mine Warfare."
[105] Morris, "The Mine Warfare Cycle."
[106] DRDC Atlantic "Mine & Torpedo Defence" fact sheet. Online at www.atlantic.drdc-rddc.gc.ca/factsheets/17_MTD_e.shtml. Accessed 14 September, 2004; See MacDonald Dettwiler "Remote Minehunting System Technlogy (sic) Demonstrator (RMS TD)." Online at halifax.mda.ca/projects/projects.asp?project=1. Accessed 22 March, 2004.
[107] Adm. Robert Natter, "Sea Trial: Enabler for a Transformed Fleet," Naval Institute Proceedings, 129 (November 2003). Online at www.usni.org/proceedings/Articles03/PROnatter11.htm. Accessed 26 January, 2004.

also be equipped with air, surface, and unmanned underwater vehicles.[108] In terms of acquisition, the six years from concept to fielding is half the usual time. This is causing concern and the success or failure of the process will determine the validity of rapid naval acquisition.

Medicine in Urban Combat

Technology-dependent armies are being drawn into complex terrain where their strengths are diminished as they face a variety of asymmetric threats. Perhaps the most worrisome area is the urban theatre. It is estimated that by "2020 approximately 60 percent of the global population will be urbanized."[109] These dense, cluttered areas "limit many current military capabilities such as stealth, mobility, communications, surveillance and reconnaissance, and GPS navigation and target designation."[110] In urban areas there is an increased chance of civilian casualties, collateral damage, and humanitarian crises resulting from combat, all of which could have immediate negative strategic effects if broadcast live by the media.

In the medical area a number of problems are posed by urban combat: "finding the wounded, evacuating the patient, types of injuries encountered, preventive medicine, medical intelligence and protection of medical facilities and patients."[111] Firstly, once a soldier is wounded it may be difficult to locate him or her in the broken terrain of the urban arena. There will rarely be enough soldiers to control all of an urban area and groups of soldiers will be dispersed to attack or defend various nodes. These widely dispersed forces will also influence the ability of medical personnel to reach the wounded in a timely manner.

Soldiers are not taught self-administered first aid and if they are heavily wounded would have difficulty applying it. Tourniquets that can be applied with one hand and bandages with special clotting agents are two means that would help with first aid. DRDC is now developing new wound dressings in order to address the concern that soldiers may not receive attention for up to 8 hours.[112] Attention to injuries could take much longer as experience in Chechnya and Somalia indicates that air and vehicle evacuation is dangerous and costly. This reduces the options to litter carrying the wounded which increases the length of time that they are required to be stabilized. In Somalia it took up to 15 hours for the wounded to receive surgical treatment.[113]

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[108] H.G. Ulrich III and Mark Edwards, "The Next Revolution at Sea, " Naval Institute Proceedings (October 2003). Online at www.usni.org/proceedings/Articles03/proulrich10.htm. Accessed 26 January, 2004.
[109] LCol. L.B. Sherrard, "The Future Battlegroup in Operations," The Army Doctrine and Training Bulletin 6 (Fall/Winter 2003), p. 6. Online at armyapp.dnd.ca/ael/adtb/vol_6/ADTB_vol6.3_e.pdf. Accessed 27 July, 2004.
[110] LCol. Bernd Horn, "Complexity Squared: Operating in the Future Battlespace," Canadian Military Journal 4 (Autumn 2003), p. 9. Online at www.journal.forces.gc.ca/engraph/Vol4/no3/command_e.asp. Accessed 27 July, 2004.
[111] Grau and Gbur Jr., "Mars and Hippocrates in Megapolis."
[112] See DRDC Toronto "DRDC Wound Dressings" fact sheet, www.dciem.dnd.ca/publications/factsheets/t20_e.pdf. Accessed 27 July, 2004.
[113] Grau and Gbur Jr., "Mars and Hippocrates in Megapolis."

