R-3373-AF/RC

Improving the Military Acquisition Process

Lessons from Rand Research

Michael Rich and Edmund Dews
With C. L. Batten, Jr.

February 1986

Rand 40 Years 1946-1986 PROJECT AIR FORCE

The research reported here was sponsored by the Directorate of Operational Requirements, Deputy Chief of Staff/Research, Development, and Acquisition, Hq USAF, under Contract F49620-86-C-0008 and by The Rand Corporation as part of its program of public service.

ISBN: 0-8330-0713-0

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A Project AIR FORCE report
prepared for the
United States Air Force

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PREFACE

Defense acquisition—the development and procurement of military systems—is a matter of widespread and increasing concern in the United States. Congressional hearings, government reports, and articles in the press suggest that the acquisition process is not working well: that development fails to produce satisfactorily working designs, that major systems incur large cost overruns, and that parts are overpriced. Although research suggests that the criticisms of defense acquisition are in many instances unfounded or exaggerated, substantial improvements are clearly needed in the acquisition process.

This report makes constructive suggestions for improving the acquisition process by drawing on the findings of the numerous Rand studies of R&D and procurement conducted over the last three decades. The emphasis here is on the acquisition of *major systems*; problems such as spare parts procurement, however important, are another story. Two kinds of improvement are sought. One is to enhance the ability of the process to get effective weapon systems into the forces as they are needed. The other is to ensure that acquisition is economically efficient.

The Rand studies drawn on here have examined a wide variety of topics, including alternative acquisition strategies, the formulation of weapon system requirements, the estimation of technical risks, the estimation of cost and cost growth, the "design-to-cost" approach to cost control, the methods of test and validation, the use of warranties and contractual incentives, the condition of the defense industrial base, the method of budgeting and programming for acquisition, the possible use of commercial practices for defense acquisition, foreign experience in acquiring weapon systems, the effectiveness of multinational development and production programs, and a variety of reliability and maintainability issues.

The Rand studies looked at various civilian systems and almost every type of military weapon and support system except Navy ships (although we did examine numbers of ship-borne systems). Included among the systems studied are aircraft, transports, turbine engines, avionics, missiles, precision guided munitions, spacecraft, armored fighting vehicles, helicopters, nuclear reactors, computers, oil platforms, pioneer process plants, federal demonstration projects, pipelines, and hydroelectric plants. Sponsors for this research have included the three military Services and the Office of the Secretary of Defense; the

Atomic Energy Commission; the National Science Foundation; the Departments of Energy, Transportation, and Health and Human Services; and The Rand Corporation itself.

The following, in chronological order, are the most notable among the studies that provided useful background or were drawn upon directly for this report.

B. H. Klein, W. H. Meckling, E. G. Mesthene, *Military Research and Development Policies*, R-333, December 1958.

R. R. Nelson, *The Economics of Parallel R&D Efforts: A Sequential-Decision Analysis*, RM-2482, November 1959.

A. W. Marshall and W. H. Meckling, *Predictability of the Costs, Time, and Success of Development*, P-1821, December 1959.

T. A. Marschak, *The Role of Project Histories in the Study of R&D*, P-2850, January 1964.

Robert Summers, *Cost Estimates as Predictors of Actual Weapon Costs: A Study of Major Hardware Articles*, RM-3061-PR, March 1965.

Robert E. Johnson and George R. Hall, *Public Policy Toward Subcontracting*, RM-4570, May 1965.

Irving N. Fisher, *Cost Incentives and Contract Outcomes: An Empirical Analysis*, RM-5120-PR, September 1966.

G. R. Hall and R. E. Johnson, *Aircraft Co-production and Procurement Strategy*, R-450-PR, May 1967.

B. H. Klein, T. K. Glennan, Jr., and G. H. Shubert, *The Role of Prototypes in Development*, RM-3467/1-PR, April 1971.

Robert Perry, Giles K. Smith, Alvin J. Harman, and Susan Henrichsen, *System Acquisition Strategies*, R-733-PR/ARPA, June 1971.

Robert Perry, *A Dassault Dossier: Aircraft Acquisition in France*, R-1148-PR, September 1973.

J. R. Nelson, P. Konoske Dey, M. R. Fiorello, J. R. Gebman, G. K. Smith, and A. Sweetland, *A Weapon-System Life-Cycle Overview: The A-7D Experience*, R-1452-PR, October 1974.

D. W. McIver, A. I. Robinson, H. L. Shulman with the assistance of W. H. Ware, *A Proposed Strategy for the Acquisition of Avionics Equipment*, R-1499-PR, December 1974.

Arturo Gándara and Michael Rich, *Reliability Improvement Warranties for Military Procurement*, R-2264-AF, December 1977.

Edward W. Merrow, Stephen W. Chapel, and Christopher Worthing, *A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants*, R-2481-DOE, July 1979.

Edmund Dews and Giles K. Smith, Allen Barbour, Elwyn Harris, Michael Hesse, *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, R-2516-DR&E, October 1979.

K. A. Archibald, A. J. Harman, M. A. Hesse, J. R. Hiller, G. K. Smith, *Factors Affecting the Use of Competition in Weapon System Acquisition*, R-2706-DR&E, February 1981.

G. K. Smith, A. A. Barbour, T. L. McNaugher, M. D. Rich, W. L. Stanley, *The Use of Prototypes in Weapon System Development*, R-2345-AF, March 1981.

Michael Rich, William Stanley, John Birkler, Michael Hesse, *Multinational Coproduction of Military Aerospace Systems*, R-2861-AF, October 1981.

Michael D. Rich and Stephen M. Drezner, *An Integrated View on Improving Combat Readiness*, N-1797-AF, February 1982.

M. B. Berman with C. L. Batten, *Increasing Future Fighter Weapon System Performance by Integrating Basing, Support, and Air Vehicle Requirements*, N-1985-1-AF, April 1983.

Glenn A. Kent, *Concepts of Operations: A More Coherent Framework for Defense Planning*, N-2026-AF, August 1983.

Michael N. Beltramo, *Dual Production Sources in the Procurement of Weapon Systems: A Policy Analysis*, P-6911-RGI, November 1983.

Edmund Dews, John Birkler, *Reform in Defense Acquisition Policies: A Different View*, P-6927, November 1983.

Allen D. Lee, *A Strategy to Improve the Early Production Phase in Air Force Acquisition Programs*, P-6941-RGI, December 1983.

Michael Rich, William Stanley, Susan Anderson, *Improving U.S. Air Force Readiness and Sustainability*, R-3113/1-AF, April 1984.

J. R. Gebman and H. L. Shulman with C. L. Batten, *The Need for a Maturational Phase During Avionics Development*, R-2908-AF, forthcoming.

W. L. Stanley and J. L. Birkler, *Improving Operational Suitability through Better Requirements and Testing*, R-3333-AF, forthcoming.

R. W. Hess and C. W. Myers, *Coping with Uncertainty in New Process Technology Cost Estimates*, R-3387-GRI, forthcoming.

In addition, this report draws on Rand research for the 1984 Defense Science Board Summer Study on Upgrading Current Inventory Equipment and on much work still in progress at Rand.

SUMMARY

Modernizing combat forces by acquiring new weapon systems to meet the need for improved operational capabilities is one of the most important, challenging, and complex tasks faced by the U.S. government. This report, drawing on more than 30 years of Rand research, evaluates past experience with defense development and production, identifies trends that will affect future acquisition activity, and recommends improvements in the acquisition process to meet future challenges.

In terms of the three most generally accepted measures for judging the acquisition process—cost growth, schedule slippage, and functional performance shortfalls—there has been steady improvement in program outcomes over time. Cost growth for programs that began full-scale development (FSD) in the 1970s averaged somewhat less than for those of the previous decade, down from 44 percent to 34 percent. In terms of total dollar cost, the decline was even more marked: Cost growth was only 20 percent for the 1970s sample, down from almost 50 percent in the previous decade. Moreover, the 1970s programs exhibited somewhat less schedule slippage than those of the 1960s, down from 15 to 13 percent. And the 1970s performance shortfall was close to zero, down from the previous 5 percent.

Programs that entered FSD in the 1980s appear to be experiencing somewhat less cost growth than programs of the 1970s, although this conclusion must be accepted with some caution, because the 1980s sample necessarily includes mostly quite young programs. Past experience shows that programs tend to accumulate problems—and thus cost growth—as they mature.

In any case, cost growth in defense programs is now no greater than in civil programs of similar character and complexity and is probably a good deal less.

Another measure for assessing the acquisition process refers to the time required to bring a new system through development into the operational inventory—the "acquisition interval." We find little evidence that the heart of the acquisition process, from the start of development to a point well into the beginning of the production phase, has been increasing during the past three decades. However, the production phase is being stretched out, primarily for budgetary reasons. This stretchout contributes to the aging of the weapons inventory. It also contributes to cost growth, especially when (as is typical) stretchout leads to repeated disruptions in production rate.

In many respects, therefore, the record of the acquisition process in the recent past may be considered to be favorable. Nonetheless, there are reasons for serious concern about the future. Four current trends will have profound effects on the problems of major-system acquisition. These trends make it imperative to find a strategy for strengthening the acquisition process to meet the needs of force modernization in the future.

- **Escalating enemy threats.** The combat capabilities of the Soviet Union and its allies have grown in geographic breadth, numerical size, and qualitative capabilities. For the first time, potential combat arenas of the future will encompass many critical elements of U.S. support infrastructure. As a result, future weapon systems must not only keep pace with the functional performance improvements in enemy weapons, but *in addition* they must be designed to allow substantial improvements in the mobility and supportability of U.S. forces, their productivity in combat, and their resiliency to attacks on their support infrastructure.
- **Resource constraints and uncertainties.** Defense budgets will almost certainly level off or even begin to decline in real terms, thereby increasing the resource pressure on defense acquisition. And trends within the defense budget may add to that pressure. To overcome the decline in the number of men and women of prime military age, pay scales may need to rise considerably, leading to a shift of budgetary resources from materiel to personnel.
- **Longer retention of weapon systems in the operational inventory.** With major weapon systems becoming increasingly capable, complex, and costly, progressively fewer new major acquisition programs are being started and, within each program, fewer units are bought each year. One result is that weapon systems are now retained in active service for longer and longer periods of time. All three Services will thus have to deal with aging systems and the associated problems of obsolescence.
- **Increasing difficulties of producing at an affordable cost.** Many programs continue to incur cost growth even after they are years past the beginning of FSD. One explanation can be found in the frequent production stretchouts and year-to-year production rate changes that they experience. Because almost all weapon systems are manufactured with out-of-date, inflexible production-line technology, this production-phase turbu-

lence makes low-cost production and effective cost control exceedingly difficult.

From the standpoint of force modernization, these trends pose several difficult challenges. It would no doubt be desirable to increase the number of new system "platforms" developed during the remainder of this century. But that number will inevitably be small, and it is never likely to be large enough alone to respond to the pace and unpredictability of changes in the threat. Therefore, the upgrading of weapon systems already in the inventory must become a major element in the U.S. acquisition strategy. Systematic product improvement—by adding, modifying, or substituting such important subsystems as sensors, fire control and navigation units, on-board countermeasures, and munitions—must be relied on increasingly to counter improvements in our adversaries' military capabilities and overcome equipment obsolescence. Because the United States will need as many of these improvements as it can afford, those responsible for weapon acquisition must find more systematic ways of planning upgrades, producing them more cheaply and efficiently, and fielding them more responsively.

The following recommendations outline the components of an *integrated* strategy for strengthening the acquisition process so that the challenges of modernization can be effectively met. No component of the strategy is novel, although each is currently an exception to general practice, at least in emphasis. For the strategy's full benefits to be realized, all the components must be integrated in a mutually supportive way.

- Improve the process of formulating requirements for needed operational capabilities.
- Make early development more austere.
- Separate critical subsystem development from platform development and use "maturational development."
- Encourage austere prototyping.
- Improve the transition from full-scale development to production through "phased acquisition."
- Focus more attention on upgrading fielded weapon systems.
- Place much greater emphasis on plant modernization and production flexibility.
- Continuously evaluate acquisition policy changes.

Although this recommended strategy has wide applicability across the range of weapon systems possessed by the military Services, it should not be rigidly applied and should not be viewed as a panacea.

However, it should strengthen the acquisition process for almost every class of weapon systems.[1]

The acquisition strategy we have recommended purposely excludes several approaches that have recently been advanced (in some cases through legislation) as worthwhile reforms:

- Mandated use of warranties for combat equipment.
- Mandated competition for prime contract awards.
- Centralized acquisition management in a single civilian defense agency.

Although these approaches have some positive features, they also have important limitations; they are not likely to add substantially to our ability to meet the new challenges of force modernization. As a consequence, they should not be allowed to divert energy from the task of strengthening the development and production process as recommended above.

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[1]We have not examined the special problems of ship acquisition, and we therefore hesitate to extend this prescription to ships without more study.

ACKNOWLEDGMENTS

This report would not have been possible without the important contributions of numerous Rand colleagues, past and present. The list of publications in the Preface and the references in the text identify most of these contributors. We also benefited from very careful readings of earlier versions by John Birkler, Paul Hill, David Kassing, Glenn Kent, Donald Rice, Giles Smith, and William Stanley, but the responsibility for any errors of course remains with us.

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I. INTRODUCTION: THE CHALLENGES OF FORCE MODERNIZATION

Modernizing combat forces by acquiring new major weapon systems is one of the most important, challenging, and complex tasks faced by the U.S. government. Probably no other public undertaking involves so many uncertainties. Substantial and unavoidable risks are involved in every step of the process: in selecting and developing technologies at the frontier of knowledge, in embodying those technologies in weapon designs, in producing items never produced before, and in integrating them with new support facilities and properly trained military personnel.

These inherent risks are further complicated by the unclear intentions and formidable capabilities of potential adversaries abroad, and by the ever-present economic pressures and resource constraints the government faces at home. The process of force modernization justifies active public interest, but its complexities and uncertainties require care in evaluating that process and restraint in suggesting ways to improve it.

Policy changes introduced during the last several years have recognized and addressed many of the challenges of force modernization. Important progress has been made, but an enormous amount remains to be done. In the report that follows, we draw on what has been learned in over three decades of acquisition research at Rand to derive recommendations to meet the current challenge. We well understand that the modernization of combat forces cannot occur in a vacuum. Policies governing the weapon acquisition process must balance a wide range of competing considerations and must reserve a large amount of flexibility for senior decisionmakers to respond to the many technical and programmatic uncertainties that inevitably occur. In formulating ways to meet the challenges of force modernization, we have kept in mind several related objectives:

- Achieving a proper balance of responsibilities between the Services and higher government levels (by reducing, where appropriate, the amount of high-level micromanagement).
- Fostering desirable coordination and collaboration among the Services (recognizing that these purposes must be served by additional changes beyond the acquisition process).

- Strengthening the government-defense industry relationship (by reducing its adversarial features, eliminating impediments to contractor innovation and efficiency, and encouraging new entrants to the supplier base).
- Furthering desirable coordination and collaboration with our Allies and security partners.

These are not addressed specifically here, but we believe that our suggestions and recommendations for improving the acquisition process support the attainment of these objectives.

In what follows Sec. II is *retrospective*: It examines the outcomes of past weapon system programs in terms of cost growth, schedule slippage, performance shortfalls, and fielding times. The next section is *prospective*: It describes four trends that will greatly affect the acquisition process in the future. Section IV is *prescriptive* in that it contains the elements of an integrated strategy for strengthening the acquisition process. The final section outlines the reasons that several widely espoused ideas for reform are not included in the integrated strategy recommended here.

