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Silicon Valley is frequently portrayed as a manifestation of postindustrial entrepreneurship, where ingenious inventor-businessmen and venture capitalists forged a dynamic, high-tech economy unencumbered by government's "heavy hand." Closer examination reveals that government played a major role in launching and sustaining some of the region's core industries through military contracting. Focusing on leading firms in the microwave electronics, missile, satellite, and semiconductor industries, this article argues that demand for customized military technology encouraged contractors to embark on a course of flexible specialization, batch production, and continuous innovation. Thriving throughout much of the Cold War, major military contractors fell on hard times when defense markets started to shrink in the late 1980s, because specialized design and production capabilities were rarely applicable to civilian product lines. But Pentagon funding for research and development helped lay the technological groundwork for a new generation of startups, contributing to Silicon Valley's economic renaissance in the 1990s.

Silicon Valley industries played a key role in Cold War weapons production. Santa Clara County (which was first dubbed Silicon Valley in 1971) produced all of the United States Navy's intercontinental ballistic missiles, the bulk of its reconnaissance satellites and tracking systems, and a wide range of microelectronics that became integral components of high-tech weapons and weapons systems. Aircraft like the F-16 tactical fighter could not fly, much less engage in combat, without the transistors, integrated circuits, and microprocessors that collected and processed flight data, linked the plane to

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Table 1 Largest Defense Contractors in Santa Clara County, 1990

Company	Key Products	Defense Sales (in $ Millions)	Silicon Valley Employees
Lockheed Missile and Space	Trident missile, spy satellites, strategic defense	5,100	20,000
Ford Aerospace	Satellites, communications, computers	1,200	7,000
FMC	Bradley fighting vehicle	600	4,000
GTE	Reconnaissance, electronic warfare systems	466	2,700
Westinghouse	Missile launchers	425	2,500
Electronic Systems Laboratories	Electronic reconnaissance, software	330	2,300
Watkins-Johnson	Electronic warfare products	310	3,300
United Technologies	Titan, Minuteman rocket motors	300	1,550

Source: Department of Defense, Eagle Eye Publishers, 1991.

external command, control, and communications systems, and guided "smart" bombs and missiles to their targets. Benefits were not one-sided; Silicon Valley derived considerable revenues from defense contracting. At the height of President Ronald Reagan's defense build-up, Santa Clara County netted almost $5 billion annually in military contracts, making it the third-largest recipient of Pentagon largesse among American counties. By the end of the Cold War, the region's nine largest military contractors alone reported more than $11 billion in defense contracts (see Table 1).[1]

Military contracting in Silicon Valley has received scant attention. Many executives deny its significance altogether, insisting that the region's success is the result of entrepreneurship unfettered by government's "heavy hand." A venture capitalist told the *New York Times* in October 2000, "I've worked in the valley since 1963 . . . and I don't think government ever had a role in it."[2] In 1991, when Lockheed and other prime military contractors became targets of antiwar protests, a spokesperson for the microelectronics firm Advanced Micro Devices (AMD) expressed concern "about publicity that would

1. Frank Barnaby, "Microelectronics and War," in *The Militarization of High Technology,* ed. John Tirman (Cambridge, Mass., 1984), 55–56; Fred Warshofsky, *The Chip War: The Battle for the World of Tomorrow* (New York, 1989), 335–36; Bennett Harrison, *Lean and Mean: The Changing Landscape of Corporate Power in the Age of Flexibility* (New York, 1994), 120.
2. "In Silicon Valley, Candidates Seek Both Money and 'Cool,'" *New York Times,* 3 Oct. 2000, A1.

make [AMD] look like a major player in the military-industrial complex, when [they] are not."[3] AMD was the fifth-largest direct supplier of integrated circuits to the Pentagon at the time.[4]

Students of military contracting during the 1950s and 1960s offer more critical perspectives. Stuart Leslie's and Rebecca Lowen's books on Stanford University have documented the impact of Pentagon-funded research initiatives on high-tech industries in the region.[5] Many firms were highly dependent on Pentagon contracts, as Leslie's and Christophe Lécuyer's studies of military contracting in the 1950s and early 1960s have shown.[6] We know little about the structures and dynamics of military contracting in Silicon Valley in more recent decades, however. AnnaLee Saxenian's *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*—perhaps the most important recent study of the region—fails to provide a detailed analysis of defense contracting and its significance for industrial development, technological change, and network-based industrial systems.[7] This omission, particularly regrettable because defense contracting contributed to the development of disintegrated production formats, which take center stage in Saxenian's study, reflects interpretive trends in the recent literature on high-technology regions. As Ann Markusen has pointed out,

> Most work written on the new industrial districts of Orange County, Silicon Valley, and Route 128 downplays or omits altogether the significance of government, with its peculiar demands, as market. The highly lauded "postindustrial" organization of manufacturing in these regions, with its flexible specialization and small-batch, custom-made product, is erroneously ascribed to the

3. "Some Technical Tangents in a New Kind of War," *San Francisco Chronicle*, 24 Jan. 1991, C3.

4. "Top Ten Direct Suppliers of Integrated Circuits to the U.S. Department of Defense," *Global Electronics*, Dec. 1992, p. 4.

5. Stuart Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York, 1993); Rebecca Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley, Calif., 1997); see also Stuart Leslie and Robert H. Kargon, "Selling Silicon Valley: Frederick Terman's Model for Regional Advantage," *Business History Review* 70 (Winter 1996): 435–72.

6. Stuart Leslie, "How the West Was Won: The Military and the Making of Silicon Valley," in *Technological Competitiveness: Contemporary and Historical Perspectives on the Electrical, Electronics, and Computer Industries*, ed. William Aspray (New York, 1993), 75–89; Christophe Lécuyer, "Making Silicon Valley: Engineering Culture, Innovation, and Industrial Growth, 1930–1970" (Ph.D. diss., Stanford University, 1999).

7. AnnaLee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge, Mass., 1996).

commercial sector, when in fact these attributes originated in their defense-based industries.[8]

Markusen's provocative thesis, with its wide-ranging implications for our understanding of industrial development, technological change, and government-industry relationships in high-tech economies, remains unsubstantiated. I argue that military contracting indeed played a key role in the development of custom production, disintegrated manufacturing formats, and flexible specialization in Silicon Valley.

Postwar technology strategy relied on small numbers of sophisticated weapons systems to offset Soviet numerical superiority. In the words of William Perry, a pioneer of Silicon Valley's defense industry who served as undersecretary of defense in President Jimmy Carter's administration, "[S]ince it seems likely that we will continue to be outnumbered, it is imperative that our military systems maintain a substantial performance advantage over the Soviets."[9] The resulting trend toward customized weapons and small production runs encouraged defense contractors in the missile, satellite, and electronic warfare industries to adopt batch production strategies and to develop highly specialized product lines. These firms, which have received little attention in the recent literature, pioneered the "post-industrial organization of manufacturing" in Silicon Valley.[10]

Lockheed, Watkins-Johnson, and a host of other defense contractors often were unable to convert from military to civilian production. In Silicon Valley and elsewhere, defense dependency was partly the result of unique business relations between contractors and their military customers. The Department of Defense (DOD), the armed forces, and other end-users of advanced military systems insisted on quality and performance standards that frequently ex-

8. Ann Markusen, Scott Campbell, Peter Hall, and Sabrina Dietrich, *The Rise of the Gunbelt: The Military Remapping of Industrial America* (New York, 1991), 248; see also Dennis Hayes, *Behind the Silicon Curtain: The Seductions of Work in a Lonely Era* (Boston, Mass., 1989), 101–11; Meric Gertler, Pạivi Oinas, Michael Storper, and Philip Scranton, "Round Table: Discussion of Regional Advantage: Culture and Competition in Silicon Valley and Route 128 by AnnaLee Saxenian," *Economic Geography* 71 (1995): 201.

9. Perry quoted in Leslie Brueckner and Michael Borrus, "Assessing the Commercial Impact of the VHSIC (Very High Speed Integrated Circuit) Program," BRIE Working Paper No. 5 (Dec. 1984), 8.

10. On Cold War weapons markets, see Ann Markusen and Joel Yudken, *Dismantling the Cold War Economy* (New York, 1982), 23–31; U.S. Congress, Office of Technology Assessment, *After the Cold War: Living with Lower Defense Spending* (Washington, D.C., 1992), 210–15.

ceeded the technological needs of civilian clients. Manufacturers who devoted their attention to meeting the military's high standards often lost sight of design and production costs, and their failure to limit spending was abetted by lenient procurement policies that allowed weapons builders to renegotiate contracts years after they had been signed. Moreover, specialization in advanced defense products frequently impeded contractors' ability to compete commercially. Lockheed, for example, built reconnaissance satellites and was ill prepared to succeed in commercial telecommunications satellite markets. The Pentagon often blocked attempts to commercialize sensitive military technology out of concern for national security, creating problems for firms such as Lockheed, which derived approximately half of its revenues from "black" programs, those so highly classified that their existence was not officially acknowledged.

The semiconductor industry differed markedly from the microwave electronics, electronic warfare, missile, satellite, and space electronics sectors. Defense contracting and custom technology shaped microelectronics during its formative years, but by the 1970s the industry derived only one-tenth of its sales from military contracting. National Semiconductor, AMD, and other microelectronics firms also eschewed flexible specialization and customization, banking instead on mass production of standardized devices. Only in the 1980s, when this strategy started to fail as a result of Japanese competition in markets for standardized memory chips, did Silicon Valley's commercial microelectronics industry switch to disintegrated production formats, custom technology, and flexible specialization, which had previously been mostly confined to defense-related industries. The Pentagon facilitated the region's transformation by supporting research and development of new products and processes, as well as through contracts that helped launch some of the specialty firms of the 1980s.

The reader should not construe this line of argument as an attempt to portray the region's economy as a byproduct of the Cold War and military contracting. As recent literature has shown, the rise of Silicon Valley's high-tech industries is attributable to a wide variety of factors, including an informal entrepreneurial culture, close industry-university relations in science-dependent industries, and the region's versatile venture capital institutions. Without disputing the relevance of these factors, I claim that our understanding of economic development and technological change in the region remains incomplete without a more nuanced analysis of defense contracting and, by implication, the role of the state in the making and remaking of Silicon Valley.

