Part I

The History of Systems Integration

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Inventing Systems Integration

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2.1 Introduction

The United States's world position changed dramatically during the twentieth century from that of being a large industrial power absorbed by its own vastness and rapid internal growth to that of being the world's dominant economic and military power, although unaware yet of the limits of its global writ. This new status not necessarily fully understood or even sought by its citizens, required significant changes in the scale and role of government in American society. Most important among these for US global dominance has been the role its armed services came to play in the development of technology. In turn, the American military has been and continues to be transformed by technology.

The United States was a late entrant in both of the World Wars that marked the first half of the twentieth century. Nevertheless, its unmatched ability to generate and project great military power in a relatively short time proved decisive in these conflicts, which were fought primarily far from American shores. Its army was built on a militia base called to national service for the war and filled out by conscription (Flynn 1993). The equipment needed to arm, train, and transport large expeditionary forces was produced rapidly via a mobilization effort that surpassed the output of all other participants (Harrison 2000: 103).[1] The feat was a largely industrial one, with government allocating private industry the resources to produce vast quantities of weapons from pre-selected designs, often borrowed from allies (Holley 1983). Although there was a parallel mobilization of scientists and engineers that had more than an occasional spectacular success—the atomic bomb, for example—the wars were won on the assembly lines producing divisions, aircraft, and ships.

A series of confrontations with the Soviet Union over the future of a war-devastated Europe and Asia led to the reconstruction, in the early 1950s, of American military power which had been mostly demobilized after the Second World War. The resulting conflict evolved into a long-term ideological struggle that required a continuous if less than full-scale societal mobilization and a military strategy that would offset the large manpower advantage the Soviet Union and its allies had over the United States. Having used nuclear weapons to hasten the end of the Second World War, it was natural for the United States to adopt a technology-focused strategy that would substitute weapon development investments for mass production and the maintenance of a large army.

Most of the weapons needed to fight the cold war—jet aircraft, helicopters, high endurance submarines, cruise and ballistic missiles, and nuclear weapons—would be found in the inventory of Second World War weapon experiments or plans. But major changes in organization and administrative practices were required for the effective development and employment of these weapons in the cold war. At American insistence, the cold war became a contest in demonstrating prowess in creating advanced technology weapons, a contest that eventually forced the bankruptcy of the Soviet Union. America avoided the same fate because it was more efficient than the Soviet Union in combining complex technologies into weapon systems and integrating advanced weapons systems into its fielded forces (Sapolsky, Gholz, and Kaufman 1999).

This Chapter describes the innovative organizational structures and administrative processes that facilitated the development and deployment of advanced weapon systems by the American military. Prime among them are system analysis and integration skills required for building and operating complex weapons (Johnson, Chapter Three, this volume; Gholz, Chapter Fourteen, this volume).

2.2 The Quest for Coordination

The Second World War gave the United States all the worries of a global power. Political leaders were concerned about the nation's ability to manage distant conflicts. The armed services were anxious to seize emerging national missions as their own. And technologists could envision potential security threats that would justify support for their most ambitious projects. Even before the war was in its final phases several of the governmental agencies managing the war effort had developed plans for the nation's long-term security needs (Friedberg 2000). Much attention was focused on the expansion of peacetime forces or activities to match new responsibilities. Victory would require an ever-vigilant global presence for US forces.

But the failures of the war were also recognized. It was usually difficult, at times impossible, to gain cooperation among the various branches of the military. In the European theatre, the Navy and the Army Air Forces argued over control of long-range aircraft important in the fight against the U-boats. In the Pacific theatre, three separate commands were established to accommodate the conflicting plans and ambitions of the services. Priorities for allocating scarce resources such as manpower and shipping were never fully reconciled. The governmental authority for assigning production priorities was in near constant flux (Gropman 1996). The national strategy for fighting the war, which gave primacy to the European Theatre over the Pacific, although clearly stated, was often contradicted by implementing agencies (Greenfield 1982). Recommendations for postwar reorganization of the defence agencies offered on the promise of solving these coordination problems gained widespread sympathetic attention.

The argument for significant reorganization was that the United States needed to create a coherent structure for managing its expanding global security responsibilities (Caraley 1965; Kinnard 1980). The mechanisms to develop and integrate broad-based intelligence, political analysis, and military assessments that many thought were required to support the formulation of international security policies were inadequate, if not entirely absent. More important, given the decentralized nature of American government, interagency coordination on important matters was achievable only through cumbersome layers of committees, most of which lacked staff and continuity. Short of commanding presidential attention, it was impossible to set enforceable priorities across agencies on national security matters or any other topic.