II. TRENDS IN OUTCOMES OF PAST WEAPON SYSTEM ACQUISITIONS

The generally accepted measures for judging the major system acquisition process are system cost growth, schedule slippage, and performance shortfalls. Another important measure is the "acquisition interval," or "fielding time"—that is, the interval between the start of development and the introduction of the new system into operational use. Admittedly, these measures do not tell us everything we should like to know about the efficiency and effectiveness of the acquisition process. Cost growth, schedule slippage, and performance shortfalls are measured with respect to goals set earlier in the program and are therefore sensitive to whether these goals were established so as to be easy or difficult to achieve. These metrics all refer to outcomes *within* an acquisition program. Comparison between acquisitions of successive generations (for example, comparing the cost differences of successive generations of fighter bombers) is also important in analyzing the acquisition process, but that is not what we are concerned with here. When we refer to cost growth, we are concerned with program cost growth, not intergeneration cost growth.

"Performance" is an especially complex set of goals, traditionally emphasizing what may be called "functional" parameters—such as speed, payload, and range—and giving much less attention to the "operational suitability" parameters—such as reliability and maintainability—that influence the mobility and supportability of the system and thus contribute critically to mission success. Admittedly, therefore, the generally accepted measures fail to capture all the important outcomes of the acquisition process. Nevertheless, when these traditional measures are applied to representative samples of programs and examined over time, they should provide useful insights about the general health of the acquisition process. In terms of these measures, we conclude that the acquisition process has been generally improving over time—contrary to what is often asserted.

COST, SCHEDULE, AND PERFORMANCE[1]

To measure cost growth, schedule slippage, and performance shortfalls, we have taken three "snapshots"—at the end of the 1960s, at the end of the 1970s, and in the mid-1980s—to examine acquisition experience with weapon systems that entered full-scale development[2] during each of these decades. Each snapshot compares the cost, schedule, and performance of a selected sample of weapon systems, as reported at the time of the snapshot,[3] with the goals established for them at the beginning of full-scale development (FSD).

For the cost comparisons, the 1960s and 1970s samples were limited to programs three or more years beyond the start of full-scale development because programs less than three years old rarely exhibit much cost growth.[4] These samples include acquisitions by all three Services and feature a wide variety of technologies and types of systems, with the important exception of ships.[5] Adjustments were made to eliminate the effects of inflation during system acquisition and of any changes in the total quantity of the system to be procured—factors that are beyond the control of acquisition program managers.

In assessing schedule slippage, we compared the milestone dates established at the start of full-scale development with the dates on which the milestones were actually achieved. For aircraft, for example, comparisons included the planned and actual times of (a) the first flight of the initial configuration, (b) the first acceptance of the production version, and (c) the delivery of the 200th production item.

For performance shortfalls, the "approved program performance parameters" defined for the weapon systems in the Selected Acquisi-

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[1]Data in this subsection are drawn from R. L. Perry et al., *System Acquisition Strategies*, R-733-PR/ARPA, June 1971; E. Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, R-2516-DR&E, October 1979; and work in progress by A. A. Barbour and S. Resetar.

[2]The start of full-scale development is the equivalent of what we currently call the Defense System Acquisition Review Council Milestone II (DSARC II). For earlier (pre-DSARC) systems, we used contract dates or, occasionally, source selection dates to represent approximately the same point in the acquisition process. The 1980s sample includes a few programs that entered FSD (or reached a corresponding stage) late in the 1970s, subsequent to the cutoff date for the 1970s sample.

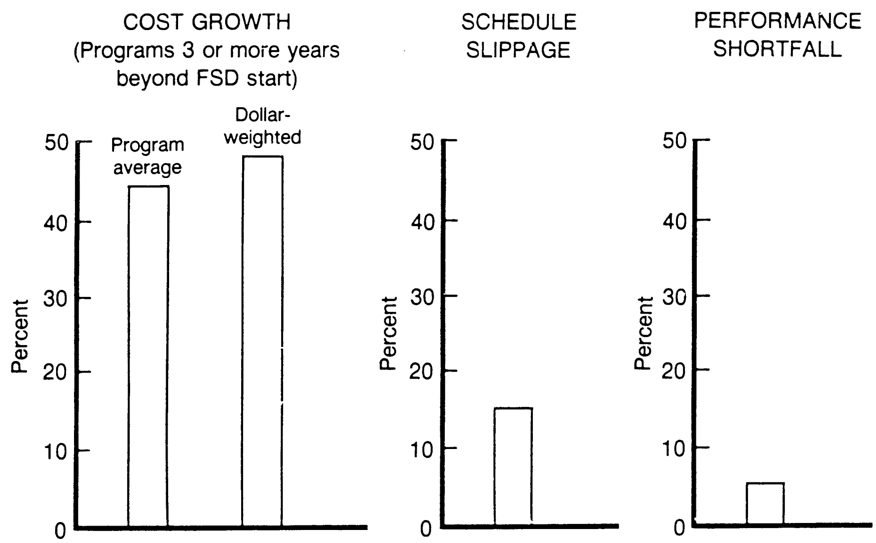
[3]Because the systems examined had not completed the acquisition process at the time of the snapshot, the reported cost, schedule, and performance data are essentially estimates. The estimates compared are: (a) the "development estimates" or goals established at or near the start of full-scale development, and (b) the "current estimates" available at the time of the snapshot.

[4]For the 1980s, however, "younger" programs were also included; otherwise the sample would have been very small.

[5]Although the samples exclude ships, they do include some ship-borne weapon systems.

tion Reports (SARs) were compared with the achieved performance to the extent such performance data were available. For the A-10, for example, these parameters included cruise speed, takeoff and landing roll, loiter time, bombing accuracy, strafing accuracy, sustained load factor, weight empty, maximum gross weight, and maintenance manhours per flight hour.

Figure 1 shows the cost growth, schedule slippage, and performance shortfall for the 1960s sample, which included six Army programs, eight Navy programs, and ten Air Force programs.[6] Program cost (adjusted to eliminate the effects of inflation and quantity change) increased 44 percent on the average, or 47 percent of the total dollar



SOURCES: R. L. Perry et al., *System Acquisition Strategies*, R-733-PR/ARPA, June 1971; E. Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, R-2516-DR&E, October 1979.

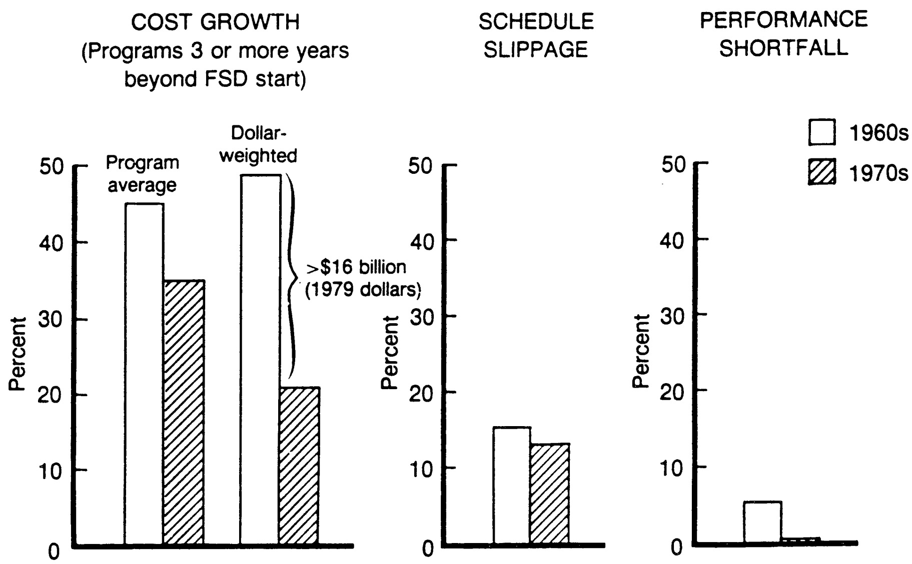
NOTE: Costs adjusted to eliminate the effects of inflation and changes in procurement quantity.

Fig. 1—Cost, schedule, and performance for programs at the end of the 1960s

[6]Army programs are the Pershing I, Pershing IA, OH-6A, Sheridan, Cheyenne, and Lance; Navy programs are the OV-10A, DIFAR, A-7A, A-7E, SQS-26AX sonar, SQS-26CX sonar, MK-48 torpedo (Mod 0), and MK-48 torpedo (Mod 1); Air Force programs are the F-111, C-5A, C-141, Titan III-C, Minuteman II Airborne Command Post, Minuteman II Guidance and Control system, A-7D, XC-142, Sprint, and SRAM.

cost of the programs in the cost sample.[7] This "dollar weighted" result reflects the fact that the more expensive programs were incurring somewhat higher cost growth than the average. Scheduled milestones took about 15 percent longer to reach than planned, and there was about a 5 percent shortfall from planned performance goals. These findings support the conventional wisdom that when acquisition problems arise, cost is the constraint most easily relaxed and schedule is next, whereas performance goals are adhered to most closely.

Figure 2 uses two "end-of-decade snapshots" to compare the 1960s outcomes with those of the 1970s. The 1970s sample includes ten Army programs, 13 Navy programs, and nine Air Force programs,[8] but



SOURCE: E. Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, R-2516-DR&E, October 1979.

NOTE: Costs adjusted to eliminate the effects of inflation and changes in procurement quantity.

Fig. 2—Cost, schedule, and performance for programs at the end of the 1960s and at the end of the 1970s

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[7]The cost sample was limited to the more mature programs of the 1960s; these numbered 13 out of the total sample of 24.

[8]Army programs are the UH-60A, M-198 howitzer, IFV (MICV) armored personnel carrier, Patriot, Copperhead (CLGP) projectile, Roland, Hellfire, AH-64, XM-1, and

of these only 17 were three years or more beyond FSD, and the 1970s cost growth shown in the figure was calculated only for these more "mature" programs. Cost growth for the 1970s programs averaged somewhat less than for those of the previous decade, down from 44 percent to 34 percent. But in terms of the total dollar cost of the programs, the cost growth of the 1970s sample was only 20 percent, a marked decrease from the almost 50 percent cost growth in the previous decade. This improvement reflects the fact that in the 1970s (unlike the 1960s) the larger programs were performing considerably better than average,[9] and this better cost performance meant that the cost of the mature 1970s sample was some $16 billion *less* (in 1979 dollars) than it would have been if it had incurred the same cost growth percentages as the 1960s mature sample. Moreover, the 1970s programs exhibited somewhat less schedule slippage than those of the 1960s, down from 15 to 13 percent. And the 1970s performance shortfall was close to zero on the average,[10] down from the previous 5 percent.

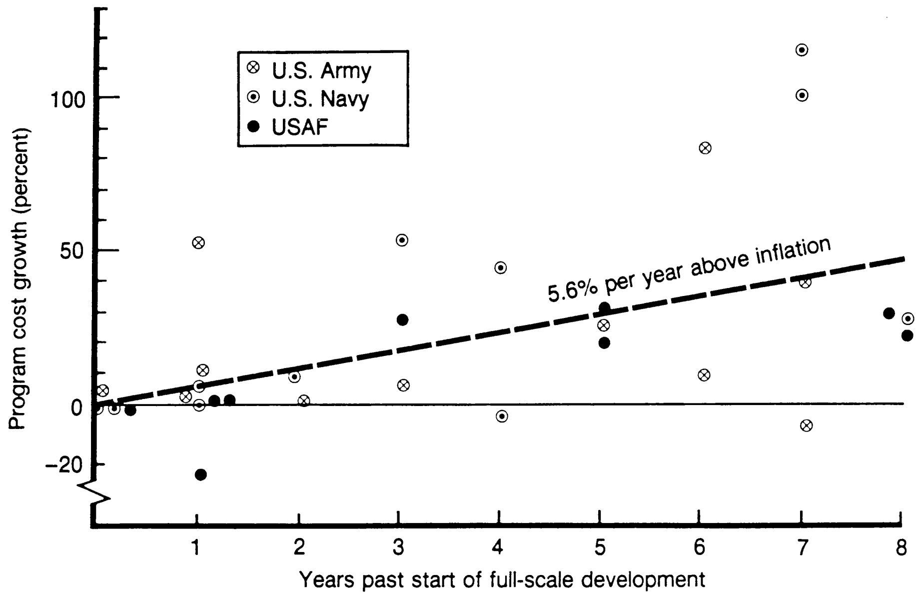
Using a single bar to represent the cost experience of a whole decade necessarily masks a great deal of variation among programs. To provide more detail, Fig. 3 breaks out the 1970s cost data to identify the Service acquiring the weapon system and to show the maturity of each program in terms of years past the start of full-scale development. Figure 3 also includes 14 programs less than three years beyond FSD—a total sample of 31. For this sample the cost growth was about 5.6 percent *per year* (the effects of inflation and quantity change again being eliminated).

Figure 3 confirms some elements of conventional wisdom by showing that programs further from the start of full-scale development tend to experience greater cost growth as they accumulate problems and as program changes occur. But it contradicts the conventional wisdom of the 1960s by showing that program size and complexity (as measured by total cost) do not necessarily go hand in hand with cost growth.

DIVAD gun; Navy programs are the Aegis fire control radar, CAPTOR torpedo-mine, AIM-9L, AIM-7F, Harpoon, Condor, LAMPS MK.III, SURTASS surveillance system, F-18, TACTAS surveillance system, Tomahawk, 5-in. guided projectile, and 8-in. guided projectile; Air Force programs are the F-15, B-1, AWACS (E-3A), A-10, F-16, DSCS III space system, Air-Launched Cruise Missile, Ground-Launched Cruise Missile, and PLSS target-location system.

[9]This has sometimes been attributed to a more conservative design philosophy in the 1970s, especially for the more expensive programs, coupled with a more rigorous control of cost-generating engineering changes.

[10]Because this is the average for the sample, it does not mean that individual programs did not suffer significant performance shortfalls.



SOURCE: E. Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, R-2516-DR&E, October 1979.

NOTE: Costs adjusted to eliminate the effects of inflation and changes in procurement quantity.

Fig. 3—Program cost growth (March 1978)

For example, the AIM-9L Sidewinder missile[11] and the CAPTOR torpedo-mine programs (the two Navy programs at the upper right of Fig. 3) are small in terms of total cost but extremely high in terms of cost growth. By contrast, the F-15 and the B-1A programs (the two Air Force programs at the lower right of Fig. 3) are the most expensive programs in this sample but they experienced much less than average cost growth in percentage terms.