Both the Russians in Chechnya and the Americans in Iraq have noticed an increase in the number of head wounds. Partly, this is because body armour decreases the number of torso injuries and increases head and extremity wounds. Yet another aspect is the increased use of high explosives rather than small arms.[114] American doctors now use 3-D medical models of injured soldiers' faces and skulls in order to plan how they will treat the injury. By modelling how they will reduce the fractures on the model first, doctors can determine the proper alignment for a reconstruction bar beforehand and thereby reduce operating times (20% by one estimate). Besides reconstructing fractures, 3-D models aid in creating custom-fitted replacements for missing skull parts.[115]

Another increasing injury results from the use of thermobaric weapons, such as the Russians used in Chechnya. The weapons work by creating an aerosol cloud of explosive that is then ignited, generating a crushing overpressure within the cloud. Medics trained to deal with traditional wounds would not be able to respond to the injuries created by these weapons: "personnel caught under the blast die immediately from flame and overpressure. Personnel on the periphery of the blast are subject to burns, broken bones, contusions from flying debris and blindness. Air embolism within blood vessels, concussions, multiple internal hemorrhages in the liver and spleen, collapsed lungs, ruptured eardrums and eyes displaced from their sockets … Peritonitis can result from displacement and tearing of the internal organs."[116] Both soldiers and medics will have to become adept at stabilizing and treating these new types of injuries.

The US has successfully fired a 25mm thermobaric round from a crew served weapon and is aiming at having the capability on individual weapons in the future.[117] In the air, the US Air Force Massive Ordnance Air Blast (MOAB) bomb weighs 21,700 pounds and is 30 feet long. While it is unlikely that this size will be prevalent, smaller scale thermobaric weapons such as the 25mm round will find increasing use, requiring changes in tactics, personnel protection and defensive position construction. Additionally, it is possible that non-state actors will acquire these types of weapons or create their own and use them in terrorist acts.[118] Russia is already producing third-generation thermobaric weapons and has developed rounds for the ubiquitous RPG-7.[119] DRDC is presently investigating enhanced blast weapons in order to determine their effects and what protection could be provided.[120]

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[114] Chuck Wagner, "Brain Injuries High among Iraq Casualties," Army News Service (November 24, 2003). Online at www4.army.mil/ocpa/read.php?story_id_key=5445. Accessed 8 April, 2004.

[115] Michael Dukes, "3-D Models Changing Face of Army Medicine," Army News Service (13 August, 2004). Online at www4.army.mil/ocpa/read.php?story_id_key=6254. Accessed 13 August, 2004.

[116] Grau and Gbur Jr., "Mars and Hippocrates in Megapolis."

[117] Jodie Daubert, "First 25mm Thermobaric Airburst Round Fired from XM307 Crew Served Weapon," US Newswire (27 October, 2003). Online at https://peosoldier.army.mil. Accessed 29 March, 2004.

[118] David Hambling, "Experts Fear Terrorists are Seeking Fuel-Air Bombs," NewScientist (17 March, 2004). Online at www.newscientist.com/news/print.jsp?id=ns99994785. Accessed 18 March, 2004.

[119] Lester Grau and Timothy Smith, "A 'Crushing' Victory: Fuel-Air Explosives and Grozny 2000," Marine Corps Gazette (August 2000). Online at fmso.leavenworth.army.mil/fmsopubs/issues/fuelair/fuelair.htm. Accessed 10 August, 2004.

[120] Hambling, "Experts Fear Terrorists are Seeking Fuel-Air Bombs."