The main legislative expression of the reforms was the National Security Act of 1947, which created a number of entities including the National Security Council (NSC), the Central Intelligence Agency (CIA), and the Department of Defense (DOD) (Hoffman 1999). The members of the NSC are the President, the Vice President, the Secretary of State, and the Secretary of Defense with the Director of Central Intelligence and the Chairman of the Joint Chiefs of Staff as their advisors. The Director of Central Intelligence heads the CIA and coordinates the activities of other intelligence agencies. DOD brought together the Army, Navy, and the newly independent Air Force to coordinate the acquisition of weapons and the training of forces through these military departments and the use of fielded forces through unified theatre and functional commands. Formally, the President considers national security policy options in a NSC-managed process and issues directives for DOD, the CIA, and other agencies to implement his decisions. It was a plan to centralize control over defence matters to avoid the policy conflicts and confusion that many said characterized the war effort. The hope was that there could be a systematic approach to policymaking that would lead to an integrated and effective strategy to deal with the troubles that seemed certain to lie ahead.

The challenges of the early cold war years, however, brought more bureaucratic conflict, not less. The easily achieved consensus on the strategy to contain Soviet expansion did not reduce the competitive urges of the armed services and other agencies to gain the choicest defence missions. Each real or imagined threat—the war in Korea, conflict over Germany's future, the Sputnik crisis, the bomber and missile scares—generated proposals to counter the Soviets and perhaps a bureaucratic rival as well.

Budgets were up, but so were the fears of agencies worried about the ambitions of bureaucratic rivals to absorb them entirely. Attempts to achieve government coordination with additional reorganizations continued but were largely unsuccessful.

The intense competition for missions may well have been beneficial. The US armed services were certainly less wedded to old military technologies and doctrines and more willing to adopt new ones than was the Soviet military. And divided as they often were over policies, the services also were less able to resist civilian interventions and the innovative idea than is their reputation (Owens 2000). Only when the bureaucratic stakes diminished as the cold war aged and the Soviet threat waned did the centralizing preferences of defence reformers seem to gain hold (Sapolsky, Gholz, and Kaufman 1999).

2.3 Building Project Organizations

Effective coordination was achieved earlier at an entirely different organizational level and for an entirely different organizational purpose. The rigid functional structure of the technical branches of the military proved inadequate for the development of aircraft and missiles needed for the cold war. So did the technical capabilities and management responsiveness of the military's own network of weapon research laboratories and arsenals. By taking one halting step after another the military learned to think about weapons as systems and to find the organizational arrangements that would facilitate the development of the most complex types. Now institutionalized, it is this way of conceiving weapons that has moved up the organizational hierarchy and that has potential for revolutionizing warfare (MacGregor 1997).

Militaries generally separate weapon procurement and supply activities from the management of combat forces. In the US military, these procurement and support activities acquired an independence that brooked little challenge to their authority. Their ties to powerful congressional committees ensured that their jurisdictional interests were protected from interference by line officers responsible for combat operations. The technical branches of the Army were organized by function (e.g. quartermaster, ordnance, signals, engineers, medical, etc.) and controlled their own depots, arsenals, and field units. In the Navy, there was from the early 1840s a sharp division between what was called the shore establishment (the technical bureaus managing shipbuilding, ordnance, and engineering activities) and the fleet.

Proposals to give a strong hierarchy to the services and to integrate their support and operating activities were slow to be adopted. The Army began to build a general staff at the turn of the twentieth century. Gradually the technical branches came under the control of the Army's Chief of Staff, but it was not until the Second World War that the technical branches themselves were linked together under a coordinating command, the Army Service Forces. There was not a unified commander for all naval forces until the Second World War, when the posts of Commander in Chief US Fleet and Chief of Naval Operations (CNO) were combined into the latter, but even then the material bureau chiefs—all naval officers—were left outside of the CNO's control—reporting, as they had for a hundred years, directly to the Secretary of the Navy. The addition of aircraft to the military's armaments meant only that eventually separate procurement and supply activities were created for aviation, a separate material unit for the Army Air Corps, and a separate bureau in the Navy. When the Air Force was made independent of the Army in 1947, it took the appropriate slice of support facilities and units with it.

Weapon procurement projects were generally managed functionally as well, with project offices assigned as subunits in type commands that were in turn parts of component divisions of functionally defined technical branches or bureaus. Airframes were acquired independently of engines and guns and bombs. Mismatches and disappointments were common as coordinated developments were rarely organized and were difficult to sustain, but it was only with the intense quest to acquire advanced weapons in the early cold war years that the problems became acute. For Americans at least, the Second World War was a weapon production race while the cold war was a weapon development race, where technological performance mattered more than numbers (Jones 1990: 315).

