Processes of Weapon Systems Innovation

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"… the procurement process itself is a weapon of war no less significant than the guns, the airplanes, and the rockets turned out by the arsenals of democracy."

Irving B. Holley, Jr.
Buying Aircraft, 1964

After a burst of military innovation in World War II and the decade after, in many cases inspired by European born scientists and engineers, the pace of new ideas in weapons technologies appeared to slow down. By the late 1950s, some circles whispered of a "technological plateau" where nuclear warfare would reach a point that no further advance could break the stalemate between the U.S. and the Soviet Union. On May 12, 1960, Senator Thomas J. Dodd called attention to the "fallacy of the ultimate technological plateau" and urged continued devotion to technological advance.[1] While at first the technological plateau meant that it was not economically feasible to seek defense from, or something more terrible than, nuclear weapons, certain quarters misinterpreted the viewpoint to mean that scientific understanding had reached a plateau. For example, Representative Melvin Price, chairman of important subcommittees on research and development, warned that the government research program was "entering a leveling-off period, a plateau, in the total dimensions."[2]

A Technological Plateau

In June 1965, Senator Henry Jackson asked for comment on the "technological plateau," which he defined as "the sense that no major breakthrough—quantum advances—in military technology are now in sight." General Thomas D. White replied that "There is no reason to think that a curve of advancement such as we can trace today is suddenly going to level off. Space is a good example… We didn't dream anybody was going to be floating in space hitched to an umbilical cord even 5 years ago." Dr. Walter H. Brattain seconded the opinion, stating that "past experience

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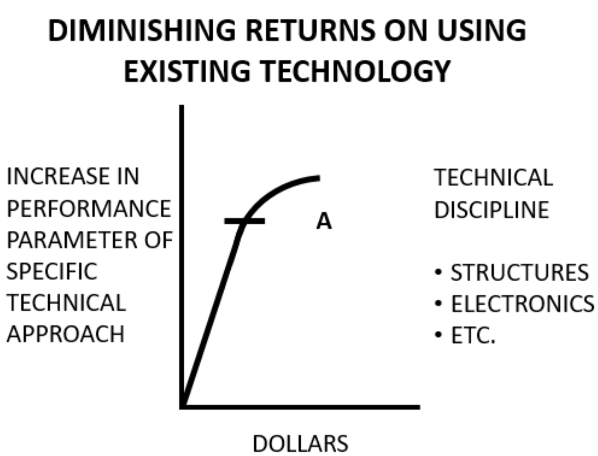
[1] Dodd, Thomas J. "The Summit and the Test Ban Fallacy." Found in Congressional Record, May 12, 1960, Senator Volume 106, Part 8, Collation 10104-10166, pp. 10137-38.
[2] Baldwin, Hanson W. "Slow-Down in the Pentagon," by, *Foreign Affairs* January 1965, pp. 263-64.

shows that whenever one thinks he understands everything, then is just the time when unexpected new understanding is most likely to occur." To show how the error of a technological plateau has been repeated many times before, Dr. Brattain quoted the famous 19th century physicist Ernest Mach who had observed the same phenomenon before him. Mach said that "The French' Encyclopaedists of the eighteenth century imagined they were not far from a final explanation of the world by physical and mechanical principles. Laplace even conceived a mind competent to foretell the progress of nature for all eternity if but the masses and their velocities were given."[3] And yet, revolutionary discoveries in electromagnetism, relativity, and quantum mechanics were just around the corner, making claims of omniscience through calculation sound naïve at best.

Despite pronouncements that military technology was not slowing down, by the start of the 1970s it became an "obvious historical trend" to Frederic Scherer that technological revolutions in "weapon systems concepts… were largely concentrated in the 1940s and the 1950s. There are some exceptions, to be sure; but they are not nearly so prominent in the 1960s." Scherer explained that the second-generation programs of the 1960s appeared a "disappointment" because they tackled "small but stubborn technical problems that were left over."[4] Where was the new generation of technologies, many wondered, that could rival radars, missiles, jet engines, transistors, and nuclear power? Writing in *Foreign Affairs*, Hanson W. Baldwin stated that "there appears to have been in the first half of the 1960s a definition reduction, as compared to the 1950-1960 period, in the evolution and production of new weapons."[5]



Reproduced figure from the 1972 Commission on Government Procurement (COGP) Report, depicting the leveling-off of performance gains as more dollars are expended on a specific technology. The figure suggests the importance of discovering new technologies, the only source of progress in the long-run.

Believing that military technology reached a plateau, Secretary of Defense Robert McNamara pushed for a different kind of innovation strategy from the freewheeling of the 1950s.[6] It focused on risk reduction through analysis without experimental effort associated with concurrency, technological leaps, and soaring costs. It meant a higher justification barrier for a project to receive funding. It required "perfection on paper" before contract effort could start. Not only did McNamara curtail new program starts, over his first few years he could perhaps be credited with canceling more

[3] "Conduct of National Security Policy." Hearings before the Subcommittee on National Security and International Operations of the Committee on Government Operations, United States Senate, Eighty-Ninth Congress, First Session, June 10 and 17, 1965, Part 2, pp. 87 and 106.
[4] Scherer, Frederic. "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 132-33.
[5] Baldwin, Hanson W. "Slow-Down in the Pentagon," by, *Foreign Affairs* January 1965, pp. 262.
[6] Murdock, Clark A. *Defense Policy Formation: A Comparative Analysis of the McNamara Era.* Albany, State University of New York Press, 1974, pp. 109-112.

programs than he started. For example, despite a clear-cut military requirement, McNamara canceled a nuclear-powered ramjet engine after $200 million had been spent. Dr. Edward Teller, father of the hydrogen bomb and catalyst to the Polaris program, said that "I believe this is the biggest mistake we have made since the years following World War II when we failed to develop the I.C.B.M."[7]

Already in July 1962, less than a year-and-a-half after McNamara took the helm, Congress noticed the Air Force struggling to innovate. In a review of the new PPBS management system, the vigilant committee staffer Herbert Roback sought to understand what had stifled new system developments. Roback suspected that the management practices of the PPBS, which RAND and the Air Force had worked on throughout the 1950s, led to a suppression of diversity and progress in systems development. Not only was it unusual for a staffer to directly question Congressional witnesses, Roback challenged the now famous General Bernard Schriever, credited with the stunning success of the crash Atlas ICBM program. He asked Schriever whether or not the program definition and cost-effectiveness effort was suppressing new system ideas. Schriever said, "I wouldn't say that is suppressing new system ideas..." and proceeded to dodge the matter. Roback then sharpened his line of questioning:

> Mr. Roback. "Well, is this the case, that there are new system concepts which are being proposed but not being acted upon? Do you consider that the emergence of new systems is proceeding at a satisfactory rate?"
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> General Schriever. "Well, from where I sit I think that we could move faster on certain of our programs. We have not really initiated a new system program for some time."
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> Mr. Roback. "For some time. Can you give in a year basis, 2 years?"
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> General Schriever. "Well, it has been over a year. We have several under consideration now in the so-called definition phase… With respect to programs which are now under consideration, it has been that we are defining programs to a higher degree than we have in the past. Essentially this has been the factor that has delayed the initiation of programs as such."

The program definition phase, Schriever admitted, delayed program starts. Program definition generally includes a systems analysis where the cost and effectiveness of alternative paper studies were compared to determine which single-best design made it to full-scale development. The process took a great deal of time and effort, resulting in decreased program starts. Schriever countered that program definition resulted more stable specifications, more realistic cost estimates, and ultimately a better program. He happily pointed to one new aircraft program authorized into development, the TFX. Schriever said of the TFX, "I might say that I completely agree with the steps that are being taken with respect to it." The benefits of a rigorous planning process, Schriever

[7] Baldwin, Hanson W. "Slow-Down in the Pentagon," by, *Foreign Affairs* January 1965, pp. 263-65. Other major programs canceled include the Dynasoar and Skybolt. Major programs of the 1960s which were already underway in the 1950s include Polaris, Minuteman, B-70, T.F.X., and AR-15 rifle.

concluded while under pressure, meant that the dearth of program starts did not, in his opinion, harm national security.[8]

Less than a decade later, the lack of new programs had reached a crisis point and became the highlight of a string of five Congressional hearings in December 1971 collectively called the "Weapon Systems Acquisition Process." Stuart Symington, the first Secretary of the Air Force and later a Senator from Missouri, made a startling complaint. "I have pictures," he said, "which prove that the Soviets have developed 13 new fighters since 1954. We have not developed one."[9] At the time of the Senator's shocking and misleading statement, the TFX aircraft—which became designated the F-111—had not been deemed fully operational. Its belated introduction into operations occurred in July 1967, but a malfunctioning horizontal stabilizer postponed full-operability when it took down three F-111 aircraft over Vietnam in 1968. Not until four years of defect correction had passed was the F-111A deemed fully operational. Without a new air superiority fighter since the Navy's F-4 Phantom II, which reached first flight in May 1958 and was then converted for Air Force use, U.S. airmen began to feel outmatched in equipment. Senator Symington reported his interactions with no fewer than a hundred pilots in Vietnam who told him that they would prefer to fly in their opponent's plane, the maneuverable Soviet MiG-21.[10]

The problem of getting new hardware to field did not limit itself to fighter aircraft. Admiral Hyman Rickover complained that "In the past 6 years the Soviets have built almost three times as many combatant ships as the United States... On a ship-to-ship basis the Soviets have designed combatant ships that are faster, more modern, and more heavily armed than their U.S. counterparts." In terms of submarine production, Rickover claimed the Soviets put out more than

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[8] "Systems Development and Management (Part 3)." Hearings before a Subcommittee of the Committee on Government operations House of Representatives Eighty-Seventh Congress, Second Session, July 1962, pp. 814-819.

[9] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 49. Although the Soviets may have put out 13 fighter aircraft between 1954 and 1971, it is not true that the U.S. failed to fully develop a single fighter over that timeframe. Senator Symington must have meant that the U.S. hasn't developed a new fighter since 1958; even then, the F-5 Freedom Fighter reached first flight in July 1959 and flew more than 2,600 combat sorties over Vietnam. It was also attractive to foreign allies. Other fighter programs were prototyped and canceled, like the YF-12, where Lockheed's Kelly Johnson sought to convert the A-12 into a fighter.

Senator Jackson's misleading points went unchallenged by an embarrassed Air Force which had adapted the Navy's A-1 Sky Raider, A-7 Corsair II, F-4 Phantom II, and the Marines OV-10 Bronco for use in Vietnam. The Air Force also relied on Navy air-to-air missiles including the AIM-7 Sparrow and the AIM-9 Sidewinder.

It was related to the Congress elsewhere that U.S. military and space RDT&E expenditures for 1971 were estimated to be nearly 30% lower than the Soviets. In constant 1968 dollars, U.S. expenditures were estimated at roughly $8 billion whereas the figure for the Soviets was $11 billion. Drawing correct conclusions from those estimates is impossible, however. See "Department of Defense Appropriations for 1972," Hearings before the House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 113.

[10] The MiG-21 (then designated Ye-2) actually reached first flight in February 1956, more than two years before the Navy's F-4 Phantom II. Despite Senator Symington's intimation that the enemy fighters fared well in Vietnam because of newer and more advanced aircraft, the primary Soviet fighter was even older than the primary U.S. fighter. However, the Soviets made numerous incremental improvements over that time. The MiG-21 had a production run of 11,496 units over 27 years. See Gordon, Yefim. *MiG-21* (Russian Fighters). Earl Shilton, Leicester, UK: Midland Publishing Ltd., 2008.

580 modern submarines over a 26 year period when the U.S. had only built 113.[11] To round out the tri-service crisis, the Army's new main battle tank, the MBT-70, proved a continuing drama of technical challenges and cost growth. The program had been in development by 1971 for close to a decade, and the projections at the time had each production unit costing four times more than its M-60 predecessor, even after removing inflationary effects.[12] Congress canceled the MBT-70 in the same month of December 1971.

Comparing Acquisition Processes

RAND analysts may have been behind many of the management methods ushered by the PPBS, but for the December 1971 Congressional hearings its analysts were reporting on the beneficial aspects of foreign organizations and processes. Robert Perry wrote a paper in preparation for the hearings entitled "European and U.S. Aircraft Development Strategies." He found that without depending on U.S. technical efforts, European aircraft firms nevertheless developed systems without any "striking inferiorities." The only exception appeared to be the complexity of installed electronics. France, for example, had developed a robust aircraft industry with an R&D budget only 10% that of the United States. Robert Perry extolled the virtues of the French company Dassault, which had "averaged one prototype a year for nearly 20 years" while keeping costs "quite low." Lavishing praise, Perry wrote of Dassault's seemingly "unlimited" ability to "create interesting options at low cost."[13] Dassault's success in foreign sales to 13 countries, representing two-thirds of its revenues in 1971, perhaps proved the point. Perry explained that European success came from a "different mode of aircraft development":

> "Dassault uses very small design and production staffs. For the Mirage IC bomber, which is a mach 2.2 supersonic bomber with a range of more than 1,000 miles, they used fewer than 85 engineers and draftsmen in the development phase. During the development of the vertical fighter they used an average of about 20 engineers and draftsman and a high of 30."[14]

Not only were the design teams nimble; the French government project offices averaged just 10 people or less. The largest project office had 40. Compare that to a typical Air Force project office which contained between 150 and 250 people. Perry wrote:

> "Government program or project offices in supporting fighter aircraft programs in France, England, and Sweden rarely contain more than 20 to 30 specialists; the ordinary government program office in the United States for a comparable program is staffed by at least five times as many specialists. The total of engineers, draftsmen, and experimental shop personnel

[11] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 344.
[12] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 154 and 262.
[13] Perry, Robert. "European and U.S. Aircraft Development Strategies." Dec. 1971, P-4748, pp. 10.
[14] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 170-71.