In urban operations preventative medicine in the form of vaccines is also required if the large number of soldiers lost to disease caused by the squalid environment is to be stopped.[121] Immunization would also be required against chemical and biological threats which may be encountered.[122] For example, a nerve agent prophylactic has been created in Canada. Private industry and DRDC Suffield have produced an enzyme that acts as a scavenger in the blood, removing nerve agent molecules.[123] The US has started a program to help injured soldiers remain in the fight or at least increase their ability for self-administered first aid. One of the technologies for this is a painkiller that soldiers can take before being wounded. RI624 should remove the sensation of pain without affective cognitive abilities by using "an antibody to keep in check a neuropeptide that helps transmit pain sensations from the tissues to the nerves."[124] Addressing the concern with reduced cognitive ability during extended operations, several countries are investigating the possibility of using caffeine to increase performance in sleep-deprived individuals.[125] For treatment of wounds DRDC is exploring hypertonic fluid resuscitation in order to reduce the need for other resuscitation and life-support measures, and to improve survival, clinical outcome, and the overall quality of life of survivors by reducing inflammatory complications.[126]

Protection

One recent study predicts an increased requirement for dismounted infantry in future operations. As opponents seek the protection of complex terrain in order to avoid Western stand-off precision firepower only dismounted infantry can ferret them out.[127] Network Enabled Operations are designed to limit the requirement for protection by providing greater situational awareness with the intent that stand-off engagement can occur. Yet many types of operations, such as peace support operations, demand that soldiers establish a presence in complex environments, which negate their stand-off capability; thus they require protection to absorb the first shot with no warning. In future operations, the definition of protection will also have to be extended to include the safety and security of both local populations and non-governmental organizations.

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[121] Grau and Gbur Jr., "Mars and Hippocrates in Megapolis."
[122] Robert Hahn II and Bonnie Jezior, "Urban Warfare and the Urban Warfighter of 2025," Parameters (Summer 1999). Online at carlisle-www.army.mil/usawc/Parameters/99summer/hahn.htm. Accessed 20 February, 2004.
[123] Porter et al., "Transformation Concepts and Technologies," p. 36; See www.nexiabiotech.com/pdf/PR%202003-03-31%20DRDC%20English.pdf.
[124] Noah Shachtman, "Saving Pvt. Ryan … From Pain," Wired (10 October, 2003). Online at www.wired.com/news/medtech/0,1286,60768,00.html. Accessed 1 March, 2004. See DARPA "Soldier Self Care," www.darpa.mil/dso/thrust/biosci/pic.htm.
[125] Tom McLellan, Doug Bell, Harris Lieberman and Gary Kamimori, "The Impact of Caffeine on Cognitive and Physical Performance and Marksmanship During Sustained Operations," Canadian Military Journal 4 (Winter 2003-2004), p. 47. Online at www.journal.forces.gc.ca/engraph/Vol4/no4/military-meds_e.asp. Accessed 27 July, 2004.
[126] "DRDC Invests in New Projects under the Technology Demonstration Program," Defence R&D Canada (April 2004). Online at www.drdc-rddc.gc.ca/newsevents/backgrounders/bg040423_e.asp. Accessed 15 September, 2004.
[127] Biddle, "Afghanistan and the Future of Warfare," p.56.

In one DRDC study the following predictions were made concerning future protection technologies:

> The development of armour and camouflage will depend heavily on new materials research. New fibres (e.g. spider silk produced by DNA modified organisms or nanotube fibre systems) as well as polymeric and ceramic multi-impact resistant materials will be developed. This fine tailoring of materials will be driven by the enormous recent increases in both the understanding and modelling of the solid-state and in the development of DNA tailored organisms.
>
> For camouflage and armour, active systems will be developed. The soldier's suit and the vehicle covering will exhibit chameleon-like properties across the electro-optical spectrum. This will require redirecting energy in a patterned way across the vehicle or the suit. For vehicles, very fast, hard kill active armour systems and electronic armour (capacitive melting shields) will be developed and will be coupled to extensive incoming target detection systems with fast reaction times. Regarding nuclear, biological, or chemical threats, the first level of protection will again be long-range remote agent detection and identification as well as accurate propagation prediction. Reactive neutralizing materials and self-decontaminating surfaces on military platforms will offer the second level of protection.
>
> All of the above developments imply that both the individual soldier and the vehicles will have access to low weight, high capacity energy sources. Surprisingly, the pace of development in this area is, and probably will be for the foreseeable future, the true technological bottleneck to achieving at a reasonable cost full spectrum protection over extended periods of time. To keep the weight to manageable proportions, effective energy generation systems will need to take full advantage of locally available materials (for example direct electrical generation from bacteria).[128]

