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The Military Technical Revolution:

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The Military Technical Revolution
From Hardware to Information

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THE CONDUCT OF WAR CHANGED DRAMATICALLY between World War II and Operation Desert Storm. The major differences resulted from a revolution in military technology. As we look ahead ten years to the world of the year 2003, we need to examine this "Military Technical Revolution" (MTR) to project how the next war will be different from Desert Storm.

An analysis of technological changes since World War II indicates that the MTR has undergone three distinct phases, which started at different times, stand today at different stages, and accordingly will culminate (or have already) at different times.

• A *military engineering revolution*, which changed weapons, platforms, and military hardware. This phase of the MTR began during World War II and virtually ended during the 1980s.

• A *military sensor revolution*, which began with the advent of computerized sensors and weapons control systems in the early 1970s. It multiplied the capabilities of individual platforms by increasing their ability to sort data effectively and control weapons at long ranges. This phase of the MTR is in its latter half and is likely to wind down in the 1990s.

• A *military communications revolution*, which began in the late 1970s with new capabilities in command, control, communications, and intelligence (C^3I) and with increased education levels in the military. It too multiplied the total force, but this time through coordinated air-sea-land operations. This phase was most manifest during Desert Storm and will continue as the lessons learned in that war are applied.

Therefore, the effectiveness of any military fighting force in the year 2003 will depend on hardware, sensors, and communications in ways that are totally different from even ten years ago. By reviewing these three areas since World

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War II and projecting changes, we see that it is likely that force structures in the year 2003 will differ greatly from those of today, especially in their abilities to integrate weapons, sensors, and communications.

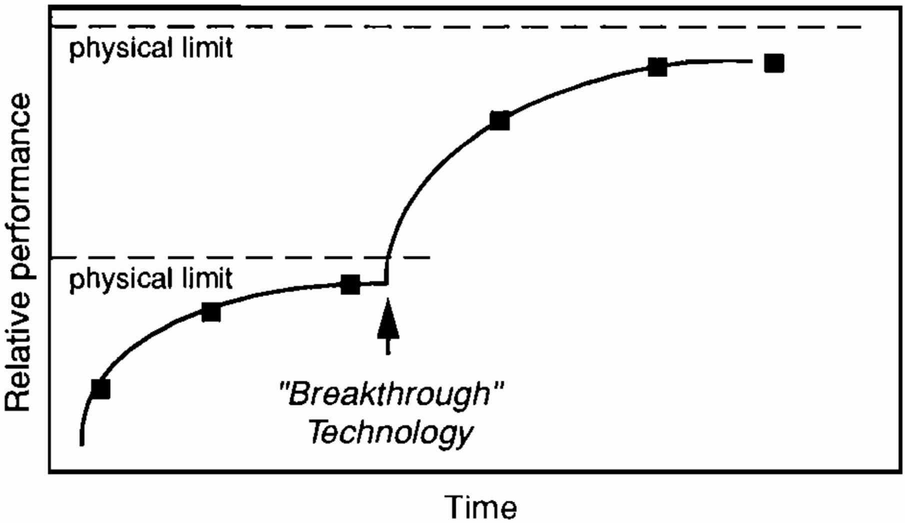
The Military Engineering Revolution: How Fast and How Far?

Technology has always had a major impact on military operations, at least as far back as the invention of gunpowder. The impact of technology became even greater, however, with two revolutions: the advent of mass production around the time of the American Civil War, and the concerted governmental support of scientific research during World War II.

At the outbreak of the Civil War, warfare was largely what it had been for the previous hundred years—as evidenced by the first Battle of Bull Run, which was reminiscent of Revolutionary War engagements. However, the manufacturing techniques often associated with Eli Whitney were at that point turned to warfare; rapid manufacture and assembly of complex weapons and ammunition allowed the large-scale employment of repeating rifles, revolvers, and ironclads, and the introduction of machine guns. In a few short years, General Grant's Richmond-Petersburg campaign demonstrated an operation of a new type, in which mass technology was a "meat grinder" that slowly but surely ground the Confederacy into oblivion.

This "meat grinder" changed little through World War I, but science again transformed warfare in World War II, mainly through the concerted efforts of both the U.S. and German governments to win the war with new technology. Technology transformed warfare in a brief period with the blitzkrieg, carrier aircraft fighting battles in which the fleets never saw each other, and the atomic bomb. All the basic types of weapons that would be in place a half-century later in Desert Storm were already employed by the military: jet aircraft, cruise and ballistic missiles, aircraft carriers, fleet (attack) submarines, and nuclear weapons. The only significant armament in use today that was not used in World War II involved space, stealth, and the mating of nuclear power and missiles with submarines.

