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Technology and War: A Bibliographic Essay

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Smith, Merritt Roe. *Military Enterprise and Technological Change: Perspectives On the American Experience.*
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War and technology have influenced every era of man's history; the literature that addresses them is vast. This essay will discuss only those works, mostly books, that have taken as their primary focus (or at least as a major theme) the interrelationship of war and technology. These will be mostly English-language books dealing with the history of the Western world. The purpose is to convey some sense of the range of this field and a sampling of the literature.[1]

The historiography of war and the historiography of technology share many characteristics. Both are seen by many traditional historians as outside the mainstream of historical scholarship, at least in the United States. Neither, for example, appears in the list of traditional "Fields of Specialization" in the American Historical Association *Guide to Departments of History*. Both are viewed with some suspicion in academic circles—military history because things military are distasteful and the history of technology because it appears esoteric or antiquarian or trivial or all of the above. Both are viewed as lacking scholarly rigor and intellectual substance, in part for good reason: some of the early writers in both fields were buffs and enthusiasts, more intent on communicating their own predilections than on surveying their topics critically and analytically.[2] A suspicion attaches to both fields that advocates write their history, a notion akin to assuming that a historian of medicine endorses the plague by studying it. Both fields require specialized knowledge, of the principles of war on the one hand and the nature of technology on the other. Neither requirement is as demanding as it seems, but both contribute to the isolation of the fields. Finally, both fields are growing more popular on American campuses, as war and technology grow more intrusive and important in contemporary life.

In some ways the two fields are different. Military history is older and more established, boasting a richer literature, a larger following, and a greater impact on traditional scholar-

1. Many of the works cited here were first brought to my attention in my graduate colloquium in military history. I am indebted to Kevin Anastas, Jack Atwater, John Bonin, Steve Chiabotti, Winston Choo, David Hogan, Yue Yeong Kwan, Jui Ping Ng, and James Pearson for their contributions. The following colleagues read the entire essay in draft and provided useful criticisms and suggestions: Robert Durden, I. B. Holley, Jr., Thomas P. Hughes, William McNeill, Thomas Misa, Richard Preston, Theodore Ropp, Merritt Roe Smith, and John TePaske.

2. Theodore Ropp chastises me for ignoring the buffs and enthusiasts who, often because of their enthusiasm, made important contributions in both fields. His point is well taken; unfortunately, there have been, I believe, too few of these.

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ship. The history of technology, emerging as a distinct field only in the last quarter-century, is still finding its way. Small enough to function more or less coherently as a community of scholars, the field is self-consciously seeking a common agenda and scholarly respectability and influence. One measure of its success is that *Technology and Culture,* the journal of the Society for the History of Technology, has already set a scholarly standard unmatched by journals of military history.

Bibliographic Aids

It is not surprising, therefore, that the best bibliographic introduction to the literature on the history of war and technology may be found in the latter field. Eugene Ferguson's 1968 *Bibliography of the History of Technology* carries very few entries under "Military Technology," but this volume nevertheless opens up the field.[3] In his introduction, Ferguson credits Brooke Hindle for suggesting to him that few books are readily identifiable as military technology because these topics are intertwined throughout the rest of the literature on technology. Military issues appear throughout the history of technology, just as technology appears often in military history. So Ferguson's entire volume is a source for material on the relationship between war and technology.[4] This pattern is also true for the "Current Bibliography in the History of Technology," prepared annually by Jack Goodwin for the April issue of *Technology and Culture,* though there the entries under "Military Technology" are fuller than in Ferguson, partly because they include periodical literature, partly because more work is now being done in the field.

The military side of technology is not entirely devoid of bibliographic aids. Robin Higham's *A Guide to the Sources of British Military History* contains two remarkably informed and detailed essays by W. H. G. Armytage, covering the period up to 1914, and an essay by Ronald W. Clark on the period from 1919 to 1945.[5] Higham's *A Guide to the Sources of United States Military*

3. Cambridge, MA: Society for the History of Technology and the MIT Press, 1968.

4. Incidentally, Brooke Hindle's *Technology in Early America: Needs and Opportunities for Study* (Chapel Hill: University of North Carolina Press, 1966) contains some excellent material on military technology.

5. Berkeley, CA: University of California Press, 1971. See W. H. G. Armytage, "The Scientific, Technological and Economic Background to 1815," pp. 167–207; and "Eco-

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History contains essays on science and technology by Edward C. Ezell for the nineteenth century and Carroll Pursell for the twentieth century, as does its supplement.[6] Robert G. Albion's *Naval and Maritime History* is especially good on covering military and civilian topics together, a reflection of the nature of the field and the literature it has attracted.[7] Technology is less easy to find in John E. Jessup, Jr. and Robert W. Coakley's *A Guide to the Study and Use of Military History,* but it is there.[8]

Classic Surveys

As is often true in the history of technology, several of the classic works on technology and war have been written by economic historians. Two of these are in a class by themselves. Werner Sombart's *Krieg und Kapitalismus,* volume two of his *Studien zur Entwicklungsgeschichte des modernen Kapitalismus,*[9] argues that war has had a positive influence on the evolution of modern capitalism, industrialization, and technology. War, in Sombart's view, has stimulated invention, investment, production, and innovation, with second-order consequences that spread far beyond military goods and services. John U. Nef attempted to refute Sombart in his *War and Human Progress: An Essay on the Rise of Industrial Civilization.*[10] Real material progress, according to Nef, arises not from physical plants and actual production, but from the emergence of new ideas. These in turn are stimulated by the advance of knowledge, by the free

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nomic, Scientific, and Technological Background for Military Studies, 1815–1914," pp. 251–98; and Ronald W. Clark, "Science and Technology, 1919–1945," pp. 542–65. Fill in World War I with Cyril Falls, *War Books: A Critical Bibliography* (London: P. Davies, 1930), dated but still useful for its extensive annotations.

6. Hamden, CT: Archon Books, 1975. See Edward C. Ezell, "Science and Technology in the Nineteenth Century," pp. 185–215; and Carroll W. Pursell, Jr., "Science and Technology in the Twentieth Century," pp. 269–91. See also the comparable sections in Robin Higham and Donald J. Mrozeck eds., *A Guide to the Sources of United States Military History; Supplement I* (Hamden, CT: Archon Books, 1981), pp. 44–55, 69–71.

7. Fourth ed.; rev. and expanded; Mystic, CT: Munson Institute of American Maritime History, 1972. There are, of course, other guides, but none so helpful as these for identifying technological topics in a military context. The *Air University Index,* for example, is especially good on recent military periodical literature, but weak on history, as is William M. Arkin, *Research Guide to Current Military and Strategic Affairs* (Washington, D.C.: Institute for Policy Studies, 1981).

8. Washington, D.C.: United States Army, 1979.

9. Munich: Duncker and Humblot, 1913. This volume has not been translated into English, but its main thesis appears in Waldemar Kaempffert, "War and Technology," *The American Journal of Sociology* 46 (January 1941): 431 ff.

10. Cambridge, MA: Harvard University Press, 1950.

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travel and communication of thinkers, by peaceful settings in which ideas can be nurtured and developed. War disrupts all these activities, says Nef, and creates a superficial and false impression of technical advance by using up the accumlated ideas of the past in an orgy of production without renewing the supply. Far from being conducive to technological advance, war is destructive of it, in more important ways than the physical devastation it brings. Neither Sombart nor Nef entirely proves his case, but between them they have posed the most profound question about the relationship between war and technology. Lamentably, the debate has made little progress in the last thirty years.[11]

Another economic historian, at least by training, is Lewis Mumford, whose classic *Technics and Civilization* deals extensively with military topics.[12] This eloquent, idiosyncratic, and provocative book, which still reads well, raises many of the concerns that scholars and intellectuals still have with technology and the military: their authoritarian bent, their dehumanizing influences, and their capacity—indeed power—for tyranny. Mumford also recognized the close, at times symbiotic, relationship between war and technology not only in modern times but throughout Western history. In this regard he anticipated what most others realized only after the experience of World War II.

Quincy Wright, a specialist in international relations, headed a group at the University of Chicago in the 1930s that produced *A Study of War*.[13] Wright developed a theory of the evolution of warfare that saw man move from animal through primitive and historic into what he called modern warfare. The dominant factors in these four periods were, respectively, biological forces or human nature, sociological forces, international law, and finally technology. Wright actually came to believe that in the period after the Renaissance the technology of war was the main, though not the only, factor in determining when, why, and where war would break out and how it would be conducted. His study trained and influenced a whole generation of scholars, like John U. Nef and Bernard Brodie, who

11. An exciting exception to this generalization is the work of Clive Trebilcock. See, for example, his " 'Spin-off' in British Economic History: Armaments and Industry, 1760–1914," *Economic History Review* 22 (December 1969): 474–90.

12. New York: Harcourt, Brace, 1934.

13. Subtitled *With a Commentary on War Since 1942* (2d ed.; Chicago: University of Chicago Press, [1942] 1965).

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would bring the same breadth and interdisciplinary approach to their studies of war and technology.

In some respects Wright's hypothesis on the relationship of technology and war had been anticipated by an economist, a Warsaw banker named Ivan S. Bloch. His study, *The Future of War in Its Technical, Economic, and Political Relations,*[14] predicted that the new technology of war, combined with the economic and political resources at the disposal of the modern state, would make war vastly more destructive and pointless than at any other time in human history. He had read the lessons of the nineteenth century, the age of what Wright was to call technological warfare, more clearly than most of his contemporaries, but his warning went largely unheeded.