Figure 4 compares the cost growth[12] of the 1960s and 1970s programs with the mid-1980s sample, which includes eight Army programs, nine Navy programs, and ten Air Force programs. At the end of 1984, the average cost growth of the 1980s programs was under 10 percent, and the dollar-weighted cost growth amounted to only 1 per-

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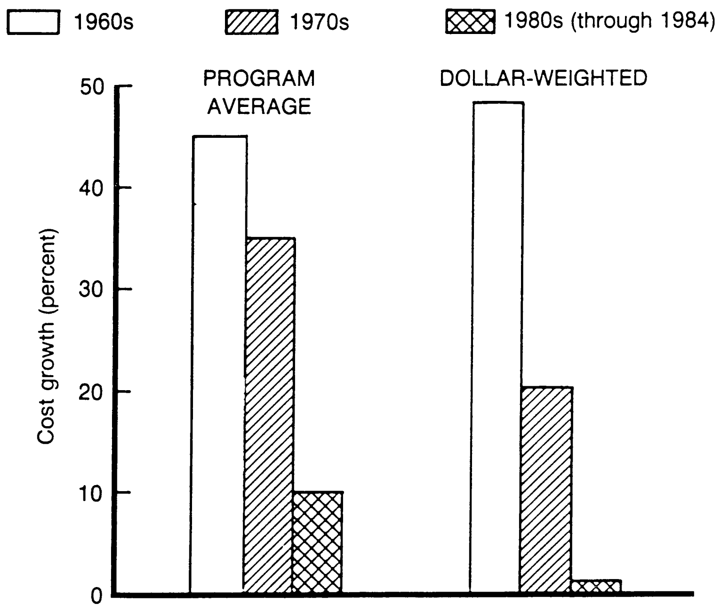
[11]Although originally developed for the Navy, the AIM-9L is also used by the Air Force.

[12]We lack comparable data on schedule slippage and performance shortfall for the 1980s.

cent. These 1980s results are, of course, limited to fairly young programs, as will be discussed later.[13]

Figure 5 compares the cost growth of major weapon acquisition programs of the 1960s and 1970s[14] with that of several different types of civil programs. Except for highway and water projects, generally characterized by only modest technical risk, the nondefense programs



SOURCE: Fig. 2 and work in progress by S. Resetar.
NOTE: Costs adjusted to eliminate the effects of inflation and changes in procurement quantity.

Fig. 4—Cost growth for programs at the end of the 1960s, 1970s, and 1984

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[13]Army programs are the ADDS, AHIP, JTACMS, JTIDS, MLRS/TGW, RPV, SHORAD, and TOW 2; Navy programs are the ASPJ, ASWSOW, CIWS, E-6, JTIDS, JVX, P-3C update, SUBACS, and Trident 2 missile; Air Force programs are the B-1B, C-5B, C-17A, CONUS OTH-B, JTIDS, KC-135R, LANTIRN, Peacekeeper, T-46A, and the WWMCCS information system. Although this sample does not include all of the 1980s programs, we believe it to be fairly representative. We tested it for sensitivity by recalculating the cost growth results with the Peacekeeper, TOW 2, and P-3C excluded from the sample, and also with the AMRAAM and DSCS III included. These changes had little effect on cost growth; in particular, the dollar-weighted cost growth of the sample remained close to 1 percent.

[14]The weapon cost growth data are for the mature samples, which comprise the systems that generally experienced the most cost growth.

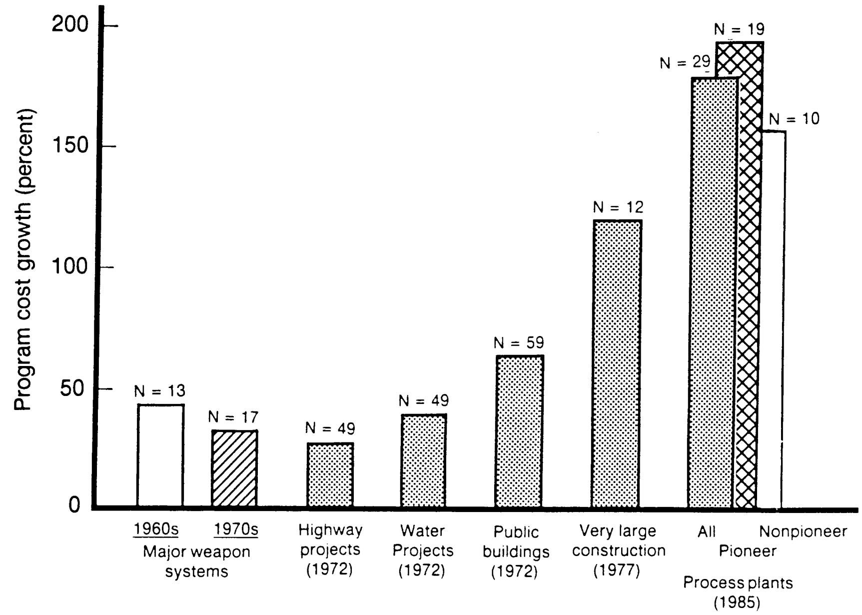
experienced greater cost growth than the defense programs, in some cases much greater. In terms of program complexity, technical risk, dependence on a large number of contractors, and duration, major weapon programs are probably most comparable with pioneer energy and chemical process plants. In this comparison, weapon system acquisitions are characterized by impressively low cost growth.

In interpreting the trends in cost-growth, schedule slippage, and performance shortfall shown in Figs. 1–4, one should keep several points in mind.

In the assessment of *cost growth*, the program costs estimated at the start of full-scale development were compared with the program costs estimated at the time of the "snapshot." Low cost growth may result from influences that cannot be easily disaggregated. For one thing, recent declines in cost growth may result from the use of more realistic cost estimates at the beginning of FSD. Such estimates may, in turn, result from improved cost estimating processes, from a growing reluctance to make new weapon systems seem attractive and affordable by attaching unrealistically low prices to them, or from a conscious decision to add a contingency margin to cover "unforeseeable" problems. In addition, low cost growth may result from improvements in development strategies, cost controls, contract arrangements, and the like.

Another point concerns the relative maturity of the programs compared. Earlier studies focused attention on cost growth mainly during development and early production, because it was believed that those phases of the acquisition process were characterized by the largest uncertainties and posed the most serious problems of cost control. As will be shown in Sec. III, such a view is too limited, considering what is now known about the problems of production instability and stretchout, the longer retention of systems in the operational inventory, and the need to upgrade systems so that they can cope with the increasing threat. In short, cost growth during the production phase has become a matter requiring serious attention. Cost growth comparisons that fail to go beyond the early production years will tell only part of the story.

As already pointed out, the 1980s sample (see Fig. 4) includes only young programs. But programs tend to accumulate problems and design changes as they mature and thus incur cost growth (see Fig. 3). The lower cost growth of the 1980s sample is therefore attributable in large part to its young programs. When this young 1980s sample is compared with the similarly young sample of 1970s programs, the result suggests that cost growth *early in the acquisition process* is no greater in the 1980s than it was in the 1970s, and it may well be somewhat less. As already mentioned, the dollar-weighted cost growth of



SOURCES: Adapted from E. W. Merrow et al., *A Review of Cost Estimation in New Technologies: Implications for Energy Process Plants*, R-2481-DOE, July 1979; work in progress by R. W. Hess and C. W. Myers.

Fig. 5—Comparative cost growth, defense vs. nondefense programs

the 1980s sample is about 1 percent; for the similarly young programs in the 1970s sample (those less than three years into FSD), it was about 4 percent.

In describing *performance*, almost all concerned—those who managed and reviewed programs as well as those who studied the acquisition process—have tended to emphasize *functional performance*. For example, Table 1 shows how functional performance measures dominate the approved program performance parameters for two tactical combat aircraft from the 1970s. But these parameters fail to capture all the physical and performance characteristics that contribute to overall mission effectiveness, especially in view of recent changes in the threat. If one were to add a representative selection of the *"operational suitability"* parameters[15] that affect demands on the support

[15]To do so now would, of course, be equivalent to changing the basis of comparison established at the beginning of full-scale development.

Table 1

APPROVED PROGRAM PERFORMANCE PARAMETERS FOR THE A-10 AND F-15

A-10	F-15
Functional performance	**Functional performance**
Cruise speed	Maximum speed
Takeoff and landing roll	Design mission radius
Loiter time	Thrust-to-weight ratio
Bombing accuracy	Engine thrust
Strafing accuracy	Takeoff and landing roll
Sustained load factor	Specific excess power
Empty weight	Radar range
Maximum gross weight	Takeoff gross weight
Operational suitability	**Operational suitability**
Maintenance manhours per flight hour	"Mean time between failures"
	Percent operationally ready

SOURCE: Selected Acquisition Reports for the A-10 and F-15.

infrastructure—including such measures as mean time between component removals—the "performance" outcomes would then surely appear in a less favorable light.

To recapitulate: Acquisition programs of the 1970s and 1980s experienced less percentage cost growth than acquisition programs of the 1960s, but we are not able to assess the degree to which different causal factors contributed to this result. The data are encouraging, but they provide no grounds for complacency, especially with respect to continued cost growth during the production phase. A decline in cost growth does not in itself tell whether the acquisition process is efficient or whether the Services are paying too much for the system they are acquiring. Nor is there reason for complacency in the data showing that "performance" outcomes are close to the goals established at the beginning of full-scale development. Until these goals include a sufficiently comprehensive selection of well-defined operational suitability parameters, the comparison of performance goals and outcomes will tell only part of the story.

ACQUISITION INTERVALS[16]

To assess whether it has been taking longer and longer to field new weapon systems, we examined fixed-wing military aircraft because they pose problems typical of most major classes of equipment.[17] For our calculations, we measured the time that elapsed from the start of full-scale development (or from the beginning of the prototype phase if there was one) to the delivery of the 200th aircraft. As Fig. 6 indicates, a typical value of this time interval appears to have increased from slightly over six years in the mid 1940s to nearly eight years in the mid 1970s. However, there is a large variation from one system to another in every time period. There is about one chance out of four that the indicated trend is a statistical anomaly and that there has been no change at all in the average time interval over that three decade period.

Measuring acquisition intervals from the beginning of the prototype phase appeared to make sense because—especially during the 1950s—there was considerable overlap between the prototype phase and the subsequent full-scale development phase. In the case of the A-10 and F-16, however, there was no such overlap. Thus if the acquisition intervals for these two programs are recomputed by beginning at the start of full-scale development (the DSARC II decision), there seems to be no overall trend toward longer acquisition intervals over the past 30 years (see the lower trend line in Fig. 6). We therefore find little evidence that the heart of the acquisition cycle, from start of development to a point well into the production phase, has been increasing in length during the past three decades.

If the middle of the acquisition process has not been lengthened appreciably, have the beginning (the planning phase) or the end (the continuing production phase) been lengthening? The duration of the planning phase is extremely difficult to track. Ideally, the issuance of a formal system requirement would identify its beginning. However, such a formal requirements document has occasionally been almost an afterthought, sometimes issued only after full-scale development has

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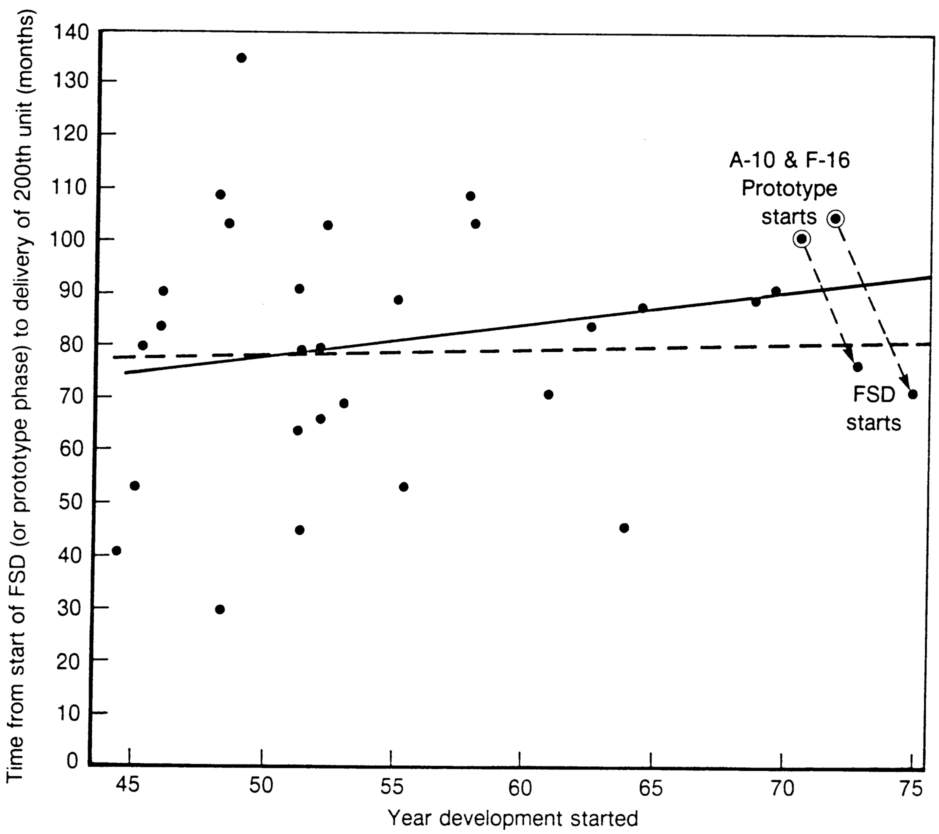
[16]Data in this subsection are drawn from G. K. Smith and E. T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, R-2605-DR&E/AF, November 1980.

[17]We examined the following aircraft: F-84, F-86, B-47, F-89, F-94, B-52, F-102, F-101, F-100, F-105, C-130, B-58, F-104, F-4, A-6, B-70, C-141, F-111, A-7, C-5, F-14, S-3, F-15, B-1, A-10, F-16, F-18, and AV-8B. In addition, Smith and Friedmann examined helicopters (AH-1, AH-64, SH-3, CH-3, CH-46, CH-47, CH-53, CH-54, UH-43, HH-52, OH-6, OH-23, OH-58, SH-34, TH-55, UH-1, UH-2, UH-60) and missiles (TM-61 Matador, SM-64 Navaho, GAR-1 Falcon, IM-99A Bomarc, GAM-72 Quail, TM-76B Mace, GAM-77 Hound Dog, GAM-87 Skybolt, AGM-69 SRAM, AGM-65 Maverick, Harpoon, ALCM/SLCM, Pershing II).



SOURCE: G. K. Smith and E. T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, R-2605-DR&E/AF, November 1980.

Fig. 6—Aircraft acquisition intervals since 1944

begun, sometimes not issued at all.[18] Other initiating events, such as the letting of contracts for funded studies or the signing of written decision directives by senior officials, have proved nearly useless for analytic purposes because of gaps in program documentation. To surmount these problems in our study of acquisition intervals, we constructed a synthetic milestone that would correspond to what is now generally referred to as Milestone I, the start of concept validation

[18]We have been unable to locate a formal statement of requirements for such important systems as the F-4, A-6, and F-14.

