Science and War

*By Alex Roland**

THE BAD NEWS is that military history has been studied often but not well; the history of science has been studied well but not often. Military histories are as old as the *Iliad* and the Old Testament, but as a genre they are dominated by operational accounts of campaigns and battles and hagiography of the great captains. The history of science and technology tends to be more scholarly and critical, but hardly any was written before this century; most of the best work has been done since World War II. Both fields remain outside the mainstream of American historiography; neither, for example, appears on the list of traditional "Fields of Specialization" in the American Historical Association's *Guide to Departments of History*. In a country "born in an act of violence" and risen to world preeminence largely on the basis of science and technology, this neglect is almost inexplicable.[1]

The good news is that we know more than we realize. While the histories of science and war have been poorly integrated in surveys of American development, and while we do lack compelling syntheses of these topics, the monographic literature is substantial and has been growing significantly in recent years. It forms, in fact, such a huge corpus that I cannot claim to have read all or even most of it. I have, however, read enough to know that it has not yet been exploited. Since it has been more than adequately described and evaluated elsewhere, I will not attempt here simply to reshuffle the materials into a new list.[2]

I propose instead to essay a tentative outline of what a synthesis of the existing literature on science and war in the United States might look like. I will try to cite the best literature and address the main issues within it, leaving the reader to consult prior bibliographic essays in this field for more comprehensive

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[1] After almost thirty years, Walter Millis's *Arms and Men: A Study in American Military History* (New York: Mentor, 1956), remains the only survey of American military history worthy of serious scholarly attention. Its only counterpart in the history of technology was published in the same year—John W. Oliver, *History of American Technology* (New York: Ronald Press, 1956)—but it has not stood up nearly so well. In the history of science, George Daniels, *Science in American Society: A Social History* (New York: Knopf, 1971) comes closest to a full survey, though Dirk Struik, *Yankee Science in the Making* (Boston: Little, Brown, 1948) carries the story well through the Civil War. None of these three, however, comes close to matching Millis's achievement.

[2] See Edward C. Ezell, "Science and Technology in the Nineteenth Century," in *A Guide to the Sources of United States Military History*, ed. Robin Higham (Hamden, Conn.: Archon, 1975), pp. 185–215; Carroll W. Pursell, Jr., "Science and Technology in the Twentieth Century," *ibid.*, pp. 269–291; Ezell, "Science and Technology in the Nineteenth Century," in *A Guide to the Sources of United States Military History: Supplement I*, ed. Robin Higham and Donald S. Mrozek (Hamden, Conn.: Archon, 1981), pp. 44–55; Pursell, "Science and Technology in the Twentieth Century," *ibid.*, pp. 69–71; and Harvey M. Sapolsky, "Science, Technology, and Military Policy," in *Science, Technology and Society: A Cross-Disciplinary Perspective*, ed. Ina Spiegel-Rösing and Derek de Solla Price (London: Sage, 1977), pp. 443–471.

new navy increased but also because the arms race was spawning improved techniques and products. Engineers and inventors in uniform produced countless new devices that often had civilian applications.[50]

Similarly, in this period the military gave to science more than it received in return. Albert Michelson went to the Naval Academy in the late 1860s because "there was no other college in the country that offered adequate instruction in physics."[51] While an instructor there, he conducted the first of the experiments that would lead to his international fame and Nobel Prize. Nor was he alone; George O. Squier, for example, took a Ph.D. in physics at Johns Hopkins University while on active duty and went on to a long and distinguished career as an inventor, scientist, and Signal Corps officer.[52] The army continued to sponsor surveys of Western lands after the Civil War, including Clarence King's famous "Geological and Geographical Exploration of the Fortieth Parallel," until this responsibility was finally vested in a civilian Geological Survey in 1879 under Civil War veteran John Wesley Powell. The army pioneered the first national weather service from 1870 to 1890, before handing the task over to the Department of Agriculture.[53]

These significant achievements notwithstanding, the last decades of the nineteenth century were, as Hunter Dupree has argued, a time of growing detachment between the military services and science.[54] Two trends were at work. First, the federal government was beginning to approve civilian agencies like the Weather Bureau and the Geological Survey to take over chores that previously had been handled by the military services only for want of another agency. Second, with the constricted budgets of peacetime, military officers were demanding that the funds they expended show immediate, practical returns on investment. Long-term research could be rationalized in some fields, like ordnance and telephony, but not so in such fields as topography, geology, and astronomy. The eventual result of this shift was to be a new emphasis on physics and chemistry that would accelerate the rise of these disciplines in the twentieth century.

The greatest contribution of science to war in this transitional period may well have been conceptual. Ever since the scientific revolution of the seventeenth century, other fields of human activity have attempted to embrace the "scientific method" or something like it in hopes of discovering the fundamental "laws" at work and learning how to master them. This impulse has spawned social science, political science, and any number of pseudosciences.

[50] Clark maintains that George O. Squier was one of the last of a dying breed of nineteenth-century scientists and engineers in uniform, men who successfully combined military careers with professional activity in science, technology, invention, and even business. Surely the rise of professionalism, both in the services and in science and engineering, made it increasingly difficult to serve more than two masters.

[51] Dorothy Michelson Livingston, "Michelson in the Navy; the Navy in Michelson," *U.S. Naval Institute Proceedings*, 1969, *95*:72; see also Livingston, *The Master of Light: A Biography of Albert A. Michelson* (New York: Scribners, 1973).

[52] Clark, "George O. Squier."

[53] One of the major issues in the creation of the Geological Survey was whether it would be a military or a civilian agency; Thomas D. Manning, *Government in Science: The U.S. Geological Survey, 1867–1894* (Lexington: Univ. Kentucky Press, 1967), Ch. 2. On the weather service, see Joseph M. Hawes, "The Signal Corps and Its Weather Service, 1870–1890," *Military Affairs*, 1966, *30*:68–76; and Donald R. Whitnah, *A History of the United States Weather Bureau* (Urbana: Univ. Illinois Press, 1965).

[54] Dupree, *Science and the Federal Government*, Ch. 9.

