

**THE TECHNOLOGICAL FIX:
WEAPONS AND THE COST OF WAR**

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FOREWORD

In April 1995, the Army War College's Strategic Studies Institute held its annual Strategy Conference. This year's theme was "Strategy During the Lean Years: Learning From the Past and the Present."

Professor Alex Roland, Professor of History at Duke University and a Visiting Professor at the Dibner Institute for the History of Science and Technology, presented this paper as a part of a panel examining "Technology and Fiscal Constraints." He makes the point that historically, technology and war have operated together. Indirectly, any military institute operates within its technology context. The Army of today is, for instance, in a period of technological transition from an Industrial Age army to an Information Age army. Directly, armies either use technology to their advantage or seek ways of lessening the impact of the other side's technology.

A tremendous faith in technology is an abiding American characteristic. The idea that technology can be leveraged to make up for shortfalls in numbers—be those numbers of troops, weapons, or dollars—is as appealing as it is traditional. In the following pages, Dr. Roland examines three instances in which states turned to technology to drive military strategy: chariot warfare in the second millennium B.C., Greek fire in the first millennium A.D., and submarine warfare in the early 19th century. These cases, distinct in time, provide a fresh perspective on issues facing the Army as it molds itself into Force XXI.

The study of the past is our most reliable guide to the future. For that reason, I commend to you the following monograph.

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BIOGRAPHICAL SKETCH OF THE AUTHOR

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The United States has always had its defense on the cheap. The main reasons, of course, are the oceans that isolate us from most of the world and the neighbors we happen to enjoy to the north and south. To say that one shares the longest undefended border in the world speaks volumes about the need for an expensive military establishment. Even during the Cold War when the Soviet Union was spending an estimated 18 percent of gross domestic product (GDP) on the military, the United States spent only 7 percent.¹ During the years of peak crisis in the 1950s, the figure averaged 12 percent, but thereafter it fell well below that level. Our greatest rate of national expenditure in the 20th century came in World War II, when spending rose as high as 39.2 percent of GDP and 89.5 percent of the federal budget. Before and after such crises, however, the United States has spent comparatively little. We were spending 1.7 percent of GDP on the military in 1940; we were back down to 3.7 percent by 1948.

Our defense budget now hovers around 4 percent of GDP.² This is lean, indeed penurious, as an earlier incarnation of this conference labeled it. We do not have reliable figures for comparison with other countries historically, but it might be fair to estimate that states have expended 5 to 10 percent of national income on the military in time of peace, considerably more in time of war. England, for example, averaged 10 to 15 percent in the 18th century, when it fought five major wars. Austria spent a like amount. Prussia, with less wealth but comparable military demands, no doubt spent a much higher percentage.³

One reason that the United States could win the Cold War while spending relatively less than its adversary was that we bought quality instead of quantity. If the Soviet Union had more soldiers and more tanks, the United States had better soldiers and better tanks. Part of this formula entails superior technology. Of course we would want superior technology in any event, for it is a force multiplier and it saves lives--always an important consideration in a democracy. But technology has a special appeal to Americans, who seem to have an abiding faith in its power.⁴

Our national optimism about the technological fix suggests to

us that technology may once again be the solution to our problems. If we are indeed in a period of lean defense budgets, can we not leverage technology still more to give ourselves the security we need at a bargain basement price? Can't dual-use technologies makes us competitive in the world marketplace and simultaneously secure from our enemies? Can't we, in the cliched icon of the Cold War, get more bang for our buck?

Well, maybe. I want to shed some light on that question by exploring it in some different historical contexts. From my own research I have selected three instances in which states have found their military strategy driven by the reigning technologies of war. These are chariots in the second millennium B.C., Greek fire in the 8th and 9th centuries A.D., and submarine warfare in the early 19th century. None of these case studies will tell us what technology can or cannot do for the United States at the end of the Cold War. They can, however, give us some perspective on our problem and perhaps suggest a few cautionary notes about our expectations.

Before beginning, it might be well to remind ourselves that some of these issues are timeless and some are peculiar to the modern age. First, war has always been expensive. At least in all the civilizations we know of boasting specialization of labor, the sheer manpower necessary to engage in organized violence imposes a significant burden on the state, both in direct subsistence and in opportunity costs.⁵ Soldiers and sailors, after all, might be better employed producing food or widgets or other services.