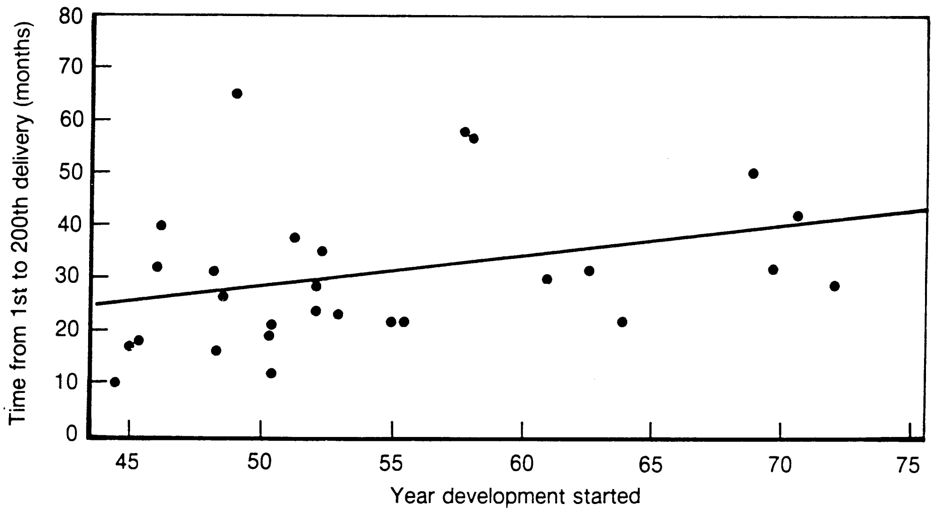
activities. (Note that Milestone I would normally occur considerably *later* in the acquisition process than the statement of system requirements.) We then examined roughly three dozen aircraft and missile programs to estimate when the Milestone I review would have occurred and treated the time between Milestone I and Milestone II (the start of FSD) as representative of the duration of the planning phase. We found that

- The duration of the planning phase in a typical program was one to two years longer during the 1970s than during the 1950s.
- This growth in the planning phase occurred primarily during the 1960s and not during the 1970s, as has often been asserted.[19]
- There have been instances of very lengthy planning phases not only in recent decades (the F-15, B-1, A-10, Pershing II, and M1) but also in past decades (the B-47, B-52, B-58, F-111, and SRAM).

At the other end of the acquisition process, the production phase has become longer in recent years. As Fig. 7 indicates, the time between delivery of the first and the 200th unit has increased about 50 percent over the past 30 years. There are two explanations for this increase. Each generation of aircraft has tended to become more complex than its predecessors, but the advances in aircraft design have not yet been matched by advances in production technology. One result of this is that the "flow times" measured from the beginning to the end of production of a given end item have tended to increase over the years. This increased flow time affects the total output achievable in the very early years of production, before something like a steady-state production rate is attained.

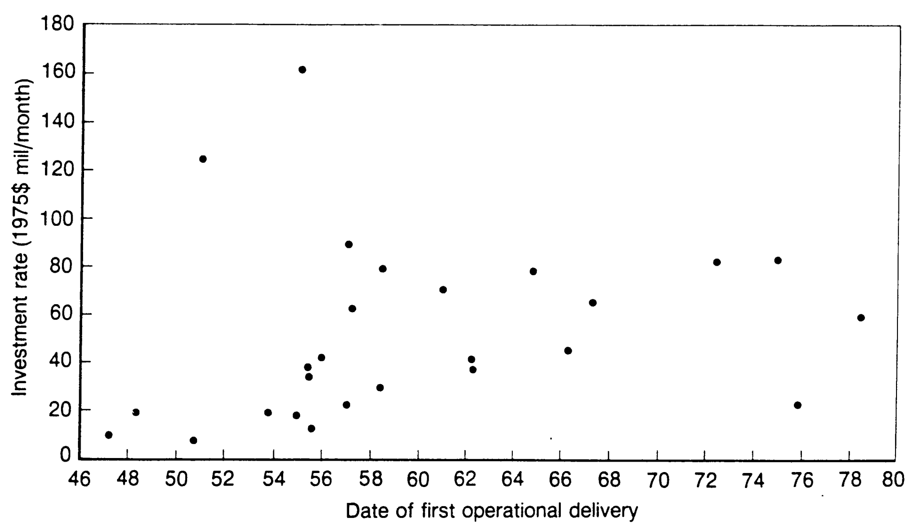
The other explanation concerns the relation between system unit cost and program investment rate—the funding provided by Congress to purchase units of the system. Whereas unit cost in real terms has tended to increase as new generations of aircraft come into production, the investment rate (again in real terms) has failed to keep pace. Figure 8 shows that for aircraft entering development between 1946 and 1980, the average monthly investment during the production phase has remained fairly level in terms of constant dollars, especially since the end of the Korean War and the production of the B-47 and B-52

[19]See, e.g., *Report of the Acquisition Cycle Task Force*, Defense Science Board 1977 Summer Study, Final Report, March 1978. The widespread impression that the "front end" of the acquisition process was lengthened during the 1970s is probably due in part to the difficulty of determining just when the process began and in part to the increased emphasis during much of this decade on many *pre-Milestone I* activities.



SOURCE: G. K. Smith and E. T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, R-2605-DR&E/AF, November 1980.

Fig. 7—Aircraft production time since 1944



SOURCE: G.K. Smith and E. T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, R-2605-DR&E/AF, November 1980.

Fig. 8—Aircraft procurement investment rates since 1946

bombers—the only aircraft procurements exceeding $120 million per month. Since 1960, as Fig. 8 shows, no investment rate has much exceeded $80 million per month in 1975 dollars. The result has been a general decline in monthly production rates and a lengthening of the time required to achieve any given total output.

III. TRENDS AFFECTING FUTURE WEAPON SYSTEM ACQUISITIONS

Four trends are certain to have profound effects on the acquisition process in the future:

- Escalating enemy threats.
- Increasing resource constraints and uncertainties.
- Longer retention of weapon systems in the operational inventory.
- Continued difficulties in controlling production costs.

ESCALATING ENEMY THREATS[1]

Force modernization must ultimately aim at deterring potential enemies. This means, among other things, that combat forces should be capable of effectively operating in the full range of plausible future conflict scenarios—scenarios that are becoming increasingly demanding.

In its competition with the United States, the Soviet Union and its allies have increased their combat capabilities in geographic breadth, numerical size, and quality (see Fig. 9).[2] Future combat environments will therefore be much more demanding, hostile, and difficult to plan for than those of past conflicts. Warning times will probably be shorter, deployment distances longer, and overseas facilities less adequate and secure.

The Soviet Union's development of a formidable long-distance attack capability poses what is probably the most serious challenge. This long-distance capability results partly from tremendous improvements in the characteristics of the Soviets' air-to-ground attack aircraft and munitions, partly from their growing long-range military airlift capability, and partly from their steadily increasing naval power with global reach. These developments have enlarged the potential combat arena to encompass many critical elements of U.S. support infrastructure: theater airbases, rearward Army facilities, and other important U.S. and Allied defense installations overseas.

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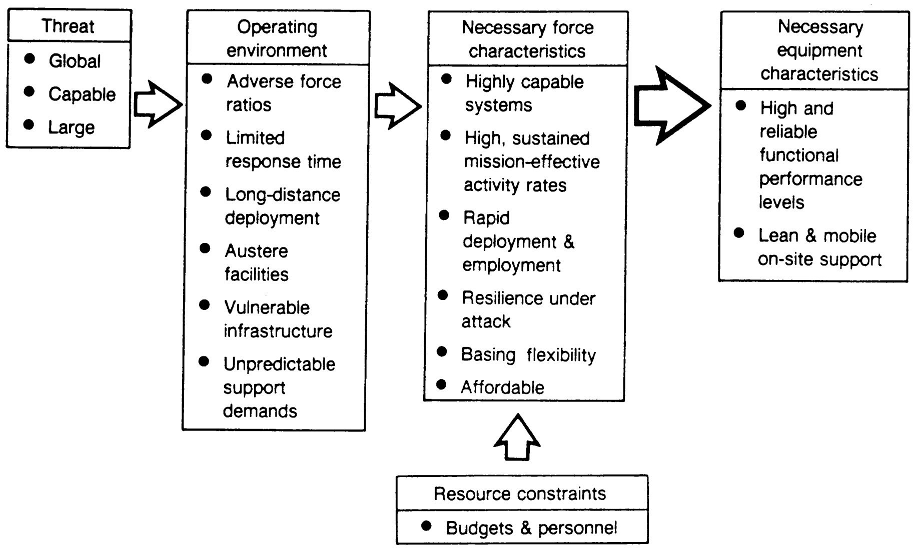
[1]Material in this subsection is drawn from M. D. Rich et al., *Improving U.S. Air Force Readiness and Sustainability*, R-3113/1-AF, April 1984.

[2]See U.S. Department of Defense, *Soviet Military Power, 1985*, Washington, D.C., April 1985; M. D. Rich et al., *Improving U.S. Air Force Readiness and Sustainability*.



SOURCE: Adapted from M. D. Rich et al., *Improving U.S. Air Force Readiness and Sustainability*, R-3113/1-AF, April 1984.

Fig. 9—Factors shaping necessary characteristics of future weapons

These Soviet developments have created the need for U.S. and Allied force capabilities that are more diverse and demanding than those sought in past modernization efforts. As in the past, U.S. systems must keep pace with Soviet functional performance improvements. But now, *in addition*, it is necessary to greatly improve the mobility and supportability of U.S. forces, their productivity in combat, and their resilience to attacks on their support infrastructure.

In addition to being capable of high levels of functional performance, future weapon systems must be able to reach these performance levels reliably and with far less dependence on collocated or nearby support facilities. Put very simply, enemy threat changes have greatly complicated the technical and operational challenges faced by U.S. weapons developers and logisticians.

From the standpoint of force modernization, these problems pose several difficult challenges:

- Translating threat and environmental changes into requirements for weapon systems that will do the required job and that we can afford to buy and support.

- Dealing effectively with the many inherent uncertainties and risks associated with developing, producing, and fielding weapon systems to meet those requirements.
- Broadening and modernizing the contractor and government-owned industrial base to strengthen its ability to produce efficiently and to surge, mobilize, and meet the highly volatile demand for end items, spare parts, and repairs for both U.S. and Allied combat forces.

RESOURCE CONSTRAINTS AND UNCERTAINTIES[3]

We must confront these challenges in an environment of increasingly troublesome resource constraints and uncertainties. Although defense budgets in recent years have steadily increased in real terms, we cannot rely on similar future increases. There is no precedent for so long a period of sustained growth in peacetime, and the signs of change were clear even before the Gramm-Rudman deficit-reduction plan became law. If this legislation successfully resists challenges, and if the cuts it mandates are carried out, we must expect that defense budgets will level off or even begin to decline in real terms. In the absence of a tax increase, or major cuts in non-defense programs, this decline may be precipitous.[4] Budgetary competition among weapon programs will become more severe, especially in the procurement phase.[5] If we are to avoid harmful program cancellations and stretchouts, the acquisition process must be made more effective and efficient.

Other trends also threaten force modernization. The recent increases in defense budgets have failed to compensate fully for acquisition underfunding during the 1970s, especially with respect to many items critical to readiness, such as the stockpile of smart munitions. Hence readiness will continue to compete with modernization for funding.

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[3]Material in this subsection is drawn from work in progress by E. Dews.

[4]Congressman Les Aspin, Chairman of the House Armed Services Committee, foresees that the Secretary of Defense "will have presided over the largest peacetime defense buildup in history—and the largest peacetime defense cutback in history." *Air Force Times,* 23 December 1985. The Georgetown University Center for Strategic and International Studies has estimated that, as a result of Gramm-Rudman, the Department of Defense may face a cut approaching a total of $300 billion less than it had projected for the five fiscal years 1986–1990. *The Wall Street Journal,* December 26, 1985.

[5]Because only a modest fraction of the annual appropriations for major system procurement is expended in the year of appropriation, a cut in procurement outlays is likely to require a much larger cut in procurement Budget Authority. This could have very serious consequences for procurement programs in *subsequent* years, not least of which would be uncertainty about program funding and declines in production rates.

And if the personnel strength of the Services remains at something like the present numbers, the recruitment of qualified personnel for an all-volunteer force is likely to become more difficult in the next few years because of declines in the number of men and women of prime military age. Pay scales may rise considerably, especially if civilian employment opportunities are good. As a consequence, the government may have to shift budgetary resources from materiel to personnel. Within the acquisition area itself, the services have undertaken major new programs, each generating very large future demands for R&D and procurement funds. Thus, there has never been a greater need to structure requirements wisely, to choose appropriate designs, and to control development and production costs.

LONGER RETENTION OF WEAPON SYSTEMS IN OPERATIONAL SERVICE[6]

With weapon systems becoming increasingly capable, complex, and costly, it is not surprising that fewer new major acquisition programs

Table 2

NEW U.S. AIR FORCE FIGHTERS, 1940s–1990s[a]

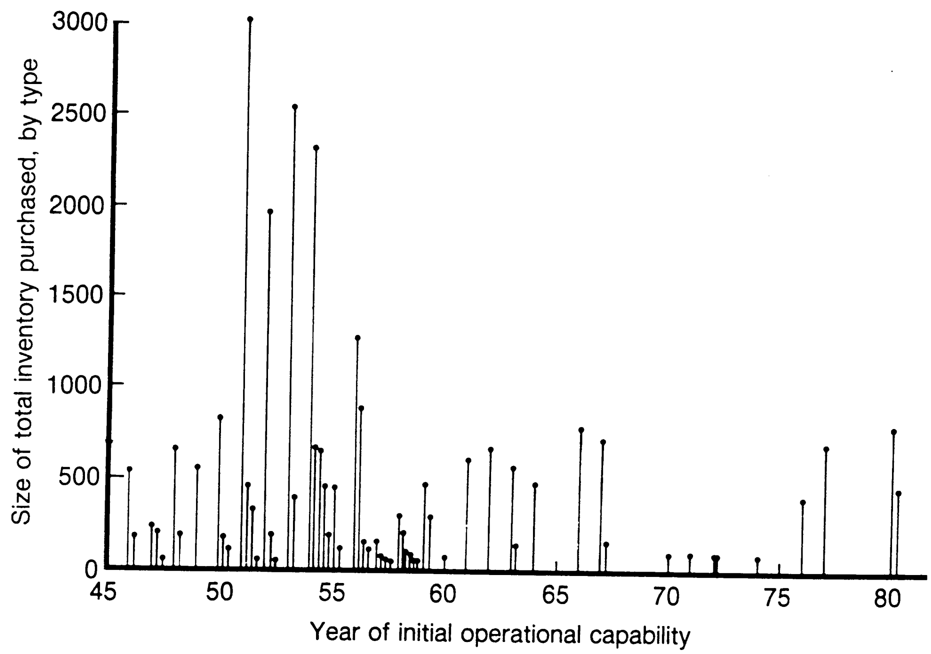
Decade	Fighters Developed
1940s	P-47, P-51, P-59, P-61, F-80, F-84, F-86, F-89, F-94
1950s	F-100, F-101, F-102, F-104, F-105, F-106
1960s	F-4, F-111
1970s	F-15, F-16
1980s–1990s	ATF (development planned)

[a]This table excludes fighters that entered full-scale development but that were not procured for inventory; it therefore understates the number of new starts funded in the 1940s and 1950s.

[6]Data in this subsection are drawn from Rand work prepared for the Defense Science Board 1984 Summer Study on Upgrading Current Inventory Equipment. That study's final report, *Improved Defense through Equipment Upgrades: The U.S. and Its Security Partners*, was published in November 1984.

are being started and that, within each program, fewer units are bought each year. If one looks at Air Force fighter aircraft, for example, during the 1940s and 1950s at least six new weapon systems were developed per decade; and during the 1960s and 1970s two new weapon systems were developed per decade (see Table 2). It seems possible, even probable, that during the 1980s and 1990s the Air Force will develop but one new fighter aircraft over a period of two decades—the Advanced Tactical Fighter (ATF). Moreover, if one looks at Air Force fighters by major model designation, fewer model variants and smaller quantities of each variant have been purchased over the last 35 years (see Fig. 10).

