STREAMLINING DOD ACQUISITION: BALANCING SCHEDULE WITH COMPLEXITY

edited

by

James R. Rothenflue, Lt Col, USAF

and

Marsha J. Kwolek

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Foreword

Since at least the late 1960s, the Department of Defense has been trapped in an escalating cycle of cost overruns and schedule delays on large acquisition programs. In particular, state-of-the-art aircraft programs have ballooned from one to five year sprints during and immediately after World War II to the 25-year marathons of the present day. An aerospace force that once blackened the skies over Europe with tens of thousands of aircraft of all shapes and sizes and swelled our nation's nuclear deterrent with thousands of leading-edge missiles and warheads now struggles to purchase a few dozen modern bombers, barely 150 fighters, and a few hundred airlifters and tankers despite enormous outlays over the last 20 years. Over this time, the average age of operational USAF aircraft has grown from just a few to approximately 24 years, and seems inevitably bound to approach 40 years within decades. In response to these trends, a parade of commissions and surveys, marching to a seemingly perpetual acquisition reform drumbeat, have proposed a dizzying array of cures for the gamut of ills effecting the acquisition corps. Yet despite these heroic efforts, program schedules and costs continue to grow, confounding even the sharpest minds of American industry.

The United States has so far been able to compensate for this growing inefficiency by leaning on the massive industrial might of the world's greatest economy. Unfortunately, it appears that the age of defeating our enemies by outspending them is ending. To begin, the American share of the world's economic output has been steadily shrinking since the end of World War II, and some estimate that the United States will be replaced by China as the world's largest economy by the year 2030 and may well slide into third place behind India by 2050. If these estimates are even approximately correct, we will no longer be able to rely on overwhelming defense outlays to protect our nation within the careers of many of the new Airmen entering the service today. Next, and even more compelling, is the fact that the strategic environment itself is changing, and the rules of the national defense game with it.

A growing chorus of academics and theoreticians are raising an alarm that the world has already entered an age in which the traditional measures of national power are no longer valid. Unfortunately, contemporary military practitioners study a craft which evolved through the agricultural and industrial ages. A common thread through these ages has been that a nation's likelihood to prevail in war is dominated by its ability to deploy and employ more men and materiel on the battlefield than its adversaries. Complex theories evolved describing the efficient transport, supply and employment of large forces—great nations moving mountains of "stuff" with which to crush their enemies. Certainly, military genius, terrain, politics, and tricks of fate have often conspired to produce victories for the lesser over the greater, but the material qualities of greatness have remained essentially unchanged throughout history. But now, harbingers like Ray Kurzweil, Joel Garreau, Thomas Barnett, Thomas Friedman, and others point to a shift in the equation of national power – a dramatic shift away from quantity to quality. Specifically, they employ the concept of "accelerating change" to describe a world in which radical and disruptive technological innovations become routine and occur with increasing frequency. In the extreme case of this analysis, the point is eventually reached in which any numerical advantage by a business or army can be overcome by even a small adversary with sufficiently up-to-date technology. From a military perspective, this future includes hyper-empowered individuals and groups, armed with the latest generation of cell phones, internet devices, lethal and non-lethal bombs, personal computers, and cheap nano and bio technologies capable of defeating "great" nations employing armies, navies, and air forces equipped with legacy hardware. In this future, change itself has become the "stuff" of war.

Even if one doesn't accept the asymptotic case of Kurzweil's "singularity," the growing importance of quality (perhaps "modernity" is a better word in this context) was clearly evident in the waning years of the Cold War. The United States overtly and successfully relied on modern military technologies to overcome significant Soviet numerical advantages. Despite inefficient acquisition practices, the US used its economic muscle to ram new technologies into its order of battle 10 to 20 years ahead of the even less efficient Soviet Union. This qualitative advantage proved to be more than sufficient to compensate for relatively few fielded troops, tanks, missiles and aircraft. The importance of this fact is often overlooked. Never before has one nation been able to consistently maintain an advantage over a numerically superior adversary over time, primarily by placing technologies in the hands of its warfighters that were only 20 or so years more up to date. Episodic disruptive technologies notwithstanding (i.e. the iron sword, the longbow, gunpowder, the breech loading rifle, etc), 20 year differences in weapon technologies were inconsequential until the 20th century. In principle, according to the theory of accelerating change, the military advantage conferred by 20-years more up-to-date hardware in the 20th century is the same as that conferred by, say, 200-years more advanced technology in the year 1800, 2000 years more advanced technology for the early Roman Empire, and will be the same as that conferred by only 2-years more advanced technology in the mid 21st

century. Although these notional timelines can be debated, it stands to reason that attempting to defend oneself with the product of a 25 year acquisition cycle in the year 2040 may well be about as effective as attempting to resist the advance of Hitler's Blitzkrieg with swords, knives and spears. It doesn't matter how many knives and spears your massive economy can produce – you lose.

Thus the motive for the studies contained in this volume. Among its several research thrusts, the Air University Center for Strategy and Technology continues to examine the need to transform defense acquisition to prepare for a future of accelerating change. For nations to survive in this "Age of Change," they must shed the inertia built into their industrial age acquisition processes. The three researchers represented herein were each given a clean slate and assigned the task of defining a vision for transforming today's pedantic acquisition system into one with the agility to outmaneuver even the most technologically savvy 21st century adversary. Three different visions emerged.

All authors agreed that the DoD acquisition system must become more agile in response to a rapidly changing strategic environment. In the first paper, Col Alvin Drew argues that Congress must scrap the entire slate of overly restrictive and prescriptive acquisition laws and regulations in order to allow the DoD to create a doctrinal environment in which program managers can more efficiently respond to changing conditions. In effect, his argument describes a contemporary acquisition environment analogous to a fighter pilot being forced clear all changes in speed and heading with Air Traffic Control during a dogfight. The second paper, penned by Maj Robert Dietrick, asserts that increasing weapon system complexity is the primary driver behind long acquisition cycles and describes how this complexity might be better managed. Finally, in the third paper, Maj James "Judge" Chittenden identifies the "Cost as an Independent Variable" philosophy as the main culprit in recent program cost and schedule overruns. Instead, programs should be schedule driven, demoting cost and performance to dependent variables in the process. It is left to the reader to dissect these arguments and determine which of these visions are true, or whether these are simply three more anonymous voices in the raucous din of acquisition reform.

-Lt Col James Rothenflue, USAF

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Chapter 1
A System as the Enemy: A Doctrinal Approach to Defense Force Modernization

By

Colonel Benjamin A. Drew, Jr., USAF

Force modernization is more like a warfighting campaign than an industrial process. Volatility, uncertainty, complexity, and ambiguity inherent in all its key factors and enablers make modernization as much an operational art as a scientific method. Therefore, modernization, like warfare, would operate more effectively and responsively under an authoritative body of doctrine rather than under layers of detailed prescriptive and legally binding regulations.

At the core of a body of doctrine is a foundational doctrine document putting forth broad guidance with fundamental principles to guide planning and execution. This study will consider principles, presented below, as candidates for such a document.

<u>Principles of Modernization</u>

1. Objective
2. Stable Program Inputs
3. Risk Management
4. Simplicity of Command
5. Economy of Effort
6. Initiative
7. Credibility
8. Synergy
9. Tempo
10. Synchronization

Together, these are the fundamental and underlying doctrinal principles for an effective and efficient force modernization program. These principles can guide modernization process improvement efforts as well as modernization programs to shorten program timelines and still deliver a quality product.

Force modernization here includes the Joint Capabilities Integration and Development System (JCIDS), formerly the Requirements Generation System, and the US Department of Defense (DoD) acquisition process. With respect to JCIDS, this paper is concerned only with material solutions feeding into the acquisition system. The analysis does not include doctrine, operations, training, leadership & education, personnel, and facilities solutions to documented needs.

The Coming Apoplectics: Shock and Awe for Modernization

The DoD acquisition process is currently in its fourth decade and fourth generation of overhaul. The policy underpinnings, the DoD 5000-series and Chairman of the Joint Chiefs of Staff (CJCS) 3710-series instructions, have been completely rewritten. They focus now on a top-town modernization process and mission needs (now "capabilities") spawned from mission area Concepts of Operation (CONOPS) for achieving strategic objectives.

Further, force modernization directives now emphasize evolutionary acquisition, system upgrades, development spirals, and incremental deployment of new systems' capabilities. This purports to bring new capabilities to field and fleet sooner—as soon as they become available as subsystems, rather than after the last capability is integrated into an entire end-system.

This force modernization is parcel to the overall defense transformation. At the heart of this effort is the concept for networking all the levels of command and all of the warfighting actors in order to achieve shared situational awareness, to overcome barriers to rapid communication, including stovepipes, and to tighten decision (Observe-Orient-Decide-Act [OODA]) loops to reflex-arc speeds that literally shock an opponent into paralysis through lightning-fast responsiveness. This prescription for warfighters, which DoD's force modernization process is to deliver, is appropriate medicine for the modernization process itself. *Force modernization itself needs to tighten its own decision cycle to keep itself from being shocked into paralysis due to its increasingly glacial responsiveness to increasingly dynamic warfighter needs*.

Acquisition Program Timelines: Too Long and Getting Longer

In 1986, Packard Commission member and future Secretary of Defense William Perry lamented the unacceptably long times, 10 – 15 years, required to field major defense systems. (45:8) Since then, F-22 development has spanned 24 years (7:4), and the V-22 should achieve Initial Operating Capability (IOC) in 2007, after 27 years of development. (20) The RAH-66 Comanche was cancelled in February 2004, due to mission obsolescence, 21 years after program inception. (21) The Joint Strike Fighter faces a similar timeline of development. With acquisition timelines now trending towards 20 – 25 years from identifying mission needs to fielding a proper fix, 10-15 years of development seems optimistic.

Dynamic Strategic Environment: Time-to-Need Increasingly Shorter

At the same time, the security environment is increasingly dynamic. Weapons coming to the flightline, field, and fleet in this decade were specified to counter threats from the Soviet Union: before the advent of humanitarian operations, before the internet, before stabilization operations, before Al Qaeda, homeland security, or even satellite or cable television. How appropriate will solutions to present-day deficiencies be between 2025 and 2030?

Increasingly, DoD future plans documents have shortened their forecast horizons from 25-year looks-ahead to ones looking out 10 – 15 years. Thus, the situation has reversed from the late 1980s, where the forecast included the first 10 – 15 years of a developing system's existence, to one in which a new system's IOC happens 10 – 15 years beyond the forecast horizon. Given this, *the dominant risk to any program is time itself*.

A review of exemplary successful historical acquisition programs reveals a common key factor among them: they benefited handsomely from stable external factors over their development phases. However, requirements, funding, personnel, and technology become increasingly volatile influences to programs with developments lasting a quarter-century or more. It's a vicious cycle that starts with planning for a lengthy program (ironically to avoid developmental risk). Lengthy programs' performances suffer from unstable influences, and program performance problems cause the program to get stretched out further. *The answer to this volatility is not necessarily to stabilize the process inputs and perturbations (it's beyond control), but to field solutions faster than the environment can change*. Short programs require agility—speed and flexibility—only afforded through having actors with unambiguous goals and latitude-in-action in novel circumstances. This latitude is available under doctrinal guidance in ways not possible with prescriptive regulations.

On Modernization: The Case for Doctrinal Principles

> *Warfighting doctrine emphasizes centralized control and decentralized execution. We seem to operate the acquisition system in direct opposition by implementing decentralized control and centralized execution of key macro processes. We manage the requirements and technology processes in a decentralized fashion, while exerting tight and central controlling on program management and budget (particularly for large programs). (11:57)*

Can disciplined force modernization replace current and future statutory and regulatory directives with doctrinal principles? For this to be true, modernization would have to have characteristics in common with warfighting such that a body of doctrine would be similarly useful.

According to historian Martin Van Creveld, applying the logic of industrial processes to warfare is dangerously myopic. Whereas industrial processes are repeatable, that is, the same input yields the same output, warfighting strategy is not, so long as it is a contest among two living wills. While manufacturing endeavors to achieve optimal production efficiency, combat must entail tremendous waste and slack as hedges against overwhelming uncertainty. While industry is the very epitome of determinism, warfare is anything but predictable. (57:311-320) An additional consideration is the consequences of failure. Commercial failures end in bankruptcy; failures in warfare result in loss of lives and often in the destruction of the losing state. Likewise, any single force modernization failure is a loss of taxpayers' revenues and warrior capability. But the fate of the Soviet Union is a cautionary example of how inability to keep modernization apace with a rapidly changing security environment can lead to extinction.

What happens at the interface of industry and warfare, where determinism meets friction and chance? A process that bridges the battlefield and the assembly line should be subject to principles from both environments, and the closer the process operates to one environment, the greater weight that environment's principles come to bear. Much of top DoD acquisition management comes from industry, and the language and guidance from them has a distinct industrial flavor: *streamlined processes*, *benchmarking,* and *business models*. The requirements generation community led by service generals has a distinctly different lexicon: *strategy*, *CONOPS,* and *campaigns*. Bridging the two force modernization communities requires a construct that includes operational art and industrial science, production line efficiency, and battlefield chaos. A body of doctrine would function to bridge and encompass these disciplines. It would clarify, to modernization's actors, the context in which they operate. It would give them guidance and latitude in interpreting their location along the process' continuum, from the laboratory to the battlespace, and in applying governing guidance with due weight. It would guide the novices and liberate the masters of the art to do what's best to meet their strategic goals.

Knowledge management databases, Defense Acquisition University guides, "Best Practices" lists, and statutory and regulatory guidance already capture much of the enduring lessons of force modernization history. What a doctrine document does is to redact that large body of literature into a concise handbook, as an introduction for novices and a ready reference for practitioners. A singular volume of doctrinal guidance is definitive, a source of ground truth, for creating policy, interpreting guidance, resolving dilemmas, and generally giving a sense of coherence to the welter of widely disparate simultaneous activities constantly undertaken in the name of force modernization.

The force modernization community and its processes are large and complex, facing the same challenges as large military units in the field: volatility, uncertainty, complexity, and ambiguity, if to a lesser degree. Operational commanders work with the understanding that their influence on battlefield events is at best second-order; they cannot control them directly. They give broad guidance (commander's intent), set boundaries (rules of engagement), and do their best to create conditions for those on the front echelons to succeed. In de-centralized execution, they *support* those peripheral echelons.

Much of acquisition has worked the other way around. The citation below implies that the need for central planning and control (i.e., generating requirements from the top down) was an undesirable aberration.

> *Secretary McNamara was hard pressed to get the Services to write requirements for more conventional weapons in lieu of nuclear weapons and therefore found himself and his staff in the business of writing requirements for the Services* (McNaugher 1989:59). (29:41)

Except in rare cases, those in the periphery identify the requirements; and acquisition executives execute centrally, requiring support from the program offices. Thinking of force modernization in its true dual nature – science and art, industrial and martial – would go far to help policymakers resist the temptation to "drive" the process.

> *[W]e need to return the military service chiefs to the chain of command for acquisition… OSD should not be running things, but overseeing procedures and decisions*. (23:74)
>
> Hon John Hamre, former Deputy Secretary of Defense

By not being prescriptive, doctrinal guidance gives innovative solutions the necessary latitude in novel situations. Innovators would then only risk having their judgment questioned – not their lawfulness – should they need to break with traditional guidance. And that wiggle room provides just the flexibility and responsiveness necessary to keep decision cycles short. Finally, the common sense that legislators and policy-makers try to capture in modernization policy and instruction better resides in a non-binding doctrine document. This serves to limit the scope of directives and instructions to only the truly mandatory guidance and to better highlight them as legal boundaries.

Modernization Principles Evolution: A Brief History of Acquisition Reform

A body of doctrinal principles exists – waiting to be explicated. They are the critical aspects of modernization, enduring and frequently repeated, such that these principles emerge as a pattern over time. The raw data containing those enduring fundamentals reside both in program case histories and in government efforts at acquisition reform. This section mines results from acquisition reform commissions' findings and recommendations for a list of candidate principles for force modernization.

Round One (1969 – 1972): Containing Cost

While the history of DoD transformation, reorganizations and reengineering date back to the National Defense Act of 1947, initiatives specifically for reforming acquisition start in 1969 with Congress mandating Selected Acquisition Reports from the Secretary of Defense. Straining under the costs of the Vietnam War, Great Society social spending, and the Apollo moon landing program, Congress began to question Cold War weapons procurement practices. The result was a series of commissions to investigate inefficiencies in the acquisition process. (29:44) In the first of them, in 1970, Undersecretary of Defense David Packard put forth the list of initiatives in Table 1. (29:45)

Table 1: 1970 Packard Initiatives

Improve the quality of information available from development.

1) Use more hardware testing.
2) Establish operational test and evaluation agencies separate from developing commands
3) Establish the Cost Analysis Improvement Group (CAIG) within OSD to improve the quality of cost estimates during development.

Enhance program flexibility.

4) Practice "design-to-cost."
5) Account for all "life-cycle costs."
6) Strengthen Program Manager (PM) independence and lengthen their tenures.
7) Reduce production concurrency…fly before you buy.