Power Systems

The quest for silent hybrid electric drives in ground vehicles and electric ships centres around one of the biggest technological hurdles in the future: that of power generation. One of the key technologies in this area will be fuel cells. These are "miniature power plants that convert the chemical energy inherent in hydrogen and oxygen into direct-current electricity without combustion. Unlike batteries, which store energy, fuel cells produce electricity as long as fuel is supplied."[129] The long life of fuel cells is currently driving private industry (e.g., cell phone manufacturers) to test micro fuel cells. Further civilian applications in housing and transportation are likely to increase. Militarily, one example is the US investigation of UAVs powered by fuel cells. Types of hydrogen fuels considered include pure hydrogen, methanol or other liquid hydrocarbons, and methane.[130] In addition, fuel distribution, size, weight, and

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[128] Porter et al., "Transformation Concepts and Technologies," pp. 36-37.

[129] Lt. Col. David Blanks, "Fuel Cells: Powerful Implications," Air & Space Power Journal (Spring 2004). Online at www.airpower.maxwell.af.mil/airchronicles/apj/apj04/spr04/blanks.html. Accessed 5 March, 2004.

[130] *Ibid*.

cost remain key issues. It is cost that continues to make conventional power sources more attractive. Yet more efficient engines would increase range and tempo of operations while reducing supply chain problems. In the land environment, vehicles with fuel cells could reduce the demand for fuel by 50 percent, significantly reducing the largest portion of the logistic support.[131] For example, fuel composed 70 percent of the total equipment tonnage shipped during the build-up to Gulf War I.[132] Additionally, vehicles powered by fuel cells would achieve fuel economies up to 2.6 times that of internal combustion engines, thereby increasing vehicle range as well as saving fuel.[133] Clearly, fuel cell technology will gain in attraction.

Electrical power will enable directed-energy weapons. Currently, "electrical components that operate at higher temperatures, such as switches and capacitors, along with superconductivity and thermal-management technologies" are being developed.[134] Improved launch packages, control and reliability, and power supplies are being attained in electrical launch platforms and propulsion through focussed research and the use of new materials.[135] A directed energy weapon on an aircraft would have the potential for limitless ammunition as long as jet fuel was available for the engine (also limitless with air to air refuelling). This compares to the chemically fuelled airborne laser which would require reloading.[136] It may also be problematic in terms of size to put chemical gas lasers into fighter aircraft.[137] In the naval sphere electrical power would allow electromagnetic rail guns. These guns would fire kinetic-energy projectiles at hypersonic speeds, creating increased destructiveness over current systems. It would also be safer than using the present chemically based ammunition and take less room.[138]

Space Environment

Enabling better surveillance from space will be cheaper launch options and smaller satellites.[139] Possible missions include surveillance of space (satellite monitoring and possible