The effort to develop turbojet aircraft, a field in which Britain and Germany substantially lead the United States in the Second World War, demonstrated the need for changes. Advances in aerodynamics had undermined the utility of reciprocating engines and forced adoption of a more systemic approach to aircraft design. Intent on gaining the advantage in jets, the US Air Force discovered that it had to coordinate its work in human physiology, aircrew training, weapon design, avionics, combat tactics, and several other fields in order to achieve the full benefits of the rapid progress it made in turbojet technology (Young 1997).

However, it was the rush to develop a competing technology, like ballistic missiles, that precipitated substantial restructuring of weapon acquisition processes and organizations. Ballistic missiles were a disruptive technology in more than just the sense that Clayton Christensen (1997) identified in his important book, *The Innovator's Dilemma*, where new technology destroys the market for existing technology. German advances in rocket technology had showed the potential for attacking from great distances and without the concern about defences. Perfected and carrying nuclear warheads, such weapons would force the retirement of fleets of strategic bombers. But they were also the weapons that prevented a direct clash between Soviet and American forces during the cold war. The potential consequences of the use of nuclear weapons were too great to risk direct engagement. And it was the development of such weapons that altered the aircraft industry, transforming it into the aerospace industry.

But because it represented work in a new technology, the development of ballistic missiles did not fit easily into the existing weapon acquisition structure. Almost from the first proposal to initiate a ballistic missile development programme, there was intense competition both within and among the services to gain approval to establish a project. The stakes seemed high. There was pressure to limit the number of projects. The costs were significant and the pool of available experts limited. A central role in the nation's security strategy seemed assured for the service or services that deployed ballistic missiles. The risk of exclusion in either the development effort or the deployment could be the loss of budget share because the projects were likely to pull resources away from other defence activities (Sapolsky 1972; Neufeld 1990: 88).

For the Air Force, ballistic missiles were an Air Force mission because they were an extension of pre-existing cruise missile projects, pilotless aircraft, only a lot bigger, longer-ranged, and faster. For the Army, they were artillery shells with a much bigger punch and obviously, the development province of its Ordnance branch that had experience with rockets. The Navy, which had both a Bureau of Ordnance and a Bureau of Aeronautics, found it had an internal rivalry as well as external quest. Multiple projects were started and the struggle to win official sanction was a public event and bitterly fought—the epitome of American bureaucratic politics at its best or worst, depending on one's policy perspective.[2]

The Air Force projects were managed by the Air Force Research and Development Command (AFRDC), but in a separate division situated nearly a continent away from its parent organization and given special contracting authority that allowed it to by-pass most standard procurement and reporting procedures (Neufeld 1992: 4–5). Top level advisory and oversight boards were established to help, guide, and protect what became known as the AFRDC's Ballistic Missile Division, even though it was in essence an independent special project command that managed the entire development, procurement, and basing of ballistic missiles. For ballistic missiles the functional organization gave way to a system manager structure.

The Navy, the other service that gained authorization to develop long-range ballistic missiles, created approximately the same management structure but by a different route. With both the Bureau of Ordnance and the Bureau of Aeronautics vying for the management task within the Navy, the decision was made to create an independent office with the status of a bureau that would be responsible for the development and deployment of the submarine-launched Fleet Ballistic Missile, what became the Polaris missile system. The Navy's Special Projects Office (later the Strategic Systems Projects Office) managed the entire Polaris system which included the development of specialized submarine navigation equipment, missile guidance and launch subsystems, the missiles themselves, crew training facilities, special communication facilities, and support bases. Like the Air Force, the Navy had established a systems management organization dedicated to the task of creating a nuclear deterrent for the United States (Sapolsky, Gholz, and Kaufman 1999).

Having two separately managed ballistic missile programmes likely accelerated technical progress. The Navy, unhappy with the prospect of utilizing volatile liquid fuels for missiles aboard ships, invested heavily in the development of solid fuels for rocket motors, a technology that the Air Force had initially supported. Success in developing safer fuel motors not only led to the deployment of the Polaris missile on submarines, but also to the Air Force's decision to abandon its liquid fuelled Atlas missiles for the more flexible and quicker reacting Minuteman missile system. Independent judgements by the programmes had similar beneficial effects on warhead design, command and control technology, and missile maintenance procedures. It also allowed for special focus on system unique needs such as defences, and crew training and support.

2.4 The Contract State

The creation of independent project organizations to manage the development of complex systems was only a partial solution to the system coordination problem. Project organizations dealt with uncooperative agencies largely by avoiding them. They could appeal to higher authority for support, but more often they duplicated needed facilities or help outside the government. There already had been a shift towards a reliance on contractors for weapon development. The use of project management offices—increasingly popular after the success of the ballistic missile programmes—accelerated it. Why risk being overruled in appeals to higher authorities when the cooperation that one sought could be achieved through the award of a contract?