All of this explains the trend, which began in the 1960s, toward extending the inventory life of fighter aircraft. Figure 11 illustrates this trend for Air Force fighters, with projections that suggest it will continue into the future. Figure 12 shows how the period of active

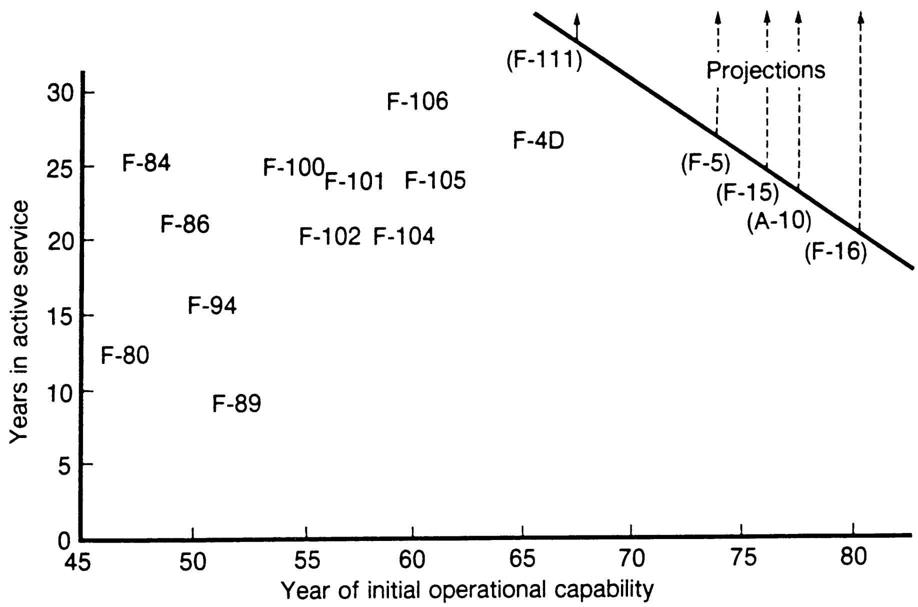


SOURCE: Based on data supplied to the Defense Science Board 1984 Summer Study by the Directorate of Operational Requirements, Office, Deputy Chief of Staff for Research, Development, and Acquisition, Headquarters USAF.

Fig. 10—Major model variants of USAF fighters and quantities purchased, 1945-1980

service of Navy aircraft is being extended beyond the planned time. This figure compares the period of service planned at the beginning of a program with the actual length of service for systems already retired or (for those not yet retired) with the currently projected length of service. In all cases but one, these weapon systems fall below the diagonal line, indicating retention in the inventory for longer than originally planned, in most cases appreciably longer.

Finally, Table 3 shows that these three related trends (fewer new weapon system starts, smaller total system buys, and extended periods in service) are not limited to Air Force and Navy aircraft.[7] For all the Services, the remainder of this century will see the initiation of only a few new weapon system programs, and those will experience rather slow buildups because of low production rates. Thus, all three Services will have to deal with aging systems either already procured and in the inventory or, in some cases, already obsolescent while still in production.

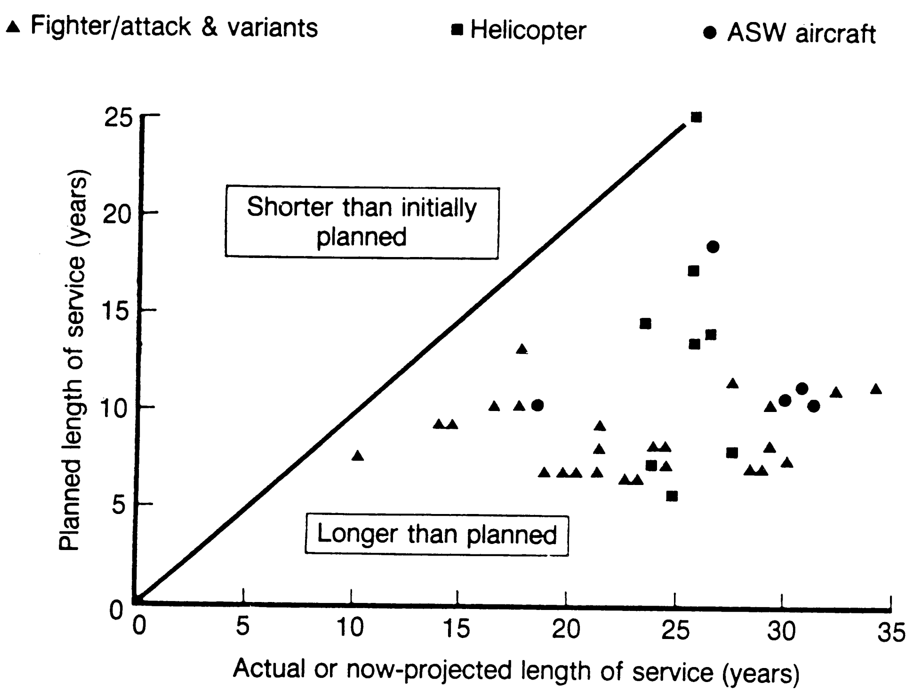


SOURCE: See Fig. 10.

Fig. 11—Length of active service, USAF fighters, 1945–1980

[7]Table 3 may even understate the problem, because it is derived from Service plans extending more than five years into the future; such plans tend to be quite optimistic concerning future schedules and production rates.

It would no doubt be desirable to increase the number of new system "platforms" developed during the remainder of this century. But that number will be small, and it is never likely to be large enough by itself to respond to the pace and unpredictability of changes in the threat. Therefore, the upgrading of weapon systems already in the inventory must become a major element in U.S. acquisition strategy. Systematic product improvement—by adding, modifying, or substituting such important subsystems as sensors, fire control and navigation units, on-board countermeasures, and munitions—must be increasingly relied on as the means of countering improvements in our adversaries' military capabilities and of overcoming the problems of equipment obsolescence. Because the United States will need as many of these improvements as it can afford, those responsible for weapon acquisition



SOURCE: Based on data supplied to the Defense Science Board 1984 Summer Study by the Directorate of Research, Development, Test and Evaluation, Office of the Chief of Naval Operations.

NOTE: Data are for all Navy aircraft that have achieved operational capability since 1960. "ASW" means anti-submarine warfare.

Fig. 12—Planned vs. actual length of service, Navy aircraft

must find more systematic ways of planning upgrades, producing them more cheaply and efficiently, and fielding them more responsively.

A systematic upgrading strategy will enable the Services to take quick advantage of technological advances in one area without having to wait for comparable advances in other areas sufficient to justify the development of an entirely new weapon system. This will enable the Services to deal rapidly with changes in threats they face and to postpone the obsolescence that eventually results when weapons are retained for long periods in the operational inventory.

INCREASED DIFFICULTIES OF PRODUCING AT AFFORDABLE COST[8]

Figure 13 updates by three years the cost growth data for the 1970s reported in Fig. 3. The sharp increases in cost growth at the left of Fig. 13 are for weapon systems that were fairly immature when the initial cost "snapshot" was taken in March 1978, and (as already discussed) weapon systems accumulate problems—and thus cost growth—as they begin to mature.

One might not expect to find such sharp cost rises toward the right of Fig. 13 (see the CAPTOR, Patriot, and UH-60), for the weapon systems in this region of the figure were many years past the beginning of full-scale development. One explanation may be that program cost estimates have recently become more realistic (that is, higher) at about the time the system enters production.[9] Another explanation can be found in program stretchouts and year-to-year production-rate changes, with production rates failing to reach, or declining from, the rates originally planned and for which investment in production facilities had been made.

Figure 14 presents data on a sample of 85 separate annual purchases representing 30 different weapon systems that were in production during the period FY 1981 to FY 1986. For each of these purchases, it compares two successive estimates: (1) the production rates[10] and unit costs in the Service program, as estimated 19 months before the beginning of a given fiscal year, and (2) the production rates and unit costs as estimated in the President's Budget 12 months later (that is, seven

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[8]Data and material in this subsection are drawn from work in progress by both A. A. Barbour and E. Dews, and from E. Dews and J. L. Birkler, *Reform in Defense Acquisition Policies: A Different View*, P-6927, November 1983.

[9]K. Terasawa (now at Rand) found evidence of this in several Army systems that entered production early in the 1980s. See *Cost of Production Rate Uncertainty*, Arroyo Center of the Jet Propulsion Laboratory, AC-RR-84-002, May 1984.

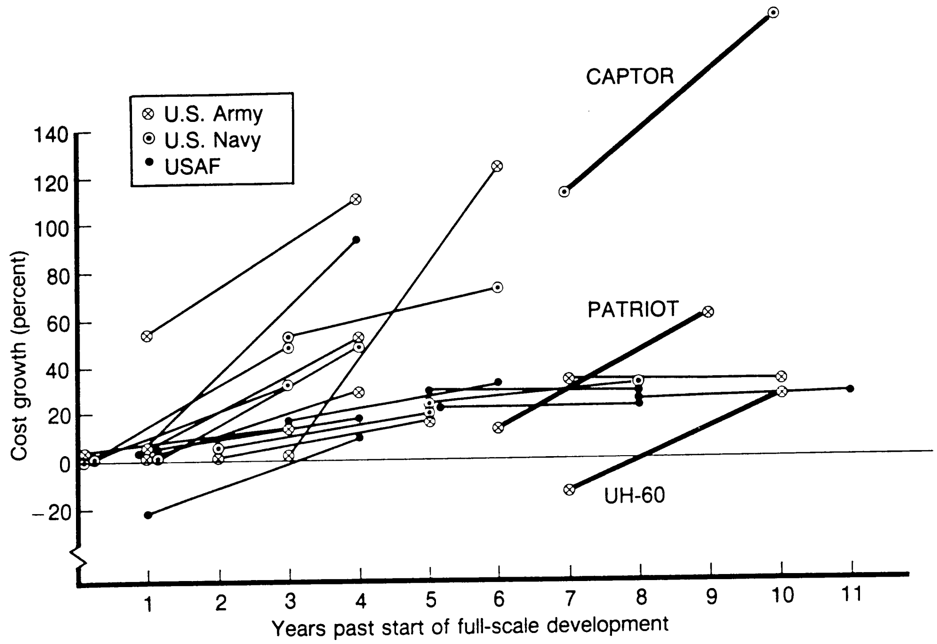
[10]The annual buy size is used here as a proxy for production rate.

Table 3

TRENDS IN PURCHASING AND RETAINING NEW SYSTEMS: NAVY, AIR FORCE, AND ARMY

Service	Projected New Starts	Implications of New Starts for Inventory in Year 2000	Average Equipment Age
U.S. NAVY			
Attack aircraft }	ATA — late 80s	ATA ~ 30%	Growing until early 90s, then slight decline
Fighter/strike aircraft }		—	Declining slightly until early 90s, then growing
Helicopters	JVX — late 80s	JVX ~ 30%	Growing until early 90s, slight decline, then slow growth in late 90s
Patrol aircraft	VSX — mid 90s	VSX ~ 15%	Growing until early 90s then slight decline
Submarines	SSN-21 — mid 90s	(No data)	(No data)
USAF			
Fighters	ATF — late 80s	ATF ~ 15%	Stable until end of century, then growing
Bombers	(Data not useful because ATB excluded.)		
Tankers	None	— }	Modest growth through rest of century
Cargo aircraft	C-17 — mid 80s	C-17 ~ 30% }	
U.S. ARMY			
Tanks	None	—	Declining until 1990, then sharp increase
Armored Personnel Carriers	None	—	Growing for rest of century
Attack helicopters	None	—	Growing especially after 1990
Air defense systems	None	—	Fire units: growing for rest of century Missiles: declining
Shoulder-fired air defense systems	None	—	Growing until 1985, then declining until 1995, growing thereafter
Scout/utility helicopter	LHX — late 80s JVX — late 80s	(No data)	(No data)

SOURCE: Based on data supplied to the Defense Science Board 1984 Summer Study by the three Services.



SOURCE: Fig. 3 and work in progress by A. A. Barbour.
NOTE: Costs adjusted to eliminate the effects of inflation and changes in procurement quantity.

Fig. 13—Cost growth update (1978–1981)

months before the beginning of the given fiscal year). In 80 percent of these cases, the production rate changed during these 12 months, and with almost every such change there was a change in the unit price. When production rates went down, prices almost invariably went up; when production rates went up, prices generally went down. The data suggest that decreases in production rates hurt more than increases helped. For the sample of 85 buys, the average change in the annual buy size was a decrease of 17 percent; the average change in unit price was an increase of 22 percent.[11]

Much of this increase in unit price is a consequence of the inflexible production-line technology still in use by most defense contractors and

[11]The unit prices are estimates in current year dollars. Because only one year separates the two estimates used in calculating each price change, and because each estimate is structured to take future inflation into account, the use of current year prices should not appreciably bias the price-change results.

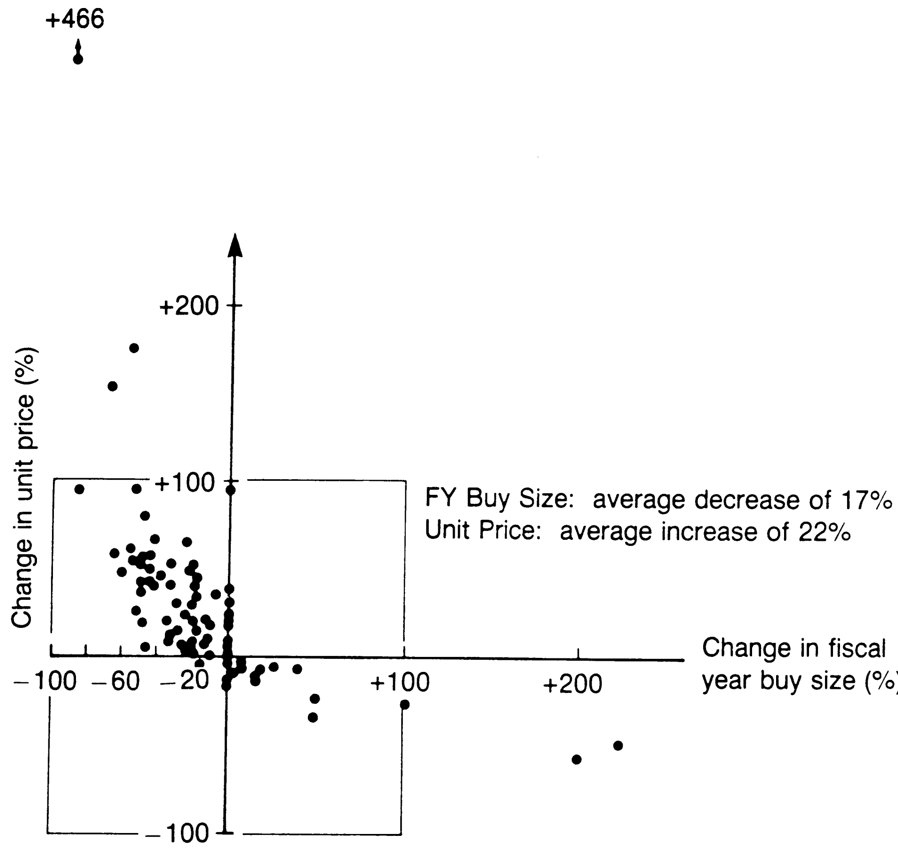


Fig. 14—Production rate instability and unit price growth (FY 1981–FY 1986)

their suppliers. Production cost with this technology is sensitive to both the magnitude of the production rate and (an underrecognized factor) to changes in production rate. Although some plants have been partly re-equipped and automated since the 1960s, defense manufacturing is still basically as inflexible as it was in World War II. Then it was highly successful in producing single designs in large quantities, over long periods of time, at low unit costs. This made good sense in the 1940s, when our strategy was to outproduce the enemy, when we bought thousands of weapon systems a year, and when designs were relatively simple and stable.

