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SAGE

By almost any measure -- scale, expense, technical complexity, or influence on future developments -- the single most important computer project of the postwar decade was MIT’s Whirlwind and its offspring, the SAGE computerized air defense system.

In Project Whirlwind many of the questions framed in chapter 2 began to find their answers. Whirlwind started out as an analog computer designed to be part of a control system. It metamorphosed into a digital machine but retained its original purpose, thus linking digital computing to control functions. Originally funded by the Office of Naval Research, the project almost expired during a prolonged crisis over its military justification. It was saved when the Air Force embarked on a search for new air defense technologies after the 1949 Soviet atomic bomb explosion. Whirlwind was chosen, by civilian scientists, as the central controller for the hugely ambitious SAGE continental air defense system. This choice saved the project and led to a vast array of technical developments, such as analog / digital conversion techniques, real-time digital computing, and extremely high reliability, that would be essential to the viability of computers in military control systems.

SAGE was the first large-scale, computerized command, control, and communications system. Although it was obsolete before it was completed, it unleashed a cascading wave of command-control projects from the late 1950s onwards, tied largely to nuclear early warning systems. These systems eventually formed the core of a worldwide satellite, sensor, and communications web that would allow global oversight and instantaneous military response. Enframing the globe, this web formed the technological infrastructure of closed-world politics.

Whirlwind and the Trek from Analog to Digital Control

Whirlwind was conceived late in 1944, in the MIT Servomechanisms Laboratory, as the Airplane Stability and Control Analyzer (ASCA), an analog device intended for use in flight simulators. By 1946, the project had been reoriented toward construction of a general-purpose digital computer. Exploring this transition will highlight the simultaneously technical, social, and institutional character of technological choice.

In the 1940s, flight simulators were servo-operated, electro-mechanical devices that mimicked an airplane's attitudinal changes in response to movements of its controls. They allowed pilots in training to practice flying in a safe and relatively inexpensive environment. A sufficiently accurate simulation could also allow engineers to study alternative sets of characteristics before building a prototype of a new design. In 1943–44 Captain Luis de Florez, director of the Navy's Special Devices Division, realized that a *general* simulator, one that could be programmed to simulate any desired set of characteristics, could in theory vastly reduce the time and expense of both aircraft development and pilot training.[1] In principle, the flight simulator was what is now known as a "dual-use" technology, equally applicable to training military and civilian pilots. But the urgency of the war made it, in practice, a military technology, and commercial potential was not a factor in justifying the project.

In 1944 Jay Forrester was an advanced graduate student at MIT. As one of Gordon S. Brown's two assistants, he had helped found the Servomechanisms Laboratory in 1940. He was present when Captain de Florez discussed the idea of a general simulator with Brown's group, and when the Special Devices Division issued a contract for the ASCA in December 1944, Forrester took charge of the project.[2]

The Servo Lab was then the most important center of analog control research in the United States, and Forrester spent his first year working on an analog computer for the ASCA. The complexity of the calculations involved -- requiring simultaneous solutions of a hundred or more differential equations -- frustrated his efforts, but it is important to emphasize that this was *not* because analog techniques were unable, in principle, to solve the equations. Forrester needed to overcome two other problems.

First, the speed of the *electro-mechanical* analog equipment in terms of which Forrester had been trained to think -- the servomechanisms and differential analyzers of the Vannevar Bush era -- was too slow. To make a simulator feel realistic, its controller would need to solve the necessary equations virtually instantaneously, that is, without a noticeable delay between the pilot's actions and the machine's response. Computational delays of even significant fractions of a second, as were typical of electro-mechanical devices, would be intolerable. This was the problem of "real-time" control. In principle, at least,

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[1] Mina Rees, "The Computing Program of the Office of Naval Research, 1946-1953," *Annals of the History of Computing*, Vol. 4, No. 2 (1982), 113.

[2] In fact the Servo Lab, according to Gordon Brown, probably had as much to do with the idea for the simulator as de Florez: Gordon S. Brown, interviewed by Richard R. Mertz, May 28, 1970. Smithsonian Computer Oral History, AC NMAH #196 (Archive Center, National Museum of American History, Washington, D.C.). The Special Devices Division was later known as the Special Devices Center. The designation "analyzer" reflects the ASCA's origins in the Bush-MIT tradition of analog "differential analyzers."

this problem was not unsolvable; electronic analog computation could have achieved the requisite speeds.

A second, more intractable difficulty was the limited accuracy of analog techniques. Because they employ measured physical quantities rather than counts of discrete units, analog devices unavoidably introduce increasingly large errors as their complexity rises. In 1945 Forrester and some associates paid a visit to MIT colleague Frank Verzuh. Verzuh had worked on Bush's Rapid Arithmetic Machine and the various differential analyzers before and during the war, but he was now helping to design the Rockefeller Electronic Calculator, a small digital computer. He "told Jay . . . he would have to use digital techniques," because the best MIT differential analyzer achieved only five significant figures, whereas the ASCA would require as many as ten.[3] Though a research effort on Whirlwind's eventual scale would surely have led to major improvements in analog accuracy, in late 1945 Forrester began to explore digital techniques.

Forrester's interest in digital possibilities was piqued by three further encounters. First, his former fellow graduate student Perry Crawford, who had written a master's thesis on applying digital computation to the automatic control of antiaircraft guns, strongly suggested that Forrester look into digital methods. Then, in late 1945, Forrester attended the Conference on Advanced Computation Techniques, whose major theme was ENIAC research. Finally, he visited the Moore School to learn about the "Pennsylvania technique" and read the ENIAC designers' widely circulated "First Draft of a Report on the EDVAC."[4] Even together, however, these did not amount to some kind of digital conversion experience. The choice, at this point, was anything but clear-cut: Forrester spent the better part of the following year weighing analog and digital methods against each other.

By mid-1946 Forrester had abandoned the analog approach and reoriented the ASCA project toward a general-purpose digital machine, the Whirlwind, that would have the flight simulator as just one of its possible applications. This move from a special-purpose to a general-purpose machine did not correspond precisely with a shift to general or theoretical goals. In keeping with Servo Lab culture, Forrester and Everett remained strongly oriented toward applications.[5]

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[3]. Frank M. Verzuh, interviewed by William Aspray, February 20, 1984. Charles Babbage Institute, University of Minnesota.

[4]. Various accounts of Forrester's conversion to digital techniques are given in Kent C. Redmond and Thomas M. Smith, *Project Whirlwind: The History of a Pioneer Computer* (Boston: Digital Press, 1980); Mina Rees, "The Computing Program of the Office of Naval Research, 1946-1953," *Annals of the History of Computing*, Vol. 4, No. 2 (1982), 103-113; and George E. Valley Jr., "How the SAGE Development Began," *Annals of the History of Computing*, Vol. 7, No. 3 (1985), 196-226. A brief version of Forrester's own account may be found in Henry S. Tropp et al., "A Perspective on SAGE: Discussion," *Annals of the History of Computing*, Vol. 5, No. 4 (1983), 375-398.

[5]. Gordon Brown, director of the Servomechanisms Laboratory, recalled in an interview that from its inception, building and testing machines under conditions of actual use was a critical part of the

In fact, the Navy continued to view the project in terms of the flight simulator, and work on cockpit design and other features of the eventual ASCA proceeded.

This practical program in simulator design separated Whirlwind from almost all other digital computer projects of this era because it required a device that could be used as a real-time control mechanism.[6] This was a far from obvious goal for a digital computer, given the technology of the day. As we saw in chapter 2, analog computing and control technologies were well developed, with sophisticated theoretical underpinnings and many real-time applications, whereas electronic digital computers had serious problems with component reliability, size, power consumption, and expense, and the logic theory underlying their operation was still quite new. The full implications of the Turing machine's generality remained to be realized, and there was still much controversy over the relative value of general-purpose programmable machines versus special-purpose, task-oriented devices for specific needs.

Furthermore, electronic analog computation presented an alternative that could, in principle, resolve the speed problems of electro-mechanical machines. Good analog engineers could develop work-arounds to correct for the machines' inherent accuracy limitations. (This approach was being aggressively pursued in RCA's Typhoon, Philbrick Research's Polyphemus, and other projects of the 1940s and early 1950s.)[7] Most other computer projects of the 1940s saw digital machines as giant calculators for scientific computation.[8] Many believed that

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Lab's ethos. "This issue of testing . . . was the great issue . . . on which the success of Whirlwind depended and also it was the issue on which it nearly foundered." Gordon S. Brown, interviewed by Richard R. Mertz, May 28, 1970. Smithsonian Computer Oral History, AC NMAH #196 (Archive Center, National Museum of American History, Washington, D.C.). Forrester and Everett walked a delicate line in moving away from the ASCA without compromising their applications-oriented approach. On the one hand they encouraged conclusions like that of Columbia's Francis Murray. Murray, in an independent report comparing Whirlwind to the IAS machine at Princeton, wrote that "the application of digital computation to simulation and control required the 'engineering development' of Whirlwind, a requirement not imposed upon the IAS computer, which was at liberty to follow a 'direction of interest to its own objective,' namely the consideration of 'purely scientific problems.'" (Murray, cited in Redmond and Smith, *Project Whirlwind*, 81.) Their machine, they argued, was a prototype, as opposed to a model, of a computer. On the other hand, once they had effectively abandoned the ASCA they could not commit to any particular application without a sponsor willing to fund the massive costs of development.

[6]. One exception was Eckert and Mauchly's BINAC computer, completed in 1949 under contract to Northrop Aircraft. See chapter 2, note 52.

[7]. On the analog research program, see P. A. Holst, "George A. Philbrick and Polyphemus," *Annals of the History of Computing*, Vol. 4, No. 2 (1982), 143-156; Mina Rees, "The Federal Computing Machine Program," *Science*, Vol. 112 (1950), 731-736; and Michael R. Williams, *A History of Computing Technology* (Englewood Cliffs, NJ: Prentice-Hall, 1985), chapter 5.

[8]. As one of Forrester's colleagues recalled, "until that time, the use of computers was, and for some time afterwards, basically scientific and engineering calculation. But the use of it for ship control, the use of it for fire control . . . was all Forrester. He was pushing very hard for real-time computer applications." David R. Israel, interviewed by Richard R. Mertz, April 22, 1970. Smithsonian

only a few would ever be needed, and even Forrester at one time apparently thought that the entire country would eventually be served by a single mammoth computer.[9]

By 1948, the ONR's interest in a supersophisticated and by then extremely expensive flight simulator was on the wane. With military budgets declining, the Navy was forced to streamline its research programs. The Special Devices Center's funding for fiscal 1948 was cut from $11 million to $5 million. Meanwhile Forrester, increasingly less interested in the simulator application and more determined to build a high-speed, highly reliable general-purpose digital computer, had openly abandoned work on the simulator cockpit in June 1948.[10] Though he tried to maintain Navy interest by describing Whirlwind as a "fire-control computer," it became clear to the ONR that this was really no more than another general-purpose machine. Since the Defense Department was funding at least twelve other projects for general-purpose digital computers, Whirlwind's justification became increasingly murky. The agency began to demand immediate and useful results in return for continued funding.