The US military traditionally relied on government owned and managed arsenals and shipyards for development of its weapons. Although their work pace was slow, these facilities nurtured military technologies between wars when the government purchases of military equipment were too little to hold the interest of many commercial suppliers. When wars broke out demand for this equipment would increase sharply and contractors would be hired to fill it. When the wars ended, orders dried up and the contractors turned again to commercial business while the arsenals soldiered on experimenting with new designs for weapons, but building few of them. Such was the general pattern until the Second World War.

Aviation was a major exception. Although the federal government did establish a civilian agency—the National Advisory Committee for Aeronautics—to conduct aviation research and the Navy did maintain its own aircraft factory—an aviation arsenal, so to speak—that designed and built aircraft, the military let the private sector take the lead in the development of aviation. The romance of flight mixed with a belief on the part of some investors that the aeroplane would be the next car, the next mass consumer product, kept fledgling aircraft manufactures funded even when there were few aeroplanes being purchased. In fact, the services exploited the enthusiasm for aviation by not always fully reimbursing the manufacturers when they won military aircraft design and production contracts (Holley 1964).

After the Second World War, the armed services came to rely more and more on contractors for weapons. Many of the contractors drafted for the Second World War wanted to stay on with defence work. The cold war promised continuing large defence budgets, enough at last to make armaments an attractive business in which to invest. The military viewed contractors as being more responsive to their direction and more competent technically than arsenals and military laboratories. Contractors were usually eager to work on the advanced technologies that the military sought to master. They also could pay their scientists and engineers higher compensation than civil service schedules allowed. And contractors were willing to lobby for projects while the arsenals and shipyards tended to believe that their futures were assured.

One administrative challenge was to find contracting mechanisms that would appropriately compensate contractors for the risks involved with defence work. This was a politically sensitive issue because wartime pressures to increase arms production rapidly with the award of lucrative non-competitive contracts had led to postwar charges of lax government oversight and contractor profiteering. The cold war's emphasis on the development of advanced military technologies meant that there were relatively few qualified contractors to do the work and that much work would be unpredictable in terms of outcomes, schedule, and costs. Although fixed price, competitive contracting where the risks of failure (not meeting the performance, schedule, or budget goals) fall entirely on the contractors is the standard for most government procurement, it was obviously inadequate for developing and buying the cold war's weapons. Instead, the practice became to limit competitions to select firms and to negotiate cost plus fixed fee contracts with winners, just skirting scandal and giving the firms little incentive to control costs. Projects were plagued by technical faults, delays, and overruns, largely because their goals were so ambitious, but also because it was so difficult to instil discipline and accountability into the process (McNaugher 1989).

Discipline and accountability were problems in weapon projects due to the dependencies that increased reliance on contractors created. The shift away from arsenals and government laboratories meant that the government's own experts were less involved in design and project management decisions. Moreover, for many of the technologies being explored, contractor or university based scientists and engineers were the most knowledgeable experts available rather than civil servants or military officers. Once a firm acquired deep expertise in some specialty, it was expensive and disruptive of carefully constructed production and deployment schedules to replace them, and it was often awarded follow-on contracts.

The policy was to shift detailed management responsibility for weapon development onto an often very willing prime contractor or weapon system manager. The prime contractor would identify and coordinate the mix of technologies and subsystems required to develop and produce complex weapon systems for the government via a network of subcontractors. The formal choice of what and to which firms to subcontract would be the government's, but obviously the prime contractor would have great influence over such decisions because of the systems knowledge it had and its necessarily special relationship with the project offices. The government needed help in defining the internal and external parameters of complex weapon systems and a way to coordinate the diverse talents and technologies required to develop them. It found such help in prime contractors able to attract skilled scientists and engineers. And it found the required coordination through the cooperation that subcontracting dollars could elicit.

As Don K. Price pointed out, the Contract State blended the public and the private in American society. The government took over the role of the private sector entrepreneur by absorbing through cost plus contracts the risks of developing new technology. Defence was the major justification for the federal government's substantial R&D investments during the cold war. In turn, the contractors became the managers of important public programmes, the design, and acquisition of weapons (Price 1954). The contractors' financial viability was dependent upon the continuing goodwill of their government customers—the only permitted buyers of exotic weapon systems costing a billion of dollars. And the government was dependent upon capabilities and honest judgements of its contractors. Given that the armed services were the government buyers, the contractors maintained goodwill by serving military priorities. This meant contracts were won and maintained largely by emphasizing weapon system performance over costs (Gholz 2001). Given the limited technical training of most officers, the government customers had to search for reassurance when making judgements on the basis of advice received from the prime contractors and other contractors, or risk disaster.