Microwave Electronics and Electronic Warfare

Microwave electronics—Silicon Valley's first high-tech industry—owed its existence to defense contracting and military-sponsored research at Stanford University. After World War II, Stanford's dean of engineering Frederick Terman (often called "the father of Silicon Valley") obtained Navy funding for basic and applied research on traveling wave tubes (TWT), a cutting-edge technology that evolved out of wartime research on electronic countermeasures. Terman also encouraged faculty and students to turn their research expertise and inventions into business opportunities, precipitating the formation of Hewlett-Packard, Watkins-Johnson, and other pioneers of Silicon Valley's high-tech economy. Most of these companies established research facilities in the Stanford Industrial Park (later renamed Stanford Research Park), which was formed in 1951 to provide a vital link between academic research and private enterprise.[11]

The history of Varian Associates, one of the region's pioneer microwave electronics firms, exemplifies regionwide trends. Cofounder Russell H. Varian had invented the klystron tube in the late 1930s with a $100 research grant from Stanford. Klystrons (electron microwave tubes that controlled and amplified electric signals) were well suited for radar and countermeasure applications. In 1948 Varian teamed up with his brother Sigurd to form Varian Associates, which provided klystron research and development, engineering, and manufacturing services to DOD, the armed services, government weapons laboratories, and prime weapons contractors. Its first major contract, issued by the Diamond Ordnance Fuse Laboratory in 1948, involved reflex klystrons for atomic bomb fuses. In 1951, the company acquired 10 acres in Stanford Industrial Park, where it became the first tenant, and a $1.5 million DOD loan financed the construction of a laboratory.[12]

Although Varian developed a lucrative ancillary business in scientific instruments, its main product line remained microwave tubes customized for radar, countermeasures, military communications, and space systems. In 1959, for example, it built a klystron—the largest of its kind in the world—for an early warning surveillance

11. Leslie and Kargon, "Selling Silicon Valley," 438–42.

12. Dean Witter & Co. Research Department, "Varian Associates," Sept. 1956, Papers of Russell and Sigurd Varian, box 4, folder 8, Department of Special Collections and University Archives, Stanford University Libraries, Palto Alto, Calif. [hereafter cited as SA]; Stanford University, Director of Communications, "Varian Associates," 15 Oct. 1951, Varian Associates—Military, folder 1, Corporate Collection, Pacific Studies Institute, Mountain View, Calif. [hereafter cited as CC-PSI]; Lécuyer, "Making Silicon Valley," 96–101.

system. Russell Varian also invented a free-precession magnetometer to measure Earth's total magnetic field strength in the upper atmosphere. The Navy, keenly interested in the device because it generated data for missile guidance and navigation, incorporated the magnetometer into its Vanguard satellite project, America's answer to the Soviet satellite, Sputnik. After several disastrous failures, a Vanguard 3 satellite was launched in 1959 from Cape Canaveral with a magnetometer manufactured by Varian as its principal payload.[13]

In 1963 the Pentagon temporarily reduced its purchases of klystrons and other microwave tubes, throwing the company (as well as large segments of the electronics industry) into turmoil. The immediate cause was Secretary of Defense Robert McNamara's decision to reduce the military's inventory of electronic devices as part of his attempt to reform defense procurement. Varian, whose sales to the military accounted for 65 percent of its business volume, reported a $1 million loss in 1964. The company's precarious financial situation set off a scramble to diversify into commercial markets; civilian demand for the company's main products slackened over the course of the 1960s, however, because semiconductors began to replace TWTs in many low-power applications. Varian soon found it impossible to maintain the clear research and development focus and flexible specialization strategy that had been the firm's great strengths in the 1950s. Edward L. Ginzton, the director of Stanford's microwave laboratory, elected president of Varian in 1961, launched ill-conceived mergers and acquisitions that turned the company into a conglomerate whose product lines included vacuum tubes, medical instruments, and semiconductor manufacturing equipment. By 1966, only 46 percent of total sales were military sales, and those were projected to decline to 25 percent by 1971. But the latter year brought another sharp net loss, revealing fundamental weaknesses in Ginzton's diversification strategy. His successors gradually raised the company's military sales back to 60 percent with orders for electro-optical system gear, amplifiers for Aegis-class destroyers and cruisers, night-vision equipment for aviators, and equipment for aircraft electronic countermeasures systems. By the mid-1980s Varian was a $1 billion firm with more than ten thousand employees, but industry analysts viewed it as a poorly managed company and deemed its earnings a "never-ending horror story."[14]

13. Frank E. Stoner, "The United States Electronics Industry's Contribution to National Defense," Papers of Russell and Sigurd Varian, box 2, folder 14, SA.

14. Edward L. Ginzton, "Address to the 17th Annual Meeting of Shareholders," 18 Feb. 1965, Papers of Russell and Sigurd Varian, box 5, folder 7, SA; Edward L. Ginzton, "Address to the New York Society of Security Analysts," 14 June 1966, ibid., box 4, folder 4, SA; "DMS Market Intelligence Report: Varian,"

Varian's checkered experience reflected broader trends in the region's microwave electronics industry. Seeking to capitalize on the strength of Stanford's electrical engineering program, as well as burgeoning demand for klystrons and related products, major extraregional firms established microwave electronics divisions in Santa Clara County during the 1950s, including General Electric, Admiral Corporation, Zenith, and Sylvania. Most of them did not survive the 1960s, because of ineffective corporate strategies, McNamara's procurement reforms, and the replacement of TWTs with semiconductors in civilian applications. GTE/Sylvania—one of the largest survivors—tried to diversify into commercial research and development but, like Varian, had to scale back these efforts for lack of competitiveness.[15]

Watkins-Johnson, another microwave electronics firm that evolved from the Stanford connection, was more successful than Varian, primarily because it pursued a more focused strategy of flexible specialization in electronic warfare products. Dean Watkins, a Stanford professor of electrical engineering, and H. Richard Johnson, a former director of Hughes Aircraft's microwave tube department, created the firm in 1957. Terman arranged startup financing and sat on the board of directors for more than two decades. Supported by a grant from the Stanford Research Institute, a research team refined a low-noise TWT that Watkins had invented in graduate school, laying the groundwork for a profitable business in passive electronic warfare products. Spurred by McNamara's cost-saving measures, Watkins-Johnson added new specialty product lines but, unlike Varian, maintained a clear technology focus in reconnaissance products and remained profitable.[16]

During the 1970s Watkins-Johnson grew into a $100 million firm that became the most profitable microwave tube company in Silicon Valley. Markets for passive reconnaissance technology grew exponentially because the armed forces and intelligence agencies added electronic reconnaissance technology to optical systems to track deployments and movements of Soviet military forces. The RC-135 spy

Sept. 1970, Varian Associates—Military, folder 1, CC-PSI; "Varian Gives New Priority to the Payoff," *Business Week* (13 Sept. 1976), 44; "A Conversation with Vincent Battaglia," *Defense Electronics* 20 (June 1988), 119; "Varian Associates," *Wall Street Journal*, 10 Dec. 1976, p. 8; "Roland 2 Air Missile System Subcontractors," *Aviation Week & Space* Technology (17 Jan. 1977), 58 [hereafter cited as *AW&ST*]; "Varian Stock Leaps On Takeover Rumors," *Los Angeles Times*, 6 Nov. 1986, part 4, p. 2.

15. Leslie, *Cold War and American Science*, 84–85.

16. DMS Market Intelligence Report, "Watkins-Johnson," Sept. 1970, Watkins-Johnson folder 1, CC-PSI; Watkins-Johnson Company, *Annual Report 1982* (Palo Alto, Calif., 1983), 1–3; "Famous First Jobs," *IEEE Spectrum* 24 (July 1987), 44.

aircraft, for example, along with the U-2 and the SR-71, the most important strategic airborne reconnaissance system in the U.S. arsenal, received a major upgrade in the mid-1970s, to which Watkins-Johnson contributed receiver components.[17]

Building on its experience in passive systems, the firm embarked on a course of flexible specialization in electronic countermeasures during the late 1970s. At that time, the armed services were updating their electronic warfare systems to deal with increasingly sophisticated Soviet jamming technology that deceived and disrupted "enemy" radar reconnaissance. To test American radar systems and train military personnel, the services needed jamming simulators that emulated Soviet countermeasures by generating disruptive electronic signals. Watkins-Johnson, which had until then specialized in passive reconnaissance technology, entered the active systems market in 1977, when it established an electronic countermeasures hardware systems program. Program manager Robert Campbell, avoiding a rigidly defined, long-range product strategy, sought to ensure program flexibility by employing what he called a "step-wise" approach to product development in which "you push in the direction where you're most successful."[18]

After testing the waters for two years with countermeasures subsystems, Watkins-Johnson developed a $4 million jamming simulator for the Navy. Its architecture incorporated vital elements of the subsystems design developed two years earlier, demonstrating a common strategy of flexible specialization in military electronics: firms frequently acquired research and development capabilities in components and subassembly design before moving into full-fledged systems development. In a departure from traditional weapons design practices, the Campbell team made extensive use of civilian technologies, including a commercial computer for systems control. Although not uncontroversial, the strategy was approved by the Pentagon, which commonly mandated the use of components that conformed to military specifications. This policy often resulted in higher costs (military specification [mil-spec] computers manufactured in small production runs could cost ten times as much as comparable civilian hardware) without substantial performance advantages over commercial products. As part of its efforts to curb "goldplating" of military systems in the early 1980s, the Pentagon encouraged systems

17. DMS Market Intelligence Report, "Watkins-Johnson," Aug. 1976, Watkins-Johnson folder 1, CC-PSI; "Watching 'Other Guys' Keeps W-J Up Front," *Palo Alto Times*, 23 Feb. 1976; "Watkins-Johnson," *Wall Street Journal*, 9 June 1976, p. 27; "Subcontractor For ECM," *AW&ST* (13 Dec. 1976), 105; "Company Expands EW System Market," ibid. (22 Sept. 1980), 15.