Restore competition to weapons acquisition.

8) Reduce risk and stimulate contractor efforts during development.

9) Prime-contractor competition through full-scale development to avoid developer monopoly at the time the initial production contract is negotiated.
   -- Regulate the OSD's involvement in acquisition.
10) Establish a Defense System Acquisition Review Council (DSARC). It shall meet to approve the start of development (DSARC I), meet again to decide on full-scale development (DSARC II), and meets a third time to approve the move to production.

At about the same time, a presidential Blue Ribbon Commission, "The Fitzhugh Panel," released their recommendations and findings from their 1969 investigation. (29:46) The following recommendations related to the acquisition process are in Table 2. (29:47)

Table 2: 1969 Fitzhugh Commission Recommendations

1) Decentralized Authority:
   Observation: Effective civilian control is impaired by the generally excessive centralization of decision-making authority at the level of the Secretary of Defense.
   Recommendation: The functions of the Department of Defense should be divided into three major groupings: Operations, Resource Management, and Evaluation…Each of these major groups should report to the Secretary of Defense through a separate Deputy Secretary.

2) Operational Test and Evaluation (OT&E):
   Observation: OT&E has been too infrequent, poorly designed and executed, and generally inadequate.
   Recommendation: A defense test agency should be created to perform the functions of overview of all Defense test and evaluation … with particular emphasis on operational testing, and on systems and equipments which span Service lines.

3) Career and Professional Development:
   Observation: The promotion and rotation systems of the Military Services do not facilitate career development in the technical and professional activities.
   Recommendation: Specialist career should be established for officers in such staff, technical and professional fields as research, development, intelligence, communications, automatic data processing and procurement…the duration of assignments for officers should be increased, and should be as responsive to the requirements of the job as to the career plan of the officer.

4) Research and Development:
   Recommendation: A new development policy for weapons systems and other hardware should be formulated and promulgated to cause a reduction of technical risks through demonstrated hardware before full-scale

development, and to provide the needed flexibility in acquisition strategies.

5) Program and Project Management
Recommendation: The effectiveness of program or project management should be improved by:
   a) Establishing a career specialty code for program managers in each Military Service and developing selection and training criteria that will ensure the availability of an adequate number of qualified officers. The criteria should emphasize achieving a reasonable balance between the needs for knowledge of operational requirements and experience in management;
   b) Increasing the use of trained civilian personnel as program managers;
   c) Providing authority commensurate with the assigned responsibility and more direct reporting lines for program managers, particularly those operating in matrix organizational arrangements; and
   d) Giving the program manager directive authority, subject to applicable laws and regulations, over the contracting officer, and clarifying the fact that the contract auditor acts in an advisory role.

The final installment to the first group of acquisition process investigations was the Commission on Government Procurement. (29:48) Their findings, published in 1972, contained the recommendations presented in Table 3. (29:49)

Table 3: 1972 Commission on Government Procurement

1) General Procurement Considerations:
   a. Finding: Void in policy leadership and responsibility and a fragmented and outmoded statutory base.
   Recommendation: Create the Office of Federal Procurement Policy within the Office of Management and Budget.
   b. Finding: The military procurement is governed by the Armed Services Procurement Act of 1947, but civilian procurement came under the Federal Property and Administrative Services act of 1949. There are inconsistencies between the two statutes.
   Recommendation: Enact legislation to eliminate inconsistencies
   c. Finding: There is a burdensome mass and maze of regulations
   Recommendation: Establish a system of government-wide coordinated and uniform procurement regulations under the direction of the Office of Federal Procurement Policy.

2) Research and Development Acquisition:
   a. Recommendation: Emphasis should be placed on basic, innovative research and the sharing of new ideas among govern-

ment agencies. There should be more cooperative industry-government relationship which maximizes the creative energies of U.S. suppliers.

b. Finding: In cost allowability principles, the independent research and development (IR&D) and bid and proposal (B&P) expenditures are in the nation's best interest to promote competition, to advance technology, and to foster economic growth
Recommendation: Establish a policy recognizing IR&D and B&P efforts as necessary costs of doing business.

3) Acquisition of Major Systems:

a. Finding: Too often the focus has been on the system product and not on its purpose…adequate attention [not given] to why and what new level of capability is needed.
Recommendation: Start new system acquisition programs with agency head statements of needs and goals.

b. Finding: Funds spent on development of alternative systems serve as insurance against the possibility of a premature and potentially costly choice involving only one system.
Recommendation:
   i) Create alternative system candidates;
   ii) Finance the exploration of alternative systems; and
   iii) Maintain competition between contractors exploring alternative systems.

c. Finding: The cost to maintain competition throughout rises substantially. Thus, systems entering production and deployment normally do so under an evolved monopoly situation, with only a single system and contractor to meet the need.
Recommendation: Procuring agencies and Congress should withhold approval for full production and use of new systems until the need has been reconfirmed and system performance has been tested and evaluated in an environment closely approximating the operational conditions.

d. Recommendation: Alleviate the problem of management layering and excessive staff reviews.

e. Recommendation: Strengthen each agency's cost estimating capability

Round Two (1981 – 1982): Avoiding Risk

It would be another 10 years before the next spate of commissions on acquisition reforms. News of overpriced hammers and toilet seats, along with a number of difficult and failed major acquisition programs in the late 1970s, gave cause for further investigations and initiatives. (29:53) The first of these were a list of initiatives from Secretary of Defense Frank Carlucci in 1981, presented in

Table 4. (29:54)

Table 4: The Carlucci Initiatives

1. Acquisition Management Principles.
    - *Long-range planning*
    - *Delegating responsibility, authority and accountability*
    - *Low-risk evolutionary technology*
    - *Economic production rates*
    - *Budgeting realistically*
    - *Improving readiness and sustainability*
    - *Strengthening the industrial base*
    - *Good relations with industry*
2. Pre-planned Product Improvement (P3I).
    This initiative is designed to ensure an evolutionary, lower-risk approach to weapon system design in order to reduce unit costs and decrease the time needed to field new equipment.

3. Multiyear Procurement.
    This initiative is designed to reduce the cost of mature, low-risk weapon programs already in production by funding economical lot buys instead of small, piecemeal, annual buys.

4. Program Stability.
    This initiative is designed to increase the stability of weapon system acquisition by adequately funding Research and Development (R&D) and procurement in order to maintain the established baseline schedule and reduce cost growth.

5. Capital Investment.

This initiative encourages, through a variety of mechanisms, capital investment by DoD contractors to increase their productivity.

6. Budget to Most Likely Cost.
   This initiative is designed to achieve realistic defense acquisition budgets, reduce apparent cost growth in weapon systems, and achieve greater program stability.

7. Economic (Stable) Production Rates.
   This initiative involves buying weapon systems at a rate that assures economical production and reduces unit costs.

8. Appropriate Contract Type.
   This initiative balances program needs and cost savings with a realistic assessment of contractor and government risk by insuring the use of the appropriate contract type.

9. System Support and Readiness.
   This initiative involves establishing readiness objectives for each weapons development program and then designing in reliability and maintainability.

10. Reduced Administrative Costs.
    This initiative reduces the administrative cost and time for procuring items by raising the dollar limit on purchase order contracts and cutting unneeded paperwork.

11. Technological Risk Funding.
    This initiative provides for evaluating, quantifying, and budgeting for technological risk.

12. Test Hardware Funding.
    This initiative requires that adequate test hardware be obtained to reduce overall schedule time and risks.

13. Acquisition Legislation.
    This initiative calls for a review of acquisition-related laws and regulations to identify and change those which are an unnecessary burden on the DoD acquisition process.

14. Reduced Number of DoD Directives and Eliminate Non Cost-Effective Contract Requirements.
    This initiative requires a reduction in the number of DoD acquisition directives and the amount of contract documentation, and non cost-effective contract requirements.

15. Funding Flexibility.
    This initiative involves obtaining legislative authority to transfer funds from procurement to R&D for an individual weapon system without the prior approval of Congress.

16. Contractor Incentives for Reliability and Support.
    This initiative requires that incentives be developed to encourage contractors to improve reliability and support.

17. Decreased Defense Systems Acquisition Review Council (DSARC) data.*This initiative requires that DSARC briefing and data requirements be reduced.*

18. Budgeting for Inflation.
    This initiative requires that weapon system budgets be prepared using realistic forecasts of inflation.

19. Forecasting the Business Base.
    This initiative entails maintaining a data exchange covering business base conditions at major defense plants for use by the Services in planning and budgeting.

20. Improved Source Selection Process.
    This initiative places added emphasis on contractors' past performance, schedule realism, facilitization plans, and cost credibility. It requires that a system be established for documenting and sharing information on contractor performance.

21. Standardization of Operational and Support Systems.
    This initiative requires the development and use of standard operational and support systems to achieve earlier deployment and better support of weapon systems. The benefits are increased force readiness and support.

22. Design to Cost Contract Incentives.
    This initiative requires that DoD provide appropriate incentives to industry by tying award fees to actual costs achieved during early production runs.

23. Implementation of the Acquisition Improvement Program.
    This initiative assigns overall responsibility to the Under Secretary of Defense (Research and Engineering) (USDRE) to assure that the Acquisition Improvement Program is implemented.

24. Decision Milestones.
    This initiative requires that Department of Defense Directive 5000.1 and Department of Defense Instruction 5000.2 be revised to reflect a reduction in the number of DSARC milestones.

25. Mission Essential Needs Statement (MENS).
    This initiative links the acquisition and Planning, Programming and Budgeting System (PPBS) processes by requiring the MENS to be submitted with the Service Program Objective Memorandum (POM).

26. DSARC Membership.
    This initiative adds the appropriate Service Secretary or Service Chief to DSARC membership.

27. Acquisition Executive.
    This initiative retains USDRE as the Defense Acquisition Executive.

28. DSARC System Criteria.
    This initiative increases the criterion for DSARC review to ~200M Research, Development, Test and Evaluation (RDT&E) and ~1B procurement in FY 1980 dollars.

29. DSARC/PPBS Integration.
    This initiative links the DSARC and the PPBS processes.

30. Program Manager Control Over Logistics and Support Funds.
    This initiative requires that logistics and support resources be shown in the Service POM by weapon system, and program managers to be given more control of support resources.

31. Improved Reliability and Support.
    This initiative involves improving reliability and support for shortened acquisition cycle programs.

32. Competition.
    This initiative is designed to enhance competition in the acquisition process in order to reduce cost.

The following year, 1982, President Reagan assembled the President's Private Sector Survey on Cost Controls (PPSSCC), "The Grace Commission," in order to "identify opportunities for increased efficiency and reduced costs achievable by executive action or legislation." (29:54) The commission's recommendations are presented in Table 5. (29:55)

Table 5: 1982 Grace Commission Recommendations

1. Improved Organization.
    Observation: Massive duplication of effort among the services and OSD
    Recommendation: Total consolidation of day-to-day acquisition functions at the OSD level.

2. Defense Contract Administration Consolidation.
    Observation: Wide variations in the procedures between the Defense Contract Administration Service…and the various related components at the service level.

Recommendation: Consolidate all contract administration at the OSD-level.

3. Regulatory Constraints.
   Observation: The Department of Defense acquisition of weapons systems operates under a complex regulatory system
   Recommendation: Defense Acquisition Regulations (DAR) should be replaced with general guidelines for DoD procurement actions.

4. Independent Research and Development Costs.
   Observation: The DoD reimbursement policy for independent research and development (IR&D) costs involves an elaborate and time-consuming technical review process.
   Recommendation: Eliminate technical review and group IR&D under overhead costs.

5. Department of Defense Laboratories.
   Recommendation: Improve data exchanges…reduce duplication, and DoD laboratories should phase out their involvement in the late stages of the development cycle.

6. Common Parts and Standards.
   Recommendation: Use standardized parts in weapons systems and decrease the use of military specifications.

7. Major Weapons System New Starts.
   Recommendation: Limit the number of new weapons programs started each year and impose stricter entry requirements for new systems.

8. Estimating Weapons systems Costs.
   Recommendation: Establish procedures to ensure more accurate estimates of weapons cost in order to permit better planning and reduce cost overruns.

9. Instability of the Weapons Acquisition Process.
   Recommendation: The DoD should commit to a stable 5-year spending plan for the acquisition of weapons systems at economical production rates.

10. Transfer of Consumable Inventory Items.
    Observation: DLA has proven its ability to manage successfully consumable items with statistically superior results over services.
    Recommendation: Of the 1.2 million inventories being managed by the Services, 900,000 should be transferred to DLA.

11. Implementation of OMB Circular A-76.

<u>Recommendation</u>: Remove various legislative requirements that serve to restrict DoD's implementation of the A-76 program. Thereby outsource commercial functions.

These preceding two lists of recommendations and ensuing reforms constituted the second generation of acquisition reforms. Their unifying theme was to prevent embarrassing mistakes associated with fraud, waste, and abuse. (23:74; 24:14)

Round Three (1985 – 1997): Acquisition Streamlining

In 1985, in preparation for the legislation that would become the Goldwater-Nichols Act of 1986, former Secretary of Defense David Packard headed a Blue Ribbon Panel, "The Packard Commission," whose charter was to review defense management and organizational structure. (29:56) The Packard Commission recommendations are presented in Table 6. (29:57)

Table 6: 1985 Packard Commission Recommendations

Acquisition Organization and Procedures

1. *Create the position of (USD (A)) as the Defense Acquisition Executive (DAE).*
2. *Services should have similar executives. They will act as Service Acquisition Executives (SAE).*
3. *The SAE appoints PEOs, each responsible for a set number of acquisition programs.*
4. *PMs are responsible to the respective PEO and report only to him on program matters.*
5. *All federal statues governing procurement be recoded into a single procurement statute.*
6. *Business-related education/experience criteria for senior-level acquisition personnel.*

7. *Establish the Joint Requirements and Management Board (JRMB) co-chaired by the CJCS and the USD(A) to define requirements and select programs for development.*
8. *Use a greater number of "off the shelf" items.*
9. *Increase use of prototypes.*
10. *Operational testing should be completed prior to high-rate production.*
11. *Increase use of commercial-style competition.*
12. *DoD should fully institutionalize "baselining."*
13. *Greater use of multi-year procurement.*
14. *Reduce requirements for data rights.*

Government-Industry Accountability

1. *Aggressively enforce federal civil and criminal laws governing defense acquisition.*
2. *Defense contractors should promulgate and vigilantly enforce codes of ethics and develop internal controls to monitor themselves.*
3. *DoD should develop specific ethics guidance on matters of DoD acquisition and train personnel on such matters.*
4. *Oversight of defense contractors must be better coordinated among the various DoD agencies.*
5. *USD(A) should establish audit policies and foster contractor self-governance.*

Former Packard Commission member and Secretary of Defense William Perry initiated a "Mandate for Change" in the mid-1990s. His Oversight and Review Process Action Team made the recommendations presented in Table 7 for streamlining the acquisition process. (29:74)

Table 7: 1994 Oversight and Review Process Action Team

1. Help field what the Warfighter needs when he needs it.
    1) The quality of the products being fielded
    2) How quickly new capabilities become available

2. Demand accountability by matching managerial authority with responsibility.
    1) The clarity of such role definition
    2) The ability of personnel to play their role without external interference
    3) Whether decisions are made at the lowest level possible

3. Promote flexibility and encourage innovation.

4. Foster constant teamwork among everyone who is a stakeholder.

5. Actively promote program stability.

6. Balance the value of oversight and review with its costs.

7. Emulate the best practices of successful commercial companies and successful government ventures.
    1) Clear command channels that is a short, unambiguous chain-of-command to the decision maker
    2) Stability in performance demanded, schedule and funding
    3) Limited reporting requirements
    4) Small, high-quality staff to manage the program rather than sell it or defend it
    5) Greater communication with users throughout the lifecycle of the system
    6) Greater use of prototyping and testing

8. Preserve the public trust.

In 1996 RAND analyzed a major defense acquisition program from each Service based on ten of their own derived criteria for program process health. The study declined to analyze each program individually; rather it awarded composite grades in each criterion and noted trends across the three programs. The key observations of concern in the study's findings were (8:xxi)

1. Program funding was unstable. Program managers spent more time defending their programs rather than managing them.

2. Program schedules were budget-driven, a powerful disincentive for attracting talent managers.

3. Risk management philosophies and practices were disparate, an indicator of weak emphasis at top managerial levels.

RAND's criteria are presented in Table 8. (8:16)

Table 8: RAND's Ten Criteria for Evaluating Acquisition Program Management and Oversight Processes within the Department of Defense

1. Lines of authority have been established and are clear. Defense Management Review issues and/or problems must not cause confusion, bickering, or a diminution of Program Manager (PM) responsibility and accountability.
2. Communication is open (no secrets – all information is divulged; using all media and avenues, e.g., e-mail, written, verbal) and continuous at and between all levels of authority.