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[131] Maj. A.P. Balasevicius, "Fuel Cell Technology: A Question of Remaining Relevant in the Future Battle Space," The Army Doctrine and Training Bulletin 6 (Summer 2003), p. 16. Online at armyapp.dnd.ca/ael/adtb/vol_6/ADTB_vol6.2_e.pdf. Accessed 5 March, 2004.
[132] *Ibid.*
[133] *Ibid.*, p. 15.
[134] Michael Kelly, "Powering the Future: Advances in Propulsion Technologies Provide a Capability Road Map for War-Fighter Operations," Air & Space Power Journal (Spring 2004). Online at www.airpower.maxwell.af.mil/airchronicles/apj/apj04/spr04/kelly.html. Accessed 5 March, 2004.
[135] Porter et al., "Transformation Concepts and Technologies," p. 60.
[136] Kelly, "Powering the Future."
[137] Maj. Gen. Donald Lamberson, Col. Edward Duff, Don Washburn, Lt. Col. Courtney Holmberg, "Whither High-Energy Lasers?," Air & Space Power Journal (Spring 2004). Online at www.airpower.maxwell.af.mil/airchronicles/apj/apj04/spr04/lamberson.html. Accessed 5 March, 2004.
[138] Natter, "Sea Trial,"; Hunter Keeter, "Electric Warship Heralds Evolution in Weapon Technologies," Sea Power (May 2004). Online at www.navyleague.org/sea_power/may_04_10.php. Accessed 18 May, 2004.
[139] Satellite classification is as follows: pico-satellites have a mass of less than 1 kg, nano-satellites are in the 1-10 kg range, micro-satellites are in the 10-100 kg range, small satellites are in the 100-1000 kg range, and large satellites have a mass in excess of 1000 kg.

ballistic missile applications), low-resolution earth environment monitoring (hyper-spectral applications) and tracking and identification of radio-frequency emitters on the earth's surface.[140]

The first Canadian micro-satellite is the Microvariability and Oscillations of Stars (MOST) satellite, launched in June 2003 as Canada's first space telescope. This space telescope measures the light variations of stars and helps determine their age. MOST has a mass of approximately 60 kg and costs less than $10 million. By contrast, the Hubble telescope weighs 11,000 kg and cost $2.2 billion. Already MOST has provided impressive findings that are challenging conventional thought.[141] Further refinements of even smaller satellites will continue. There is already ongoing development in Canada of nano-satellites. The Canadian Advanced Nanospace eXperiment at the University of Toronto developed the CanX-1 (weighing less than 1 kg and measuring 10 centimetres cubed), which was launched in June 2003, and plans for two more similar satellites.[142]

The future of satellites has been proposed as the end of the "space mainframe" and the beginning of an "age of systems that are re-configurable, upgradeable, and responsive to our changing needs."[143] In the United States, DARPA is investigating autonomous, reconfigurable, and upgradeable space systems. Rather than putting large satellites into space with technology that is already becoming obsolete, DARPA envisions being able to constantly upgrade the components of smaller, more affordable satellites. New technologies include electric micro-thrusters requiring only a few grams of propellant to shift satellites and chemical micro thrusters that enable quick manoeuvres, among others.[144] The first test of the concept will occur in 2006 when two satellites will dock in orbit and exchange a battery and a computer.[145] The attractiveness of micro- and nano-satellites lies in their ability to be developed by a small team in a short period at a much-reduced cost than larger satellites. These benefits will result in intelligence and surveillance capabilities for small countries, private groups, and transnational networks.[146]

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[140] Porter et al., "Transformation Concepts and Technologies," p. 45.
[141] See MOST website at www.astro.ubc.ca/MOST/index.html and University of Toronto Institute for Aerospace Studies website www.utias-sfl.net/index.html; "MOST (Microvariability and Oscillation of Stars)," Canadian Space Agency. Online at www.space.gc.ca/asc/eng/csa_sectors/space_science/astronomy/most.asp. Accessed 5 March, 2004; Peter Calamai, "Tiny Telescope Exceeds High Hopes," Toronto Star (February 28, 2004). Online at www.utias-sfl.net/RecentNews/News.html. Accessed 5 March, 2004; Peter Calamai, "Getting the MOST out of Space: All-Canadian microsatellite to study far planets," Toronto Star (29 June, 2003). Online at www.dynacon.ca/index.php/full_story_19/NewsID/74.html?sesn=ced7e6670251904663f66aa4ab2f7789 . Accessed 5 March, 2004.
[142] See University of Toronto Institute for Aerospace Studies website www.utias-sfl.net/index.html.
[143] John Evans, "Laptops in Space," DARPATech 2004 (March 9-11, 2004). Online at www.darpa.mil/DARPAtech2004/proceedings.html. Accessed 28 April, 2004.
[144] *Ibid.*
[145] Noah Shachtman, "Pentagon Harbors Wild Space Plans," Wired (13 March, 2004). Online at www.wired.com/news/technology/0,1282,62631,00.html?tw=wn_story_top5. Accessed 15 March, 2004.
[146] Porter et al., "Transformation Concepts and Technologies," p. 45.