18. "Company Expands EW System Market," *AW&ST* (22 Sept. 1980), 15.

suppliers to substitute commercial parts for mil-spec components wherever possible. The use of commercial components buttressed flexible specialization strategies by enabling medium-sized contractors to devote their limited design resources to custom components. Watkins-Johnson's hardware systems team, for example, concentrated on the development of an innovative antenna design whose unique combination of bandwidth, beam shape, and other capabilities enhanced the performance of the Navy jamming simulator.[19]

Because of flexible specialization in electronic warfare technology, Watkins-Johnson was well positioned during the 1980s to take advantage of surging demand for active and passive systems, stealth technology, and tactical missiles. The latter included the $10 billion Advanced Medium-Range Air-to-Air Missile (AMRAAM), a "fire-and-forget" system based on an active radar seeker that enabled pilots to launch a missile without having to aim it precisely. The contract for the radar seeker went to Watkins-Johnson in part because its hardware design team managed to reduce the size of the seeker to dimensions that were compatible with the small AMRAAM airframe. This marked a significant turning point for the company, which henceforth integrated forward into miniaturized subsystems. According to CEO Keith Kennedy, Watkins-Johnson developed a new specialty in "'multiple function assemblies,' where we put more functions in a smaller size than competitors. That business has been growing, fueled by the AMRAAM missile seeker."[20] Forward integration into product lines that were closely related to its existing specialty, coupled with the strong performance of its core business, bolstered sales and profits through much of the 1980s, making Watkins-Johnson one of the most consistently profitable companies in Silicon Valley.[21]

The microwave electronics industry spawned dozens of startup companies, including several that became major defense contractors in the 1970s and 1980s. The startups, notably Applied Signal Technology, Electronic Systems Laboratories, California Microwave, Con-

19. Ibid.; "Special Report: Electronic Warfare," *AW&ST* (27 Jan. 1975), 63–70; "Subcontractor for ECM," ibid. (13 Dec. 1976), 105; "Packard Panel Urges Reorganization to Stop Weapons Goldplating," ibid. (14 April 1986), 19; see also U.S. Congress, Office of Technology Assessment, *Assessing the Potential for Civil-Military Integration: Technologies, Processes, and Practices* (Washington, D.C., 1995).

20. "Electronic Warfare, Part II," *AW&ST* (18 Sept. 1989), 115; see also "AMRAAM Seeker," *Navy News & Undersea Technology* (11 Nov. 1991), 7; "Raytheon Co.," (21 Sept. 1992), 2; "Watkins-Johnson," *Jane's Defence Weekly* (1 Nov. 1994), 8.

21. "Watkins-Johnson," *Jane's Defence Weekly* (1 Nov. 1994), 8; see also "AMRAAM Seeker," *Navy News & Undersea Technology* (11 Nov. 1991), 7; "Raytheon Co.," *Defense & Aerospace Electronics* (21 Sept. 1992), 2.

dor Systems, and Rolm Computers, usually emerged as specialty producers in niche markets such as electronic warfare, weapons software, and military computers. Many were spinoffs from pioneer firms. In 1964 William Perry, a former GTE/Sylvania executive, formed the Sunnyvale-based Electronic Systems Laboratories (ESL) and conducted systems analysis and software development for the Department of Defense, the Central Intelligence Agency (CIA), and the National Security Agency (NSA). ESL initially concentrated on analytical software for strategic reconnaissance systems and electronic countermeasures, and in 1969 it added light manufacturing capabilities to produce computer hardware for the region's prime weapons and satellite contractors. Building on its expertise in strategic systems, it branched out into battlefield reconnaissance hardware with the development of a patented direction-finding subsystem that was incorporated into many tactical applications. In 1977, when Perry was appointed undersecretary of defense for research in the Carter administration (he later served as President Bill Clinton's secretary of defense), ESL was acquired by TRW. Over the next several years, it won almost $100 million in prime contracts for the Guardrail intelligence-gathering system and other tactical electronics systems.[22]

In the 1990s shrinking defense budgets dealt debilitating blows to the electronic warfare and microwave electronics industries, whose defense dependency had increased during the procurement bonanzas of the 1980s. Attempts at defense conversion often led nowhere because firms were unable to develop viable commercial product lines that required the specialized design expertise and technical know-how they had been using to build advanced military systems. Leading firms that came adrift in the 1990s included Watkins-Johnson, which was unable to win major Pentagon contracts to exploit its new specialty in miniaturized subsystems or to amortize major investments made during the Reagan defense buildup. Limping along on AMRAAM follow-up contracts, the firm tried to diversify into semiconductor manufacturing equipment to commercialize its military microwave electronics expertise. Watkins-Johnson abandoned the venture after several years because it lacked marketing skills, a common problem among medium-sized defense contractors accustomed to dealing with a handful of government customers. Ac-

22. Hambrecht & Quist, "ESL Incorporated: Underwriting Follow-Up Report," Feb. 1971, ESL, folder 1, CC-PSI; Hambrecht & Quist, "ESL, Inc.: Progress Report," 31 Oct. 1975, ibid.; ESL Incorporated, *1975 Annual Report* (Sunnyvale, Calif., 1976), 1–5; "ESL," *Wall Street Journal*, 22 Dec. 1977, p. 2; "ESL," ibid., 30 Dec. 1981, p. 8; "Next Inc., TRW Unit Team Up; Firms Hope to Sell Service to Agencies," *Washington Post*, 17 Jan. 1990, G1; Joseph C. Anselmo, "Nondefense Products Bring Mixed Results to Aerospace," *AW&ST* (28 Feb. 1994), 63–64.

knowledging that it had reached a strategic dead end, the firm liquidated its defense business in 1997 and repositioned itself as a wireless telecommunications company. ESL converted from battlefield electronics and software to "smart highways," building traffic surveillance and management systems in Atlanta and San Francisco. Unfortunately for the TRW subsidiary, however, the Department of Transportation awarded a prized $150 million program to develop a futuristic automated highway system to a consortium led by General Motors, forcing ESL to subsist on bread-and-butter contracts for the remainder of the 1990s.[23]

Missiles, Satellites, and Space Electronics

Although Silicon Valley's microwave tube and electronic warfare industries were among the nation's largest, they were dwarfed by the missile, satellite, and space electronics sector, which included the Bay Area's largest industrial employers during the Cold War. From the 1960s to the end of the Cold War, the sector usually employed 14 percent of Silicon Valley's manufacturing work force.

Santa Clara County entered the space age in January 1956, when Lockheed relocated its Missile Systems Division from an engineering loft near company headquarters at Burbank, California, to a 275-acre site in Sunnyvale. The division, later renamed Lockheed Missile and Space Corporation (LMSC), became the largest industrial employer in Silicon Valley during the Cold War. Leading military spacecraft contractors also included Philco Corporation, a Philadelphia-based manufacturer of radios, semiconductors, and computers that entered the satellite business in 1957 with the establishment of the Western Development Laboratories in Palo Alto. Westinghouse Marine Division in Sunnyvale, another major player in the satellite and missile industry, built missile launcher subsystems for the Navy, as well as the Air Force's MX intercontinental ballistic missile.

Lockheed, Philco, and Westinghouse were drawn to missiles and satellites because the market for such systems grew exponentially during the postwar years. Initiating a major shift in Cold War military strategy, the administration of Dwight Eisenhower decided to use ballistic missiles as delivery systems for nuclear weapons that previously had been carried only by long-range bombers. This deci-

23. "Watkins-Johnson," *Electronic Buyers News* (14 April 1997), 14; "DOT Picks GM Team for 'Smart' Highways," *Engineering News-Record*, 17 Oct, 1994, p. 3.

sion resulted in the creation or acceleration of key missile programs, including the Jupiter and Thor intermediate-range ballistic missiles; the Atlas, Titan, and Minuteman intercontinental ballistic missiles; and the Polaris sea-launched ballistic missile. By 1958 the Air Force had spent $2.1 billion on Atlas missile development alone, creating an irresistible lure for manufacturers and research organizations in the airframe, electronics, and computer industries.[24]

LMSC and Philco decided to locate their missile and satellite operations in Santa Clara County primarily because they wanted to tap Stanford's electrical engineering department for research expertise and graduates. To strengthen their ties with the university, both firms established research laboratories in Stanford Industrial Park, where LMSC became the largest tenant, with a 22-acre facility. Both firms recruited Stanford's electrical engineering faculty as research consultants to strengthen their ability to develop advanced guidance systems. Moreover, LMSC helped rebuild the university's dilapidated aeronautical engineering program by convincing Nicholas Hoff, a supersonic aerodynamics specialist, to accept a professorship at Stanford and paying half of his salary as head of the aeronautical engineering department. For research support in hypersonic aerodynamics, LMSC and Philco turned to the Ames Research Center in Sunnyvale, established in 1940 by the National Advisory Committee on Aeronautics.[25]

LMSC's payroll grew from 200 (in 1956) to 25,000 (in 1964) as it geared up for the Polaris Fleet Ballistic Missile (FBM) program, which produced 492 sea-launched ballistic missiles for deployment on nuclear submarines. Missile design and construction were performed at Lockheed's 8 million-square-foot Sunnyvale complex, which remained the largest corporate real estate complex in Silicon Valley until the 1990s (see Figure 1). Buildings housed a full-scale model of a Navy submarine weapons loading facility, a hydrostatic chamber, and other production and testing facilities. Building 107, the most clandestine edifice in the defense industry, housed black projects. The Polaris missile contract that provided the impetus for the construction of the complex netted LMSC $3.5 billion through 1967 alone, with subsequent repair and maintenance needs generating a sizable amount of follow-up work. By the late 1960s Lockheed's Sun-

24. Walter A. McDougall, . . . *The Heavens and the Earth: A Political History of the Space Age* (New York, 1985), 127.

25. Leslie, *Cold War and American Science*, 110–32; Elizabeth A. Muenger, *Searching the Horizon: A History of Ames Research Center, 1940–1976* (Washington, D.C., 1985).