With the basic weaponry in place by the end of World War II, the ensuing arms race between East and West was at first a struggle of engineering rather than science. Weapons became better, but only in a few cases did they change dramatically, and even then the changes derived from old technologies. In case after case, the arms spiral produced new generations of weapons that were significantly more complex and expensive yet offered new capabilities that were less than commensurate with their cost. This pattern is normal for engineering new technologies. As shown in figure 1, a new technology when introduced has marked advantages over the old but is still far from optimum. Refinement



Increasing Effectiveness of New Technology as a Function of Time

Figure 1

Squares represent new generations of platforms or weapons.

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of engineering rapidly increases the performance of the new system. However, all technology is ultimately limited by some physical law; while performance improves in successive generations of hardware, the rate of increase slows as the technology approaches its physical limit. If we examine several of today's systems, we can see that they are currently approaching, or have already reached, many such boundaries and may be difficult to improve in the future.

Limits on Range. The size of the tactical battlefield has increased continually throughout history. From World War II to the Persian Gulf, the distance from which a tactical commander can destroy a target increased from that which a single aircraft can fly, to one that embraces the entire globe. An intercontinental ballistic missile can target a site anywhere in the world; today's ICBMs carry only nuclear weapons, but that is a doctrinal choice, not a technological one. A B-52 can take off in the continental United States, drop its bombs in Kuwait, and land in Diego Garcia, half a world away. The president can control predeployed forces worldwide and, as Jimmy Carter showed, command a helicopter raid on Tehran from the White House.

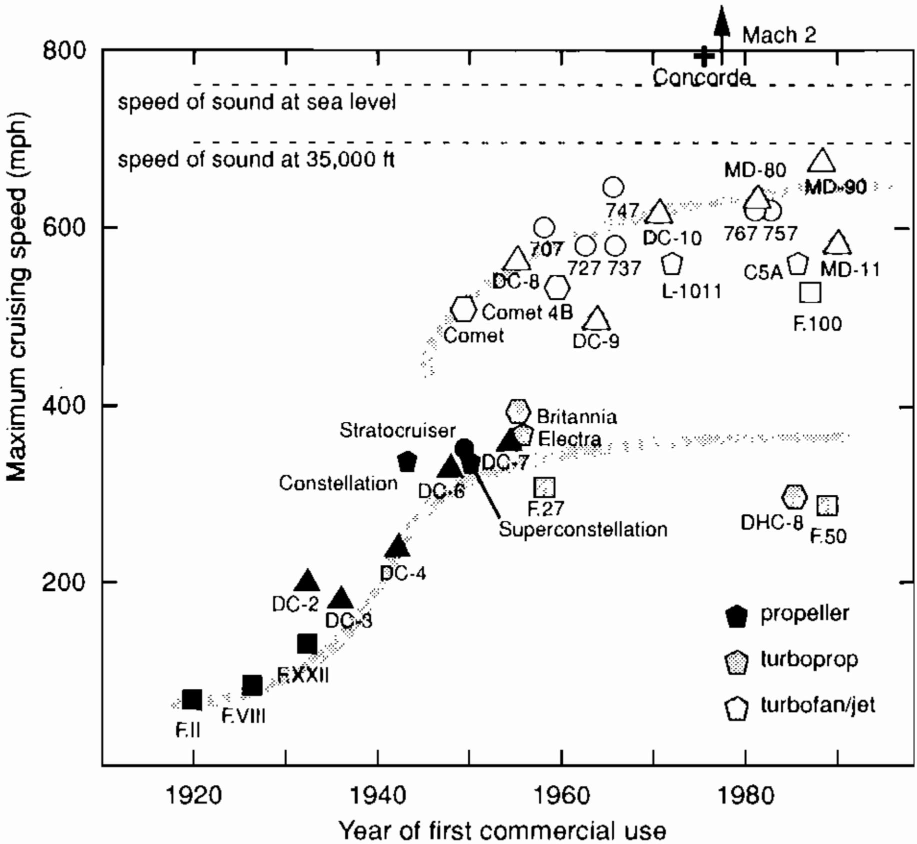
The current limit on the tactical range of military forces is in fact "the ends of the earth." In short, it is unlikely that the range of tactical forces will increase in the foreseeable future—the entire globe is already the battlefield.