3. Cost/Schedule Control System, Cost Performance Measurement, and other management reports are used as indicators of trends in program progress and for reporting program status.
4. Risk-management techniques have been implemented.
5. Program stability has been achieved through control of requirements.
6. A strong government-industry support team (Program Office, functional support, Defense Plant Representative Offices [DPROs]) is present and has explicit mechanisms for coordinating responsibilities.
7. Incentives for the Program Manager are adequate and positive.
8. Funding is stable and adequate.
9. Selection of best-qualified personnel for key acquisition-management positions is objective and regulated
10. Security requirements do not restrict adequate and sufficient management.

Round Four (2001 – Present): Transformation

Finally, in this decade Undersecretary for Defense Acquisition, Technology, and Logistics [USD(AT&L)] Pete Aldridge issued five goals in support of "Acquisition Excellence." (24:17)

Table 9: Aldridge's Five Goals in Support of Acquisition Excellence

1. Achieve credibility and effectiveness in the acquisition and logistics support process.
2. Revitalize the quality and morale of the DoD (AT&L) acquisition workforce.
3. Improve the health of the defense industrial base.
4. Rationalize the weapon systems and infrastructure with defense strategy.
5. Initiate high-leverage technologies to create the warfighting capabilities, systems, and strategies of the future.

And within the Air Force, Assistant Secretary of the Air Force for Acquisition (SAF/AQ) Marvin Sambur issued a series of his own initiatives in keeping with Air Force transformation. (2:4, 58-108)

Table 10: SAF/AQ Marvin Sambur's Air Force Acquisition Transformation Initiatives

- Challenge Over-Restrictive implementation of the Law and "Zero-Based" perspective.

  All programs start with a "zero-based" perspective. All activities, reports, plans, coordination or reviews except those mandated by statute or previously approved by a person in the execution chain, must *buy their way into the program by demonstrating that the benefit gained clearly equals or outweighs the resources expended* (p. 58)

- Shift from avoiding risk.

  Success in meeting our objective requires a shift from avoiding risk to managing it, and sometimes, simply accepting it. Taking risks will sometimes produce failure. That is acceptable as long as those in the execution chain understood the risks and we learn from the failure. (p. 64)

- Operational urgency.

  The primary mission of our acquisition system is to rapidly deliver to the warfighter affordable, sustainable capability… Speed is important. In devising and implementing acquisition approaches, the concept of time or schedule as an independent variable is one that must override prior concepts of delivering the ultimate capability at whatever cost and schedule is necessary to do so. Every key decision must have an operational sense of urgency. (p.74)

- Credibility.

  Credibility is essential. We must create and maintain realistic expectations. PMs must continually manage expectations so that senior acquisition and warfighter leadership are never surprised by sudden cost growth or schedule slippages. Each program must have a clear, unambiguous set of priorities among cost, schedule, performance and supportability. Normally, the senior leadership of the requiring MAJCOM should set these priorities as part of the initial requirement. (p. 84)

- Full teaming.

  Teaming among warfighters, developers/acquirers, technologists, testers, budgeters and sustainers must begin when the requirements are being defined, not after. PMs, through the MDA, are responsible for making decisions and leading implementation of programs, and are accountable for results. The PM, as the accountable agent for executing the program, has a responsibility to seek resolution if asked to do something that goes counter with meeting the Commander's Intent. (p. 94)

- Staffs are advisors.

  Staffs at all levels exist to advise the MDA and PM and assist them with their responsibilities. Councils, committees, advisory groups, panels and staffs are advisors at the discretion of the PM, PEO, DAC or MDA. The MDA, PEO or DAC, and PM are accountable for the overall program results. Those not accountable for the program outcome are expected to provide program inputs to the program decision process, but do not have decision-making authority. (p. 100)

- Solid systems engineering.

> *Solid systems engineering is required at the outset of a program to ensure a robust foundation and flexible architecture that can accommodate future requirements with minimal redesign.* (p. 108)

To date, the DoD 5000 series instructions for acquisition have been revised and coordinated, with a similarly revised CJCS 3710 series instructions. Together, they are the defense acquisition system and the Joint Concept Integration and Development System, and they form the body of instruction for defense modernization. DoD Instruction 5000.2-R, a prescriptive and regulatory guide book on acquisition procedures, was rescinded in lieu of the Defense Acquisition Guidebook, which made the procedures only advisory in nature. (2:23)

Summary of Acquisition Reform Efforts

Since 1969, DoD Acquisition has gone through four generations of acquisition reform to contain costs, impose quality controls, improve efficiency through streamlining, and maintain responsiveness as DoD undergoes transformation. The reviews and initiatives offer conflicting, but often reinforcing, findings about the acquisition process. On the one hand, the repeated findings are evidence of tenaciously insoluble problems with the process; on the other hand, they give insight into consistent and enduring themes, fodder for a body of principles. The scope and level of findings varied widely, and the truly profound ones suffered for attention amidst the clutter. The warfighting analog offers dividends. Acquisition is an extension of policy, and strata for acquisition (strategic, operational, and tactical levels) serve to de-confound narrow prescriptive findings from broader more general ones. Important themes, repeatedly manifest were

- More power and autonomy needed for program managers to execute the strategy
- Longer tours/less turnover needed for program office personnel
- The need for fewer levels of management and fewer audits and reviews
- The need for stable funding and realistic budgets, properly padded to program risk
- The need for fewer laws and directives, more general guidance
- The need to return program managers to the job of management instead of program advocacy
- An emphasis on avoiding risk instead of managing it
- The importance of the industrial base as a factor affecting force modernization
- The growing need to meet requirements in a timely manner

Around 1997, former Lockheed-Martin CEO Norman Augustine presented a tongue-in-cheek version of his laws for acquisition program management. They offer a canny view of the process from a contractor's perspective as well as a good indication of the effectiveness of prescriptive efforts of acquisition reform up to then. Augustine's observations are presented in Table 11.

Table 11: Augustine's Checklist for an Acquisition Adventure

- ☐ Settle for less than the best people – Reduce payroll costs
- ☐ Build an adversarial relationship between buyer and seller
- ☐ Change management frequently – Provide opportunities
- ☐ Avoid evolutionary growth to new capabilities – Take grand leaps
- ☐ Continually revise schedule and funding – Generate excitement
- ☐ Include all features anyone wants – Make everybody happy
- ☐ Allow no margins in funding, schedule or technical approach – Nothing will go wrong
- ☐ Divide management responsibility among several individuals – Two heads are better than one
- ☐ Whenever difficult problems are encountered, start all over with a new approach having no (known) problems
- ☐ Promote continued debate over goals throughout the life of the project – Variety is the spice of life
- ☐ Give reliability low priority – Especially avoid redundancy
- ☐ Develop underlying technology and end-product concurrently
- ☐ Do not plan intermediate test milestones – Just one glorious display
- ☐ Create as many interfaces as possible – Help people get to know each other
- ☐ Focus on the big picture – The details will take care of themselves
- ☐ Disregard seller's track record – The law of averages will work out
- ☐ Cut costs by reducing testing – Especially environmental and full-system testing
- ☐ Ignore the users – They don't understand high-tech
- ☐ Choose among the sellers based on what they promise – Nobody likes a pessimist
- ☐ Get a head-start on work prior to finalizing goals, schedule and cost – This is especially true for software – which is easy to change
- ☐ Share authority for project direction with staff advisors
- ☐ Eliminate independent checks and balances – They just create friction
- ☐ Don't compete potential suppliers at the outset – Pick a friend
- ☐ Once underway, continue to compete selected supplier with outsiders – Change as often as possible to assure "Freshness"
- ☐ Minimize managers' latitude for judgment – Rely on regulations
- ☐ Deal harshly with anyone surfacing problems – One can't afford troublemakers
- ☐ Never delegate – Hold authority at the top where people really know what's going on
- ☐ Maximize individual incentives – Teamwork is just the sum of the parts

- ☐ Make up for schedule slips by overlapping design and build – Especially when test results are disappointing
- ☐ Include at least as many auditors on the project as workers – Reviews give everyone a chance to participate
- ☐ Do all possible to minimize profits of participating contractors – Save the money
- ☐ Don’t waste time communicating (especially face-to-face) – It just takes time; and time is money
- ☐ Eschew strong systems engineering – It complicates decision-making
- ☐ Delay establishing configuration control until the last minute – Reduce the cost of management
- ☐ Always pick the low bidder – They must know something special and are often courageous
- ☐ Don’t worry about the form of the contract – Just enforce it

Principles of Warfare

[D]octrine is a statement of officially sanctioned beliefs, warfighting principles, and terminology that describes and guides the proper use of … forces in military operations. (1:ix)

Doctrine is the best way to do things… all things being equal

1. *All things are NEVER equal*
2. *You NEVER know what things aren't equal*
3. *The same things are NEVER equal*

LtGen Michael Short, JFACC, Operation ALLIED FORCE

At the core of any basic doctrine document, principles of warfare exist to serve as a guide to formulating warfighting strategy. Doctrine contains the accumulated lessons from experience in a discipline and puts forth the most effective methods for success. It describes how to achieve an objective, but it doesn't prescribe which objectives to achieve. Doctrine applies to disciplines not governed by definitive deterministic laws; they offer the 70-90% solution. As such, they are not directive or binding in nature. Decision-makers should neither blithely ignore doctrine, nor follow its dictates by wrote without an understanding of the peculiarities of their own situations. Doctrinal proposals originate from observation and experience, and scientific method refines it into theory. Once doctrine is published and applied, constant feedback from operational experience serves to update it. (1:87)

Principles are the enduring characteristics of successful combat operations and form the foundation of warfighting doctrine. (41:2-4) They indicate the dimensions of conflict considered universally true and relevant. (1:19) The US Army first listed its original nine principles of war in 1921 and has refined them with the experience of 20th century conflicts. Today, all of the service and the joint doctrine documents acknowledge these principles. (41:21) The current principles are listed on the following page, and definitions of these principles are in

Appendix B

Expanded Principles of War

- Objective
- Unity of Command
- Offense
- Mass
- Maneuver
- Economy of Force
- Security
- Surprise
- Simplicity

Candidate Principles for Force Modernization

This section lists and defines candidate force modernization principles in order to vet them against the lessons of hard experience in force modernization. It distills the previous lists of initiatives, findings, and recommendations into a draft list of principles for modernization, intended as a keystone for building a basic modernization doctrine. Like the principles of war, these principles may or may not work together in congruence; the demands of some may constrain or oppose the demands of others. Every modernization program is unique; therefore, the appropriate weight to give towards pursuit of any one principle will vary from program to program. Achieving the right balance requires judgment and mastery, not a rigid algorithm. Hence, modernization, like warfighting, is as much an art as a science.

The earlier review of acquisition reform yielded 135 different findings and initiatives. Ten major themes emerged as candidate principles. They were germane to the findings and initiatives, and they showed up on numerous occasions across the range of panels, commissions, and Secretaries' initiatives.

1. Objective: The unifying focus behind any modernization effort. All subordinate tasks must be consonant with the overall objective of a modernization effort, and any modernization effort's goals must be consonant with the objectives of the concept of operations to which it is linked. In this context, Objective refers to system performance, the operational effectiveness and suitability of the product system, and its linkage to higher strategic objectives.

2. Simplicity of Command: Modernization's corollary to the warfighting principle of Unity of Command/Effort. Beyond unity, Simplicity of

Command requires as short a chain of command and as short a line of communication as possible between program managers and decision-makers. *It also exclusively associates authority and responsibility*. As in battlefield operations, it enables a more agile tempo and therefore mitigates vulnerability to external perturbations such as funding instability. It is a necessary condition for program stability and responsiveness.

3. Tempo: To remain viable, a program must be more dynamic than the events driving it, at the tactical level (contract changes, technical developments), the operational level (budget turbulence, schedule changes), and at the strategic level (mission changes, new priorities). Tempo includes those items affecting program agility, flexibility and responsiveness, the speed and effectiveness of its OODA cycle.

4. Risk Management: The very objective and the underlying method of force modernization. Modernization programs are undertaken in order to mitigate an unacceptable risk to warfighters and/or national security, and the elements of modernization strategy: analysis, prototyping & testing, competition, tracking & reporting are all in place to manage (identify, track and mitigate) risks to program objectives of cost, schedule and performance. *Residual risk inevitably requires insurance in the form of a commensurate management reserve*.

5. Centralized Control/Decentralized Execution: Centralized Control is traceability and linkage of disparate efforts back to the over-arching objective. It includes direction (policy, commands, decisions, approval and funding) as well as feedback (reporting, reviews, audits, evaluations and inquiries). Centralized Control is necessary to some degree to focus and organize efforts. Decentralized Execution prescribes execution at the point of action, at the lowest level appropriate. It gives robustness and agility to execution.

6. Economy of Effort: Keeping the scope of the organization and process for a modernization effort to the minimum sufficient for the objective. Economy of Effort has its basis in the KISS (Keep It Simple…) principle. It includes conservation of manpower, man-hours, funds, or any critical finite resource. It also recognizes the risk, due to complexity, of losing focus on the objective and loss of responsiveness when programs and processes grow unnecessarily large or lengthy.

7. Stable Program Inputs: The need for requirements, funds, schedule and personnel turnover to be stable if a program is to operate efficiently

and effectively. It also recognizes realistic cost estimates, technology maturity and a robust industrial base as necessary preconditions.

8. Initiative: The modernization process' corollary to the warfighting principle of Offense. It dictates being proactive, anticipating and responding in advance of challenges, at all levels, and using creativity and innovation where necessary. To maintain an optimum tempo, a program requires momentum. Initiative is the means by which program leadership maintains and controls that momentum.

9. Workforce Quality & Credibility: The lubricant of the entire modernization process and machinery. People, expectations and agreements must all have credibility in order to maintain an optimum tempo while containing risk. Without trust, processes stall while parties pursue bona fides and formal contracts. The most effective programs have all run on informal communications and arrangements made possible with credibility.

10. Synergy & Synchronization: Synergy is the tight integration of interdisciplinary and inter-organizational teams toward a unifying objective, the antithesis of stove-piping. It requires rapid communication and coordination among all stake-holding communities involved in a modernization effort, and in turn enables (i.e. it's necessary but not sufficient for) the remaining principles. Where synergy is coordination across disciplines, synchronization is coordination across processes. While any modernization process is ideally event-driven, interfaces with the modernization process may be calendar-driven (Planning, Programming, Budgeting and Execution System) or subject to their own event-driven sequence (CONOPS Development). To be most effective, a modernization strategy should plan ahead for times to make required inputs or receive necessary outputs of those interfacing systems.

The frequency of occurrence of these principles across the findings and initiatives from the presidential and congressional panels and secretariat initiatives is presented in Table 12.

Table 12: Acquisition Reform Findings/Initiatives and Principles Correlation

	Objective	Simplicity of Command	Tempo	Risk Management	Centralized Control/Decentralized Executio	Economy of Effort	Stable Program Inputs	Initiative	Workforce Quality & Credibility	Synergy & Synchronization
Packard Initiatives	1			5	2	2	3			1
Fitzhugh Commission Recommendations		2		2	1		2		3	
Commission on Government Procurement	1		1	2	1	6	1	2		1
Carlucci Initiatives	6	1	4	7	3	13	10	2	4	4
Grace Commission Recommendations	1		2			5	4			3
Packard Commission Recommendations	3	1	1	4	4	4			4	2
Oversight and Review Process Action Team	3	2	2	1	2	4	2	1	2	2
RAND's 10 Criteria	2	2		2	1	1	2		2	2
USD (AT&L) 5 Goals	1						2	1	2	
SAF/AQ Initiatives	1	1	2	1		1			1	1
	19	9	12	24	14	36	26	6	18	16

Among the candidate principles, Economy of Effort, Stable Program Inputs, and Risk Management (Avoidance) received the most attention in acquisition reform investigations and initiatives. The candidate principles of Objective, Workforce Quality & Credibility, Synergy & Synchronization, and Centralized Control/Decentralized Execution all appeared very frequently. The candidate principles of Tempo, Simplicity of Command, and Initiative also appeared on occasion. None showed a bias in time in that no particular principle's appearance tapered off or gained in frequency with respect to the time of the findings. These results do not guarantee sufficiency. A candidate principle, neither visible to senior investigators nor overwhelmingly affecting them, would likely escape attention but rather manifest at other echelons of management. Just as victors write the history books, senior leaders write the findings and initiatives.