Human Element

The attitudes of people towards technology will play an ever-increasing role in military transformation. In the post-First World War period a denigration of 'learning' persisted in the British Army. Serious study was unusual and reading books was cause for an officer to be regarded as peculiar.[147] Rather than merely seeing the military as an occupation, it has to be ingrained that it is a profession which requires constant study and thought. The Germans in the post-First World War period encouraged a culture that was intellectually rigorous and open to innovation (although there were still large numbers of doubters as regards armoured warfare even after the first campaigns of the Second World War). For the purpose of investigating various aspects the First World War the Germans established 57 expert committees composed of over 400 officers. From these investigations came the German theory of combined arms warfare.[148] By contrast, the French in the inter-war period strongly discouraged any critique of the official doctrine.

While the focus is often on expensive high technology equipment, there is a requirement to continue linking to low-technology. For example, American special forces in Afghanistan were required to relearn the skills of how to ride horses and maintain pack animals while maintaining their skills at high-technology combat. Only what has been called "intellectual malleability" or the flexibility of individuals, combined with the new technology, will result in success.[149] Leadership, creativity, and decisiveness will be critical elements at all levels of the chain of command.

One of the most important elements will be trust. The American Chairman of the Joint Chiefs of Staff, General Richard Myers, remarked in 2002 that transformation involves an intellectual element (the requirement to adapt to an uncertain environment) and a cultural element (changing the operating culture).[150] This cultural challenge is to create truly joint forces that trust each other and abandon service specific cultures, doctrine, technology, etc. One example of newfound trust between the services is the use of B-52s to drop JDAMs in Afghanistan. During Vietnam close air support was provided at low levels and the ground units could see the air support when they gave the command to release their ordnance. With the B-52s there was no chance that the ground element would see the B-52s at 20,000 feet and had to trust implicitly that the air element was lined-up correctly. Technology, especially integrated and interoperable C4ISR suites, will help create shared knowledge between services, other government departments, and allies. Only trust will allow a faster decision cycle to occur from the acceptance of that shared knowledge.[151] Recently, DRDC started a three-year study into the psychological phenomena of trust. It will examine trust in the military and the implications for the Canadian Forces. Interpersonal trust and also trust in

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147 Murray, "Armored Warfare,"p. 23.

148 *Ibid*., p. 37.

149 Comment made by General Franks. Secretary of Defense Donald Rumsfeld, "'21st Century Transformation' of the U.S. Armed Forces," Remarks before the National Defense University, Washington, D.C. (January 31, 2002). Online at www.defenselink.mil/speeches/2002/s20020131-secdef.html. Accessed 30 March, 2004.

150 General Richard Myers, "Transformation of the Military Instrument of National Power," Remarks before the 2002 Eisenhower National Security Conference, Washington, D.C. (September 27, 2002). Online at www.dtic.mil/jcs/chairman/eisenhower_27sep02.htm. Accessed 30 March, 2004.