Limits on Speed. Time is the other major factor in increasing combat capability. For a tactical commander, this translates to: "How fast can I get people or ordnance on target?" Therefore, tactical capability depends on the "speed limits" of hardware.

In the past, we could always think of increasing tactical capability by increasing the speed of the platform or weapon. Now we have to rethink our developmental concepts, because in virtually every case the latest platforms and weapons already approach "speed limits" that would require defeating physical law to exceed. Examining air, sea, and land platforms individually, we can see that there are both absolute limits imposed by the laws of physics and de facto limits imposed by cost-gain tradeoffs within current scientific knowledge. It is also apparent that though in many cases "revolutionary new" systems are under development to bypass the speed limit, they have remained "new" for many years, because they are too costly or inefficient to gain widespread use.

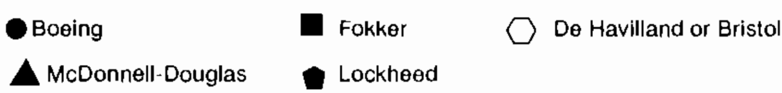
Transport Aircraft Speed Limit: The Speed of Sound. In atmospheric flight the major speed limit is mach 1.0, the speed of sound. To exceed this limit requires a significant increase in airframe strength and fuel consumption, which limits payload. Airframe strength depends on the chemical bonding of the molecules in its fabric; fuel efficiency depends both on chemical bonding strengths at high temperatures in engine components and on the energy density stored in the chemical bonds in the fuel. Since wing loading depends both on the strength of wing components and on the physical limit of atmospheric lift, any extra weight that goes into airframe or fuel is weight that cannot be carried as payload. Therefore, transport aircraft effectiveness is a complex tradeoff dependent on the chemical bonding strengths and energy densities of aircraft materials.

A detailed look at the increase in commercial transport aircraft cruising speeds since 1920 indicates that there have been speed limits on both propeller-driven and jet airliners. As shown in figure 2, the maximum cruising speed of propeller aircraft increased rapidly from under 100 mph in 1920 to almost 350 mph in 1953.[1] Even with the introduction of the turboprop engine, the maximum cruising speed of propeller-driven aircraft has not increased in the last forty years. This is probably due to a de facto limit at the optimum tradeoff between maximum propeller thrust at low altitudes and minimum airframe drag at high altitudes. With the introduction of jet airliners in the late 1940s a "breakthrough" curve for cruising speed appeared, the maximum increasing from 490 mph in



The Development of Maximum Cruising Speeds of Airliners
Figure 2

Propeller-driven aircraft are represented by black symbols, turboprop by grey, and jet or turbojet aircraft by white. Grey lines show general asymptotic trends.



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1949 (the De Havilland Comet) to 640 mph in 1966 (the Boeing 747). However, there has been no major increase in airliner speed since the 747 (i.e., over the last twenty-six years), as airliner speed approaches mach 1.

The single exception is the Concorde—an exception that proves the rule. The Concorde was a supersonic design introduced in 1976 that was advertised as "revolutionizing" the world of air transport. However, after almost two decades of service, the Concorde remains at best a curiosity, showing how "breaking the speed limit" is too costly to affect the commercial air market noticeably. The Supersonic Transport, or SST, project was abandoned for the same reason, and the Space Plane has never really lived up to its promise.

Cruise Missiles Speed Limit: The Speed of Sound. The speed limit for cruise missiles is the same as that for transport aircraft, and for the same reasons; actually, the constraints have been even more severe for cruise missiles, which are not able to carry large conventional warheads in small missile airframes. To date, the energy cost of flying large warheads at supersonic speeds has been too high. Several attempts at supersonic cruise missiles were tried in the late 1950s (the Mach 2 Regulus II and Hound Dog missiles), but like the Concorde, they were replaced by smaller subsonic missiles.[2] From the German V-1 through the Harpoon to the Tomahawk, the most effective cruise missiles have been small airframes that approach the speed of sound; but that speed is unlikely to be exceeded in the next decade.