Lynn White, Jr. belongs in a class by himself. He made the history of technology intellectually respectable with his classic *Medieval Technology and Social Change.*[15] In that volume, and in other studies before and after it, he demonstrated the significance and legitimacy of studying the relationship between war and technology. War was by no means the only context for his investigations of technology, but he demonstrated that technology was worth studying in whatever setting it emerged. Just as war was an important aspect of medieval life, so too was it an important setting for the evolution of technology.

Though not himself trained as an economic historian, William H. McNeill has entered this category with his *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000.* Expanding his earlier *The Rise of the West* and *Plagues and People,*[16] McNeill here undertakes to study the political, social, and economic consequences of the ways in which states, especially those in the West, have organized and equipped themselves for war. He attributes the economic and military preeminence of the West to the emergence of free market economies in the late middle ages, replaced in more modern times—especially the twentieth century—by "command technology," the systematic

14. Trans. by R. C. Long (New York: Garland Publishing, [1899] 1972). This is actually a translation of the sixth and last volume of his major study, *Budushchaia Voĭna.*

15. Oxford: Oxford University Press, 1962. See also his works cited in n. 177 below.

16. Chicago: University of Chicago Press, 1982; Chicago: University of Chicago Press, 1963; and Garden City, NY: Doubleday, 1976. Many of the citations appearing in this essay first came to my attention in *The Pursuit of Power.* For the source of one of McNeill's most provocative theses, see Frederic C. Lane, *Profits from Power: Readings in Protection, Rent and Violence-Controlling Enterprises* (Albany: State University of New York, 1979).

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manipulation of the sinews of war by the state for the purposes of the state. This provocative and wide-ranging book will likely set the agenda in this field for many years to come. Its rich and erudite argument echoes the tone of early Lewis Mumford, casts serious doubt on the thesis of John U. Nef, and elaborates the argument of Carlo Cippola.

Cippola, another economic historian, is among those who have taken war and technology as the focus of somewhat narrower studies. He argues in *Guns, Sails, and Empires: Technological Innovation and the Early Phases of European Expansion, 1400–1700* that European mastery of cannons and sailing vessels enabled the European explorers to establish hegemony over the entire coastal world.[17] A comparable work, in both theme and quality, is Daniel R. Headrick, *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century.*[18] V. J. Parry and M. E. Yap have collected a set of revealing essays on the evolution of *War, Technology and Society in the Middle East.*[19] Several scholars have addressed these issues from a variety of perspectives in Monte D. Wright and Lawrence J. Paszck, eds., *Science, Technology, and Warfare: Proceedings of the Third Military History Symposium, 8–9 May 1969.*[20] Elting E. Morison has built upon his study of Admiral Sims and naval gunnery (see below) in several insightful essays in *Men, Machines, and Modern Times* and *From Know-How to Nowhere; The Development of American Technology.*[21]

Others have focused on war and included large doses of technology in their analyses. G. N. Clark's *War and Society in the Seventeenth Century* is especially strong on the relationship of war to the emerging scientific movement.[22] In *The Military Revolution, 1560–1660* Michael Roberts examines how a technological revolution in gunpowder weapons led to a thoroughgoing revolution in the methods of conducting war.[23] Joseph P. Smaldone, in *Warfare in the Sokoto Caliphate: Historical and Sociological*

17. New York: Minerva, 1966.

18. New York: Oxford University Press, 1981.

19. London: Oxford University Press, 1975.

20. Washington, D.C.: Office of Air Force History, Headquarters USAF, and United States Air Force Academy, 1971.

21. Cambridge, MA: The MIT Press, 1966; and New York: Basic Books, 1975.

22. Cambridge: Cambridge University Press, 1958.

23. Belfast: Queens University Press, 1956. See also *Essays in Swedish History* (London: Weidenfeld & Nicolson, 1967). See also Geoffrey Parker, "The 'Military Revolution' 1550–1660—a Myth?" *Journal of Modern History* 48 (June 1976): 195–219.

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Perspectives, analyzes the effects of changing military technology, including transportation and communications, on the nature of warfare in the Western Sudan from 1790 to 1963.[24] Yigael Yadin engages his own talents as a soldier and archaeologist to explore *The Art of Warfare in Biblical Lands in Light of Archaeological Study,* an analysis rich in artifactual evidence.[25] Klaus Knorr has attempted to evaluate *The War Potential of Nations,* one ingredient of which is technology.[26] J. M. Winter's edited collection *War and Economic Development* delivers more technology than its title suggests.[27]

Some others have produced broad surveys that pay unusual attention to war and technology. Good examples are William H. McNeill, *The Rise of the West: A History of the Human Community*[28] and David S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present.*[29] Both are models of how the history of technology and war may be profitably woven into a survey of a larger topic. Among the surveys of the history of technology, *Technology in Western Civilization* by Melvin Kranzberg and Carroll W. Pursell, Jr. stands out for the strength of its military contributions.[30] This may well be a reflection of initial sponsorship of the project by the United States Armed Forces Institute, which was in search of a text "to explain the critical role of technology in our present society."[31]

The Traditional Weapons Surveys

The most familiar form in which studies of technology and war appear are the survey histories of weapons. Most of these limit themselves to the evolution of the weapons themselves, rather narrowly defined. The best of them analyze the influence of the weapons on war but seldom mention the influence of the weapon on civilian technology. In general these are military

24. London: Cambridge University Press, 1977.

25. New York: McGraw-Hill, 1963.

26. Princeton: Princeton University Press, 1956. See also his *Military Power and Potential* (Lexington, MA: Heath Lexington Books, 1970).

27. Cambridge: Cambridge University Press, 1975.

28. Chicago: University of Chicago Press, 1963.

29. London: Cambridge University Press, 1969.

30. 2 vols.; New York: Oxford University Press, 1967.

31. Ibid., vol. II, p. vi. Sadly and ironically, R. R. Palmer's contribution on military technology is uncharacteristically weak.

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histories that pay little attention to the relationship between the military and civilian communities.

Among those that attempt to survey all of Western history, none is entirely satisfactory. The best of the available works is Bernard N. Brodie and Fawn Brodie, *From Crossbow to H-Bomb.*[32] This study is weak on the period before the nineteenth century and concentrates more on science than technology, but it is the most thoughtful and technically informed. Tom Wintringham and J. N. Blashford-Snell's *Weapons and Tactics* is the best of the studies that attempt to link, from the earliest times, the changing nature of warfare to the evolution of weaponry.[33] Though it lacks documentation, it presents an interesting cyclical theory of warfare that has real insights. J. F. C. Fuller's *Armament and History* is in the same category.[34] Trevor N. Dupuy's *The Evolution of Weapons and Warfare* is in a class by itself, a disappointing encyclopedic collection of fascinating information that fails to trace the evolution promised in its title.[35]

Other studies focus more narrowly on shorter time periods or more limited ranges of weapons. Early arms and armor have attracted scores of writers, often buffish and antiquarian. Among the best of these are R. Ewart Oakeshott, *The Archaeology of Weapons: Arms and Armor from Prehistory to the Age of Chivalry*;[36] H. Robinson, *The Armour of Imperial Rome*;[37] Anthony M. Snodgrass, *Arms and Armour of the Greeks*;[38] C. J. Ffoulkes, *Arms and Armament: A Historical Survey of the Weapons of the British Army*;[39] Howard L. Blackmore, *British Military Firearms, 1670–1850*;[40] and O. F. G. Hogg, *Clubs to Cannon: Warfare and Weapons before the Introduction of Gunpowder.*[41]

32. Rev. and enl. ed.; Bloomington, IN: Indiana University Press, 1973. See also P. E. Cleator, *Weapons of War* (New York: Thomas Y. Crowell, 1968).

33. Harmondsworth, Eng.: Penguin Books, 1973. This is an update of Wintringham's *The Story of Weapons and Tactics from Troy to Stalingrad* (Boston: Houghton Mifflin, 1943). See also Jac Weller, *Weapons and Tactics: Hastings to Berlin* (London: Nicolas Vane, 1966); and A. V. B. Norman and Don Pottinger, *A History of War and Weapons, 499 to 1660* (New York: Crowell, 1966).

34. Subtitled *A Study of the Influence of Armament on History From the Dawn of Classical Warfare to the Second World War* (New York: Scribner's Sons, [1945] 1960).

35. Indianapolis: Bobbs-Merrill, 1980. See also Edwin Tumis, *Weapons: A Pictorial History* (Cleveland: World Publishing Co., 1954).

36. New York: Praeger, 1960.

37. New York: Scribner's, 1975.

38. Ithaca, NY: Cornell University Press, 1967.

39. London: G. Harrap & Co., 1945.

40. London: H. Jenkins, 1961.

41. London: Gerald Duckworth & Co., 1968. See also Charles Boutell, *Arms and Ar-*

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Some weapons have received individual attention. Artillery has been studied, sometimes in conjunction with fortifications, in Eric W. Marsden's two-volume *Greek and Roman Artillery*;[42] Bryan Hugh St. John O'Neill, *Castles and Cannon: A Study of Early Artillery and Fortification in England*;[43] Warren Ripley, *Artillery and Ammunition of the Civil War*;[44] and O. F. G. Hogg, *Artillery: Its Origin, Heyday, and Decline.*[45] The bow is analyzed in Robert Hardy, *Longbow: A Social and Military History,*[46] which deals with the Hundred Years' War, and more broadly by Victory Hurley in *Arrows Against Steel: The History of the Bow.*[47] The definitive work on the crossbow is still Ralph W. F. Payne-Gallwey, *The Crossbow: Medieval and Modern, Military and Sporting: Its Construction, History, and Management.*[48] Tanks are examined in Richard M. Ogorkiewicz, *Armour,*[49] and in Basil H. Liddel-Hart, *The Tanks: The History of the Royal Tank Regiment and Its Predecessors, Heavy Branch, Machine-Gun Corps, Tank Corps, and Royal Tank Corps, 1914–1945,* the best piece of historical scholarship by one of the great military historians of our time.[50]

Several specialized studies defy categorization. Basil Perronet Hughes, *Firepower: Weapons Effectiveness on the Battlefield, 1630–1850,* examines one of the most important aspects of modern warfare during the period in which it was emerging in its contemporary form.[51] John Ellis, *A Social History of the Machine Gun,* traces the impact of this modern weapon on the people

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mour in Antiquity and the Middle Ages (London: Cassell, Petter & Galpin, 1869); Robert Held, *The Age of Firearms: A Pictorial History* (New York: Harper, 1957); James D. Lavin, *A History of Spanish Firearms* (New York: Arco Publishing, 1965); and George C. Stone, *A Glossary of the Construction, Decoration and Use of Arms and Armour in All Countries and All Times* (New York: Jack Brussel, [1934] 1961).