151 *Ibid.*

automated systems or in automated advisors, will be considered. How trust develops, especially in small teams, is a main point of interest but issues surrounding trust between arms and environments are also a concern.[152]

While intellectual flexibility will be critical, morals will also play a role. In the discussion of UAVs it was already noted that the human-in-the-loop concept would continue due to legal and ethical concerns about UAVs in combat. A related factor is human acceptance of new technologies. Cognitive sciences have made progress in recent years with implantable and peripheral devices and there appears to be hope for machine augmentation of human performance. Yet brain-machine interface may be advancing faster than society's ability to accept its results. The invasive nature of the interface will provoke legal, moral, and ethical debate.[153]

In the end, new technology and new systems will have to take into account human operator capabilities and limitations. Increased education of soldiers and enhanced simulation training should determine what these limits are.

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[152] Chris Wattie, "Military Allots $800,000 for Trust Study," National Post (17 July, 2004). Online at www.canada.com. Accessed 17 July, 2004.
[153] Porter et al., "Transformation Concepts and Technologies," pp. 68-70.

Conclusion

The future science and technology environment will be full of opportunities. While there is a temptation to focus on technology-intensive solutions, low-tech, legacy systems will continue to play a large role. Systems will be made more easily configurable and upgradeable. The land forces will transform the most, as air and naval forces are already far superior to opponents' capabilities. Surveillance and force protection will be driving forces in any transformation. Bridging the cultural divide between allied military forces and with local populations will be one of the most important challenges. The interdependence of defence and diplomacy will be evident in precision and stand-off engagements, fewer handling facilities being required, and less collateral damage experienced during conflicts. Two of the great future challenges will be providing suitable power sources as well as taking into account human capabilities and limitations during the introduction of new technologies. Finally, the diffusion of technology in both the military and civilian sectors will mean that any given technological superiority will not last and it will be met by asymmetric responses. This will drive continuing transformation and result in constantly emerging new concepts and technologies requiring that a disruptive technology watch be maintained. In sum, the future S&T environment will change rapidly and the military must be able to respond. As borne out of the historical record, the fierceness and confusion of battle, the psychological effect, and social upheaval envisioned by Jean de Bloch will continue to play a role in future wars.

List of symbols/abbreviations/acronyms/initialisms

BLEEX	Berkeley Lower Extremities Exoskeleton
C4ISR	Command, control, communications, computers, intelligence, surveillance, and reconnaissance
CanX-1	Canadian Advanced Nanospace eXperiment
CF	Canadian Forces
CIMIC	Civil-military cooperation
DARPA	Defense Advanced Research Projects Agency
DND	Department of National Defence
DRDC	Defence R&D Canada
GPS	Global positioning system
HUMINT	Human intelligence
IIR	Imaging infrared
INS	Inertial navigation system
ISN	Institute for Soldier Nanotechnologies
JDAM	Joint Direct Attack Munition
MCM	Mine countermeasures
MOAB	Massive Ordnance Air Blast
MOST	Microvariability and Oscillations of Stars
PGM	Precision guided munition
QF	Quick-firing
R&D	Research and development
RPG	Rocket propelled grenade

S&T	Science and technology
TDP	Technology Demonstration Program
UAV	Uninhabited aerial vehicle
UCAV	Unmanned combat air vehicle
UGV	Unmanned ground vehicle

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14. ABSTRACT

An examination of several military technologies of the 20th century reveals that successful innovation arises from a combination of technology, doctrine and organization. Future military transformation will be marked by technological turbulence as rapid innovation decreases the longevity of any one technological innovation and the increasing diffusion of commercial technologies makes militarily significant technology more available. Open source analysis of some of the future science and technology areas that will be relevant to military transformation include: weapons of mass effect, information technology, the role of culture, strategic lift, footprint reduction, mobility, nanotechnology, uninhabited systems, countering the maritime mine threat, medicine in urban combat, protection, power systems, and the space environment. Success in the future will involve constant and rapid insertion of innovations combined with a disruptive technology watch.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

Future S&T environment; Transformation; Disruptive technology; Weapons of mass effect; Information technology; Culture; Strategic lift; Footprint reduction; Mobility; Nanotechnology; Uninhabited systems; Sea mine; Medecine; Urban combat; Protection; Power systems; Space

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