The costs of war have affected states differentially over history. Predator states that choose war as an instrument of policy have had to make war pay, either by taking booty or by exacting tribute. Nonaggressive states have sought defense on the cheap, usually in the form of fortifications and citizen soldiers. An element of what we would now call dual use attaches to both. Fortifications were dual-use technologies in the sense that they drew upon corvee labor during down-time in the agricultural season to build monumental architecture that both bonded the citizen to the state and provided security for the society's wealth. Standing armies served dual use in that they fought the state's external enemies while also providing a force for internal security.

A peculiarly modern aspect of the economy of war is that

governments in the last century have taken on many roles unknown to the ancient world. As late as the 16th century, Machiavelli could advise Lorenzo de' Medici that war was the first business of the prince.⁶ Today's prince may well believe that business is the first business of the state, followed perhaps by social welfare, the environment, public utilities, and the like. In times of military emergency, princes still give war the attention it deserves. Otherwise, however, it is just one of the components of what is now called national security. As we look at the calculus of funding war in earlier times, it is well to remember that the equations were simpler if nonetheless burdensome.

Chariots.

A chariot revolution swept the Levant in the 18th century B.C. A technology that had been evolving for at least 500 years suddenly achieved a take off that propelled it in short order to dominance on the battlefield. For half a millennium, this new weapon was to reign over the battlefields of the Near East with a dominion analogous to that of the mounted knight in the Middle Ages and the tank in the mid-20th century.

I use the term revolution advisedly. George Roux has used it before me to describe this transformation of ancient warfare.⁷ William McNeill called the chariot "the supreme arbiter of the battlefield in all Eurasia," "the new superweapon, "the master weapon of the age."⁸ Albrecht Goetze said of these ancient vehicles that when they were "used in massed assault, no infantry could possibly withstand them."⁹ O. R. Gurney, who dates the appearance of the war chariot around 1600 B.C.E., says "it created a revolution in the nature of warfare: henceforward speed was to be the determining factor in the battle."¹⁰

There were three to five components of the revolution. First, the ox or ass that had pulled the clumsy Sumerian war wagon of the third millennium B.C. was replaced by the horse. Second, a light chariot evolved boasting standard features that transcended regional variations—two spoked wheels, a central, curved draft pole harnessing two to four horses, a fixed axle set beneath the rear of the rider's box, and a railing to support the driver and passengers, who numbered from one to three.¹¹

Third, the chariot seems to have been paired regularly with

the composite bow. Laminating animal sinew and bone on a wooden frame greatly increased the power of the bow and furthermore allowed it to be shorter. The shortened bow was ideal for firing over the walls of the chariot.¹² With this innovation, the chariot became a potent mobile firing platform, capable of approaching enemy formations at great speed, dispensing a deadly barrage of arrows, and, say some analysts, retiring before the enemy could return fire effectively. Most students of chariot warfare in the second millennium B.C.E. believe this was the primary use of the chariot, complemented by pursuit of a fleeing enemy. These scholars doubt that the chariot was capable of "shock," of plunging directly through the enemy line, like the modern tank to which the chariot is often compared. The evidence on this issue, however, is mixed.¹³

The last two components of the chariot revolution are less clear. Some scholars believe that field fortifications were essential to protect the chariot on campaign. And some believe that layered body armor became more widely used in the period. They guess that the chariot crew needed such armor to protect themselves from enemy missile fire as they approached the enemy's lines. This theory may or may not be reconcilable with the notion that chariots used as missile platforms were comparatively immune to enemy counterfire.¹⁴

The chariot was used in several ways.¹⁵ In the Iliad we see the most familiar use—as a jeep to carry the aristocrat to the place of battle, where he dismounts and fights on foot. More often in the Levant, the chariot probably served as a mobile firing platform, carrying archers in a caracole before the enemy infantry formation. Another likely use was to carry archers in mobile assaults on the flanks and rear of enemy formations. Finally, of course, the chariot might have been used in frontal, shock attacks. Though most scholars doubt this possibility, the evidence is mixed. We certainly know that Alexander the Great and Caesar both encountered frontal attacks with chariots centuries later;¹⁶ there is no conclusive reason to believe they were not employed in the second millennium.

Physically and psychologically, the chariot seems to have been "decisive".¹⁷ For 500 years it dominated the battlefields of the Near East. States that wanted to be competitive had to take up this arm. Huge chariot corps developed, often manned by a special

class of warriors. The *maryannu*, or "chariot warrior," was apparently an international mercenary, though perhaps initially of Mittani origins.¹⁸ Among such specialists, standardized tactics and strategy seem to have evolved, even though it is difficult now to know exactly what they were.