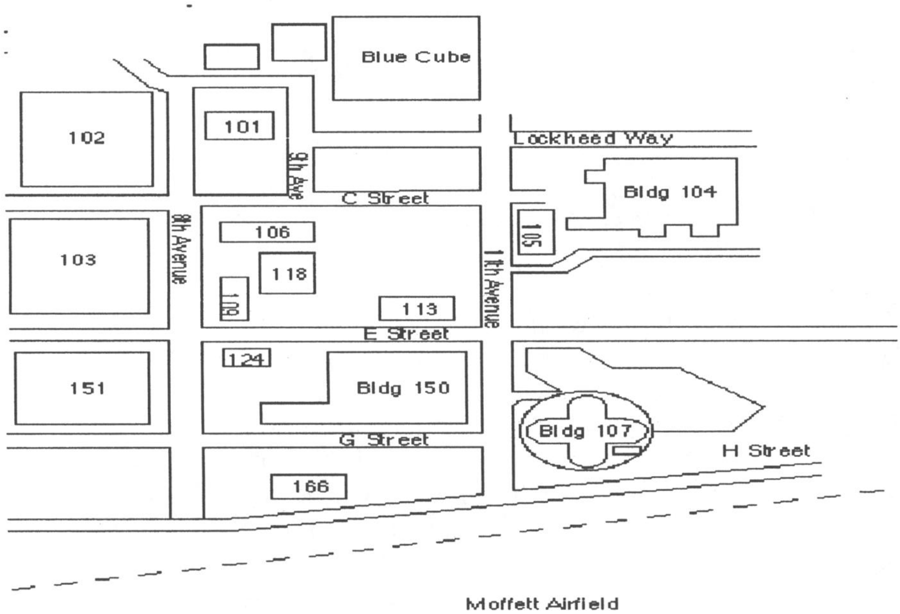


Figure 1 Lockheed Missile and Space Corporation's Sunnyvale Campus. Major buildings: Building 101: Administration; Building 102: Telecommunications; Building 104: Satellites; Building 107: Black Projects; Building 151: Missile Engineering, Blue Cube: Air Force Satellite Control Network Facility, logistics management handled by Lockheed and Ford Aerospace.

nyvale division had established itself as the nation's only producer of Navy strategic missiles to receive all subsequent FBM work without having to compete for the contracts.[26]

In 1973 the Navy awarded LMSC a $6.6 billon Trident I C4 missile contract that produced 336 deployable missiles, each carrying eight nuclear warheads.[27] LMSC's greatest challenge was extending the range of the missile by 60 percent over its predecessor without increasing its size. Trident I's had to fit into submarines designed for

26. Graham Spinardi, *From Polaris to Trident: The Development of U.S. Ballistic Missile Technology* (Cambridge, Mass., 1994), 39–56; Harvey M. Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Governmen*t (Cambridge, Mass., 1972), 167; Julie Eisele, "Facilities Professionals Accomplish Their Missions at Lockheed," *Buildings* 87 (July 1993), 40–42.

27. The contract came at a particularly fortuitous time for Lockheed, LMSC's parent company, which was on the verge of bankruptcy as a result of contract problems involving the notorious C-5 Galaxy military transport plane and the troubled Tristar airliner program. The giant Trident and spy satellite contracts made LMSC Lockheed's only profit-making division through much of the 1970s and early 1980s.

an earlier generation of FBMs. The LMSC design team accomplished the task by increasing the efficiency of the propulsion system, miniaturizing on-board computer systems, and adding an "aerospike" that increased Trident I's range by 300 miles.[28]

Reflecting the need to invest heavily in production facilities for each new weapons program, LMSC retooled its missile plant in Sunnyvale for Trident I production in the mid-1970s, adding ultra-high-speed milling tools to precision-cut aluminum parts, rayon casting equipment to craft casings for the booster nozzles and reentry vehicles, and custom-made tools to process graphite-epoxy composites for post-boost vehicles. Like Polaris, Trident I production relied extensively on disintegrated formats involving hundreds of subcontractors for specialty components, subsystems, systems, and testing equipment. Hewlett-Packard, which had collaborated with LMSC in previous FBM programs, became a sole-source supplier of testing systems for the missile, and the Sunnyvale-based Chemical Systems Division of United Technologies Corporation received subcontracts for solid propellant rockets. LMSC also worked closely with the Westinghouse Marine Division in Sunnyvale, which won prime contract awards for sublauncher systems. Extraregional contractors, notably Texas Instruments and Motorola, supplied microelectronics to LMSC.[29]

The FBM programs contributed to the escalation of the nuclear arms race, which in turn generated demand for reconnaissance satellites to gather intelligence on Soviet deployments and to track missile launchings. In the 1950s Lockheed already enjoyed a commanding lead in reconnaissance technology because its Skunk Works at Burbank had designed and built the U-2 spy plane, a job that provided valuable experience for LMSC's satellite projects. The first innovation developed at Sunnyvale was the Agena satellite system, a platform for military space payloads attached to launch boosters such as Atlas and Titan missiles. First built in 1956, Agena became the workhorse of the space reconnaissance program, launching 392 satellites from 1959 to 1987. LMSC also built many spy satellites carried into orbit by Agena, starting with 145 Corona-class imaging reconnaissance satellites for the Air Force and the CIA. The sophistication of reconnaissance satellites grew precipitously, requiring ever increasing inputs of cutting-edge technology. Corona and other early

28. Marc Simon, "Lockheed Awards H-P Sole-Source Trident Pact," *Electronic News* (19 Aug. 1974); "New Propellant Evaluated For Trident Second Stage," *AW&ST* (13 Oct. 1975), 15.

29. Richard G. O'Lone, "Small ICBM, Solid Rocket Motor Contracts Spur Expansion at CSD," *AW&ST* (25 March 1985), 87; see also "High-Speed Machining Taking Wing in Aerospace," *Production* 100 (Feb. 1988), 52–53.

reconnaissance satellites weighed only several hundred pounds and had a relatively short service life, circling Earth a few hundred times before ejecting a film capsule for retrieval by aircraft and shutting down. Later spacecraft, such as the 20-ton KH-12, were designed for a service life of several years and transmitted electro-optical digital images to ground terminals. LMSC built three KH-12s for approximately $1 billion during the late 1980s and early 1990s.[30]

At the height of the Reagan defense buildup in 1983, LMSC became the prime contractor for the $1 billion Military Strategic, Tactical and Relay (Milstar) satellite program, which provided jam-resistant communications for tactical and strategic nuclear forces. LMSC produced the spacecraft and subcontracted the seven satellites to Hughes Aircraft and TRW. The project generated subcontracts for many high-tech firms in the region, including National Semiconductor in Santa Clara, which produced radiation-hardened microchips for Milstar. Although the top-secret program was plagued by cost overruns and scheduling problems that delayed deployment for several years, the Air Force awarded LMSC a $1.6 billion contract for the follow-up Milstar II in 1992, the year Milstar I was finally launched into orbit.[31]

Like the FBM program, satellite research and development drew on laboratories, academic consultants, and subcontractors in Santa Clara County and other locations. At Stanford, Nicholas Hoff recruited Robert Cannon, an expert on inertial guidance who became an LMSC consultant and established the university's Guidance and Control Laboratory, which conducted Air Force–supported research in an area critical to satellite technology. On the manufacturing side, regional subcontractors included Hiller Aircraft Company, a helicopter manufacturer that assembled satellites for LMSC at its Palo Alto plant; Ampex Corporation at Sunnyvale, which produced satellite data recorders for on-board and ground-based applications; and Sunnyvale-based Applied Technology, a supplier of optical equipment and antennas. LMSC's most important extraregional subcontractor in the KH-12 program was TRW in San Diego, which had extensive experience in digital image satellite technology.[32]

30. Walter J. Boyne, *Beyond the Horizons: The Lockheed Story* (New York, 1998), 264–305; "Space Reconnaissance Dwindles," *AW&ST* (6 Oct. 1980), 18.

31. "Lockheed Awarded Milstar System Contract," *AW&ST* (25 July 1983), 20; "Milstar Satellite/Booster Cost Reaches $1 Billion Per Mission," ibid. (9 May 1988), 27; "Restructured MILSTAR Proceeds," *International Defense Review* (1 Jan. 1993), 15.

32. Leslie, *Cold War and American Science*, 124–26; Glenn E. Bugos, "The Aerospace Impetus to Silicon Valley," *Journal of the West* 36 (July 1997): 98;

LMSC's satellite business also boosted high-tech building construction, which later became vital for the region's semiconductor industry. LMSC, Philco, and other aerospace companies learned quickly that satellites malfunctioned when zero gravity dislodged tiny particles, which caused havoc in delicate on-board devices. Spacecraft producers launched a quest for ultra-dust-free production facilities known as "clean rooms," hermetically enclosed buildings whose air supply was filtered for microscopic particulates. During the 1960s LMSC erected a 520,000-cubic-foot clean room, one of the largest facilities of its kind in the world. Design, engineering, and construction were handled by building contractors such as Rudolph and Sletten of Foster City, California, which garnered its first experience in the construction of high-tech manufacturing and research facilities at LMSC. Rudolph and Sletten later became one of the largest high-tech building contractors in Silicon Valley; its customers included Sun Microsystems and Microsoft. The semiconductor industry, which became the largest user of clean rooms in the 1970s and 1980s because its submicron-size transistors, circuits, and chips were susceptible to damage by dust particulates, profited from the early development of the technology at LMSC.[33]

Philco's Western Development Laboratory, whose initial purpose was to provide tracking equipment and services for LMSC-built reconnaissance satellites, quickly emerged as a satellite contractor in its own right. Acquired by the Ford Motor Company in 1961, the laboratory (which later became part of Ford Aeroneutronics/Ford Aerospace) carved out a niche in military communications satellites. The Philco lab's first major success in this area was its selection in 1964 as the Air Force's prime contractor for the Initial Defense Communications Satellite. Together with Stanford University, the division later researched satellite-based navigation systems under contract with the Air Force. In the late 1960s Ford Aerospace received a British defense contract for four Skynet I military communications satellites, modified versions of which were built for the North Atlantic Treaty Organization to provide voice, fax, and digital data transmissions in the 1970s and 1980s. (Varian's Canadian division in

James Bamford, "America's Supersecret Eyes in Space," *New York Times Sunday Magazine* (13 Jan. 1985), 39; "3,000 Space, Defense Workers Face Layoffs at TRW," *San Diego Union-Tribune*, 2 Feb. 1988.