42. Subtitled *Historical Development* (Oxford: Clarendon Press, 1969) and *Technical Treatises* (Oxford: Clarendon Press, 1971). See also Barton C. Hacker, "Greek Catapults and Catapult Technology: Science, Technology, and War in the Ancient World," *Technology and Culture* 9 (January 1968): 34–50; and Ralph W. F. Payne-Gallwey, *A Summary of the History, Construction and Effects in Warfare of the Projectile-Throwing Engines of the Ancients, with a Treatise on the Structure, Power and Management of Turkish and Other Oriental Bows of Medieval and Later Times* (London: Longmans, Green, 1907).

43. Oxford: Clarendon Press, 1960.

44. New York: Van Nostrand, 1970.

45. Hamden, CT: Archon Books, 1970.

46. New York: Arco Publishing, 1976.

47. New York: Mason/Charter, 1975.

48. London: Longmans, 1903.

49. London: Stevens & Sons, 1960.

50. 2 vols; New York: Praeger, 1959.

51. New York: Scribner's, 1975.

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who used it and the people it was used against.[52] Robert V. Bruce, *Lincoln and the Tools of War,* describes the unprecedented extent to which this president became involved in the development and employment of weapons and provides an excellent example of how war brings out all manner of geniuses and crackpots with ideas for new and "decisive" weapons.[53] E. T. C. Werner, *Chinese Weapons,* makes use of the linguistic roots of weapons' names to reach conclusions about early Chinese weaponry.[54] Chemist J. R. Partington traces the early development and interrelationship of two important weapons components in his ill-organized but authoritative *A History of Greek Fire and Gunpowder.*[55]

Nonweapons Technology

The technology of war, however, entails more than just weapons and armament. Armies need almost everthing civilian populations do: food, clothing, shelter, medicine, communication, transportation—all of which have peculiar technologies. Furthermore, armies perform some special functions (besides fighting) that may or may not have civilian parallels: engineering, cryptography, chemical and biological warfare, etc.

Logistics comes quickly to mind as a noncombat dimension of military activity that has always been indispensable to success on the battlefield. An overall view of this topic may be found in Hawthorne Daniel, *For Want of a Nail: The Influence of Logistics on War.*[56] A narrower but more scholarly treatment appears in Martin Van Creveld, *Supplying War: Logistics from Wallenstein to Patton,* a well-documented study emphasizing supply and transportation but concentrating more on World War II than its title suggests.[57] Donald W. Engels employs exhaustive scholarship, interdisciplinary research, and a good measure of common sense to unravel the story of *Alexander the Great and the Logistics*

52. New York: Pantheon, 1975. See also G. S. Hutchinson, *Machine Guns: Their History and Tactical Employment* (London: Macmillan, 1938).

53. Indianapolis: Bobbs-Merrill, 1956. Merritt Roe Smith recommends Carl L. Davis, *Arming the Union: Small Arms in the Union Army* (Port Washington, NY: Kennikat Press, 1973) and Grady McWhiney and Perry D. Jamieson, *Attack and Die: Civil War Military Tactics and the Southern Heritage* (University, AL: University of Alabama Press, 1982).

54. Shanghai: The Royal Asiatic Society North China Branch, 1932.

55. Cambridge: Heffer, 1960.

56. New York: Whittlesay House, 1948.

57. London: Cambridge University Press, 1977.

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of the Macedonian Army, and in the process destroys some myths and lends credence to J. F. C. Fuller's assertion that "supply was the basis of Alexander's strategy and tactics."[58] Equally distinguished scholarship graces Geoffrey Parker's *The Army of Flanders and the Spanish Road, 1567–1659: The Logistics of Spanish Victory and Defeat in the Low Countries Wars,* a model of social history that succeeds in explaining Spanish military experience in the Low Countries without addressing any battles or campaigns.[59] James A. Huston's *The Sinews of War: Army Logistics, 1775–1953* is a volume in the U.S. Army historical series limited to American experience.[60] Richard Goff has studied the logistics of the South in the Civil War in *Confederate Supply,*[61] and R. Arthur Bowler has done the same for the British in the American Revolution in *Logistics and the Failure of the British Army in America, 1775–1783.*[62]

Military transportation has received more attention than most other fields of military technology. Railroads are a special case. Dennis Showalter's *Railroads and Rifles: Soldiers, Technology, and the Unification of Germany* is a model of how effectively war and technology can be integrated in historical studies with findings that reach far beyond the battlefield.[63] Denis Bishop and Keith Dans have studied *Railways and War before 1918,*[64] and D. W. Ronald and J. R. Carter have provided detailed coverage of *The Longmoor Military Railway,* including doctrine, training of operators and maintenance personnel, and technical information on British engines and rolling stock.[65] Nor are these modern studies the only worthwhile books in the field.[66]

58. Berkeley: University of California Press, 1978, quote from page 1, citing J. F. C. Fuller, *The Generalship of Alexander the Great* (London: EYRE & Spottiswoode, 1958), pp. 52–53. Some of the statistical assumptions in the study warrant scrutiny, but this hardly compromises the overall value of the work.

59. Cambridge: Cambridge University Press, 1972.

60. Washington, D.C.: Office, Chief of Military History, Department of the Army, 1966.

61. Durham, NC: Duke University Press, 1969.

62. Princeton: Princeton University Press, 1974.

63. Hamden, CT: The Shoe String Press, 1975.

64. New York: Macmillan, 1972.

65. Newton Abbot [Eng.]: David and Charles, 1974.

66. See also H. R. Richardson, *Railroads in Defense and War* (Washington, D.C.: Bureau of Railway Economics Library, 1953); Edwin A. Pratt, *The Rise of Rail Power in War and Conquest, 1833–1914, with a Bibliography* (London: P. S. King and Son, 1916); T. H. Thomas, "Armies and the Railway Revolution," in *War as a Social Institution: The Historian's Perspective,* ed. by J. D. Clarkson and T. C. Cockran (New York: Columbia University Press, 1941).

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A more generalized study of military transportation is Forest G. Hill's *Roads, Rails and Waterways: The Army Engineers and Early Transportation,* which is also strong on the relationship between military and civilian activity.[67] More specialized studies are John Maurice Brereton, *The Horse in War,*[68] and Odie B. Faulk, *The U. S. Camel Corps: An Army Experiment.*[69] Other work on military transportation is scattered; for example, R. J. Forbes' treatment of land transport and roads, including Persian and Greek military land communications and the evolution of Roman roads, appears in volume 2 of his *Studies in Ancient Technology.*[70]

Military architecture has received less attention than it deserves, given its influence on civilian architecture. Horst De La Croix, *Military Considerations in City Planning: Fortifications,*[71] and Keith Mallory and Arvid Ottar, *The Architecture of War,*[72] are among the few that have paid attention to the civilian aspects of this issue. For surveys see Sidney Toy, *A History of Fortifications from 300 B. C to A. D. 1700*;[73] Ian V. Hogg, *Fortress: A History of Military Defense*;[74] and James Quentin Hughes, *Military Architecture.*[75] More specialized treatments include Christopher Duffy's two complementary volumes, *Siege Warfare* and *Fire and Stone,*[76] and two revisionist studies: Byron Tsangadas's *The Fortifications and Defense of Constantinople*[77] and Vivian Rowe's *The Great Wall of France: The Triumph of the Maginot Line.*[78] Some of the original classics in the field can also be

67. Norman, OK: University of Oklahoma Press, 1957. See also Hill's "Formative Relations of American Enterprise, Government and Science," *Political Science Quarterly* 75 (September 1960): 400–419.

68. Newton Abbot [Eng.]: David and Charles, 1976.

69. New York: Oxford University Press, 1976.

70. 9 vols.; Leiden: E. J. Brill, 1955–1964.

71. New York: G. Braziller, 1972.

72. New York: Pantheon Books, 1973. This volume, which has interesting material on concrete, the geodetic dome, prefabrication, and high-speed road networks, is unfortunately limited to the first half of the twentieth century.

73. London: Heinemann, 1955.

74. London: MacDonald and Jones, 1975.

75. London: Evelyn, 1974. See also the chapter on fortifications in Albert Neuberger, *The Technical Arts and Sciences of the Ancients,* trans. by Harry L. Brose (London: Methuen, 1930).

76. Subtitled, respectively, *The Fortress in the Early Modern World, 1494–1660* (London: Routledge & Kegan Paul, 1979) and *The Science of Fortress Warfare, 1660–1860* (Newton Abbot [Eng.]: David and Charles, 1975).