Military affairs proved to be no exception. Beginning at least with Sebastien de Vauban (1633–1707), claims have arisen that the traditional art of war is complemented by a science of war.[55] Karl von Clausewitz and Baron Jomini, for example, both studied Napoleon—one saw art; the other, science.[56] In the last hundred years, infatuation with the science of war has reached unprecedented levels. The Prussians launched this latest enthusiasm with their quick and conclusive victories over the Austrians and the French in the late 1860s and early 1870s. Their *Kriegsakademie*, general staff, planning, and superior management techniques seemed to have reduced war to a science at just the time when German science was beginning to emerge as superior both in its achievements and in its educational system. As the nineteenth century gave way to the twentieth, countries all over the world adopted the general staff model for their armies and the graduate research laboratory for their universities. The Johns Hopkins University and the restructuring of the armed forces instituted by Secretary of State Elihu Root drew on a common conceptual base.[57]

A closely related development was to have an equally dramatic impact on the military. Scientific management, or Taylorism, came into vogue around the turn of the century, riding the same cultural horse as the general staff concept and the model of the German university. It was applied quickly and with varying success at army arsenals, at navy yards, and in the plants of military contractors.[58] In the form advocated by Frederick Taylor, scientific management has fallen from grace in a way that the general staff and the research university have not. But it made its contribution nonetheless to the emergence of the modern concept of military men as "managers of violence."

THE FIRST WORLD WAR, 1914–1940

The influence of science and technology on World War I is a source of controversy among historians. Daniel Kevles has challenged one body of conventional wisdom—that this was a chemist's war. He has argued in a number of persuasive publications that the contributions of science in general, and physics in particular, have been overlooked by historians.[59] Paul A. C. Koistinen has argued,

[55] Henry Guerlac, "Vauban: The Impact of Science on War," in *Makers of Modern Strategy*, ed. Edward Mead Earle (Princeton: Princeton Univ. Press, 1943), pp. 26–48; and Daniel R. Beaver, "Cultural Change, Technological Development, and the Conduct of War in the 17th Century," in *New Dimensions in Military History*, ed. Russell F. Weigley (San Rafael, Calif.: Presidio Press, 1975), pp. 75–89.

[56] Carl von Clausewitz, *On War*, ed. and trans. Michael Howard and Peter Paret (Princeton: Princeton Univ. Press, 1976); Henri Jomini, *The Art of War*, trans. G. H. Mendell and W. P. Craighill (Philadelphia: Lippincott, 1862).

[57] Walter Millis calls the military side of this the "Managerial Revolution," an attempt to control and exploit the forces unleashed by the democratic and industrial revolutions. In *Arms and Men*, he notes that "it was natural, in that age to find an immediate answer in 'science'; and the scientific and methodical Germans led the way" (p. 123).

[58] Hugh G. H. Aitken, *Taylorism at Watertown Arsenal: Scientific Management in Action* (Cambridge, Mass.: Harvard Univ. Press, 1960); and Holden A. Evans, *One Man's Fight for a Better Navy* (New York: Dodd, Mead, 1940).

[59] Daniel J. Kevles, "Flash and Sound in the AEF: The History of a Technical Service," *Milit. Affairs*, 1969, *33*:374–384; Kevles, "George Ellery Hale, the First World War, and the Advancement of Science in America," *Isis*, 1968, *59*:427–437; and Kevles, *The Physicists*, Chs. 8, 9. See also Kevles, "Testing the Army's Intelligence: Psychologists and the Military in World War I," *Journal of American History*, 1968, *55*:565–581; and Kevles, "Federal Legislation for Engineering Experimental Stations: The Episode of WW I," *Technol. Cult.*, 1971, *12*:182–189.

however, that it was engineers and managers, men who saw themselves as "doers" and not researchers, who contributed most to the outcome of the war. This runs close to, but does not quite overlap, Walter Millis's assertion that World War I introduced the "mechanization of war," in contrast to the "scientific revolution" that would follow in World War II.[60]

Whatever the relative merits of these interpretations, several features of the conflict are clear. First, it was a war of industrial production. The Germans were never really defeated in the field; rather, they ran out of the fodder of war, a fate they came close to inflicting on England with submarine warfare. Second, the machine gun and the submarine were the critical technologies. As seen in the previous section, the United States prepared better for the latter technology than the former, both in developing the craft and then in developing the means to combat it. Kevles maintains, with some effect, that this was where the physicists played a role more important than the chemists, for the submarine was more important than chemical warfare and munitions.[61]

Third, some new technologies proved less effective on the battlefield than they might have because their potential was never fully exploited. Surely this is true of the aircraft, largely because of the lack of a doctrinal base, as shown by I. B. Holley in his classic study *Ideas and Weapons*.[62] Gas warfare and the tank were dramatically effective when first employed in battle, but adequate preparations had not been made to exploit the opportunities they offered. By the time the weapons were ready for exploitation, the surprise had worn off and countermeasures had been instituted. Radio was used to good effect at sea, but it was not yet reliable enough to fulfill its potential. A similar pattern emerged on land, where the stasis of trench warfare made conventional land lines appealing, so long as they could be protected against artillery barrage. In the end the runner, a technology as old as warfare, was often preferred to modern inventions. The motor car still took second place to the horse. The machines on the home front producing bullets and canning beans contributed more to the outcome of the war than did any machines on the battlefield, save perhaps the machine gun.

The influence of World War I on science and technology was more pronounced. The Great War was the first of the total wars, in which the entire resources of the state—or very nearly so—were mobilized for military purposes. Not the least of the resources were science and technology. The result was what William McNeill has called a command economy, the end to which Western states had been gravitating since at least A.D. 1000.[63] Virtually all of national life was bent to war.

In the United States the heart of this enterprise was in Washington, where the second major impact of World War I on science and technology occurred. Continuing precedents established in the American Revolution and the Civil War, the government created scientific and technical institutions that would sur-

[60] Koistinen, *The Military-Industrial Complex* (cit. n. 16), Ch. 2; and Millis, *Arms and Men*, Chs. 4, 5.

[61] Kevles, *The Physicists*, Ch. 9.

[62] I. B. Holley, Jr., *Ideas and Weapons: Exploitation of the Aerial Weapon by the United States During World War I: A Study in the Relationship of Technological Advance, Military Doctrine, and the Development of Weapons* (New Haven, Conn.: Yale Univ. Press, 1953).