This dissatisfaction was due in part to the management of Whirlwind by the ONR's theoretically oriented Mathematics Branch, where the value of a real-time control machine was not well recognized, and in part to Whirlwind's truly enormous expense. Whereas the cost range of computers like the Harvard Mark III and the UNIVAC lay in the hundreds of thousands of current dollars, start-to-finish (most between $300 and $600 thousand), the Whirlwind group was planning to spend $4 million or more. From the Navy's point of view, this money was going to support the useful but hardly defense-critical technology of flight simulation.

MIT requested $1.5 million for Whirlwind in fiscal 1949. This figure would have consumed nearly 80 percent of ONR's mathematics research funds, or almost 10 percent of the *entire* ONR budget for contract research.[11] The actual grant for that year was $1.2 million -- still an amazing level of investment, by any standard, in a single project. (Whirlwind's ultimate cost of about $5 million was over five times that of any other computer built during this period -- ten to twenty times that of most.)[12]

Computer Oral History Project, AC NMAH #196 (Archive Center, National Museum of American History, Washington, D.C.).

[9]. George W. Brown, interviewed by Richard R. Mertz, March 15, 1973. Smithsonian Computer Oral History Project, AC NMAH #196. (Archive Center, National Museum of American History, Washington, D.C.).

[10]. The reason proffered to the ONR was that construction of the cockpit, far simpler than its computer controller, should wait until the computer was ready.

[11]. Kenneth Flamm, *Creating the Computer* (Washington, D.C.: Brookings Institution, 1988), 54.

[12]. See the list of early computer projects in Flamm, *Creating the Computer,* 76-77.

As the conflict over funding approached a critical phase, Forrester began to cast about for a new, more urgent, and more fundamental military justification. He was in a good position to do this for a number of reasons. First, during the war he had spent time on an aircraft carrier on a combat mission, and so had direct experience with one version of the air defense problem.[13] Second, his laboratory entertained a steady stream of visitors from both industry and military centers, each of whom brought questions and ideas about how a machine like the Whirlwind might be used to automate their operations. Forrester's notebooks indicate that between 1946 and 1948 these visitors raised dozens of possibilities, including military logistics planning, air traffic control, damage control, life insurance, missile testing and guidance, and early warning systems.[14] Perhaps the most significant of these contacts was Perry Crawford, now at the Special Devices Center. As Forrester recalled in interviews, "it was . . . Crawford who pushed the whole idea of combat information and control with digital computers."[15] Crawford "circulated through the Navy and through the Washington scene, explaining the ideas to people and developing the necessary backing and funding so that the Navy was in a position to support the early development of the work."[16]

Third, the Whirlwind staff was composed largely of graduate students whose studies had been punctuated by military experience: "people coming back for their master's degrees who had completed an engineering undergraduate degree and anywhere up to perhaps four or five years in military service," Forrester recalled.[17] As a group, such students brought with them more concrete

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[13]. This was an accident. Forrester had been installing some MIT-built servo equipment on the ship. While he was below decks, the ship sailed for a Pacific combat zone. He kept himself busy by maintaining the equipment until the ship was torpedoed and forced to return to port. (Gordon S. Brown interview, May 28, 1970.) Forrester's colleague Robert Wieser speculated in an interview that "with a fire control background, I think one of the first things that occurred to Jay . . . was the application of the computer to coordinated antisubmarine warfare and air defense, which has certain similarities with ASW that is a multiple tracking system with, if you like, a battle management kind of function built into it too." C. Robert Wieser, interviewed by Richard R. Mertz, March 20, 1970. Smithsonian Computer Oral History Project, AC NMAH #196 (Archive Center, National Museum of American History, Washington, D.C.).

[14]. Jay W. Forrester, "Computation Book," November 27, 1946, to December 10, 1948. Magnetic Core Memory Records, 1932-1977, MC 140, Box 4, F27 (Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts).

[15]. Forrester, in Henry S. Tropp et al., "A Perspective on SAGE: Discussion," *Annals of the History of Computing,* Vol. 5, No. 4 (1983), 376.

[16]. Forrester, interviewed by C. Evans, 1975. *Pioneers of Computing* Series, Science Museum of London. (Available from Charles Babbage Institute, University of Minnesota.)

[17] Forrester, interviewed by Marc Miller, April 19, 1977. Oral History Collection, Institute Archives. Massachusetts Institute of Technology, Cambridge, MA.

ideas about applications than might students on a more traditional career path. Fourth, Forrester feared the looming prospect of a nuclear-armed USSR and, like many of his peers, hoped his work could make a significant contribution to national defense.[18]

Forrester and his group had in fact been considering the issue of military applications all along. In early 1946, when he had first reported to the Navy on his emerging plan to switch from analog to digital techniques, he had included several pages on military possibilities. There he speculated that ultra-fast, real-time digital computers could replace analog devices in "offensive and defensive fire control," and he foresaw highly automated Combat Information Centers with "automatic defensive" capabilities that would be necessary for "rocket and guided missile warfare."[19] He also mentioned the probable utility of such computers in carrying out other military research and general applications in science and engineering. At a symposium Forrester, commenting on Crawford's paper about computers for missile guidance, predicted the use of computers "as complete control systems in certain defensive and offensive applications" such as "triangulation computations on approaching aircraft" and automatic tracking, targeting, and destruction of incoming ballistic missiles.[20] In October 1947, Forrester, Crawford, and Whirlwind co-leader Robert Everett had published two technical reports (designated L-1 and L-2) on how a digital computer might be used in antisubmarine warfare and in coordinating a naval task force of submarines, ships, and aircraft.[21] That year, in frequent meetings at its Sands Point headquarters, Crawford and other SDC personnel had encouraged Forrester and Everett to continue developing, refining, and planning the blue-sky, systems control ideas of their L-1 and L-2 reports.[22]

The following year, as continuation of ONR support became increasingly uncertain, MIT president Karl Compton requested from Project Whirlwind a report on the future of digital computers in the military. The group produced a comprehensive, compelling vision of computers applied to virtually every arena of military activity, from weapons research and logistics to fire control, air traffic control, antiballistic missile defense, shipboard combat information centers, and broad-based central command-control systems. It presented a plan for a crash 15-

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[18] Redmond and Smith, *Project Whirlwind*, 150.

[19]. Forrester, cited in ibid., 42. For more on Combat Information Centers, a World War II Navy innovation, see chapter 7**.**

[20]. Jay W. Forrester, "Discussion of the paper 'Application of Computing Machines to Guided Missile Problems' by Mr. Perry Crawford, Office of Naval Research" (undated, 1947?), Vannevar Bush Papers, Box 39, Library of Congress.

[21]. Project Whirlwind Report L-1, J. W. Forrester and R. R. Everett to Director, Special Devices Center, subj: "Digital Computation for Anti-submarine Problem," October 1, 1947. Project Whirlwind Report L-2, J. W. Forrester and R. R. Everett to Director, Special Devices Center, subj: . "Information System of Interconnected Digital Computers," October 15, 1947. Cited in Redmond and Smith, *Project Whirlwind*, 58, note 24.

[22]. Redmond and Smith, *Project Whirlwind*, 120.

year, $2 billion (current) program leading to computerized, real-time command-control systems throughout the armed forces, projecting development timetables and probable costs for each application.[23]

From this point on, Forrester's commitment to the goal of real-time military control systems increasingly differentiated Whirlwind from other digital computer projects. As he recalled later, "from 1948 on, we were seeking machines to go into real-time control systems for military operations. Our circuits had to be extremely reliable compared to anything that previously had been thought necessary or possible. Our applications required very high speed, so we were working at speed ranges that were two and three orders of magnitude above [the Harvard and IAS computer] projects, and at a reliability level that was very much higher than the Institute for Advanced Study. Higher also than Aiken's [Harvard] work."[24] These commitments were realized not only in Whirlwind's technical efforts, but in the language of its self-representation.

Mutual Orientation: Constructing the Future

In one sense, Forrester's (and MIT's) increasingly grand attempts to imagine military applications for Whirlwind represented expert "grantsmanship," or deliberate tailoring of grant proposals to the aims of funding agencies. Grant writing is often dismissed as a kind of game. The usual argument is that grant proposals justifying basic research in terms of eventual applications are simply a vehicle to obtain funds that both recipients and agencies know will really be used for something else.

In the case of Whirlwind, however, a much more significant relationship between funding justifications and practical work also obtained, one we might call *mutual orientation*.

The Whirlwind studies of possible military applications of digital computers and the group's contacts with military agencies expanded the Whirlwind group's sense of possibilities and unsolved technical problems. At the same time, they served to educate the funding agency about as yet undreamt-of possibilities for automated, centralized command and control. While the ONR was not ultimately convinced, the thinking and the documents produced in the exchange kept funding going for several years. Later, these efforts proved crucial in convincing the Air Force to take over support for Project Whirlwind.

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[23]. Jay W. Forrester et al., "A Plan for Digital Information-Handling Equipment in the Military Establishment," Project DIC 6345, MIT Servomechanisms Laboratory, September 14, 1948. MIT Archives.

[24]. Forrester interview, April 19, 1977.

The source of funding, the political climate, and their personal experiences oriented Forrester's group toward military applications, while the group's research eventually oriented the military toward new concepts of command and control.[25] Forrester's group, MIT administrators, the SDC, and the ONR all directed each other's attention toward new arenas of concerns and solutions, centered around the articulation of the goals and meanings of a pre-paradigmatic technology. By forcing this articulation, conflicts among the groups' goals -- Forrester's high-speed digital research ambitions, MIT's military-based empire-building, the SDC's long-range applications approach, the ONR's budgetary concerns and bureaucratic politics -- generated a steady stream of new formulations and an increasingly coherent vision.[26]

Outside the unique circumstances of 1949 and 1950, this vision might have languished. But in the event, Whirlwind's discourse of computerized military control systems lay waiting, ready-made, for a second round of mutual orientation. This time, it would take part in the realignment of Air Force culture and strategy toward its fully modern incarnation as an automated, centralized, computerized command-control system.

To understand how Whirlwind helped reorient the Air Force, we must first understand how the Air Force reoriented Whirlwind. The following section explores how the issue of air defense was understood in the late 1940s. At that time, for a variety of reasons, the Air Force itself had dismissed continental air defenses as impractical. After the USSR's 1949 atomic test and the outbreak of the Korean War in 1950, the Air Force suddenly found itself hard pressed to justify this position. It initiated crash programs designed as much to assuage public anxiety as to provide genuine area defenses. Entering upon this scene, Whirlwind became caught up in a vast web of concerns: political problems of nuclear fear, strategic and tactical problems of air warfare, technical and cultural issues of central control, and, through them, the emerging discourse of the closed world.

Cold War Politics, Strategic Doctrine, and Air Defense

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[25]. In a group retrospective organized by Henry Tropp in 1983, the principals involved, including Forrester, Everett, and military sponsors, emphasize this process of mutual influence (Tropp et al., "A Perspective on SAGE").

[26]. On MIT's institutional interests in ongoing military funding, see Henry Etzkowitz, "The Making of an Entrepreneurial University: The Traffic among MIT, Industry, and the Military, 1860–1960," in Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart, eds., *Science, Technology, and the Military* (Boston: Kluwer Academic Publishers, 1988).

The strategic task of the postwar Air Force, largely self-defined, pivoted on the new weapon -- as did its role within the armed forces as a whole.