Fighter Aircraft Dogfight Maneuvering Limit: Two g's. In World War I, fighter aircraft flew at 100 knots and turned at 35 degrees per second in dogfights; in World War II speed increased to 250 knots but at a turning rate of only 24 degrees per second. Jet aircraft in the Korean War flew at 500 knots in dogfights but turned only at 15 degrees per second, and in Vietnam speed increased to 600 knots but turning rate remained at 14 degrees per second. Even though dogfighting has gone from biplanes to jets, and current dogfights fill much larger volumes of sky than in World War I, turning rates have changed little since then. Turning radius in a dogfight depends on a complex set of factors related to the angle of bank during a turn; as the banking angle increases, lift decreases, and the plane loses altitude more rapidly or even stalls. Also, the ability of the pilot to aim or even orient himself decreases while turning at large gravity (or "g") forces.[3] Since all the above turning rates involve about two g's, the limit on dogfighting may be in the human ability to react to a rapidly changing tactical picture, while maintaining altitude, under stressful conditions.

The maximum emergency maneuvering speed of fighter aircraft has ultimately been limited by the physical limits of the human body. While the plane may be able to exceed nine g's, no one has designed a pilot who will not black out at those stresses.

Ballistic Missile Speed Limit: 18,000 mph. Ballistic missiles depend on gravity and air resistance to bring them to their targets. If a missile is boosted to greater than 18,000 mph, it will begin to orbit the earth. Therefore, whether the missile is a V-2, Scud, Pershing, or Trident, it will have an identical flight path for a given range, governed by the law of gravity. Recent attempts to "revolutionize" space warfare have depended on bypassing this speed limit by using low-mass "platforms" such as particle beams or lasers. These systems exploit the low momentum of individual particles or photons, which can be redirected much more effectively from earth orbit—but the low momentum itself of these phenomena may ultimately limit their effectiveness.

Sea Transport Speed Limits: 30 Knots and 15 Knots. The USS *Bainbridge* (DD 1) in 1901 had a maximum speed of twenty-nine knots, yet almost a century later the top speed of the USS *Spruance* (DD 963) is thirty-two knots.[4] While several classes of destroyers during the 1930s neared forty knots, overall there has been a de facto speed limit for shipping, one that was reached by 1900 when ships were still powered by reciprocating engines and coal. This limit is a function of the energy density that can be packed into a naval power plant and transmitted to the water through a propeller, and also of the energy cost—i.e., drag—involved in moving water molecules out of the way as a hull advances. Since the power-to-speed relationship for moving a hull through the water can be almost quadratic (i.e., doubling speed quadruples power required), the most efficient cruising speed for most ships on the ocean is twelve to fifteen knots, while maximum speed is somewhere near thirty knots (except for large combatants with nuclear propulsion). Therefore, since speed has not increased with the changeovers from coal to oil and from steam turbine to gas turbine, it is unlikely that any task force will cruise faster in the next decades.

Attempts to bypass this speed limit, as for others, have been in progress for decades but have remained "revolutionary" curiosities rather than viable alternatives. The hydrofoil, surface effect ship, Howard Hughes's legendary "Spruce Goose," and the wing-in-ground "Caspian Sea Monster" have all depended on making a ship into an aircraft—but aircraft must lift themselves as well as their payloads into the air, all at high energy cost.

Land Transport Speed Limit: "55 mph." The fastest secure method of conveying messages across the desert during Desert Storm was the motorcycle. As long as land vehicles roll and use conventional fuels it is unlikely that we will do better than a motorcycle. The American fifty-five-miles-per-hour speed limit reflects the fact that faster land transport is both energy-inefficient and, due to human reaction times, unsafe. Another factor, which comes into play in off-road transportation, is the effect on the human body; an off-road vehicle is limited to speeds at which its suspension can reduce vibrations enough that bones are not broken.

Attempts to defeat this land speed limit for troop transport have depended on making the land vehicle, in effect, a low-flying aircraft. Helicopters and surface effect ships can move people and equipment rapidly but are inevitably inefficient of energy because they *are* aircraft, not ground vehicles.

The End of the Engineering Revolution. The engineering advances of the arms race have ultimately led to a single result: huge increases in hardware cost and complexity for marginal increases in performance. The first generation following a "breakthrough" is significantly more capable than the last generation of the old technology (e.g., the nuclear submarine *Nautilus* versus a Foxtrot-class diesel boat). The next generation is also a marked improvement, much better than the opposition's first-generation model (e.g., *Permit* versus November-class nuclear attack submarines). Even though the opposition is always a generation behind, continued development lessens the absolute difference in performance so that the relative lead decreases (e.g., *Sturgeon* versus Victor classes, to *Los Angeles* vs. Victor III and then Akula-class attack submarines). Finally the next generation is so costly that its production becomes problematic (*Seawolf*).