> engaged in such a European program rarely exceeds 700… In American experience, from two to ten times as many comparable specialists are employed."[15]

As a result, European aircraft were "characterized by simpler design, fewer production changes, and lower indirect costs." Overall, Perry found "program costs" to be "plainly lower in France and Sweden than in the United States, and probably at least as low in Great Britain." Despite his praise, Perry cautioned over-enthusiasm for a European system that also struggled to integrate complex electronics. But his testimony to the Congress pointed at two major differences between the European and U.S. acquisition systems. First,

> "… the ordinary European aircraft developer does not invest heavily in the sorts of elaborate program analysis that we do. They run computerized program tracking, things like PERT, for example, one of our favorite systems, in France, in Sweden and in Great Britain. But they ordinarily run them at a level of just about 10 percent of ours. They simply don't invest in that sort of detailed analysis."

Dassault Mirage IIIV vertical take-off and landing aircraft. Two prototypes were developed in 1965 and 1966, but the project was abandoned shortly after one crashed. The number of engineers and draftsmen on the project peaked at 30.

While U.S. contractors were subjected to myriad management control systems, their European counterparts remained largely unrestricted. In fact much of the reduction in government staff was achieved through streamlining information reporting and approvals. Perry found, for example, that the French government requirements for the vertical-lift aircraft totaled only 15 pages. In terms of continuous reporting during project execution, the Dassault Mirage III-G variable sweep-wing fighter program—comparable to the F-111 in the U.S.—provided two reports a month, totaling a mere 10 pages, in addition to a short quarterly project summary.

"Second," Perry continued, "they don't make any substantial production commitment until they are very sure that what they are going to put into production will perform." His paper elaborated that Europeans insisted on "early proof testing" of subsystems and delaying production decisions until "subsystems have been appropriately demonstrated." However, early austere testing and incremental changes neither led to inferior performance nor longer development times. Measured risks were taken. For example, Dassault flew the vertical-rise fighter prototype just nine

[15] Perry, Robert. "European and U.S. Aircraft Development Strategies." Dec. 1971, P-4748, pp.7. Perry later wrote that "… it would be preposterous to attempt to impose on Dassault the sorts of data and reporting requirements common to U.S. aircraft development. Dassault entirely lacks the staff to cope with such demands, and even if it could satisfy them neither the Air Force nor the Ministry could find the people to review the product. No one at Dassault bemoans that shortage." See "The Dassault Dossier: Aircraft Acquisition in France," 1973.

months after approval to start design, and the Mirage III-G prototype 16 months after design start. Prototypes were able to make it to production in relatively short order because employee "rewards are not for innovation, for new ideas, but for simplicity and cost effectiveness in initial design." Perry explained that "Dassault does not tolerate engineers who propose expensive or hard-to-produce parts, or who suggest costly 'improvements' that may also require high cost operating or maintenance procedures."

Perhaps just as important as proper incentives is stability in the employment base. The French achieved such stability by funding development independently of production. Perry explained that "We pay for development as part of a system process, as the prelude to production. In France, it is paid for separately; it is separate contractually and in time. That is an important distinction." As a result, some designers at Dassault had been "doing essentially the same tasks for 20 years."[16] In contrast, Oliver Williamson had observed large variations in U.S. contractor employment due to the fits of starts and stops concerning major winner-take-all programs.[17] Intermittent funding of major developments as a prelude to production corresponds with a weak ability for U.S. contractors to build institutional knowledge and a culture of success.

Aircraft systems development in the Soviet Union was similarly characterized by simplicity, incrementalism, and flexibility at the bottom. Arthur J. Alexander, also from RAND, told the Congressmen that Soviets development also relied on a minimum of reports and a separation of acquisition stages. "One of the major differences," Alexander explained of the Soviet aircraft industry, "is that the research institutes, the design bureaus, and the manufacturing plants are... autonomous and separated from each other. They are not linked together in a vertical structure." Even though all prototype designs must be approved by the Ministry, lead designers had absolute authority and responsibility. The Soviet pre-project document which solicited designs from the bureaus, equivalent to the U.S. Government's request for proposal, "does not appear to be a complicated document." Rather, it was primarily a list of goals and relative importance. For example, an "all-weather interceptor was described in three pages."[18]

The built-in flexibility at the bottom reportedly came from Stalin himself, who believed that "the designer was the one individual who could be held responsible for success or failure, that the designer has the duty of protecting the integrity of his design from the demands of others… The designer must not be at everybody's beck and call. He has to protest irresponsible demands… It is hard to make a good machine and very easy to spoil it and it is a designer who is responsible." To go along with their responsibility, designers received large rewards for successfully getting

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[16] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 171.
[17] Williamson, Oliver E. "The Economics of Defense Contracting: Incentives and Performance." In *Issues in Defense Economics,* ed. Roland N. McKean, 1967, pp. 221.
[18] Alexander, Arthur J. "R&D in Soviet Aviation." November 1970, R-589-PR, pp. 18.

sound aircraft into production. On the flip side, entire design bureaus that did not perform adequately were broken up.

Evaluation and accountability of broadly independent bureaus was achieved through a "multi-stage decision process." The functional stages of acquisition, including research, development, and production, were separated from each other and were further diversified into several independent organizations. The centralized Ministry retained the power to decide hand-offs into production based on fully tested hardware. The lack of developments satisfying the customer, and earning a production commitment, signaled the doom of the lead designer and his bureau. "Ironically," Alexander concluded, "Soviet aircraft production is similar to the way the American industry operated before the government began to participate heavily in project management... Soviet aircraft production is similar to what I would call profit-motivated capitalism, and that have taken over the best points of our pragmatic system of trying and experimenting before making decisions."[19]

The Soviets achieved through organization that which the Europeans achieved through contract: a separation of R&D from production. For the Soviets, this organizational separation extended further down the stages of production to piece parts and raw materials. Alexander found that the Aircraft Ministry could not depend on delivery of critical inputs and had to several of their processes in-house. The capitalist features of Soviet aircraft production were then limited in their dimensions. The French Dassault company, in contrast, was able to dependably rely on Western markets to fulfill most of their needs. It allowed Dassault to outsource almost the entire production process of its aircraft except final assembly, critical for maintaining competence in design. (Perhaps more important to the firm's structure was Mr. Dassault's non-market experiences when his capital twice became nationalized.)[20] The Soviet Aircraft Ministry, by contrast, struggled severely with the dependability of supply from other ministries. As just one example, it prevented the use of titanium in all engine designs in 1958.[21]

Not only did advanced foreign countries reject the intensive management processes associated with the PPBS, they successfully separated system development from its production. Whereas the Soviets did so organizationally, the Western Europeans did so contractually. And while U.S. emphasis on concurrency in theory led to faster innovation, the smaller French industry had kept

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[19] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 190-200.

[20] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 170-71. The total staff of around 12,500 developed and produced an impressive array of aircraft due to the emphasis on subcontracting. Over a 15 year period in fighter aircraft alone they produced over 1,500 units of various models. See also, Perry, Robert. "A Dassault Dossier: Aircraft Acquisition in France." Sept. 1973, R-1148-PR.

[21] Alexander, Arthur J. "R&D in Soviet Aviation." November 1970, R-589-PR, pp. 12. Later in 1982, Alexander had noticed the Soviets putting more emphasis on production and internal fears that "an excessive orientation to production and involvement in the innovation process could impair the country's fundamental research potential." See "Soviet Science and Weapons Acquisition," pp. 22-23.

pace in most respects. McNamara had, in fact, attempted to separate development from production in connection to his R&D cycle policies as well as the Total Package Procurement (TPP). Yet it wasn't until a change in presidential administrations in 1969 that emphasis on concurrency seemed to break, and with it came numerous other reforms designed to promote decentralization and advanced prototyping.

Reform

The elephant in the room seemed to go completely ignored in the December 1971 hearings on the Weapons System Acquisition Process. Less than five months before, Secretary of Defense Melvin Laird and his Deputy, David Packard, released the first of the 5000-series regulations. It sought to officially implement many of the processes that Perry and Alexander found so beneficial in Western Europe and the Soviet Union. For example, the 5000.1 attempted to decentralize responsibility to a single program manager and shield him from the detailed reporting demands of OSD. Further, it limited OSD's role to deciding program progress at major acquisition milestones that effectively separated developmental decisions from the production decision. None of this was new of course. The 5000.1 released on July 13, 1971 was based on a May 28, 1970 memo from Packard and built on the supposedly decentralized milestone process of the Defense Systems Acquisition Review Council established on May 30, 1969. Yet the Congress never had any formal hearings on the Laird and Packard reforms which eventually solidified into the 5000-series.[22]

Though the reforms largely avoided scrutiny during the Vietnam War, the acquisition system did not. The Jackson Committee hearings on the PPBS immediately preceded the President's Blue Ribbon Defense Panel, which issued the "Fitzhugh Committee Report" on July 1, 1970.[23] Additionally, the Commission on Government Procurement (COGP) formed in 1969 and continued to study the problem even after it issued a report in 1972. The recommendations of these studies were also arrived at, by-and-large, by Laird and Packard. Packard remarked that "The actions we have taken represent both a continuation of efforts we began shortly after taking office in early 1969 and an initiation of new proposals drawn from our own subsequent experience and the work of the Blue Ribbon Defense Panel."[24]

The first major change Packard attempted was to disengage OSD from formulating and managing acquisition programs. He returned to the services the initiative to formulate program

[22] The reforms were briefly mentioned in two hearings to the Joint Economic Committee in 1969 and 1970, as well as various times to the Appropriations Committee, such as by Laird on Feb. 20, 1970. The most thorough treatment was by Packard on Mar. 18, 1971. Almost two years after the reforms had started, Congressmen expressed how new the information was to them. It appears that the House and Senate Armed Services Committees were never formally informed about what would become the 5000-series.

[23] "Report to The President and the Secretary of Defense on the Department of Defense by the Blue Ribbon Defense Panel," 1 July 1970..

[24] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 27.

concepts and determine the alternatives, a critical function centralized by OSD systems analysts for the better part of the 1960s. Packard retained for OSD the power to set general policy, collect information, and evaluate major programs at three critical points in the acquisition life-cycle called program "milestones." The three milestones that initiated OSD involvement went as follows: "First, when the sponsoring service desires to initiate contract definition—or equivalent effort; second, when it is desired to go from contract definition to full scale development; and third, when it is desired to transition from development to production for service deployment."[25]


David Packard: electrical engineer; co-founder of Hewlett-Packard; and Deputy Secretary of Defense (1969-1971).

To make decisions on behalf of the Secretary of Defense at each milestone review for major defense programs, Packard created the Defense Systems Acquisition Review Council (DSARC), which included representatives from DDR&E, ASD Installations & Logistics, ASD Systems Analysis, and ASD Comptroller. The DSARC advised the Secretary of Defense or his Deputy on whether he should approve a program onto the next phase of the acquisition life-cycle. The most important document in the reviews was the Development Concept Paper (DCP)—later the Decision Coordinating Paper—which outlined the program's requirements, technical solution or approach, and cost and schedule estimates. Packard said that "The DCP is a concise statement describing the project, what is to be done, and how it is to be done. It covers the technical uncertainties, the operating requirements and the alternatives. It requires the originating Service to carefully prepare its case on a proposed new weapons program."[26] Comptroller General Elmer Staats provided an interpretation of the DCP. "It serves," he said, "to some extent, as a written agreement between the services and the Secretary of Defense. The DSARC and DCP are intended to be complementary; together, they constitute the formal DOD system for managing the acquisition of major weapon systems."[27]

While the DSARC process separated distinct phases of acquisition, the DCP was in part intended to reduce the amount of bureaucratic reporting. Packard issued a directive in October 1970 requesting recommendations to streamline acquisition. He testified to the Congress that "of the 1,227 directives reviewed, 35% could be canceled outright or through consolidation and 29%

[25] Memorandum from Deputy Secretary of Defense David Packard, May 30, 1969, "Subject: Establishment of a defense systems acquisition review council."
[26] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 16.
[27] "A Critique of the Performance of the Defense Systems Acquisition Review Council: Billions of Public Funds Involved." Report to the Congress by Elmer D. Staats, Comptroller General, PSAD-78-14; B-163058. January 30, 1978, pp. 3. Staats had a long tenure as Comptroller General from 1966 to 1981.

could be simplified through modification."[28] Not only were top level directives reduced, but the services were brought back into the process of deciding budgets. Under participatory management, the services could once again "propose how their monies should be spent."[29] Packard said that the fiscal year 1972 budget "was the first time in over ten years that the Defense program submitted to the Congress was one developed at the initiative of the Military Departments and the JCS rather than the initiative of the Secretary of Defense."[30] Still, only OSD had the power to approve major program decisions which set the framework for service execution. The policy-administration concept, which up until this time had been used to further centralize powers, was for the first time used by Laird and Packard to decentralize power.