33. Bugos, "Aerospace Impetus to Silicon Valley," 98; "California," *Engineering News-Record* (7 Dec. 1992), 59; "Lockheed Renovates Clean Room for Work on Large Satellites," *AW&ST* (12 June 1989), 303; "Cleaning Up Clean Room Design," *Engineering News-Record* (12 April 1984), 20; John Wilson, "Making Submicron Chips," *Business Week* (10 June 1985), 88.

Georgetown, Ontario, built microwave power amplifiers for the system.)[34]

Although defense communications satellite research and development provided a lucrative side business, Ford Aerospace's main product line remained spacecraft tracking and management systems. In 1963 it won a National Aeronautics and Space Administration (NASA) contract to build and staff the Mission Control Center at the Manned Spacecraft Center in Houston. Ford Aerospace later established a subdivision in Houston whose fifteen hundred employees helped launch the Apollo and space shuttle missions. In 1989 the company won a $500 million follow-up contract to modernize the control center in preparation for the international space station. Ford Aerospace also provided computer hardware, software, and technical services for the Air Force North American Air Defense Command in Colorado. As part of its Colorado operations, Ford Aerospace began providing software development and systems integration for the Army's Maneuver Control System in 1982, and several years later this function generated a $42 million subcontract to Hewlett-Packard for workstations.[35]

Military satellite builders rarely succeeded in civilian markets. Ford Aerospace's attempts to commercialize its expertise in military communications satellites remained unsuccessful until 1976, when it won a $235 million contract from the International Telecommunications Satellite Organization (ITSO) for Intelsat 5 satellites. The program quickly ran into trouble. Ford Aerospace's relatively small Palo Alto plant lacked sufficient capacity to complete the seven commercial satellites on time, causing delayed launches. Moreover, several navigation systems malfunctioned in space, requiring costly repositioning of the satellites. Diversification into civilian telecommunications suffered an additional setback when Hughes Aircraft won the bidding war for the $525 million contract for Intelsat 6, leaving Ford Aerospace with little commercial work in the mid-1980s, when mili-

34. Ford Aerospace & Communications Corporation, Western Development Laboratories Division, "A History of Achievements in Satellite Communications," n.d., folder Ford Aerospace—Military, CC-PSI; "Stanford, Ford-Philco Get Satellite System Contract," *Palo Alto Times*, 6 Aug. 1970; "Big Money in Hardware Orders," *Business Week* (21 May 1977), 44; "Contract Awards," *Northern California Electronics News* (29 Oct. 1979).

35. Ford Aerospace & Communications Corporation, Western Development Laboratories Division, "Worldwide Communications," n.d., folder Ford Aerospace—Military, CC-PSI; "Ford Motor Co.," Raytheon Papers, box 10, folder 11, SA; "Technology Behind the Moonshoot," *Palo Alto Times*, 15 July 1969; "Spadoc Phase 4 Subcontractors," *AW&ST* (9 Dec. 1985), 68; "Ford Aerospace Corp. Awards $42-Million Workstation Contract to HP," *Business Wire* (28 Feb. 1989).

tary orders started to fall off. Determined to elbow its way into the commercial satellite business and secure an outlet for its flagging Palo Alto division, Ford Motor Company acquired a controlling share of the Starnet Corporation, a San Diego–based telecommunications company, with the intent of turning the $11 million company into a $500 million satellite service provider by 1990. Industry analysts, convinced that Ford lacked "the expertise for the operation of a telecommunications network," predicted that this somewhat ambitious scheme would be short-lived. Ford in fact sold Starnet in 1987, leaving its aerospace division without a long-range business plan for the post–Cold War era. A $400 million contract for Intelsat 7, issued to Ford by ITSO in 1988, was hailed as a strategic breakthrough that would give Ford Aerospace a secure foothold in commercial satellites, but the program suffered from design problems, missed deadlines, and cost overruns. When Ford Motor Company sold the division to Loral Corporation at the end of the Cold War, Ford Aerospace still derived more than 70 percent of revenues from military and NASA sales.[36]

Loral's subsequent success in civilian telecommunications was largely the result of major departures from defense contracting practices. Most importantly, Loral revamped the aging physical plant, designed in the early 1960s to build small series of military satellites. To increase annual production capacity from two satellites to twelve, Loral rebuilt large sections from scratch, including two assembly halls and a payload production plant. Rejecting military contracting standards that discouraged partnerships with foreign suppliers, Loral developed commercial satellites in collaboration with Daimler-Benz Aerospace, France's Aerospatiale, and other European firms. Joint ventures made extensive use of computerized design and manufacturing, creating what Loral touted as a "virtual factory" in which satellites were built in Palo Alto and shipped to France for assembly. These strategies enabled Loral to stage a decisive breakthrough in commercial markets, boosting annual revenues from $355 million in 1990 to $1.4 billion in 1996. In that year, Loral sold its defense assets to Lockheed for $9.1 billion and reorganized as Loral Space and

36. Ford Aerospace & Communications Corporation, Western Development Laboratories Division, "A History of Achievements in Satellite Communications," n.d., folder Ford Aerospace—Military, CC-PSI; "Stanford, Ford-Philco" *Palo Alto Times*, 6 Aug. 1970; "Big Money in Hardware Orders," *Business Week* (21 May 1977), 44; "Contract Awards," *Northern California Electronics News* (29 Oct. 1979); "In-Orbit Checks Start on Two Satellites," *AW&ST* (15 June 1981), 53; "Ford Aerospace Tries a Risky New Orbit: Satellites," *Business Week* (20 Aug. 1984), 111.

Communications, a commercial satellite construction and service provider.[37]

LMSC's attempts to develop commercial product lines faced other formidable obstacles. Unlike Ford Aerospace, whose experience in military communications satellites was applicable to telecommunications, LMSC specialized in reconnaissance spacecraft. Telecommunications satellites developed by spy satellite builders were notoriously overdesigned and expensive, characteristics that doomed most LMSC bids for commercial work from the start. In 1975, when LMSC vied with Hughes, TRW, and Ford Aerospace for the Intelsat 5 contract, its proposals received the lowest financial and technical ratings, eliminating it from the competition. When the military order backlog started to shrink in the late 1980s, LMSC tried to exploit the synergy of its core business in surveillance technology and space-based aerial photography to gain a foothold in the growing market for remote sensing systems used in geological research, urban planning, and forestry. LMSC seemed poised for success because its spy satellites reputedly produced one-meter resolution imagery, or ten times the resolution produced by the best available commercial systems in the late 1980s. However, the Pentagon and the Department of Commerce, fiercely protective of the technology, refused to grant LMSC a license enabling the company to commercialize spy satellite technology. (Government objections also thwarted Lockheed initiatives to refurbish retired Fleet Ballistic Missiles as commercial satellite launch vehicles.)[38]

In a parallel attempt to develop viable civilian telecommunications satellite operations, LMSC formed the Lockheed Commercial Space Company to consolidate a variety of research and development programs and to cultivate new business. Shortly after its founding in 1991, the subsidiary won a $700 million contract for seventy-seven Iridium communications satellites from a telecommunications consortium headed by Motorola. Initially hailed as a model telecommunications satellite system, Iridium became an unmitigated disaster. Costs exceeded original estimates by one-third. Sixteen satellites failed in orbit. Designed to provide mobile phone service anywhere in the world, the system covered vast areas where cellular phone use was rare or nonexistent. Revenues fell short of the $10 million in

37. "Space Systems/Loral Quietly Moving Ahead," *AW&ST* (5 Aug. 1996), 58–59; "Commercial Transition a Matter of Survival," *Electronic Engineering Times* (14 Oct. 1996), 50–51; "Loral Deal Creates $30 Billion Lockheed," *Flight International* (17 Jan. 1996).

38. "Lockheed Missile and Space," *AW&ST* (29 March 1976), 21; "Three Aerospace Companies," ibid. (6 April 1992), 15; "Lawmakers Warn Clinton on Satellite Imagery Sales," ibid. (22 Nov. 1993), 38.

monthly operating expenses, sending the consortium into a tailspin that ended in bankruptcy. The satellite network was acquired by a company that provided cellular phone service to the Pentagon, which became Iridium's largest user.[39]

Semiconductors

The early history of Silicon Valley's microelectronics industry is well known. In 1955 William Shockley, one of the coinventors of the transistor at Bell Laboratories, established Shockley Semiconductor in Palo Alto, his home town. Three years later eight of his employees left the company to establish Fairchild Semiconductor, which emerged as a semiconductor powerhouse along with Texas Instruments and Motorola. Former Fairchild employees, in turn, founded several dozen new companies in the 1960s and 1970s. Like Fairchild, most of these startups were based in Silicon Valley, which became the throbbing core of the American semiconductor industry.

Fairchild and most other semiconductor companies of the 1950s produced transistors for military programs, which absorbed almost half of the industry's aggregate output. Fairchild's first contract, signed in October 1957 with International Business Machines' Federal Systems Division in Oswego, New York, involved the conversion of strategic bomber electronics from vacuum tubes to transistors. A year later, when the Air Force decided to use semiconductors for the Minuteman intercontinental ballistic missile, Fairchild booked a $1.5 million contract for silicon-diffused transistors. As Christophe Lécuyer has shown, the firm vastly improved its manufacturing processes to meet the stringent quality requirements of the Minuteman reliability improvement program.[40]

Fairchild's commitment to reliability became a major asset when the company entered civilian markets in the 1960s, enabling it to compete successfully on product quality with more established firms like Texas Instruments. Furthermore, profits from the Minuteman contracts financed Fairchild's development of the planar process, a major innovation that made it possible to deposit a flat insulating layer on the surface of a silicon chip through oxidation and heat diffusion, dispensing with manual cutting and wiring. The planar process, in turn, enabled Fairchild's Robert Noyce to develop the integrated circuit (IC), which incorporated several transistors on a

39. "Lockheed Eyes Commercial Market," *AW&ST* (7 Sept. 1992), 39.