77. East European Monographs, No. 71 (New York: Columbia University Press, 1980).

78. London: Putnam, 1959.

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rewarding; see, for example, Sebastien Le Prestre Vauban, *A Manual of Siegecraft and Fortification,*[79] and Eugene Emmanuel Viollet-Le-Duc, *Military Architecture.*[80]

Cryptography has attracted much attention in recent years, largely because of the revelation that the Allies had broken the German code during World War II. In this case not only did a technology influence the conduct of the war, but knowledge of the technology is also altering the historiography of the event. David Kahn's *The Codebreakers: The Story of Secret Writing* provides a general historical survey.[81] On the breaking of the German code in World War II, see F. W. Winterbotham, *The Ultra Secret*;[82] Reginald Victor Jones, *The Wizard War: British Scientific Intelligence, 1939–1945*;[83] and Ronald Lewin, *Ultra Goes to War.*[84] Chemical and biological warfare is another topic currently in the news; the best work is Frederick J. Brown, *Chemical Warfare: A Study in Restraints.*[85]

Other topics that have received noteworthy historical treatment are as varied as the nature of war and the preparation for war. In the field of weaponry are Malvern Lumsden's *Incendiary Weapons,*[86] and Constance McLaughlin Green, Harry C. Thompson, and Peter C. Roots, *The Ordinance Department: Planning Munitions for War,* one of the more thoughtful and analytical volumes in the Army series on World War II.[87] Alfred Price's *Instruments of Darkness: The History of Electronic Warfare* addresses an important but secrecy-enshrouded topic.[88] David MacIsaac has analyzed the effects of strategic bombing on military and civilian targets in *Strategic Bombing in World War Two:*

79. Trans. by A. Rothrock (Ann Arbor: University of Michigan Press, 1968).

80. Trans. by M. Macdermott (London: James Parker, 1879).

81. New York: Macmillan, 1968.

82. New York: Harper and Row, 1974.

83. New York: McCann and Geoghegan, 1978.

84. New York: McGraw-Hill, 1978.

85. Princeton: Princeton University Press, 1968. See also Steven Rosse, *CBW: Chemical and Biological Warfare* (Boston: Beacon Press, 1969); Samuel P. Jones, "From Military to Civilian Technology: The Introduction of Tear Gas for Civil War Control," *Technology and Culture* 19 (April 1978): 151–68; and John H. Perkins, "Reshaping Technology in Wartime: The Effect of Military Goals on Entomological Research and Insect-control Practices," ibid., pp. 169–86.

86. Cambridge, MA: The MIT Press, 1975.

87. Washington, D.C.: Department of the Army, 1955. Other volumes in the series on Technical Services are rich in materials on technology, though not all are of this caliber.

88. London: MacDonald and Jones, 1977.

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The Story of the Strategic Bombing Survey.[89] Brian Pearce suggests the potential of a sadly neglected topic in "Elizabethan Food Policy and the Armed Forces."[90] Much more work is needed in this area and in others like medicine, engineering, sanitation, clothing, communication, and electronics.

Naval and Air Forces

Navies and air forces have a special relationship with technology, for the vehicles in which they conduct their missions are complex machines, usually embodying the most sophisticated technology of their day. Men can fight on land with the most primitive equipment, in fact with no equipment at all, but fighting on or under the sea or in the air requires technical support. Thus it is that navies, and later air forces, have always been more alive to technology than their land-based counterparts, which does not mean they have necessarily been more progressive.[91] Furthermore, ships and planes may carry both guns and butter: many advances in maritime and aeronautical science and engineering affect both civilian and military applications. Ideas flow more freely between the two realms, and many craft often find use in both peace and war. Thus the institutions that foster technological progress at sea and in the air often mix civilian and military purposes.

Naval warfare has been conducted in three great eras, defined by the ships that dominated them: galley, sail, and steam. Some histories cover all, or most, of these periods. Bjorn Landström's *The Ship*[92] is the best of these, but it may be profitably supplemented with Philip Cowburn, *The Warship in History.*[93] On galley warfare see R. C. Anderson, *Oared Fighting*

89. New York: Garland Publishing, 1976. *The United States Strategic Bombing Survey* (339 vols.; Washington, D.C., 1945-1947), on which Dr. MacIssac based his study, is itself a remarkable resource for historians investigating the resistance of modern industrial society to the effects of conventional weapons.

90. *Economic History Review* 12 (1942): 39–45.

91. See, for example, Lance C. Buhl, "Marines and Machines: Resistance to Technological Change in the American Navy, 1865–1869," *Journal of American History* 61 (December 1974): 703–27, and the works by Elting Morison cited below.

92. Garden City, NY: Doubleday, 1961.

93. New York: Macmillan, 1965. Viking craft were a special case; see A. W. Brøgger and Haakon Shetelig, *The Viking Ships: Their Ancestry and Evolution,* trans. by Katherine John (Oslo: Dreyers Forlag, 1953).

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Ships, from Classical Times to the Coming of Steam[94] and John F. Guilmartin's brilliant and stimulating *Gunpowder and Galleys: Changing Technology and Mediterranean Warfare at Sea in the Sixteenth Century,*[95] a work to place beside Frederic C. Lane's classic *Venetian Ships and Shipbuilding of the Renaissance.*[96] Romula Anderson and R. C. Anderson have treated sail in all ages in *The Sailing Ship: Six Thousand Years of History,*[97] while its greatest exploitation in war has been addressed by E. H. H. Archibald in *The Wooden Fighting Ship in the Royal Navy, A.D. 879–1860* and by C. N. Longridge, *The Anatomy of Nelson's Ships.*[98] The transition to the age of steam is analyzed in James P. Baxter's classic *The Introduction of the Ironclad Warship.*[99] The best survey is Bernard Brodie, *Sea Power in the Machine Age,*[100] to be complemented by Edgar C. Smith, *A Short History of Naval and Marine Engineering,* which is especially strong on the relation of civil to military developments.[101] Richard G. Hewett and Francis Duncan have extended the story into the *Nuclear Navy, 1946–1962.*[102]

Specialized studies in naval technology abound. In the vast literature of submarines, mines, and torpedoes, see especially J. S. Cowie, *Mines, Minelayers, and Minelaying*;[103] Alex Roland, *Underwater Warfare in the Age of Sail*;[104] and two biographies of

94. London: P. Marshall, 1962. See also John W. Morrison and R. T. Williams, *Greek Oared Ships, 900–322 B.C.* (London: Cambridge University Press, 1968); and Lionel Casson, *The Ancient Mariners: Seafarers and Sea Fighters of the Mediterranean in Ancient Times* (New York: Macmillan, 1959).

95. London: Cambridge University Press, 1974.

96. Baltimore: Johns Hopkins Press, 1934. See also Lane's "The Crossbow in the Nautical Revolution of the Middle Ages," *Explorations in Economic History* 7 (Fall 1969–1970): 161–71; this too sheds light on the transition from galley to sail.

97. London: George G. Harrap, 1926.

98. London: Blanford Press, 1968; London: Percival Marchall, 1955. See also G. J. Marcus, *Heart of Oak: A Survey of British Seapower in the Georgian Era* (London: Oxford University Press, 1975); and Howard I. Chapelle, *The History of the American Sailing Navy: The Ships and Their Development* (New York: Norton, 1949).

99. Cambridge, MA: Harvard University Press, 1933. See also Frank M. Bennett, *The Monitor and the Navy Under Steam* (Boston: Houghton, Mifflin, 1900).

100. Princeton: Princeton University Press, 1941.

101. Cambridge: Printed for Babcock and Wilcox Ltd. at the University Press, 1937. See also Brian Ranft, ed., *Technical Change and British Naval Policy, 1800–1939* (London: Hodder and Stoughton, 1977); Oscar Parkes, *British Battleships "Warrior" 1860 to "Vanguard" 1950: A History of Design, Construction and Armament* (rev. ed.; London: Seeley Service, 1966); and Stanley Sandler, *The Emergence of the Modern Capital Ship* (Newark: University of Delaware Press, 1979).

102. Chicago: University of Chicago Press, 1974.

103. London: Oxford University Press, 1949.

104. Bloomington, IN: Indiana University Press, 1978.

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key inventors: Edwin Gray, *The Devil's Device: The Story of Robert Whitehead, Inventor of the Torpedo,*[105] and Richard K. Morris, *John P. Holland, 1841–1914: Inventor of the Modern Submarine.*[106] Navigation is treated from Ulysses to Captain Cook in E. G. R. Taylor, *The Haven-Finding Art,*[107] and more narrowly in David W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times.*[108] The insatiable appetite of sailing navies for good wood and the effects of this on civilian economies are treated in Robert G. Albion's classic *Forests and Sea Power: The Timber Problem of the Royal Navy, 1652–1862*[109] and in Paul W. Bamford, *Forests and French Sea Power, 1660–1789.*[110] Naval arms and armament are covered broadly in P. Padfield, *Guns at Sea,*[111] and more narrowly in Michael Lewis's revisionist study, *Armada Guns: A Comparative Study of English and Spanish Armaments.*[112] J. J. Keevil has addressed an otherwise neglected topic in *Medicine and the Navy: 1200–1900,*[113] as has Sir Arthur Hezlet in *The Electron and Sea Power.*[114] The collection of pieces by Ken J. Hagan and others on *Naval Technology and Social Modernization in the Nineteenth Century* fits no particular category but is representative of the best scholarship that is currently being done.[115]

The literature on the technology of military flight is more vast than profound. More than any other military field save heraldry, this one is still dominated by buffs and tail-number counters. Still, there are enough significant exceptions to this

105. London: Seeley, 1975.

106. Annapolis, MD: United States Naval Institute Press, 1966. See also John D. Alden, *The Fleet Submarine in the U.S. Navy: A Design and Construction History* (Annapolis, MD: United States Naval Institute Press, 1979).

107. New York: Abeland-Schulman, 1957.

108. New Haven, CT: Yale University Press, 1958. See also Rupert T. Gould, *The Marine Chronometer: Its History and Development* (London: The Holland Press, 1960); and Humphrey Quill, *John Harrison: The Man Who Found Longitude* (London: Baker, 1966).