During the McNamara years, OSD's policy-making apparatus encroached on defining not only what must be accomplished, but the specifications on how to accomplish it using a systems analysis. The milestone process, incorporating the DSARC and the DCP, returned program definition and execution to the services while retaining OSD's accountability to Congress; only it could approve policies with respect to program requirements, initiation, and progress. Using language that may have sounded familiar to Ferdinand Eberstadt more than twenty years before, Packard asserted that "the services have the responsibility to get the job done… It is the responsibility of OSD to approve the policies which the services are to follow, to evaluate the performance of the services in implementing the approved policies, and to make decisions on proceeding into the next phase in each major acquisition program."[31] Dr. John Foster, Director of Defense Research and Engineering and DSARC chairman, provided Congress with the following interpretation:

> "Decentralization, as we intend it, means that each DOD component, or military department, is responsible for identifying the new defense systems deemed necessary to meet potential threats to our national security and for proposing the systems to the Secretary of Defense for his approval. Upon such approval, it becomes the responsibility of the DOD

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[28] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 30. Interestingly enough, one of ASD Comptroller Charles Hitch's first tasks was to review and reduce existing directives on reporting, numbering more than a thousand, and achieved considerable success. One interpretation is that the cycle of slow regulatory growth and an occasional purge an institutionally viable method for adaptive governance. Some reports, and their concomitant processes, persist. For example, PERT—becoming configuration management in 1967—and the Cost and Economic Information System (CEIS)—becoming the CCDR in 1973—were two of various winners from Hitch's consolidation of reports.

[29] Moyer, Jr., Burton B. "Evolution of PPB in DOD," *Armed Forces Comptroller*. Spring 1973, pp. 22.

[30] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 29. The policy-administration dichotomy was also used in the Soviet Union. "We have no intention of dictating to you the details of research topics," L. Brezhev said to the Academy of Sciences in 1974, "that is a matter for the scientists themselves. But the basic directions of the development of science, the main tasks that life poses, will be determined jointly." It was in administration as well as science that "looking to the West… was the norm as well as the goal." See Arthur J. Alexander, "Soviet Science and Weapon Acquisition," pp. 24-29.

[31] Acker, David D. *Acquiring Defense Systems: A Quest for the Best*. Defense Systems Management College (DSMC) Press, Technical Report TR 1-93, Ft. Belvoir, VA, July 1993, pp. 147.

> component to conduct the program within pre-established and mutually agreed-upon limitations."[32]

The process of establishing policy and evaluating progress at major milestones assumes that a third-party, in this case the Office of the Secretary of Defense, can properly evaluate a diverse set of complicated programs. The assumption becomes especially problematic in areas of research and development, where outside experts have a poor record of predicting the winners and losers. If OSD policy-makers are to be truly accountable, proper evaluation requires a "show me" attitude. Yet due to the expense of full-scale development of major systems, McNamara wanted to be shown a systems analysis of alternative concepts. Packard, on the other hand, wanted to be shown functional prototypes to discover which of the alternative concepts most accords with reality, and to learn more about potential costs. Instead of interfering with service administration, prototyping improves systems acquisition by introducing early test articles that generate knowledge and reduce program risks. The focus then shifts from paper studies and mathematical analysis to forming metal and writing computer code. It brings forward functional hardware and software that improves the basis of third-party evaluation—particularly when it can be compared to a competitor. The French Dassault company insisted on continuous prototyping of individual components, even when developing new aircraft, to limit the cost and complexity of integration and testing.[33] The process allows for a rapidly evolving family of proven designs.

Prototyping

Packard told the Congressmen how systematic prototyping efforts can alleviate "two problems" that had grown under the McNamara years which had led to "excessive costs and unsatisfactory results." He explained:

> "One is the excessive reliance on paper studies and paper analysis. This difficulty has been evident in all stages of past programs, advanced development, full development, and production. The other problem is the concurrency between development and production—simply that development has not been sufficiently complete before production is started.
>
> "We believe that adopting the prototype approach on new programs will help to minimize these two difficulties…
>
> "The programs we are recommending for prototyping generally will not have the objective of producing a complete operational system. For example, the fighter aircraft prototype will primarily be used to demonstrate the capability of the airframe and engine in actual

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[32] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 60.
[33] Perry, Robert. "A Dassault Dossier: Aircraft Acquisition in France." Sept. 1973, R-1148-PR, pp. 24-28.

> aerodynamic performance but it will not include all of the avionics, weapons, et cetera, which are necessary for a fully operational weapons system."[34]

Alluding to Robert Perry and others' work, Packard stated that "We have looked at how the French buy a new aircraft. They do not do it by getting a big new weapons system program going and using a great deal of paperwork and controls. They simply go to the contractor and say, 'If you can give us a model that will fly and do this, we will pay you so much money.'" To deal with the "stop-and-go fashion" of U.S. defense programs, Packard even went so far as to discuss fixing design team budgets and letting them operate with relative autonomy. For "about $25 million per year," Packard believed, "we would obtain from each team two prototype models about every 3-4 years."[35] The "design-to-cost" approach reached similar ends, where program unit costs instead of organizational funding were fixed. In either case, Packard encouraged creative freedom to generate new solutions instead of pursuing pre-conceived ones:

> "If these prototype programs are to be efficient, they must be managed with the minimum of constraints. They should be designed to meet performance goals, not detailed specifications.
>
> "They should not require detailed confirmation of requirements nor careful consideration of all alternatives in advance because the very purpose of building prototypes is to use operational testing of hardware to confirm requirements and evaluate alternatives."[36]

Top military brass enthusiastically supported Packard's prototyping approach on visits to Senate and House committees on September 9 and 16, 1971. "The Army is enthusiastic about the broadened use of prototyping," Chief of Army R&D General W. C. Gribble said. "The Navy would like to add its enthusiastic support to this concept," Rear Admiral T. D. Davies chimed in. Air Force General K. R. Chapman followed suit. Yet Packard and his military leadership went to the Congress for more than just an informational briefing. Fiscal year 1972 had already started more than two months before, on July 1, 1971. Packard, however, wanted additional funding for prototypes in fiscal year 1972 without forcing the DoD to pilfer funds from existing programs. "We believe," Packard said to the Senate, "this should be an authorization rather than a reprograming or tradeoff action." In other words, Packard asked the Congress to retroactively increase the DoD top line. After explaining how vital the new prototypes were to national security, Packard threatened that "If the prototyping can only be supported at the expense of existing programs, I think the emphasis and scope is likely to be reduced." Senator Vernon Sikes asked plainly, "You are proposing to add $67.5 million for 1972?" Packard confirmed that "We are requesting an add-on in this amount for the specific programs." Though Chairman John C. Stennis

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[34] "Advanced Prototype." Hearings Before the Committee on Armed Services, United States Senate, Ninety-Second Congress, First Session. 9 September 1971, pp. 3-4.
[35] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 55-56.
[36] "Advanced Prototype." Hearings Before the Committee on Armed Services, United States Senate, Ninety-Second Congress, First Session. 9 September 1971, pp. 3-4.

was taken aback with the size of the request after the fiscal year had runout, he expressed pleasure with the direction of management.

The military representatives then introduced their proposed prototypes. The Army requested $23.5 million, including $8.0 million for an unmanned aerial vehicle and $3.5 million for a clean air engine. The Navy requested an additional $20 million for anti-submarine sensors, ship-based missile launchers, and vertical/short take-off and landing (V/STOL) aircraft. The Air Force requested an additional $24 million, including $5 million for a very low radar cross section test vehicle, $5 million for a Medium STOL transport, $4 million for quiet aircraft, and $10 million for a small lightweight fighter.[37] The Weapon Systems Acquisition Process hearings that took place three months later had a pivotal role in the outcome of the request. On December 14, just six days after the hearings, Congress authorized two of the Air Force's four requests, and actually increased the small lightweight fighter's funding to $12 million for fiscal year 1972.[38]

Four months after requesting additional funds from the Congress and one month after having the funds authorized, the Air Force solicited contract proposals for the Lightweight Fighter (LWF) program in January 1972. In February, five companies submitted proposals and on April 13, the Air Force selected General Dynamics and Northrop to design and build two prototypes each.[39] For business in the Pentagon, the turn-around was lightning fast. One defense contractor estimated that it took between nine months and a year from the time the DoD received a price quote to the final documentation going out to the contractor;[40] the LWF contracts took far less than half the time. The official first flight for General Dynamics' YF-16 took place on February 2, 1974, and for Northrop's YF-17, it was June 9, 1974. Over the next seven months, as many pilots as possible were found to test the YF-16s and YF-17s. Although the prototypes never flew against each other, they were pitted against Soviet MiG-17s and MiG-21s "acquired" by the Air Force.[41] Overall, the two YF-16 prototypes underwent 417 hours of testing during 330 flights while the YF-17s underwent 345 hours of testing during 299 flights. On January 13, 1975, the Air Force announced that the YF-16 had won the competition due to "advantages in agility, in acceleration, in turn rate and endurance. These factors applied principally in the transonic and supersonic regimes… This is indicative of the fact that the YF-16 has lower drag and was a cleaner design."[42] The YF-16 achieved high maneuverability at the expense of airframe stability, requiring a revolutionary "fly-by-wire" computer system to make instantaneous adjustments without the pilot's input.

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[37] "Advanced Prototype." Hearings Before the Committee on Armed Services, United States Senate, Ninety-Second Congress, First Session. 9 September 1971, pp. 523-539. All of the Air Force prototype programs, aside from the transport, were for "stealth" aircraft in the original sense.
[38] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 133-34.
[39] Sanibel, Michael. "Quest to Build a Better Fighter." *Aviation History*, Jan. 2011.
[40] Baldwin, Hanson W. "Slow-Down in the Pentagon," by, *Foreign Affairs* January 1965, pp. 263.
[41] "YF-16: Birth of a Fighter." http://www.f-16.net/f-16_versions_article25.html.
[42] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 199.

General Dynamics' lead designer, Harry Hillaker, remarked on the contracting process that made the LWF competition such a success. "The contract for the lightweight fighter prototype was for a best effort. We did not have to deliver an airplane, legally. Once we spent our $3 million, we could have piled all the parts on a flatbed trailer and said to Mr. Air Force, here's your airplane." The competition sought to achieve performance goals without pre-specifying detailed designs, leaving the contractors with near-total decision rights to build the best product. Hillaker, called the "Father of the F-16," said that "my point is that we were not working against a difficult, but arbitrary schedule... The airplane was simply a technology demonstrator."[43] DDR&E Malcolm R. Currie told Congress that such a competition in fighter aircraft had not been done "for over 20 years" and resulted in "virtually no increase in the overall cost of ownership."[44] Robert Perry from RAND wrote in 1975 that "in my judgement the F-16 is the first American aircraft in nearly twenty years that not only outperforms its Dassault-designed contemporary in every respect but if developed as now planned probably will cost no more."[45] Belgium, Denmark, Norway, and the Netherlands were so enthusiastic about the YF-16 at the Paris Air Show that they ordered a total of 348 aircraft on June 7, 1975, more than two months before General Dynamics started work on the first full-scale development unit.

Though the YF-16 provided capabilities the Air Force needed to complement the more advanced and costly F-111 and F-15 aircraft in a "high-low" mix, Northrop's YF-17 was not without attractive features. Navy airmen liked the safety of its twin-engines for operations over water. Most attractive to the Navy was the YF-17's ability to operate at very low speeds, improving the reliability of carrier landings. While the YF-16 fell into a spin on at least three occasions during the tests, the YF-17 was virtually stall-proof. The two YF-17 prototypes could circle around each other at speeds as low as 37 miles-per-hour with their nose faced upward, a move that looked like two cobra snakes facing off and indicated the aircraft's nickname, the "Cobra." Looking for a lightweight fighter complement to the F-14, the Navy received carrier-suitable redesigns of the YF-16 and YF-17 a month before the Air Force selected its winner. By May 1975,

General Dynamics' YF-16 (bottom) and Northrop's YF-17 (top).

[43] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991.
[44] "Major Systems Acquisition Reform: Part 1, Air Combat Fighter Programs." Hearings Before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, United States Senate, Ninety-Fourth Congress, First Session, 20 May 1975, pp. 62.
[45] "Major Systems Acquisition Reform: Part 2." Hearings Before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, United States Senate, Ninety-Fourth Congress, First Session, June 16 – July 24, 1975, pp. 599.

the Navy selected a derivative of the YF-17, but this time with Northrop as the junior partner to McDonnell Douglas. Though the aircraft looked superficially like the YF-17, it received a new engine and was structurally different enough to earn a new designation, the F-18. Without another prototype, the F-18 went into full-scale development and first flew on November 18, 1978. When the F-18 got into dogfights with the Air Force's top-end F-15 in the spring of 1981—an opportunity the Air Force denied the F-16—the F-18 won all four engagements due to its operability at low speeds, its ability to get behind its opponent, and most surprisingly, its endurance.[46]

The LWF prototype competition was a stunning success and seemed to prove Packard's management philosophy. It resulted in two of the finest weapon systems in the U.S. arsenal, the F-16 and the F-18, which due to their affordability became Air Force and Navy work-horses for decades to come. Other notable prototype competitions included the Advanced Attack Helicopter (YAH-63A versus YAH-64A), the STOL Transport program (YC-14 versus YC-15), and the A-X Close Air Support program (YA-9 versus YA-10). For the A-10, another Air Force work-horse that proved extremely robust and a tremendous value, the DSARC did not approve production until after two years of testing.[47] "Test program participants were convinced," reported Robert Perry, that the A-10, F-16, and UH-60 "would not have been selected had only paper designs been evaluated."[48]

An example of prototyping without competition came with the B-1 next generation swing-wing bomber. Packard said that "it was too expensive to develop two new bombers, and test them against each other." Instead of a competition, he explained how "The contractor will build three prototypes and we will thoroughly test those before a production decision is made."[49] Despite Packard's hope that the B-1 prototype effort would save "several hundred million dollars," the program began to falter and was canceled for a time by President Jimmy Carter in 1977. Pierre Sprey told Congress in 1975 that "if we cannot afford to execute a program under competitive prototype conditions, then I would conclude that that is probably an indication that we are not ready for that program, that we have not developed enough of the components to be sure that the

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[46] Orr, Kelly. *Hornet: The Insight Story of the F/A-18*. Presidio Press, Novato CA, 1990. Though Kelly Orr says on page 48 that the nickname "Cobra" came from a test pilot, James P. Stevenson reports in *The Pentagon Paradox* (pp. 77-78) that the YF-17 was derived from Northrop's P-530 Cobra, suggesting the nickname was already floating around before the YF-17 ever flew.