[63] McNeill, *The Pursuit of Power* (cit. n. 46).

vive the war and become more or less permanent promoters of scientific and technical development. The first of these was the National Advisory Committee for Aeronautics (NACA), created in 1915 for "the scientific study of the problems of flight with a view to their practical solution." Though not a military institution itself, NACA was formed during the war, because of the war, as part of the Naval Appropriations bill of 1915; it had military members on its main committee and subcommittees, and it was committed to research in support of government aviation programs—all of which were military at the time.[64] A few months later, Secretary of the Navy Josephus Daniels invited Thomas Edison to chair a Naval Consulting Board to provide outside technical advice to the navy. Though the Board proved a disappointment, it helped spawn the Naval Research Laboratory, one of the most successful government research establishments in American history.[65] Disgruntled over the lack of scientists on the Naval Consulting Board, George Ellery Hale promoted the creation of a research arm for the National Academy of Sciences, which had done little science advising to the federal government, either in the Civil War or in the intervening years. This was to be the primary conduit through which the scientific talent of the United States would be enlisted in the war effort.[66] Rounding out the principal battery of agencies established to draw on America's scientific, engineering, and industrial talent was the National Defense Advisory Commission (NDAC), an umbrella organization heavily slanted toward the mobilization of economic and industrial resources in war production. In it, at least one scholar has seen the real origins of the military-industrial complex that came so clearly to the fore after World War II.[67]

Collectively these agencies—and the science and technology they attempted to marshal—contributed little to the course of World War I. Like all prior wars, this one was fought with the weapons in existence at the outset. Scientists and engineers made some real contributions in highly technical fields like aviation, underwater acoustics, and artillery spotting, but problems of producing the technology at hand always outweighed those of developing new technologies. By war's end, the services remained skeptical of the uses of science if not of technology. The war did little to draw the scientist and the soldier into the kind of close collaboration that might have made both more appreciative of each other's potentials, limitations, and needs.

WORLD WAR II, 1941–1945

It was this barrier between science and the military that Vannevar Bush sought to raze as World War II approached, by first tapping scientific talent in the National Defense Research Committee (NDRC), then bringing this talent into closer collaboration with the military users of their ideas through the mechanism of the

[64] Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915–1958*, 2 vols. (Washington, D.C.: NASA, 1985).

[65] David Kite Allison, *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory* (NRL Report 8466) (Washington, D.C.: NRL, 1981); A. Hoyt Taylor, *The First Twenty-Five Years of the Naval Research Laboratory* (Washington, D.C.: Department of the Navy, 1948).

[66] Kevles, *The Physicists*, Ch. 8; Kevles, "George Ellery Hale" (cit. n. 59); and Helen Wright, *Explorer of the Universe: A Biography of George Ellery Hale* (New York: Dutton, 1966).

[67] Koistinen, *The Military-Industrial Complex* (cit. n. 16) Ch. 2.

Office of Scientific Research and Development (OSRD). In doing so he demonstrated the inadequacy of previous institutional arrangements intended to exploit science and technology for war—save the National Advisory Committee for Aeronautics, on which NDRC was modeled.[68] By war's end Bush had evolved an institutional form that he thought was too powerful and too important to be left to the generals.

NDRC and OSRD instituted several critical changes in the relationship between science and war in the United States—changes that turned out to be permanent. First, it drew scientists into warfare at an unprecedented rate. Engineers, inventors, and industrialists had served in large numbers before; now scientists joined them on a comparable scale. Second, the scientists stayed at their home institutions or moved into new ones built for them, such as the Radiation Laboratory at MIT; in general, they did not get into uniform and they did not migrate to government arsenals or industry. Third, they were funded by contract, not to produce a product (as contracts would require in the postwar world) but to conduct research. In essence, the government purchased the scientific method on faith that its end result would be worth the candle. Fourth, information was compartmentalized in the interests of secrecy, a radical departure from standard scientific practice that was more or less accepted as a necessary if unpalatable and often counterproductive concomitant of war. Finally, the soldier and the scientist were drawn into close collaboration, so that the developments in the laboratory would be suited to the requirements of the battlefield. Scientists became advisers at the highest levels of policymaking, while soldiers posed some of the questions addressed in the laboratory.

Though none of these features of scientific research in World War II were entirely unprecedented, the scale on which they were conducted and the rigor with which the process was pursued fomented a revolution in the relation of science to war in the United States. This does not necessarily mean that warfare increased the scale and significance of science in society as a whole; Derek de Solla Price's research indicating the contrary has still not been successfully challenged after a quarter of a century.[69] But science was surely serving a different patron on a scale never before seen in America, raising issues such as secrecy,

[68] The National Defense Research Committee was created in June 1940, on the model of the National Advisory Committee for Aeronautics, of which Bush was chairman. One year later, the Office of Scientific Research and Development was created, absorbing NDRC. OSRD was needed to provide for development, to effect coordination with the services, and to provide an institutional umbrella for the Committee on Medical Research, a parallel organization to NDRC. See Irvin Stewart, *Organizing Scientific Research for War* (Boston: Little, Brown, 1948); see also James Phinney Baxter, *Scientists Against Time* (Boston: Little, Brown, 1948); A. Hunter Dupree, "The Great Instauration of 1940: The Organization of Scientific Research for War," in *The Twentieth Century Sciences: Studies in the Biography of Ideas*, ed. Gerald Holton (New York: Norton, 1972), pp. 443–467; and Carroll Pursell, "Science Agencies in World War II: The OSRD and Its Challengers," in *The Sciences in the American Context*, ed. Reingold (cit. n. 3), pp. 359–378.

[69] Derek de Solla Price, *Science Since Babylon* (New Haven: Yale Univ. Press, 1961); and Price, *Little Science, Big Science* (New York: Columbia Univ. Press, 1963). In the latter work Price says that World War II "looms as a huge milepost, but it stands at the side of a straight road of exponential growth" (p. 19). He does allow, however, that "the cost of research on a *per capita* basis and in terms of Gross National Product seems to have remained constant throughout history until about World War II and only since that time has met with the new circumstance of an increase that keeps pace with the growth of scientific manpower" (p. 94). He fails to associate this with the Cold War.

ethics, autonomy, and the conflicts between basic and applied research and between the arsenal and the contract.[70]

Nor did the huge infusion of science into World War II mean that science won the war. True, this was the first war in which the weapons in use at the end were significantly different from those available at the outset, but the new weapons were not decisive. The technology that had the greatest impact on World War II was the internal combustion engine. Employed in tanks, airplanes, motor vehicles, and submarines, it dominated the battlefield. Unlike World War I, this was a war of movement and maneuver. Like World War I, it was a war of industrial production. The other great innovations of the war, such as operations research, radar, the proximity fuze, and jet aircraft, were remarkable achievements of science and technology, but they did not determine the war's outcome.[71]

The one possible exception to this generalization, the atomic bomb, warrants special attention. If it has been a "decisive" weapon—and this remains to be seen—it has been so in a way not normally considered: that is, it may have prevented World War III in the last forty years. It can hardly be credited with winning the war in the Pacific; submarines contributed more to that end.[72] In fact, it is not at all clear that ending the Pacific war was the primary goal of the bombing of Hiroshima and Nagasaki. The men who decided to drop the bomb did so because it was there; surely the government was not about to explain to the taxpayer why it spent $2 billion on a weapon it never used. The official rationale was that it spared the lives, both American and Japanese, that would have been lost in an invasion. But it is difficult to see in retrospect why an invasion was necessary. Japan could have been blockaded and bombed into submission. The real objective of the atomic bombs was more likely the Soviet Union—both to end the Pacific war before Russia became more deeply involved and to make clear what power the United States had at its disposal at war's end. Just because the atomic bombs ended the war does not prove that they caused the end.[73]

[70] Cf. the list in Stewart, *Organizing Scientific Research for War*, pp. 325ff.