As was true of the warrior *class* in Medieval Europe to which the *maryannu* bear strong resemblance, the horses and related equipment of their weapon system demanded land and money. The states of the Levant that gave over to chariot warfare in the period tended to organize themselves feudally, mostly to support the huge chariot corps required to be competitive in warfare. It was not unusual for an army to appear in the field with hundreds, even thousands, of chariots, each one requiring several crew, two or more horses in traction and a comparable number in reserve, and a huge logistics train.¹⁹ Faced with such expense, states either hired out mercenaries for the duration of an emergency, or they established some socio-political arrangement, such as feudalism, to support the charioteers.²⁰ The first alternative came at a high price and bought but fleeting loyalty to the state. The second alternative introduced in the state a warrior class that could demand or take political power. As with many new military technologies, the chariot raised the costs and the stakes in war.

Furthermore, chariotry placed logistic demands on the state for which the only precedent was siege warfare. Hitherto armies had been limited in range and capability only by the endurance of the men and the amount of food that they could take or scavenge on campaign. Even if they took a siege train, as states going back to ancient Sumer seem to have done, most of the engines were built on site from local resources, mostly trees. Not so chariot warfare. The vehicles themselves required specialized manufactories and often imported materials. Skilled workers were needed for the various components—smiths, for example, for the indispensable metal fittings. The composite bows required specialized arsenals of their own. The horses required stables and pasturage. And when the army hit the road, some field version of all this had to accompany it. Egyptian depictions of the famed battle of Kadesh (1294 B.C.) show workers repairing chariots on campaign. Written sources from the period speak of what the field arsenals would be called upon to do, from repairing spokes to straightening poles.²¹

This fabulous infrastructure collapsed almost as quickly as it had appeared. Around 1200 B.C.E., in the violent upheaval known as "the Catastrophe," the chariot was overthrown. In its place emerged a greater reliance on infantry and cavalry. The darkness and mystery that surround the Catastrophe engulf the eclipse of the chariot as well. Both have attracted multiple explanations; neither has achieved historical consensus.

The Catastrophe was a violent, mass movement of IndoEuropeans in the 13th century B.C.E. It appears that the incursion of barbarian tribes, perhaps Illyrians, in the Balkans set off a cascade of forced flight and resultant invasion by refugees. The chain effect echoed down the Aegean and the eastern Mediterranean, culminating in the invasion of Egypt by the so-called "Sea Peoples" and the arrival of the Philistines, from whom Palestine would take its name. Ramses III, the last great pharaoh, finally arrested the onslaught.²²

Why the chariot would disappear at just this time has puzzled historians. William McNeill has argued that warriors invading the Near Eastern plains from the mountains of Anatolia brought with them iron weapons which were better suited to fighting chariots.²³ The most recent analysis of this problem, and the most thorough, posits that the invaders from the Steppe brought with them new tactics. We know from Alexander and Caesar that trained, disciplined troops can readily defeat chariots if they are prepared, resolved, and well led. It is entirely possible that the chariot dominated the Levant for half a millennium because people thought it was invincible. Tough warriors from the steppe who did not know enough to be frightened might have broken the spell and brought down a psychological icon.²⁴

A third possibility, the one most pertinent to this conference, is simply that the chariot fell of its own weight. Or rather the chariot complex fell of its own weight. An arms race of 500 years' duration had built up a fabulously expensive infrastructure and a technological stagnation that suffocated the state and precluded innovation. As long as the chariot seemed to be the *sine qua non* of military preparedness, states no doubt perceived that they had no choice but to pay the enormous upkeep and to maintain what Mahan would have called "fleets in being," even in time of peace. After all, in the event of emergency, there would be inadequate time to train and equip a chariot corps

competitive with the *maryannu*. As soon as this oppressive system showed the least vulnerability to new weapons or new tactics, it was bound to collapse with great speed. In other words, the economic pressure of maintaining an expensive military establishment can force dramatic and rapid shift to cheaper systems once the old formula is challenged. We don't know enough about the economics of ancient states to make any confident judgments, but it is even possible that economic pressure by itself precipitated the collapse that historians have subsequently attributed to the introduction of new weapons and tactics.

Greek Fire.

Almost two millennium after the collapse of chariotry in the Levant, another pivotal technology appeared dramatically in the region and soon became the dominant weapon of its age. Greek fire, as it came to be called many years later by Western Crusaders, was reportedly carried to Constantinople by Kallinikos, a Syrian engineer, around 678 A.D.²⁵ At that time, the legendary Moslem caliph Mu'awiya was in the 5th year of a naval siege of the Byzantine capital. The Moslems could not breach the sea walls of the city, nor could they starve it into submission, for they controlled neither the land access nor the northern water approaches to the city protected by the Golden Horn. It was a stalemate.