After the F-18's dogfights with the F-15 in 1981 (pp. 172-173), Admiral Gillcrist said that "I was totally astonished… Here I was flying in an airplane that had been highly criticized for its lack of internal fuel capacity, and I just ran the highly touted long-range Eagle out of fuel. Amazing!"

[47] McLucas, John L. *Reflections of a Technocrat: Managing Defense, Air, and Space Programs during the Cost War*. Air University Press, Maxwell Air Force Base, Alabama, August 2006, pp. 99 and 123. Also, the A-10 was the result of the first U.S. prototype competition ever performed, according to Pierre Sprey.

[48] Perry, Robert. "American Styles of Military R&D." June 1979, P-6326, pp. 25.

[49] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 17.

program will be a success."[50] Though several prototypes without competition were successful, they often limited new technology by making maximum use of mature components. For example, the F-117 prototype achieved a remarkable airframe design, but leveraged numerous existing components including the engine from the T-38A, flight controls from the F-16, landing gears from the A-10, and environmental systems from the C-130.[51]

In 1979, the former head of air warfare for DDR&E Chuck Myers provided Congressmen with a chart of tactical aircraft costs in constant (inflation-adjusted) FY 1980 dollars. It showed the production cost of a P-51 at less than $1 million in 1944, with costs of successive fighters increasing along an exponential curve. From the P-51 to the F-86 and onto the $2 million F-100 and $3.5 million F-104; then in 1960 the F-4B cost $6 million, in 1968 the F-111 cost $23 million, and in 1972 the F-14 cost $26 million. It seemed that the next aircraft might cost so much that it should jump off the chart, but it did not. In 1977, the A-10 cost just $5 million and two years later the F-16 cost roughly $7 million. Though the prototyped aircraft created a downward shift in the cost trend, the un-prototyped F-15 and F-18 had uncomfortably high unit costs of roughly $15 million each and seemed to renew the exponential trend upward. Myers told Congress that "YF-17 to F-18 growth came as a Navy coup. It was explosive and appeared to erase the cost difference between it and the F-14 it was meant to complement. The F-16 growth was more subtle." Myers explained how the desire for the services to pursue multi-role missions with futuristic technology would renew the exponential cost growth of aircraft unless proven and effective systems were pursued.[52]

As it turned out, the services continued a policy of increasing sophistication which increased costs and reduced the frequency of new programs. The relative success of the F-15, F-16, F-18, and A-10 aircraft were by no means secured with the seemingly well-designed policies of the Laird and Packard administration. The aircraft may well have never flown had the reforms not fortuitously aligned with the doggedly anti-social behavior of a few men willing to contravene Air

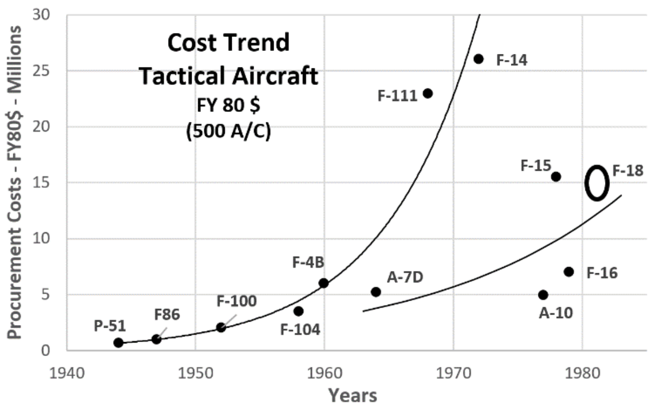
[50] "Major Systems Acquisition Reform: Part 2." Hearings Before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, United States Senate, Ninety-Fourth Congress, First Session, June 16 – July 24, 1975, pp. 248.

[51] Goodall, Hames C. "The Lockheed F-117A Stealth Fighter," in *America's Stealth Fighters and Bombers: B-2, F-117, YF-22, and YF-23.* Motorbooks: St. Paul, MN, 1992.

[52] "Hearings on Military Posture and H.R. 1872 [H.R 4040] and H.R. 2575 [S. 429], and H.R. 3406, Part 2." pp. 856-860. Note that the unit costs are both inflation adjusted, meaning it controls for the purchasing power of the dollar, and they are adjusted for quantities. Myers explained, "In this case, all of the planes have been reduced to common production quantities, say, 500 airplanes. In other words, if you were buying 500 of each of them in fiscal year 1980 dollars, that is the relative cost."

Sandy McDonnell was an early advocate for multi-mission aircraft. In 1954, the Navy wanted a new interceptor but McDonnell convinced them to develop a multi-mission aircraft. "If substantial quantities of aircraft are procured," McDonnell said, "the effect of the 'learning curve' is so powerful that it will more than compensate for the muiltimission aircraft size and weight, which is greater than some of the single mission aircraft such as the day interceptor." The Navy agreed and the result was the F-4 Phantom II, which significantly underperformed in Vietnam relative to the F-86 Sabre's experience in Korea. Some of the performance differences may be explained by an engineering appraisal using John Boyd's EM-Theory. See Glenn E. Bugos (1996) *Engineering the F-4 Phantom II*, pp. 24; and Frans Osinga (2007) *Science, Strategy, and War*.

Force doctrine, including Chuck Myers, Pierre Sprey, and perhaps most of all, John R. Boyd. The extreme irregularity with which the "teen" series aircraft were developed, and the personal nature of interventions required, provides a glimpse into the systemic rigidities against non-consensual innovation in the Department of Defense and suggests the limitations to reforms envisaged by Packard.



Aircraft cost trend presented by Charles ("Chuck") Myers to the Congress in 1979. The unit costs have the effects of inflation removed relative to 1980, and were further adjusted to a total procurement quantity of 500 aircraft. Note the F-18 has a larger circle to represent uncertainty in its costs, still years out from Initial Operational Capability (IOC). Reproduced figure.

Precarious Prototypes

The LWF concept may start in 1960 as Captain John Boyd packed his bags to go study industrial engineering at Georgia Tech. At thirty-three years old, Boyd was already a famous Air Force pilot. While instructing tactics at Nellis Air Base, he offered a running bet that he could beat anyone in mock air combat within forty seconds or he'd pay them forty dollars. Never having lost, he earned the nickname "40 second Boyd." He had also recently finished his "Aerial Attack Study," which became the definitive encyclopedia on air-to-air combat. But it was in his time at George Tech that Boyd began developing a theory that would transform aircraft design and assessment. Within two years Boyd "discovered he could explain air-to-air combat in terms of energy relationships, in which the altitude is potential energy to be traded for speed—kinetic energy—and vice versa."[53] The concept, completed with Thomas Christie at Eglin Air Force Base, became known as Energy-Maneuverability (EM) Theory. Due to the logical and mathematical rigor behind it, as well as Boyd's unique status, EM Theory quickly found acceptance in the Air Force. After receiving several awards, Boyd was sent to the Pentagon in 1966 to help a new F-X aircraft succeed where the F-111 failed. His reaction to the F-X in its early stages was typical of Boyd. "I could fuck up and do better than this," he

[53] Osinga, Frans P. B. *Science, Strategy, and War: The Strategic Theory of John Boyd*. Routledge: London and NY, 2007, pp. 20-25. The LWF concept could also start with Chuck Myers, who early on criticized government requirements that forced the TFX to weigh 80,000 pounds. He explained to a sympathetic Alain Enthoven the merits of a gun-fighting aircraft, and later in 1963 wrote a paper on the requirements for a "close-combat cannon equipped fighter." As Myers recalled, "It wasn't that the whiz kids were screwed up. We aviators were doing a poor job of explaining the problem of air-to-air combat." See *The Pentagon Paradox* by J. P. Stevenson, pp. 21-29. Apparently it was Myers who, using a friend in DDR&E, got John Boyd his Pentagon assignment by lobbying the Air Force Chief of Staff to rescind Boyd's order to Okinawa. Myers may also be credited with coining the term "stealth" aircraft, though in his initial concept, he wanted to "reduce all the signatures, the visual, acoustical, radar, and infrared." Funding for lightweight and quiet aircraft were then part of the stealth movement. The A-10 has elements of reduced infrared signatures. Today, stealth refers almost solely to aircraft with a very low Radar Cross Section (RCS), like the F-117.

said.[54] Boyd worked tirelessly to reduce the weight and complexity of the F-X design in order to improve its "fast transient maneuvering," in accordance with EM Theory. Others in the Air Force pushed back on the basis that modern combat required a powerful radar to see the enemy first and a long-range missile to destroy him before close air combat commences. Such capabilities required a larger platform at the expense of agility. The F-X project, eventually the F-15 Eagle, went to McDonnell Douglas for full-scale development in 1969 without a prototype.

Still displeased with the design compromises made by responsible elements in the Air Force that resulted in a less agile plane, Boyd and a handful of likeminded pilots, analysts, and engineers pushed for a fighter weighing about 20,000 pounds, less than half that of an F-15. The core group included John Boyd, Pierre Sprey, Harry Hillaker, Everest Riccioni, Thomas Christie, and Chuck Myers. Already in 1967, Boyd and Sprey were briefing leadership on a lightweight fighter but disengaged after getting no results from the Commander of the Air Force Systems Command, who had already committed substantial funding to the F-15. Undeterred and without official authorization, Sprey sketched designs of a lightweight "F-XX" aircraft in 1968. The next year he wrote a paper on the F-XX concept which fell flat in the Air Force. Yet the dissident group slowly grew in numbers and influence. Engineer Harry Hillaker got on board shortly after encountering Boyd in an officer's club while Boyd was loudly disparaging his company's aircraft, the F-111. Hillaker remembered that the group was once called a "mafia" by people in the Air Force because they "were viewed as an underground group that was challenging the establishment."[55] Other sources have Colonel Riccioni coming up with the group's name, playing on the post-WWII "bomber mafia." In either case, the name of Boyd's group became the "fighter mafia." And as the name suggested, the fighter mafia would have to throw out the rule book out in order to get the unlikely LWF program off the ground.

After Pierre Sprey's F-XX paper was rejected by the Air Force in 1969, he presented it to the American Institute of Aeronautics and Astronautics (AIAA) in a meeting at McDonnell Douglas' St. Louis facility.[56] It seemed to bear fruit when "125 McDonnell guys" became interested in the LWF concept. Despite their obligation to the F-15, McDonnell Douglas engineers provided assistance to General Dynamics, most notably on the fly-by-wire system critical to the YF-16 design.[57] The LWF designs were helped further by Colonel Riccioni, who obtained funding for an innocuously named study. General Dynamics and Northrop understood the real objectives of

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[54] Burton, James G. *The Pentagon Wars: Reformers Challenge the Old Guard*. Naval Institute Press, Annapolis, MD, 1993, pp. 14. Also see Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 75-76. Boyd reportedly got the weight of the F-X down from 60,000 to 40,000 pounds and removed the possibility of a swing-wing design like the F-111. Later models of the F-15 saw their weight increase to 70,000 pounds.

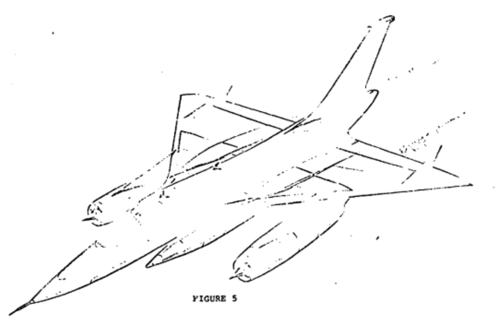
[55] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991. For Riccioni and the Bomber Mafia, see Hammond, Grant. *The Mind of War: John Boyd and American Security*. Smithsonian Press, Washington, D.C: 2001, pp. 85.

[56] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 184.

[57] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991.

the study were to pursue a lightweight fighter; Boyd and Sprey contend that without it, the F-16 program wouldn't have existed. Riccioni was a master promoter of the LWF concept but rubbed some officials the wrong way. In December 1970, Riccioni got himself removed from the Pentagon by Vice Chief of Staff John C. Meyer after a heated argument on the lightweight fighter.

While Riccioni's study kept it breathing, the lightweight fighter was given new life the very next month when Lockheed's Kelly Johnson unexpectedly submitted a proposal to prototype a low-cost aircraft based on the F-104. Three companies followed Lockheed with unsolicited proposals, prompting DDR&E John Foster to inform Packard of the situation. Packard responded with the instructions that "two, at least, aircraft should be obtained. Only the price shall be firm. All specifications shall be open. A plan for fly-off testing will be required."[58] Boyd wanted to influence the prototype competition to reflect his lightweight concept. However, he soon got word of an Air Force conspiracy to waste time by moving his proposal up to the highest level before receiving ultimate rejection. In response, Boyd used a friend close to Packard to successfully go over the head of the Air Staff.[59] On August 25, 1971, Secretary of Defense Laird personally intervened by issuing a memorandum directing the Air Force to establish a LWF program.[60] A couple weeks later, Packard brought General Kenneth R. Chapman before the Congress to find additional funds specifically for the LWF competition. Even with substantial help from Packard, the fighter mafia's Harry Hillaker judged that the F-16 would never have flown without buy-in from Air Force regulars, including General Chapman.[61]



A faded 1968 sketch of the F-XX, presented by Pierre Sprey to Congress in December 1971. Funding for the lightweight competition was authorized by Congress within a week.