40. "Interview with Charles Sporck," 2000, Silicon Genesis Video Tape Oral Histories, SA; Lécuyer, "Making Silicon Valley," 190–95.

single silicon chip and performed simple logic functions. Although the military did not contribute directly to the invention of the IC, military demand for increasingly miniaturized electronics created a powerful incentive for Noyce and others to pursue the technology. In the early 1960s almost all ICs manufactured in the United States went into the Minuteman II missile program or NASA's Apollo program. While Fairchild became the principal IC supplier for Apollo, Signetics Corporation, General Microelectronics, and other Fairchild spinoffs supplied the Minuteman II program.[41]

Fairchild entered civilian markets during the 1960s but remained an important military contractor. At the end of the decade, it developed radiation-hardened ICs for the Poseidon missile that were capable of withstanding the electromagnetic impulse (EMI) generated by nuclear explosions. First observed during high-altitude nuclear tests in the early 1960s, EMI generated high-energy particle streams that caused malfunctions in electronic systems, raising the possibility that a single nuclear warhead detonated 250 miles above the United States could "decapitate" the nation's entire communications infrastructure. Working in close cooperation with the Navy and the Air Force, Fairchild and other military IC contractors developed a range of radiation-hardening techniques, including junction isolation and dielectric isolation for ICs used in missiles, satellites, and other strategic systems.[42]

Interestingly, Pentagon research and development funds supported the company's efforts to develop radiation-hardened chips, a notable exception to Fairchild's general rule of avoiding military involvement in research. Noyce, who claimed that military funds never accounted for more than 4 percent of Fairchild's total research and development budget, argued that the armed services usually knew little about semiconductors: "You were dealing with a critic of the research . . . who was not capable of critiquing the work. . . . There are very few research directors anywhere in the world who are really adequate to the job . . . and they are not often career officers in the Army."[43] Equally important, avoiding federal research and develop-

41. Richard C. Levin, "The Semiconductor Industry," in *Government and Technical Progress: A Cross-Industry Analysis*, ed. Richard R. Nelson (New York, 1982), 59–64.

42. Fairchild Camera and Instrument Corporation, *Annual Report 1971* (Palo Alto, 1972), 6; Lester Hogan, "Speech at the Meeting of the New York Society of Security Analysts," 9 Sept. 1969, Fairchild, folder 2, CC-PSI; DMS Market Intelligence Report, "Fairchild Camera," Aug. 1969, Fairchild, folder 2, CC-PSI.

43. Noyce quoted in Ernest Braun and Stuart McDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics* (Cambridge, Mass., 1978), 142.

ment funding allowed Fairchild to retain proprietary process and architecture rights that the government would otherwise claim.[44]

During the late 1960s several Fairchild executives went on to head other semiconductor firms or form their own companies. General manager Charles Sporck left in 1967 to become president of National Semiconductor Company in Santa Clara. Noyce, Gordon Moore, and others quit to form Intel in 1968, followed a year later by Jerry Sanders, who founded AMD. The personnel drain, combined with increasing competition, dealt a severe blow to Fairchild, whose profits became lackluster even though it remained one of the largest firms in the industry.[45]

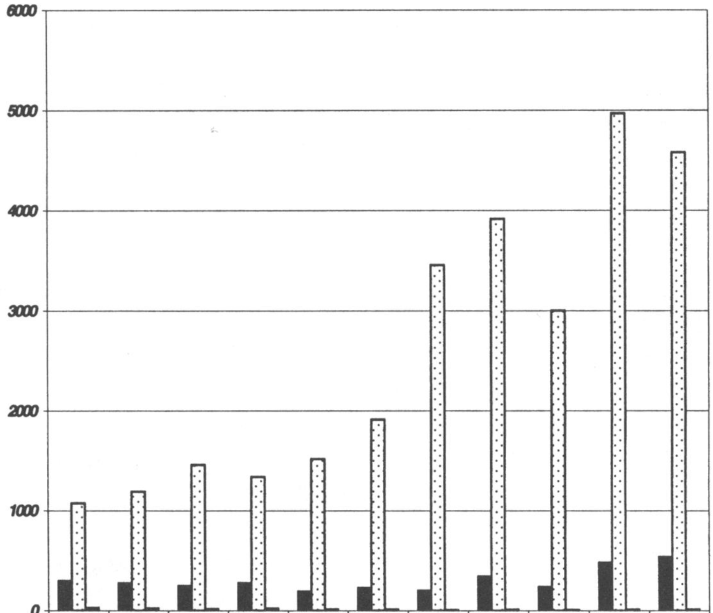
As the 1970s progressed, civilian semiconductor markets dwarfed military ones as microelectronics firms thrived on the growing demand for commercial microelectronics for minicomputers, automobile electronics, calculators, digital watches, television, telecommunications, and—toward the end of the decade—personal computers (see Figure 2). At National, for example, inflation-adjusted sales grew by a factor of ten and profits increased fourteenfold over the course of the decade. Much of this growth was attributable to dynamic random access memory (DRAM) chips, which replaced magnetic cores in most computer applications. By 1980 DRAMs had emerged as the industry's first billion-dollar market, up from $15 million in 1971, and had become Silicon Valley's most important microelectronics product.[46]

DRAM production fundamentally changed the structures and dynamics of the region's semiconductor industry. Research and development costs grew dramatically (National's inflation-adjusted chip development costs almost tripled from 1975 to 1980) as major firms sought to maintain their competitive edge by cramming more transistors and gates onto a piece of silicon. The only way to amortize skyrocketing research and development costs, it seemed, was to manufacture standardized memory chips in very large production runs of

44. In the 1960s NASA adopted a policy of claiming patent rights for inventions developed by private contractors under government sponsorship and licensing them to other contractors. The policy was later adopted by other federal agencies; see Robert W. Wilson, Peter K. Ashton, and Thomas P. Egan, *Innovation, Competition, and Government Policy in the Semiconductor Industry* (Lexington, Mass., 1980), 155, and U.S. Congress, Office of Technology Assessment, *After the Cold War*, 214–15.

45. Standard & Poor, "Fairchild Camera & Instrument," 15 March 1971, Raytheon Papers, box 7, folder 2, SA; "Interview with Charles Sporck," and "Interview with Gordon Moore," both 2000, Silicon Genesis Video Tape Oral Histories, SA.

46. Wilson, Ashton, and Egan, *Innovation, Competition, and Government Policy*, 90–94.



	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
■ Defense Shipments	297	274	247	275	193	228	201	344	239	480	536
□ Total Shipments	1074	1189	1457	1337	1519	1912	3458	3916	3001	4968	4583
■ Percentage Defense Shipments	27.7	23.0	17.0	20.6	12.7	11.9	5.8	8.8	8.0	9.7	11.7

Figure 2 U.S. Shipments of Semiconductors, 1967–1977 (in $millions). Source: U.S. Department of Commerce, Bureau of the Census, 1967–1977.

at least 100,000 units. This approach quickly replaced batch production of customized devices, which had played a pivotal role during the industry's formative years. Moreover, to survive in the fiercely competitive memory chip market, semiconductor firms placed growing emphasis on proprietary fabrication technology, with the unintended result of severing the industry's once vital ties with university research centers. Often lacking the enormous resources necessary to acquire process rights and build fabrication facilities, such centers faced growing obstacles in implementing their microelectronics research initiatives, leading some observers to conclude that "university engineering and computer science departments were getting shut out of much of the microelectronics revolution."[47]

Most microelectronics breakthroughs originated in corporate research and development, which pulled ahead of academic and de-

47. Ibid., 88–90; "Homebrew Chips," *Byte* 10 (May 1985), quotation at p. 363; National Semiconductor Corporation, *1977 Annual Report* (Santa Clara, Calif., 1978), 8.

fense-related semiconductor research. This was particularly true for the microprocessor, a programmable "computer-on-a-chip" featuring logic, arithmetic, and control circuitry that stored and manipulated data. Invented by an Intel research team headed by Ted Hoff in 1971 for a Japanese calculator company, the microprocessor was first introduced in cash registers, controllers for traffic signals, factory production lines, and other commercial applications, unlike the two other major innovations in microelectronics, the silicon transistor and the integrated circuit, which were initially used almost exclusively in military systems. Intel's 8008 eight-bit device superseded the 4004 microprocessor in 1972 and was followed two years later by the famous 8080, which powered the first personal computers. Although the armed forces were keenly interested in microprocessor technology because it improved signal-processing capabilities and speeds, military applications lagged far behind their civilian counterparts, in part because the process of developing military standards for the technology was so cumbersome. All semiconductor companies producing high-reliability military devices had to conform to joint Army-Navy standards that required IC production in American plants under a stringent quality-assurance system. Intel released its sixteen-bit 8086 commercial microprocessor in June 1978, but the military version followed only two years later, after Intel had already shipped the follow-up 8088 model to civilian customers. Military research and development support for Intel's microprocessor programs was nonexistent, partly because of Noyce's aversion to military research funding, dating from his tenure at Fairchild.[48]

The armed services became major beneficiaries of civilian research and development, which provided critical new components for the weapons and reconnaissance systems of the 1970s and 1980s. Most of these devices were mil-spec versions of commercial chips. National, for example, which derived 15 percent of its revenues from sales to the Pentagon, the armed services, and prime contractors (see Table 2), supplied mil-spec ICs for F-14 and F-15 jet fighters, all air-to-air missiles in the U.S. arsenal, and the space shuttle. Intel mean-

48. Intel Corporation, "M8255 Programmable Peripheral Interface, 1978," FARM Collection, Intel Museum Archives, Santa Clara, Calif. [hereafter cited as Intel Archives, FC]; Intel Corporation, "Military Products Data Catalogue, 1979," Intel Archives, FC; Intel Corporation, "Intel Marches On," n.d., Intel Archives, FC; "2900 Bipolar Microprocessor Family," Raytheon Papers, box 6, folder 3, SA; Rocky Evans, "The Microprocessor Revolution in Military Systems," *Military Electronics/Countermeasures* 4 (Feb. 1978), 14–15; "Sixteen Bits of Military Power," ibid. 6 (July 1980), 63–67; Lenny Siegel and John Markoff, "High Technology and the Emerging Dual Economy," in *Computers in Battle: Will They Work?* ed. David Bellin and Gary Chapman (Boston, Mass., 1987), 263.