Now, however, we face a different threat and our basic defense strategy has changed. In a conventional war in defense of NATO, we would find ourselves outnumbered in both personnel and weapons. To win outnumbered, we rely on qualitative superiority—on forces using weapon, support, and control systems superior to those of our potential adversaries. Today we buy only hundreds—or perhaps only tens—of these systems a year; unit costs are high; and change (both in design and numbers purchased annually) is almost continuous. But to purchase today's small buys of weapon systems at reasonable cost, flexible production facilities are needed that can maintain high utilization rates and keep overhead rates low by producing a variety of different items, that can easily change the production rate of a given item, and that can quickly and cheaply adapt production to changes in design. Such flexibility, which substitutes economies of scope for economies of scale, is now becoming available in computer-integrated automatic manufacturing facilities—mainly in the nondefense sector. But there is still a basic mismatch between our defense production needs and the manufacturing facilities available to fulfill them, for most of these facilities are efficient only when they can produce stable designs at high production rates.

IV. A STRATEGY FOR STRENGTHENING THE ACQUISITION PROCESS

The interval between the initial recognition of a deficiency in our ability to defend our national interests and the fielding of an effective improvement in our weapons inventory can be well over a decade. The inevitable technical and environmental "surprises," together with our adversaries' attempts to thwart our advances, make weapon system R&D and procurement a process with many complicated and interrelated steps. Efforts to improve its overall effectiveness must therefore consider each stage of the complete process consistently so that changes in the process will work together toward the desired goal.

The following recommendations for change constitute an *integrated strategy.* No component of this strategy is novel, although each is currently an exception to general practice, at least in emphasis. Each of these actions could be considered a reform. But none alone would go far toward solving the problems we have identified. Improving the defense acquisition process requires coordination of effort to address each of these problems, and that is what this strategy aims to achieve.

- Improve the process of formulating requirements for needed operational capabilities.
- Make early development more austere.
- Separate critical subsystem development from platform development and use "maturational development."
- Encourage austere prototyping.
- Improve the transition from full-scale development to production through "phased acquisition."
- Focus more attention on upgrading fielded weapon systems.
- Place much greater emphasis on plant modernization and production flexibility.
- Continuously evaluate acquisition policy changes.

Although this recommended strategy has wide applicability across the range of weapon systems possessed by the military Services, it should not be rigidly applied, nor should it be viewed as a panacea. There are no easy or assured means of effectively responding to the emerging challenges to force modernization. However, this strategy should strengthen the acquisition process for almost every class of major weapon systems.[1]

IMPROVE THE PROCESS OF FORMULATING REQUIREMENTS FOR NEEDED OPERATIONAL CAPABILITIES[2]

Assessing the adequacy of our current and programmed military forces to counter an aggressively developing threat will always be a tremendously difficult undertaking. So will the formulation of operational concepts for obtaining needed improvements in military capabilities through new tactics and new systems or improvements to existing systems.

A strong, central, and coordinated focus is needed to exploit and integrate the unique capabilities of each Service, eliminate unnecessary and undesirable duplication, and assure common analytic approaches for dealing with a common threat. We need to continue and intensify not only recent initiatives emphasizing cross-Service mission area planning, such as the Joint Requirements and Management Board (JRMB), but also efforts to develop and demonstrate improved mission area analysis techniques. We should continue to elevate the role of the major operational commanders in the requirements formulation process, because of their warfighting responsibilities and their familiarity with current equipment capabilities and logistic limitations.

The growing importance of upgrades as a means of force modernization reinforces the need for planning that addresses entire categories of equipment (fighter aircraft, helicopters, and attack submarines, for example) rather than individual weapon systems. Such planning should consider the weapon system's missions, its predicted useful lifespan, and relevant technological trends in subsystems and components. There are several good examples of modernization plans that cover an entire equipment class; this approach should be followed much more systematically and comprehensively than in the past.

Force modernization planning has traditionally focused directly on the weapon system "platform" (or "vehicle"). This is unsatisfactory for several reasons. Force planning should first consider the general capabilities needed to underwrite U.S. strategies and commitments, and then examine preferred concepts of operations and the specific military capabilities implied by these concepts. Moreover, the weapon system

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[1]As noted earlier, the problems of ship acquisition may require a somewhat different strategy.

[2]Material in this subsection is drawn from Rand work contributing to the Defense Science Board 1984 Summer Study on Upgrading Current Inventory Equipment.

platform is by no means the whole system. The expansion of the combat environment, causing more and more of the support infrastructure to be at risk, means that the overall combat effectiveness of a weapon system in the future will be a function of more than the performance of the platform alone. The requirements formulation process should therefore be structured to more comprehensively exploit the possible tradeoffs among the various characteristics of the platform and its associated munitions, support systems, and basing modes in carrying out the concept of operations.[3]

MAKE EARLY DEVELOPMENT MORE AUSTERE[4]

Too often in the past, the Services have provided narrow and constraining guidance to the development community, making a diverse and imaginative menu of competing system concepts difficult or impossible. When concept validation efforts are initiated with detailed, technically oriented guidelines, these efforts are made needlessly expensive, the number of alternatives that can be explored is limited, and the designers' freedom to innovate is severely constrained.

Rather than beginning programs by stipulating a particular type of system or design and indicating the preferred technical solutions for achieving the desired system performance, the Services must find the discipline to limit early guidance to:

- Mission and general system performance requirements.
- Details of the expected operational environment.
- Constraints and targets for unit cost and critical support resources (such as airlift and sealift assets, airbase and harbor facilities, and skilled personnel requirements).

As mentioned earlier, this guidance should be structured so as to allow contractors to exploit tradeoffs among the characteristics of the whole weapon system, not just the platform. This will require substantial improvements in the way operational needs are stated before

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[3]For a discussion of the relation among defense planning, concepts of operations, and the acquisition of sytems with appropriate capabilities, see G. A. Kent, *Concepts of Operations: A More Coherent Framework for Defense Planning*, N-2026-AF, August 1983. For an illustration of the approach to requirements formulation that exploits tradeoffs among the characteristics of the platform and its munitions, support systems, and basing modes, see M. B. Berman with C. L. Batten, *Increasing Future Fighter Weapon System Performance by Integrating Basing, Support, and Air Vehicle Requirements*, N-1985-1-AF, April 1983.

[4]Information in this subsection is drawn from R. L. Perry et al., *System Acquisition Strategies*, R-733-PR/ARPA, June 1971; G. K. Smith et al., *The Use of Prototypes in Weapon System Development*, R-2345-AF, March 1981; and unpublished work by R. L. Perry and M. D. Rich.

demonstration and validation activities begin. Historically, the way operational needs have been expressed has not provided an adequate context for design tradeoff studies. Descriptions of the specific constraints expected in the operating environment, quantitative expressions for the desired operational suitability characteristics, and explanations of priorities among the various needs have been inadequate or lacking. Although this needed kind of early guidance is in some respects detailed, it is quite different from the guidance that called for a particular type of system and outlined its technical specifications.

Avoiding detailed technical specifications and drastically cutting paperwork requirements in the early stages of a program will promote creativity and reduce both government and contractor management costs. This approach has worked well in numerous "black" programs; it has also worked well in the few instances it has been seriously applied in "white" programs.[5]

Making the initial stages of new programs more austere is a key step toward increasing new program starts, increasing the number of different concepts evaluated in each program, and weeding out unpromising concepts before they attain too much momentum. The logic of exploring multiple alternatives within constrained resources requires that many alternatives be discontinued in timely fashion—something notoriously difficult to do unless the acquisition process is designed to facilitate it.

SEPARATE CRITICAL SUBSYSTEM DEVELOPMENT FROM PLATFORM DEVELOPMENT AND USE "MATURATIONAL DEVELOPMENT"[6]

For the foreseeable future, U.S. forces will be modernized principally by upgrading current weapon systems with new subsystems featuring higher levels of functional performance and superior reliability and maintainability characteristics. To assure the availability of an adequate menu of *mature* subsystem options for system upgrades, fundamental changes must be made in the way certain types of equipment are developed, especially combat-related electronics.

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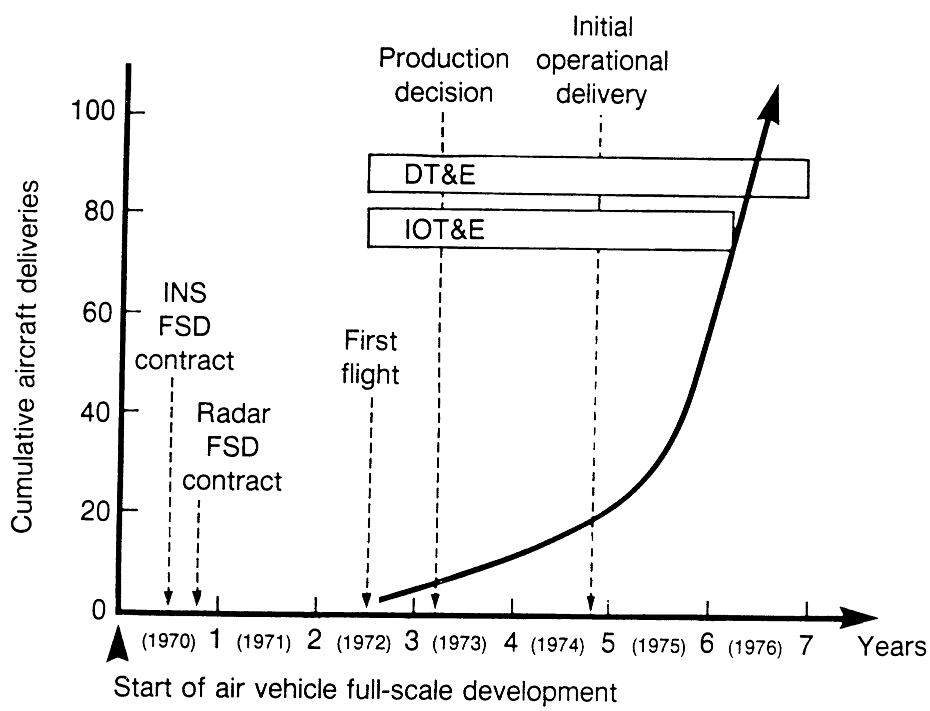
[5]The best recent examples are the Air Force's Lightweight Fighter and AX programs. See G. K. Smith et al., *The Use of Prototypes in Weapon System Development*, R-2345-AF, March 1981.

[6]Data in this subsection are drawn from D. W. McIver et al., *A Proposed Strategy for the Acquisition of Avionics Equipment*, R-1499-PR, December 1974; J. R. Gebman et al., *The Need for a Maturational Phase During Avionics Development*, R-2908-AF, forthcoming.

Currently, the full-scale development of electronic subsystems is begun well after the full-scale development of the platform in which they will be incorporated. This is so for both aircraft avionics and the increasingly sophisticated electronic equipment embodied in surface systems. Figure 15 shows the timing of avionics development for the F-15, which is typical of the way avionics have been developed for most other modern tactical aircraft. For the F-15, the air vehicle FSD began roughly eight months before the inertial navigation system FSD (see "INS" in Fig. 15) and roughly 11 months before the fire control radar FSD. In general, the developer of an electronics subsystem has less than two years to mature his equipment before it must be installed in a pre-production platform. The pace and phasing of subsystem development present difficulties not only for the equipment developer but also for the decisionmaker, because the unavailability or immaturity of



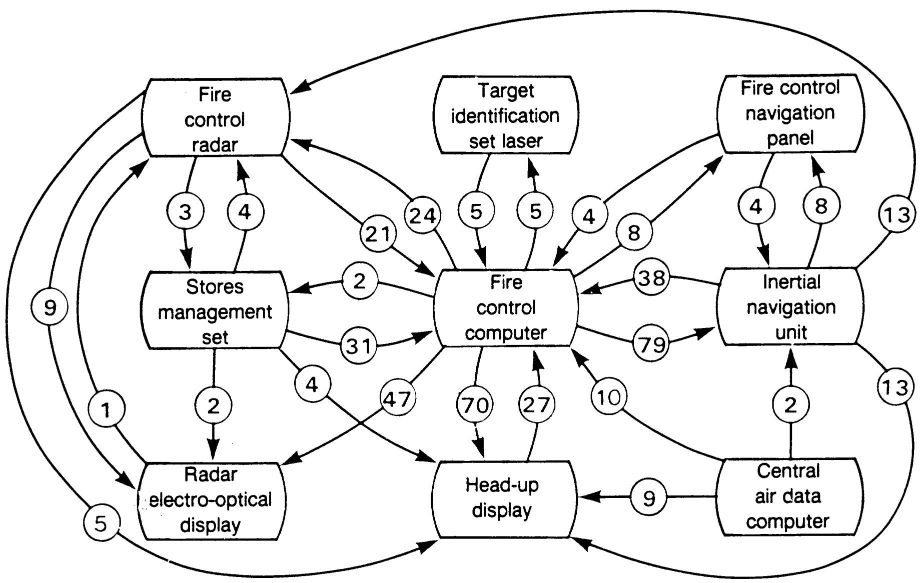
SOURCE: Various program documents; M. D. Rich et al., *Multinational Coproduction of Military Aerospace Systems*, R-2861-AF, October 1981.

Fig. 15—The timing of avionics and airframe development: The case of the F-15

critical subsystems and their associated support elements (support equipment, technical orders, etc.) during early testing detracts from the quality of the test information used in evaluating a system's readiness for production. The F-15 radar, one of the most critical subsystems on the aircraft, first flew in a pre-production F-15 just two months before the production decision.

This approach would be troublesome even if the challenge were only to develop individual electronics subsystems to high levels of functional performance. Now, however, for the levels of overall system performance necessary to counter the threat, our platforms feature sophisticated *integrated* electronics suites, consisting of many individual subsystems, each of which must be highly reliable. Figure 16 shows, for example, the interrelations among the fire-control computer and other subsystems of the F-16, certainly not the most complex of our contemporary fighter aircraft.

The need for systems that can sustain operations without large amounts of support from nearby logistics facilities is steadily



SOURCE: J. R. Gebman et al., *The Need for a Maturational Phase During Avionics Development*, R-2908-AF, forthcoming.

NOTE: The numbers in the figure refer to data word types.

Fig. 16—Complex interrelations among avionics subsystems: The case of the F-16

increasing, and this in turn means that system developers must achieve vastly better reliability and fault isolation capability than in the past. Figures 17 and 18 show the consequences of failing to provide adequate time to develop high levels of reliability and fault isolation capability.

Figure 17 records a three-month history of removals of avionics components from a fairly typical F-15.[7] Similar problems occur on the F-16 and on Navy fighters. With this F-15, there are repeated removals of the inertial measurement unit in the inertial navigation subsystem and of the receiver and the analog computer in the radar subsystem. These recurring removals reflect difficulties in isolating faults that may be noticed by pilots but that generally go unreported in our standard reporting systems. In practice, pilots continue to fly training sorties that do not require their inertial navigation and radar subsystems to function as fully as would be needed in wartime.