[71] This interpretation is supported by I. Bernard Cohen, "Science and the Civil War," *Technology Review*, 1946, *48*:167; Lincoln R. Thiesmeyer and John E. Burchard, *Combat Scientists* (Boston: Little, Brown, 1947), p. 53; and Millis, *Arms and Men*. Many take the opposite view. Baxter, for example, in *Scientists Against Time*, quotes the German admiral Karl Doenitz as saying in December 1943: "For some months past the enemy has rendered the U-boat ineffective. He has achieved this object, not through superior tactics or strategy, but through his superiority in the field of science." (p. 46) Even Baxter's account, however, does not establish that the submarine could have decided the war. On specific developments, see Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins Univ. Press, 1980); Allison, *New Eye for the Navy* (cit. n. 65); on napalm, see Louis F. Fieser, *The Scientific Method: A Personal Account of Unusual Projects in War and Peace* (New York: Reinhold, 1964); on the proximity fuze, see Ralph Baldwin, *The Deadly Fuze* (San Rafael, Calif.: Presidio Press, 1980). See also the official histories of the divisions within OSRD, such as William Albert Noyes, ed., *Chemistry: A History of the Chemistry Components of the National Defense Research Committee, 1940–1946* (Boston: Little, Brown, 1948); and John E. Burchard, ed., *Rockets, Guns, and Targets: Rockets, Target Information, Erosion Information, and Hypervelocity Guns Developed During World War II by the Office of Scientific Research and Development* (Boston: Little, Brown, 1949).

[72] Clay Blair, *Silent Victory: The U.S. Submarine War Against Japan* (Philadelphia: Lippincott, 1975).

[73] For more traditional views that nonetheless embody the evidence to support this conclusion, see Herbert Feis, *The Atomic Bomb and the End of World War II* (Princeton: Princeton Univ. Press, 1966); Len Giovannitti and Fred Freed, *The Decision to Drop the Bomb* (London: Methuen, 1967);

THE COLD WAR, 1945 TO THE PRESENT

The impression created at home by the atomic bomb, however, was something else again. Combined with the other technical developments of the war, the bombs led many to believe that science had won the war, or at least that it would win the next one. The result was a five-year period in which the national military and political establishments raced headlong in opposite directions. The civilians attempted to dismantle the military establishment, while the services sought to bedeck it with the once and future technology. True to tradition, Congress insisted upon a precipitous demobilization, a policy President Truman compounded by imposing on the military services painfully low budget ceilings. The services responded by reorganizing and scrambling to refight the last war with nuclear weapons. The air force led the way by institutionalizing its own mechanisms for getting scientific and technical advice and research and development, which established patterns subsequently followed by the other services.[74] While Vannevar Bush struggled to make permanent the wartime organization of science he had overseen, the Naval Research Laboratory funded most of the basic science the government chose to support.[75]

The struggle reached a climax in the first six months of 1950. In that fateful period, the United States approved development of the hydrogen bomb, formulated a national security policy (NSC 68) that committed the nation to permanent mobilization in the Cold War, committed American troops to the crusade against communism in Korea, and created the National Science Foundation. These steps meant that the nuclear scientists would be unable to prevent the arms race they had predicted and instigated, that the United States would be saddled with the standing military establishment it had always dreaded, that these decisions would be ratified in blood in Korea (making them virtually indelible in the short run), and that the government would fund a modest amount of basic research through a civilian agency and not through the military services. In many ways it was the arms race that proved most important for science, for it opened the government purse wider than ever before in peacetime and set off the mad scramble for new weaponry that President Eisenhower would come to call the military-industrial complex. In the same speech, Eisenhower also warned against the domination of the scientific and technical elite that he knew would come into increasing power as that complex grew.[76]

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and Lawrence Freedman, "The Strategy of Hiroshima," *Journal of Strategic Studies*, 1 May 1978, pp. 76–97.

[74] Harvey Sapolsky maintains that "neither the navy nor any of the other services was a convert to science at the end of World War II"; "Academic Science and the Military" (cit. n. 3), p. 381. This was surely not true of the air force. See Thomas A. Sturm, *The USAF Scientific Advisory Board: Its First Twenty Years, 1944–1964* (Washington, D.C.: U.S. Air Force Historical Division Liaison Office, 1967); Nick A. Komons, *Science and the Air Force: A History of the Air Force Office of Scientific Research* (Arlington, Va.: Historical Division, Office of Information, Office of Aerospace Research, 1966); and Bruce L. K. Smith, *The Rand Corporation: Case Study of a Nonprofit Advisory Corporation* (Cambridge, Mass.: Harvard Univ. Press, 1966).

[75] Vannevar Bush, *Science, the Endless Frontier: A Report to the President* (Washington, D.C.: GPO, 1945); Daniel J. Kevles, "Scientists, the Military, and the Control of Postwar Defense Research: The Case of the Research Board for National Security, 1944–1946," *Technol. Cult.*, 1975, *16*:20–47; and Kevles, "The National Science Foundation and the Debate over Postwar Research Policy, 1942–1945," *Isis*, 1977, *68*:5–26.

[76] A good overview is Herbert York and G. A. Greb, "Military Research and Development: A

Before Eisenhower made that warning, one more ingredient was added to the stew: Sputnik. As Walter McDougall argues, Sputnik set off a revolution of its own, one comparable in impact to World War II and the momentous decisions of 1950, for it threw nominally civilian activities like space exploration into the total equation of national strength and security.[77] Less than four years after Sputnik I went up, President Kennedy and the Congress committed the United States to a race to the moon, a $25 billion stunt to demonstrate American scientific and technical superiority.[78] All of this was part of the Cold War, a permanent competition in which science and technology play a leading role, quality seems to matter more than quantity, the lines between civilian and military blur, and war becomes more total than ever before. Now all the resources of the state are thrown into the balance—in peace and in war—and scientific expertise weighs as heavily as any other factor save wealth.