Before 1947 the Army and Navy were separate services, each with its own cabinet-level representative. During World War II the then Army Air Force (AAF) played such a significant strategic role that it began to seek a place as a third service. The three agencies often saw themselves as competing for military assignments, resources, and prestige.

The AAF seized on the bomb in 1945 as a means to expand its military role. So-called strategic bombing, or area bombing of cities with the aim of killing or disabling the employees of war industries and destroying civilian morale -- as opposed to attacking industrial targets directly -- was a central strategy of the Allied air forces during World War II (especially in Asia), occasional official pronouncements to the contrary notwithstanding. In addition, World War II-era aerial bombardment had very low accuracy, especially when bombers flew high (as they often did) to avoid antiaircraft fire. This meant that even when industrial or military installations were the intended targets, bombing generally destroyed wide areas around them as well. Thus area bombing was the *de facto* strategy even when not *de jure*.

The postwar *Strategic Bombing Surveys* of Great Britain and the United States showed that this strategy had been relatively ineffective, significant mainly in disrupting enemy fuel and supply lines near the war's end. But the atomic bomb's apparent success in securing Japan's abrupt and complete surrender swept aside their highly skeptical conclusions about air power.[27] Postwar plans, despite the surveys, relied on general attacks against cities and assumed that Hiroshima-like devastation would lead automatically to the enemy's surrender. Nuclear weapons, which unavoidably destroyed everything within miles of ground zero, fit perfectly into this strategic doctrine. Almost without debate, city bombing became the nuclear strategic policy of the new Air Force.

"Prompt Use"

By 1946 the Air Force had drafted a nuclear war plan that called for fifty bombs to be dropped on Russian cities -- despite the fact that even a year later the United States had only thirteen bombs, only one of which could have been prepared for

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[27]. Gregg Herken, *Counsels of War* (New York: Knopf, 1983), 24. According to Herken, the surveys pointed out that despite strategic bombing, German arms production rose steadily until mid-1944, judged that effects on civilian morale had been relatively slight, and concluded that at least in the British case the cost of the bombing in lives and money had been higher than the damage caused to the other side.

use in less than two weeks. In 1947 the National Defense Act elevated the Air Force to the status of an independent service and began, but did not complete, the process of uniting all three services under the new cabinet office of the Secretary of Defense (OSD).[28] In 1948 NSC-30, one of the early directives of the National Security Council (also created by the 1947 National Defense Act), authorized Air Force planners to assume the availability of increasing numbers of nuclear weapons and to establish a policy of “prompt use.”

In essence, this was a doctrine of preemptive strike. The Air Force planned an all-out nuclear attack against the USSR in any situation where it appeared the USSR might be about to launch a strike of its own.

The reasoning behind this policy grew in part from the cowboy ethic of Air Force culture. Between the wars, World War I AAF commander Billy Mitchell had mounted an enormous media campaign to promote air power as a kind of ultimate weapon that could make ground warfare obsolete. World War I newsreels more or less commissioned by Mitchell showed airplanes under his command sinking enemy ships. Mitchell’s airmen called this activity “air defense” since it involved destroying the sources of enemy fire, a usage which continued until World War II, causing some understandable confusion about the difference between defense and offense in air warfare.[29] It was not until about 1941 that the official Army Air Corps definition of air defense excluded “counter air force and similar offensive operations which contribute to security rather than air defense.”[30] As late as 1952, during an interview on national television, General Hoyt Vandenberg reiterated the idea that destroying the sources of enemy fire -- in this case, enemy air bases -- was the most fundamental tactic of air defense.[31]

Mitchell continued to proselytize after World War I with mock air raids on American cities and articles in the major general-interest magazines *Collier’s*, the *Saturday Evening Post*, and *Liberty*. In these forums, during 1924–25, Mitchell challenged the sanctity of civilian lives in modern warfare. He argued that since enemy cities produced munitions and other military matériel, and since their inhabitants directly and indirectly supported this military role, cities (and their populations) were legitimate military targets. Once its industrial centers were bombed with high explosives and tear gas, Mitchell believed, any enemy would be forced to capitulate. Wars could be won from the air. The tireless Mitchell also disseminated his views through Walt Disney films and

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[28]. Unification of the services under the OSD was not fully achieved until 1961; even then, interservice competition for roles, missions, and money continued.

[29]. Kenneth Schaffel, *The Emerging Shield: The Air Force and the Evolution of Continental Air Defense 1945-1960* (Washington, D.C.: Office of Air Force History, United States Air Force, 1991), 8 and passim.

[30]. Ibid., 36, citing official policy.

[31]. Ibid., 180.

eventually published a book, *Winged Defense*.[32] His aggressive public attacks on Secretary of War John Weeks and other officers who disagreed with his views eventually led to his court-martial and conviction for insubordination.

Mitchell's flamboyant, swashbuckling image became a basic icon of Air Force culture. (A popular 1955 film, *The Court-Martial of Billy Mitchell*, lionized him as a military prophet.)[33] As we have seen, the very doctrine of strategic bombing that led to his court-martial became official Air Force strategy during World War II. Mitchell viewed air forces as an ultimate war-winning power that required nothing from conventional armies but to be given free rein. This vision became the dream the Air Force pursued to its apotheosis in the Strategic Air Command (SAC), under the flamboyant, cigar-chewing General Curtis LeMay.

The policy of prompt use originated in this culture of the offensive. LeMay reportedly once told an assembled group of SAC pilots that he "could not imagine a circumstance under which the United States would go second" in a nuclear war. Yet because it so deeply contradicted the ideology of America as a nation armed only for its own defense, the policy remained a high-level secret, kept so effectively that according to Gregg Herken "it is likely that few in the government or at Rand [an Air Force think tank] actually knew enough details of Air Force war planning to appreciate the extent to which American nuclear strategy by the mid-1950s was based upon the premise that the United States would land the first blow with the bomb."[34]

There were also, however, significant strategic reasons for the policy of prompt use of nuclear weapons. First, World War II experience with aerial combat and air defense had shown that it was extremely difficult to defend (in the ordinary sense) even relatively small areas against a determined air attack. Second, radar technology of the 1940s could neither see beyond the horizon nor detect low-flying airplanes. Even an ideal radar system using then-current technology could have provided at best one to two hours' advance warning. Worse, attackers flying below 1,000 feet could have evaded it altogether. Third, the enormous length of the U.S. perimeter made complete radar coverage a gigantic and extremely expensive undertaking. Finally, and perhaps most importantly, commanders generally estimated that even excellent air defenses could prevent only about 10 percent of attacking airplanes from reaching their targets -- 30 percent, according to the most hopeful, at an absolute maximum.[35]

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[32]. H. Bruce Franklin, *War Stars* (New York: Oxford University Press, 1988), 96.

[33]. This film and a spate of others about heroic airmen also demonstrate how completely, by the mid-1950s, the Air Force and the notion of victory through air power had captured the popular imagination. See Franklin, *War Stars*.

[34]. Herken, *The Emerging Shield*, 97. The quotation from LeMay, reported by Herken, originates with an unnamed Air Force intelligence officer present for the briefing.

[35]. British planes and antiaircraft guns successfully repulsed a major German air assault during the Battle of Britain in 1940 by shooting down only about 10 percent of the attacking planes.

But if the invaders carried nuclear weapons aimed at cities, even a kill ratio of 90 percent would be unacceptably low.

Thus the principle that “the best defense is a good offense” applied in spades to the issue of defense against nuclear-armed bombers. Atomic bombs seemed to produce an even more overwhelming advantage for that offense -- which, to Air Force thinking, *was* the defense. By 1950 fifty bombs had been built and many more were on the way. Air defense programs developed at a desultory pace, receiving only minimal commitments of funds and attention. In fact, the Air Force pushed *against* air defense, fearing it would pull resources and commitments away from the Strategic Air Command.

“A Dangerous Complacency”: Resisting Air Defense

In August 1947 a panel of officers of the Air Staff reflected the prevailing view within the forces that the AAF neither could nor should plan to provide air defense of the entire United States. Because of its size, they believed, such a commitment might endanger the national economy. Worse, however, it would “leave little room for the air offensive”; this “would be disastrous since real security lay in offensive capability.”[36] The panel recommended only point defense of strategic targets.

A Rand Corporation report, commissioned by Air Force science advisor Theodore von Karman, agreed. Rand invoked a favorite Air Force icon: “such an investment [in expensive, near-obsolete, ineffective air defense systems] might . . . foster a dangerous ‘Maginot Line’ complacency among the American people.”[37] Thomas K. Finletter’s 1947 Air Policy Commission, appointed by Truman to create an integrated air strategy, insisted that the Air Force by 1953 should equip itself with the best, most modern defensive electronics, jet fighters, and ground-based weapons. But in language strikingly similar to Rand’s, the commission opposed a total radar coverage system because it might “divert us -- as the Maginot Line diverted France -- from the best defense against an atomic attack, the counter-offensive striking force in being.”[38]

The opposing position was represented by Maj. Gen. Otto Weyland, Assistant Chief of Air Staff for Plans, who pointed out in an exchange with General Earle Partridge (his counterpart in Operations, Commitments, and

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[36]. Air Defense Policy Panel, report to Air Force Chief of Staff, August 14, 1947, cited in Schaffel, *The Emerging Shield*, 66.

[37]. Schaffel, *The Emerging Shield*, 67, citing *Preliminary Rand Report, subj.: Active Defense of the United States against Air Attack*, July 10, 1947, revised and reissued February 5, 1948.

[38]. Ibid., 75, citing Finletter Commission report dated January 1, 1948.

Requirements) that the AAF now faced a policy contradiction. The agency sought the chief responsibility for air defense but had assigned virtually no equipment or personnel to that task. Weyland argued that at least some minimal system must be built and maintained to demonstrate the AAF's commitment.[39]

Some measures were in fact already under way. Even before the war's end, Army Ordnance and the Air Force had commissioned Bell Laboratories to study continental air defense against high-altitude, high-speed bombers. The result was the Nike antiaircraft missile project. Ground-based analog computers and radar, along the lines of Bell's analog gun directors, would guide the Nike missiles to their targets, where they would be detonated by remote control. Nike R&D was not finished until 1952, and installation was not completed until about 1954.[40] Even then, the Nike-Ajax was a point (as opposed to an area) defense system, and it was controlled by the Army. In a period of intense interservice competition, the Air Force saw the Nike-Ajax project as worse than no defense at all, because it might lead not only to a "dangerous complacency" but to Army control of continental air defense.

Increasingly bellicose Cold War politics, both global and domestic, ultimately mooted the debate. The Air Force role in this process was to amplify fears of Soviet aggression while constructing a military container -- in the form of forward SAC bases and nuclear weapons -- to hold back the red tide.

By 1948 Air Force intelligence -- contrary to the estimates of both Army and Navy intelligence services and to those of the Central Intelligence Agency -- had come to believe strongly in the possibility of imminent Soviet attack. This view bordered on the bizarre. Such an attack would have required (a) the Tu-4 Bull long-range bombers demonstrated for the first time in a 1948 Soviet air show and not produced in any quantity until the following year, (b) a suicide-mission strategy since the Tu-4 could hold enough fuel to reach the United States from the USSR, but not to return, and, most absurdly, (c) the USSR's willingness to risk American atomic retaliation at a time when it possessed only conventional weapons. The Air Force leadership, grounding its faith in the demonizing discourse of the Cold War, thought the kamikaze strategy a real possibility and apparently suspected, on the thinnest of evidence, that the necessary elements of this strategic scenario might be much more advanced than they seemed.[41]

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[39]. Ibid., 65-66.