Kallinikos broke the stalemate with an incendiary device analogous to napalm. "Sea fire," as the Byzantines called it, or "Roman fire," as the Moslems called it, was a burning fluid that could be shot from the nozzles of pressure cannons mounted in the bows of Byzantine naval vessels. Like some of the other incendiary weapons known in the Near East for centuries, Greek fire stuck to what it touched and burned under water. Once doused with this stream of fire, ships and men were doomed to horrible extinction. Kallinikos fire drove off the Moslems in 678 and inflicted psychological scars that were to shape naval warfare in the eastern Mediterranean for centuries to come.

In the ensuing years, the incendiary seems to have been improved still further, apparently in a conscious research and development program.²⁶ The weapon came to be mounted on a specially designed ship, heated and pressurized below decks to increase its range and volatility, pumped to a nozzle in the bow, and sprayed

with great force onto enemy vessels.²⁷ In this improved form it drove off a second and larger Moslem assault on Constantinople in 717-718. The Moslems did not return.

Like the chariot, Greek fire proved to be a super weapon of sorts. Against it there was no known defense in the ancient world. Because of its power and its mythical role in saving Constantinople from the infidel, Greek fire was treated as a state secret. As best we know, it was the first truly secret military technology, the only one to appear in the ancient, classical, or medieval worlds.²⁸ The Byzantines maintained the secret in very modern fashion. They used the Coca Cola method of bottling the secret formula in a single, central arsenal where the emperor could personally oversee access to it. And they used compartmentalization to ensure that no individuals who might fall into enemy hands knew more than a part of the entire system. Some knew how to make the mixture; some knew how to design and construct the special ships, some knew how to make the cauldrons used to heat and pressurize the fluid; some knew how to operate the system in combat. No one but the emperor and reportedly one other family knew the whole system—and they never left the capital.²⁹

One would expect that monopolization of the dominant weapon of the age would have ensured the security of the Byzantine empire. Instead, the Byzantines suffered repeated naval defeats around the Aegean and the Mediterranean. In 698, a Byzantine fleet dispatched to retake Carthage from the Moslems proved unequal to the task. The Arabs took Crete in 826 and Sicily in 827. The battle of Thasos in 829 witnessed the complete destruction of the Byzantine fleet by corsairs operating out of Crete.³⁰

The reason for these incongruous defeats seems to be that the Byzantines reserved Greek fire for the defense of the capital. Constantinople was the heart of an empire built on trade—the financial, religious, and political hub of an entity that otherwise had no more cohesion than the eastern half of the Roman Empire from which it sprung. As Constantinople went, so went the Byzantine empire.³¹ When the capital was secure and prosperous, the emperor had the focus and finances to pursue the unique brand of politics and international relations that became known as Byzantine. They would fight when they had to, and often did. But they were equally likely to achieve their political and diplomatic

objectives by bribery, tribute, and outright purchase. The Byzantine empire, in short, ran on money, and Constantinople was the great market.

For two reasons, then, successive emperors reserved Greek fire for the defense of Constantinople. First, they wanted to husband this precious weapon for the only defense that really mattered. Provinces and outposts could fall to Moslems and other enemies; so long as the capital stood, the empire stood. The Byzantines actually maintained not one but three navies.³² One set of navies was raised by the regional themes at their own expense for local defense. A second imperial navy was funded by the capital for command of the major sea routes over which Byzantine commerce flowed—in the Black Sea, the Aegean, the Mediterranean. And a third fleet, under direct control of the emperor, was reserved for the immediate defense of the capital. Only to the last was Greek fire entrusted.

Part of the reason for this was no doubt economic. All maritime powers know that navies are fabulously expensive to build and maintain. States that have experienced naval success have usually done so by raising their fleets in the face of necessity. When the emergency passes, the temptation to lay up the ships and pension off the sailors is compelling. Such economizing often invites a revival of piracy at first and finally renewed naval challenge for command of the sea. While this cycle is predictable, it is not by and large escapable. Most states before the British in the *Pax Britannica* simply could not afford the cost of a fleet in being if there was no clear and present danger to justify the expense. So, too, with the Byzantines.

But why, one asks, did they not equip a small, economical fleet with Greek fire if this weapon was so dominant? Surely this was an instance where the penury of naval peace could nonetheless sustain a relatively cheap deterrent. It seems analogous in many ways to the United States now maintaining a reduced and comparatively inexpensive nuclear deterrent in the wake of the Cold War.