109. Cambridge, MA: Harvard University Press, 1926.

110. Toronto: University of Toronto Press, 1956.

111. New York: St. Martins, 1974. See also Frederick L. Robertson, *The Evolution of Naval Armament* (London: Constable, 1921).

112. London: George Allen and Unwin, 1961. Lewis concludes it was seamanship and logistics that gave victory to the English, not guns, which did comparatively little damage. See also Herman T. Wallinga, *The Boarding Bridge of the Romans: Its Construction and Its Function in the Naval Tactics of the First Punic War* (Groningen, Neth.: J. B. Wolfers, 1956), for an instance of a revolutionary, once secret, and often decisive weapon.

113. 4 vols.; London: E&S Livingstone, 1957.

114. New York: Stein and Day, 1975.

115. Manhattan, KS: *Military Affairs* and the American Military Institute, 1976.

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sad rule to provide a useful introduction to the field. The best of the general surveys is Ronald Miller and David Sawers, *The Technical Development of Modern Aviation,* in spite of its emphasis on civilian aviation.[116] Complement this with John D. Anderson, Jr., *Introduction to Flight: Its Engineering and History* (a technical text with brief historical sketches);[117] *Research and Development Contributions to Aviation Progress (RADCAP): Joint DoD-NASA-DoT Study*;[118] and J. L. Nayler and E. Ower, *Aviation: Its Technical Development,* for the British view.[119] Robert Schlaifer and R. D. Heron, *Development of Aircraft Engines and Aviation Fuels,*[120] remains the best work on aviation propulsion, to be supplemented with L. J. K. Setright, *The Power to Fly: The Development of the Piston Engine in Aviation,* [121] and Edward Constant's thoughtful and analytical *The Origins of the Turbojet Revolution.*[122] Institutions that have fostered the technical development of aviation are treated in George W. Gray, *Frontiers of Flight: The Story of NACA Research*[123] and Percy B. Walter, *Early Aviation at Farnborough: The History of the Royal Aircraft Establishment.*[124] Monte Wright's *Most Probable Position: A History of Aerial Navigation to 1941* does for flying what Taylor and Waters have done for sailing.[125]

Procurement

Nowhere does the military have a greater impact on technology—including civilian technology—than in procurement. It is

116. New York: Praeger, 1970.

117. New York: McGraw-Hill, 1978.

118. Washington, D.C.: Department of Defense, National Aeronautics and Space Administration, Department of Transportation, 1972. Though this volume reaches just the conclusions one would expect from its sponsors, it is probably accurate nonetheless and has the virtue of postulating a list of the major advances in aeronautical technology.

119. Philadelphia: Dufours Editions, 1965.

120. Subtitled *Two Studies of Relations between Government and Business* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1950; Elmsford, NY: Maxwell Reprint Co., 1970).

121. London: George Allen & Unwin, 1971.

122. Baltimore: Johns Hopkins University Press, 1980.

123. New York: Alfred A. Knopf, 1948. See also Alex Roland's *Model Research: The National Advisory Committee for Aeronautics, 1915–1958* (2 vols.; Washington, D.C.: NASA, 1985).

124. 2 vols.; London: MacDonald, 1971–1974. For a glimpse into the world of the aircraft designer, a crucial but little-known figure in aviation development, see E. H. Heinemann and Rosario Rausa, *Ed Heinemann: Combat Aircraft Designer* (Annapolis, MD: United States Naval Institute Press, 1980).

125. Lawrence, KS: University of Kansas Press, 1972.

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here that military needs and specifications determine what and how the civilian economy will produce. Sometimes the military will simply buy what is available on the civilian market; more often it will insist upon custom-made materials, produced either by civilian firms under contract or by its own arsenals. The research to develop new and better products for military use is supported in the same two ways. In any case, the military often acts as the major purchasing and subsidizing arm of the national government, developing and buying technology on a scale that dwarfs most private enterprise.

Studies of arms manufacture comprise the classic form of military history in this field. Charles J. Ffoulkes's richly informed studies of gunfounding in Europe have served as something of a model for this kind of study and have held up well.[126] A more recent study, employing the latest rubrics of scholarship and addressing questions of contemporary concern to historians of technology, is Melvin H. Jackson and Carel de Beer, *Eighteenth Century Gunfounding: The Verbruggens at the Royal Brass Foundry: A Chapter in the History of Technology.*[127] I. B. Holley's monumental *Buying Aircraft: Matériel Procurement for the Army Air Forces,* another volume of official history in the Army series on World War II, is a model of meticulous research and exhaustive analysis of one of the most arcane yet crucial facets of modern military experience.[128] J. A. Stockfisch provides a more popular, broad-ranging survey of the hazards of modern military procurement in *Plowshares into Swords: Managing the American Defense Establishment.*[129]

Perhaps the most interesting issue in military procurement is the choice between contracting out to civilians and producing materials directly in government arsenals. On this topic generally, see M. M. Postan, D. Hay, and J. D. Scott, *The Design and Development of Weapons: Studies in Government and Industrial*

126. *The Armourer and His Craft from the 11th to 15th Century* (New York: B. Blom, [1917] 1967); and *The Gun-Founders of England, with a List of English and Continental Gun-Founders from the XIVth to the XIXth Centuries* (Cambridge: Cambridge University Press, 1937).

127. Washington, D.C.: Smithsonian Institution Press, 1974. See also Claude Gaier, *Four Centuries of Liège Gunmaking* (London: Eugène Wahle and Sotheby Parke Bernet, 1977) on an early-modern center of European arms manufacture; and Fritz Redlich, *The German Military Enterpriser* (2 vols.; Weisbaden: F. Steiner, 1964) on mercenaries, with some attention to arms manufacture and sale.

128. Washington, D.C.: Office of the Chief of Military History, Department of the Army, 1964.

129. New York: Mason and Lipscomb, 1973.

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Organization;[130] and Tibor Scitovsky, Edward Shaw, and Lorie Tarshis, *Mobilizing Resources for War: The Economic Alternatives.*[131] Arsenals (and much else besides) are addressed in one of the most distinguished studies in the history of technology in recent years, Merritt Roe Smith's *Harpers Ferry Arsenal and the New Technology: The Challenge of Change,*[132] which may be profitably complemented by Edward Ames and Nathan Rosenberg, "Enfield Arsenal in Theory and History,"[133] and by several European studies: O. F. G. Hogg, *The Royal Arsenal: Its Background, Origin, and Subsequent History*;[134] H. A. Young, *The East India Company's Arsenals and Manufactories*;[135] and P. M. J. Conturie, *Histoire de la fonderie nationale de Ruelle, 1750–1940, et des anciennes fonderies de canons de fer de la marine.*[136] On contracting see Philip Noel-Baker, *The Private Manufacture of Armaments.*[137] Traditional studies of specific experiences, like Felicia Johnson Deyrup, *Arms Making in the Connecticut Valley*;[138] John Anderson Miller, *Men and Volts at War: The Story of General Electric in World War II*;[139] and Frank E. Vandiver, *Ploughshares into Swords: Josiah Gorgas and Confederate Ordnance,*[140] should be supplemented with investigations of war profiteering [141] and histories of industries with close ties to the military.[142] Closely related to contracting are the entrepeneurs, whose careers make for fascinating biography. In addition to the numerous

130. London: HMSO, 1964.

131. New York: McGraw-Hill, 1951. See also Arthur Forbes, *A History of the Army Ordnance Services* (3 vols.; London: Medici Society, 1929).

132. Ithaca, NY: Cornell University Press, 1977. See also Russell I. Fries, "British Response to the American System: The Case of the Small Arms Industry after 1850," *Technology and Culture* 16 (July 1975): 377–403.

133. *Economic Journal* 78 (December 1968): 827–42.

134. 2 vols.; London: Oxford University Press, 1963.

135. Oxford: Clarendon Press, 1939.

136. Paris: Impr. nationale, 1951.

137. 2 vols.; New York: Oxford University Press, 1937.

138. Subtitled *A Regional Study of the Economic Development of the Small Arms Industry, 1798–1870* (York, PA: Shumway, 1970).

139. New York: Whittlesay House, McGraw-Hill, 1947.

140. Austin: University of Texas Press, 1952.

141. For example, Richard F. Kaufman, *The War Profiteers* (Garden City, NY: Doubleday, 1972); and Berkeley Rice, *The C-5A Scandal: An Inside Story of the Military Industrial Complex* (Boston: Houghton Mifflin, 1971).

142. For example, Arthur Pine VanGelder and Hugo Schlater, *History of the Explosives Industry in America* (New York: Arno Press, [1927] 1972); and Alan P. Cartwright, *The Dynamite Company: The Story of African Explosives and Chemical Industries Limited* (Cape Town: Purnell, 1964).

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studies of the Krupp and Vickers dynasties,[143] see Charles B. Dew, *Ironmaker to the Confederacy: Joseph R. Anderson and the Tredegar Iron Works*;[144] Leonard A. Swann, Jr., *John Roach, Maritime Entrepeneur: The Years as Naval Contractor, 1862–1866*;[145] and Thomas P. Hughes's model study of *Elmer Sperry: Inventor and Engineer,* whose remarkable career moved in and out of military contracting.[146]

World War II and the Cold War

The influence of technology on war (not to be confused with the influence of war on technology) has undergone three great revolutions in the course of Western history. The gunpowder revolution is treated in the weapons surveys cited above. The second came with the industrial revolution and played itself out between the Napoleonic wars and World War II. During this period machine weapons increased long-range firepower dramatically, expanded the size of the battlefield, gave an advantage to the defensive, and turned large-scale conflicts into wars of industrial mobilization. World War II, itself a conflict of industrial attrition, precipitated a third revolution in the technology of war by instituting an era in which the quality of military technology, more than the quantity of industrial production, was widely viewed as the most important predictor of success in the next war. The technological era that Quincy Wright saw beginning with the industrial revolution did not really come into full flower until his study was published. After World War II technology really did become a prime determinant of how and why wars would start, and traditional military conservatism toward new weapons was transferred almost overnight into an enthusiasm for new and better weapons and a technological arms race of such rapid pace that obsolescence became its hallmark.