[40]. See M. D. Fagen, ed., *A History of Engineering and Science in the Bell System* (Murray Hill, NJ: Bell Telephone Laboratories, 1978), chapter 7.

[41]. In the distorted mirror typical of superpower nuclear strategy, one reason for the Air Force belief in a Soviet kamikaze strategy may have been SAC's own plans, which involved something only a little better. SAC's medium-range bombers, even with aerial refueling and forward bases, could leave the USSR after a strike but could not return to the United States. SAC planned for pilots to ditch their aircraft in Afghanistan, Iran, Scandinavia, or northern Canada and attempt somehow to straggle home. B. Bruce-Briggs, *The Shield of Faith* (New York: Touchstone, 1988), 78.

The strange 1948 emergency alert provides good evidence of the strength of these implausible assumptions. In March of that year, USAF Headquarters ordered the existing skeleton emergency air defense system onto 24-hour alert. The alert lasted nearly a month, until it was suddenly canceled in mid-April. It apparently resulted from reports by Lt. Gen. Ennis C. Whitehead, AF commander in the Far East, of a series of "strange incidents and [Soviet] excursions" over Japan, combined with a change in Soviet European military alignments after the communist coup in Czechoslovakia.[42]

Whatever its causes, this event had the effect of drawing attention to the severe limitations of continental air defense at a time when the so-called Radar Fence Plan was stalled in Congress. This plan, one of several (unimplemented) interim air defense plans proposed between 1945 and 1950, would have used the obsolete World War II-era radars to build a national network including 411 radar stations and 18 control centers, staffed by 25,000 Air Force personnel and 14,000 Air National Guardsmen. The Radar Fence would have cost $600 million and was to become operational in 1953 -- the earliest date the USSR's first atomic weapons were expected. Despite the emergency alert, Congress balked at the plan's cost. Only in March 1949 did it finally approve an air defense bill, the much smaller Lashup radar system comprising only 85 radar stations and costing a mere $116 million.[43]

The budgetary tide -- and the political fortunes of the Air Force -- turned hard in September 1949, when the Soviets exploded an atomic bomb years ahead of the schedule forecast by U.S. intelligence. The Truman administration immediately began planning for a two-sided nuclear war.

In the spring of 1950, the National Security Council warned that the Soviets were actually ahead of the United States in the arms race. NSC-68 looked to 1954 as the "year of maximum danger," when Soviet forces would have enough bombs to disarm the United States in a surprise attack. The report recommended spending 20 percent of the nation's gross national product on a massive defense buildup. The outbreak of war in Korea the following year provided the crisis necessary to implement NSC-68's recommendations.[44] By January 1951 Truman had set in place a vast range of new policies for the successful prosecution of a much escalated Cold War. Emergency war powers and renewal of selective service were rushed through Congress. Truman's $50 billion defense budget roughly conformed to NSC-68's guidelines. He increased Army troop strength by 50 percent to 3.5 million men, built new bases in Morocco,

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[42]. Schaffel, *The Emerging Shield*, 77.

[43]. Ibid., 83 and passim.

[44]. The Korean War also provided an occasion for the application of Air Force strategic bombing doctrine. Less than three months after its entry into the war, the United States had already bombed every major city in North Korea. The use of nuclear weapons was seriously considered and publicly mentioned. But just as in World War II, the bombing failed to produce the automatic victory Mitchell had theorized. Nor did the nuclear threat.

Libya, and Saudi Arabia, raised aid levels to the French in Vietnam, initiated proceedings for bringing Greece and Turkey into NATO, and opened discussions with Gen. Francisco Franco in which American aid was eventually traded for military bases in Spain. He also doubled the size of the Air Force, to ninety-five air groups.[45] In less than four years, annual spending for nuclear strategic forces would more than quadruple from 1950 levels.[46]

While its other assumptions about Soviet capabilities and intentions remained implausible, the fact that only Air Force intelligence had predicted a 1949 Soviet nuclear weapon had the effect of vindicating its other views and magnifying its influence on strategic decision-making. The case for air defense suddenly acquired much greater force. Civilians, especially those in the state of Washington (near Boeing Aircraft and the Hanford nuclear facilities), began to clamor for protection. To preserve its credibility, the Air Force would have to come up with something more politically effective than reassurances about the overwhelming power of its offensive forces -- especially, perhaps even paradoxically, since the prompt-use policy must remain secret. General Hoyt Vandenberg, now Air Force Commander in Chief, told the Joint Chiefs of Staff in a November meeting that “the situation demanded an urgency and priority similar to the Manhattan District Project.”[47]

For the short term, the Air Force initiated a crash program in early warning, stepping up the schedule for the Lashup system. In addition, plans were approved to proceed hastily with the radar “fence” along the polar approaches to the United States, despite the technical problems discussed above.

To get around the problem of low-altitude radar blindness, a colossal network of visual observation posts was established, staffed by civilian volunteers. During the Korean War the Air Force recruited these volunteers with inflammatory -- and disingenuous -- radio advertisements such as the following:

> Who will strike the first blow in the next war, if and when it comes? America? Not very likely. No, the enemy will strike first. And they can do it too -- right now the Kremlin has about a thousand planes within striking distance of your home.[48]

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[45]. Stephen Ambrose, *Rise to Globalism*, 4th ed. (New York: Penguin, 1985), 126.

[46]. Measured in constant 1981 dollars, spending on nuclear forces climbed from the equivalent of $9.6 billion in 1950 to $43.3 billion in 1953. Paul Bracken, *The Command and Control of Nuclear Forces* (New Haven: Yale University Press, 1984), 77.

[47]. Schaffel, *The Emerging Shield*, 116.

[48]. Cited in ibid., 158.

At its peak in 1953 the Ground Observer Corps operated more than 8,000 observation posts, twenty-four hours a day, using over 305,000 volunteers. Commanders generally recognized the GOC as unreliable and too slow to provide significant warning. Nevertheless, it continued to function until 1959. The GOC was another buttress for the wall of the container America was building, another support for closed-world discourse. Its function, like so much of the macabre apparatus of nuclear war, was primarily ideological: a genuine defense being impossible, a symbolic one was provided instead.

For the long term, the Air Force turned to scientists for new ideas. Happening almost by chance upon Forrester's crisis-torn computer project, the architects of the long-term solution found a technology neatly packaged together with a ready-made, highly articulated vision of central command and control using digital techniques. They resurrected it from near oblivion and transformed it into the core of the SAGE continental air defense system. Whirlwind, injected with almost unlimited funding and imbued with the intense urgency of nuclear fear, suddenly became a central pillar in the architecture of the closed world's defensive dome.

From Whirlwind to SAGE

In December 1949 the Air Force established the Air Defense System Engineering Committee, headed by MIT professor George E. Valley. The Valley Committee, as it was known, worked for two years, beginning its program with a study of the radar-based air defense of Great Britain during World War II. It emerged with a comprehensive plan for the air defense of North America, a plan that became reality as the Semi-Automatic Ground Environment -- SAGE.

Valley's was not the only plan, however, and digital computers were not the only technology. Fierce debates raged inside the Air Force over the issues of centralization and automation. Parallel to the centralized digital system, research proceeded on a less automated, decentralized analog control technique. In the end the MIT scientists and engineers won out, converting the Air Force simultaneously to air defense, central control, and digital computers. They did so not, or not only, by creating a superior technology, but by generating a discourse that linked central automatic control to metaphors of "leakproof containers" and "integrated systems" -- Maginot Lines (as the Air Force called them) for a new technological age.

According to Valley's memoir, he immediately comprehended the enormity of the mathematical problem for a wide-area defense. To triangulate the positions and velocities of aircraft, sightings from two or more radar units would have to be integrated through calculations.

> The earth's curvature meant that hundreds, if not thousands, of radars would be required to detect low-flying aircraft. . . . There was no conceivable way in which human radar operators could be employed to make [the necessary] calculations for hundreds of aircraft as detected from such a large number of radars, nor could the data be coordinated into a single map if the operators used voice communications. The . . . computations were straightforward enough. . . . It was doing all that work in real time that was impossible.[49]

Apparently independently, Valley came up with the idea of using digital computers for this purpose. A month later, in January 1949, Jerome Wiesner told him about the Whirlwind project.

The timing of Valley's encounter with Whirlwind was serendipitous. The ONR was just coming under the influence of a report by the Ad Hoc Panel on Electronic Digital Computers convened by the Committee on Basic Physical Sciences of the Defense Department's Research and Development Board. The panel's major recommendation -- that the entire Defense Department effort in digital computation be centralized under a new committee -- was never implemented, but its criticisms of Whirlwind were strong and influential. According to its analysis, completing Whirlwind would require about 27 percent of the $10 million DoD computer research budget, which was then supporting thirteen machines from eight suppliers.[50] Without a more urgent end use, the panel held, Whirlwind's expense could not be justified.[51]

By March 1950 the ONR had cut the Whirlwind budget for the following fiscal year to $250 thousand. Compared with the $5.8 million *annual* budget Forrester had at one point suggested -- as a comfortable figure for an MIT computer research program leading to military and other control applications as well as state-of-the-art scientific and engineering problem-solving capability -- this was a minuscule sum.[52] According to James R. Killian, Jr., then president of MIT, "Project Whirlwind would probably have been canceled out had not George

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[49]. Valley, "How the SAGE Development Began," 205.

[50]. Redmond and Smith, *Project Whirlwind*, 154. In the end, Whirlwind cost nearly twice the panel's estimate.

[51]. Oddly, at the same time the panel "criticized the general conduct of computer research and development because it did 'not include sufficient emphasis on real-time computation'" -- precisely Whirlwind's forte. Redmond and Smith, *Project Whirlwind*, 161.

[52]. Forrester's log-book entry for July 15, 1948, invites an even grander vision, invoking World War II icons: "Consideration should be given to establishing an independent set-up similar to that of the Radiation Laboratory, or perhaps even of the Manhattan District on a smaller scale." Jay W. Forrester, "Computation Book," November 27, 1946, through December 10, 1948. Magnetic Core Memory Records, 1932–1977, MC 140, Box 4, F 27 (Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts).

Valley . . . come up with the pressure to use Whirlwind as part of the SAGE system."[53]

The Air Force had handed Valley a blank check. Though he initially heard mostly negative things about Whirlwind from others at MIT, Valley made contact with Forrester, who immediately handed him the 1947 L-1 and L-2 reports on digital computers as central controllers for naval warfare. Forrester and Everett also showed him some plans for air traffic control, but the naval-warfare documents impressed Valley more. Air traffic control was qualitatively different from air defense problems: in the first case pilots are cooperating with controllers and providing information; in the second they are doing the opposite.

Valley approached Whirlwind with some hesitation. He thought of the digital computer application as little more than a way to prove a point about the potential of digital techniques in the control field, then entirely dominated by analog methods, and he took seriously Whirlwind's reputation as an overblown behemoth. He therefore started by proposing that ADSEC rent the Whirlwind for only one year, and he continued to explore other possibilities. (These included another digital-computer-based, but decentralized and lower-speed, system proposed by Northrop Aircraft, former sponsors of the ill-fated BINAC.)[54] Fortunately for Forrester, Whirlwind was finally reaching full operational status -- by the end of the year it was regularly running scheduled programs -- and with his charisma, energy, and enormous intellectual capability as an additional influence, Valley soon became a believer.