The answer, it seems, is proliferation. The Byzantines restricted access to Greek fire lest the ultimate weapon of their age fall into enemy hands and thus be turned against them. So long as they alone controlled Greek fire, they knew that Constantinople

could never fall. But if the Moslems ever showed up at the sea walls with Greek fire of their own, then the city and hence the empire were forfeit. It was for this reason that they denied Greek fire to the imperial fleet. And it was for similar reasons that they denied it to the regional theme fleets. Second only to the Moslem threat on Constantinople was the threat of internal insurrection led by the powerful families that controlled the regional themes of the empire. To place Greek fire in their hands was to invite yet another kind of enemy to show up at the sea walls and challenge the reigning emperor for control of the city and the empire.

Thus it came to pass that successive emperors of Byzantium seem to have believed that it was more important to protect Greek fire than exploit it. So successful were they in keeping the secret that it finally became, I am convinced, secret even to them. When passing Crusaders took the capital in 1204 A.D., they found no trace of Greek fire. I believe that the Byzantines had actually lost the secret long before then, perhaps as early as the 10th century. The legend of the weapon lived on and apparently deterred a revival of the Moslem attacks that had threatened the city in the late 7th and early 8th centuries. Though the Moslems themselves grew proficient in some forms of incendiary warfare, they never seem to have figured out the ultimate weapon that might have opened the door to Constantinople.

Lest the Byzantines appear silly for failing to exploit the full potential of Greek fire, it is important to remember that their empire lasted a thousand years, longer than any other in Western history. In many ways Greek fire served their purposes. But in another sense they were victims of their own *success*. Penury, the unwillingness to support an adequate navy in peacetime, drove them to over-reliance on a technological fix. The fix was so sweet that they hardly dared use it. As had been true with the chariot, it dominated war in its time because people thought it dominated war. But it was a hollow shell through much of its history, and it collapsed of its own weight long before it was overcome by other technology.

Underwater Warfare.

Submarines in the age of sail were also seen as a technological fix for a certain kind of security problem. In that

era, between the battle of Lepanto in 1588 and the *Monitor* and the *Merrimac* in 1862, naval warfare was dominated by what Theodore Ropp calls a hierarchy of power.³³ Ships of a certain rate were all but invulnerable to smaller vessels. This put a premium on large numbers of ships of the line, i.e., ships large enough to fight in the main battleline against the best of the enemy's fleet. Ships of the line, displacing upwards of 1,200 tons and carrying 60 guns or more, were the most complex and expensive technology of their day.³⁴ In a sense they were floating fortresses, built up in peacetime at great expense and exercised whenever possible to sharpen the skills of the crew. Unlike land fortresses, however, they were dynamic machines operating in a hostile environment. They required constant maintenance and replacement, and their crews demanded sustenance and training.³⁵ The burden they imposed upon the state far exceeded that of comparable land forces.

England came to dominate the age of sail through a succession of naval wars in the 17th and 18th centuries. Its fleet was the nation's first line of defense. Into it the nation poured its national treasure at a rate few states could match. With the fleet, England established a worldwide colonial and economic empire. The country became wealthy through commerce and developed sophisticated techniques for extracting revenues from its own citizens and others.

In the 18th century, the French became the last nation to challenge England for command of the sea in the age of sail. The French faced a dilemma born if not of penury then at least of excess demand on finite resources. Forced by ambition, geography, and history to be a major land force on the continent while challenging England for sea power, France had to support an army and navy simultaneously. During much of the period, France even had ships of superior quality, but it could never match the seamanship or gunnery of the British. Ironically, it never matched their daring either. The French could afford to lose their fleet, for their army was still proof against invasion. England, in contrast, never dared lose its fleet, for fear of being defenseless against an invading French army. Nonetheless, the British repeatedly risked all in its naval wars with France, constantly seeking decisive engagement. The policy culminated in the Nelsonian tactics that crushed the French at Trafalgar.

Before the French lost all at Trafalgar, they were offered a

technological fix by an enterprising American painter, inventor, and opportunist named Robert Fulton.³⁶ Penetrating the reigning paradigm of naval warfare, Fulton perceived that the hierarchy of power was inviolate only if one played by the rules. Ships of the line were invulnerable to lesser vessels only if those lesser vessels attacked in the regular way. The sides of these great leviathans were made of solid oak, as much as three feet thick. Enemy fire might damage such hulls, but it would never break them. Normally, ships were lost only when their crews or their rigging were disabled, destroying their ability to maneuver and defend themselves.