CONCLUSIONS

What conclusions might be drawn from the history outlined above? The most significant inference might well be that the role of the military as patron of science in the United States has changed over the years.[79] From the informal and haphazard utilization and appreciation of science in the Revolutionary War, the military has passed through periods of supporting the earth and life sciences as well as oceanography and astronomy, even while integrating the potentials of science only poorly into the actual conduct of war. This remained true until World War II, when a conviction arose that science and technology would determine the outcome of future wars. Since then the military services have supported the physical sciences on an unprecedented scale. Scientists, like scholars in general, often turn bad money to good purposes, but no amount of rationalization can gainsay the dramatic, though often hidden, ways in which patrons shape the work of their benefactors. Illuminating these subtle influences will be one of the most important contributions of the coming scholarly synthesis. Some aspects of the problem are already apparent.

The moral dilemma of the scientist in the service of war is as old as Leonardo,

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Postwar History," *Bulletin of the Atomic Scientists*, Jan. 1977, *33*(1):12–27. On the hydrogen bomb decision, see David Alan Rosenberg, "American Atomic Strategy and the Hydrogen Bomb Decision," *J. Am. Hist.*, 1979, *66*:62–87. The division of the scientific community over the Hiroshima and Nagasaki bombings, the Baruch Plan, and the hydrogen bomb decision may be traced in Alice Kimball Smith, *A Peril and a Hope: The Scientists' Movement in America* (Chicago: Univ. Chicago Press, 1965); Robert Gilpin, *American Scientists and Nuclear Weapons Policy* (Princeton: Princeton Univ. Press, 1962); Arthur Steiner, "Baptism of the Atomic Scientists," *Bull. Atomic Sci.*, Feb. 1975, *31*(2):12–28; Brian Villa, "A Confusion of Signals: James Franck, the Chicago Scientists and Early Efforts to Stop the Bomb," *ibid.*, Dec. 1975, *31*(10):36–43; and Herbert York, *The Advisors: Oppenheimer, Teller, and the Superbomb* (San Francisco: Freeman, 1976). On NSC 68 and the Korean War, see Samuel Wells, "Sounding the Tocsin: NSC 68 and the Soviet Threat," *International Security*, Fall 1979, *4*:116–158. On the NSF see J. Merton England, *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945–1957* (Washington, D.C.: NSF, 1982).

[77] Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985).

[78] Vernon Van Dyke, *Pride and Power: The Rationale of the Space Program* (Urbana: Univ. Illinois Press, 1964); and John Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge, Mass.: MIT Press, 1970).

[79] On the theme, see Richard Westfall, "Science and Patronage: Galileo and the Telescope," *Isis*, 1985, *76*:11–30.

if not Archimedes.[80] In a democracy such as that of the United States, in which a modicum of popular support is necessary to sustain a war, scientists have not until recently been much troubled by the ethics of serving the military. In peace they were not called upon; in war they contributed in the same spirit of patriotism as their fellow citizens. Spared the worst carnage of World War I, American scientists did not begin to worry about their contributions to total war until the atomic bomb made the modern drift of events all too clear.[81] Since that cathartic event, the scientific community has been torn by the growing tension between the allure of lucrative military grants and contracts and the increasingly obvious and deadly consequences to which their research can contribute.[82] Nothing in the foreseeable future suggests that this tension will soon decrease.

The conflict between basic and applied research is also older than the republic; it too emerged early in our national history. The Revolution had reinforced a pragmatism already rampant in the colonies. While the Founding Fathers were not hostile to science, neither were they anxious to spend government funds on activities with no practical return. Still, the "common defense" is a broad term, as vague as our current "national security." Under the former banner the government funneled support for science through the military services throughout the nineteenth century. Sometimes the military payoff was obvious, as in the arsenals. In other cases, such as exploration and weather analysis, the armed services had the only infrastructure and the only constitutional mandate available. After the Civil War, when the government began to support science under the provisions of the general welfare clause, basic research found other sources of support and the military returned for a while to a narrower construction of practical application. In recent decades, the distinction between basic and applied research has blurred, and arguments have been advanced that basic research provides the indispensable base on which applications are built. Though this reasoning persuades few outside the choir, it is true that the military services attach fewer strings to their research funds than other federal agencies.[83]

The institutionalization of science and technology for purposes of war is a multifaceted problem still wrapped in controversy. The relative merits of government arsenals and contracting with private firms remain unclear after almost

[80] See Roland, *Underwater Warfare in the Age of Sail* (cit. n. 10), passim; Bernard Brodie, "Defense and Technology," *Technol. Rev.*, 1941, *43*:109; and Monte D. Wright and Lawrence J. Paszek, eds., *Science, Technology, and Society: Proceedings of the Third Military Symposium,* 8–9 May 1969 (Washington, D.C.: Department of the Air Force, 1971).

[81] Smith, *A Peril and a Hope* (cit. n. 76).

[82] R. W. Reid, *Tongues of Conscience: Weapons Research and the Scientists' Dilemma* (New York: Walker, 1969). See also Leonard A. Cole, *Politics and the Restraint of Science* (Totowa, N.J.: Rowman & Allanheld, 1983), which argues persuasively that this problem is not peculiar to military research; and Carol Gruber, *Mars and Minerva: World War I and the Uses of the Higher Learning in America* (Baton Rouge: Louisiana State Univ. Press, 1975), which is equally persuasive in establishing that the problem is not peculiar to science. To see the dilemma in context, see Fieser, *The Scientific Method* (cit. n. 71); and Robert Harris and Jeremy Paxman, *A Higher Form of Killing: The Secret Story of Chemical and Biological Warfare* (New York: Hill & Wang, 1982).