Even after Packard and Laird's personal intervention generated extra funding to pursue to the LWF competition, its progress proved to be in continual jeopardy. Several Congressmen, most notably Senator Howard Cannon in a statement entitled "Lightweight Fighters No Panacea," railed against the LWF concept and viewed it as a less-capable threat to fighters already in development. Packard assuaged Congress and the Air Force by repeatedly stating that the LWF competition was a technology demonstrator making no commitment to production orders.[62] Major General William "Hollywood Bill" Evans picked up on the line that the LWF program did not fulfill a requirement,

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[58] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 97-103.
[59] Burton, James G. *The Pentagon Wars: Reformers Challenge the Old Guard.* Naval Institute Press, Annapolis, MD, 1993, pp. 19.
[60] Gable, Deborah. *Acquisition of the F-16 Fighting Falcon 1972-1980.* Report No. 87-0900, United States Air Force Air Command and Staff College, Air University: Maxwell Air Base, March 1987, pp. 8-9.
[61] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 134-35.
[62] "Weapon Systems Acquisition Process" Hearings Before the Committee on Armed Services United States Senate, Ninety-Second Congress, First Session, December 3-9, 1971, pp. 281 and 69.

but merely demonstrated technology to be incorporated into other production aircraft. As the YF-16 and YF-17 were preparing for their first flights toward the end of 1973, the Air Force attempted to squash the program by underfunding it in the next budget submission. Both LWF management and General Dynamics believed the program would be killed. Once again, fighter mafia proponents got the ear of incoming Secretary of Defense James Schlesinger, who sympathetically added $36 million to missionize the LWF program for eventual production in January 1974.[63]

The LWF program would have continued to threaten the Air Force's F-15 if not for two developments. First, the Nixon Doctrine provided a requirement for low cost aircraft to assist equipping foreign allies. In 1970, Northrop's inexpensive F-5 won the International Fighter Aircraft (IFA) competition, prompting Lockheed's unsolicited proposal that got the LWF competition underway. Later, when U.S. allies went looking for more fighters in 1974, it was clear that an outdated F-5 and a pricey F-15 did not provide attractive options, especially with a new Dassault Mirage F-1 competitor. Lieutenant General John J. Burns claimed that the F-16 entered the Air Force not because of its combat effectiveness, but to bump up production quantities to keep costs down and win the international competition. "They were going to buy about 350, so we had to buy 650," Burns said.[64] Second, Schlesinger authorized increasing the number of Air Force fighter air wings by six on July 29, 1974.[65] This came a year after cost growth had caused the Air Force to request a reduction in the number of authorized air wings by five, from 24 to 19.[66] Schlesinger wrote that the force structure increase was "approved specifically for the purpose of accepting [LWF] deliveries."[67] With additional funding carved out in the budget that supported both the F-15 and the new F-16 programs, Air Force resistance fell away. As General Robert T. Marsh reflected, "I do not believe, it is fair to say that anybody in the United States Air Force, in a senior position, planned to inventory the F-16. I think it was thrust upon us."[68]

Permission to Innovate

The obstacles faced by the fighter mafia are not unique to the Air Force; the obstacles are common to the administration of large organizations. Two processes in the DoD exacerbate the obstacles: the unified program budget and the DSARC. The program budget requires definition not of program means, such as personnel, supplies, and contracts, but of the program itself, and not just of what must be accomplished, but often how to accomplish it. The program budget was

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[63] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 153-61.
[64] Mets, David R. "Boydmania."*Air & Spacepower Journal*, Fall 2004, Vol. XVIII, no. 3, pp. 98-107.
[65] Pierre Sprey interview on Pentagon Labyrinth, "Pierre Sprey and the Birth of the A-10" POGO.
[66] "Memorandum for Dr. Kissinger. Subject: FY 75 Defense Program and Budget." 10 August 1973. Written by Phillip Odeen. The Air Force was authorized to have 24 fighter air wings, they could only fill 22. Note that Foster states the air wing increase to be five, not six given by Sprey or four as given by Odeen. See Foster, Peter R. *F-16: Fighting Falcon*. Ian Allan Ltd. London, pp. 3.
[67] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 176. The LWF concept in the Air Force was named the Air Combat Fighter (ACF).
[68] Marsh, George T. "Interview," United States Air Force Oral History Program, pp. 251.

introduced to the DoD specifically to provide top leadership the information to decide upon program requirements and eliminate duplicative projects. Before new concepts get there, a program definition phase weeds out innovation which does not justify itself before-the-fact to a crowd of people with veto power. The DSARC provided a forum for consensus building on program costs and requirements starting at Milestone I, before any prototypes are built. Under the formal process, the ability to innovate in the DoD requires permission from both competitor programs and from the established experts. Otherwise, as the LWF story suggests, it takes a nearly impossible appeal to political powers. Henry Hillaker recalled the fighter mafia facing institutional resistance for two similar reasons.[69]

First, the fighter mafia threatened the viability of the F-15, a competitor program. In a program budget, the total cost of acquisition programs must be estimated up-front. The authorization of F-15's development also committed the Air Force to a large procurement that would tie up much of the tactical aircraft budget. For a once in a generation plane, the fighter mafia had a fair shake in defining the F-15. Then they wanted a whole new program, and if it went into production, there may not be enough funding for the F-15. The result might be reduced F-15 quantities leading to increased unit costs, possibly spiraling into cancellation. F-15 program advocates then had legitimate interests in the LWF program because they all drew from the same limited source of funding. Further, the F-15 program could claim that the F-16 met no mission requirement; lightweight was associated with low capability. Even when adequate funds for both programs were provided, it did not erase the memory of subversion. Just two months before the Air Force selected McDonnell Douglas for full-scale development, fighter mafioso Chuck Myers wrote a critical memo of the F-15 requirements in a last-ditch effort to push the lightweight concept.[70] In a resourced constrained environment, successful developments can have long term implications on the forecasted life cycle budgets of established programs. Competitor programs whose budgets have already been justified can then use the authorization as a counter argument to any threatening new development.

Second, the fighter mafia moved against expert advice and was "perceived as being anti-technology."[71] Post-war experts in air combat agreed, and not without good reason, that fighter aircraft needed a high top speed, advanced avionics, and long range missiles. Despite the troubles encountered by the F-111, its all-weather terrain following radar proved highly capable. The fighter mafia took a very different view, arguing that the primary mission of air-to-air combat required agility. Though the YF-16 and YF-17 were state-of-the-art in their own rights, their LWF concept did not seek to over-engineer the planes with negative consequences to agility, reliability, and cost. Skeptics interpreted the fighter mafia to be anti-technology, particularly Pierre Sprey, who was called "a true Luddite" by General John M. Loh, the LWF program manager during the

[69] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991.
[70] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993
[71] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991.

critical stages.[72] Though the slogan "Make it simple" pervaded fighter mafia thinking, Hillaker recalled it being an oversimplification. "We didn't articulate ourselves well early on," Hillaker said more than twenty years later.[73] If the fighter mafia wanted to shape the F-15 program, the LWF program, or any major program, it would have to influence the entire set of experts solidified in the Air Staff, or, as it turned out, go over their heads.

The pursuit of defense innovation requires the support of numerous officials at the service staff level, the service headquarters level, the OSD level, and even from the President and Congress. The involvement arises because advanced development efforts continued to be as much a prelude to full-scale development as full-scale development was a prelude to production. Both the competitor and the expert can, in almost all circumstances, provide a plausible case that a new project either meets no military requirement or is duplicative with the requirements sought by an existing program. In both requirements and duplication, program nay-sayers found especially easy targets in the lightweight F-16 and F-18. More than a year after Schlesinger authorized the LWF program to be missionized and just as they were entering full-scale development, the services still had no formal requirement for the F-16 or the F-18. The point was raised to the Congress by the GAO, which formed the opinion that the F-16 and F-18 programs must be curtailed until requirements were detailed and agreed upon with Congress.[74] When the Air Force got around to formalizing requirements, competitive meddling continued as F-15 advocates laid claim to the air-to-air superiority mission and pushed the F-16 toward an air-to-ground role not envisioned by the fighter mafia, in some ways corrupting its design.[75] F-14 advocates in the Navy successfully pushed for even more substantial changes to the requirements of the F-18, a plane which was very nearly killed by an increasingly interventionist Congress.

We Are in Trouble!

In some ways, the institutional challenges faced by the F-16 pale in comparison to those faced by the F-18. The program faced cancellation by Congress in every year of the F-18's development.[76] The Navy first caught the ire of Congressmen when the Naval Air Systems Command (NAVAIR) blatantly disregarded their direction. Congress wanted the Navy to select a derivative of the Air Force's winner, still undecided at the time. In a September 18, 1974 conference report, the House Committee on Appropriations said that "Adaption of the selected Air Force Air Combat Fighter to be capable of carrier operations is the prerequisite for use of the funds

[72] Bjorkman, Eileen. "The Outrageous Adolescence of the F-16." *Air & Space Magazine*, March 2014.
[73] "Harry Hillaker—Father of the F-16." Interview by Eric Hehs. *Code One Magazine.* April and July, 1991.
[74] "Major Systems Acquisition Reform: Part 2." Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress, pp. 217.
[75] Stevenson, James P. *The Pentagon Paradox: The Development of the F-18 Hornet*. Naval Institute Press, Annapolis, MD, 1993, pp. 74 and 178.
[76] Orr, Kelly. *Hornet: The Insight Story of the F/A-18*. Presidio Press, Novato CA, 1990, pp. 126.

provided."[77] $20 million provided by Congress was then fenced off for the winner of the Air Force competition. But Navy participants did not feel that they have a voice at the source selection board determining the joint service aircraft. On November 1, 1974, the Deputy Secretary of Defense Clements wrote a letter to the chairmen of both House and Senate appropriations committees requesting that the $20 million be made available to pursue derivatives from either the YF-16 and the YF-17. Neither chairman objected, but that was before the Air Force selected its winner. Completed proposals were received by the Navy on January 13, 1975, the same day that the Air Force selected the YF-16. As the Navy evaluated the designs, General Dynamics fully expected to also win the Navy effort; they must have thought that the Navy was spending time evaluating among its three derivative proposals to the YF-16. But on March 7, 1975, Clements again wrote the Appropriations' committee chairmen requesting for $12 million to go toward derivative designs from "both of the original Air Force ACF competitors" and the remainder towards a "contract with the selected firm to refine its design and sustain its engineering effort… whichever firm is selected." Both chairmen again wrote back with "no objection."[78] Perhaps House Appropriations chairman George H. Mahon would have objected at the time had he knew the details. On May 2, 1975, the Navy selected the derivative of the YF-17 and Mahon quickly reversed direction. He seemed genuinely bewildered by the Navy's decision:

> "This Committee has supported the Air Force Lightweight Fighter Prototype development program. The Committee's objective has always been that this program would develop a lightweight, low cost, advanced technology fighter aircraft that could meet both Navy and Air Force requirements. While the Lightweight Fighter program appears to have developed prototypes that fulfill this objective, the Navy has disregarded Congressional intent and is initiating development of an entirely different, larger and more expensive aircraft… Since the Navy has proceeded in an entirely different direction, the Committee recommends deletion of all the funds requested."[79]

What is more curious about Chairman Mahon's turnaround is that he previously expressed doubt over the benefits of commonality. While discussing the A-X Close Air Support aircraft in a 1971 hearing, Mahon said that "We think commonality is good, but, we do not want to undertake to achieve something that cannot be realistically achieved."[80] In 1975, however, Mahon pointed to the F-4 and A-7 as joint service planes that benefited from "the large production run" provided by commonality. Yet those aircraft were designed for the Navy and "stripped down" for the Air Force. Removing weight from naval aircraft is easier than adding weight to handle the stress of

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[77] House of Representatives Report No. 93-1363, 93rd Congress, 2nd Session, Sept. 18, 1974.
[78] "F-18 Navy Air Combat Fighter." Hearings Before a Subcommittee of the Committee on Appropriations, U. S. Senate, First Session, on H.R. 9861 hearings, Oct. 1975, pp. 73-74. After reading Deputy Secretary of Defense Clements' letter, one can easily come away with the wrong impression about the Navy's intent, and perhaps the chairmen (and their staff) did not fully understand what was being asked of them.
[79] "F-18 Navy Air Combat Fighter." Hearings Before a Subcommittee of the Committee on Appropriations, U. S. Senate, First Session, on H.R. 9861 hearings, Oct. 1975, pp. 181.
[80] "Department of Defense Appropriations for 1972," Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Second Congress, First Session, Part 2, 18 March 1971, pp. 36.

catapult launches and arrested landings, to increase wing area for carrier approaches, and to overcome various other matters besides, as discovered in the F-111B which the Navy backed out of.[81] Admiral William D. Houser said that for carrier operations, "you have to add several thousands of pounds of structural weight so it becomes heavier. You have to add a great deal to the wing area and complicated devices that fold in and out of the wings to give it its approach characteristics… And then it is too heavy for the same engine." Moreover, neither of the LWF competitors had ever built a naval aircraft, requiring them to team up with an experienced partner.