		Head-up Display	Inertial Navigation		Radar		SORTIES
Date	Component	Processor	Inertial Measurement Unit	Attitude Reference Gyro	Receiver	Analog Processor	
May	1						22
	6						
	10						
June	2						29
	3						
	4						
	5						
	10						
	11						
	22						
July							28

SOURCE: Special Rand-USAF data collection.
NOTE: Units removed and replaced are identified by the dark rectangles.

Fig. 17—Avionics removals from F-15 No. 7133

[7]During these three months, 49 percent of the F-15s in the 49th Tactical Fighter Wing had more removals per sortie.

Figure 18 records a three-month history of removals of avionics components from an F-15 experiencing more serious problems.[8] Here one observes the source of the frustration that sets in when maintenance personnel cannot identify and solve problems in avionics subsystems. In the case of this radar system, maintenance personnel repeatedly removed various components; then on June 11 they removed all components, but still they could not solve the problem.

For sophisticated electronics functions that are critical to the combat performance of our platforms—fire control radars, navigation and ranging, surveillance and target acquisition, electronic countermeasures, and the like—the approach should provide sufficient development iterations to ensure that the equipment meets the required level of reliability and maintainability. This approach is known as "maturational development." In the strategy we favor, the development of the

		Flight Control	Inertial Navigation	Head-up Display	Radar				SORTIES
Date	Component	Computer	Inertial Measurement Unit	Display	Receiver	Target Processor	Data Processor	Analog Processor	
May	1			■					9
	15			■					
	20	■				■			
	23						■		
June	5			■	■			■	4
	8				■				
	11				■	■	■	■	
	27						■		
July	2		■						27
	15							■	
	16					■			
	20						■		
	21						■		

SOURCE: Special Rand-USAF data collection.
NOTE: Units removed and replaced are identified by the dark rectangles.

Fig. 18—Avionics removals from F-15 No. 7109

[8]During these three months, 16 percent of the F-15s in the 49th Tactical Fighter Wing had more removals per sortie.

platform would be decoupled from that of critical electronic subsystems, so as to allow the necessary "head start" in their development.[9]

The required functional performance capabilities of the subsystems can usually be demonstrated within a single development cycle. That level of performance would then be "frozen." In the extra time made available by this approach, the subsystem would be subjected to as many cycles of design, test, and evaluation as might be needed to attain the required level of reliability and to demonstrate the required capability for fault isolation.

A look at the guidance subsystems for the Minuteman I and the Carousel Transport shows that problems with reliability, maintainability, and fault isolation do not result from the inherent nature of the equipment. Rather, they result from the process by which the equipment is developed.

The inertial guidance system for the Minuteman I met its functional performance goals after its initial development phase, but it experienced a mean time between removals (MTBR) of 600 hours. For an avionics (aircraft) subsystem, this would represent outstanding reliability, corresponding to almost two years of system availability in the field. For the Minuteman I, however, which must operate 8700 hours per year to be ready for immediate firing, an MTBR of 600 hours represented extremely poor reliability. It meant that the inertial guidance system had to be removed from the Minuteman once every 25 days and replaced with a new one, which had then to be warmed up and calibrated. Each time this occurred, the missile was out of service for about seven days. To solve this serious reliability problem, the functional performance of the Minuteman I's inertial guidance system was frozen, and a second development cycle was instituted solely for the purpose of improving reliability. This second development cycle yielded a 15-fold reduction in the removal rate of this subsystem.

A similar process was used for the Carousel's navigation system. Although it met its functional performance goals after its initial development phase, it experienced an MTBR of only 100 hours. To solve this problem, functional performance was frozen and a second development cycle was instituted; but that development cycle failed to yield an acceptable MTBR, so a third development cycle was instituted, which produced an MTBR of 1500 hours.

By contrast, the inertial navigation system for the F-15 has gone through only one development cycle—involving an investment of between $7 million and $8 million—with a resulting MTBR of only 75

[9]Maturational development without decoupling would often be desirable if only for retrofits, but to achieve its full benefits it is necessary to provide the early start that decoupling facilitates.

hours. The high removal rate of this subsystem is one of the major problems the F-15 faces in meeting its ambitious sortie generation goals and mobility requirements.

Maturational development—such as has been used successfully with many space and ballistic missile systems and with many electronic subsystems for commercial use—is the way to avoid such problems. It is essentially the same strategy that the Air Force has successfully adopted for turbine engine development. With such a development strategy, the "matured" building blocks become available in time to be used in more than one weapon system—in new systems and in upgrading systems already in the inventory. Not only is subsystem reliability improved, but the development of almost-duplicative subsystems can be avoided, and the test community can provide decisionmakers with more meaningful test results as inputs to the decision to proceed from development to production.

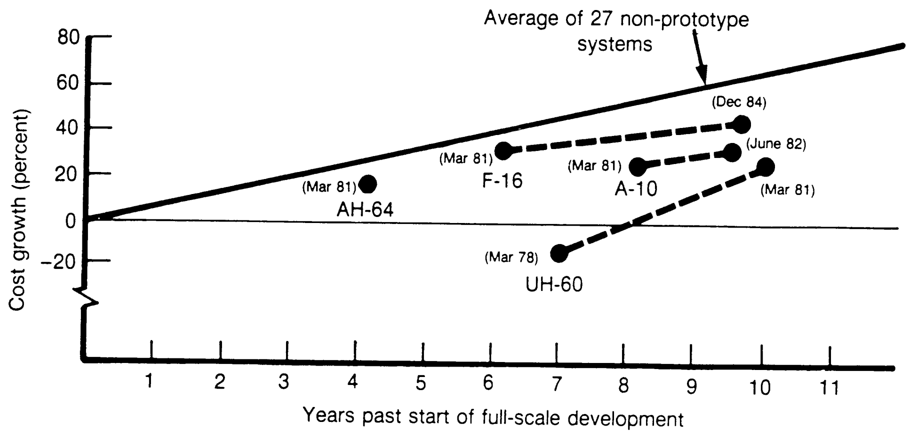
ENCOURAGE THE USE OF AUSTERE PROTOTYPING[10]

The use of full-scale demonstration models before formal full-scale development—sometimes known as "fly-before-you-buy"—has gone in and out of fashion over the past 40 years. Because its benefits usually outweigh its costs, as standard practice the Services should reinstate the building of full-scale models embodying the more risky design features and subsystems of the projected final weapon system.

Figure 19 illustrates a plausible relationship between prototyping and reduced cost growth by comparing the average cost growth of a sample of nonprototyped weapon systems with the cost growth of four prototyped aircraft of the 1970s: the F-16 fighter, the A-10 attack aircraft, the UH-60 Black Hawk helicopter, and the AH-64 Apache helicopter. In each case, the weapon system that used prototyping enjoyed a lower than average cost growth.

In most cases, the added costs associated with prototyping were modest compared with total program cost. See Table 4. The low costs of prototyping for the F-16 and the A-10 resulted from the Air Force's austere development approach. The higher costs of prototyping for the Apache and Black Hawk helicopters were the result of the Army's less austere development strategy with large program management offices and extensive documentation requirements. In the case of the Black Hawk, prototyping costs were approximately doubled because full-scale prototypes were developed by *two* competing contractors who were both funded throughout the full-scale development phase.

[10]Data in this subsection are drawn from G. K. Smith et al., *The Use of Prototypes in Weapon System Development*, R-2345-AF, March 1981.



SOURCE: Adapted from G. K. Smith et al., *The Use of Prototypes in Weapon System Development*, R-2345-AF, March 1981, with data later than March 1981 from Selected Acquisition Reports.

NOTE: Costs are adjusted to eliminate the effects of inflation and changes in procurement quantity.

Fig. 19—Cost benefits of prototyping

Prototyping seems to help in controlling cost growth, but its most important direct benefit is probably earlier and more confident identification of serious engineering problems. In the A-10 program, prototype flight tests revealed engine-inlet airflow distortion, unexpectedly high aerodynamic drag, problems with the stability augmentation system, and pilot dissatisfaction with the cockpit layout. In the F-16program, the prototype tests led to many refinements in the fighter's novel fly-

Table 4

PROTOTYPE PHASE COST AS PERCENT OF TOTAL ACQUISITION COST

Program	Percentage
F-16 aircraft	1
A-10 aircraft	3
AH-64 Apache helicopter	7
UH-60 Black Hawk helicopter	15

SOURCE: G. K. Smith et al., *The Use of Prototypes in Weapon System Development*, R-2345-AF, March 1981.

by-wire and autostabilization system, and significant modifications to the fuel control system. Prototyping also helps to enhance the accuracy of early cost estimates, the understanding of subsystem interface difficulties and requirements, and the overall effectiveness of program management. In short, this approach to early development, especially when coupled with the "maturational development" of critical subsystems, will greatly enhance the chances of success in the subsequent full-scale development phase.

If conducted austerely early in development, with minimal requirements for documentation and government supervision, a program with prototypes built by one developer, or even by several competing developers, can be conducted for a small fraction of the total acquisition cost. For a large program, that may be as little as 1 percent.

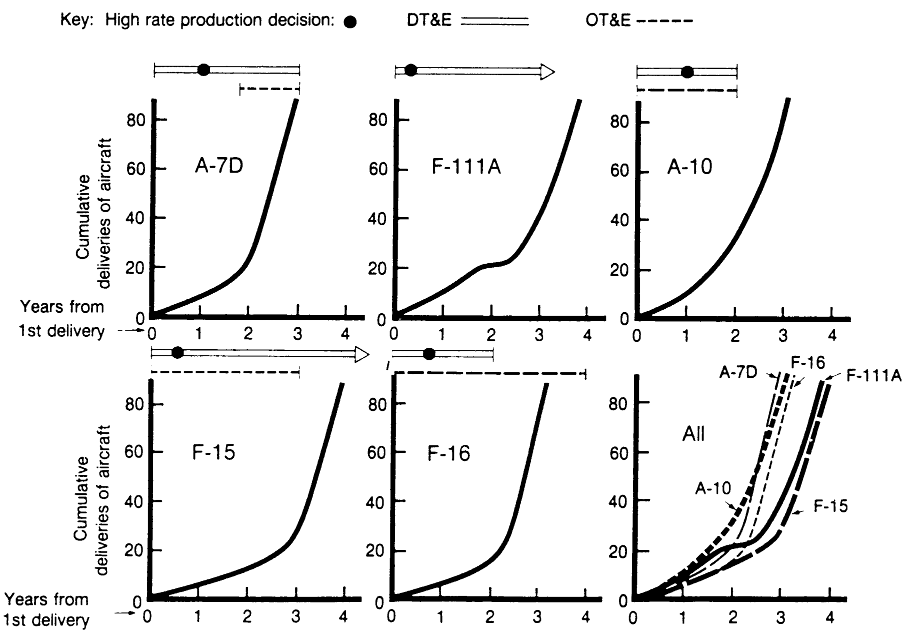
IMPROVE THE TRANSITION FROM FULL-SCALE DEVELOPMENT TO PRODUCTION THROUGH "PHASED ACQUISITION"[11]

The conduct of full-scale development has improved markedly over the years. The recent emphasis on independent and realistic operational testing is a major step forward. However, in the transition from full-scale development to production, the test results have typically not been fully used, because a commitment to high-rate production has been made well before development testing and operational testing were complete.

Figure 20 shows the delivery schedule of five tactical aircraft acquired by the Air Force over the years: The A-10 and F-16 used prototyping; the A-7D, F-111A, and F-15 did not. The bars above the panels represent the development and operational tests; the dots above the panels show the timing of the high-rate production decisions. This figure illustrates three features characteristic of the way the Air Force has traditionally managed the transition from development to production:

- High-rate production decisions occur long before the end of testing: usually before the end of development testing (DT&E), and sometimes even before the *beginning* of initial operational testing (IOT&E).

[11]Data in this subsection are drawn from J. R. Nelson et al., *A Weapon-System Life-Cycle Overview: The A-7D Experience*, R-1452-PR, October 1974; M. D. Rich and S. M. Drezner, *An Integrated View on Improving Combat Readiness,* N-1797-AF, February 1982; and A. D. Lee, *A Strategy to Improve the Early Production Phase in Air Force Acquisition Programs*, P-6941-RGI, December 1983.



SOURCE: Adapted from M. D. Rich and S. M. Drezner, *An Integrated View on Improving Combat Readiness*, N-1797-AF, February 1982; data based on various program documents.

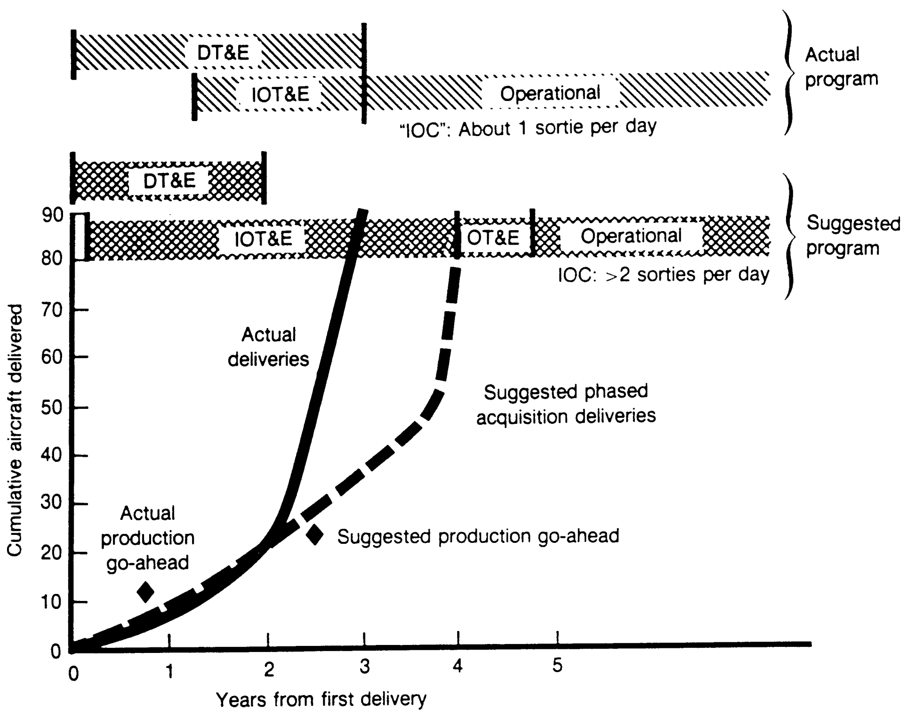
Fig. 20—Transition from development to production: The case of five aircraft

- Substantial numbers of units are produced and delivered to the field before the conclusion of testing.
- These patterns exist whether or not early prototyping is part of the development strategy.

By the time testing is concluded, test data fully analyzed, and desirable design changes identified, many units having the original system configuration are typically already in the field. It would be quite expensive to go back and incorporate the desirable changes in these units. For recent fighter aircraft, work in progress at Rand indicates that these costs could amount to several hundred million dollars for radar improvements alone. Faced with such costs, the Services have often chosen to live with the degraded system capability.

This failure to exploit available test information undermines the purpose of testing and, if continued, will *negate* the benefits to be expected from the recent testing initiatives[12] as well as reduce the advantages to be derived from austere prototyping. The decision to begin high-rate production must not occur so early that the lessons of operational testing cannot be exploited.

This means that one should plan for longer periods of low-rate production than in the past, but it does not imply a delay in the initial start of production activities. To exploit the usefulness of test information more effectively, we recommend the *phased acquisition* approach. Figure 21 shows how such an approach would have affected the A-7D aircraft program. The actual acquisition history of the A-7D is indicated by the solid line, the phased acquisition approach by the



SOURCE: Adapted from J. R. Nelson et al., *A Weapon-System Life-Cycle Overview: The A-7D Experience*, R-1452-PR, October 1974.