The Candidate Principles Applied to Recent Programs

These candidate principles should be decisive factors in the success, troubled nature, or outright failure of modernization efforts. The scope of this section is to look at six major defense acquisition programs (MDAP) started within the last 30 years. The first two programs are ones widely considered successful if not exemplary. The next two programs are ones surviving to date but considered troubled in terms of cost and schedule. The final two programs were terminated after considerable investment. In each case, program circumstances are compared with the list of candidate principles to see if they are applicable. Where a candidate principle is a factor in a program history narrative, that principle appears in brackets. If a program is found to have been deficient in observing that principle, a minus sign appears in parentheses next to the principle in brackets. In the summary tables,

- "+" indicates the program was found to have observed a candidate principle
- "-" indicates the program failed to appropriately observe a candidate principle
- "+/-" indicates the program both observed and violated the principle at different times
- A blank cell indicates that the program's observance or violation of a principle was not evident from its case history

The Good: Exemplary Acquisition Programs

> The ones [indicators] we settled on as being most indicative of problems in the program was the acquisition cycle, the length of time from the beginning of full scale development, to the fielding of the system, to establishment of initial operating capability. On a typical defense program, that takes 8, 10, or 12 years, somewhere in that range. *On the truly well run, most excellent programs we looked at, that was done in 4 or 5 years.*
>
> Dr. William Perry, testimony before Congress, 1985 (55:34-37)

F-117 Nighthawk. The F-117 Nighthawk is a low-observable light bomber/attack airplane. It had its genesis in 1976. Following a successful Advanced Research Projects Agency (ARPA) investigation into radar signature suppression, HAVE BLUE began as a technology demonstration of an experimental jet aircraft applying those signature suppression methods. [Stable Program Input] Even as testing was underway, the contractor began designing the F-117, based on lessons learned from building the two demonstrators. [Risk Management] With the success of HAVE BLUE, the F-117 development program initiated with Engineering Manufacturing Development (EMD) in 1978, and the first lot was delivered to the Air Force in 1982, four years from the establishment of a requirement. (8:8-10) [Tempo] Development on the F-117 continued after fielding; the efforts centered mainly on reliability and maintenance of the low radar signature [Objective(-)], but the aircraft fielded successfully with a total of 13 months schedule slippage. (8:9) Despite its technological novelty, the F-117 acquisition cost was only 3% above initial estimates. (8:41) [Stable Program Input] [Economy of Effort] Eleven years from contract award, the USAF had successfully employed the F-117 in air combat operations. [Objective]

RAND's analysis of the F-117 acquisition program derived the following findings: (8:47-43)

- A narrow mission with a limited number of performance requirements [Objective] [Economy of Effort]
- Flexibility and responsiveness in decision-making [Initiative]
- Program manager latitude on making cost, schedule and performance trades [Simplicity of Command]
- An exceptionally small, handpicked program staff (36 people) with great autonomy [Workforce Quality & Credibility]
- Stable requirements due to security and limited insight among staffs with divergent interests
- Stable support from DoD and USAF executives [Stable Program Inputs]
- Delegation of authority to lowest levels practicable [Decentralized Execution]
- Tolerance for risk/ waiver of numerous controls [Risk Management]
- Significant trust between agencies involved as well as between the government and the contractor [Synergy]
- Inadequate consideration to reliability and maintainability of the radar absorbing materials [Objective (-)]

These findings, related to the success of the F-117 acquisition program, as they related to the candidate principles are summarized in Table 13:

Table 13: Candidate Principles as Factors in the F-117 Program

+/-	Objective
+	Simplicity of Command
+	Tempo
+	Risk Management
+	Centralized Control/Decentralized Execution
+	Economy of Effort
+	Stable Program Inputs
+	Initiative
+	Workforce Quality & Credibility
+	Synergy & Synchronization

RQ-1A Predator ACTD. The RQ-1A, a remotely piloted/remotely operated reconnaissance unmanned aerial vehicle (UAV), had its inception in 1993 when the Joint Requirements Oversight Council (JROC) validated a requirement for a medium altitude endurance UAV and incorporation it into a pilot program for Advanced Concept Technology Demonstration (ACTD). (56:11) The objective of ACTDs is to shorten the time for fielding ripe and useful technologies. [Stable Program Inputs] [Tempo] The ACTD concept is to match maturing technologies with warfighter needs and to evaluate prototypes in actual operations over a 30-month trial. [Synergy] Concepts with operational utility enter the acquisition process at the appropriate point and the prototypes are left with the warfighters. The prototype first flew in 1994, and the UAVs were operating over Bosnia by 1995. The ACTD completed in 1996, with Predator UAVs flying in operations in Bosnia. [Tempo] DoD transitioned the RQ-1A into formal acquisition that year, and the US Air Force began taking deliveries of an upgraded RQ-1B in August 1997—less than five years from program start. The transition had some issues. The Air Force was designated as the lead agency for transition late in the ACTD. Being that it was originally a demonstration, foundational documentation such as an Operational Requirements Document, a Logistics Support Analysis, and a Test and Evaluation Master Plan had to be developed in parallel with EMD. [Risk Management] Nevertheless, the system fielded on schedule, with only a 6% cost overrun. (56:45) [Stable Program Input] [Economy of Effort]

A RAND study of the program made the following findings: (56:78)

- "Flexibility and creativity were key to the success of the Predator ACTD…. (1) An emphasis on informal communication and (2) Limited CDRL (Contract Data Requirements List) items." (56:55) [Economy of Effort] [Decentralized Execution]
- "Given the necessarily fast pace of the ACTD process, confident, effective, and innovative individuals are critical to the success of a program." [Workforce Quality & Credibility]
- Requirements analysis and logistics planning need to start as soon as there are inklings that the demonstration will transition to a formal acquisition. [Tempo (-)]
- ACTDs operate differently due to fast pace, small staffs, and limited guidance. [Tempo]
- The ACTD used a nonbinding CONOPS rather than formal requirements in assessing performance. [Initiative]

- “The small size of the government and contractor teams of the Predator ACTD required an *integrated team approach*, which is founded on mutual trust, limited documentation, and novel management techniques. (56:32) [Synergy] [Credibility] [Economy] [Initiative]
- Success—in part, due to stability of funding [Stable Program Inputs]
- The need for reliability and maintainability goals [Objective (-)]
- The need for a life cycle cost estimate [Economy of Effort (-)]

These findings, as they related to the candidate principles are summarized in Table 14.

Table 14: Candidate Principles as Factors in the RQ-1Program

-	Objective
	Simplicity of Command
+/-	Tempo
+	Risk Management
+	Centralized Control/Decentralized Execution
+/-	Economy of Effort
+	Stable Program Inputs
+	Initiative
+	Workforce Quality & Credibility
+	Synergy & Synchronization

The Bad: Troubled (but Surviving) Acquisition Programs

The next programs under review are characterized as troubled—experiencing cost and/or schedule overruns well in excess of the Nunn-McCurdy limits of 25%. The purpose of this analysis is to determine any correlation between principles and program troubles and survival.

F-22 Raptor. The F-22 Raptor is the air superiority fighter currently being fielded to succeed the F-15 Eagle. Its beginning was in studies that commenced in the late 1970s, culminating with USAF requirements developed for the Advanced Tactical Fighter Program in 1981. (19) The demonstration and validation phase stretched out as the Air Force subsequently added stealth requirements. [Stable Program Inputs (-)] Lockheed’s YF-22 prototype won a fly-off competition at the end of demonstration/validation in 1991. [Risk Management] [Economy of Effort] The original program goals called for a fleet of 750 F-22s, a 1995 IOC date, and a total program cost of $80.7 B ($12.6 B for development). (4:238) The program experienced numerous technical difficulties in EMD throughout the early 1990s; finally, Congress imposed spending caps. The dynamic changes in the security environment brought questions about the value of a fighter being built to counter would-be Soviet fighter threats. [Stable Program Inputs (-)] At IOC in December 2005, 10 years after the projected IOC (111% schedule overrun) [Tempo (-)], the Air Force plans to field 178 (23.7%) of the original 750 aircraft [Objective (-)]; total program cost is congressionally capped at $63.8 B, but USAF spent $28.7 B for development (127% overrun). (54:4-5) [Economy of Effort (-)] A RAND study made the following findings: (63:57)

- The need for realistic cost and schedule estimates up front with minor adjustments over time [Stable Program Inputs (-)]
- Stable team structure, proper team expertise, clear lines of responsibility/authority, and a single lead contractor as critical to success [Stability (-)] [Simplicity of Command (-)]
- The necessity for experience among government and contractor management teams [Quality Workforce (-)]
- The added risk of developing technology for a baseline design concurrently with manufacturing development [Risk Management (-)] [Stable Program Inputs (-)]
- The utility of planned technology insertion, as technology stabilizes, as a risk management tool [Risk Management (-)] [Stable Program Inputs (-)]
- The need to carefully monitor key leading indicators of design instability [Centralized Control (-)][Risk Management (-)]
- The need for an appropriate management reserve for flexibility in containing cost growth [Risk Management (-)] [Stable Program Inputs (-)]

These findings, with respect to the F-22 program’s difficulties but continued survival, as they related to the candidate principles are summarized in Table 15.

Table 15: Candidate Principles as Factors in the F-22 Program

-	Objective
-	Simplicity of Command
-	Tempo
+/-	Risk Management
	Centralized Control/Decentralized Execution
+/-	Economy of Effort
-	Stable Program Inputs
	Initiative
-	Workforce Quality & Credibility
	Synergy & Synchronization

V-22 Osprey. In 1981, following the success of the XV-15 tilt-rotor technology demonstration [Risk Management], DoD began the Joint Services Advanced Vertical Lift (JVX) program to meet the vertical lift requirements of all the services. In 1983 the US Army withdrew as lead for the development program (but still committed to procuring the production model), and the Department of the Navy assumed program lead. [Stable Program Inputs (-)] By 1984, the program goals included delivery of 913 V-22 Osprey tilt-rotor aircraft to the services, with an IOC in 1992. Bell and Boeing partnered to bid on the V-22 development. The Navy obliged them to accept a fixed-price development contract and to compete against one another for production. [Synergy (-)] [Risk Management (-)] Development began in 1986. (48:18) During development, the Army abandoned its procurement commitment and, citing cost overruns, then-Secretary of Defense Richard Cheney cancelled funding in 1989. [Stable Program Inputs (-)] Congress restored funding for the V-22 to continue as a test program. In 1993, the Clinton administration restored program funding, and a re-designed V-22 entered EMD in 1994. (42:3) The Defense Acquisition Board (DAB) permitted the program into Low-Rate Initial Production (LRIP) in 1997, based on testing of the *original* design. [Risk Management (-)] LRIP halted after a number of in-flight incidents; two catastrophic accidents revealed design limits not discovered in testing. In 2003, after a new round of development testing, the V-22 re-started LRIP. The DAB approved Full Rate Production in 2005. Bell and Boeing will build 458 V-22s for the Marine Corps and for Air Force Special Operations, with an IOC in 2007. Unit cost will be $85 M, up from the $24 M per aircraft estimated in 1986 (42:9) [Economy of Effort (-)] When delivered, the V-22 will have had a 15-year (200%) schedule overrun and a $26.7 B (354%) cost growth. [Tempo (-)] A survey of V-22 program history literature reveals the following highlights: (42:9-13)

- Program stability was chaotic due to widely varying support across Defense Secretaries' tenures [Stable Program Inputs (-)]
- The initial contract structure inhibited contractor latitude in development [Initiative (-)]
- The requirement for competition among partners for manufacturing poisoned the teaming relationship [Synergy (-)]
- The program proceeded into production without adequate developmental/operational testing (44:6) [Risk Management (-)]
- Marine Corps response to operational test failures was to revise requirements [Objective (-)]
- The V-22 program benefited from constant congressional support [Stable Program Input]

V-22 program lessons, with respect to its difficulties but continued survival, as they related to the candidate principles are summarized in Table 16.

Table 16: Candidate Principles as Factors in the V-22 Program

-	Objective
	Simplicity of Command
-	Tempo
+/-	Risk Management
	Centralized Control/Decentralized Execution
-	Economy of Effort
+/-	Stable Program Inputs
-	Initiative
	Workforce Quality & Credibility
-	Synergy & Synchronization

The Downright Ugly: Cancelled Acquisition Programs

A-12 Avenger II. The A-12 Avenger II was a low-observable, aircraft carrier-based attack aircraft intended to succeed the Navy's A-6. Planners envisioned 1,200 aircraft for the Navy, Marine Corps, and Air Force, with first flight due in 1990. (14:2) The program began in 1983 with Deputy Secretary of Defense direction to the Navy to undertake development. The Navy did this reluctantly, absent the spare money or technology necessary for such a major effort. To contain cost risk, the Navy bid the development contract as fixed-price. [Risk Management (-)] [Initiative (-)] The two contractors with ongoing stealth aircraft development experience, Lockheed and Northrop, declined to bid the contract—citing excess risk—and the Navy awarded the contract to the McDonnell-Douglass/General

Dynamics team, the only responsive bid. Neither had any experience with the composites technology necessary for stealthy airframes. [Workforce Quality (-)] Following a major program review in 1989 and Secretary of Defense testimony before Congress that program performance was healthy, the A-12 program office announced an 18-month slip in the date of first flight. [Credibility (-)] The ensuing inquiry from OSD staff revealed a program badly broken. Having spent $3 B of the $4.77 B development budget, the aircraft design was 5,000 lb overweight [Objective (-)], two years behind schedule [Tempo (-)], and $500 M over budget [Economy of Effort (-)]. (14:7) Furthermore, Navy program management had been aware of this and had not only withheld the information from the Secretary of Defense major review but had successfully quashed a DoD comptroller memorandum stating the situation. [Credibility (-)] By this time, the advocacy had reversed. Amidst a shrinking post-Cold War force, the Air Force and the Navy were in a cutthroat roles competition over deep strike, and Naval aviation was now committed to the A-12. [Stable Program Inputs (-)] In reaction to the findings, key members of the A-12 acquisition chain of authority were relieved and/or disciplined, and Secretary Cheney ordered the program terminated for cause in 1991. (14:1-5)

The ensuing litigation between the contractors and DoD revealed further misdoings. In order to force a bid within the Navy's established budget for the program, the Navy had misled the McDonnell-Douglass/General Dynamics team and others into believing that the contractors were bidding competitively, when in fact they were the sole bidders. [Credibility (-)] Although the Navy bid reviewers had uncovered a critical error in the team's weight estimation, the Navy neglected to share this with the contractors, fearing that the revised bid would be higher. (35) [Credibility (-)] The Navy had not developed stealth technology, but the program depended on it. OSD had directed the Air Force to make its low-observables expertise available to the program. The Air Force, having assumed all of the previous risk and expense of developing stealth, and in fierce competition with the Navy for the deep strike role, was reticent to share its data, and the contractors had to develop that knowledge by themselves. (35) [Synergy (-)] The events of the A-12 program failure as they related to the candidate principles are summarized in

Table 17.

RAH-66 Comanche. The RAH-66 Comanche was a Reconnaissance-Attack helicopter designed to replace US Army observation helicopters and its AH-1 Cobra attack helicopter. The effort began as the Light Helicopter Experimental (LHX) program in 1983. (21) It specified a fleet of 5,023 single-seat rotorcraft, with ambitious goals for aircraft stealth, flight performance,

Table 17: Candidate Principles as Factors in the A-12 Program

-	Objective
	Simplicity of Command
	Tempo
-	Risk Management
	Centralized Control/Decentralized Execution
-	Economy of Effort
-	Stable Program Inputs
-	Initiative
-	Workforce Quality & Credibility
-	Synergy & Synchronization

targeting and fire control, and communications. (9:1) In 1985, the Army determined that single-
seat operation was hazardous, and they subsequently specified a crew of two. [Stable Program Input (-)] The contractor team won in a "fly-off" solely via modeling and simulation. [Risk Management] [Economy of Effort] In 1993, facing financial constraints, the US Army cut the buy to 1,292 aircraft, extended program technical development until 2000, and scheduled EMD from 2000 – 2006, with fleet production through 2028. [Stable Program Input (-)] [Tempo (-)] During the 17-year technical development, the program underwent five restructurings. (9:5) The avionics mission equipment package underwent continual flux, due to evolving communications and interface standards [Stable Program Input (-)], while the program struggled unsuccessfully to manage airframe weight [Objective (-)]. In 2000 the DAB sent the program into EMD amidst growing concern over the validity of the original requirements for this weapon system. Not only was the helicopter designed for an extinct threat but the UAV technology, conceived, developed, and fielded during the span of the RAH-66 technical development had supplanted the helicopter for tactical reconnaissance. [Stable Program Input (-)] [Tempo (-)] The EMD plan came under fire for excessive risk taking: going into full-rate production before finalizing configuration, making a full rate-production decision before completing operational testing, and continuing avionics technical development during manufacturing development [Risk Management (-)]. (9:8) In February 2003 the Army cancelled the program, claiming it no longer needed the aircraft and wished to reprogram the money for more urgent issues. (36) The lessons of the case history, in that the RAH-66

program ultimately failed, as they related to the candidate principles are summarized in Table 18.

Table 18: Candidate Principles as Factors in the RAH-66 Program

-	Objective
	Simplicity of Command
-	Tempo
+/-	Risk Management
-	Centralized Control/Decentralized Execution
+	Economy of Effort
-	Stable Program Inputs
	Initiative
	Workforce Quality & Credibility
	Synergy & Synchronization

Analysis of Candidate Principles across the Six Acquisition Program Case Studies

In the review of acquisition program case histories, some new recurring themes stand out. First, the two exemplary programs developed in five to six years, and they both had logistics supportability problems early in fielding. This implies that time-to-field and thorough logistics supportability work against one another, and that at some point, a manager must deliver with the logistics on hand in order to balance against risk due to time (i.e., make schedule). Second, informal communications, trust, and a sense of esprit-de-corps were common among the two exemplary programs, weak in the two troubled programs, and notably absent in the A-12 case. This implies that the proportion of formal communications and agreements among members of a development team correlates to the degree of artificial trust needed to compensate for genuine rapport and should be a leading indicator for senior decision-makers for potential program troubles. Third, on two occasions the Navy required fixed-price development contracts and imposed onerous conditions upon the contractors; in both cases the contractors failed to deliver. This implies that short-term risk-avoidance is not the same as prudent risk management. The F-117 development ran the opposite tack, calculatingly assuming risks and giving contractors wide latitude. Finally, the most successful programs had the least number of stakeholders and the narrowest operational objectives. This implies that too many interests can spoil the program and that start-up programs require a gatekeeper who will prevent too many disparate requirements from attaching themselves to a funded development. The F-

117 program's classification served this function, and the Predator's high-level interest and advocacy did likewise for it.