Table 2 Defense Production at Leading Integrated Circuit Firms, 1978

Supplier	Sales of ICs to Military and Aerospace Contractors (in $ Millions)	Percent of Supplier's Total IC Sales
Texas Instruments	63.5	11
National Semiconductor	39.0	15
Motorola	32.0	11
Advanced Micro Devices	30.0	30
Signetics	30.0	15
Fairchild Camera & Instrument	24.5	9
Harris	24.0	27
Others	143.0	11
Total industry	386.0	12

Source: Integrated Circuit Engineering Corp., 1979.

while solidified its leading position in mil-spec microprocessors. In 1980 Gordon Moore signed a royalty-free license transfer of the 8080 design to the Sandia National Laboratories, the Department of Energy weapons laboratory, which developed a radiation-hardened version of the microprocessor for military and space applications. Over the next two decades Intel provided Sandia with similar licenses for almost every microprocessor and compiler developed by the company. Radiation-hardened 8080 microprocessors were installed in the guidance system of the Pershing II and Hellfire missiles, the Navy's Aegis ship-borne radar system, and F-18 fighter plane electronics. To support mil-spec microprocessors, Intel developed military versions of a wide range of processor extensions, starting in 1982 with the customized M8087 numeric data processor. The M8087 and its successors were designed to "unburden" the central processing unit by performing specialized arithmetic and logic functions to compute target trajectories in advanced systems such as "fire-and-forget" missiles. Intel manufactured the chips at a new facility in Chandler, Arizona, which opened in 1980 and produced microelectronics for telecommunications, automobile, and military applications.[49]

DOD, the armed services, and prime contractors valued technological spillovers from the commercial semiconductor industry because it saved them billions of dollars in development costs for military-grade devices, but the relationship was far from trouble-free.

49. National Semiconductor Corporation, *1975 Annual Report* (Santa Clara, 1976), 8; U.S. Congress, Office of Technology Assessment, *Contributions of DOE Weapons Labs and NIST to Semiconductor Technology* (Washington, D.C., 1993), 27; Intel Corporation, "Military Numeric Data Processor and Jovial Compiler, 1982," Intel Archives FC.

Silicon Valley's strategic emphasis on standardized technology received a good deal of criticism because DRAMs were not well suited for most military systems. Edith W. Martin, deputy undersecretary of defense for research and technology, claimed in 1983, "We now find that existing commercial tech-based capabilities are no longer adequate for defense" systems, which continued to rely on custom and semi-custom component technology.[50]

Microprocessors offered a partial solution to DOD's customization problem, because software programming made it possible to tailor devices for specific applications and combine them with customized processor extensions. In integrated circuitry and transistor technology, however, Silicon Valley's emphasis on standard devices contributed to shortages of customized devices for military and specialized commercial systems. This result forced many prime weapons contractors and commercial end-users of customized chips to work with standard devices. Others developed customized ICs in house or turned to small, highly specialized semiconductor firms such as Stanford Telecommunications, which developed application-specific integrated circuits (ASICs) for advanced weapons systems in the early 1980s. The solution to DOD's customization problem came later in the decade, when specialized startups emerged as a new source of defense-related microelectronics.[51]

The commercial semiconductor industry entered a crisis phase in the early 1980s. In 1975 American firms still produced 90 percent of the world's DRAM output, but the technology quickly became the provenance of Japanese firms, which took a commanding lead over their American competitors with better product quality and lower prices. By 1986 Japanese DRAM producers had forced all but two large American semiconductor firms to abandon the market, and the U.S. share of the global standardized memory market had shriveled to a mere 5 percent. The crisis had major technological implications, because DRAMs were "technology drivers" that provided the basis for most innovations in the semiconductor industry. The loss of market leadership in this strategic sector raised concerns about the long-term viability of the American semiconductor industry, particularly in the Pentagon, which feared that U.S. weaponry would become critically dependent on foreign—that is, Japanese—suppliers. These worries were reinforced by the worst economic crisis in the history

50. *Department of Defense Appropriations for 1984*, part 7, 98th Cong., 1st sess., House Subcommittee on the Department of Defense of the Committee on Appropriations (Washington, D.C. 1983), 919.

51. Wilson, Ashton, and Egan, *Innovation, Competition, and Government Policy*, 86–90; Saxenian, Regional Advantage, 92–93.

of Silicon Valley, as commercial microelectronics firms responded to staggering losses in memory chip sales by shutting down development programs and production lines. National, which clung to its doomed DRAM operations until the mid-1980s, reported a 9.6 percent loss in 1986, the worst operating result in its history.[52]

The region's recovery from the DRAM chip crisis was mostly due to the successful introduction of new semiconductor devices, such as application-specific integrated circuits and other customized chips, and to diversification into new product lines such as disk drives, computer peripherals, and innovative computer designs. These technologies emerged from a variety of largely uncoordinated initiatives. In many instances, executives and engineers whose efforts to implement innovative projects at AMD or National received neither attention nor funding founded their own startups, including T. J. Rodgers, who left AMD to found Cypress Semiconductor. Other new technologies evolved within established firms that had a long record of product innovation, notably Hewlett-Packard, which became the region's leading producer of personal computers and peripherals. Another (and often ignored) factor in Silicon Valley's technological and economic revival in the 1980s was the Pentagon, which funded a variety of important research and development initiatives and became a major customer of startups.

Pentagon-sponsored research at Stanford, the University of California at Berkeley, and other universities emerged as a significant source of innovation. During the 1970s many academic institutions found themselves isolated from corporate research and development, raising concerns that their computer science centers would miss cutting-edge developments in microelectronics. To gain financial support for their academic initiatives, scientists turned to the Office of Naval Research, the Defense Advanced Research Projects Agency, and other Pentagon and armed services agencies that funded research on computer architecture, computer-aided design, and programming languages. With active support from their sponsors, academic researchers eventually commercialized the resulting products and processes through startups like Silicon Graphics, Sun Microsystems, and Microlinear Corporation.

52. National Advisory Committee on Semiconductors, *A Strategic Industry at Risk: A Report to the President and the Congress* (Washington, D.C., 1989); Dorinda G. Dallmeyer, "National Security and the Semiconductor Industry," *Technology Review* 90 (Nov. 1987): 46; *Decline of U.S. Semiconductor Infrastructure*, 101st Cong., 2d sess., House Committee on Energy and Commerce (Washington, D.C., 1989), 3; Stephen Aubin, "The U.S. Memories Fiasco," *Air Force Magazine* (April 1990), 88–90.

A little-known episode in the history of Sun Microsystems illustrates the contribution of Pentagon-sponsored academic research to Silicon Valley's technological and economic renaissance. Most studies attribute Sun Microsystems' meteoric rise to prominence in the workstation market to its unconventional "open systems" strategy, which granted competitors liberal access to technical knowledge developed under company sponsorship. The open systems approach was unquestionably a key ingredient in the firm's success, because it established the Sun workstation design as the industry standard, contributing to the growth of compatible multisystem networks, which in turn generated demand for Sun workstations.

Workstation technology was not the result of strictly corporate sponsorship, however. The technology originated in 1977, when the Defense Advanced Research Projects Agency (DARPA) began to support a variety of research initiatives on submicron chip design and fabrication, as well as on computer architecture.[53] Berkeley's David Patterson and others developed new computer architectures in which computing tasks were "pipelined" to parallel microprocessors, each of which was programmed to complete a limited part of the computation. Known as reduced instruction set computing (RISC), the proposed computer architecture vastly increased circuit utilization, which in turn produced higher processing speeds. DARPA, which was interested in the technology because signal processing speeds were critical for target recognition systems and other advanced applications, funded a variety of these programs, including several at Stanford that enabled Forrest Baskett and others to develop the Stanford University Network (SUN). Baskett, envisioning SUN as a system of stand-alone units, each of which had the computational capacity of a minicomputer, assigned workstation development to doctoral candidate Andreas Bechtolsheim under a DARPA research grant. In 1982 Bechtolsheim teamed up with William Joy, a Berkeley re-

53. DARPA, founded in 1958 in response to the Sputnik scare, was initially responsible for basic research in space and missile electronics. After civilian space research had been transferred to the newly founded National Aeronautics and Space Administration, the agency supported research on ballistic missile defense, nuclear test detection, and counterinsurgency for the Vietnam War. In the 1970s, the agency refocused toward basic and applied research in space-based weaponry, stealth technology, and information processing. The latter emerged as a core activity in the 1980s, when the bulk of DARPA research funding was devoted to its Strategic Computing Program; Richard H. Van Atta, Sidney Reed, and Seymour J. Deitchman, *Institute for Defense Analyses Paper P-2538: DARPA Technical Accomplishments, vol. 3: An Overall Perspective and Assessment of the Technical Accomplishments of the Defense Advanced Research Projects Agency, 1958–1990* (Alexandria, Va., 1991).

searcher who had recently improved the Unix operating system with DARPA funding, to form Sun Microsystems in Mountain View.[54]

In addition to sponsoring workstation technology, the Pentagon helped create a customer base for compatible networks. In 1983 DARPA provided financial support for universities to acquire workstations from Sun Microsystems, which produced as much as 80 percent of its output for academic institutions. The Pentagon meanwhile encouraged weapons laboratories and prime contractors to adopt workstation networks for collaborative systems design and software development, creating a booming market in defense-related fields. Sun Microsystems became General Electric Aerospace's sole-source supplier of workstations for use in electronic computer-aided design and computer-aided software engineering. Silicon Graphics, whose founder James Clark had developed a high-performance workstation chip under a DARPA research grant at Stanford in the early 1980s, successfully carved out a niche in the high-end graphics market, supplying workstations to LMSC, General Dynamics, and Boeing.[55]