Realistic speculation that Congress would only fund a derivative of the Air Force winner drove the teaming arrangements for Navy designs. Northrop first approached Ling-Temco-Vought (LTV) to help on the YF-17, but LTV turned them down because by the summer of 1974, it looked like the YF-16 would win the Air Force competition. LTV took an inferior offer from General Dynamics, pushing Northrop into a deal that made them the junior partner to McDonnell Douglas on the navalized YF-17. The teaming arrangement mattered greatly, because both General Dynamics and LTV were based in the Dallas-Fort Worth area of Texas, the home state of Chairman Mahon. And it was clear to all involved that a joint service aircraft ensured plenty of defense dollars for local jobs. While Mahon's congressional district was a couple counties away from Fort Worth, perhaps affecting his opinion, junior member Dale Milford served the suburban area in between Dallas and Fort Worth, and Milford railed loudest against the Navy's decision. "Will Congress surrender its constitutional prerogatives," Milford asked with a hint of excess, "by permitting an executive agency to act in clear defiance of the law?" He called the Navy's actions a "ripoff" due to the projected $2 billion savings provided by commonality; a projection perhaps not made by the most independent of sources, Milford's own constituents, General Dynamics and LTV.[82]

On May 9, 1975, LTV submitted a formal protest to the Navy's decision citing Congressional language. Apparently, many in the Navy were unaware of the matter until after the protest. NAVAIR General Counsel Harvey Wilco exclaimed "Holy moly! We are in trouble!"[83] Indeed they were. Within a couple weeks, Representative Milford brought the protest and a personal statement before the Senate to discuss the matter.[84] The two issues Milford later identified were

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[81] Some claim that the F-14 was only a slightly redesigned F-111B, and that the Navy could simply not accept a joint aircraft for the sake of the matter.

[82] "Major Systems Acquisition Reform." Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress, First Session, Part 2. Government Printing Office, Washington: 1975, pp. 6 and 44. A savings of $1 billion was estimated on page 2. On May 12, 1975, just 10 days after the Navy decision on the F-18, Rep. Milford asked Chairman Stennis of the Senate Armed Services Committee to be invited to any hearings on the F-18 program.

[83] Orr, Kelly. *Hornet: The Insight Story of the F/A-18*. Presidio Press, Novato CA, 1990, pp. 55-56.

[84] "Major Systems Acquisition Reform: Part 1 Air Combat Fighter Programs." Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress, pp. 86.

first, is the F-18 cost-effective? And second, did the Navy break the law?[85] With respect to the first, the Navy built a convincing case that all proposed F-16 derivatives were unsuitable for carrier operations. LTV's navalized 1600 model, for example, added 38 percent to the empty weight of the YF-16 and increased the wing area and horizontal tail areas by 32 and 76 percent, respectively. The 1600 model also proposed a different engine than the F-100 used in both the F-15 and F-16, reducing commonality further. By contrast, the F-18 was only 23 percent heavier than the YF-17, 14 percent larger wing area, and saw no change to either the horizontal and vertical tail areas. But the required changes do not speak to effectiveness. Admiral Kent Lee and the source selection committee found that, the unlike the LTV proposals, the "F-18 substantially meets or betters all… requirements."[86] The YF-17's natural operability at low speeds put the F-18 in a good position to win the Navy effort. Appreciating the deficiencies of their designs, LTV argued that they may have won had they also deviated from the Congressional requirement of commonality with the F-16.[87] The claim did not hold water, considering LTV submitted three designs of 60, 15, and 1-2 percent commonality with the F-16. Of the least common 1602 model, Admiral Kent Lee said that "It was essentially a new airplane."[88]

The Navy made a convincing case that the F-18 was more cost-effective than an F-16 derivative, and OSD's independent cost office verified that the F-16 program was cost-effective enough to proceed without the benefits of joint production orders. Yet all sides agreed that the Navy went against the language of the conference report, and the matter ultimately came down to legality. The Congressional Research Service wrote a legal opinion on September 12, 1976, stating that "matters resolved at conference and passed by both Houses of Congress must be absolutely determinative."[89] Though the opinion went against the Navy, it was overruled by the General Accounting Office (GAO) on October 1, 1975. The GAO decided that the Navy's F-18 award was valid because conference report language is not legally binding. The GAO went further to say that the Navy award "does not represent a violation of moral or ethical standards."[90]

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[85] "Major Systems Acquisition Reform." Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress, First Session, Part 2. Government Printing Office, Washington: 1975, pp. 6 and 44. A savings of $1 billion was estimated on page 2. On May 12, 1975, just 10 days after the Navy decision on the F-18, House representative Dale Milford asked Chairman Stennis of the Senate Armed Services Committee to be invited to any hearings on the F-18 programs.

[86] "F-18 Program." Hearings Before a Subcommittee of the Committee on Appropriations, U. S. Senate, First Session, on H.R. 9861 hearings, Sept.-Oct. 1975, pp. 29-33. The one exception was approach speed, which was still too high for the F-18 design, but still much better than the three YF-16 derivatives.

[87] "Major Systems Acquisition Reform: Part 1 Air Combat Fighter Programs." Hearings before the Subcommittee on Federal Spending Practices, Efficiency, and Open Government of the Committee on Government Operations, U.S. Senate, Ninety-Fourth Congress.

[88] "F-18 Navy Air Combat Fighter" Hearings Before a Subcommittee of the Committee on Appropriations, U.S. Senate, First Session, on H.R. 9861 hearings, Oct. 1975, pp. 77.

[89] Robert Thornton, Legislative Attorney. "Effects of Language in a Conference Report on an Appropriations Measure on the Use of Monies Appropriated Therein."

[90] "Decision, Matter Of: LTV Aerospace Corporation." Comptroller General of the United States, October 1, 1975, File B-183851, pp. 1.

The Navy's successful defiance was a rather unlikely outcome, and demonstrated to many the need for additional Congressional involvement in the requirements definition of weapons systems. Senator Barry Goldwater's sentiments may have been typical of Congressmen. "I want to make it clear," Goldwater said, "that I don't oppose the F-18 weapon system. I oppose the way that they have gone about obtaining it."[91] And like many Congressmen, Goldwater still held hopes that joint service programs would generate substantial savings. He admitted that "This may only be an impossible dream that some of us have, but… we cannot continue forever to pay for these separate air forces." Non-consensual programs not only had to contend with institutional biases within the services, but the biases from OSD, the President, Congress, and the public, who associated cost savings with economies of scale. "But," as Edward Luttwak aptly pointed out, "conflict is not like civilian business and efficiency is the wrong goal to pursue." He continued:

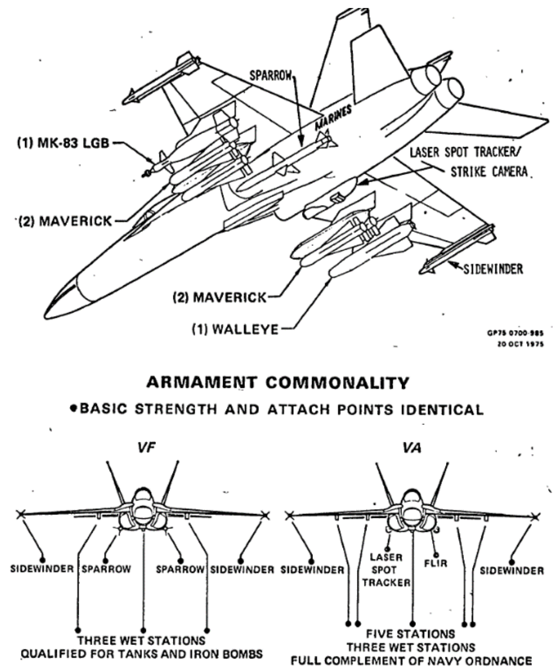

Figure presented to the Congress on 8 Oct. 1975 showing the fighter and attack variants of the F-18, which were similar enough to eventually merge into the F/A-18. Because fighter and attack definitions overlap, the aircraft may be simply referred to as the F-18.

> "… efficiency in making a radar or refueling a ship, of course; efficiency in making radars, or refueling ships, no, for efficient economies of scale in purchasing radars lead to a single mass-produced radar that will be more easily counter-measured, and efficient refueling leads to a few large fleet oilers that are more easily intercepted and destroyed by the enemy. (Each of our majestic aircraft-carrier task forces is now dangerously dependent on a single, very large, very efficient resupply ship.) Conflict *is* different."[92]

Consolidating capabilities into single platforms not only creates combat risk, but it also increases the risk of missing out on alternative technologies, including those the enemy may stumble upon. Unlike a market economy, where various entrepreneurs independently pursued the option space, diverse lines of development must be consciously pursued in the military. Armen Alchian wrote, "In the private economy other competing firms can duplicate or take different points of view about the nature of desirable products. But there are not two departments of defense to provide the competitive survival and selection of preferred products." The defense acquisition process itself had to act in lieu of a market through an endless cycle of testing alternative solutions to reimagined requirements. Yet as the lightweight fighter case study has shown, intragovernmental competition was actively suppressed. For all the debate about the benefits of prototyping and competition,

[91] "F-18 Navy Air Combat Fighter" Hearings Before a Subcommittee of the Committee on Appropriations, U. S. Senate, First Session, on H.R. 9861 hearings, Oct. 1975, pp. 6.
[92] Luttwak, Edward. *The Pentagon and the Art of War: The Question of Military Reform,* 1985, pp. 136-38.

policy-makers still concerned themselves with finding the single best system to fulfill the most possible missions. In the lightweight fighter case, as with others, the Navy and Air Force were expected to produce one common aircraft. The lack of diversity was noticed by the Commission of Government Procurement which found that the U.S. had only two fixed-wing and one helicopter "design bureaus," whereas the Soviet Union had two helicopter, eight fixed-wing, and six engine design bureaus, with an additional six research institutes.[93]

Resistance

In retrospect, the lightweight fighter concept proved a good value for first the Air Force and later the Navy. Yet as a brief impression of institutional challenges facing the LWF programs demonstrates, it was unlikely to have ever happened. It required foresight and determination, as well as the personal intervention of unusually sympathetic leadership at the Secretary of Defense level who went to bat for beleaguered outsiders. Usually, career military insiders outlast a particular administration to get their way on major programs. In the case, LWF advocates successfully appealed to Laird as well as his replacement, Schlesinger. By then it was too late to stop. Boyd's fighter mafia was uncommon in their willingness to criticize as well as their ability to appeal to the highest echelons of government. Frederic Scherer observed that "There is a common belief at the intermediate levels of the military decisionmaking hierarchy that one should not rock the boat too vigorously through criticism at the start of a program."[94] The common belief was not shared by men in the fighter mafia.

The lightweight fighter programs followed a pattern of military innovation overcoming resistance. Historian James F. Nagle found that in the early twentieth century, "Developments like the airplane and submarine… had to be engrafted onto military thought. They could not evolve."[95] One seemingly mundane innovation at the time which met heavy resistance was an elevation system to keep naval guns steady while the ship pitched and rolled at sea. The technology, called continuous aim-firing, undoubtedly revolutionized naval gunnery. In 1966, historian E. E. Morison put forward a generalized process that brought the Navy continuous aim-firing at the turn of the twentieth century:

> "1. The essential idea for change occurred in part by chance but in an environment that contained all the essential elements for change and to a mind prepared to recognize the possibility of change.

[93] "Report of the Commission on Government Procurement," pp. 68-71. This count neglects U.S. contractors as a center for design, but, in the defense innovation process, only a small part of contractor expenditures go toward independent R&D, or R&D performed outside the requirements and control of the Government.
[94] "The Military Budget and National Economic Priorities." Hearings Before the Subcommittee on Economy in Government of the Joint Economic Committee, Ninety-First Congress, Part 1, Jun 1969, pp. 403.
[95] Nagle, James F. *A History of Government Contracting: Second Edition*. The George Washington University, Washington D.C., 1999, pp. 223.

"2. The basic elements… were put in the environment by other men, men interested in designing machinery to serve different purposes or simply interested in the instruments themselves.

"3. These elements were brought into successful combination by minds not interested in the instruments for themselves but in what they could do with them…

"4. [They] were opposed on this occasion by men who were apparently moved by three considerations: honest disbelief in the dramatic but substantiated claims of the new process, protection of the existing devices and instruments with which they identified themselves, and maintenance of the existing society with which they were identified.

"5. The deadlock between those who sought change and those who sought to retain things as they were was broken only by an appeal to superior force, a force removed from and unidentified with the mores, conventions, devices of the society."[96]

All five steps are as readily apparent in the lightweight fighter case as they are for continuous aim-firing; and the same is true for the atomic bomb[97] and ballistic missiles,[98] if not a host of other technologies.[99] Yet the first three steps alone relate to technological innovation while the fourth and fifth relate to the process of innovating, or changing, the social institutions that embed the new technologies. The cases presented all required a "superior force" to break the deadlock, which is by no means certain. If the acceptance of technological innovation depends on social adaptability, and, as Morison suggests, societies in the military services have trouble reforming themselves without outside direction, the extended implications present a "discouraging thought." Morison asked what if "no society can reform itself? Is the process of adaptation to change, for example, too important to be left up to human beings?" He invoked the Bessemer steel process as one instance where the broader industrial economy adapted slowly to technological change. Two readily available examples could be added, the standard shipping container and the electric motor.[100] Morison recommended, as a partial remedy, for individuals to think of their mission more broadly and not wed themselves to particular technologies or doctrines. It implies the need for individuals to learn continuously and foster what Morison called an emotionally "adaptive society."[101]

The problem of adaptiveness in weapons acquisition led Robert Perry to question not only the systems approach, but also the evolutionary approach to innovation pushed by Armen Alchian,

[96] Morison, Elting E. *Men, Machines, and Modern Times*. The M.I.T. Press, 1966, pp. 37-38.
[97] "Can Weapon Leadtimes Be Shortened By Atom Lessons?" *Armed Forces Management*, Nov. 1966, pp 79-83.
[98] Perry, Robert. "The Ballistic Missile Decisions." October, 1967, P-3686, pp. 25-26. See also "Innovation and Military Requirements: A Comparative Study." August, 1967, RM-5182-PR.
[99] "Significant examples can be cited where the establishment actively resisted the introduction of a materiel system (Jeep, Christie Tank, P-51 Fighter Aircraft, SIDEWINDER and… US Army rifles)." See AMARC Report Vol. II, April 1974, pp. I-7.
[100] Harford, Tim. *Fifty Things That Made the Modern Economy*. Little, Browen Books, 1997.
[101] Morison, Elting E. *Men, Machines, and Modern Times*. The M.I.T. Press, 1966, pp. 37-44.