Fig. 21—Phased acquisition for the A-7D program

[12]The establishment of a directorate for Operational Test and Evaluation in the Office of the Secretary of Defense, for instance.

broken line. For fighter aircraft, the implication is that phased acquisition would postpone the high-rate production decision by something like 18 months so as to make good use of test data. Although such a delay decreases the number of aircraft reaching the field in the early years of production, this time can be used to increase the warfighting capabilities of the inventory as a whole. With the acquisition approach actually followed, the A-7D could generate about one sortie per day at the time of initial operational capability (IOC). With the phased acquisition approach, we estimate that the A-7D could have achieved a rate of more than two sorties per day.

With such an approach, the acquisition process would benefit from the identification and correction of many system performance problems that would otherwise receive insufficient attention or that could be corrected only later and at much higher cost. Another benefit would be the assurance that the final high-rate production decision, although occurring somewhat later in time, would be better informed. This would increase confidence in any decision to accelerate the inventory buildup by going to higher than normal production rates after the end of the low-rate production phase.

FOCUS MORE ATTENTION ON UPGRADING FIELDED WEAPON SYSTEMS[13]

The increasing importance of upgrading fielded weapon systems as the most cost-effective means of modernizing U.S. forces requires additional changes in the acquisition process. The Services need to collect engineering data in realistic operational settings throughout a system's operational life. This special extended form of "operational testing" should explore the system's suitability for combat in the full-range of plausible conflict environments. Because its purpose is to identify equipment deficiencies and needed enhancements of subsystem and system capabilities, this type of testing and analysis calls for much more active and direct participation by contractor design engineers during the system's operational phase than has been common in the past.

In the acquisition process, the last review by the Defense Systems Acquisition Review Council is now usually scheduled to occur *before* the beginning of high-rate production. Even with the introduction of a phased acquisition strategy—which would mean that substantial

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[13]For additional information on this topic, see *Improved Defense Through Equipment Upgrades: The U.S. and Its Security Partners,* Final Report of the 1984 Defense Science Board Summer Study on Upgrading Current Inventory Equipment, November 1984.

IOT&E results would be available *before* rather than after this review—this is still too early in the life-cycle of a modern weapon system to abandon controls at the level of the Office of the Secretary of Defense. There is therefore a case for introducing additional formal reviews—perhaps a DSARC IV—to stimulate and assess upgrade options and to review and approve proposals for major modifications and retrofits.

The emphasis on system upgrading should be formalized as a major feature of force modernization strategy. Upgrades should be explicitly encouraged in parallel with and in competition with new system programs. In many circumstances, this kind of "virtual" competition promises greater benefits than the usually much more costly method of supporting two prime contractors through full-scale development. It also increases flexibility in adapting to many of the uncertainties that surround the acquisition of defense systems.

PLACE GREATER EMPHASIS ON PLANT MODERNIZATION AND PRODUCTION FLEXIBILITY[14]

The defense industry in the United States has established world leadership in the design of weapon systems, but this advantage cannot be fully exploited because it is not supported by modern production facilities. Generally speaking, defense procurement relies on some of the oldest manufacturing plants in the United States, and the rate of investment in new equipment actually used for defense production appears to be quite low. This handicap is difficult to overcome, however competent contractor and Service managers may be, especially when there are frequent changes in design and production rate. It goes a long way to explain the high production costs, long flow times, and limited surge capabilities that characterize much of defense procurement.

Recommendations to improve the defense acquisition process have usually aimed at modifying the behavior of the buyer. We believe it is essential also to modify the behavior of the producer, especially his investment decisions. Although defense production has been automated to some degree since 1960, the kind of automation adopted has done little to increase flexibility in handling changes in production rate and product design. Substantial investment is needed in the new

[14]Material in this subsection is drawn from published work and work in progress by E. Dews and J. L. Birkler; see, e.g., Dews and Birkler, *Reform in Defense Policies: A Different View*, P-6927, November 1983.

manufacturing equipment that can quickly shift from item to item and produce very small quantities with nearly the same efficiency as traditional production lines can produce large quantities. In place of economies of scale, it achieves economies of scope through high utilization rates and distribution of fixed costs among different products. This emerging computer-integrated production technology[15] not only improves productivity, it also:

- Complements and interacts with computer-aided design to lower the cost and shorten the time required for the transition between development and production.
- Produces economically in small quantities (the goal is "economic quantities of one").
- Lowers the cost of design changes during production.
- Adapts quickly and cheaply to changes in production rate.
- Improves quality control.
- Provides the real-time data for improved factory management and cost control.
- Lends itself to production surges under emergency or mobilization conditions.

Flexible production technology is now ready to be applied to the manufacture (and repair) of many kinds of components, subsystems, and spare parts, and it holds the promise of much wider application in the near future. The modernization of defense manufacturing facilities should thus be a major element in any long-term acquisition strategy that emphasizes the *process* of development and production. Useful initiatives are now underway (IMIP, TECHMOD, MANTECH, and the like), but they represent only modest efforts with limited goals. New and more effective ways must be developed to invest in the kind of flexible plant that will be increasingly needed in the future, when it may be even more difficult to assure stable production rates than in the past, and when we will have to rely more and more on rapid system upgrades to maintain qualitative superiority. Among other steps to be taken, the Services should make sure that production technology is emphasized in the allocation of the funds they provide contractors for independent research and development and that flexible production facilities are emphasized in source selection as early as the beginning of full-scale development.

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[15]This production technology is variously known as a Flexible Manufacturing System (FMS), as Computer Aided Design/Computer Aided Manufacturing (CAD/CAM), or as Computer Integrated Manufacturing (CIM).

CONTINUOUSLY EVALUATE ACQUISITION POLICY CHANGES

The weapon acquisition process has for many years been the subject of frequent reviews and reforms, including important initiatives in the Reagan administration. Many recent changes have been substantial; almost all will require many years for their full effects to be felt. We are therefore in the position of having to assess the effect of changes during the course of a dynamic process. Although this fact should not—and does not—inhibit critical reviews, it should underscore the need for improvements in our ability to track, analyze, and evaluate the results of major changes in acquisition policy. That ability appears to be no better in the mid-1980s than it was in the 1970s.[16]

Although we have abundant mechanisms for following the fiscal and technical progress of acquisition programs, those mechanisms were not designed to isolate the effects of specific acquisition policies, procedures, and techniques. We should devise appropriate metrics and data systems, and assign responsibilities for both the day-to-day monitoring and the more in-depth analyses that are needed by senior managers and policymakers to assess the long-term effects of policy changes and to help in the initiation of new policies when the evidence shows that they are desirable.

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[16]For the situation in the 1970s, see E. Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, R-2516-DR&E, October 1979.

V. CONCLUSIONS

THE NEED TO BEWARE OF FALSE SOLUTIONS

The acquisition strategy we have recommended purposely excludes several approaches that have recently been advanced (in some cases through legislation) as worthwhile reforms:

- Mandated use of warranties for combat equipment.
- Mandated competition for prime contract awards.
- Centralized acquisition management in a single civilian defense agency.

Each of these reforms may have some value, but none directly addresses the fundamental problems of the defense acquisition process. None plays an important part in the integrated strategy we propose. Consequently, we believe that these reforms should not be allowed to divert energy from the task of strengthening the acquisition process along the lines we recommend.

Mandated Use of Warranties[1]

The concept of a warranty is naturally appealing and entirely appropriate for many types of products purchased by the defense establishment, especially "off the shelf" items. However, the notion that a warranty will ensure better design, development, and production practices, resulting in a more reliable product, is generally unfounded when applied to the acquisition process for combat equipment. For one thing, we can find little evidence that warranties have ever had a strong effect on subsequent design decisions, even in commercial applications where they have generally been marketing devices introduced well after the basic design features of the product have been established. Like all written contractual instruments, a warranty is most effective when the conditions that trigger its application are simply and unambiguously specified. It is not surprising, then, that most warranties apply only when a product suffers a confirmed total failure resulting solely from an intrinsic defect.

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[1]Material in this subsection is drawn from A. Gándara and M. D. Rich, *Reliability Improvement Warranties for Military Procurement*, R-2264-AF, December 1977; and work in progress by J. R. Gebman and H. L. Shulman.

Unfortunately for today's combat systems, performance degradations short of failure, and "false removals," are much more serious problems (from the standpoint of mission success and the reduction of system dependence on local logistic support) than are the rather rare events defined by the typical warranty clause. Although some progress has been made, it is generally quite difficult to phrase and enforce contractual clauses that would effectively address problems of this kind. The attempt to do so over a wide range of items is likely to proliferate litigation and make the relationship between the buyer and the contractor much more adversarial than is desirable. The steps necessary to minimize in-service performance degradations and maximize fault isolation capability are well understood and achievable, and they are part of the integrated strategy we recommend. These steps should be implemented *directly* rather than through attempts to use the indirect incentives of contractual language for their accomplishment.

As more is learned about the use of warranty clauses and as testing improves (especially the kind of extended operational testing we recommend), there may be a place for the increased use of warranties in the overall acquisition strategy. At best, however, their utility will be limited and their use should be highly selective. Mandating their general use will almost certainly be counterproductive.

Mandated Prime Contractor Competition in Production[2]

Prime contractor competition is frequently referred to in public discussions of acquisition policy reform, but the subject is nonetheless poorly understood. Most of these discussions fail to recognize the vigorous rivalry that occurs regularly during the early stages of almost every new weapon system program. They also tend to overlook the high cost of establishing production competition among prime contractors—a cost that the government must almost always bear.

It is true that "winner take all" competitions have generally produced cost savings[3] for the government buyer, but such competitions are appropriate only in limited circumstances: generally speaking,

[2]Material in this subsection is drawn from K. A. Archibald et al., *Factors Affecting the Use of Competition in Weapon System Acquisition*, R-2706-DR&E, February 1981; M. L. Beltramo, *Dual Production Sources in the Procurement of Weapon Systems*, P-6911-RGI, November 1983.

[3]Cost savings should not, of course, be considered the only benefits that might be derived from competition. The noncost benefits can include improved designs, reductions in technical risk, and hedges against threat uncertainty. But these benefits are obtained in substantial part from design rivalry among competing developers early in the development phase (especially if there is prototyping) or from virtual competition between new and upgraded systems.

where there are several competitors already qualified to produce or the costs of qualifying the competitors are low, the design of the product is well established, the contract is firm-fixed price, the total quantity can be determined in advance, and this total buy can be funded in the appropriations for a single fiscal year (or within the limits of multiyear procurement). The situation for major weapon system acquisitions is quite different. The cost of qualifying a second prime contractor is usually high, the product is produced over a period of many years during which development continues and the design changes, the size of the total buy is uncertain (especially early in production), and procurement funding depends on successive annual appropriations over a period of typically six or more years.

When carefully examined, past experience with "dual sourcing" (or "split buys") turns out to have been extremely mixed; its overall net cost benefits are doubtful and may even be negative, although there have been a few well-publicized successes and some current programs are claiming substantial savings. The evidence that qualifying dual prime contractors will result in lower net costs to the government is still too limited and uncertain to justify mandating dual sourcing as a general requirement for major system acquisitions.

If adopted as a *selective policy*, dual sourcing can no doubt contribute to the improvement of the acquisition process. The difficulty lies in the method of selection. The criteria for selecting those acquisitions where prime-contractor production dual sourcing can be expected to achieve savings are not yet well established; much research in this area is still needed. The evidence available so far suggests that it is much easier to establish such criteria for the production of parts and components than for major systems.

The uncertainties associated with high technology research and development, and the ever-present possibility that there will be a surge in the demand for defense items, suggest that it is important to exploit at least the less costly forms of prime-contractor rivalry, as we recommend in the use of austere prototyping and of virtual competition between new and upgraded systems. It is also important to foster more vigorous price competition among producers of parts, components, etc. in the lower tiers of the defense industrial base.

Centralized Acquisition Management in a Single Civilian Defense Agency

The distribution of responsibility for developing and managing resources among the various levels of the defense establishment is important and ought to be the subject of frequent review. When combat resources are involved, the criteria for assigning responsibility and authority should include wartime effectiveness as well as peacetime economic efficiency.

The question of whether to centralize research, development, and other acquisition functions in a single Department of Defense agency is a complex one. Some steps in the development process would no doubt profit from better coordination and collaboration. For many other steps, however, centralized administration offers no advantages and may even be counterproductive.

On balance, we believe the establishment of a single Department of Defense agency responsible for acquisition for all the Services is undesirable. The advantages of scale are irrelevant to most research and development activities, and the research and development organizations of the military Services are already quite large.

Proponents of centralization frequently note that most European nations have a single agency responsible for acquiring weapon systems for all their armed Services. Although that is true, it should not carry much weight in deliberations about whether the U.S. Defense Department should follow suit. Weapon program outcomes in Europe are generally less satisfactory than those in the United States,[4] especially in terms of schedule length and slippage during the development phase. Although there are examples of very successful acquisition programs and fine defense systems in Europe—Dassault's series of Mirage aircraft, for instance—those successes are best explained not by centralized acquisition management but by the application of a development process embodying many of the elements in the prescription outlined above.

It is sometimes claimed that more civilianization of defense acquisition management would be beneficial. But the record of nonmilitary agencies with large scale acquisition functions is by no means superior to that of the Department of Defense—on the contrary. Moreover, the knowledge and insights of the military users are critical inputs to the acquisition of weapon systems. User inputs probably receive insufficient attention even today, and it is difficult to believe that the interests of the users would be better represented by a more civilianized management.

A better approach to meeting the serious challenges of the future is to focus on the acquisition *process* itself: increasing early coordination

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[4]See M. D. Rich et al., *Multinational Coproduction of Aerospace Systems*, R-2861-AF, October 1981; R. L. Perry, *A Dassault Dossier: Aircraft Acquisition in France*, R-1148-AF, September 1973.

and collaboration among Services in the requirements formulation phase (with the Office of the Secretary of Defense, the Organization of the Joint Chiefs of Staff, and the commanders of major operational commands playing a heightened role) and making the other improvements recommended here for strengthening the subsequent phases of the acquisition process.

THE NEED FOR AN INTEGRATED APPROACH

Past experiences involving cost growth, schedule slippage, performance shortfalls, and acquisition intervals suggest that the acquisition process has been more successful than many critics have claimed. However, the observable trends involving escalating enemy threats, resource constraints and uncertainties, longer retention of weapon systems in the active inventory, and increased production cost difficulties suggest that major weapon systems—and the process by which they are acquired—will face increasingly serious challenges.

To meet these challenges, we argue that the Department of Defense and the Services should not rely on such erroneous "solutions" as mandated use of warranties for combat equipment, mandated competition for prime contract awards, and centralized acquisition management in a single civilian defense agency. Rather, what is needed is the adoption of an integrated strategy focusing on the acquisition *process* and including each of the following elements:

- Improving the formulation of requirements for needed operational capabilities.
- Making early development more austere.
- Separating critical subsystem development from platform development and using "maturational development."
- Encouraging austere prototyping.
- Improving the transition from full-scale development to production through "phased acquisition."
- Focusing more attention on upgrading fielded weapon systems.
- Placing greater emphasis on plant modernization and production flexibility.
- Continuously evaluating acquisition policy changes.

RAND/R-3373-AF/RC