Sun Microsystems and other systems producers often shifted from programmable devices to application-specific integrated circuits, whose logic circuits were specifically designed to meet the needs of a given system. In the Sun-3 workstation, for example, seventy standard devices were replaced with five ASICs that were more compact, lighter, faster, and more reliable than standard chips. In this strategic move, Sun Microsystems both profited from and facilitated the resurgence of custom technology, which had been Silicon Valley's stepchild for more than a decade. In the 1970s the key problem had been high ASIC design costs that were difficult to amortize because custom chips were by definition manufactured in small production runs. Subsequent advances in computer-aided design and manufacturing systems not only brought down development costs but also shortened design cycles. By the 1980s Silicon Valley was teeming with startups that specialized in ASIC technology, including Interna-

54. Committee on Innovations in Computing and Communications, *Funding a Revolution: Government Support for Computing Research* (Washington, D.C., 1999), chap. 4; Richard H. Van Atta, Sidney Reed, and Seymour J. Deitchman, *Institute for Defense Analyses Paper P-2429: DARPA Technical Accomplishments, vol. 2: A Historical Review of Selected DARPA Projects* (Alexandria, Va., 1991), 17.1–17.B.14. Studies of Sun Microsystems include Raghu Garud and Arun Kumarawamy, "Changing Competitive Dynamics in Network Industries: An Exploration of Sun Microsystems' Open Systems Strategy," *Strategic Management Journal* 14 (1993): 351–69; Jonathan Khazam and David C. Mowery, "The Commercialization of RISC: Strategies for the Creation of Dominant Designs," *Research Policy* 23 (1994): 89–102.

55. Khazam and Mowery, "Commercialization of RISC"; Breck Henderson, "Workstations Speed Aircraft, Avionics Design," *AW&ST* (19 Aug. 1991), 51–52.

tional Microelectronics Products, VLSI Technology, LSI Logic, and Weitek Corporation.[56]

Like Fairchild in the 1960s, the startups rarely drew on direct DOD research support, but sales to the Pentagon, the armed services, and prime contractors often figured prominently in their revenues. Given the acute shortage of custom chips that plagued the Pentagon and military systems producers when mainstream semiconductor companies switched to standardized devices, demand for military ASICs was substantial, creating major opportunities for the startups. LSI Logic, founded in 1981, quickly emerged as a key supplier of military devices, including RISC chips for the Air Force's advanced tactical fighter and the Army's LHX helicopter, as well as highly classified NSA data encryption devices. By the end of the Cold War, LSI Logic netted $80 million annually (more than 20 percent of total revenues) from its military business. Performance Semiconductor, a Sunnyvale startup founded in 1984 that employed 425 people by the end of the Cold War, derived 60 percent of its revenues from military sales. Performance was in fact so dependent on Pentagon work that it folded in the early 1990s when defense appropriations started to shrink.[57]

Conclusion

The role of the federal government in the development of Silicon Valley has long been the subject of political controversy. In 1993 Cypress Semiconductor president T. J. Rodgers asked rhetorically in a discussion of federal technology policy, "Does any of us really believe that Washington can play a decisively helpful role in fields as complex as semiconductors, high-performance computers, or electronic data superhighways?"[58] Similar sentiments surfaced during the 2000 presidential campaign, when Republican George W. Bush's call for minimalist federal intervention into the high-tech economy resonated with many executives. One argued that Silicon Valley's

56. Saxenian, Regional Advantage, 123.

57. Ibid., 117–22; Steven Greenhouse, "Revving Up the American Factory," *New York Times*, 11 Jan. 1987; David Card, "Atten-shun! You Will Now Design ASICs the Military Way," *Electronic Business* (1 Nov. 1988), 98; "Performance Semi's Fab on Block," *Electronic News* (21 March 1994), 1; "LSI Logic Corp., " *AW&ST* (9 April 1990), 53; "New NSA Encryption Chips," *Data Communications* 15 (Sept. 1986): 15.

58. *Technology Policy: Information Infrastructure [Information Superhighways and High Performance Computing]*," vol. 3, 103d Cong., 1st sess., Senate Subcommittee on Technology, Environment and Aviation of the Committee on Science, Space, and Technology (Washington, D.C., 1993), 228.

success was attributable to "people [who] are left on their own with a minimum of interference, red tape and bureaucracy." This executive elaborated: "People here look at [Democrat Al] Gore and see a bureaucrat, a politician, and someone from Washington."[59]

The view that government played no role in the rise of Silicon Valley ignores a sizable portion of the region's industrial base—firms in the missile, satellite, space electronics, and electronic warfare sectors that derived the bulk of their revenues from defense contracting, employed as much as a quarter of the region's work force directly, and accounted for roughly 30 percent of its manufacturing revenues in the 1980s. It ignores the significance of military contracting for Silicon Valley's vaunted "postindustrial" organization of manufacturing (disintegrated production formats, customization, and flexible specialization), which originated and flourished in defense-related production well into the 1980s. And those who insinuate that the federal government cannot play a decisive role in fields such as semiconductors and computers overlook DOD-sponsored research that produced critical new technologies as recently as the 1980s, including RISC chips and workstation architectures.

Military demand for sophisticated designs and products shaped the structures and dynamics of Silicon Valley's defense-related high-tech industries, which included the microelectronics sector of the 1950s and 1960s. The result was a large variety of complex systems such as missiles featuring ever increasing degrees of accuracy, electronic warfare systems that collected and decoded exponentially growing amounts of data, customized microelectronics systems that turned military hardware into "smart weapons," and military satellites that transmitted increasingly detailed images of "enemy" weaponry and troops in real time. Because few firms could expect to develop the required expertise and production capacity in house, prime contractors often recruited hundreds of specialty firms as subcontractors in a system of disintegrated production. The swift pace of change in Cold War weapons technology meanwhile encouraged military contractors to embark on a course of flexible specialization. Drawing on the resources of academic institutions that conducted both basic and applied research, missile and satellite builders, electronic warfare specialists, and microwave electronics firms expanded into new niche technologies and markets that were closely related to their existing core specialties: from passive into active countermeasures systems, from spy satellite tracking systems into military communications satellites, and from strategic into tactical software.

59. "In Silicon Valley," *New York Times*, 3 Oct. 2000.

Flexible specialization in advanced defense systems rarely enhanced a firm's commercial competitiveness. An Office of Technology Assessment report concluded that flexible specialization in fact impeded success in commercial markets:

> Most large defense contractors that assemble complex weapons systems or make major subsystems are geared to low-volume production of highly specialized, expensive equipment. In designing the equipment, the main emphasis is on technical performance and meeting DOD requirements. In contrast, many commercial products have to combine reliability and affordable cost with high-volume manufacture. . . . Many firms or divisions of companies, that learn to work with DOD's demands for high technical performance, to meet confining and sometimes outmoded military specifications, and to live with detailed supervision, simply restrict most of their business to defense.[60]

LMSC's and Ford Aerospace's troubled attempts to develop a viable commercial satellite business in the 1970s confirm this analysis. Loral redesigned and retooled the Palo Alto satellite factory while liquidating its defense business to focus on civilian technologies and markets. Lockheed, unable to stage a decisive commercial breakthrough, largely abandoned conversion attempts, instead opting to increase its share of the shrinking military market through a merger with Martin Marietta that created the world's largest defense company.

The semiconductor industry followed a different trajectory. The sheer size of the military semiconductor market, with its emphasis on application-specific devices, encouraged pioneer firms to concentrate on custom technology and batch production until the 1960s, but the subsequent emergence of mass markets for commercial products precipitated the swift introduction of standard microelectronics. Volume production enabled leading firms to amortize skyrocketing research and development costs and in some instances produced significant technological spinoffs for military applications. By the early 1980s, however, most firms were unable to fend off the Japanese challenge in the "memory race," leading to fears about a possible collapse of the American semiconductor industry. Product diversification and the resurgence of customized microelectronics facilitated Silicon Valley's economic and technological turnaround in the 1980s, in some instances supported by Pentagon research funds and patronage.

60. U.S. Congress, Office of Technology Assessment, *After the Cold War*, 213–14.

These findings are relevant to a variety of scholarly debates. First, they confirm AnnaLee Saxenian's view that external economies and disintegrated production formats played a critical role in Silicon Valley, but the extent to which industrial networks were primarily region-based, as Saxenian claims, remains a matter of dispute. Although many firms developed long-term relationships with local suppliers, weapons systems producers also relied extensively on extraregional linkages. Defense contractors were hardly unique in this respect. Loral's telecommunications satellite business, for example, was based on transatlantic production linkages. Richard Gordon's research has determined that two-thirds of all components that went into new systems in the late 1980s were produced outside Silicon Valley, casting doubt on Saxenian's claim that the region can be seen as a modern counterpart to the regional-network-based industrial systems of nineteenth-century Philadelphia or the Third Italy.[61]

Second, these findings strengthen the case for a more systematic analysis of the state, defense policy, and weapons procurement in studies of batch production industries. Most scholars working in this field—me included—have concentrated on civilian products such as woolen textiles, locomotives, jewelry, and steamships but paid little heed to military items. This focus is perhaps appropriate for studies dealing with the nineteenth and early twentieth centuries, when large-scale defense markets emerged only intermittently during wartime. But it is inadequate for the Cold War period, when the forty-year arms race with the Soviet Union created long-term demand for new types of custom technologies: nuclear warheads, strategic missiles, spy satellites, stealth bombers, aircraft carriers, and military computers. No account of postwar batch production industries is complete without a close look at the Strangelovian netherworld of defense policy, military procurement, Pentagon-funded research and development, and weapons production.

61. Richard Gordon, "Collaborative Linkages, Transnational Networks and New Structures of Innovation in Silicon Valley's High-Technology Industry," Report No. 4, "Industrial Suppliers/Services in Silicon Valley," Silicon Valley Research Group, University of California at Santa Cruz, Jan. 1993.

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