One can look at the "cutting edge" of virtually every area of military weaponry and see that the hardware today pushes physical limits so closely that the next generation would require "redesigning" Newton's laws, chemical bonds, or the human body. In fact, hardware has not improved markedly since Vietnam, twenty years ago. Compare the speed, range, and maneuverability of Vietnam-era platforms with their Desert Storm equivalents: the nuclear aircraft carrier *Enterprise* with the *Nimitz*; *Sturgeon* nuclear attack submarines with *Los Angeles*; F-4 Phantom with F-14 Tomcat fighter aircraft; P-3A with P-3E Orion antisubmarine aircraft; the B-52 bomber with (still) the B-52, and with the F-117 stealth bomber; and the German Panther with the U.S. M1A1 tank.

Even when one looks at the weapons carried on these platforms, today's hardware is still not fundamentally better than that of World War II. The Mark 48 torpedo is not significantly faster than the Mark 16 steam weapon; the thirty-year-old Sidewinder missile is still the state of the art; the Tomahawk missile's only real hardware advantage over the V-1 "buzz bomb" is its range; 500-pound bombs still make holes about the same size as they did during World War II. The description of a terror bombardment with short-range missiles applies equally well to the German V-1 and V-2 bombardment of London as to the Iraqi Scud bombardment of Israel. By any comparison, the platforms employed in Desert Storm were not very different in their speed, range, maneuverability, and ability to inflict or absorb (non-nuclear) damage, from those that fought in Vietnam and, in most cases, not significantly better than those that fought in Korea.

Therefore, it appears that the "engineering" phase of the MTR is essentially over. Engineering technologies have pushed materials and human bodies so near their physical limits that new generations of weapons and platforms will be grossly more expensive, for marginal gain. No country today can afford the huge military budget required to produce and maintain a new generation of any weapon. Any country building up a military force must choose: one stealth aircraft or several Mirages? One *Seawolf* or several *Sturgeons*? Given that sort of choice, it is unlikely that any opponent in the year 2003 will have any platforms or weapons superior to current U.S. capabilities. The major question now will be: how many platforms comparable to *current* U.S. hardware can they afford?

The Military Sensor Revolution: Information Management

The weapon *systems* in Vietnam were superior to those in Korea, and they were better still during Desert Storm. By then, satellites could carry cameras, radar, or infrared sensors; target detection was no longer limited by range. Missiles could be detected virtually as they left their launch silos. Aircraft and ships could be counted as they sat on the runway or lay in their homeports. The major advances in military weaponry since Korea (at least since the USS *Nautilus*) have been in information systems. The ability to collect, process, and disseminate information has become the new revolution in military technology. This military information phenomenon has proceeded through two stages, which represent, respectively, the second and third phases of the MTR: the optimization of the individual platform, and then the coordination of many.

The first information revolution—the "sensor revolution"—in the U.S. and Nato militaries (and to some extent in the Soviet forces) occurred during the 1960s and 1970s, with the computerization of individual platforms and weapon systems. Sensors became more sensitive through computer image enhancement, data-averaging techniques, and new displays. Weapons became more potent with computerization of control systems; tactical missiles became truly guidable over the horizon. An individual platform could now detect, track, and destroy an individual ship or aircraft well beyond visual range, with long-range missiles such as the Harpoon, Talos, or Phoenix, or long-range guidable torpedoes such as the Mark 48. The overall result was that individual platforms became much more potent by virtue of their increased information-gathering ability with long-range guidable weapons to match it.

However, this revolution too had a physical limit: the ability of an individual human brain to process the enormous quantities of information that were now available. A platform with new sensors that could "see" five times as far as before could thereby cover twenty-five times as much ocean or airspace and detect twenty-five times as many contacts. Often these "contacts" were image-enhanced blips or lines on a radar or sonar display, and a major tactical decision in any encounter was determining which were friends, foes, or neutrals. The battle, in the age of "information overload," was now won by the platform that could sort through the data most quickly and then fire the first salvo. Major military disasters—the Beirut Marine barracks, the USS *Stark*, and the USS *Vincennes*—were rooted in inability to discriminate friend from foe quickly enough.

In response to this data overload, human sensor evaluators became pre-eminent, and tactical education at all levels of command became a top priority. A new billet, "information manager," was added to most command structures, either explicitly or by changing the major duties of a senior officer.

• Starting with the F-4, new fighter aircraft had a second seat for a sensor operator, because one person could no longer both fly the plane and deal with the flood of tactical information.