Burton Klein, and others. If decision makers are wedded to particular technologies or doctrines, then the evolutionary approach can lead to dead ends while high-value opportunities go unpursued. Robert Perry pointed to the "misconstrued technological logic" associated with evolution; for example, "any sensible military engineer" expected cruise missiles to precede ballistic missiles, and similarly would expect turboprop engines to precede the supposedly "much more complex, much less efficient" turbojet engines.[102] In the case of ballistic missiles, the error arose from "a set of value judgments accepted uncritically by Air Force analysts." In the case of the jet engine, "the Americans seem to have overstated the difficulty and underestimated the worth on every possible occasion."[103] Why were new technologies misrepresented? Perry concluded that "the answer seems plain enough: cultural resistance."[104] Such resistance may lead to endless tinkering along safe and well-trodden lines, as seemed to happen in the Navy bureau and Army arsenal systems before the WWII. "The assumption," Perry wrote, "that technology and doctrine will alike change in traditional, evolutionary ways is comfortable, but it is not necessarily true, and as some of the instances noted above suggest, it may also be an invitation to disaster."[105]

One issue with the evolutionary approach is knowing when to pursue, or by how much to follow-up on, a new branch of technical demonstrations. Here, the problem of institutional bias is particularly acute. In the case of ballistic missiles, analysts misjudged the option to be unlikely and eliminated it early on. "I feel confident," Vannevar Bush testified on ballistic missiles, "it will not be done for a long period of time to come."[106] Variable sweep airframes and jet engines were eliminated, even after technical feasibility was demonstrated, because civil and military "institutions… could not be diverted from their preoccupation with marginal, evolutionary improvements in the sorts of mechanisms they were familiar with."[107] Prevailing attitudes may still reject change even when new options follow through with convincing technical demonstrations and find useful employment elsewhere. In the evaluation of substantial military technologies, subjectivity cannot be avoided. When decision-makers think narrowly, the evolutionary approach may neglect new designs that branch off in unfamiliar patterns. The risk is particularly worrisome because, as Perry put it, "success is in many respects a random event that

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[102] Perry, Robert. "The Ballistic Missile Decisions." October, 1967, P-3686, pp. 2. Perry wrote that "Too few appreciated that a highly accurate 5000-mile ramjet-powered cruise missile… was perhaps a more ambitious undertaking than the atomic bomb, much less the B-29." See "The Interaction of Technology and Doctrine in the USAF," Jan. 1979, pp. 9-11.
[103] Perry, Robert. "Innovation and Military Requirements: A Comparative Study." August 1967, RAND, RM-5182-PR, pp. 28.
[104] Perry, Robert. "The Air Force and Operations Research: A Commentary of I. B. Holley's Paper. " August 1969, RAND, P-4114, pp. 15-16.
[105] Perry, Robert. "The Interaction of Technology and Doctrine in the USAF," Jan. 1979, RAND Corp., P-6281, pp. 20.
[106] Perry, Robert. "The Ballistic Missile Decisions." October, 1967, P-3686, pp. 7.
[107] Perry, Robert. "Innovation and Military Requirements: A Comparative Study." August 1967, RAND, RM-5182-PR, pp. 76. John Boyd's EM-Theory provided a foundation for trading off fixed-wing vs. variable sweep design aircraft, first incorporated in the F-15.

does not conform to any standard pattern of behavior."[108] Standard patterns of behavior are precisely what good administrators intend to accomplish; but as administrative theorist Lyndall F. Urwick described, the paradox of a leader is "to protect from their wrath the originals, the inventors, the crazy people to whom order is anathema… because it is from this lunatic fringe that he is most likely to derive something original."[109] Similarly, of inventors E. E. Morison wrote that:

> "A surprising number turned out to be people with little formal education, who drank a good deal, who were careless with money, and who had trouble with wives or other women. This is also, I suppose, what is now called a good stereotype of the painter or poet. And it is quite probable that the inventor who is also something of an engineer is, like all great engineers, an artist."

Theorists and practitioners, however, avoided the matter of the individualistic inventor with the argument that modern systems had become so complicated that they could only arise from teams of highly specialized personnel using rigorous management control systems. Morison addressed the matter briefly, stating that "We have pretty well left the point where the most interesting work can be done by single men working all alone… which is one way of saying that the virtuosity of the inventor has on the whole given way to systematic research and development." [110] Even theorists oriented toward decentralized processes, such as Alfred Whitehead and Joseph Schumpeter, believed that innovative processes in the twentieth century required large teams with directed objectives, sidelining entirely the motives and sentiments of individuals that make the teams work.

Stage-Gates

The defense innovation process did not stress the career path of employees and how they contribute to military solutions, but the lifecycle of military projects and the formulation of their requirements. In 1965, RAND analyst Thomas K. Glennan bucketed the technical development process into two categories, requirements-pull and technology-push. He wrote, "Technology-push efforts are those efforts where the research personnel determine what research efforts will contribute to needs as they, the researchers, perceive them. Requirements-pull efforts are efforts where the needs are perceived by those external to the research efforts, the research is initiated by planners and operationally oriented organizations… If the decisions are made at the top of the organization we have clear requirements-pull efforts. If they are made at the bottom, by the individual researcher, they are technology-push."[111] Utilizing the framework, Robert Perry

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[108] Perry, Robert. "Innovation and Military Requirements: A Comparative Study." August 1967, RAND, RM-5182-PR, pp. 1-2.
[109] Urwick, Lyndall F. *Leadership in the 20th Century.* Found in Borklund, C. W. "Cost-Effectiveness' vs. Creativity: Part 1, Is Indecision Stifling Innovation?" *Armed Forces Management*, August 1967, pp 51 – 53.
[110] Morison, Elting E. *Men, Machines, and Modern Times*. The M.I.T. Press, 1966, pp. 9-12.
[111] Glennan, Thomas K. "Policies for Military Research and Development." RAND Corp., Nov. 1965, P-3253, pp. 27-29. "In passing," Glennan elaborated, "it should be noted that this [the requirements-pull approach] is the

rejected the predominating systems approach because it was entirely requirements-pull. He also rejected the evolutionary approach for the opposite reason, that it was entirely technology-push. "The flaw in all these viewpoints," Perry wrote in 1967, "is that they tend to ignore the reactive influence of innovative technology on requirements, and of requirements on the handling of innovations." Perry advocated what at first appears to be a different matter, a three-step decision process that resembles "the classical investment model."[112] A project may start with either a validated requirement or an invention, and at specified points, technical feasibility will be demonstrated for leadership who would then provide feedback on their requirements and ensure the military feasibility of the technology.

Despite Robert Perry's appreciation for the interaction between requirements and technology, his recommended three-step process—fully embraced by defense acquisition policymakers as program milestones—became associated with the "linear" model of innovation. In the linear model, a program matures in sequential steps, such as from scientific knowledge to product engineering to customer diffusion. "Non-linear" models of technology transition emphasize a back-and-forth process of communication. Engineers generate questions for scientists to answer as much of scientists generate knowledge for engineers to apply. Similarly, customers provide guidance to technologists as much as technologists provide option-spaces for customers.[113] Performing such interactions only three times does not generate the required communication for success.

The linear approach to development may be characterized by Dr. Winston W. Royce's 1970 classic, "Managing the Development of Large Software Systems." In it, he outlined a linear path from system requirements through coding, testing, and operations. By analyzing first the system, then the software requirements, a program design can be constructed which would then be executed, tested, and fielded, in that order. This linear model later became known as the "waterfall" process of software development and may equally apply in principle to hardware items. However, what is often forgotten is that in the same paper Dr. Royce understood that successful developments must iterate.[114] "I believe in this [linear] concept, but the implementation described above is risky and invites failure." Dr. Royce recommended "doing it twice," or changes in

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'comfortable' way for the entire organization to proceed. It appears that it knows where it is going and is able to direct its R&D resources toward efficiently fulfilling these needs." In contrast, Glennan found that "One of the problems with technology-push types of projects is that they require faith on the part of the people outside the project. The payoffs are not obvious."

[112] Perry, Robert. "Innovation and Military Requirements: A Comparative Study." August 1967, RAND, RM-5182-PR, pp. 1. To the systems and evolutionary approaches Perry adds the "incremental" approach which "calls for using only thoroughly proven technology." Both the incremental and evolutionary approaches appear to be in the same camp, as they are primarily based on "technology push" concepts. In "Reforms in System Acquisition," July 1975, Perry links incrementalism to countries with smaller technology bases, such as France, and evolution as applicable to countries that can afford a large and diverse technology base, such as the U.S.

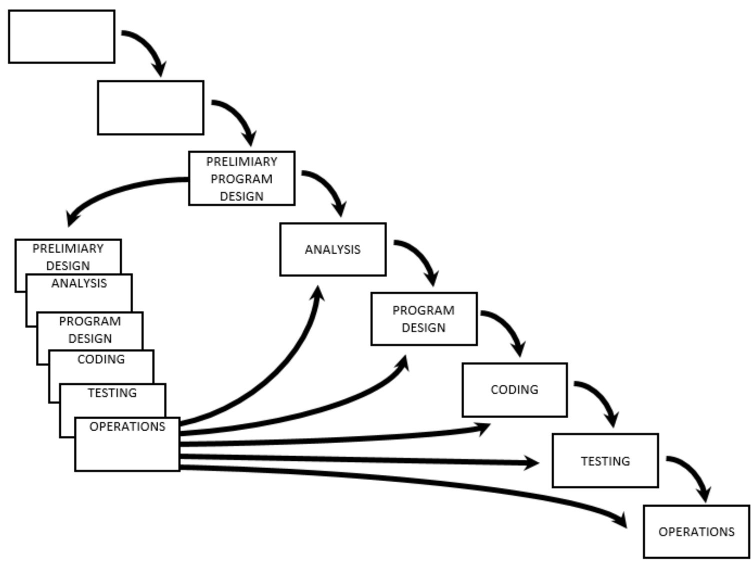
[113] "Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems." Committee on Accelerating Technology Transition, National Research Council, 2004.

[114] Palmquist, Steven M. et al. "Parallel Worlds: agile and Waterfall Differences and Similarities." Software Engineering Institute, 2013.

requirements could create "up to a 100-percent overrun in schedule and/or costs." Critical aspects must be addressed in a "pilot model" which can generate important feedback and buy-in from the customer early on.[115] This delivering of incremental capabilities became the basis of iterative, spiral, and agile methods of software development.[116]

Perhaps an idea once popularized sheds the underlying complexity to its truth, only to be rediscovered by successive generations using the language and concepts of their own time. Though Robert Perry and Winston Royce could perhaps be pointed to as exemplars of the linear model, they certainly thought in terms of non-linear implementations. Two general circumstances necessitating non-linear processes are first, when critical information is provided after product launch, and second, when a project's mission is not only to reduce uncertainty about previously settled requirements, but also to create new options and new requirements.[117] Non-linear approaches to technology development can be loosely described as communication between innovators and users; early feedback and advocacy from users is central to product success. Elements of non-linearity include "flexibility, a willingness to take risks, open communication without regard to hierarchy, a sense of responsibility that replaces unquestioned authority, and a commitment to success that goes beyond functional roles."[118]

The linear three-step decision making process was closely followed by David Packard in the 5000-series and continued to guide policy for major acquisitions more than forty years later. The top award in acquisition excellence is attached to David Packard's name. Yet his vaunted connection to acquisition reform is curious considering he largely rebranded McNamara's existing policies. DoD Instruction 3200.6, dated June 7, 1962, defined the same three key decision that later became program milestones.[119]



Reproduced figure from Winston Royce (1970) showing non-linear implementation of the linear developmental process. Labeled "Figure 7. Step 3: Attempt to do the job twice - the first result provides an early simulation of the final product."

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[115] Royce, Winston W. (1970). "Managing the Development of Large Software Systems." *Proceedings, IEEE WESCON*, pp. 1-9. Retrieved from http://www-scf.usc.edu/~csci201/lectures/Lecture11/royce1970.pdf.
[116] For example, see: Boehm B, "A Spiral Model of Software Development and Enhancement", ACM SIGSOFT Software Engineering Notes, ACM, 11(4):14-24, August 1986; and Kent Beck et al. (2001) "Manifesto for Agile Software Development". Agile Alliance.
[117] Remi Maniak, Christophe Midler, Sylvain Lenfle, and Marie Le Pellec-Dairon. "Value management for exploration projects." 2014, *Project Management Journal*.
[118] "Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems." Committee on Accelerating Technology Transition, National Research Council, 2004.
[119] Meyerson, Martin. "Price of Admission into the Defense Business." *Harvard Business Review*, July-August, 1967, pp. 113-114.