2.5 The Non-profit Solution

The prime task that the prime contractors performed was systems integration. Weapons were being conceived as complex systems that required the design and simultaneous development of component subsystems such as the platforms, sensors, weapons, and propulsion that were both compatible with each other and optimized for overall systems performance (Johnson, Chapter Three, this volume; Gholz, Chapter Fourteen, this volume). Tradeoffs had to be made among the component subsystem to meet standards and achieve desired system characteristics. Systems reliability, ease of maintenance, and crew needs also had to be considered. The prime helped qualify and monitor subcontractors and provide necessary documentation for the system. Military officers serving as project monitors usually rotated to other assignments, but the primes assured continuity, staying on because the systems could not operate without them. For fielded systems they often managed the provision of spare parts and periodic overhauls and upgrades. Thus, the integration was across disciplines and time.

Two concerns worried senior officials. One was the ability of contractors to be sufficiently knowledgeable about the full range of relevant technologies. The obvious candidates for prime status were the large manufacturers, especially the aircraft builders. For familiar weapons like aircraft where systems thinking evolved through experience, the risk was low that the job was too much for a Boeing or a Lockheed. There were several firms with sufficient background in managing major projects to provide the government with the opportunity to complete the systems integration task. But for newer systems such as ballistic missile, early warning, and nuclear-powered submarines there were no firms with broad enough experience to give comfort about their ability to handle the work.

The other worry was that the firms given the integration task for new and evolving systems could abuse their position. The primes would have an intimate knowledge of the systems and government preferences. It could reserve for itself the most lucrative and commanding technologies. Or it could take information obtained from subcontractors to enter their businesses at opportune times, including competing with them on other projects. Proprietary information could be jeopardized. The involvement of one giant firm might discourage another from offering its services. Little firms might fear bigger ones. And because manufacturing promised the greatest returns through the provision of spare parts as well as the purchase of original equipment, the judgement of manufacturing primes about design tradeoffs and systems assignments had to be taken with some scepticism.

Air Force programmes demonstrated these problems most clearly. The Air Force had pioneered the weapon systems manager concept and was inclined to utilize the same programme format for its major new efforts in ballistic missiles, early warning systems, and satellites. Although still preoccupied with the acquisition of its bomber fleet, the Air Force had responsibility for developing land-based intercontinental ballistic missiles. The civilian officials and scientists who advocated the acceleration of ballistic missile projects in the face of reports in the early 1950s of Soviet progress in long-range missiles had doubts about the capabilities of the Air Force's usual primes and standard procedures to do the job even if a crash programme were initiated to ensure an American lead. When such a programme did in fact gain quick approval, they reiterated their advice about the need for rethinking project management arrangements. The Air Force responded by selecting an engineering consulting firm, the Ramo–Wooldridge Corporation, to be the deputy to General Bernard A. Schriever, the officer in charge of the ballistic missile development effort, and gave it responsibility for the programme's systems engineering and technical direction. Thus Ramo–Wooldridge was made part of the Air Force's command structure and held line control over the other contractors working on the ballistic missile projects. It was to be the systems integrator for Air Force ballistic missiles (Neufeld 1990: 102–5, 111).

Several of the contractors objected to Ramo–Wooldridge's favoured position. Even though the Air Force had barred Ramo–Wooldridge from competing for hardware contracts, they thought it was rewarded too much and had too much inside information. Their concerns grew when the firm merged with Thompson Productions, an automotive parts manufacturer, forming Thompson–Ramo–Wooldridge, now TRW. Under congressional pressure, the Air Force required TRW to spin-off its ballistic missile engineering integration business, conveniently housed as a subsidiary called Space Technology Laboratories (STL), into a non-profit organization chartered to do Air Force work. Soon STL was renamed the Aerospace Corporation (Neufeld 1990: 210–12).

The Air Force in another major programme—the effort to create an early warning system of radars across Northern Canada and Alaska—had addressed similar issues with a similar solution. Known as the DEW Line (for Distant Early Warning) the radars were intended to detect and track Soviet bombers on a mission to attack the United States with nuclear weapons. The concept and design for such a system evolved from studies produced by various scientific advisory committees and Lincoln Laboratory, a radar research facility managed by the Massachusetts Institute of Technology (MIT) (Needell 2000: 199–258). When a deployment decision was made, the Air Force assumed that MIT would be the systems integrator, coordinating the advanced development and site engineering of various radar, computer, and communications components required for this large network. MIT was reluctant to become so involved with the detailed engineering of the project and the direct supervision of firms like IBM, General Electric, and AT&T that were likely to be the component contractors. In turn, none of these companies were comfortable with one of the others as the systems integrator, given the advanced technologies involved. The Air Force then helped MIT spin-off sections of Lincoln Laboratory into a separate non-profit organization called MITRE, to do the required systems engineering and technical direction work for the DEW Line. MITRE would go on to do systems integration and design consulting for the Air Force on a number of other command and control programmes (Trainor 1966; Wats 1970; Office of Technology Assessment 1995; Defense Science Board 1997).