[83] The classic studies are C. W. Sherwin and R. S. Isenson, *First Interim Report on Project Hindsight: Summary* (Washington, D.C.: Office of Director of Defense Research and Engineering, 1966); and Illinois Institute of Technology Research Institute, *Technology in Retrospect and Critical Events in Science (TRACES),* 2 vols. (Chicago: IIT Research Institute, 1968). Compare these with *R & D Contributions to Aviation Progress (RADCAP): Joint DOD–NASA–DOT Study* (Washington, D.C.: DOD, NASA, DOT, 1972); and W. Henry Lambright, *Governing Science and Technology* (New York: Oxford Univ. Press, 1976), pp. 118–119.

two centuries of experience. The think tank, a relatively modern variant on this dichotomy, exists in both military and private forms; its main distinction from the arsenal or other contractors is that it seldom has facilities for production or laboratory research.[84] How to buy, maintain, and operate research equipment is a related problem with sharply contending advocates, as is the dilemma of maintaining a scientific infrastructure without putting the scientific community on permanent retainer. All of these problems of institutionalization hover on the fringes of the military-industrial complex, insulated from the worst controversies of that political morass by the fact that scientific research usually remains aloof from production and does not operate for profit. When scientists cross those thresholds, as they do from time to time, the issues of science and war usually disappear in a fog of political rhetoric.[85]

Secrecy is as old as warfare; compartmentalization is its modern version. The former precludes scientists from publishing research results with military implications; the latter, which came into prominence in World War II, precludes the scientist from exchanging views with his colleagues unless he can establish a priori that they need to know his ideas to prosecute their own work.[86] Both restraints are anathema to the scientist and disruptive of the advancement of knowledge as the scientist understands the process. The existing literature boasts countless instances where these policies have retarded or even precluded important military technologies; more work is needed on where the line might practically be drawn.[87]

Warfare has politicized science in the Cold War, influencing not only the agenda of science but the method by which science proceeds.[88] David Rittenhouse might suspend his peacetime pursuits to help the colonists find better ways of producing gunpowder, but this lasted only for the duration of the war. Joseph Henry placed his duties at the Smithsonian Institution first; in his spare time he evaluated inventions and advised the government on the technology of the Civil War. In the Cold War, however, science is permanently mobilized. Scientists sit on advisory panels, assess military needs, evaluate enemy capabilities, and finally advise the government on what can and should be done. No amount of detachment and objectivity in the first three tasks can make the last one anything but a political act, as scientists learned in the hydrogen bomb decision, the test-ban controversy of the late 1950s, and the Vietnam War. In some of these cases, scientific research agendas are shaped to prove or disprove one

[84] See Paul Dickson, *Think Tanks* (New York: Atheneum, 1971). The National Aeronautics and Space Administration was free to select either arsenals or contracting when it was created in 1958; it opted instead for a combination of both; see Arnold S. Levine, *Managing NASA in the Apollo Era* (NASA SP-4102) (Washington, D.C.: NASA, 1982). On the pitfalls NASA hoped to avoid, see Nieburg, *In the Name of Science* (cit. n. 17).

[85] Nieburg, *In the Name of Science*. The best introduction to the vast literature on the military-industrial complex is Steven Rosen, ed., *Testing the Theory of the Military-Industrial Complex* (Lexington, Mass.: Lexington Books, 1973).

[86] The classic rationale for this policy is given in Leslie Groves, *Now it Can Be Told: The Story of the Manhattan Project* (New York: Harper, 1962), pp. 167–169.

[87] See, e.g., John Sloop, *Liquid Hydrogen as a Propulsion Fuel, 1945–1959* (NASA SP-4404) (Washington, D.C.: NASA, 1978); and Constant, *Origins of the Turbojet Revolution* (cit. n. 71).

[88] Joseph Rotblat, *Scientists in the Quest for Peace: A History of the Pugwash Conferences* (Cambridge, Mass.: MIT Press, 1972). For the views of two insiders, see James R. Killian, Jr., *Sputnik, Scientists, and Eisenhower: A Memoir of the First Special Assistant for Science and Technology* (Cambridge, Mass.: MIT Press, 1977); and George B. Kistiakowsky, *A Scientist at the White House: The Private Diary of President Eisenhower's Special Assistant for Science and Technology* (Cambridge, Mass.: Harvard Univ. Press, 1976).

political position or another.[89] The dispassionate search for truth that characterizes the scientific endeavor often disappears in the struggle.

The conclusions one might draw about the influence of science on war in American history are at once simpler and less clear. Science and technology have not decided any American wars, with the possible exception of Vietnam, which we may have lost through overreliance on inappropriate technology. But science and technology have been decisive in preventing a war with the Soviet Union, which surely would have come save for nuclear weapons.

By these sweeping and intentionally provocative generalizations I do not mean to suggest that science and technology have been unimportant in America's wars. British logistics in the American Revolution, the railroad and the telegraph in the Civil War, sonar in World War I, radar in World War II, the helicopter in Korea and Vietnam—all had significant impact, but they did not decide the outcome. The reason is not that the technology of war is unimportant; quite the contrary, it grows more important all the time. The reason is that since the Industrial Revolution, during which the United States was born, most nations have come to appreciate the importance of the technology of war and have striven to arm themselves with the best and most modern weapons they can afford. Because the arms bazaar is and has been for many decades an international market, most combatants come to the field of battle comparably equipped. Technologies tend to cancel each other out. In practice, new technologies are indispensable. In theory, they are decisive. In fact, they seldom decide anything.

Vietnam provides the clearest example of the national myopia about the role of technology in warfare. The argument is often made, understandably enough, that smart bombs were decisive in Vietnam, forcing the North Vietnamese back to the bargaining table for the concluding talks that brought a settlement early in 1973.[90] Advocates of this position forget, however, that the United States lost the war. Helicopters, gun ships, electronic sensors, B-52s, saturation bombing, defoliants, infrared gunsights—the whole electronic battlefield[91] was conquered by a determined and ruthless enemy who recognized that politics wins more wars than science. Military historians might profitably spend more time investigating how science and technology—and scientists and technologists—shape warfare as a social institution, and less time trying to decide what was decisive.

NEEDS AND RESOURCES

The historian who attempts the synthesis suggested here will find the existing secondary literature surprisingly rich. The works cited above suggest some of the spadework already done. Several characteristics of this literature deserve special mention. First, it is alive with biographies and autobiographies that rise far above the hagiography and insipid memoirs of earlier generations. Thomas Hughes's model study of Elmer Sperry, for example, provides penetrating

[89] Harold Jacobson and Eric Stein, *Diplomats, Scientists, and Politicians: The United States and the Nuclear Test Ban Negotiations* (Ann Arbor: Univ. Michigan Press, 1966); and Robert A. Divine, *Blowing on the Wind: The Nuclear Test Ban Debate, 1954–1960* (New York: Oxford Univ. Press, 1978).

[90] See, e.g., U. S. G. Sharp, *Strategy for Defeat? Vietnam in Retrospect* (San Rafael, Calif.: Presidio Press, 1978).