LtGen Trey Obering, Director of the Missile Defense Agency, declared himself program manager for major programs under his agency. He felt that he needed the weight of a Lieutenant General to fend off the flock of narrow but powerful interests threatening to defocus and derail his programs. Coincidentally, joint task force (JTF) commanders leading campaigns are three-star generals and admirals. Thinking of a major defense acquisition program as a campaign for national security suggests that its campaign commander, the program manager, ought to carry the rank and authority of a JTF commander. Smaller programs can accommodate managers with lesser rank and authority. A summary of correlation between the six acquisition program case histories and the candidate principles is presented in Table 19.

The candidate principles of Risk Management, Economy of Effort, and Stable Program Inputs were factors across all program experiences. The candidate principles of Objective, Tempo Initiative, Workforce Quality & Credibility, and Synergy & Synchronization were factors in most of the cases examined. The candidate principles of Centralized Control/Decentralized

Table 19: Acquisition Program Histories and Principles Correlation

	Objective	Simplicity of Command	Tempo	Risk Management	Centralized Control/Decentralized Executio	Economy of Effort	Stable Program Inputs	Initiative	Workforce Quality & Credibility	Synergy & Synchronization
F-117	X	X	X	X	X	X	X	X	X	X
RQ-1	X		X	X	X	X	X	X	X	X
F-22	X	X	X	X		X	X		X	
V-22			X	X		X	X	X		X
A-12	X			X		X	X	X	X	X
RAH-66	X		X	X	X	X	X			
	5	2	5	6	3	6	6	4	4	4

execution and Simplicity of Command were factors in half or fewer of the cases reviewed. The results, combined with those relating to acquisition reform in Table 12, support the following
conclusions, in that time after time these principles were causal in the studied programs' successes or lack thereof:
The data *most* strongly supported the candidate principles of

- Economy of Effort
- Stable Program Inputs
- Risk Management

The data strongly supported the candidate principles of

- Objective
- Credibility
- Tempo
- Initiative

The data moderately supported the candidate principles of

- Workforce Quality & Credibility
- Centralized Control/Decentralized Execution
- Simplicity of Command

Therefore, the data support the hypothesis that there is a useful body of broad and enduring principles to be reaped from the lessons of DoD's experience with force modernization, and that those principles have utility in current modernization programs and in efforts to transform the modernization process. However, the number of case studies, reviewed to evaluate the candidate list of principles, is not statistically compelling; it simply gives an indication for further investigation. An analysis with a greater number of case studies would help to discern other principles or to definitively eliminate candidates from the proposed list.

Modernizing Modernization: Applying Doctrinal Principles to Current DOD/USAF Directives, Instructions, and Processes

What do the principles and their degree of support from acquisition reform and acquisition program experience portend for the current concepts for transforming the acquisition process? How well do these concepts adhere to the principles? This section examines the current processes with respect to the candidate list. The current process is top-down driven [Centralized Control]. Joint and Service staffs develop concepts of operation, based on strategic objectives [Objective], with tasks allocated to DoD

Mission Areas. Each Mission Area completes a Mission Area Assessment to determine the necessary enabling capabilities, and then conducts a gap analysis to compare mission requirements with actual (or projected) capability. Gaps, from the analysis, become *needs* (identified holes in mission capability), and Mission Solution Analysis considers the spectrum of options (DOTMLPF) to close the gaps [Economy of Effort]. Those needs requiring a material solution generate an Initial (needed) Capabilities Document. A Requirements Oversight Council [Centralized Control] [Risk Management] validates or refines the documented need, and an Analysis of Alternatives for the material solution gets underway [Economy of Effort] with the acquisition community participating. [Synergy] From this analysis of costs, operational effectiveness, and operational suitability criteria comes a preferred solution and a set of performance requirements for that solution. [Credibility] [Objective] (26: A-7ff)

Evolutionary acquisition has become the DoD-preferred method for acquiring new capabilities. It encompasses a variety of techniques, including preplanned product improvement (P3I), spiral development, and incremental acquisition. The concept is to manage (mitigate) risk due to time [Risk Management] in a modernization program by fielding required technologies as they mature [Tempo], thereby continually improving systems untilthey meet the entire requirement. It requires faith on behalf of the warfighter that partially met needs won't cause cancellation of future development funds [Credibility], and it assumes the solution systems will be designed such that they facilitate system upgrades after initial product delivery. [Objective]

The Capabilities Review and Assessment (CRRA) is a USAF process by which it considers its entire portfolio of programs in one of its roles or mission areas. [Centralized Control] The intent is to compare solutions to the CONOPS [Objective] and the mission needs to assess them for sufficiency, necessity, and risk. [Economy of Effort] [Risk Management] Given funding constraints, it renders a portfolio-wide allocation of resources for the upcoming programming and budget cycle. [Synchronization]

From these processes, principles not evident are

- Simplicity of Command
- Stable Program Inputs
- Initiative
- Decentralized Execution

While the current processes make an effort to mitigate time-to-need with incremental deployment of capability, they do nothing to accelerate the delivery of final capability [Tempo(-)]. Risk management initiatives center exclusively around risk avoidance and neglect prudent risk taking. [Risk Management (-)] Still notably absent are any efforts to empower program managers or any other workers at the tactical level. [Decentralized Execution (-)] The strength of analytical support for the candidate principles gives rise to the following conclusions about the current processes for transforming force modernization:

The new processes *will likely fall short* in the following areas in that they do not observe the corresponding most-strongly supported principles

- Stable Program Inputs
- Risk Management (i.e., prudent risk taking)
- Tempo

This implies that, at the *operational* level, future programs will be subject to the same vicious cycle of risk avoidance, long *acquisitions, and subsequent instabilities.*

The new processes *may fall short* in the following areas in that they do not observe the corresponding strongly supported principles

- Decentralized Execution
- Simplicity of Command
- Initiative

This implies that *tactical* responsiveness in future programs will suffer as program managers with insufficient empowerment and conflicting guidance will not have the latitude to innovate in anticipation of, or in reaction to, incipient crises and fleeting opportunities. It also indicates that the very talent needed to take on such challenges will flee or avoid program management jobs.

And the new processes *will probably succeed* in the following areas in that they observe the corresponding principles

- Workforce Quality & Credibility
- Synergy & Synchronization
- Risk Management (i.e. calculated risk avoidance)
- Objective
- Centralized Control
- Economy of Effort

This portends that *strategic* level portfolio management should improve as senior decision makers approach harmony and integration among overarching modernization themes and that initial legislative and executive buy-in will be easier to obtain. However, maintaining that buy-in will prove difficult when programs fail to execute as planned, due to operational and tactical difficulties not adequately addressed.

Conclusions and Recommendations

The analysis of the history of acquisition reform commissions, senior Defense executive initiatives for acquisition reform, and case studies of selected acquisition programs appear to support (1) The hypothesis that there is a useful body of broad and enduring principles to be reaped from the lessons of DoD's experience with force modernization, (2) That those principles have utility in current modernization programs and in efforts to transform the modernization process, and (3) That those principles form the cornerstone of a body of modernization doctrine that is better suited for governing the modernization processes than is the current prescriptive mass of laws, regulations, and instructions.

The candidate list yielded a number of principles with moderate to strong regularity of occurrence among the historical records. Although the small number of program histories considered in this study makes confidence in these candidate principles less than certain, they may be used, with caution, to evaluate current force modernization transformation efforts.

The conclusions from that evaluation reveal a process with strong adherence to principles controlling central direction, risk avoidance, and program credibility that does not address the critical problem stated in this paper's introduction—that of program responsiveness in a dynamic environment. The enabling conditions for such an ability—stable program inputs, decentralized execution, simplicity of command (i.e., protection from disparate narrow interests), appropriate risk-taking, and initiative—are opportunities being missed. If modernization is to have a chance at outpacing the strategic environment, it must adopt a doctrinal approach and give due regard to these neglected principles. Therefore, the following actions are recommended:

1. The force modernization communities should enlist a doctrine development center to formulate a draft force modernization doctrine document.
2. They should conduct an exhaustive analysis of acquisition program case histories to develop a definitive list of truly broad and enduring principles for force modernization.
3. With a force modernization doctrine document in place, eliminate all but the truly oblige tory statutes and policy mandates (i.e., treaty obligations, ethics, and environmental constraints) from acquisition and requirements regulations, directives, and instructions.

4. The force modernization community should evaluate alternative concepts for force modernization as well as suggestions for improvement and innovation within the context of its new doctrine. This would serve to vet the concepts and to exercise and mature the doctrine.

APPENDIX A

ACRONYMS AND ABBREVIATIONS

AFDD – Air Force Doctrine Document
AIP – Acquisition Improvement Program
ARPA – Advanced Research Projects Agency (now DARPA)
CAIG – Cost Analysis Improvement Group
CJCS - Chairman of the Joint Chiefs of Staff
CONOPS – Concept of Operations
DAB – Defense Acquisition Board
DAE – Defense Acquisition Executive
DAR – Defense Acquisition Regulations
DARPA – Defense Advanced Research Projects Agency
DFAR – Defense Federal Acquisition Regulations
DLA – Defense Logistics Agency
DoD -- Department of Defense
DoDD -- Department of Defense Directive
DoDI - Department of Defense Instruction
DPRO – Defense Plant Representative Office
DSARC – Defense System Acquisition Review Council (now DAB)
EMD – Engineering and Manufacturing Development
FM – Field Manual
FSD – Full Scale Development (now EMD)
JCIDS - Joint Capabilities Integration and Development System (JCIDS)
JCS – Joint Chiefs of Staff
JDAM – Joint Direct Attack Munition
MDAP - Major Defense Acquisition Program
MENS – Mission Essential Needs Statement
MNS – Mission Needs Statement
NSC – National Security Council
OMB – Office of Management and Budget
OODA – Observe, Orient, Decide, Act
OSD – Office of the Secretary of Defense
OT&E – Operational Test and Evaluation
P^3I – Preplanned Product Improvement
PEO – Program Executive Officer
PM – Program Manager
POM – Program Objective Memorandum

PPBS – Planning, Programming and Budgeting System
R&D – Research and Development
SAE – Service Acquisition Executive
SAF/AQ – Assistant Secretary of the Air Force for Acquisition
SecDef – Secretary of Defense
USD (A) – Under Secretary of Defense (Acquisition)
USD (AT&L) – Under Secretary for Defense Acquisition, Technology and Logistics
USDR&E – Under Secretary of Defense (Research and Engineering)

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Appendix B

EXPANDED PRINCIPLES OF WAR

Objective Objective is directing military operations toward a defined and attainable end state that contributes to strategic, operational, and tactical aims. The purpose of the objective is to achieve a unity of effort, with clear and complementary subordinate goals even in the absence of a united command.

Unity of Command Unity of command means that all forces operate under a single commander with the requisite authority to direct all forces employed in pursuit of a common purpose. The purpose of unity of command is to ensure unity of effort under one responsible commander for every objective.

Offense Offensive is to act rather than react and to dictate the time, place, purpose, scope, intensity, and pace of operations. The purpose of an offensive action is to seize, retain, and exploit the initiative.

Mass Orchestrating all the elements of combat power where they will have decisive effect on an enemy force in a short period of time is to achieve mass. The purpose of mass is to concentrate the effects of combat power at the place and time to achieve decisive results.

Maneuver Maneuver is the movement of forces in relation to the enemy to secure or retain positional advantage, usually in order to deliver — or threaten delivery of — the direct and indirect fires of the maneuvering force.

Economy of Force Economy of force is the judicious employment and distribution of forces. The purpose of economy of force is to allocate minimum essential combat power to secondary efforts.

Security Security consists of actions taken to protect friendly forces -- reducing vulnerability to hostile acts, influence, or surprise. The purpose of security is to never permit the enemy to acquire unexpected advantage.

Surprise Surprise is to strike the enemy at a time or place or in a manner for which it cannot prepare. The purpose of surprise is to help the commander shift the balance of combat power and thus achieve success well out of proportion to the effort expended.

Simplicity Simplicity is ensuring that guidance, plans, and orders are as simple and direct as the objective will allow. The purpose of simplicity is to allow subordinate commanders the freedom to operate creatively within their battle-space, and to allow better understanding and troop leading at all echelons -- permitting branches and sequels to be more easily understood and executed.

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Chapter 2

Impact of Weapon System Complexity on Systems Acquisition

by

Robert A. Dietrick, Major, USAF

The purpose of studying the new sciences is simple... We want to learn to understand war through the most powerful means available... to encompass the ideas contained in quantum mechanics, nonlinear systems, and chaos and complexity theories.

—Lt Gen Paul K. Van Riper

There seems to be strong consensus that the current "acquisition system" is broken. It takes too long and costs too much to develop and produce the next generation of weapon systems. Programs frequently overrun both cost and schedule targets. Focusing on long cycle times the following perspectives have been offered:

> 1986: "We believe that it is possible to cut this cycle time in half." -- The Packard Commission
>
> 1986: "The most important way technology could enhance our military capability would be to cut the acquisition cycle time in half." -- Chairman of the Joint Chiefs of Staff
>
> 1997: "We need a fast-paced acquisition system." -- William Cohen, Secretary of Defense
>
> 2002: "We still have an acquisition system that takes years, and years, and years, notwithstanding the fact that technology is changing in 18, 20, 24 months."
> -- Donald Rumsfeld, Secretary of Defense[1]

These observations actually go back further than 1986 and have been the impetus for a number of studies, research reports, commissions, and reform initiatives. As early as 1980 there were nearly 30 studies either underway or publishing findings.[2] That trend has largely continued to the present day with the Department of Defense (DoD) Directive 5000.1, "The Defense Acquisition System," being revised in 1996, 2000, and 2003. To some extent all of these efforts have followed a "search for the Holy

Grail" type of mentality, that there is a solution out there, it just needs to be found. More often than not, the solution seems to be viewed in the singular sense; that a single solution, the adoption of a single process such as evolutionary acquisition will result in tremendous improvement.

The possibility that long acquisition cycle times are a byproduct of enormously complex systems has been frequently ignored or rejected. For example, Dr. Jacques Gansler noted that development times for defense systems have increased as system complexity has increased, but added that DoD development times are significantly longer than commercial systems of comparable complexity.[3] Unfortunately, Gansler offers little proof and never actually defines complexity. This is typical of another problem with many of the search for the Holy Grail studies. These studies often make extensive use of soothsayers, subject matter experts offering unsubstantiated opinions on problems and solutions. "Regardless of the precise form, this approach [expert opinion] relies on the *intuition* of knowledgeable individuals [emphasis in original]."[4] The obvious problem is that the possibility exists that all or nearly all of the experts are wrong. Consider the example of Copernicus who proposed that earth orbited the sun instead of the other way around.

This study seeks to minimize the influence of expert opinion and explore the other possibility for long acquisition cycle times. Despite the burden of federal and DoD acquisition regulations and processes, increasing weapon system complexity drives development schedules and is the prime acquisition challenge. This paper explores the nature of complexity as applied to weapon systems, specifically the exponential growth of aircraft avionics complexity, and develops a suitable definition. It then establishes the link between increasing complexity and increasing development times and the corresponding impact on acquisition programs. Finally, based on a belief that solutions do not exist, suggestions for limiting complexity and coping with complexity are offered.

Understanding Weapon System Complexity

Although our intellect always longs for clarity and certainty, our nature often finds uncertainty fascinating.

—Carl von Clausewitz

The term "complexity" has been frequently used with respect to weapon systems but establishing a good definition is not easy. Complexity has been defined circularly, used interchangeably with cost, and associated with schedule. For example, one researcher offered this circular explanation of complexity, "These systems are inherently 'complex' because of the dramatic increase in the complexity of the hardware and software that are used in the development of even 'simple' products."[5] This chapter explores the historical associations of complexity with cost and schedule as evidence of the lack of precision with which the term has been used. Complexity theory is reviewed to develop a more precise definition for weapon system complexity. Finally, measures of complexity are proposed.