The Aerospace Corporation and MITRE are what are called Federally Funded Research and Development Centers (FFRDCs), non-profit organizations dedicated to serving federal agency interests related to technology and usually given long-term contracts for their services. Some are policy focused like RAND and the Center for Naval Analyses; others are basic research and applied engineering oriented. Lincoln Laboratory, mentioned above, is in that category. Aerospace and MITRE are the only FFRDCs dedicated in providing systems engineering assistance. Most are chartered to work for a single agency, although RAND actually manages four FFRDCs, one for the Air Force, one for the Army, one for the Office of the Secretary of Defense, and one for the Department of Health and Human Services. The biggest are the systems engineering FFRDCs that worked for the Air Force (Neufeld 1997).

At least into the 1960s, systems integration was more of a government developed and furnished skill in the Navy than it was in the Air Force. The Navy had more of an in-house industrial base and engineering tradition than did the Air Force. When nuclear power arose as a propulsion option for submarines, the Navy built its own engineering staff to manage the development effort. The desire was to build the true submersible, a submarine that did not need to come to the surface to recharge batteries. The officer in charge of the programme, Admiral Hyman G. Rickover, feared the political consequences of reactor accidents to the Navy's ability to deploy nuclear submarines and took tight control of all aspects of the programme to avoid them. He recruited able assistants for the Nuclear Power Division in the Bureau of Ships (now the Naval Reactors Directorate in the Naval Sea Systems Command), his Navy billet, and insisted that all commanding officers assigned to the submarines be qualified in nuclear reactor operation. He was tyrannical in his relations with the contractors and shipbuilders involved in the programme, demanding rigid conformity to his directions and total dedication to the task of building a nuclear fleet, and became a hero to the Congress in large part because of it (Duncan 1990). Admiral Rickover, however, had a dual appointment in the Atomic Energy Commission (AEC; now the Department of Energy), the civilian-managed agency responsible for the development and manufacturing of nuclear weapons as well as the promotion of peaceful applications of nuclear energy. Through the AEC he had access to the AEC's network of very capable national laboratories, including two dedicated to his needs in the design and development of naval reactors, the Bettis Atomic Power Laboratory in Pennsylvania operated by Westinghouse, and the Knolls Atomic Power Laboratory in New York State operated by General Electric (Hewlett and Duncan 1974).

As effective as it was, Admiral Rickover's office in either the Navy or the AEC did not control all aspects of the nuclear submarine system. Other parts of the Navy shore establishment held jurisdiction for the hull design, weapons, and sensors. The development of the nuclear submarine as an effective weapon system was evolutionary. The first nuclear-powered submarine was the Nautilus, commissioned in 1954. The first submarine utilizing the efficient teardrop hull was the Albacore, a 1953 diesel-powered submarine, but it was not until the Skipjack was commissioned in 1959 that the design was incorporated into the nuclear-powered fleet. The Polaris missile first went to sea in 1960. And the Mark-48 torpedo, an effective anti-submarine weapon, did not reach service until the mid-1970s (Cote 2003).

The Special Project Office (SPO), the organization that developed the Polaris ballistic missile, had a larger writ. It was created to develop a ballistic missile capability for the Navy. Initially, that capability was expected to be a version of the Army's liquid Jupiter missile. At the time the Army had the approved development programme and the Navy did not. Because it was teamed with the Army's Jupiter project, SPO chose Chrysler, the Jupiter prime contractor, as its own to marry the missile to a naval platform, a submarine or a surface vessel. But once the Navy gained permission to develop a new solid fuelled ballistic independent of the Army, SPO decided against hiring a prime and chose instead to do much of the systems design and integration inside its own organization. Like Naval Reactors, it brought into the project a number of capable engineers to supervise the contractors that would be selected to develop subsystems, which in the case of the Polaris included the missile, the submarine, the missile guidance and fire-control systems, the launcher, the submarine navigation system, and required bases and communication systems. Only the reactors for the submarines and the warheads for the missiles lay beyond SPO's management scope.

The SPO's immediate task was to define and assure the compatibility of the systems interfaces, the boundary requirements for each subsystem. Captain (later Vice Admiral) Levering Smith, the project's technical director, oversaw the process. Smith, like Rickover, earned a reputation for being in control of the details and for his devotion to the mission, acquiring a vital new capability for the Navy. But unlike Rickover, Smith was not willing to rely entirely on programme civil servants and naval officers, as capable as he thought they were, for the programme's systems integration and monitoring needs. Instead, he brought in two contractors to advise and assist, one a non-profit and the other a commercial entity. The Applied Physics Laboratory at Johns Hopkins University, a FFRDC, helped by conducting system tradeoff studies, proposing component boundary lines, and analysing system test results. The Vitro Corporation documented and monitored system interfaces. Lockheed, as the contractor responsible for the keystone systems component, the missile, was called upon to perform additional staff services such as report preparation and public relations, but neither it nor the Applied Physics Laboratory and Vitro could be fairly described as weapon systems manager or the programme's systems integrator. Instead Smith managed a team that included them and the SPO staff to do these jobs (Sapolsky 1972: 82).