Valley's timing was also lucky in that the Air Force Cambridge Research Center (AFCRC), for reasons having nothing to do with computation, had recently developed methods for digital transmission of data over telephone lines. Their goal was to compress radar information, which was then transmitted over expensive microwave channels, into a bandwidth small enough for telephone transmission. To do this they had created a system known as Digital Radar Relay (DRR). Making such transmissions reliable -- in a system designed from the start for analog voice signals -- was the key issue.[55] The DRR research, begun just after World War II, had taken four years to complete. Its availability solved one of the many analog-to-digital conversion problems faced by the eventual SAGE.

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[53]. Killian, quoted in Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882–1982* (Cambridge, MA: MIT Press, 1985), 282–283.

[54]. Irving S. Reed, interviewed by Robina Mapstone, December 19, 1972. Smithsonian Computer Oral History, AC NMAH #196 (Archive Center, National Museum of American History, Washington, D.C.). According to Reed, the Valley committee granted Northrop $150 thousand to pursue radar and computer research for this project.

[55]. John V. Harrington, "Radar Data Transmission," *Annals of the History of Computing*, Vol. 5, No. 4 (1983), 370.

The budding air defense program thus intersected neatly with newly available digital technologies, including Whirlwind. Simultaneously, Forrester's vision of centralized control systems intersected with the Air Force's recent *tactical* innovation of ground control command.

The original tactics of air-to-air combat sprang from World War I dogfight-style pursuit, with individual pilots identifying their own targets and engaging them on a one-to-one basis. This evolved into a group pursuit strategy in which each group leader chose his own targets from the air, eventually aided by information from ground-based radar. In 1935 Army Air Force Capt. Gordon Saville tested a ground-based control technique in which commanders identified incoming targets using radar and directed interception centrally from their headquarters. Now ground controllers would exercise not "air liaison," but "air command."[56] Saville's approach initially met with resistance from pursuit-group leaders, who were used to commanding their own forces. Tests proved it more effective than the traditional system, however, and by the time of World War II ground control of air defense had been generally adopted -- albeit reluctantly, and with a residue of decentralized and loosely organized command structures. When the Royal Air Force successfully employed a ground-control approach in the Battle of Britain in 1940, the Saville method's dominance was assured.

Early in 1950 Saville, by then an Air Force general, was appointed the first Deputy Chief of Staff for Development. In this role, with a swollen budget and virtual carte blanche from his superiors for his technologically oriented tactical imagination, he assumed the role of Air Force liaison to the Valley Committee. When Valley convinced him that digital computers offered the core of a solution to the air defense problem, Saville joined Air Force chief scientist Louis Ridenour as the highest-ranking advocate of centralized computer control within the Air Force command.

Converting the Air Force to Air Defense

The Valley Committee's work was soon extended by other groups. The Weapons Systems Evaluation Group (WSEG), in the Office of the Secretary of Defense, conducted an independent study of air defense beginning in early 1950. In Project Charles, at MIT, a committee of distinguished scientists spent the first six months of 1951 looking into the air defense problem and recommended establishing an air defense laboratory (the eventual Lincoln Laboratory). The East River study of summer 1951, under the Air Force and the National Security Resources Board, found civil defense measures not only dependent on adequate early warning

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[56]. Schaffel, *The Emerging Shield*, 16.

(requiring a much improved radar network) but useless without highly effective air defense. It concluded that computerized systems could improve the prospects for air defense. Finally, in 1952 a Summer Study Group of Lincoln scientists and others, led by MIT physicist Jerrold Zaccharias and including Valley associate Albert Hill and physicists Isidor I. Rabi and J. Robert Oppenheimer, evaluated Lincoln's progress and assessed prospects for a full-scale system.

These committees, led in their thinking by Valley's group, constructed a grand-scale plan for national perimeter air defense controlled by central digital computers that would automatically monitor radars on a sectoral basis. In the event of a Soviet bomber attack, they would assign interceptors to each incoming plane and coordinate the defensive response. The computers would do everything, from detecting an attack to issuing orders (in the form of flight vectors) to interceptor pilots. The plan was first known as the Lincoln Transition System, after MIT spun off its huge Lincoln Laboratory to run the air defense project.[57] It was redesignated SAGE (Semi-Automatic Ground Environment) in 1954.

The final report of Project Charles, while pessimistic about "any spectacular solution of the air defense problem," also expressed "considerable optimism about the contribution to air defense that will be made by new basic technology . . . , [especially] the electronic high-speed digital computer."[58] The Summer Study Group went much further, crystallizing the Lincoln ideas into an overarching vision around the concept of a highly integrated, computerized air defense control system. Coupled with Arctic distant early-warning radars (a concept rejected by Project Charles), the group expected that such a system could achieve kill ratios of 60–70 percent, an estimate far higher than any Air Force prediction.[59]

Throughout the first half of the 1950s, high-ranking Air Force officers continued to oppose the plans developed by the study groups. Robert Oppenheimer, in an article in the July 1953 *Foreign Affairs*, noted a comment made to him by a high-ranking officer to the effect that "it was not really our policy to attempt to protect this country, for that is so big a job that it would interfere with our retaliatory capabilities."[60] Air Force culture, with its emphasis on the nuclear offensive, its pilot-oriented cowboy ethic, and its aversion to defensive strategies, saw the cocky civilian engineers as military naïfs, unable to

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[57]. Air Force Secretary Thomas K. Finletter called Lincoln Labs "the Manhattan Project of air defense." Cited in Samuel P. Huntington, *The Common Defense* (New York: Columbia University Press, 1961), 329.

[58]. F. W. Loomis, letter of transmittal, "Final Report of Project Charles," August 1, 1951, cited in Richard F. McMullen, *The Birth of SAGE, 1951-1958* (Air Defense Command Historical Study No. 33, 1965), 4.

[59]. McMullen, *The Birth of SAGE*, 8.

[60]. J. Robert Oppenheimer, "Atomic Weapons and Foreign Policy," *Foreign Affairs*, Vol. 31, No. 4 (1953), 531.

comprehend battlefield logic and antagonistic to its deeply held traditions and beliefs. Air defense, Project Charles leader and Manhattan Project veteran Jerrold Zacharias claimed, was finally "sold to Truman over the dead body of the Air Force."[61]

Most of the enthusiasm for air defense, especially in this new, high-technology guise, thus came from civilian scientists and engineers. The latter tended toward the messianic in their promotion of the new technical and strategic concepts. According to one participant, physicist Richard Garwin, Zacharias once told him that "if these people don't come to the right conclusion, then I'll dismiss them and begin another study." Many of them believed deeply that a defensive strategy would prove less provocative than a nuclear sword of Damocles; they saw their work as a kind of end run around their government's belligerent Cold War policies. "We all knew the conclusions we wanted to reach," one summer study group scientist admitted.[62]

Forrester's group and its Project Charles/Summer Study backers were ridiculed within the Air Force as "the Maginot Line boys from MIT" who supported a "Great Wall of China concept."[63] General Hoyt Vandenberg called the project "wishful thinking" and noted that

> the hope has appeared in some quarters that the vastness of the atmosphere can in a miraculous way be sealed off with an automatic defense based upon the wizardry of electronics. . . . I have often wished that all preparations for war could be safely confined to the making of a shield which could somehow ward off all blows and leave an enemy exhausted. But in all the long history of warfare this has never been possible.[64]

The Air Force especially feared that emphasis on air defense would reduce SAC budgets. In an appearance before Congress, Vandenberg reiterated the Air Force dogma that "our greatest *defensive and offensive* weapon is our strategic force plus that part of our tactical force that is based within striking range of the

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[61]. Zacharias , quoted in Herken, *Counsels of War*, 63.

[62]. Zacharias and an unnamed Project Charles scientist, quoted in ibid., 64.

[63]. Letter, Gen. Ennis C. Whitehead to Gen. Thomas D. White, December 14, 1953. Thomas D. White Papers, Box 1, Library of Congress.

[64]. Gen. Hoyt S. Vandenberg, cited in Kenneth Schaffel, "The US Air Force's Philosophy of Strategic Defense: A Historical Overview," in Stephen J. Cimbala, ed., *Strategic Air Defense* (Wilmington, DE: Scholarly Resources Inc., 1989), 15.

airdromes that would be used by the Soviets."[65] But the Soviet hydrogen bomb explosion of 1953, before the American "super" was ready, renewed public fear of a nuclear holocaust, and this, combined with the "can-do" technological mindset of the 1940s and 1950s, generated the momentum needed to push the SAGE perimeter defense project ahead. President Eisenhower ended up supporting both SAC and the continental air defense program under his high-technology, nuclear-oriented New Look defense strategy.

Centralizing Command, Mechanizing Control

Even when they cooperated, major elements within the Air Force continued to distrust the "nebulous" Lincoln plan. The degree of centralization, especially, concerned commanders. "There was significant concern by the military operators over whether a centralized system . . . was the right way to go or whether one ought to have an improved decentralized system operating at the radar sites much as the old system operated," recalled one of the Air Force backers of SAGE.[66]

The centralization issue arose again later, vastly exacerbated by interservice rivalry, over the question of whether to integrate Army antiaircraft batteries into SAGE. In 1956 Lt. Gen. S. R. Mickelsen, chief of the Army Antiaircraft Command, engaged in intense verbal sparring with Continental Air Defense Command head Gen. Earle Partridge, noting that "early warning and target information from Air Force sources will enhance the effectiveness of AA weapons; detailed control will most certainly degrade it."[67] After a protracted conflict, the issue was taken to Secretary of Defense Wilson, who resolved it in favor of centralized control under SAGE. In interesting contrast, the USSR's eventual air defense program favored a decentralized approach, also advocated by early Rand Corporation and Stanford Research Institute studies. According to one military observer, the Soviet results were excellent: it was "organized like a field-army air defense system -- no central control; everybody shoots at anything that looks hostile with everything he has. . . . The Soviet system is what you do when you are *serious* about continental air defense."[68]

Furthermore, to officers steeped in a tradition of human command, the idea of a machine analyzing a battle situation and issuing orders was at best

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[65]. Vandenberg, "House Hearings on Air Force Appropriations for Fiscal Year 1954," March 6, 1953, 28–29, cited in McMullen, *The Birth of SAGE*, 13. Italics added.

[66]. Maj. Gen. Albert R. Shiely (ret.), in Tropp et al., "A Perspective on SAGE," 379.

[67]. Lt. Gen. S. R. Mickelsen, "ARAACOM to CONAD re. 'Integration of SAGE into CONAD Operations,'" February 15, 1956, cited in McMullen, *The Birth of SAGE*, 48.

[68]. Bruce-Briggs, *The Shield of Faith*, 100.

suspicious, at worst anathema. Digital computers were still the province of a tiny élite of scientists and engineers, incomprehensible to the average person. Even for the Air Force, the armed service most open to technical innovation, the Lincoln plan entailed an unprecedented scale of automation using an unknown technology.