Below the waterline, however, these vessels were soft and thin. The oak hull was not reinforced there as it was on the sides and it was mushy from immersion in sea water and attack by worms and other sea life. A blow to this Achilles heel could send a floating fortress to the bottom. And one did not need a comparable fortress to deliver such a blow.

Fulton proposed to build and operate a submarine for the French, imitating his countryman, David Bushnell, who had essayed just such a project during the American Revolution. French naval authorities were skeptical that he could succeed and indignant that the French navy could be reduced to such vulgar expedients. Still, Napoleon's government was desperate to beach the British whale; it would try almost anything. Fulton received some modest support, and with it he built a submarine he called the *Nautilus*. With a small crew he actually took this man-powered craft into the English Channel in attacks on blockading British vessels.

Espionage being what it was in the Napoleonic wars, the British knew of Fulton's schemes and simply sailed away from his underpowered craft when it came hunting. But the very fact that he could field such a weapon gave them pause. They lured him into defection with flattery and lucre, and kept him ineffectively on retainer until Nelson had done with the French. With the threat gone, they dismissed Fulton to crawl home to his native land, a bitter, thwarted man with a taste for revenge. Came the war of 1812, Fulton turned his inventive genius to designing and building the *Demologos*, the first steam ship of war the world had ever seen. It was completed too late to exact Fulton's revenge on the British.

The point of Fulton's sad, almost comical story is not that he failed but that he had the basic ideas right. The technological ceiling hanging over the turn of the 19th century precluded the success that he craved. But he had nonetheless seen through the hierarchy of power. He predicated his own system on what Basil Liddell Hart would have called the indirect approach, i.e., attacking the enemy where he is least prepared.³⁷

More importantly for our purposes here, Fulton justified his schemes on economic grounds. He could build and sail his submarine for a fraction of the cost of a ship of the line. Of course such an argument carried weight with the French, who were fighting their enemies on land and sea. It was a tougher sell to the British, who were resigned to a kind of economic warfare with Napoleon. To convince them, Fulton actually deployed a modern, sophisticated economic argument which he borrowed from William Congreve. Fulton and Congreve participated together in the British raid on Boulogne in 1804, where Congreve had a chance to demonstrate his rockets. To sell these new devices to his government, Congreve had developed a cost-effectiveness argument which compared them to traditional artillery. Fulton adopted the same method to compare his submarine warfare to the cost of ships of the line. The Royal Navy still scoffed at this dishonorable form of warfare, but the argument seems to have made some impression in Whitehall. Even states that are trying to drive their enemy to bankruptcy, as the United States did with the Soviet Union, will want to save money where it can. Perhaps such states need to save money even more than those engaged in more traditional strategies.

When submarine warfare finally broke through the technological ceiling that constrained Fulton, it proved effective in just the way he had predicted. In fact, at the turn of the 20th century, the Jeune École movement within the French navy proposed to use this emergent technology just as Fulton had recommended, as an inexpensive weapon system to literally undermine the great ships of the line.³⁸ At this time those vessels were the battleships of the Anglo-German naval race. The French movement garnered inadequate support, but its potential was revealed at the battle of Jutland, when Jellicoe turned away at the crucial moment for fear of torpedo attack. Given the relative cost of battleships on the one hand and submarines and torpedo boats on the other, the reign of the battleship was clearly in eclipse.

Still, it was primarily as an instrument of economic warfare that the submarine achieved its greatest impact. Once the industrial revolution turned war into a contest of industrial production in the first half of the 20th century, attacking the enemy's logistics was as effective as attacking its main battle fleet. A dollar spent on submarines could do more damage to the enemy than a dollar spent on battleships. In other words, it gave more bang for the buck.

Conclusions.

Beyond the observations already made, these three case studies suggest some conclusions that might help us see our contemporary problems more clearly. First, these problems are not new. As far back as we can see in human history, states have been seeking ways to get more bang for their buck. The primary difference between now and then may be the expanded definition of the purpose of the state. In ages past when war was the primary business of the state, it may have been easier to secure funding for military purposes than it is in modern times when so many other issues seem to influence what we now conceive of as national security. The barbarian at the gate was a powerful persuader; the new barbarians are poverty, education, environmental deterioration, industrial infrastructure, and research and development—all of which are besieging penurious governments for scarce resources, all of which are claiming to be indispensable to national security.