The big technological steps the American military took during the cold war required the coordination of many disciplines and organizations. Although some defence contractors had experience in managing complex aircraft projects for the government, the belief was that the financial opportunities the new technologies appeared to offer would be too tempting to place them in charge again. The government itself could take control, but many worried that there would soon be recruitment and retention problems. Government careers, except for the military, lacked status in American society. There were some very able military officers available to run the projects, but would there be enough of them to sustain the effort required?[3] The answer to this problem lay in the creation of a new set of institutions, non-profit organizations dedicated to government service, but able to pay salaries competitive with industry to attract talent. These organizations overlapped in function with industry, but were restricted in terms of the kinds of contracts they could accept from government. MITRE, the Aerospace Corporation, Lincoln, the Applied Physics Laboratory, and the AEC's national laboratories taken together were a social invention that helped the United States win the cold war. To varying degrees the armed services had to rely on specially created non-profit systems design and integration organizations to build the strategic deterrent, warning, reconnaissance, and command and control systems that kept America ahead and that exhausted the Soviet Union in its attempt to match them.

2.6 Thinking Systemically About Policy and War

Systems thinking appeared first on the operational side of the military, but was slower to spread there than on the weapons development side. Pioneering work in operations research techniques was applied on several fronts during the Second World War. In the Battle of the Atlantic, American, British, and Canadian scientists calculated the preferred convoy routing, and ship and aircraft search patterns to thwart the highly destructive attacks by German U-Boats on Allied shipping (Tidman 1984: 17–94). Earlier, British scientists had demonstrated the military effectiveness of operations research in their effort to improve the intercept rates of fighters in the Battle of Britain, the Royal Air Force's defence of Britain against German air attacks. These were interdisciplinary efforts that applied scientific methods to military problems in order to improve the efficiency of operations and the design of equipment (Tidman 1984: 12–16).[4]

Although American practitioners of the art found employment in nearly every corner of the military after the war, operations research had less impact on warfare than its Second World War contribution seemed to promise. Generals and admirals resisted intrusions into their domain by scientists with little or no combat experience. To many of them, success in war was certain to remain as the product of sound professional training and judgement in the face of the great confusion and horror of the battlefield (Rau 2000). Moreover, the reliable quantitative information needed to analyse military problems was hard to obtain due to the difficulty in conducting realistic experiments short of war.

The military's resistance grew stronger when scientists broadened their inquiry to include policy issues as they did almost immediately on questions related to nuclear weapons. Senior officers were worried that the pacifist/ arms control inclinations of the scientists would influence the public and interfere with plans for rapidly expanding nuclear forces (Needell 2000: 241–5).[5] Much to their annoyance, the systems analytic framework that scientists developed both in and outside of government to consider nuclear weapons issues did gain legitimacy and was later used by civilian officials, most especially Secretary of Defense Robert McNamara who served in the 1960s, to limit military requests for nuclear and non-nuclear weapons. Secretary McNamara countered the military claim to professional expertise with a claim of expertise in systems analysis, the quantitative oriented approach to defence policy problems that scientists favoured (Kantor 1979; Rosen 1984).

Although political and professional judgements still dominated policy-making, the rational scientific approach that systems analysis seemed to offer found widespread appeal in official discussions of policy where politics and personal agendas cannot easily be expressed. At a disadvantage in these policy discussions, the military built up their own systems analysis capabilities and support organizations. RAND, The Center for Naval Analyses, and other FFRDCs that served a single armed service were often the generators of studies that promoted service programmes in the face of challenges by the Secretary's staff or the other services. Analysis, easily shaped to reach desired outcomes because of its dependence on the policy assumptions and measures selected became another weapon in the bureaucratic wars over programmes and budget (Esell 1968; Lucas and Dawson 1974; Lehman 1988; Donohue et al. 1993; Vistica 1997).