There was an alternative. Another system, based on analog computers and automatic assistance for manual techniques, was proposed by the Willow Run Research Center at the University of Michigan at about the same time. The proposal involved adapting and automating the British Comprehensive Display System (CDS), in which radar data sent via telephone and teletype were manually plotted. An individual CDS site could track up to a hundred planes, but there was no way for sites to exchange information automatically. The Willow Run group proposed to automate transfer of data between sites and to provide analog devices to assist in the plotting of tracks and interceptor courses in an Air Defense Integrated System (ADIS). Command would be more decentralized -- and much less automated -- than under the Lincoln program.

The ADIS project acquired a substantial minority backing within the Air Force, which continued to fund Willow Run research until 1953. Even then, the Air Force only canceled the project when MIT threatened to quit if it did not commit to the digital approach. In fact, it was the Willow Run proposal that catalyzed Lincoln’s own proposal for the Lincoln Transition System, a partial implementation of the computerized scheme that the laboratory claimed could be operational by 1955. The Air Force, fearful of losing the goodwill of one of its major technical resources, made a final choice in favor of MIT’s centralized digital design. ADIS was canceled, and Lincoln/SAGE development began in earnest.

Working feverishly, the Lincoln group had been able to demonstrate the basic elements of the system -- tracking aircraft and controlling interception using radar data relayed over telephone lines -- in 1952, using the Whirlwind computer. By then IBM had signed on to design a production version of Whirlwind, the AN/FSQ-7. (Actually the FSQ-7 was modeled on Whirlwind II, the successor machine Lincoln Laboratories had designed specifically for air defense use.) Larger demonstrations followed, such as a reduced-scale experimental SAGE sector in 1954. Meanwhile, Lincoln also designed improved radars and, in collaboration with the Canadian Air Force, ringed the far northern perimeter of North America with radar stations (the Distant Early Warning Line, completed in 1957). Thus three radar networks -- the Pinetree Line on the Canadian border, the Mid-Canada Line, and the DEW Line -- fed the SAGE system a picture of air traffic as far north as the Arctic Ocean. In a 1957 interview, Gen. Earle Partridge, now commander of the newly created North Atlantic Air Defense Command (NORAD), estimated that 200,000 people worked for the air defense network. He predicted that its total cost between 1951 and 1965 would reach $61 billion.[69]

The Air Force held opening ceremonies for the first SAGE sector at McGuire Air Force Base on June 26, 1957. By 1961 the system's 23 sectors were complete and SAGE was fully operational. Its control centers had cost more than a billion dollars to construct.

SAGE's implementation thus marked the final outcome of an extended political battle within the Air Force. As we have seen, to characterize this as a struggle over strategy and technology would be too narrow, even insofar as the debate took place within the Air Force and its civilian advisory groups. But the debate was not, in fact, so limited. It encompassed wider public arenas as well. There, nuclear fear transcended the technical and strategic merits to transform the debate into a contest of ideology.

Between 1952 and 1955, while development proceeded in the face of fierce Air Force efforts to downscale the project, the air defense study groups sought public support. Many of the scientists involved in the groups saw their work as a way to soften or even eliminate a dangerously aggressive, offensive orientation in national strategy. When they could, they used the national press to present their. In 1953, for example, MIT President James R. Killian, Jr., and Lincoln Laboratory director A. G. Hill published an impassioned plea for better air defenses in the *Atlantic Monthly*. They began by noting that one hundred Soviet atomic bombs, successfully delivered, would kill or injure "not just hundreds or thousands but millions of people" and that existing forces could circumvent "only a small percentage" of such an attack. With the caveat that perfect defenses were not possible, they went on to argue that present capabilities could be improved "manyfold. . . . Not 100 percent, or even 95 percent" of attacking planes would be downed by the improved system they backed, but it would nevertheless produce "a great gain over our existing powers of attrition."[70] The *Boston Globe*, *Christian Science Monitor*, and *Bulletin of the Atomic Scientists* each republished a condensed version of the essay, and House minority leader John McCormack circulated copies throughout the government.[71]

Whatever the scientists' own beliefs about effectiveness, the nonspecialist opinion leaders they influenced generally exaggerated the prospects for defensive technology. In early 1952's "Night Fighters Over New York," for example, the *Saturday Evening Post* reported that (even before SAGE) a "stupendous, history-making system of defense against an enemy's atom bombs . . . already covers all

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[69]. "2-Hour Warning Against Sneak Attack: Interview with Gen. Earle E. Partridge," *U.S News & World Report* (September 6, 1957), 77.

[70]. James Killian and A. G. Hill, "For a Continental Defense," *Atlantic Monthly* (November 1953), 37-38.

[71]. Bruce-Briggs, *The Shield of Faith*, 83.

approaches to the country." Having committed hundreds of millions of dollars to the radar early warning system and the Air Defense Command, the nation would soon see "thousands of these new supersonic terrors [i.e., jet interceptors] . . . beating up the airwaves in . . . the most formidable defense network in history."[72] In a series of articles in 1953, syndicated columnists Joseph and Stewart Alsop, probably aroused by conversations with their contacts among the scientists in the air defense study groups, accused the Air Force of dragging its feet on air defense. They asserted that with an additional yearly investment of $4 billion, the United States could have a virtually leakproof air defense shield within five years.[73]

Such interpretations, with their underlying concept of an impenetrable barrier surrounding the country -- just as the Air Force feared, a Maginot Line -- helped constitute the discourse of a closed world protected by high technology. Civilian opinion leaders, the incipient corps of military technocrats, and scientists and engineers with an instinctive belief in technological solutions thus allied *against* the Air Force leadership. The work of producing SAGE was simultaneously technical, strategic, and political. Its ultimately produced not just a new kind of weapon system but a profound reorientation of strategic doctrine.

Technological and Industrial Influences of SAGE

A central thesis of this book is that computer technology and closed-world discourse were mutually articulated. If this is true, closed-world politics shaped nascent computer technology, while computers supported and structured the emerging ideologies, institutions, language, and experience of closed-world politics. Nothing better illustrates this mutual influence than the history of Whirlwind and SAGE.

Technology

Whirlwind and SAGE were responsible for a vast array of major technical advances. The long list includes the following inventions:

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[72]. Phil Gustafson, "Night Fighters Over New York," *Saturday Evening Post* (February 2, 1952), 33, 66.

[73]. Joseph Alsop and Stewart Alsop, "Matter of Fact: Air Defense Ignored in Political Shuffle," *Washington Post* (May 9, 1952); Alsop and Alsop, "We Accuse!," *Harper's* (October, 1954), 25-45.

- magnetic core memory
- video displays
- light guns
- the first effective algebraic computer language
- graphic display techniques
- simulation techniques
- synchronous parallel logic (digits transmitted simultaneously, rather than serially, through the computer)
- analog-to-digital and digital-to-analog conversion techniques
- digital data transmission over telephone lines
- duplexing
- multiprocessing
- networks (automatic data exchange among different computers)

Readers unfamiliar with computer technology may not appreciate the extreme importance of these developments to the history of computing. Suffice it to say that much-evolved versions of all of them remain in use today.[74] Some, such as networking and graphic displays, comprise the very backbone of modern computing.

Almost as importantly, Whirlwind's private publication efforts disseminated knowledge of these advances widely and rapidly. Whirlwind had its own reports editor and printing operation. The project distributed some 4,000 short memoranda, biweekly progress reports, engineering reports, and "R" series reports on major achievements to its own staff. In addition a mailing list of about 250 interested outsiders received Whirlwind quarterly reports and some of the more significant engineering and "R" papers. Internal coordination was one purpose of these publications, but another explicit purpose was "maintaining support and an outside constituency."[75]

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[74]. Even core memory still sometimes finds a use, preferred over silicon RAM in high-radiation environments such as those encountered by satellites.

[75]. Forrester interview, April 19, 1977.

Many of Whirlwind’s technical achievements bear the direct imprint of the military goals of the SAGE project and the political environment of the postwar era.[1] As a result, despite their priority of invention, not all of these technologies ultimately entered the main stream of computer development via Whirlwind and SAGE. Some, such as core memory, almost immediately made the transition to the commercial world. Others, such as algebraic languages, had to be reinvented for commercial use, for reasons such as military secrecy and their purpose-built character. I will mention only three of many possible examples of this social construction of technology.

First, the Cold War, nuclear-era requirement that military systems remain on alert twenty-four hours a day for years, even decades, represented a completely unprecedented challenge not only to human organizations, but to equipment.[76] The Whirlwind computer was designed for the extreme reliability required under these conditions; in the 1950s, this involved a great deal of focused research. The solution Whirlwind’s designers came up with was duplexing -- an extremely expensive as well as technically difficult method, since it more than doubled the number of components. Whirlwind research also focused heavily (and successfully) on increasing the reliability of vacuum tubes.[77] The results were impressive. Down time for FSQ-7 computers averaged less than 4 hours per year. Well into the 1970s, other computers frequently counted yearly down time in *weeks*.

Second, SAGE was a control system, and control is a real-time operation. This meant much faster operating speeds than any other machine of the period, not only for the central processing units but for input and output devices as well. For example, the DRR methods of converting radar data into digital form found their first practical uses in SAGE. While high processing speed might seem inherently desirable, in the 1950s the (then) extreme speed of Whirlwind was unnecessary for other computer applications. In non-real-time applications, input/output (I/O) bottlenecks, including human preprocessing and interpretation of results, mattered far more than computer speed in determining overall throughput. Whirlwind thus helped to define both the meaning and the uses of “speed” in early digital computing.[78]

Finally, both the transmission of data from radars and the coordination of the SAGE centers employed long-distance digital communication over telephone

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[76]. Bracken, *The Command and Control of Nuclear Forces*, passim.

[77]. Robert R. Everett, “WHIRLWIND,” in N. Metropolis, J. Howlett, and Gian-Carlo Rota, eds., *A History of Computing in the Twentieth Century* (New York: Academic Press, 1980), 367–369 and passim, and Jay W. Forrester, “Reliability of Components,” *Annals of the History of Computing*, Vol. 5, No. 4 (1983), 399-401.

[78]. This argument parallels Donald MacKenzie’s discussion of notions of accuracy in ICBM development in *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press, 1990).

lines (some of the first modems[79] were built for this purpose). The computers at different SAGE sectors also exchanged some data automatically. The massive integration of a centralized, continental defense control system required such communications. SAGE was thus the first computer network, structured directly by the needs and locations of the military system it controlled.[80]

Industry

As the history of computer technology bears the imprint of SAGE, so does the history of the emerging computer industry. SAGE contributed devices and ideas to commercial computer technology, increased the competitiveness of American manufacturers vis-à-vis their foreign competitors, and swayed the fortunes of individual companies. For example, IBM built fifty-six SAGE computers at a price of about $30 million apiece. At the peak of the project over 7,000 IBM employees, almost 20 percent of its total workforce, worked on SAGE-related projects; the company's total income from SAGE during the 1950s was about $500 million. Between SAGE and its work on the "Bomb-Nav" analog guidance computer for the B-52 strategic bomber, more than half of IBM's income in the 1950s came from military sources.[81]

The benefits to IBM went far beyond profits. They also included access to technical developments at MIT and the know-how to mass-produce magnetic core memory -- the major form of random access storage in computers from the mid-1950s until well into the 1970s -- and printed circuit boards. IBM's SABRE airline reservation system, completed in 1964, was the first networked commercial real-time transaction processing system. Its acronym stands for Semi-Automatic Business-Research Environment, a direct reference to SAGE (Semi-Automatic Ground Environment), whose essential network structure it

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[79] "Modem" means "modulator/demodulator." A modem converts (or "modulates") digital information into analog form for telephone-line transmission; the receiving modem "demodulates" the analog signal back into digital form. The system is necessary because telephone lines are optimized for voice (sound, an analog signal) transmission.