Previous Cost, Schedule, and Complexity Relationships

Historically, acquisition researchers have associated complexity with cost. With the cost of modern tactical aircraft increasing sharply, studies during the 1980s investigated the tradeoff between platform and weapon complexity. Bruno Manz and Kenneth Smith compared the alternative approaches of improving munitions or improving the delivery platforms with procurement cost as the measure of merit.[6] The study was hypothetical in nature, concluding that a general answer did not exist but was dependent on the parameters of a specific scenario (i.e., actual platform and munitions costs, threat level, and sortie rates). Although they never specifically defined complexity, they used the terms cost and complexity interchangeably and noted that cost and complexity are "inferentially" related; that platform and weapon system performance are enhanced as the cost of components increases "and supposedly component complexity."[7] Similarly, Robert Lowe investigated the link between technical complexity and production cost for tactical aircraft. Using regression analysis, he established a strong link between the level of technology or complexity and production cost.[8]

Complexity has also been related to design iterations and development schedules. According to Robert Grady and Deborah Caswell, the nongovernmental Software Metrics Council pursued the development of software difficulty measures based on the belief that complexity is correlated with longer development schedules.[9] Offering a deeper explanation for this relationship, Tyson Browning found that the number of design iterations increases as system complexity increases. According to Browning, "Multiple configurations are put up as strawmen, additional details are added, and many virtual and sometimes physical prototypes are necessary to reveal issues initially overlooked."[10] Browning found this relationship applied equally to both the DoD and private sectors, noting that between 13% and 70% of total semiconductor development time at Intel was the result of development iterations and that iteration was the primary cause of variability in development schedules.[11] Yet, Browning never offered a clear definition or objective measures for complexity.

Another view has been to use complexity as a synonym for technology and in terms of technical performance measures. Lowe offers a typical view: "Technology can be measured using data describing the 'engineering' sophistication of a system (an input measure) or using data describing the performance of a system (an output measure)."[12] He goes on to use the terms technology and complexity interchangeably. In analyzing the relationship between performance and cost for tactical aircraft, Lowe uses payload, range, maneuverability, and useful speed as measures of complexity.[13]

But viewing complexity strictly in terms of system performance greatly reduces its meaning because performance generally improves over time. Therefore, system complexity would merely be a function of time. For example, Lowe found the technology level of previously fielded tactical aircraft a "significant predictor" of the production cost for the next generation of aircraft.[14] By using aircraft performance as the measure of technology, Lowe found that performance generally improved from one generation of tactical aircraft to the next in a predictable manner based on the time interval between the two aircraft. Looking at the explosive growth of computer software, Frame notes that "the first word processing software packages easily fit onto a 360 KB disk; 10 years later, packages occupied 9MB of disk space."[15] Frame attributes this phenomenon to the fact that the growth of knowledge is cumulative, implying that increased knowledge leads to increased complexity.[16] Defining complexity as a synonym for cost or technology squanders an important system characteristic.

Complexity Theory

Complexity theory offers a different view of complex systems, emphasizing the impact of interactions within the system. According to

Waldrop, one of several leading experts on complexity theory, complexity stems from the interactions between entities within a system.[17] Offering a definition for complex systems, Waldrop states that they are dynamic and adaptive, with the ability to self-organize.[18] Frame agrees, noting that "Consensus is emerging that complexity is closely tied to the adaptive behavior of systems."[19] This leads to the conclusion that static objects or systems can be complicated, but they cannot be complex.[20] Formally, because weapon systems and weapon system designs lack the ability to self-organize, they are static with respect to complexity theory. Weapon system designs evolve through various stages of maturity only through the efforts of the design team. Despite the subtle distinction used in complexity theory, this paper will use the terms complicated and complex interchangeably. In both static and dynamic systems, interactions between system components contribute to complexity.

Before moving on, there is yet another view of complexity that should be addressed. Dr. George Perino, with over 25 years of experience in DoD acquisition, offers the view that complexity is not a characteristic of the system but is in the mind of the observer.[21] According to Perino, "It is the observer's inability to grasp the interplay of multiple factors and events that lead to 'complex' problems, issues or systems."[22] Although arguably valid, this view transforms complexity into a binary variable. When an observer's view of a system causes confusion, the system is complex; otherwise it is not complex. This would make any comparison of the complexity between multiple systems meaningless. Instead, by viewing complexity as a system characteristic linked to the number of interactions within a system, the complexity of multiple systems can be compared, which is consistent with the intent of this research.

In addition to entity interactions within a system, sheer technical difficulty should also be considered in defining system complexity. Frame associates system complexity with technical difficulty and notes that multiple alternatives can lead to "paralysis through analysis."[23] In comparing the relative complexity of a Minuteman III guidance upgrade to the original intercontinental ballistic missile development, Col Steve Suddarth also seems to use complexity in reference to technical difficulty.[24] Others, however, have used the terminology of technological advance to capture this element of technical difficulty.[25] This is more precise and enables the following program terms to be defined:

1. Technological Advance: An assessment of the extent to which existing technology must be extended or new technology developed to meet required performance. The AFRL Technology

Readiness Levels are an example of one measurement scale for this characteristic.
2. System Complexity: A measure of either actual or potential number of interactions between entities comprising the system.
3. Technical Difficulty: The aggregate of Technological Advance and System Complexity.

Measures of Complexity

Although counting the number of interactions between entities within a system would be a very good measure of system complexity, this would be difficult to accomplish. As Frame identifies, the upper limit for the number of interactions within a system is:

$$Interactions_{\max} = \frac{n(n-1)}{2} \quad \text{E}$$

Where *n* is the number of entities within the system.[26]

But even this assumes a maximum of one interaction between any two entities. In considering subsystem relationships in systems decomposition, Thomas Pimmler and Steven Eppinger proposed four categories of interactions:

1. **Spatial:** A spatial-type interaction identifies needs for adjacency or orientation between two elements.
2. **Energy:** An energy-type interaction identifies needs for energy transfer between two elements.
3. **Information:** An information-type interaction identifies needs for information or signal exchange between two elements.
4. **Material:** A material-type interaction identifies needs for materials exchange between two elements.[27]

Additional categories could include thermal (heat transfer) and electromagnetic fields, neither of which is clearly captured under the category of energy. Thus, for a system with even 500 entities, there could be as many as 748,500 interactions. Clearly, attempting to identify and count the exact number of interactions directly for anything more than a trivial system would be very difficult and beyond the scope of this research effort.

Instead, the number of system entities can be used to estimate the complexity of a system using EQ-1. The key to applying this approach is to translate the term entity into something actual to enable the counting. For an electronics hardware system, integrated circuit boards are probably a good measure at the system level. However, the complexity of the boards also needs to be considered, using circuit components as the measure. Thus, one highly integrated system design may contain relatively few densely populated boards and alternative modular design for the same functionality might utilize more boards with lower population densities. By merely applying EQ-1 at the system level, the highly integrated system may appear less complex than the modular system when in reality the more highly integrated system is more complex because of the higher complexity of its circuit boards.

For software intensive systems, complexity can be assessed by using the number of software modules or executable source lines of code (ESLOC or just SLOC). For measuring software complexity, Walter Perry et al identified the three standard methods as SLOC, object points, and function points. Object points is basically the number of software modules and function points is essentially a more direct measure of system inputs, outputs, interfaces, and internal logic.[28] Although both object points and function points are newer and potentially more meaningful measures of complexity, they require more information for support. For this paper, the number of software modules will be estimated based on the SLOC.

Summary

In order to better understand the impact of complexity on weapon systems development, a better definition of complexity is required based on the interactions occurring within a system. However, direct and exact measure of the number of interactions is difficult, so the number of potential interactions will be used as the quantification of complexity. This number is provided by EQ-1. It is important to remember that at this stage, complexity is only a characteristic of a system and relationships with cost and schedule have not yet been identified. Thus, a system with a complexity factor of 500 will not necessarily take 10 times longer to design or cost 10 times as much to develop or build than a system with a complexity factor of 50. It is simply 10 times more complex.

Increasing Complexity

After the year 2015, there will be no more airplane crashes. There will be no takeoffs either, because electronics will occupy 100 percent of every airplane's weight.

—Norman Augustine

Although it can be safely assumed that Augustine's above quote was made only in jest, it singles out aircraft avionics as an increasingly significant contributor to the overall weight, cost, and *problems* of modern aircraft.[29] Complexity estimates for the avionics of five aircraft from the 1965 F-111 to the 2005 F-22A, plus complexity estimates for two next generation airborne sensors, are presented in this section. These systems were chosen based on the availability of data and because of the explosive growth of software. As the charts of complexity $\log_{10}$ clearly show, the estimated complexity is growing exponentially.

Aircraft Avionics

The proliferation of electronics in both performance and quantity is a major contributor to increasing weapon system complexity. Norman Augustine, former CEO of Lockheed, encapsulated this trend with his Law Number XIV, that by 2015 "electronics will occupy 100 percent of every airplane's weight."[30] Augustine based this law on the exponential increase of electronics as a percentage of tactical aircraft empty weight. The actual plot of the data presents a less sensational perspective of electronics weight perhaps leveling off at 6-10 percent of empty weight as early as the 1960s. Still, considering Moore's law of doubling the number of transistors in a processor about every 24 months, the same amount of electronics has vastly more performance capability today than in the 1960s. This growth is not just limited to tactical aircraft. The typical communications satellite had around 250 circuits in 1965, 4,000 in 1970, and 30,000 by 1985.[31]

In addition to increasing in size, weight, and number of processors, the amount of software in aircraft avionics has increased dramatically. This is unlikely to come as a surprise to anyone familiar with modern jet age aircraft, but the scale of the increase and the impact on system complexity may be surprising. According to Alexander Hou, early models of the F-4 did not include digital computers and, consequently, did not have any software.[32] Digital processors and primitive assembly language software for fire control tasks appeared during the 1960s, and the number of processors and lines of higher order language code have increased considerably over the last 40 years.[33] The data presented in Table 1 show the relationship between lines of software and complexity. For the 1960s, it should be noted that 0.2 KSLOC (KSLOC = 1000 SLOC) actually refers to 4-8 bit words of assembly language. The number of modules is estimated based on 100 SLOC per module, which is a general target for developing easily maintained software.[34] For 1960s assembly language, the number of modules was set equal to the number of words because the assembly code is inherently more complicated than the higher order languages that followed. Calculating the potential number of interactions between software modules and the $\log_{10}$ is then straightforward. Of course, the resulting complexity numbers are only estimates, but assuming that the actual number of interactions as a percentage of the maximum possible number of interactions has remained relatively constant over time, the complexity factors should be reasonable in a relative (but not absolute) sense. Ultimately the complexity of aircraft software appears to be increasing exponentially.

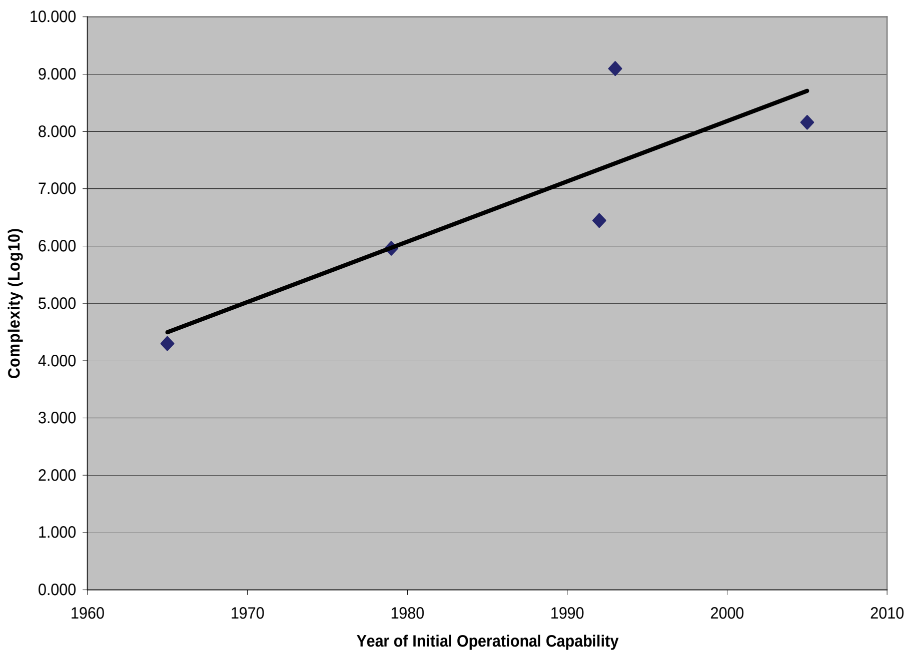


Figure 1: Increasing Complexity of Aircraft Avionics

Airborne Sensors

One of the main distinguishing characteristics of the latest generation of airborne intelligence, surveillance, and reconnaissance (ISR) sensors is the increased amount of airborne data processing prior to transmitting sensor data to the ground. Previously, airborne sensors on the high altitude U-2 collected only relatively raw data and transmitted this information to ground stations for processing. In the case of a synthetic aperture radar (SAR) imaging sensor, data was transmitted from the air to the ground for processing to include image formation. This scheme of operation forces trade-offs between image size and resolution based on the available bandwidth of the air-to-ground data link.

Table 20: Software Size and Corresponding Complexity Numbers

Time-frame (IOC)	Platform	KSLOC [35]	Modules (Estimated)	Complexity $n(n-1)/2$	Complexity Log_{10}
1965	F-111	0.2	200	19,900	4.299
1979	F-16A	135.0	1,350	910,575	5.959
1992[36]	F-14D	236.0	2,360	2,783,620	6.445
1993[37]	B-2	5,000.0	50,000	1,249,975,000	9.097
2005[38]	F-22[39]	1,700.0	17,000	144,491,500	8.160

The advent of significantly more powerful digital processors enabled image processing to
move from the ground to the air. However, this also requires processing image data in real-time to avoid the prohibitive additional weight of airborne digital storage of pre-processed data. To process the data in real-time requires many parallel digital signal processors and adds substantially to the complexity of the resulting sensor. The result of more powerful digital processors is demonstrated in Table 2. The names of the systems have been concealed to protect the contractors, but System 1 is a “legacy” sensor relying on ground processing for exploitation of sensor data. Systems 2 and 3 are next generation systems with airborne processors and are substantially more complex. The year of Initial Operational Capability (IOC) has been estimated for Systems 2 and 3. For System 2, it is very unlikely to slip because early versions of the sensor have been operating effectively since late 2004. System 3 is less mature and has not yet entered flight test. Due to this fact, it is conceivable, but judged unlikely, that the actual year of IOC could slip. The resulting complexity log_{10} for

these systems is plotted in Figure 2. The previously plotted complexity numbers for the aircraft avionics are retained for comparison.

Table 21: Airborne Sensor Complexity

System	Year of IOC	Development Time (years)	Number of Processors	KSLOC	Number of Modules (Estimated)	Complexity $n(n-1)/2$
1	1994	4	40	197.5	1,975	1,949,325
2	2006	8	178	542.3	5,423	14,701,753
3	2007	5	76	503.9	5,039	12,693,241

Source: Sensor contractor program offices (specific names concealed for their protection), interview by author, 12 January and 16 February 2006.

Reasons for Increasing Complexity

Next generation weapon systems are developed on the premise that they deliver enhanced performance over the systems that they will replace. In general, development programs fall into three broad categories: new capability programs such as the Airborne Laser program, replacement programs such as the F-22A, and modification programs such as an F-16 block upgrade. In some respects, programs delivering new capability have the most flexible requirements in that they are not competing against an already fielded weapon system. For example, the first generation Intercontinental Ballistic Missiles (ICBMs), Atlas and Titan I, were fielded from 1957-1961 but deactivated by 1965.[35] These early systems had been rushed into service as a “stop-gap” measure until more capable systems such as the Minuteman and Titan II could be developed and

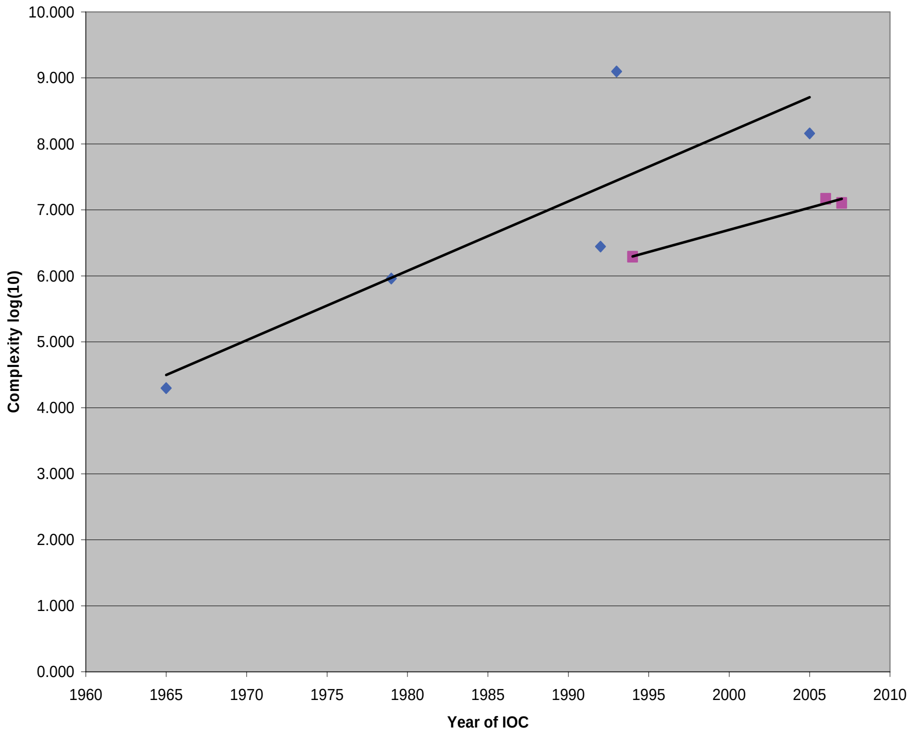


Figure 2: Increasing Complexity of Airborne Sensors

fielded. The first generation systems simply had to work; the follow-on replacement systems had to have equal or better range and accuracy, improved reliability, and increased survivability.