143. Gert von Klass, *Krupp: The Story of an Industrial Empire,* trans. by James Cleugh (London: Sidgwick and Jackson, 1954); William Manchester, *The Arms of Krupp, 1587–1968* (Boston: Little, Brown, 1968); Bernhard Menne, *Blood and Steel: The Rise of the House of Krupp,* trans. by G. H. Smith (New York: L. Furman, 1938); Wilhelm Bardrow, *The Krupps: 150 Years of Krupp History* (Berlin: P. Schmidt, 1937); J. D. Scott, *Vickers: A History* (London: Weidenfeld and Nicolson, 1962); and Clive Trebilcock, *The Vickers Brothers: Armaments and Enterprise, 1854–1914* (London: Europa, 1977).

144. New Haven, CT: Yale University Press, 1966.

145. Annapolis, MD: United States Naval Institute Press, 1965.

146. Baltimore: Johns Hopkins University Press, 1971. See also Alden Hatch, *Remington Arms: An American History* (New York: Rinehart, 1956); and H. W. Dickinson's short but suggestive *John Wilkinson: Ironmaster* (Ulverstone: Hume Kitchin, 1914).

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The sources of the revolution may be found in the history of World War II itself. Alan Milward treats the war "as an economic event" in *War, Economy and Society, 1939–1945,*[147] and argues that in modern, capital-intensive wars like WWII, economics—and by extension technology—is decisive. The story of traditional industrial mobilization is presented in such studies as Michael M. Postan, *British War Production,*[148] and Robert Howe Connery, *The Navy and Industrial Mobilization in World War II.*[149] But the real difference in this war occurred in the systematic harnessing of science and technology to the needs of the state, as described in James Phinney Baxter, III, *Scientists Against Time*;[150] James G. Crowther and R. Widdington, *Science at War*;[151] and Guy Hartcup, *The Challenge of War: Britain's Scientific and Engineering Contribution to World War II.*[152] Studies of individual developments may be found in such books as Louis F. Fieser, *The Scientific Method* (napalm);[153] Ralph B. Baldwin, *The Deadly Fuze: Secret Weapon of World War II* (proximity fuse);[154] and Robert Morris Page, *The Origins of Radar.*[155] Of course, the great weapons revolution of World War II, the one that really set the tone for the postwar world, was the development of the atomic bomb, described most ably in two official histories: Richard G. Hewlett and Oscar E. Anderson, Jr., *The New World, 1939–1946,*[156] and Margaret Gowing, *Britain and Atomic Energy, 1939–1945.*[157]

147. Berkeley: University of California Press, 1979.

148. History of the Second World War, United Kingdom civil series (London: HMSO, 1952).

149. Princeton: Princeton University Press, 1951; New York: Capo Press, 1972.

150. Boston: Little, Brown, 1946.

151. New York: Philosophical Library, 1948.

152. New York: Taplinger, 1970. See also Leslie E. Simon, *Secret Weapons of the Third Reich: German Research in World War II* (2d ed.; Old Greenwich, CT: We Inc., 1971); and Ronald W. Clark, *The Rise of the Boffins* (London: Phoenix House, 1962). Compare these with Carol S. Gruber, *Mars and Minerva: World War I and the Uses of the Higher Learning in America* (Baton Rouge; Louisiana State University Press, 1975).

153. New York: Distributed by Reinhold Publishing, 1964.

154. San Rafael, CA: Presidio Press, 1980.

155. Garden City, NY: Doubleday, 1962. See also David Kite Allison, *New Eye for the Navy: The Origin of Radar at the Naval Research Laboratory,* NRL Report 8466 (Washington, D.C.: Naval Research Laboratory, 1981); and Albert Percival Rowe, *One Story of Radar* (Cambridge: Cambridge University Press, 1948); both of which focus on the institutional setting in which these developments took place and the relationship of those institutions with the scientific community in academia. And see Reader's Digest Association, *The Tools of War 1939/1945, and a Chronology of Important Events* (Montreal: RDA, 1969).

156. Vol. 1 of A History of the Atomic Energy Commission (University Park: Pennsylvania State University Press, 1962).

157. London: Macmillan, 1964. See also Henry deWolf Smyth, *Atomic Energy for Mili-*

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With the topic of atomic energy, the story of the relation between war and technology slides quickly into the period of the Cold War.[158] The literature increases exponentially as experts in science, technology, government, political science, international relations, national security, management, economics, and public policy join historians in analyzing the relationship between war and technology. This essay cannot hope to sample even the best of this literature, let alone provide a comprehensive survey. It can, however, mention two areas that have attracted some of the best scholarship and suggest (in the following section) some of the most interesting themes that are emerging in the literature and prompting reexamination of previous eras in the light of contemporary experience.

The handmaiden of nuclear weapons has been the missile, which transformed these unprecedented devices of destruction into virtually unstoppable ones. The roots of this story and the technology at work can be traced in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility.*[159] The critical role played by Wernher von Braun is best recorded by Frederick I. Ordway III and Mitchell R. Sharpe in *The Rocket Team.*[160] The development of this technology into a military weapon is thoughtfully analyzed in Edmund Beard, *Developing the ICBM: A Study in Bureaucratic Politics,*[161] and Harvey M. Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Government.*[162] Ernest J. Yanarella has investigated the integration of technology into national policy in *The Missile Defense Controversy: Strategy, Technology, and Politics, 1955–1972.*[163]

How to get the maximum military advantage from the new

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tary Purposes: The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government, 1940–1945 (Princeton: Princeton University Press, 1945); Leslie R. Groves, *Now It Can Be Told: The Story of the Manhattan Project* (New York: Harper, 1962); David Irving, *The German Atomic Bomb: The History of Nuclear Research in Nazi Germany* (New York: Simon and Schuster, 1968); and Arnold Kramish, *Atomic Energy in the Soviet Union* (Stanford: Stanford University Press, 1959).

158. See, for example, the sequels to the volumes of official history cited above: Richard G. Hewlett and Francis Duncan, *The Atomic Shield, 1947–1952* (Chicago: University of Chicago Press, 1974); and Margaret M. Gowing, *Independence and Deterrence: Britain and Atomic Energy, 1945–1952* (2 vols.; New York: St. Martin's Press, 1974).

159. Detroit, MI: Wayne State University Press, 1964.

160. New York: Crowell, 1979.

161. New York: Columbia University Press, 1972. See also Ernest G. Schwiebert, *A History of the U.S. Air Force Ballistic Missiles* (New York: Praeger, 1965).

162. Cambridge, MA: Harvard University Press, 1972.

163. Lexington:University Press of Kentucky, 1977.

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technology of nuclear weapons and missiles has attracted the widest variety of scholarship. Among the better overviews are Bernard Brodie, *Strategy in the Missile Age*;[164] John Erickson, *The Military-Technical Revolution: Its Impact on Strategy and Foreign Policy*;[165] and Stefen Possony and J. E. Purnelle, *The Strategy of Technology: Winning the Decisive War.*[166] A unique perspective is provided in Herbert York's lively and insightful *Race to Oblivion: A Participant's View of the Arms Race*;[167] his forthcoming history of weapons development in the Cold War may prove to be the definitive work in the field. An observation by York prompted the title of Mary Kaldor's *The Baroque Arsenal,* a biased but penetrating study of the built-in obsolescence and dysfunction of today's most sophisticated weapons.[168]

Military Themes

Military historians have achieved no explicit consensus on the important themes in the study of technology and war. Most who address this topic treat it tangentially. Those who take it as their primary focus have emphasized the effect of weapons on combat. Only a handful have dealt with topics like logistics, industrial mobilization, procurement, and innovation, at least for the period before World War II. For the postwar period, a flood of studies have swamped the field without yet carving out a clearly defined new landscape. This general lack of consensus makes the few themes that have emerged all the more striking.

The military-industrial complex is the most familiar theme, and in some ways the most representative, for it provides a clear example of postwar interests being projected back into earlier periods to reveal new insights. Numerous studies have examined the topic in its postwar setting: for example, Stephen Rosen, ed., *Testing the Theory of the Military-Industrial Complex,*[169]

164. Princeton: Princeton University Press, 1959. Brodie was one of the first to see clearly the consequences of the atomic bomb; see his "War in the Atomic Age' in Bernard Brodie, ed., *The Absolute Weapon* (New York: Harcourt Brace Jovanovich, 1946).

165. New York: Praeger, 1966.

166. New York: Dunellan, 1970. This is the most extreme work, arguing a kind of technological determinism.

167. New York: Simon and Schuster, 1970. See also his "Military Technology and National Security," *Scientific American* 221 (August 1969): 17–29.