Secretary McNamara retained the initiative by exploiting the natural competitiveness of the services. He would pit one against another, selectively offering opportunities or imposing penalties, to avoid having them form a united front against his policies. The policies McNamara favoured were greater centralization of support functions, joint weapon developments, limits on nuclear forces, and coordinated operations (Hitch 1967; Johnson 2000). During his tenure he reduced significantly the government's ability to design and build its own equipment by closing arsenals and shipyards (Assistant Secretary of the Navy for Manpower, Reserve Affairs and Logistics 1978). Contractors were asked to bid on the entire acquisition of a weapon, the so-called Total Package Procurement initiative first used with less than stellar results in the purchase of the C-5A transport (McNaugher 1989: 176). And the services were forced to buy the same aircraft irrespective of which one of them had developed it (Art 1968; Hallion 1994). An unpopular war, America's long struggle in Vietnam eventually forced McNamara, its senior manager, out of office. Many of his specific reforms did not survive very long—the Navy, for example, cancelled its participation in the joint acquisition with the Air Force of the F-111 aircraft within hours of his departure—but his underlining criticism that the services focused too narrowly on their interests and neglected common ones clearly did Survive (McNaugher 1989: 176). Nearly every military failing since then, from disappointment in weapon acquisition to combat disaster in the field, has been blamed on service parochialism and lack of integration among the armed services (Hoffman 1999). McNamara's endorsed proposals that there should be more jointness in both procurement and military operations became gospel, with the Congress, long the protector of service interests, enshrining them into law in the Goldwater–Nichols Act in 1986, which amended The National Security Act of 1947, and which increased the authority of the military's joint organizations. Even the F-111 idea of joint service development of aircraft is back in the form of the tri-service Joint Strike Fighter, the F-35 (Brinkley 2000). The services too have embraced jointness in the belief that greater coordination among them did not necessarily mean greater integration. They have used the increased importance of the Joint Staff and the joint commands in the US military structure, mandates of Goldwater–Nichols, to gain agreement among themselves about the sharing of missions. They rarely break ranks publicly when resources are at issue. Joint projects are increasingly common, but without much impact on the share of the budget or the assignment of missions among the services.[6] The promise of real integration, however, lies just ahead, we are told. Advances in communications and computers lead many to believe that a revolution in military practice is about to take place. There are visions of networked battlefields where surveying sensors identify targets and pass the information on to dispersed weapons platforms, which engage as needed while remaining aware of the location and status of friendly forces. Queued from space or unmanned aircraft, the weapons are precise. The connections are seamless between platforms, services, and commands. In these visions wars are fought by a military that utilizes 'systems of systems' (Owens 2000). The American military, according to its own documents, is working to transform itself into precisely such a force (Flournoy 2001).

2.7 Discovering the Limits

The American military in the cold war forced the pace of technology in a number of large complex weapon projects. Spurred on by its own internally competitive structure, it learned and helped others to learn systems integration skills, the art of conceiving, designing, and managing the development and deployment of large systems involving multiple disciplines and many participating organizations. The skills became central to the work of several aerospace firms, some government agencies, and a few specially created non-profit organizations dedicated to public service. Their efficiency in creating complex weapon systems eroded the Soviet Union's confidence in its ability to compete and surely contributed to the peaceful end of the cold war.

The systems integration skills were narrowly focused on weapons. They did help increase America's military power relative to others. But the thought that a similar level of integration can be achieved in policymaking or that war fighting can be made into a manageable systems problem seems illusionary. Reorganizations have centralized authority within the American Department of Defense without offering a comparable increase in the ability to process relevant information, make effective decisions, or gain full compliance in their implementation. Moreover, too much of importance to America's security lies beyond the scope of the Department of Defense or the influence of weapons.

The danger is to expect too much from those practising the art of systems integration.[7] The success achieved in building weapon systems for the cold war has lead to much hubris about the efficacy of systems thinking and the ability of the military to manage very complex operations. At least some of today's generals and admirals could benefit from a bit of the scepticism their predecessors showed when dealing with the claims of the operations researchers and other scientists after the Second World War. Technology has changed much about the way wars are fought, but it has not yet lifted the fog of war.

To the engineering mind, however, the need is to keep trying to apply a systems approach to all problems, civil or military. As Simon Ramo of Ramo–Wooldridge and systems integration fame expressed it, 'The system is there. It exists, designed or not, analyzed or not' (1969: 106). For Ramo, the systems approach/systems integration was the cure for chaos. Most organizations want very much to order their environments and thus cannot resist the call of the engineers. The result, however, is always another partial system, perhaps a step better, but inevitably only the reason for the next try for more order, and not the cure for chaos.

Notes

1. See Figure 5.1 Fitted logistic curves of war production: five cases.
2. The list of studies of missile programmes with this focus is long. A place to start is with Armacost (1969).
3. Apparently, the Air Force still struggles with this issue. See Simon (2002).
4. A claim for the first business application of systems engineering/systems design is made in Aris (2000).

5. For a British parallel, see Mary Jo Nye's comments on P. M. S. Blackett, the British geophysicist, who was an Operations Research leader (Nye 2002).
6. Cindy Williams (2001) explores a defence budget where the shares move due to competition for missions, but the total stays fixed.
7. The promise of great contributions of the systems approach in solving social problems, also disappointed, came earlier. See Webb (1969), Sayles and Chandler (1971), and especially Jardini (2000).

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