In general, greater performance can be delivered by either new technology or “larger amounts” of the same technology. Considering ICBMs, the relative perfection of solid fuel boosters enabled the Minuteman I to easily deliver improvements in operational robustness, maintainability, and survivability over its Atlas and Titan I rivals. As for aircraft avionics, the technology has been essentially the same for an extended period of time. The digital processors of today are not much different from the first digital processors decades ago. They simply pack more gates or transistors into vastly smaller sizes producing greater performance in exchange for greater complexity.

Complexity as the Prime Challenge

The last 10 percent performance generates one-third of the cost and two-thirds of the problems.

—Norman Augustine

Having demonstrated the increasing nature of weapon system complexity, this section will examine its impact. From previous research and available data, complexity appears to drive both cost and schedule for development programs. This perspective conflicts with other views that attribute acquisition slowness and expense to funding instability and bureaucracy, but on closer examination, complexity seems to offer the better explanation.

Complexity Drives Cost

In addition to being used as a pseudonym for cost, complexity is also related to production cost when technology is advancing. The level of integration (the number of electronic gates or transistors per chip) and subsystem weight have been used as the independent variables for estimating the production cost of various avionics subsystems.[36] Combined, the level of integration and subsystem weight essentially capture the interaction nature of complexity. As the number of gates involved increases, the expected number of interactions can also be expected to increase. Using data from 1959 through 1995, R.W. Hess et al. concluded that "Each time the level of integration [number of gates per chip] increases by an order of magnitude, [avionics] subsystem costs increase between 10 percent (controls and displays) and 48 percent (fire control radars)."[37] Hess attributed this to "performance push" which "has driven avionics to higher and higher levels of complexity to fully exploit the advances in microelectronics technology."[38] So despite decreasing costs for each electronic gate, the overall cost of aircraft avionics has been increasing as a function of the level of integration or level of complexity of the components.

Complexity has also been linked to development costs for electronics. A proprietary cost estimating system for development and production costs, PRICE, was originally developed by RCA and is now in use by multiple defense contractors and government acquisition offices. Due to the proprietary nature of PRICE, the exact nature of the cost estimating equations is not available, but inferences have been made regarding general relationships. For PRICE-H, the hardware module of the system, cost estimates are primarily a function of types of components, weight, component density, power dissipation, testing, types of materials, and manufacturing methods.[39] Component density is similar to complexity as defined here. As component density increases, the number of planned and unplanned interactions between components will likely increase. Unplanned interactions could include interactions such as electromagnetic fields and heat. In general, development and production cost can be expected to increase as the level of complexity increases.

Development cost growth has also been linked to development schedule. As a general rule, programs with longer development schedules cost more than programs with shorter schedules. Various factors likely contribute to this relationship. Jeffrey Drezner et al. offer one possible cause, "Longer programs allow more time for unanticipated events to occur that [negatively] affect cost performance."[40] Another possible explanation is that programs with longer schedules are pushing beyond the region where a linear or nearly linear extrapolation from previous experience is valid for cost estimating. This would complicate the cost estimating process and would likely result in more discrepancies between estimated and actual costs. Regardless of the mechanism, the evidence of a relationship is there. Studying 67 development programs, including 15 that either completed under budget or stayed within budget, Drezner noted a strong relationship between cost growth and program duration from acquisition program approval (Milestone I) to first operational delivery. He concluded that the longer the actual program duration, the more likely a program was to experience a cost overrun and the larger the cost growth as a percentage of planned program cost.[41]

Cost and Schedule Relationship

Other researchers have also investigated the potential for a relationship between cost and schedule. At a fundamental level, system development is often a very labor-intensive effort, and longer schedules provide the opportunity for more man-hours, increasing cost. Program management and overhead functions are also performed over a longer period of time, and indirect costs for facilities and infrastructure accumulate over a longer period of time. Although not always recognized, data suggests a strong positive correlation between development schedule and development cost. Analyzing the relationship between cost and development schedule, McNutt notes that for 154 DoD projects, the best fit line correlating development time with cost (in millions of dollars) is provided by:[42]

$$DevelopmentCost = \left(0.03 \times DevelopmentTime_{months} + 1.36\right)^4$$ E

McNutt is quick to point out that a number of factors influence this relationship, including the complexity of requirements, which presumably correlates with the complexity of the resulting weapon system.[43] Ultimately, however, it should be clear that cost is related to schedule.

Since development cost is proportional to complexity and development cost is proportional to development schedule, development schedule must also be proportional to complexity. From a mathematical perspective, if development cost is a function of complexity and development cost is also a function of development schedule, then development schedule must also be a function

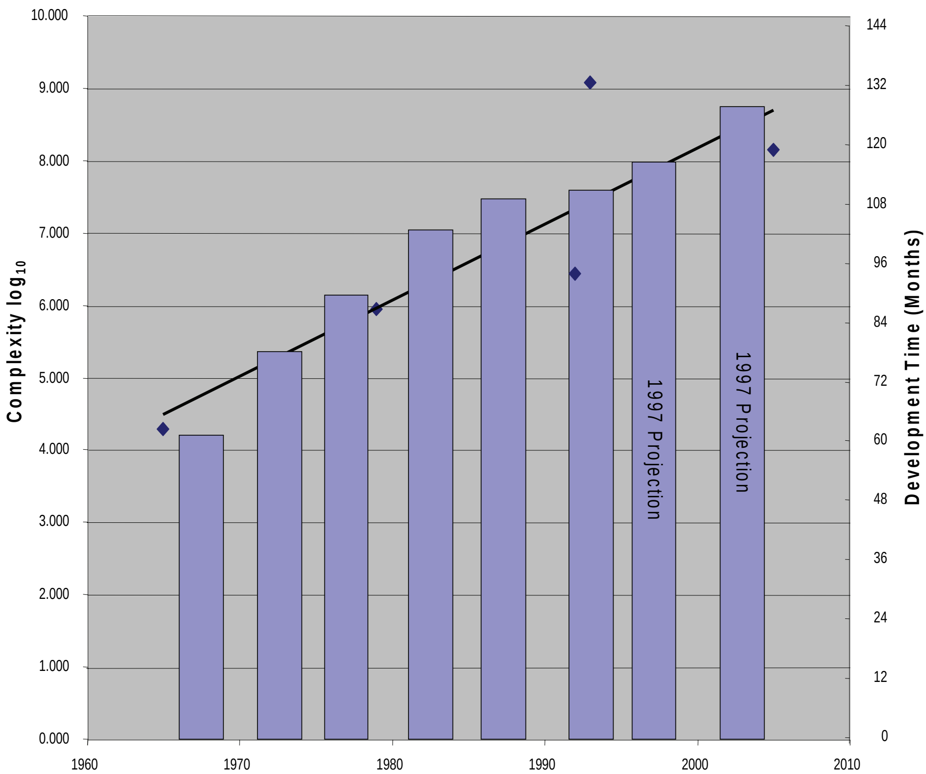


Figure 3: Complexity and Acquisition Cycle Time
Source: Development Time data from Maj Ross T. McNutt, *Reducing DoD Product Development Time: The Role of the Schedule Development Process*, 33

of complexity. This does not imply that complexity is the only variable but merely that it is at
least one of the variables. Figure 3 overlays the increase in average acquisition cycle time (development schedule) for major defense acquisition programs against the previously plotted exponential increase in complex-

ity of aircraft avionics. Assuming the increase in avionics complexity is representative of the increase in complexity of major defense acquisition programs in general, then there would appear to be a very strong correlation between the exponential growth of complexity and the linear increase in acquisition cycle time.

Funding Instability and Bureaucracy

Still, not everyone is convinced that increasing weapon system complexity is the prime issue for systems acquisition. One counterargument is that increased congressional involvement in the defense budget is a major problem for acquisition programs. Dr. Barry M. Blechman, CEO of Defense Forecasts, Inc., International, provides fuel for this belief with the data in Tables 3 and 4. The percentage of the defense budget requiring authorization rose from a mere two percent in 1961 to a complete 100 percent in 1983. But more to the point, the appropriation for research, development, test, and evaluation, went from zero percent requiring authorization in 1962 to a full 100 percent in 1963. Also, Table 4 highlights the increase in the number of requested deliverables and the number of adjustments to authorizations and appropriations by Congress. According to Blechman, the participation in this time-consuming congressional review process results in a "quite significant" cost to the nation.[44] Blechman, however, never attempts to quantify this cost nor provide a specific cause and effect mechanism. He merely implies that first, DoD personnel spend an inordinate amount of time responding to congressional inquiries and second, the budget adjustments result in a lack of funding stability. As a solution, Blechman argues that "legislative enactment of the FYDP [Future Years Defense Program] would cause the Pentagon to take the 'out years' of its programs more seriously," and that Congress should enact two-year defense budgets to enhance budget stability.[45]

The problem with this argument is that the data lacks sufficient detail to determine its effect on development programs. The data does not identify how many of the requested studies and reports should be developed anyway in the course of normal business, the cost in dollars and schedule of producing these reports, nor the number of programs affected. Also, the data does

Table 22: Percentage of Defense Budget Requiring Authorization, 1961-1983

Fiscal Year	Personnel	Operations & Mainte-nance	Procurement	Research, Development, Test & Evaluation	Construction	Percent of total re-quiring au-thorization
1961	0	0	0	0	90	2
1962	0	0	75	0	90	27
1965	0	0	74	100	94	37
1967	0	0	63	100	93	32
1969	4	0	55	100	93	29
1971	6	0	70	100	94	31
1972	100	0	71	100	94	63
1982	100	100	73	100	93	91
1983	100	100	100	100	94	100

Source: Dr. Barry M. Blechman, *The Politics of National Security*, 31

Table 23: Congressional Initiatives on the Defense Budget, 1970-1988

Type of action	1970	1976	1982	1985	1988
Requested studies and reports	36	114	221	458	719
Other mandated actions	18	208	210	202	n/a
General provisions in law	64	96	158	213	179
Number of programs adjusted:					
in authorization	180	222	339	1,315	1,184
in appropriation	650	1,032	1,119	1,848	1,579

Source: Dr. Barry M. Blechman, *The Politics of National Security*, 41

not identify how many funding adjustments are decreases and how many are increases. Considering the primacy of local politics and the reluctance congressmen have displayed in closing military bases in their districts, it is likely that many of the adjustments are actually "adds" to improve the funding for programs with local interest. Essentially, this argument is the result of a Washington-centric mindset that searches for problems and solutions exclusively within the nation's capital while ignoring the fact that systems are actually developed through the collaboration of contractors, program offices, and the operational users.

The issue of funding instability was also raised by the Affordable Acquisition Approach study conducted by Air Force Systems Command in 1983. Relying on subject matter experts, this study highlighted the growth of funding instability as a major program issue (see Table 5). Although this may be true in some instances, it should be viewed skeptically. First, it has been concluded that most of the factors identified in the study are interdependent.[46] Since the factors are interdependent and cause and effect has not been established, firm conclusions cannot be made regarding the impact of funding instability on program performance. For example, since the incidence of technical complexity closely parallels the incidence of funding instability, it is possible that programs encounter execution problems stemming from complexity, which later results in funding instability. Alternatively, if complexity is lengthening the minimum time required to complete a program, then that program is subjected to more budget cycles, increasing the cumulative probability of funding instability over the length of the program. Although funding instability is a likely contributor, there is insufficient information to determine if it is a root problem or just another symptom of increasing complexity.

Table 24: Schedule Impact Factor Percentages

Factor	Pre 1970	1970-1983
Technical Complexity	52%	61%
Technical Problems	70%	36%
Technical Advance Impacts	67%	46%
Funding Instability	48%	64%
External Management Impact	41%	68%

Source: Cited in Eric K. Nelson, *Independent Schedule Assessment FSD Study*, 2-10.

Technical Complexity - The existence of large numbers of technical interfaces, subsystems, or components

Technical Problems - The occurrence of unanticipated major technical problems

Technical Advance Impact - Unstable configurations and undemonstrated performance of [sub-] systems at the start of FSD [Full Scale Development]

Funding Instability - Large or frequent changes in or restrictions to program funding resulting from budget decisions by HQ USAF, OSD, or Congress

External Management Impact - The occurrence of program decisions at levels above the program office or the occurrence of program reviews at HQ USAF or higher levels[47]

On the contrary, Table 3 provides additional evidence that complexity is a growing program issue. Note that the definition used by the Affordable Acquisition Approach study for complexity captures the factors that lead to interactions, so this definition is congruent with the definition used here. The percentage of programs reporting technical complexity issues increased moderately from 52% to 61%, despite sharp declines in the percentage of programs reporting technical problems or technical advance impacts. This increase reinforces the conclusion that less technically advanced systems relatively free of technical problems can still encounter considerable program problems simply due to the size and scope of the technical effort.

In addition to funding instability, another competing claim is that increasing levels of bureaucracy are a prime reason for a slow acquisition cycle. In this view, lengthy requirements and funding processes, combined with an inherently slow decision cycle, dramatically reduce the responsiveness of the acquisition cycle.[48] Of course, these symptoms of bureaucracy can be overcome with sufficient need. The GBU-28 "Bunker Buster" program offers interesting insights. In the week after Desert Storm combat operations began, the Air Force asked industry for ideas about a weapon to support targeting of the Iraqi hardened command bunkers.[49] The resulting GBU-28 "was conceived, developed, tested, and deployed in approximately 28 days."[50] This type of process was repeated more recently to support operations in Afghanistan. On October 11, 2001, the Defense Threat Reduction Agency (DTRA) organized a quick-response team to pursue the development of enhanced munitions for targeting cave complexes in Afghanistan. "This new thermobaric bomb, designated as BLU-118/B, was developed within 67 days and subsequently supported Operation Enduring Freedom."[51] These two munitions programs provide examples of rapid development when overwhelming need trumps business as usual mindsets.

Turning to larger systems, the F-117A is another example of the speed possible in weapon systems development. Following the initial development of math models and wooden mockups in 1975-76, development of the F-117 flying prototype Have Blue required just 20 months; flight test started in December 1977.[52] With follow-on contracts for a production configuration and delivery of 59 aircraft, initial operational capability was achieved in October 1983,[53] about seven years after Have Blue prototype development. On the surface, it appears that the F-117, GBU-28, and

BLU-118/B programs demonstrate the promise of an acquisition system free of bureaucracy.

In reality, however, all three systems are relatively less complex systems. For example the rapid production of the GBU-28 was possible only through the reuse of existing systems integrated in an innovative way.[54] Essentially, the same applies to the BLU-118/B. As for the F-117A, the Skunk Works made extensive use of existing subsystems and components. In the words of Ben Rich, head of the Lockheed Skunk Works:

> We took our flight control actuators from the F-111 tactical bomber, our flight control computer from the F-16 fighter, and the inertial navigation system from the B-52 bomber. We took the servomechanisms from the F-15 and F-111 and modified them, and the pilot's seat from the F-16. The heads-up display was designed for the F-18 fighter and adapted.[55]

And enabling the hopeless diamond to fly, the fly-by-wire system was adapted from the F-16 with significant reuse of existing software.[56] As a result, by 2001 the F-117 avionics still had only 500,000 source lines of code, compared to over 1.1 million for the Block 50 F-16C, making it far less complex by comparison.[57] Despite the technological challenge of mastering stealth, the extensive use of existing components made the F-117A a less complex weapon system, which enabled its rapid development.

Although many variables, to include funding instability and bureaucracy, combine to influence the duration of development programs, weapon system complexity appears to be the dominant factor. Confirming the intuition of early researchers, complexity also drives development and production costs but should not be used as a mere pseudonym for cost. Complexity has been successfully minimized in some development efforts. In fact, minimizing complexity appears to be an essential part rapid development.

Recommendations

Any complex activity, if it is to be carried on with any degree of virtuosity calls for appropriate gifts of intellect and temperament. If they are outstanding and reveal themselves in exceptional achievements, their possessor is called a "genius."

—Carl von Clausewitz

One obvious approach to addressing weapon system complexity is to attempt to minimize it. As Grady and Caswell observed, there are two categories of complexity: inherent complexity, "the basic property of a problem that requires its solution to be more complex than that of another," and unnecessary complexity, "complexity which is built into a solution that is not inherently required."[58] Since even the inherent level of complexity in modern weapon systems is extremely high, the other necessary approach is to better cope with complexity. Modular design offers one approach for reducing design complexity; embracing acquisition as analogous to Clausewitzian warfare offers an approach to better cope with inherent complexity.