168. New York: Hill and Wang, 1981.

169. Lexington, MA: Lexington Books, D. C. Heath, 1973.

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and Carroll W. Pursell, Jr., ed., *The Military-Industrial Complex.*[170] Others like Benjamin Franklin Cooling and Paul A. C. Koistinen have convincingly demonstrated that the phenomenon had a long history before President Eisenhower, in his 1960 farewell address, gave it the currency it now enjoys.[171] Many of the studies are highly critical of the military-industrial complex in its modern form and take on the air of exposés: Ralph E. Lapp, *Arms Beyond Doubt: The Tyranny of Weapons Technology,*[172] and H. L. Nieburg, *In the Name of Science*[173] are in this category, as is Berkeley Rice, *The C5-A Scandal: An Inside Story of the Military Industrial Complex.*[174] Others like Kenneth S. Davis, W. Henry Lambright, and Jacques S. Gansler, view the topic more dispassionately.[175] At least one author has essayed a defense of the military-industrial complex.[176] The issue seems to be turning not on whether the military-industrial complex exists, but on whether it works very well, whether it produces security commensurate with its cost, and whether it is in any event too powerful and subversive a force to be in the long-term best interests of the republic. The same questions may be profitably asked of other societies and other times in which close cooperation has grown up between the state and the manufacturers of arms.[177]

170. New York: Harper & Row, 1972.

171. Benjamin Franklin Cooling, *War, Business, and American Society: Historical Perspectives on the Military Industrial Complex* (Port Washington, NY: Kennikat Press, 1977); and *Gray Steel and Blue Water Navy: The Formative Years of America's Military-Industrial Complex, 1881–1917* (Hamden, CT: Shoe String Press, 1979); Paul A. C. Koistinen, *The Military-Industrial Complex: A Historical Perspective* (New York: Praeger, 1980).

172. New York: Crowell, 1970. See also his *The Weapons Culture* (New York: W. W. Norton, 1968).

173. Chicago: Quadrangle Books, 1966.

174. Boston: Houghton Mifflin, 1971. See also Seymour Melman's *Pentagon Capitalism: The Political Economy of War* (New York: McGraw Hill, 1970) and *The Permanent War Economy: American Capitalism in Decline* (New York: Simon and Schuster, 1974).

175. Davis, *Arms, Industry and America* (New York: H. H. Wilson Company, 1971); Lambright, *Shooting Down the Nuclear Airplane* (Indianapolis: Bobbs Merrill, 1967); and Gansler, *The Defense Industry* (Cambridge, MA: The MIT Press, 1980). See also J. A. Stockfisch, *Plowshares into Swords.* The F-111 evoked similar studies: Robert F. Art, *The TFX Decision: McNamara and the Military* (Boston: Little, Brown, 1968); and Robert Coulam, *Illusions of Choice: The F-111 and the Problem of Weapons Acquisition Reform* (Princeton: Princeton University Press, 1977).

176. John Stanley Baumgartner, *The Lonely Warriors: Case for the Military-Industrial Complex* (Los Angeles: Nash Publishing, 1970).

177. Of course, this issue is closely tied to procurement, discussed above. See the works cited there, and the modern classic, Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1962).

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No topic in the historiography of technology and war has been dominated so thoroughly by one scholar as has doctrine by I. B. Holley, Jr. In his classic *Ideas and Weapons,* he virtually invented the field, demonstrating in a study of American aircraft in World War I that new technologies will not be exploited fully until a doctrine is developed prescribing their use in war.[178] His work is now widely cited, especially in the aviation literature, and his ideas have been incorporated in many recent studies. Of course other works have treated this topic independently of Dr. Holley's example,[179] but much remains to be done.

Military engineering antedates civililan engineering by centuries, and engines of war gave the profession its name; yet studies of military engineers are sadly lacking. The ambitious U.S. Army Corps of Engineers Historical Program is beginning to fill this gap for the United States, including in its agenda a forthcoming *Biographical Dictionary of the U.S. Army Corps of Engineers, 1775–1980.* Yet most of the studies done and projected are institutional and programmatic histories, and the other services have no such undertaking in train. The richness of this neglected field has been suggested by Forest G. Hill's *Roads, Rails and Waterways: The Army Engineers and Early Transportation* and Russell F. Weigley's *Quartermaster General of the Union Army: A Biography of M. C. Meigs.*[180] More has been done on naval engineering, such as Edward W. Sloan, III, *Benjamin Franklin Isherwood, Naval Engineer: The Years as Engineer in Chief, 1861–1869*;[181] Harold G. Bowen, *Ships, Machinery, and Mossbacks: The Autobiography of a Naval Engineer*;[182] and Elting E. Morison, *Admiral Sims and the Modern American Navy.*[183] Among the important issues deserving further study are the creation of

178. Subtitled *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, CT: Yale University Press, 1953; Hamden, CT: Archon Books, 1971). His thesis may be profitably compared with Alfred D. Chandler's structure-strategy concept, presented in *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Belknap Press of Harvard University Press, 1977).

179. Doctrine is insightfully addressed in Liddell-Hart, *The Tanks*; and Ronald and Carter, *The Longmoor Military Railway,* to say nothing of such classics as Vauban, *A Manual of Siegecraft and Fortification.*

180. New York: Columbia University Press, 1959.

181. Annapolis, MD: United States Naval Institute Press, 1965.

182. Princeton: Princeton University Press, 1954.

183. Boston: Houghton Mifflin, 1942.

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technical schools to train career officers in engineering[184] and the relations between the engineers and the line combat officers.

Military officers were traditionally viewed as technologically conservative, often preparing to fight the last war with yesterday's weapons.[185] Since World War II they have been seen as technological enthusiasts, trading yesterday's weapons for tomorrow's without exploiting the former or understanding the latter.[186] Neither behavior is especially surprising, for the military profession has always been a life-and-death business that values the tools it knows over those that have yet to prove themselves in the test of battle, and the Cold War has upset that proclivity with a conviction that the next year will be decided by the most advanced technology. But these stereotypes need to be tested more thoroughly than they have been, and the notion of "decisive weapons" needs further scrutiny.

The influence of international law and the unwritten rules of war on the introduction and use of new military technology has received just enough scholarly attention to suggest how fruitful a field it is for further study. Maurice Keen's model study of *The Laws of War in the Late Middle Ages*[187] traces this theme in the period when modern international law was in the making. Frederick Brown focuses on it in his equally fine *Chemical Warfare: A Study in Restraints.*[188] Alex Roland has examined its application to an exotic field of weaponry in *Underwater Warfare in the Age of Sail.*[189] The names that military men gave to new weapons often suggested the moral issues surrounding their use, as is demonstrated in Edwin Gray's *The Devil's Device*[190] and Milton F. Perry's *Infernal Machines.*[191] The literature to date suggests that military communities have shied away from

184. For now see John P. Lovell, *Neither Athens nor Sparta: The American Service Academies in Transition* (Bloomington, IN: Indiana University Press, 1979).

185. See, for example, Cowie, *Mines, Minelayers, and Minelaying*; Morris, *John P. Holland*; and Morison, *Admiral Sims and the Modern American Navy.*

186. See, for example, Beard, *Developing the ICBM*; Frederic A. Bergerson, *The Army Gets an Air Force: Tactics of Insurgent Bureaucratic Politics* (Baltimore: Johns Hopkins University Press, 1980); and the works cited above for the military-industrial complex.

187. London: Routledge & Kegan Paul, 1965.

188. Princeton: Princeton University Press, 1968.

189. Bloomington, IN: Indiana University Press, 1978.

190. London: Seeley, 1975.

191. Subtitled *The Story of Confederate Submarine and Mine Warfare* (Baton Rouge: Louisiana State University Press, 1965). See also Lumsden, *Incendiary Weapons.*

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weapons they view as unmanly or unfair, but that once one side employs them, usually in desperation, the other side feels compelled to accept them as well, ratcheting ever upward the technology of violence. Established powers tend to outlaw the radical technological innovations of the aspiring nations.

The military need for secrecy imposes special constraints on the development of the technology of war. Greek fire is a classic example of a decisive weapon owing at least part of its success to secrecy. So well kept was the secret of its composition that scholars today are still unsure of its makeup, in spite of the vast amount of scholarship it has attracted.[192] Another early case study embroiled in scholarly debate is Herman T. Wallinga, *The Boarding Bridge of the Romans: Its Construction and Its Function in the Naval Tactics of the First Punic War,* which addresses among other topics the first use of a new weapon on an unsuspecting and unprepared enemy.[193] Modern examples include Simon, *Secret Weapons of the Third Reich*[194] and Baldwin, *The Deadly Fuze.*[195] Edward Constant has dealt with the extent to which excessive secrecy between different units of the same national project can retard development in *The Origins of the Turbojet Revolution*;[196] the issue appears as well in the histories of the Manhattan Project.

Several other themes that have received less attention in the literature suggest areas military historians may investigate with profit. Systems engineering and operational analysis introduced in World War II have had far-reaching effects in both military and civilian sectors, yet have received little historical analysis.[197] The moral and political position of the scientist and the engineer in the service of the state has received some attention, but far more needs to be done.[198] A special aspect of this

192. Begin with Partington, *A History of Greek Fire and Gunpowder*; and see also D. Ayalon, *Gunpowder and Firearms of the Mamluk Kingdom* (London: Frank Cass and Co., 1956).

193. Groningen, Neth.: J. B. Wolfers, 1956.

194. 2d ed.; Old Greenwich, CT: We Inc., 1971.

195. San Rafael, CA: Presidio Press, 1980.

196. Baltimore: Johns Hopkins University Press, 1980.

197. Brodie and Brodie treat this topic in *From Crossbow to H-Bomb.* See also I. B. Holley, Jr., "The Evolution of Operations Research and Its Impact on the Military Establishment; the Air Force Experience," in Wright and Paszek, eds., *Science, Technology, and Warfare,* pp. 89–109; and the commentary by Robert L. Perry, ibid., pp. 110–21.

198. See, for example, Baxter, *Scientists Against Time*; Bruce, *Lincoln and the Tools of War*; Clark, *The Rise of the Boffins*; and R. W. Reid, *Tongues of Conscience: Weapons Research and the Scientists' Dilemma* (New York: Walker, 1969).