Second, technology has always been one method by which states have sought to get more bang for their buck. Not until the 17th century did we begin to think about "technology" as a conceptual entity with power to shape the future. But there is ample evidence that states nonetheless thought of specific technologies—chariots, Greek fire, submarines—as sources of military power. While not as self-conscious in such pursuits as we are in the modern world, the ancients nonetheless supported research and development, subsidized infrastructure, adjusted social relationships, and in the case of Greek fire at least even maintained state secrecy in order to promote technologies that enhanced the military power of the state.

Finally, it may be concluded that technological solutions to

security problems, while not necessarily deterministic, can nonetheless generate powerful inertial forces that are difficult to reverse or redirect. Commitment to huge chariot corps seems to have been a self-fulfilling prophecy, one that led to a long-standing but nonetheless fragile faith in the invulnerability of this method of combat. Maintained at ruinous cost over a period of centuries, the whole concept collapsed when challenged by a group of outsiders who did not realize they were supposed to lose.

So, too, with Greek fire. Introduced initially as the miracle weapon that saved Constantinople, it soon came to be seen as fit for no other purpose. But even as it took on mythic qualities as the defender of Constantinople, so, too, did it pose the converse threat of arming the enemy with the one weapon that might bring down Constantinople. Thus, secrecy took control of the weapon; it seemed more important to deny it to the enemy than to have it oneself. The same enthusiasm surrounded the introduction of the proximity fuse in World War II. In some ways it drives the controversy over proliferation of nuclear weapons now. In the case of Byzantium, the emperor and his inner circle finally succeeded in keeping the secret even from themselves.

There was also a technological inertia at work in 18th-century naval warfare. Just as Levantines faced with huge chariot corps built huge chariot corps of their own, so too did governments of the age of sail build huge fleets of battleships to contest huge fleets of battleships. Perhaps in their time these were an appropriate technological investment, but they bred a worship of the battleship.³⁹ So beguiled were Alfred Thayer Mahan and his contemporaries that they were unprepared for the submarine and the aircraft carrier when these technologies came along.

Finally, note that all of the weapons systems explored here were as important psychologically as they were physically. Chariots dominated the battlefield because people thought they were invulnerable. Greek fire kept the Moslems at bay long after the Byzantines had lost the power to deploy it because the Moslems remembered the horror of Constantinople. Jellicoe turned away at Jutland because he feared what torpedo boats might do to his fleet, and he was, in Churchill's memorable phrase, the only man who could lose the war in an afternoon. Whatever technology one buys in times of penury, it is well to remember that its effectiveness will be measured as much by what people think it can

do as by what it can really do.

ENDNOTES

1. *Budget of the United States Government. Historical Tables. Fiscal Year 1995*, Washington: Executive Office of the President, Office of Management and Budget, 1994, pp. 17, 82-88.

2. *Ibid.*, p. 88.

3. John Brewer, *The Sinews of Power: War, Money and the English State. 1688-1783*, Cambridge, MA: Harvard University Press, 1990, pp. 40-41.

4. The exception that proves this rule is Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change*, Ithaca, NY: Cornell University Press, 1977.

5. Of course some barbarian states make war the principal economic activity of the state, thus combining the army and the work force in a single body.

6. Niccolò Machiavelli, *The Prince*, chap. 14.

7. George Roux, *Ancient Iraq*, 2d ed., London: Penguin, 1980, p. 230.

8. William H. McNeill, *The Rise of the West: A History of the Human Community*, Chicago: University of Chicago Press, 1963, pp. 104, 115.

9. Albrecht Goetze, "Warfare in Asia Minor," *Iraq*, Vol. 25, 1963, p. 125.

10. O. R. Gurney, *The Hittites*, London: Penguin, 190, p. 104.

11. M. A. Littauer and J. H. Crouwel, *Wheeled Vehicles and Ridden Animals in the Ancient Near East*, *Handbuch der Orientalistik*, Vol. VII, No. 1, 1979, pp. 1-72.

12. William H. McNeill, *The Rise of the West*, p. 104; Yadin, *The Art of War in Biblical Lands*, Vol. I, pp. 39, 80.

13. J. K. Anderson is surely correct when he says "there was no single 'proper' system of chariot-tactics in antiquity." "Greek Chariot-Borne and Mounted Infantry," *American Journal of Archaeology*, No. 79, 1975, p. 187. See also Alan Richard Schulman, "The Egyptian Chariotry: A Reexamination," *Journal of the American Research Center in Egypt*, Vol. 2, 1963, pp. 75-98, esp. pp. 88, 90.