• P-3 Tactical Coordinators collated sensor operators' inputs and "flew" for the pilots once in the operating areas.

• Surface ship commanding officers (COs) changed their battle station from the bridge to the Central Information Coordination Center, since battles were now won or lost by sensors.

• Junior officers attended the Surface Warfare Officer Department Head Course, the Submarine Officers Advanced Course, or Top Gun School prior to assuming responsibility for combat control teams. Sensor operators pursued almost continuous schooling whenever they were in port.

The real revolution of this phase of the MTR in the U.S. military was in the better combat efficiency that arose from the ability of individual platforms to collect, collate, and react to huge quantities of sensor data quickly and effectively, and rapidly launch highly sophisticated and programmable ("smart") weapons. This ability was due mainly to education throughout the chain of command and also to more broadly distributed responsibility in combat situations. Petty officers who used to collect sensor data now had computers to collect it and were themselves now first-level evaluators, doing junior officer jobs. Junior officers were now looking over the petty officers' shoulders, sorting through the glut of information and making tactical decisions as to who was friend or foe and what represented the major threat—doing senior officer jobs. Petty officers or junior officers made, for each mission, fundamental decisions using tactical doctrine that was already preset into complex weapons. Someone in the tactical chain, either an aircraft's naval flight officer or Tactical Coordinator, or a warship's executive officer, assumed the role of information manager, assimilating the rapidly changing tactical picture to advise the pilot or CO. Indeed, pilots and COs had all they could do to respond quickly enough to the tactical picture, even depending almost completely on the critical evaluations of their operators, junior officers, and information managers.

The military sensor revolution is almost complete in the U.S. military, where continuous education is a way of life. Additionally, its highly motivated professional volunteer force has the intellectual ability to be able to "fleet up," so that petty officers and junior officers in the tactical chain of command do the jobs that, only twenty years ago, their superiors did. This professionalism and training is also evident, for instance, in the British and Israeli armed forces.

However, this revolution never started in the Soviet forces or those of any other non-democratic nations, because the heart of this revolution is education—and education is very dangerous in a totalitarian military. For the sensor revolution to work, all members of the military force must be educated not only in the capabilities of their own platforms and their opponent's platforms, sensors, and weapons but also in analysis, in taking responsibility, and in making decisions. A highly educated, analytical, thinking military is the most likely source of a coup in any totalitarian regime, so any totalitarian chain of command plays with fire if it teaches disseminated responsibility within its ranks. Therefore, the hallmark of the former Soviet military—a tightly controlled and rigid chain of command—is also characteristic of all Soviet-trained forces worldwide. This sensor revolution is, therefore, essentially over; the Americans, British, Germans, Israelis, and some others are already past it, and totalitarian forces are reluctant even to allow it to start.

The Military Communication Revolution: The Total Integrated Force

The other phase of the information phenomenon—that of communication—began in the late 1970s with the advent of new command, control, communications, and intelligence (C^3I) systems to begin to handle the flood of data cooperatively; they led in turn to the concept of "total force integration." Sensor systems could now collect a huge amount of data, even over the horizon, and satellite systems could gather data worldwide. However, as long as sensor data was used on an individual-platform basis, the problem of the USS *Vincennes* would remain—we could detect, track, and shoot very rapidly but often did not know whom or what we were shooting at. The answer was total force integration, depending on instant communications to pass sensor, intelligence, tracking, fire control, and command information among interconnected forces.

The 1970s to Desert Storm. In the Navy, the first signs of such a need came in the early 1970s, when Soviet nuclear attack submarines (SSNs) became so quiet that no single unit could track them. The only answer was a team effort, and new integrated tactics were developed to hunt a very quiet adversary. Satellite and fixed sea-bottom listening systems could give first warning of Soviet submarine sailings, which could then be passed to maritime patrol aviation so that it could attempt open-ocean tracking. Early warning from these sources could then alert the screen of a carrier battle group (CVBG) to the possible Soviet SSN. The CVBG distant screen was itself an SSN acting in a direct-support role, since a submarine provides the best anti-SSN detection capability. Again, the direct-support SSN usually made detections at long range; it would then vector in carrier-based aircraft or screening frigates, which are superior localizing and attack platforms. The key to Soviet SSN interdiction, then, was a coordinated air-sea-SSN-intelligence effort dependent on C^3I. Other than the addition of satellite communications, today's C^3I hardware itself is hardly superior to that in Vietnam; again, the major revolution was in computerization and standardization to accelerate data handling, coupled with massive training efforts in all communities involved. During the 1980s, updating C^3I systems and constant total-force training revolutionized all U.S. armed services.