[91] Paul Dickson, *The Electronic Battlefield* (Bloomington: Indiana Univ. Press, 1976).

the White thesis is discredited,[26] but readers must form their own conclusions. Surely, an argument for technological determinism—that the stirrup produced feudalism—has been disproved, but White's argument was always more complex than that.

Military topics may appear more deterministic than those in other branches of technology because war itself and the factors shaping its outcome often appear deterministic. The world wars were wars of industrial production. World War I was the chemist's war; World War II the physicist's war. Both changed the course of history inalterably. The mushroom cloud has become the great icon of the second half of the 20th century, symbolizing both the awesome power of science and the terrible power of military force to shape events. The green revolution or the discovery of penicillin may have farther-reaching effects on history, but the technology of war has about it an immediacy and a vividness that demand attention. Perhaps they seem more deterministic because we wish they were less so.

* * *

Another distinguishing characteristic of the science and technology of war is that they operate in a unique marketplace. To historians of technology it seems like no marketplace at all. Because of its roots in economic history and its abiding concern with the nature of technological change, the history of technology has always looked to market forces as a powerful category of analysis. It was fundamental to the model of invention, development, and innovation that enjoyed great currency in the 1970s. It remained important to model builders such as the late Hugh Aitken, whose histories of the development of radio assumed the operation of a free market.[27] Even a modeler such as Edward Constant, whose story of the origins of turbojets lies in the netherworld between the marketplace and the military, leaves unaddressed the different ways in which development works in those two realms.[28]

Historians of science, it should be noted, find the absence of a traditional marketplace less disruptive, for their subjects have seldom,

[26] Philippe Contamine, *War in the Middle Ages*, trans. Michael Jones (Oxford, 1984), pp. 179–84; and Kelly DeVries, *Medieval Military Technology* (Lewiston, N.Y., 1992), pp. 95–110.

[27] Hugh G. J. Aitken, *Syntony and Spark: The Origins of Radio* (New York, 1976), and *The Continuous Wave: Technology and American Radio, 1900–1932* (Princeton, N.J., 1985). This insistence is surprising in a scholar who had written so insightfully on technological change in the nonmarket environment of a government arsenal; see his *Taylorism at Watertown Arsenal: Scientific Management in Action* (Cambridge, Mass., 1960).

[28] Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore, 1980).

until recent times, been driven by market forces. Across time, science has been driven by church and state, by private patrons, by sheer curiosity, and by education. Only in recent times has the commercial marketplace provided much incentive. In this regard, science is much more like the military than is technology.

Thus, historians of science and historians of technology have tended to handle the absence of a marketplace differently. For historians of science, military support is simply another form of patronage. It carries all the questions that traditional forms of patronage have carried. What autonomy can the scientist maintain? Will the research be pure or applied? Is the level of support commensurate with the strings that are attached? What is the institutional setting of the research—a private laboratory or a government arsenal? To these are added the increasingly urgent question of the morality of military research. From the moral certitude of Fritz Haber to the moral ambivalence of J. Robert Oppenheimer, scientists in the 20th century have ranged across the entire spectrum of ethics and politics in their search for a comfortable and defensible position.[29] While the search goes on, some scientists accept military funding, others eschew it, and most worry about it.

For historians of technology, the absence of a traditional marketplace has greater implications. How, for example, can one explain the evolution of the computer without measuring the role of the military?[30] In such a story, what forces are driving events? Surely not the market alone, for some of the products never enter the market; furthermore, government subsidy of research and development, to say nothing of government purchasing policies, distorts the market irretrievably. Surely, it is not the public consumer alone, for often the government is the only consumer, a situation of monopsony. In such an environment, evolutionary theories of technological development may prove to have more power than market theories, for they treat the entire environment in tracing technological change and

[29] L. F. Haber, *The Poisonous Cloud: Chemical Warfare in the First World War* (Oxford, 1986); Herbert F. York, *The Advisors: Oppenheimer, Teller and the Superbomb* (Stanford, Calif., 1989).

[30] I. Bernard Cohen, "The Computer: A Case Study of the Support by Government, Especially the Military, of a New Science and Technology," in *Science, Technology and the Military*, ed. Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart, 2 vols. (Dordrecht, 1988), 1:119–54. See also Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology* (Washington, D.C., 1988); Herman H. Goldstine, *The Computer from Pascal to von Neumann* (Princeton, N.J., 1993).

lives and the lives of their subordinates on that technology. Arms and equipment that had been proven in battle were bound to appear more secure and trustworthy than new technology yet to win its spurs. Indeed, Morison went so far as to argue in another article that we would do well to recognize "the destructive energy in machinery." His examination of the navy's skepticism about the revolutionary warship *Wampanoag* after the American Civil War presents naval conservatism in a new light, almost as an early aversion to the dangers of autonomous technology.[35]

The great irony about traditional military conservatism toward technological change is that it reversed itself completely after World War II. This was the first war in which the weapons deployed at the end were significantly different from those with which it was launched; the most familiar examples are jet aircraft, ballistics missiles, proximity fuses, and, of course, the atomic bomb. These developments convinced the services that the desideratum of modern war was shifting from industrial production to technological development. The next war would be won in the research laboratory fully as much as the factory. Thus began the hothouse environment of military research and development that produced the international arms race, military-industrial complexes here and abroad, and the expansion of military interest and funds into new realms such as computers, communications, spaceflight, microelectronics, astrophysics, and a host of other fields. Scientists and engineers took up positions of power and influence in government, two of them—Harold Brown and William Perry—rising to become Secretary of Defense. Indeed, so enthusiastic and intemperate did the services become in their quest for new technology that institutional barriers had to be erected between them and their suppliers.[36]

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The final distinguishing characteristic of this field of scholarship is a growing confusion about the boundaries of the topic. As Hacker has noted in his presentation at Madison and elsewhere, war and the

[35] Morison, "Men and Machinery," in *Men, Machines, and Modern Times*, pp. 98–122; quotation at p. 120.

[36] The Advanced Research Projects Agency (ARPA) was created in 1958 with just this purpose in mind, as was the office of the Director of Defense Research and Engineering. Both institutions have survived numerous organizational transformations to perform essentially the same function today, though ARPA has become more of a promoter of technology than a screen.

military are not the same thing.[37] Military institutions are those social constructs put up by states to prepare for and conduct war. In turn, war is organized, armed conflict between states. Though practitioners are wont to talk about military science and the art (i.e., the technique) of war, in fact there is very little science or technology in war. War, as John U. Nef was at pains to argue over forty years ago, is a consumer of science and technology and a destroyer of the social and institutional bases from which they spring.[38] Military institutions, however, are another matter. Since earliest recorded history, the military has stimulated and promoted the development of science and technology.