[80]. Thomas Parke Hughes's concept of technological system-building partly explains these relationships. Once the commitment to a nuclear strategy had been made, a whole host of technologies also had to be developed to support the nuclear forces: aircraft and missiles, obviously, but also command and early-warning systems (radar, communications networks, and high-flying reconnaissance planes). The commitment to nuclear forces rapidly ramified into extremely far-reaching commitments to aerospace, electronics, and communications technologies. From this perspective, computers resolved a key "reverse salient" in the system: slow and noisy human communications, information integration, and command decision-making. See Thomas Parke Hughes, "The Evolution of Large Technological Systems," in Wiebe Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems* (Cambridge, MA: MIT Press, 1987), 51-82.

[81]. Flamm, *Creating the Computer*, 87-89.

copied. Many employees of IBM and Lincoln Labs who learned about computers from working on SAGE went on to start important companies of their own. IBM's decision to participate in the SAGE project may have been, according to Kenneth Flamm, the most important business decision it ever made.[82] Many other computer and electronics firms, including Burroughs, Western Electric, and Bell Laboratories, also benefited from SAGE-related contracts. "Above all," Stan Augarten has written, "SAGE taught the American computer industry how to design and build large, interconnected, real-time data-processing systems."[83]

SAGE also had a critical impact on software. Here IBM proved less foresighted; the company might have achieved even greater dominance in the nascent industry had it elected to do the programming for SAGE as well as building its hardware. IBM declined, according to one participant, because "we couldn't imagine where we could absorb two thousand programmers at IBM when this job would be over someday."[84]

SAGE engineer Norman Taylor's analysis of the effects of SAGE on software technology is worth quoting at length:

> The need for real-time software in the true aircraft-movement sense made the work doubly demanding, since the proper software had to be operated in the proper part of core in synchronism with a real-time clock pacing aircraft as they moved. . . . To the software world, these activities were as basic as the core memory and the Whirlwind I computer were to the hardware world. When these concepts were later expanded to the full FSQ-7 SAGE computer in the late 1950s, it became clear that the manual tasks of core register assignments, opening and closing interactive routines, calling programs... became a mountainous undertaking . . . and thus began the basic thinking of using the computer itself to assign its own addresses for core register assignments (now known as assemblers) and later for the automatic collection and chaining of program subroutines. . . . [These basic ideas] later developed into concepts of compilers and interpreters. Coincident with these operational software problems,

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[82]. It was MIT that chose the SAGE computer supplier, and in the words of one SAGE engineer, "in those days, picking IBM was sort of a surprise, because Eckert-Mauchly and [Remington] Rand were the leaders commercially in high-speed computers of this type. . . . IBM had no name in computers." Israel interview, April 22, 1970. Smithsonian Computer Oral History Project, AC NMAH #196 (Archive Center, National Museum of American History, Washington, D.C.). Frank Verzuh confirms Israel's memory that Forrester and Everett initially looked to Remington Rand. (Rand merged with Sperry in 1955.) In 1952 Remington Rand owned Eckert and Mauchly's UNIVAC, and it had just acquired Engineering Research Associates, the company staffed by former Navy Communications Security Group members which produced the ATLAS (see chapter 4). Verzuh told Forrester he thought IBM would soon "gobble up the competitors again" (Verzuh interview, February 20, 1984).

[83]. Stan Augarten, *Bit by Bit: An Illustrated History of Computers* (New York: Ticknor & Fields, 1984), 208.

[84]. Robert P. Crago, in Tropp et al., "A Perspective on SAGE," 386.

> Whirlwind became the testing ground for . . . software diagnostic programs to help an operator to detect and diagnose trouble first in hardware malfunction and later in software ambiguities. This work formed the basis of building real-time systems reliable enough for military use, and capable of self-diagnosis and self-switching to an alternate mode whenever reliability was in question.[85]

After Lincoln Labs had written software for the first three sectors, the Rand Corporation was given the job of programming SAGE. Rand assigned 25 programmers to this work, a number that seems modest but in fact represented about one-eighth of all programmers anywhere in the world then capable of doing such work. Rand spun off its SAGE software division (the System Development Division) in 1957, forming a separate Systems Development Corporation. SDC grew to four times Rand's size and employed over 800 programmers at its peak. The SAGE program code, at a quarter of a million lines, was by far the most complex piece of software in existence in 1958, when it was mostly complete. As one of its programmers recalled, "highly complex programs were being written for a variety of mathematical, military, and intelligence applications, but these did not represent the concerted efforts of hundreds of people attempting to produce an integrated program with hundreds of thousands of instructions and highly related functionality."[86] Here again the spinoff effect was large, as SDC programmers left to start companies and join corporate programming staffs.[87]

Despite these many technical and corporate impacts, I would argue that the most essential legacy of SAGE consisted in its role as a support, in Michel Foucault's sense, for closed-world politics. For SAGE set the key pattern for other high-technology weapon systems, a nested set of increasingly comprehensive military enclosures for global oversight and control. It silently linked defense- and offense-oriented strategic doctrines -- often portrayed as incompatible opposites -- around centralized computer systems. It provided the technical underpinnings for an emerging dominance of military managers over a traditional experience- and responsibility-based authority system. At the same time, ironically, SAGE barely worked.

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[85]. Norman Taylor, personal communication to Karl L. Wildes and Nilo A. Lindgren, cited in Wildes and Lindgren, *A Century of Electrical Engineering and Computer Science at MIT*, 340.

[86]. Herbert D. Benington, "Production of Large Computer Programs," *Annals of the History of Computing*, Vol. 5, No. 4 (1983), 351.

[87]. Claude Baum, *The System Builders: The Story of SDC* (Santa Monica, CA: System Development Corporation, 1981).

SAGE as Political Iconography

A SAGE center was an archetypal closed-world space: enclosed and insulated, containing a world represented abstractly on a screen, rendered manageable, coherent, and rational through digital calculation and control.

Each of the 23 control centers received and processed not only digitally coded radar data, which it handled automatically, but weather reports, missile and airbase status, flight plans of friendly aircraft, reports of the Ground Observer Corps, and other information transmitted verbally over telephone and teletype, which operators incorporated into the computer's overall situation picture. It also communicated with other centers, automatically coordinating activities across sectors. Each center tracked all aircraft in its sector and identified them as friendly or unknown. "Air-situation display scopes" superimposed information about aircraft over a schematic map of the sector. Display operators watched the picture of the unfolding air situation and decided on responses. The computer generated interception coordinates and relayed them automatically to the automatic pilots of the interceptors. Unless overridden by their human pilots, the interceptors flew to within closing range of the unknown aircraft under fully automatic control. Eventually SAGE controlled many other weapons systems as well, such as the Air Force BOMARC and the Army Nike-Hercules antiaircraft missile.

Each SAGE center lodged in a windowless four-story blockhouse with six-foot-thick blast-resistant concrete walls, occupying two acres of land (see figure 2). The building's entire second story was taken up by the AN/FSQ-7 computer -- actually two identical computers operating in tandem, providing instantaneous backup should one machine fail (a technique known as "duplexing"). Weighing three hundred tons and occupying 20,000 square feet, the FSQ-7's seventy cabinets contained 58,000 vacuum tubes. Display consoles and telephone equipment required another 20,000 square feet of floor space.[88] Each center had its own electric power plant to run the computer, air conditioning, and telephone switching systems inside. Additionally, the dedicated generators insulated the control center from failures of, or attacks on, the commercial power grid. Communications among the centers, however, relied on AT&T commercial telephone lines.[89]

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[88]. Ibid., 32.

[89]. For extended descriptions of the SAGE system and how it operated, see Robert R. Everett, Charles A. Zraket, and Herbert D. Benington, "SAGE: A Data-Processing System for Air Defense," in *Proceedings of the Eastern Joint Computer Conference* (Washington, D.C.: Institute of Radio Engineers, 1957), reprinted in *Annals of the History of Computing*, Vol. 5, No. 4 (1983), 339-345; C. Robert Wieser, "The Cape Cod System," *Annals of the History of Computing*, Vol. 5, No. 4 (198), 362-369; John F. Jacobs, "SAGE Overview," *Annals of the History of Computing*, Vol. 5, No. 4 (1983), 323-329; and Schaffel, *The Emerging Shield.*

The SAGE centers were the original version of the windowless Infiltration Surveillance Center built a decade later for the Vietnam War.[90] Dim blue light from the consoles illuminated their interiors, known as "blue rooms," where operators used light guns to connect blips on video displays. A 1957 *Life* magazine pictorial on SAGE captured the strange blue glow of the scene within the blockhouse, as well as the eerie calm of battle as an automated process for rational managers. The "huge electronic computer," according to *Life,* could "summarize [data] and present them so clearly that the Air Force men who monitor SAGE can sit quietly in their weirdly lighted rooms watching its consoles and keep their minds free to make only the necessary human judgments of battle -- when and where to fight."[91] The abstract electronic architecture of the world represented on their screens, harbinger of the electronic battlefield's virtual reality, was an icon for the political architecture of the closed world.

Strategy and Automated Command

To a casual observer military forces, with their strict hierarchies and authoritarian ethos, epitomize a rigid, rule-bound bureaucracy (and this is, unquestionably, a well-deserved reputation). Scrutinized more closely, however, traditional military hierarchies are anything but mechanical. At every level, individuals *bear responsibilities* rather than *perform functions.* A field officer may be ordered to "take that hill," but the whole point of such an order is that *how* he carries it out is up to him.[92] We may call this system the "command tradition." In the 1950s, within the space of a very few years, the Air Force command traditionalists who had opposed the computerized air defense system either became, or were replaced by, the most vigorous proponents of centralized, computerized warfare anywhere in the American armed services.

One reason this happened was the dawning realization, and then the necessity, that SAGE-style technology could be used for central control of offensive weapons as well as for defense. By the mid-1950s it became obvious that missile warfare would soon augment or even replace airplanes in strategic nuclear war. This rendered the glorious role of the pilot irrelevant. It also decreased response times by an order of magnitude. Only centrally coordinated systems could cope with such speed requirements.

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[90]. See chapter 1 on Operation Igloo White.

[91]. "Pushbutton Defense for Air War," *Life* 42:6 (1957), 62-67.

[92]. One of the most common genres of war story recounts a soldier's ingenious bypassing of formal structures to carry out orders more effectively.

SAGE -- Air Force project 416L -- became the pattern for at least *twenty-five* other major military command-control systems of the late 1950s and early 1960s (and, subsequently, many more). These were the so-called “Big L” systems, many built in response to the emerging threat of intercontinental ballistic missiles (ICBMs). They included 425L, the NORAD system; 438L, the Air Force Intelligence Data Handling System; and 474L, the Ballistic Missile Early Warning System (BMEWS). SAGE-like systems were also built for NATO (NADGE, the NATO Air Defense Ground Environment) and for Japan (BADGE, Base Air Defense Ground Environment).