Similarly, the Development Concept Paper (DCP) of 20 pages or less was initiated by McNamara in 1967 in order to streamline reporting. What Packard seemed to accomplish was to emphasize prototyped hardware in advance of the full-scale development decision, instead of relying on paper studies. Yet the characterization is not totally accurate, as McNamara followed a "building block" approach in advanced development, proving out components and subsystems. It was the bridge to full-scale development where McNamara suffered. The only real change Packard, and his boss Laird, introduced was a return to providing budget ceilings for the services, who then formulated programs which OSD would approve. Clarke Murdock observed in 1974:

> "At the level of general defense policy-making, changes initiated by the new administration represent a return to the practices of the 1950s. In the area of weapons innovation and acquisition, however, despite rhetoric to the contrary, Laird's innovations represented for the most part a renewed commitment to trends begun by McNamara… Laird's 'fly before you buy' systems development approach, despite his efforts to differentiate it publicly from practices under McNamara, contained many similar features."[120]

[Termites]Despite a renewed commitment to sequential decision making in the defense innovation process, concurrency remained a severe problem in defense programming. In practice, the program budget has been a consistent force for concurrency by locking in program production plans at the start of development, and, more importantly, suppressing competitors. Consider the daunting task to starting a program. Before significant sums of money can be put to any R&D effort, the program must be defined in the budget, but such programming only occurs after hard requirements have been coordinated and agreed upon by numerous layers of bureaucracy. Decisions made through the DSARC acquisition process do not authorize funding. It is necessary for the Secretary of Defense, under the authority of the President and Congress, to first line up funding through the Planning-Programming-Budgeting (PPB) System for a program to become approved. Any program decision made through the DSARC had to be anticipated 29 months ahead of time in the PPBS for funding to be available when the project needs it.[121] The matter is more problematic for getting new efforts approved, as programs which already have a wedge in the budget can first survive on existing funds, and second, they can seek changes later in the PPB process than a new programming effort.

[120] Murdock, Clark A. *Defense Policy Formation: A Comparative Analysis of the McNamara Era.* Albany, State University of New York Press, 1974, pp. 167 and 175.
[121] "Report of the Navy Marine Corps Acquisition Review Committee." Volume 1, Office of the Secretary of the Navy, January 1975, pp. VII-90.

The services' hold on concept and budget formulation was short-lived. In 1972, the Commission on Government Procurement found such decentralization a "serious flaw" and a year later Comptroller General Elmer Staats agreed that the Secretary of Defense needed to provide more "comprehensive and objective analyses of missions and weapons requirements."[122] In 1976, OMB Circular A-109 established new acquisition rules for the executive branch, seeking central authorization of mission needs before the start of any prototyping or analysis of alternatives. In doing so, it restricted subsystem and component development until its requirements were vetted and identified with a system for full-scale development.[123] In January 1977, Secretary of Defense Harold Brown sought to implement OMB Circular A-109 by implementing Milestone 0, which sought approval for whether or not a mission need in fact existed.[124] Any exploration of alternative technologies or requirements would first have to be tied to a mission needs statement approved through the DSARC process. Milestone 0 proved too cumbersome a process, and was canceled just five years later, but complex interactions between the acquisition and budgeting cycles continued to create forces towards a top-down, or requirements-push, approach.

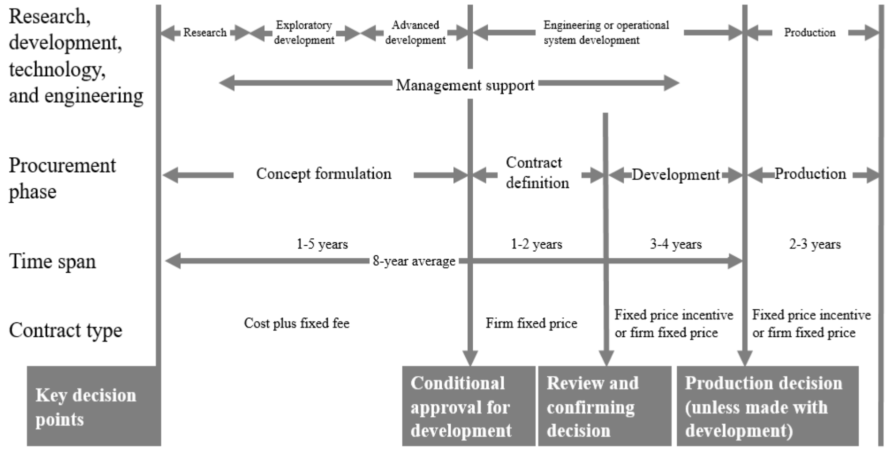

Figure depicting the DODI 3200.6 R&D cycle, dated June 7, 1962. The McNamara innovation process was largely retained by Laird and Packard. Reproduced from Martin Meyerson's 1967 article, "Price of Admission into the Defense Business."

Addendum: Implications for Cost Analysis

At the turn of the 21st century, defense innovation builds up from decisions made in research and development to production decisions, and from there to matters of sustainment. Once a requirement is validated and a program is defined in the budget, questions of R&D shape the technical specifications and cost of the system. Based on the capabilities provided in R&D and the funding available, production quantities are updated. Operating units then receive weapons systems several years after they had provided front-end guidance on requirements. The specification and quantity of systems received is generally determined independently of the funding required to operate and maintain the systems. Though life-cycle costs are supposed to be considered early on, in many cases the estimates do not come to pass, being superseded by events arising in R&D and production. For

[122] "Recommendations made by the Comptroller General to the House Armed Services Committee, March 29, 1973."
[123] OMB Circular No. A-109, Subject: Major System Acquisition, April 5, 1976, pp. 12.
[124] A Critique of the Performance of the Defense Systems Acquisition Review Council: Billions of Public Funds Involved. Report to the Congress; by Elmer D. Staats, Comptroller General. PSAD-78-14; B-163058. January 30, 1978.

example, joint programs often assume lower sustainment costs due to economies of scale. Yet costs may in fact be higher when commonality decreases over time or when complex new components that require costly new sustainment procedures are introduced to make interoperability work.[125] Regardless of how many systems were procured, operating units with a certain budget can only keep so many systems in the field. Readiness in the field, then, becomes a pressure relief valve for inadequate sustainment funding to match the systems and quantities procured.[126]

The Department of Defense has a program budget with respect to systems acquisition. R&D and production decisions are joined under a program such that authorization into R&D almost assures full-rate production, with a few high-profile exceptions often involving Congress. Sustainment accounts, however, are primarily organization and object oriented. The budget does not clearly specify sustainment by program, though Government expenditures are tracked by program.[127] Whereas acquisition programs place numerous cost controls and reporting requirements on contractors, sustainment efforts do not have nearly so much institutional oversight of contractors. In short, analysts in the defense innovation process join questions of R&D and production, and then treat as separate questions of sustainment, which generally do not receive the same types of systems analysis. After all, specifications and quantities were already decided, implying that sustainment is entirely an incentives and funding problem of an otherwise known process.

A major problem with the state of defense acquisition cost analysis is that the data and analytical methods it employs is more suited to sustainment as opposed to research and development, particularly in peacetime.[128] Sustainment involves repeated activities of known processes using existing systems. The emergence of big data sets on costs, inventories, and activities can provide actionable insights into resource allocation. However, research and development is by its very nature an exploration of the unknown. Past data is largely irrelevant as a guide to future action in matters of the unknown. Indeed, such expert analysis, as has been suggested above, is more likely to be biased or short-sighted. As famed tech entrepreneur and venture capitalist Ben Horowitz wrote: "When you are building a company, you must believe there is an answer and you cannot pay attention to your odds of finding it… I don't believe in statistics. I believe in calculus."[129] Phil Rosenzweig agrees that management and leadership is not about statistical analysis. Much of the prediction literature is based on elements that the forecaster cannot affect. Innovators, however, can and do affect outcomes, and therefore must put their whole attention to the task at hand.[130] Sylvain Lenfle found that traditional project management methods do not work in exploratory developments for two reasons. First, "important information—namely about market and uses—appear after product launch. Second, the

[125] For example, see Alex Haber and Jeff Jeffress, "Pentagon Must Treat Carefully on 'Joint' Weapon Acquisition." *National Defense*, June 2015.
[126] See Bruce Harmon, Institute for Defense Analysis.
[127] The VAMOSC systems used by the services tracks Government expenditures on Operations and Support.
[128] As repetitive runs of known systems requiring large investments of direct labor and materials becomes less important over time (in other words, as production itself becomes less important—think software, pharmaceuticals, additive manufacturing, etc.), the two surviving analytical methods will be for R&D and sustainment.
[129] Horowitz, Ben. 2013. *The Hard Thing About Hard Things.* Harper, New York: NY, pp. 59.
[130] Rosenzweig, Phil. 2014. *Left Brain Right Stuff: How Leaders Make Winning Decisions.*

project does not only provide information to reduce uncertainty about predefined variables, it provides new variables.[131] RAND analysts Armen Alchian, Kenneth Arrow, Burton Klein, Robert Perry and others agreed that the statistical methods of cost analysis were largely inapplicable to matters of research and development, though all remained open to such analysis in production and sustainment.

Full-rate production of known systems has a similar analytical underpinning as sustainment; statistics can provide actionable information on production decisions. However, repetitive runs of known systems requiring large investments of direct labor and materials have become less important over time. In other words, the marginal cost of production itself is becoming less important (think software, databases, platform design, lean and additive manufacturing, supply chains, and so forth). The importance of repetitive production to the defense acquisition process is likely to continue decreasing over time. The two analytical methods requiring the greatest attention will be R&D and sustainment. For R&D, overhead structures will be of primary concern, whereas for sustainment, direct labor and material costs will continue to be significant contributors in the foreseeable future.[132]

Another paradigm for defense innovation, first espoused by Armen Alchian, is that the defense innovation process should be separated from production and operations decisions, and further, that operations should inform production choices, which in turn inform the choices made by researchers who compete to make it into production.[133] A brief description of the "backwards" flow is as follows. Current expectations about future military environments, including sustainment cost considerations, determines which systems are required and in what number. Production decisions, so determined, are constrained to those systems which have been fully developed and tested. Matters of production and sustainment are then a separate issue from those of R&D, which, because of the inherent uncertainty involved, proceeds on an evolutionary basis without any pre-commitment to production and therefore sustainment. If budget accounts for research and development were separated by organization, managers can be held responsible; the inability of a manager to get any developments into production, based on the valuations of the men and women operating the systems, signals poor performance. Innovators will then be incentivized to involve operators early using prototype models to receive feedback and gain project advocates. If operating units made production choices based on fully tested systems, then they in turn would be accountable for their own readiness. In contrast, the current inability of operating units to keep systems in the field, despite expending 70% of total program dollars, is not entirely their fault considering the technology, funding, and quantities handed down to them.[134] Likewise, acquisition professionals do not have to live with the result of their choices in production and R&D.

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131 Sylvain Lenfle et al. "Value management for exploration projects." http://www.sylvainlenfle.com/images/Publications/PMJ_Value_2014.pdf.

132 Haskel, Jonathan and Stian Westlake. 2018. *Capitalism Without Capital: The Rise of the Intangible Economy*. Princeton University Press.

133 Alchian, Armen A and Kessel, Reuben A. "A Proper Role of Systems Analysis," RAND Corp., 1954.

134 For one example of the readiness issue, see Sydney Freedberg, "Navy, Marine F-18s in 'Death Spiral' As Readiness Plummets." *Breaking Defense*, 07 Feb. 2017.

Though the Department is analytically oriented towards R&D and production on the one side and sustainment on the other, all of the systems processes were joined in one office: Acquisition, Technology & Logistics (AT&L). However, a 2016 Congressional act sought to split up AT&L by February 1, 2018, separating the Research & Engineering (R&E) functions from the Acquisition & Sustainment (A&S) functions.[135] A report to Congress stated that "special challenges" will be encountered due to the fact that the two organizations "approach risk from such different perspectives." To mitigate such challenges, a third organization under the Chief Management Officer (CMO) will coordinate cost management frameworks.[136] Yet the reorganization intends to create a dynamic between the conflicting cultures an innovative R&E and a cost-focused A&S.[137] Those cultures align with the alternative paradigm for major systems decision making outlined above.

It remains to be seen how defense cost analysis will be affected by the reorganization, but there is not yet planned any major changes in budgeting or contractor reporting systems. Therefore, cost and budget data will continue under existing structures even if the data flows along different lines of authority. If the Undersecretary of R&E was separated from the Undersecretary of A&S because they entail different processes and objectives, then it is up to cost analysts to determine what kinds of cost data and methodologies are appropriate for each organization. Some have argued that cost focused acquisition reform has increased costs rather than reduce them, and reform should instead focus on incentives and culture.[138] A non-discretionary application of costing principles may be counter-productive, particularly in research and development. More investigation is required by the cost community to determine how non-monetary costs may properly enter analyses of research and development efforts. However, the application of traditional cost analysis still has much to offer in production and sustainment. Integrating cost analysis of production and sustainment elements provides new challenges and potentially large benefits for the Department of Defense.

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[135] See Section 901 of the National Defense Authorization Act for Fiscal Year 2017 (Public Law 114-328).
[136] "Report to Congress: Restructuring the Department of Defense Acquisition, Technology and Logistics Organization and Chief Management Officer Organization." August 2017.
[137] Blume, Susanna V. "In the Pentagon's AT&L reorg, beware of the Valley of Death [Commentary]." *Defense News*, 6 Nov. 2017.
[138] Trail, Scott. "Focusing on Cost is Not the Answer." *National Defense*, June 2015.