Though it may seem to be mere sophistry to distinguish between war and the military, the distinction is neither trivial nor unimportant. Throughout history states have chosen a place for themselves on a spectrum ranging from warlike to peaceful. Those that chose to live by war—Assyria is the prototype—naturally cultivated the tools of war. Many states that preferred a less aggressive policy were nonetheless compelled by their neighbors to defend themselves. They too developed instruments of war. Until modern times, war was, in Machiavelli's phrase, the first business of the prince. To the extent that science and technology were state-supported, they were as likely as not to be supported for military purposes. Eratosthenes said that the main reason for doing cube roots was to calculate the settings for ballistae.[39] Dionysius I of Syracuse set up the first-known research and development laboratory in order to develop siege equipment.[40] Archimedes is reported to have turned his considerable talents to the defense of Syracuse. Even apparently civilian technologies, such as monumental architecture and road building, were often driven by military purpose. War consumed science and scientists, technology and technologists. But military institutions in preparation for war were among the principal patrons of these activities.[41]

[37] Barton C. Hacker, "Military Institutions, Weapons, and Social Change: Toward a New History of Military Technology," *Technology and Culture* 35 (October 1994): 768–834.

[38] John U. Nef, *War and Human Progress: An Essay on the Rise of Industrial Society* (Cambridge, 1950).

[39] Werner Soedel and Vernard Foley, "Ancient Catapults," *Scientific American* 240 (March 1979): 159.

[40] Brian Caven, *Dionysius I: War-Lord of Sicily* (New Haven, Conn., 1990), pp. 94–95.

[41] A. Rupert Hall, *Ballistics in the Seventeenth Century: A Study in the Relations of Science and War with Reference Principally to England* (Cambridge, 1952); Robert K. Merton, *Science, Technology and Society in Seventeenth-Century England* (1938; reprint, New York, 1970).

In modern times, the relationship between the state and war has changed. War may remain in the minds of many the first business of the state, but it is no longer the main business of the state. The role of the military as a consumer and promoter of science and technology has shifted accordingly, but the new pattern is filled with contradictions. In the United States, for example, things military account for only 23 percent of federal expenditures, but in 1985 the military accounted for approximately 60 percent of the federal government's research and development.[42] The Department of Defense now costs the federal government less than social security and less than Health and Human Services with social security left out; by the end of the century, it is projected to cost the federal government less than the interest on the national debt. At the same time, however, it also provides more support for research and development than all other government agencies combined. If one accepts the argument of Walter McDougall and others that government activities such as the space program and the Department of Energy are really quasi-military manifestations of the Cold War, and if one adds the so-called black budget that is hidden in other budget categories, then the figures would change significantly. In all cases, however, military funding has a proportionally larger impact on research and development than military spending has on the national budget.

Some generalizations seem warranted. Military institutions continue to play a large role in many aspects of national life, though not as large in the United States as at the height of the Cold War. Because science and technology have become ever more important in modern war, the military plays a disproportionate role in their development. The military-industrial complex is likely, therefore, to remain fertile ground for research by historians of science and historians of technology. But the distinction between things military and civilian is becoming increasingly blurred, and traditional definitions of these realms will likely prove increasingly inadequate. A quick perusal of the list of "critical technologies" recently identified by the Department of Defense will suggest how porous the barrier between military and civilian has become: semiconductor materials and microelectronic circuits, software engineering, high-performance computing, machine intelligence and robotics, simulation and modeling, photonics, sensitive radar, passive sensors, signal and image processing, signature control, weapon system environment, data fusion, computational fluid dynamics, air-breathing propulsion, pulsed power, hypervelocity projectiles and propulsion, high energy–density materials, com-

[42] Jacques S. Gansler, *Affording Defense* (Cambridge, Mass., 1991), p. 214.

posite materials, superconductivity, biotechnology, and flexible manufacturing.[43]

Any attempt to fit these technologies into traditional notions of the tools of war is bound to fail. The focus must become the military as a social institution, one that plays an enormously important but very complex role in the development of science and technology.

* * *

The preceding catalog of distinguishing characteristics notwithstanding, it is important to note that technology and war as a field of study probably has more in common with other branches of technology than it has differences. First, it is important to remember that the term "technology" is a product of the 17th century, "scientist" a product of the 19th. Though the phenomena we now call science and technology have existed throughout human history, they were not understood in earlier ages in the same sense we now understand them. So too with military science and technology. Though we now think of these fields as the desiderata of modern warfare, ancient practitioners did not. They may well have deployed what we would now call science and technology, but they seldom thought of these fields as the primary source of military power. In that respect, these fields are like other branches of the history of science and technology, ranging from medicine to manufacture to astronomy. Practitioners used their understanding and manipulation of the material world to help do their business, but they hardly thought about science and technology as conceptually distinct categories of human activity that were to be deployed as a precondition of successful healing or producing or studying—let alone successful fighting.

Another similarity is that technology has grown more important in warfare in the period since the Industrial Revolution. Quincy Wright argued that technology became the most important determinant of war after the introduction of gunpowder, from about 1500 on.[44] Few other scholars would go quite that far, though most who study the subject allow the importance of the gunpowder revolution. The real change came in the 19th century. Since then, great-power war has been measured in industrial production. And in the 20th century, technological innovations have often been closely tied to scientific research, from gas warfare to electronics, from materials research

[43] National Research Council, Commission on Engineering and Technical Systems, Board on Army Science and Technology, *Star 21: Strategic Technologies for the Army of the Twenty-First Century* (Washington, D.C., 1992), pp. 277–80.

[44] Quincy Wright, *A Study of War* (Chicago, 1942; reprint, 1965).

their "dream of power," these were the "engines of fulfillment."[47] For good or ill, the technology of war has become increasingly important to an understanding of the evolution of Western civilization.

And the distinction between things military and civilian is disappearing. Soldiers worry about the erosion of the warrior ethic as they become managers of violence. Civilians worry about the militarization of society as war and preparation for war spread from the military-industrial complex into hitherto pristine corners of our social fabric. And science and technology find themselves increasingly permeated by military influences and increasingly subverted to military purposes. The list of critical technologies reproduced in the previous section suggests that military and civilian considerations are becoming indistinguishable. So too is the history of technology and war likely to become indistinguishable from any other history of technology.

[47] Mumford, *Technics and Civilization* (n. 6 above), p. 40.