In Desert Storm, the effectiveness of the military communications revolution was the real key to the swift victory. The interchangeability and cohesion of forces, on a minute-by-minute basis and on such a large scale, was unprecedented. Previous invasions such as that of Normandy involved as many troops, but the forces then were "programmed" beforehand; having launched them, the generals watched while individual units fought. In Desert Storm, instantaneous communication coupled with precise navigation and remote sensors operated by professional coordinated forces ushered in a new era in warfare:

- Laser-guided bombing of individual buildings or bridges required satellite reconnaissance data passed from rear-area analysts to air force and naval bomber and electronic strike forces, themselves coordinated by airborne platforms (Awacs) and brought to their targets by precision navigation.
- B-52 bombers were vectored from bases in the United States to targets in Kuwait and then to landing fields in Diego Garcia.
- The swift end-run on the ground was, again, a C^3I miracle, in which multinational army and Marine ground forces coordinated with army, air force, and naval tactical air support.
- The reputation of the total integrated force outlived Desert Storm. When Yasser Arafat's plane crashed in the desert in April 1992, officials of the Palestine Liberation Organization approached the United States to use satellites to find the wreckage and vector-in rescuers.

Perhaps the largest change brought about by the integration afforded by the communications revolution has been a much "flatter" command structure (i.e., one with fewer echelons) in the U.S. military, accompanied by a much more dispersed decision-making structure. Developments there have been caused by several factors. First, there is so much information to be analyzed at every level that all members need to know the jobs of the people above and below in the command structure if they are to evaluate properly their inputs or commands. Similarly, in a given tactical situation any individual in the chain may be the weak link with respect to "information overload"; the structure must be flexible enough for the people above and below to handle a failure. A breakdown without backup can cause another *Stark* disaster. Finally, passing information up and down the line is now so efficient compared with the past that a commander can essentially call up by computer all the information available to anyone below in the chain of command.

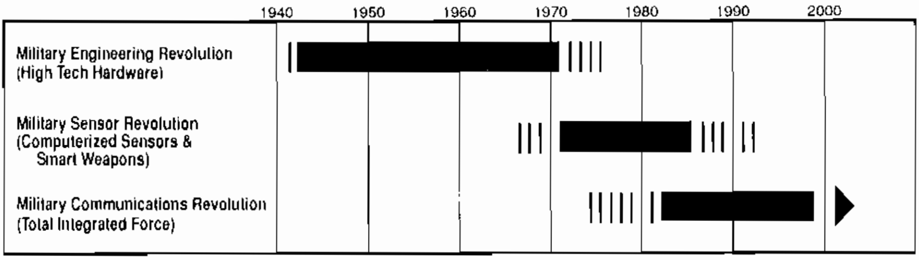
End-Points and Challenges. Notwithstanding, in this MTR phase, as in the others, there are boundaries. Some are matters of physical law; in fact, as in the "engineering revolution," speed limits exist. A basic one is the communication speed limit: the speed of light, the ultimate speed limit in the universe. This limit has already come into play in the design of hardware for communications equipment and computers. All communications equipment that use electromagnetic radiation can pass information at the speed of light. This has already become a problem in controlling deep-space probes such as Voyager, where there is a time lag of many seconds in transmission. However, no attempts to speed transmission have been made, because, to our current knowledge, no physical system can exceed the speed of light. Some new-generation computers are so fast that they are impeded by the measurable time it takes electrons to cross a microchip, even near the speed of light. "Parallel processing" is the engineering approach to bypassing the light-speed boundary, by computing along several "short" pathways simultaneously rather than along a single "long" one.

There is also a decision-making speed limit: the speed of thought. The operational result of technological advances is that the time required to engage a target is now limited by the speed at which the human brain can make a tactical decision. As both the USS *Stark* and *Vincennes* incidents indicated, in the age of "information overload" the slowest component in the tactical chain is the human being making the decision whether or not to shoot. Therefore, as we have seen, any technological advances that increase the volume or rate of information collection will only further burden a commander's decision-making ability.

Indeed, the biggest challenge of the military communication revolution is to decide who is the best person to make each decision. In the past, decisions were made at a given level because only that level had the information to do so, but now everyone in the chain of command has access to that information. Now the Commander in Chief can decide to drive helicopters in Iran from the White House, or to sleep while Tripoli is bombed. The commander now has to know when to give an order and when to hang up the telephone and let the organization do its job. In a sense, General Norman Schwartzkopf's brilliance in Desert Storm was in knowing when to be quiet.