14. McNeill, p. 105.

15. Mary Aiken Littauer, "The Military Use of the Chariot in the Aegean in the Late Bronze Age," *American Journal of Archaeology*, No. 76, 1972, pp. 145-57; S. Yeiven, "Canaanite and Hittite Strategy in the Second Half of the Second Millennium B.C.," *Journal of Near Eastern Studies*, pp. 101-107; Alan R. Schulman, "Chariots, Chariotry, and the Hyksos," *Journal for the Society for the Study of Egyptian Antiquities*, No. 10, 1980, pp. 105-53.

16. Julius Caesar, *The Gallic War*, 4:33; Arrian, *Expeditions of Alexander*, 3:12 - 3:13.

17. V. Gordon Childe, "Wheeled Vehicles," in *A History of Technology*, ed. by Charles Singer, et al., 8 vols., Oxford: Clarendon Press, 1954-1984, Vol. I, p. 722.

18. W. F. Albright, "Mitannian Maryannu, 'chariot-warrior,' and the Canaanite and Egyptian Equivalents," pp. 217-221. N.K. Sandars notes that maryannu means literally "young here." *The Sea Peoples: Warriors of the Ancient Mediterranean,, 12,50-1150 BC*, rev. ed., London: Thames and Hudson, 1985, p. 38.

19. Alan Schulman is skeptical of the most extreme numbers, but there is nevertheless reason to believe that chariot corps did actually achieve enormous size. One scholar estimates that 7,000 chariots were on the field at the battle of Kadesh. See Yadin, Vol. II, p. 286.

20. McNeill, *Rise of the West*, pp. 127, 144; Sandars, *The Sea People*, p. 38.

21. Yadin, Vol. I, 90.

22. Roux, *Ancient Iraq*, p. 246.
23. McNeill, *Rise of the West*.
24. Robert Drews, *The End of the Bronze Age: Changes in Warfare and the Catastrophe ca. 1200 B.C.*, Princeton: Princeton University Press, 1993; N. K. Sandars concludes from the Biblical account of Deborah's victory over Canaanite chariots that "a clever enemy, who did not 'stick to the rules,' could outmanoeuvre an army whose strength lay in its chariots, and which fought according to the conventions of the chariot warfare established between the great powers." *The Sea Peoples*, p. 72.
25. The following account is drawn largely from Alex Roland, "Secrecy, Technology, and War: Greek Fire and the Defense of Byzantium," *Technology and Culture*, No. 33, October 1992, pp. 655-679.
26. Byron C. P. Tsangadas, *The Fortifications and Defense of Constantinople*, New York: Columbia University Press, 1980, p. 123.
27. J. Haldon and M. Byrne, "A Possible Solution to the Problem of Greek Fire," *Byzantinische Zeitschrift*, No. 70, 1977, pp. 91-99.
28. Pamela O. Long and Alex Roland, "Military Secrecy in Antiquity and Early Medieval Europe: A Critical Reassessment," *History and Technology*, No. 11, 1994, pp. 259-290.
29. Roland, "Secrecy, Technology, and War."
30. *Ibid.*, p. 671.
31. George Ostragorsky, *History of the Byzantine State*, trans. by Joan Hussey, rev. ed., New Brunswick, NJ: Rutgers University Press, 1969.
32. Hélène Ahrweiler, *Byzance et la mer: La marine de guerre, la politique et les institutions maritimes de Byzance aux VII^e - XV^e Siècles*, Paris: Presses universitaires de France, 1966.
33. This account is drawn primarily from Alex Roland, *Underwater Warfare in the Age of Sail*, Bloomington: Indiana

University Press, 1978; the citation to Ropp is on page 3.

34. Peter Goodwin, *The Construction and Fitting of the Sailing Man of War*, London: Conway, 1987, says (p. 263) that vessels of 60 guns displaced 1,191 tons, those of 100 guns displaced 2,000 tons.

35. John Brewer reports that HMS *Victory* cost £63,174 to build in 1765; in that period the navy spent £26,000 a year to maintain a first-rate battleship. *Sinews of Power*, pp. 34-35.

36. Actually, Fulton offered two fixes. One was the submarine described below; the other was a fleet of barges towed by steamships. On these barges Fulton proposed to tow an invading army across the English Channel on a day when the British fleet was becalmed.

37. Basil H. Liddell Hart, *Strategy: The Indirect Approach*, 2d ed., New York: Praeger, 1968.

38. Theodore Ropp, *The Development of a Modern Navy: French Naval Policy, 1871-1904*, Annapolis, MD: U.S. Naval Institute Press, 1987.

39. John U. Nef, *War and Human Progress: An Essay on the Rise of Industrial Civilization*, London: Routledge & K. Paul, 1950.

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