Project 465L, the SAC Control System (SACCS), was among the largest of these successors. Its software, at over a million lines, reached four times the size of the SAGE code and consumed 1,400 man-years of programming; SDC invented a major computer language, JOVIAL, specifically for this project. The SACCS was the first major system ever programmed in a higher-level language.[93] In 1962 the SACCS was expanded to become the World-Wide Military Command and Control System (WWMCCS). The WWMCCS, with a global network of communications channels including military satellites, theoretically enabled centralized, real-time command of American forces worldwide. During the Vietnam War this system was actually used by the Johnson administration to direct the air war from Washington (though not in real time). Ultimately the Air Force connected the distant early warning systems originally utilized by SAGE, the BMEWS, and others with computer facilities at the NORAD base under Colorado’s Cheyenne Mountain for completely centralized ICBM detection and response.[94]

In chapter 1, I defined three versions of closed-world politics: the West as a world enclosed inside its defenses; the USSR as a closed world to be penetrated or “opened”; and the globe as a world enclosed within the capitalist-communist struggle. In the Big L systems, each of these versions of the closed world found its own embodiment in computerized command and control. SAGE began the process with enclosure of the United States inside a radar “fence” and an air-defense bubble. SACCS continued it with a control system for penetrating the closed Soviet empire. WWMCCS completed it with a worldwide oversight system for total global “conflict management.” But while SAGE was still a laboratory experiment, Air Force leaders already conceptualized “the defense of

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[93]. Baum, *The System Builders*, 56 and passim. JOVIAL found wide application in other military command-control systems but never became a commercial software language. See Jean Sammet, *Programming Languages: History and Fundamentals* (Englewood Cliffs, NJ: Prentice-Hall, 1969).

[94]. Alan Borning, “Computer System Reliability and Nuclear War,” *Communications of the ACM*, Vol. 30, No. 2 (1987), 112-131, presents a lengthy history of NORAD computer failures, some serious enough to lead to escalations in the alert status of nuclear forces. Problems of complexity and reliability in these systems became a cultural trope for nuclear fear, as reflected in films and novels from *Dr. Strangelove*, *Fail Safe*, and *Colossus: The Forbin Project* in the 1960s to *War Games* and *The Terminator* in the 1980s, all of which involved some variation on the theme of computer-initiated nuclear holocaust.

the air space above the Free World [as] a global task"[95] -- by which they meant, following pre–World War II strategic doctrine, that intercontinental offensive striking power constituted the best hope of domestic defense. Closed-world discourse was never a simple case of military vs. civilian, liberal vs. conservative, intellectual vs. popular, or defense vs. offense; most positions within the mainstream spectrum of opinion were caught up in its terms, metaphors, experiences, and technologies. Though they often saw themselves as opposites, the builders of both defense- and offense-oriented military systems thus constructed closed-world discourse together.

Despite its importance, the history of SAGE is filled with ironies. It was an Air Force–run project to accomplish a goal most Air Force commanders opposed: air defense against nuclear weapons. It was obsolete before it was complete, rendered militarily worthless by the ICBM and technologically outdated by the transistor and the integrated circuit.[96] Yet it continued to function well into the 1980s. Six SAGE centers were still operating in 1983, using their original vacuum-tube equipment, though by 1984 all had finally shut down, their functions absorbed by more modern elements of the nuclear early warning system.

Perhaps the most telling irony, from the perspective of closed-world discourse, was that the *automatic* control SAGE promised was then, and remains today, largely an illusion. Whatever the abilities of the computers and their programs, much of the total task still remained to human operators and their organization.[97] Attempts to "program" *this* part of the work -- in the form of formal procedures encoded in manuals -- always faltered against the unruly complexities not yet enclosed within the system.[98]

> It was impossible to specify in advance all of the contingencies that would be faced in the course of actual operations. Reliance on formal written procedures proved impractical, and unwritten work-arounds soon developed among the human operators of SAGE. Controllers were even

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[95]. Gen. Hoyt S. Vandenberg, "Suggested Remarks before the Joint Civilian Orientation Conference," March 26, 1953. Hoyt S. Vandenberg Papers, Box 91, Library of Congress.

[96]. IBM built an experimental transistorized machine, the AN/FSQ-32, for SAGE, but only one copy was made. Replacing the others would have been absurd: expensive, of course, but also strategically useless.

[97]. An enormous literature now exists on the interplay between computer technology and organizations. For entrées, see Charles Dunlop and Rob Kling, eds., *Computerization and Controversy* (New York: Academic Press, 1991); Kling and Walt Scacchi, "The Web of Computing: Computing Technology as Social Organization," *Advances in Computers*, Vol. 21 (1982), 3-85; Terry Winograd and Fernando Flores, *Understanding Computers and Cognition: A New Foundation for Design* (Norwood, NJ: Ablex, 1987); Lucy Suchman, *Plans and Situated Actions: The Problem of Human-Machine Communication* (New York: Cambridge University Press, 1987); and Shoshana Zuboff, *In the Age of the Smart Machine* (New York: Basic Books, 1988).

[98]. I borrow the phrase "unruly complexity" from Peter Taylor; see his "Building on the Metaphor of Construction in Science Studies," ms., Dept. of Science and Technology Studies, Cornell University, 1994.

> reluctant to specify to engineers the exact operating procedures they would employ in particular situations. . . . For example, small amounts of radar jamming could paralyze SAGE if rule book procedures were followed. Oral agreements between operators could fix this, but these never showed up in official reports.[99]

The closed world was a leaky container, constantly patched and repatched, continually sprouting new holes.

Two problems with automated command thus became dimly visible in the SAGE project. First was the impossibility of providing for, or even articulating, every possible situation in advance, and the consequent need to rely on human judgment. Since the 1950s critics of computer technology (though far outnumbered by optimists who project future solutions) have elevated this incapacity to the status of a philosophical principle.[100] Second was the difference between the formal level of organization, with its explicit knowledge and encoded procedures, and the much larger and more significant informal level, with its situated knowledge and tacit, shifting agreements.[101]

These problems, whatever their visibility, were ignored for reasons that have been elegantly articulated by Paul Bracken. Bracken shows that during the Cold War, command structures evolved from traditional systems based on infrequent periods of full mobilization, with days or weeks of advance warning, to nuclear-era systems based on continuous mobilization, with hours or minutes of warning. This shift required a “vertical integration” of warning, command, and political liaison -- essentially, a flattening of the hierarchy of responsibility into an increasingly automatic, and therefore rigid, system able to act on a few minutes’ notice. Bracken adduces technological reasons for this shift: the vast increases in the speed of weapons delivery, the amount and complexity of sensor information to be integrated, and the scale of response to be mounted. “To protect itself a nuclear force does the opposite of what a conventional army does. It tries to ‘manage’ every small threat in detail by centralized direction, reliance on near real-time warning, and dependence on prearranged reactions.”[102] Under

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[99]. Bracken, *The Command and Control of Nuclear Forces*, 12.

[100]. See Harry Collins, *Artificial Experts: Social Knowledge and Intelligent Machines* (Cambridge, MA: MIT Press, 1990); Hubert Dreyfus, *What Computers Can't Do: The Limits of Artificial Intelligence*, 2nd ed., (New York: Harper Colophon, 1979); Hubert Dreyfus and Stuart Dreyfus, *Mind Over Machine* (New York: Free Press, 1986); Joseph Weizenbaum, *Computer Power and Human Reason: From Judgment to Calculation* (San Francisco: W. H. Freeman, 1976); Winograd and Flores.

[101]. See Suchman, *Plans and Situated Actions*.

[102]. Bracken, *The Command and Control of Nuclear Forces*, 55. In his chapter on Vietnam-era command systems, Martin Van Creveld (*Command in War* [Cambridge, MA: Harvard University Press, 1985]) concurs with Bracken about the provenance of computerized control.

such conditions, centralized, automated control seemed imperative. In chapter 4 we will see how the promise of automatic control, proffered by SAGE, its descendants, and other emerging uses of computers for strategic analysis, contributed to a realignment of military leadership toward what we may call a “managerial model.”

Conclusion

The computerized nuclear warning and control systems both embodied and supported the complex, heterogeneous discourse of closed world politics. Containment doctrine, scientists’ and engineers’ public pronouncements on strategy, Air Force culture and traditions, public anxiety about nuclear war, and the anti-communist hysteria of the 1950s all participated at least as much as technological changes in the construction of military, rhetorical, and metaphorical containers for the capitalist-communist conflict. Beginning with SAGE, the hope of enclosing the awesome chaos of modern warfare (not only nuclear but “conventional”) within the bubble worlds of automatic, rationalized systems spread rapidly throughout the military, as the shift to high-technology armed forces took hold in earnest.

Yet the *military* potential of SAGE was minimal. Many, perhaps most, of those who worked on the project knew this. Such understanding was reflected in another irony of SAGE: the failure to place the control centers in hardened underground bunkers, the only place from which they might have been able actually to control an active defense in a real war. The Air Force located most SAGE direction centers at SAC bases.[103] This decision had only one possible strategic rationale: SAC intended never to need SAGE warning and interception; it would strike the Russians first. After SAC’s hammer blow, continental air defenses would be faced only with cleaning up a weak and probably disorganized counterstrike. In any case, SAGE would not have worked. It was easily jammed, and tests of the system under actual combat conditions were fudged to avoid revealing its many flaws.[104] By the time SAGE became fully operational in 1961,

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[103]. “So many Air Defense Command centers were colocated with SAC bases that the Soviets could take out both with only 15 more bombs than it would take to eradicate SAC alone. Fewer than a hundred bombs not only would kill all of SAC that had not launched, but would decapitate the air defense apparatus as well” (Bruce-Briggs, *The Shield of Faith*, 129). As Bracken notes, this was part of a consistent policy. “The theory behind the ‘soft’ design for command and control was that the purpose of all of these systems was to get warning in order to launch a nuclear attack” (*The Command and Control of Nuclear Forces*, 188). A more mundane rationale was that SAGE commanders wanted access to the excellent officers’ facilities at SAC bases.

[104]. Les Earnest, personal communication. See Bruce-Briggs, *The Shield of Faith*, 96, for an account of one such test.

SAC bases were unprotectable anyway (because of ICBMs), and SAGE control centers would have been among the first targets destroyed in a nuclear war.

Still, in another important sense, SAGE *did* “work.” It worked for the research community, which used it to pursue major intellectual and technical goals. It worked as industrial policy, providing government funding for a major new industry. Perhaps most important, SAGE worked as ideology, creating an impression of active defense that assuaged some of the helplessness of nuclear fear.[105] SAGE represented both a contribution and a visionary response to the emergence of a closed world.

What makes SAGE such an interesting case is its origins within the academic science and engineering community -- *not* with military imperatives, though its military funding sources and key geopolitical events spurred it on. Instead the initiative lay with the scientists and engineers, who developed not only machines but a vision and a language of automated command and control. But the construction of SAGE also boosted the redesign and reorientation of an extremely traditional institution -- the armed forces -- around an essentially technological concept of centralized command. Seen in this light, SAGE was far more than a weapons system. It was a dream, a myth, a metaphor for total defense, a technology of closed-world discourse.

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[105]. I borrow the idea of ideological “work” from Vincent Mosco.