Prospects. The military communications revolution hit its stride in Desert Storm. There were, certainly, many problems in interoperability. An example was the incompatibility of the Navy's air strike communication system with that of Army and Air Force; computer disks had to be flown daily from Saudi Arabia to the CVBGs in the Persian Gulf. For U.S. and Nato forces, therefore, the communications phase of the MTR is now at a stage at which the lessons learned in Desert Storm must be applied to improve force compatibility, interoperability, and coordination. The increasing portability of precision navigation devices, satellite communications systems, and sensors portends continued change in the capabilities of U.S. forces, which again must be coupled with concentrated and continual training and improved decision-making doctrine.

This phase of the MTR may, like the sensor phase, totally bypass totalitarian military forces. The Soviets tried to accomplish this coordination with intensive communications updating and training, but force integration did not work effectively without a basis of individual platforms equipped and trained for the earlier sensor revolution. Integrated forces need to know even more and must



Phases of the Military Technical Revolution

Figure 3

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make more independent decisions than those that work singly with smart weapons. The extra dimension is that integrated forces must continually pass and receive sensor, targeting, and command data, all of which must be evaluated both upon transmission and reception. Computers can help present the data, but as always, evaluation and decision-making—now required with increased frequency in proportion to the capacity and number of communications channels—must be done by an operator or officer, most effectively at the lowest possible level. The need for education in the chain of command is multiplied accordingly, and with it the problems a totalitarian force faces trying to enter the military communications revolution. Not only must all members of the force be able to think independently, but they must also know how to communicate and work with the rest of the force. A smart, educated, coordinated military team in a totalitarian regime is truly an oxymoron.

Though we are today still in the midst of a Military Technical Revolution (see figure 3), the character of that revolution is continually changing; the revolution has evolved from one of high-technology hardware to one of computerized sensors and smart weapons, and now to one of communications. Characteristics of the MTR over the next decade will probably follow patterns started in World War II. First, high-technology hardware has reached limits imposed by physical laws and by stresses on the human body. It is unlikely that any nation will develop new generations of platforms or weapons better than the current U.S. inventory. However, proliferation of twenty-year-old technology will mean that current American hardware will be only marginally better than that available on the open market. Secondly, the proliferation of smart weapons and computerized sensors will itself be difficult to control; the same technology that can make Nintendo games can make smart weapons. However, the level of education required at all levels of a force to utilize them effectively is well in the future for most totalitarian regimes and Third World countries. Finally, proliferation of new C^3I systems will also be difficult to control, since satellite navigation and communications devices are available for private aircraft and pleasure boats. However, a totally integrated force requires an education level and commitment to individual responsibility attainable currently only in such democracies as the United States, Great Britain, Israel, Germany, and Japan.

Notes

1. Compiled from J.L. Naylor and E. Ower, *Aviation: Its Technical Development* (Philadelphia: Dufour Editions, 1965); P.M. Bowers, *Boeing Aircraft Since 1916* (Annapolis, Md.: Naval Institute Press, 1989); R.J. Francillon, *Lockheed Aircraft Since 1913* (Annapolis, Md.: Naval Institute Press, 1987); R.J. Francillon, *McDonnell Douglas Aircraft Since 1920* (Annapolis, Md.: Naval Institute Press, 1988); and *Jane's All the World's Aircraft 1988–1989* (Coulsdon, Surrey, U.K.: Jane's Information Group, 1988).

2. K.P. Werrell, *The Evolution of the Cruise Missile* (Maxwell AFB, Ala.: Air Univ. Press, 1985), pp. 113–129.

3. M. Spick, *Fighter Pilot Tactics: The Techniques of Daylight Air Combat* (New York: Stein and Day, 1983), pp. 56–60.

4. Naval History Division, *Destroyers in the United States Navy* (Washington: U.S. Govt. Print. Off., 1962), pp. 7–39; and Norman Friedman, *U.S. Destroyers: An Illustrated Design History* (Annapolis, Md.: Naval Institute Press, 1982), pp. 392–422.

Ψ

We were nearly one of the last to realize that in the age of information science the most expensive asset is knowledge.

Mikhail Gorbachev, 1989

The American mind is slow to grasp an idea to which it is not accustomed beforehand.

The Comte de Paris,
with the Federal army during
the Peninsula campaign, 1862