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problem, the argument by weapons developers that they will make war horrible in order to eliminate it, has become especially important in the nuclear era, though it has deep and largely unexplored historical roots.[199] In fact, virtually all the modern issues surrounding the development and employment of the technology of war have historical antecedents worthy of study.

Technology Themes

The themes and issues historians of technology have come to focus upon lend themselves to treatment of military technology. Thomas Hughes has done more than any other scholar in the field to identify and define these themes.[200] A sampling of these issues and the military literature that pertains to them will suggest how fruitful additional research may prove.

The role of systems and institutions in technological development is nowhere more evident than in the technology of war. In fact we owe our modern appreciation of the importance of systems to the emergence of weapons systems development during and since World War II, and of course the military has always been an institutional mold forming that technology. Weapons systems are as old as warfare; Lynn White has shown how a single technological innovation like the stirrup can upset the entire military structure and usher in a revolution in warfare like the shift from foot to cavalry, with other components of the system—saddle, armor, lance, sword, and comunication—undergoing changes in turn.[201] The English longbow, gunpowder weapons, and the Swiss halberd all contributed to the termination of the resulting cavalry cycle and introduced a new tactical paradigm in which these weapons were integrated in different but still coherent fighting systems. Modern weapons systems are simply more self-conscious and more sophisticated in achieving the same ends.

Governments have always subsidized technological development by being the primary institution to stimulate the introduction of new weapons. Though most studies of this phenomenon

199. See Roland, *Underwater Warfare in the Age of Sail.*

200. See especially Thomas P. Hughes, "Emerging Themes in the History of Technology," *Technology and Culture* 20 (October 1979): 697–711; and "Convergent Themes in the History of Science, Medicine, and Technology," ibid., 22 (July 1981): 550–58.

201. White, *Medieval Technology and Social Change.*

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focus on the twentieth century, there is evidence that research on earlier periods can be just as rewarding.[202] *R & D Contributions to Aviation Progress (RADCAP): Joint DoD-NASA-DoT Study*[203] was consciously designed to show how its sponsoring agencies contributed to the advance of American aviation, both military and civilian. Numerous other studies have focused on specific government agencies in an attempt to trace their impact on weapons development. Among these might be singled out Merritt Roe Smith's *Harper's Ferry Arsenal and the New Technology,*[204] remarkable for its contrast of two different arsenals, and David Allison's *New Eye for the Navy,* which takes the institutional influence on technology as one of its major themes.[205]

Differences in national and regional style can be seen in almost any survey of international weapons development, from early swords and body armor to modern aviation and space development. Carlo Cippola has contrasted Western developments in ships and ordnance with those in the rest of the world in *Guns, Sails, and Empires.*[206] John F. Guilmartin has neatly isolated the peculiarities of Mediterranean naval warfare and their effect on the technology of the region in *Gunpowder and Galleys.*[207] Ken Hagan and his coauthors have compared and contrasted the naval technologies of Russia, China, and the United States in *Naval Technology and Social Modernization in the Nineteenth Century.*[208] Melvin Jackson and Carel de Beer have demonstrated how so minor a factor as the sulphur content in the soil can alter a region's military technology in *Eighteenth*

202. See, for example, Baxter, *Scientists Against Time*; Kendall E. Bailes, *Technology and Society under Lenin and Stalin* (Princeton: Princeton University Press, 1978); Hartcup, *The Challenge of War*; and Postan, Hay, and Scott, *The Design and Development of Weapons.* A. Rupert Hall has demonstrated the influence of guilds and governments on artillery development in *Ballistics in the Seventeenth Century: A Study in the Relations of Science and War with Reference Principally to England* (Cambridge: Cambridge University Press, 1952).

203. Washington, D.C.: Department of Defense, National Aeronautics and Space Administration, Department of Transportation, 1972.

204. Ithaca, NY: Cornell University Press, 1977.

205. NRL Report 8466 (Washington, D.C.: Naval Research Laboratory, 1981). See also Gray, *Frontiers of Flight*; Green, Thomson, and Roots, *The Ordnance Department*; Hewlett and Anderson, *The New World*; Hogg, *The Royal Arsenal*; Walter, *Early Aviation at Farnborough*; and Young, *The East India Company's Arsenal and Manufactories.*

206. New York: Minerva, 1966.

207. London: Cambridge University Press, 1974.

208. Manhattan, KS: *Military Affairs* and the American Military Institute, 1976.

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Century Gunfounding.[209] Michael Lewis has traced the effects of differing approaches to guns and tactics in *Armada Guns.*[210] Richard Ogorkiewicz's *Armor*[211] examines differences in weapons and tactics among nine countries. These studies, and many others like them, reveal how fruitful a topic national and regional style can prove to be because military technology is by definition one in which contrasting styles will find their way into direct confrontation with each other. What really needs more attention is the extent to which the transfer of ideas (another theme in the history of technology) between arms makers has produced homogenization of international weaponry and military techniques. Some work has been done in this field, but more is needed.[212]

The relation of science to technology in war and preparation for war is another fruitful theme that has received less attention than it deserves. A. Rupert Hall's *Ballistics in the Seventeenth Century* finds the science and technology of artillery, at least in that period, difficult to separate.[213] Brooke Hindle has examined the influence of war on science and science on war in the context of the American Revolution.[214] In more modern times, the Manhattan Project has proved to be a remarkably revealing case study of scientists taking the lead in weapon development—from first conception through ultimate use. As science and technology grow more dependent on each other in the contemporary world, the dividing line between their contributions will continue to blur.[215]

The Carthaginians learned the importance of appropriate

209. Washington, D.C.: Smithsonian Institution Press, 1974.

210. London: George Allen and Unwin, 1961.

211. London: Stevens & Sons, 1960.

212. See, for example, Lynn White, Jr., "Jacopo Aconcio as an Engineer," *Medieval Religion and Technology: Collected Essays* (Berkeley: University of California Press, 1978), pp. 149–73; and "The Crusades and Western Technology," ibid., pp. 277–96; Partington, *A History of Greek Fire and Gunpowder*; and Faulk, *The U.S. Camel Corps.* For an interesting departure from this theme, see Arnold Krammer, "Technology Transfer as War Booty: The U.S. Technical Oil Mission to Europe, 1945," *Technology and Culture* 22 (January 1981): 68–103.

213. See also Hall's essay "Science, Technology, and Warfare, 1400–1700," in Wright and Paszek, eds., *Science, Technology, and Warfare,* pp. 3–29.

214. Hindle, *The Pursuit of Science in Revolutionary America* (Chapel Hill: University of North Carolina Press, 1956).

215. See Fieser, *The Scientific Method*; and Charles Susskind, "Relative Roles of Science and Technology in Early Radar," *Actes,* 12th International History of Science Congress, Paris, 1965.

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technology when they first faced the Roman corvus at Mylae.[216] Chance favors not the "superior" technology nor the most sophisticated technology, but rather the technology best suited to the resources and circumstances at hand. The French were subjected to the same lesson under fire from the longbow in the Hundred Years' War[217] and behind their Maginot Line in 1940.[218] Americans encountered this problem in Vietnam, and in the eyes of some analysts are up against it now in strategic weapons.[219] But the currency of the issue should not be allowed to obscure the fact that there are countless historical examples of this phenomenon that have yet to receive adequate investigation by scholars.

Technological momentum is a common theme in modern weaponry,[220] from the overall strategic arms race itself to the endless refinement of specific weapons like the fighter plane and the tank. Similar examples are available throughout recorded history, from the accretion of layers to the fortifications around Constantinople to the proliferation of artillery types in early modern Europe. Some recent examples have received scholarly treatment, as in Edward Constant's *The Origins of the Turbojet Revolution*[221] and Thomas Hughes's insightful "Technological Momentum in History: Hydrogenation in Germany, 1893–1933,"[222] but more research is needed on earlier examples of this phenomenon and the motivations of the decisonmakers of the time.

The influence of policy on technological development is seldom more clear than in military activities. Warlike nations committed to conquest and expansion naturally adopted weapons and techniques suited to their purposes. Their neighbors often responded with fortification or imitation. Such decisions dictated the technologies that would be employed and shaped not only the nature of warfare, but also, in many cases, the nature

216. Wallinga, *The Boarding Bridge of the Romans.*

217. Hardy, *Longbow.*

218. Rqwe, *The Great Wall of France.*

219. Kaldor, *The Baroque Arsenal.* See also York, "Military Technology and National Security."

220. Thomas P. Hughes defines technological momentum as "loosely connected, mutually reinforcing components that constitute a system of vested interests involving people, institutions, ideas, and artifacts. The system has a momentum that tends to resist change and softly determine the course of events." (Personal communication.)

221. Baltimore: Johns Hopkins University Press, 1980.

222. *Past and Present* (August 1969): 106–32.

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of the society itself. Many studies investigate policy and some examine technology, but not enough analyze the relationship between the two. Bruce's *Lincoln and the Tools of War*[223] suggests the rewards of this type of investigation, as do David MacIsaac's *Strategic Bombing in World War II*[224] and Michael Armacost's *The Politics of Weapons Innovation.*[225] Comparable studies of earlier periods are needed.

Generally, in studies of major themes in the history of technology as they apply to warfare, more good work has been done on the contemporary period than on earlier times. No doubt this reflects in part the youth of the field and the fact that modern technological growth helped bring it into existence. Surely the history of contemporary military technology will continue to attract productive scholars who will contribute significantly to our understanding of this complex phenomenon. But in the plethora of modern topics, the historical community should not lose sight of the rewarding and revealing issues from earlier periods that await attention. These too have important lessons to teach, not only about the evolution of war and technology, but also about the contemporary problems we face in these intertwined fields.

223. Indianapolis: Bobbs-Merrill, 1956.
224. New York: Garland Publishing, 1976.
225. New York: Columbia University Press, 1969.

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