Reducing Complexity

The use of modular design methods provides one approach for reducing the inherent complexity of a system. Modular design standardizes interfaces and seeks to isolate subsystems such that changes to one subsystem do not impact other subsystems.[59] Modular design can minimize complexity by finding the optimal balance between a system of many simple subsystems and a

system with only a few very complex subsystems. For example, suppose 100 components are required to provide the necessary level of performance for a system and these components can be arranged in various different ways to form subsystems that then form the overall system. If at the system level each subsystem is considered an entity and if at the subsystem level each component is considered an entity, then there is at least one optimal design that will use all 100 components and simultaneously minimize the theoretical maximum number of interactions at the system and subsystem levels. In this arbitrary example constrained to just three levels (the system, subsystems, and components), the optimal system design with respect to complexity would be a system of ten subsystems, each comprised of ten components (10 subsystems x 10 components/subsystem = 100 components).

Although system development in the real world is never as arbitrary as in the above example, the theory is still applicable. In studying avionics programs, Tondreault noted that one of the cost drivers of an approximately ten-pound hardware subsystem was excessive component integration, resulting in very low manufacturing yields.[60] The manufacturing yield was increased from only 5% to 95% by redesigning the subsystem using a more modular architecture to significantly decrease the level of component integration.[61] In this real world example, the excessive component integration was leading to unmanageable complexity at the circuit card level. Dramatic improvement was possible by reducing this level of complexity.

In another similar real world example, Tondreault studied a project that was cancelled when the production microwave monolithic integrated circuits (MMICs) failed to meet the same performance of the prototypes. According to Tondreault,

> [The design] concept centered around a small number of highly integrated and complex MMICs (an alternate approach would have been a larger number of less complex MMICs). These complex MMICs became the core of the new design and were marketed as the team's technical discriminator.[62]

It can be inferred that the team was trying to present a system level design that had the appearance of being very simplistic, composed of just a few MMICs. But the penalty for this seemingly elegant system level design was again unmanageable subsystem complexity. The application of modular design and efforts to balance the level of system and subsystem complexity should always be considered during the development process.

Coping with Complexity

Systems development is an inherently nonlinear process similar in nature to Clausewitzian warfare. According to Alan D. Beyerchen, one of the more recent interpreters of Clausewitz, "*On War* is suffused with the understanding that every war is inherently a nonlinear phenomenon, the conduct of which changes its character in ways that cannot be analytically predicted."[63] Clausewitz attributes this unpredictability of war to the very nature of the interactive processes as two separate actors each simultaneously seek victory. In some sense, systems development is nothing more than an exercise of exerting one's will upon a lifeless mass. However, its essence remains nonlinear because development programs generally involve many thinking individuals, each trying to exert his own will on an otherwise lifeless mass giving rise to multiple interactions between individuals and subsystems during the development process. In part, this explains a common rule of thumb--to limit the size of both contractor and government development teams to the smallest possible size.[64] Still, the development process will always be nonlinear and, therefore, resistant to accurate prediction.

Resembling Clausewitzian warfare, systems development is characterized by fog and friction. In systems development, cost, schedule, and performance estimates roughly correspond to intelligence estimates of opposing forces. Clausewitz warned that many reports are false and most are uncertain.[65] Similarly, many acquisition researchers have noted that most programs overrun cost and schedule, and many fail to achieve expected performance.[66] For Clausewitz, friction was the accumulation of unforeseeable minor incidents combining to lower the level of performance.[67] The inability to accurately predict the course of development, to perfectly analyze system performance prior to test, or to identify and correct every design flaw or software bug, also leads to friction. Friction leads to designs that fail to meet performance objectives resulting in iterations. In one study of seven different avionics programs, it was noted that all involved an iterative approach whether planned or unplanned.[68]

Clausewitz noted that friction could be overcome with iron willpower.[69] Willpower was one of several necessary elements contributing to a "genius" for war. The same applies for acquisition. In the 1950s General Bernard Schriever generated a sense of urgency regarding the need to develop and deploy ICBMs and produced amazing results. The first generation Atlas was developed and deployed in three and one-half years, the follow-on Titan I achieved operational status in less than six years, and the solid-fueled Minuteman reached initial operational capability in approximately four years.[70] In contrast, the B-47 required almost eight years, the B-52 about nine and one-half years, and the B-58 over eleven years.[71] Certainly, some attribute Schriever's accomplishments to freedom from bureaucracy and generous funding. These factors, however, seem to be overestimated. For example, in 1956 "the ICBM operational plan underwent sharp scrutiny by the Air Force Ballistic Missile Committee," resulting in funding cuts and efforts to stretch the program.[72] This activity seems indicative of both some level of bureaucracy and funding instability. The ICBM acquisition and deployment serves as an example of the impact acquisition genius can have by infusing energy into development programs to overcome friction.

Acquisition genius must be cultivated with experience and independent study. The assertion that acquisition officers and civilians must gain experience in their trade seems obvious, yet the current system does not seem to recognize it. The current system, based on certification levels for different acquisition specialties, encourages "ticket punching," which in one instance "allowed an otherwise unqualified officer to replace an experienced physicist as chief technologist simply because the officer had APDP [Acquisition Professional Development Program] 'Level-III' certification."[73] Certifications can be obtained without any relevant program experience.[74] As for independent study, current DoD acquisition training focuses primarily on learning the processes as dictated by regulation. Acquisition professionals would be better served by studying the research reports being produced by students at the Air Force Institute of Technology, Air Command and Staff College, Air War College, and the Massachusetts Institute of Technology Lean Aerospace Initiative, as well as the RAND reports. These reports serve as a better analogy to the type of history that Clausewitz encouraged military commanders to study.

In studying research reports, acquisition leaders must remember that development is complex and defies simplistic approaches. Because development is nonlinear, it is very sensitive to initial conditions, which will never be precisely the same on two separate programs. Differences will likely exist in program objectives, government personnel, and contractors. Application of the same methods across two different programs is no more likely to guarantee success than applying the same strategy to two different wars. If the balance of power is sufficiently great or the program objectives sufficiently easy, nearly any approach will be successful. As the balance of power becomes less favorable or program objectives more challenging, great skill will be required to deliver success.

Conclusion

The trend of increasing development schedules and rising program costs has been well documented. Contrary to the beliefs proposed by various subject matter experts that funding instability and bureaucracy are the main problems confronting acquisition, system complexity appears to be a larger factor. This realization is made possible by moving past dated inferences that weapon system complexity is merely a synonym for cost or technical challenge and establishes a formal definition of complexity based on the interactions between the entities comprising a system. Based on this definition, analysis of data for aircraft avionics and airborne reconnaissance sensors convincingly suggests that system complexity is indeed increasing exponentially. Assuming the increase in avionics complexity is representative of the increase in complexity of major defense acquisition programs in general, there would appear to be a very strong correlation between the exponential growth of complexity and the linear increase in acquisition cycle time.

Systems development is complicated; frustrating efforts to determine the cause and effect relationships that drive long schedules and high cost. Regarding the complexity of a system, evidence does suggest that exponentially increasing system complexity correlates to linear increases in development schedule, which in turn drives costs significantly higher. On the other hand, although funding instability may contribute to longer schedules, there is no apparent explanation for how funding instability would drive system complexity. Therefore, it seems more logical to conclude that system complexity is a root cause and enables funding instability and bureaucracy to play larger roles in the overall schedule and cost of defense programs.

No simple solution exists for addressing this trend of increasing complexity. Attempts can be made to limit the amount of complexity of future weapon systems while still providing adequate performance increases and/or to better cope with complexity. In regard to the latter, it has been suggested that acquisition is analogous to Clausewitzian warfare in some key respects and that the cultivation of acquisition genius should be pursued in like manner to the cultivation of war genius. To improve performance, the DoD will need to pursue both approaches in concert with defense contractors.

In the near term, further research should provide additional insight into complexity and system development. Recommended research topics include collecting and analyzing additional data sets to develop a more direct linkage between the complexity of a system and the development schedule for that system, in-depth case studies of how high or low complexity impacted the development of a specific system and systems engineering methods to minimize complexity and better enable program managers and systems engineers to cope with higher levels of complexity.

Chapter 3

Faster Is Better…Can the USAF Acquisition Process Be SAIV'D?

by
James L. Chittenden, Major, USAF

… all too often the Air Force has suffered from development costs and schedule overruns which have, in turn, led to fielding delays, lower production quantities, and even reduced capabilities.

- Acting SECAF Pete Geren, September 2005[75]

While "transformation" and "responsive agility" have become buzzwords of the current administration's defense policy, particularly in fighting the Global War on Terror (GWOT), the Department of Defense's (DOD) acquisition system continues to be mired in schedule and cost overruns and unfulfilled promises to the war fighter. There have been at least 128 reform studies trying to address the myriad of problems within the acquisition system and prevent its perceived culture of fraud, waste, and abuse.[76] Yet, despite this seemingly endless number of investigations, initiatives, and congressional mandates, the DOD's 26 major acquisition programs[a] are currently $43 billion over-budget in research, development, test, and evaluation (RDT&E) costs.[77] Perhaps more alarmingly, these programs have also incurred an average schedule overrun of more than 20 percent and an overall program duration of an amazing 15 years.[78] These schedule delays directly contribute to cost overruns, create budget instability, and prevent emerging technologies from being fielded to combat forces who increasingly require more adaptive weapon systems. In order to resolve these enduring concerns, the United States Air Force (USAF) should pursue using schedule adherence or "SAIV" (schedule as an independent variable) as the first order programmatic driver for the majority of its acquisition programs. SAIV is a comprehensive strategy that re-

[a] Major defense acquisition programs are programs identified by the DOD as requiring $365 million in eventual RDT&E expenditures or $2.19 billion in procurement expenditures in fiscal year 2000 constant dollars.

quires disciplined baselining upfront and then balances schedule, cost, and operational requirements utilizing schedule incentives and penalties to compel program success.

This refocusing of acquisition management is particularly crucial now. The DOD, and the USAF in particular, is emerging from a period of procurement sluggishness in the 1990s with a renewed investment in defense spending, especially in weapon systems offering technologically advanced capabilities tailored to fighting the GWOT (Table 1). Not only will responsible management of this enormous investment directly enable future combat capability but timely delivery of weaponry has become increasingly important in current asymmetric combat operations. Military operations in Iraq and Afghanistan are causing accelerated wear on existing hardware, thus making the requirement for their replacement systems even more urgent.[79] On-going combat operations also have severe budget implications for the acquisition community –ever more programs not delivering promised capability to the war fighter on time will simply be cancelled or rebaselined to obsolescence.

	FY96	FY98	FY00	FY02	FY04	FY05	FY06	FY07	96-07 increase
Procurement	19.6	18.5	21.5	25.5	33.7	36.1	32.8	32.2	64%
RDT&E	15.6	17.3	16.6	15.9	21.1	20.5	21.7	24.4	56%

Table 4. USAF RDT&E and Procurement Funding (Billions of constant FY06 dollars)[80]

The causes of these rampant schedule delays are as far-reaching as their unintended consequences. There is a direct relationship between cost and schedule overruns, as well as a significant impact on procurement funding requirements, when delays in RDT&E extend the start of a program's production run. The delays often cause increased congressional oversight, which induces a death spiral of continued schedule modifications and program extensions. Consequently, DOD and contractor management often myopically focus on program survival and not weapon systems delivery, ultimately resulting in fewer fielded systems. Furthermore, in today's environment of accelerating technological change, not only are RDT&E and production delays preventing critical system enhancements from being fielded, but often military hardware (particularly computer systems) is technologically obsolete upon delivery. The principle of SAIV addresses both budget discipline concerns and technology insertion opportunities while ultimately increasing the number of weapon systems delivered.

This emphasis on schedule adherence is not entirely new to acquisition program management. In the past it simply received secondary attention to technical requirements or cost performance or both. Yet, there exist historical examples where schedule-driven programs fielded their required systems capabilities on time. These examples range from the five generations of fighter aircraft developed during World War I to the Intercontinental Ballistic Missiles (ICBM) of the late 1950s to the current Small Diameter Bomb (SDB) program.[81] These programs suggest using schedule as a first order driver can, at a minimum, provide capabilities on time while also increasing the likelihood of delivering them on budget.

Still, some critics have concerns with making schedule a first order programmatic driver. Chief among these is the assertion that today's military weapon systems are more complex than ever and thus too multifaceted to adhere to a disciplined procurement schedule. This argument is hollow. While military aircraft have become more complex as technology has advanced (today's C-17 is clearly more complex than the C-47 of the 1940s), today's military systems are not significantly more complex than their current commercial counterparts. In fact, some of the most technologically advanced military hardware, such as the USAF's first operational jet fighter and the Minuteman missile, were schedule-driven programs. Similarly, the assertion that schedule adherence is only realized, or can be realized, when defense budgets are robust is unsupported. Historical analysis indicates that the ability of the defense industry to deliver systems on time has been largely independent of overall RDT&E outlays.

The bottom line is the US defense industry is interested in its bottom line—making a profit. The USAF must recognize this fact and shape its acquisition strategies accordingly. The defense industry must be encouraged to apply SAIV by using properly constructed incentive fee contracts to motivate on time product delivery. Similarly, defense contracts must be structured to penalize contractors when programs don't meet schedule, principally by using liquidated damages assessment. To facilitate this, the USAF must ensure technologies are mature enough to guarantee fielding within a specified timeframe before contracting for their development. The benefits of this initiative are substantial, as it focuses contractors on technologies that can be delivered within five years, with riskier or emerging technologies incorporated in future spiral upgrades. This combination of positive and negative performance consequences with "time and technology assured" development will synergistically drive future schedule success.

Over 90 years ago the US made a critical decision not to build military aircraft in large all-encompassing government arsenals but to instead rely on the private sector to purchase the most advanced technologies available.[82] The USAF must now use SAIV to ensure America's current and future investment in military aviation reaps capability-enhancing, cost-effective results. The USAF, its aerospace industrial base, and America's citizens cannot afford for the acquisition community's current path of waste and inefficiency to continue.

This research paper is limited to unclassified and previously classified acquisition programs which are now wholly unclassified. It assumes certain baseline knowledge of government/contractor relationships as well as an introductory understanding of the DOD 5000-series acquisition regulations. It also assumes future conflicts and threats will require the USAF to build more adaptive weapon systems. The study primarily focuses on USAF air-breathing weapon systems. Many space acquisition programs and satellite systems are classified due to their payloads. In addition, space acquisition has been historically DOD-centric with minimal commercial development activity available for comparison. However, since space acquisition is now dominated by a select number of defense contractors, the fifth section's concept of incentivizing delivery performance through profit-driven competition against the calendar is still relevant.

Problem Refinement and Consequences

> *… there is just too much uncertainty in the Air Force's plans. There are some great things planned, but it would be nice to know they will show up in the time frame [the Air Force predicts.]*

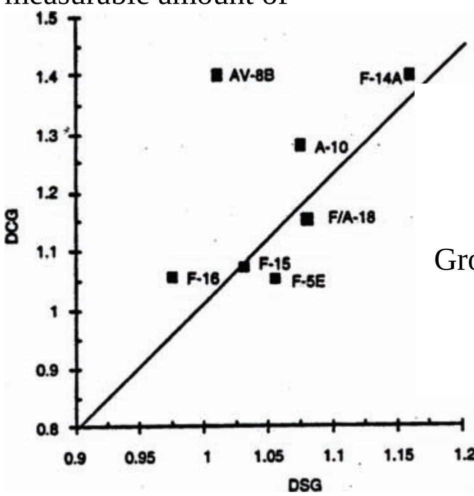
- Lt Gen Larry Dodgen, Head of US Army Missile Programs, February 2006[83]

Ever since the US Army Signal Corps' Aeronautical Section contracted the Wright Brothers to develop heavier than air machines, there has always been an element of risk in the development and production of aerial systems. At times, as the role and predominance of aircraft in military doctrine and operational concepts evolved, the government procurement of these systems encountered setbacks and delays. Today, it appears nearly all major USAF acquisition programs are mired in an unprecedented cycle of schedule and cost overruns. Moreover, the consequences of today's schedule overruns extend beyond their considerable effects on the delayed program itself. These schedule delays directly contribute to cost increases, increased budget instability, and intensified congressional oversight. They also prevent the evolution and fielding of critical emerging technologies and damage the USAF's ability to contribute in an increasingly joint combat environment.

Selected analysts on both the government and contractor sides of the defense industry contend that schedule delays and cost overruns are an inherent by-product of military purchasing and current concerns are merely consistent with past developments. Analysis indicates, however, that the procurement problems that began in the 1960s and heightened in the 1970s and 1980s are more prevalent now than ever. A RAND study of major DOD acquisition programs from the mid-1960s to 1993 indicated average cost growth fluctuated around 20 percent.[84] Since the early 1990s, despite numerous acquisition reform initiatives by the DOD and Congress, the problem has progressed to today's current debacle of 42 percent average cost growth.[85] Indeed, the problem is getting even worse. The top five defense programs (of which the USAF owns four) have seen costs skyrocket from $281 billion to $521 billion during the last four years. The trend isn't improving. In the past year alone, estimates of cost and time growth on those five programs increased 14 % and 6% respectively.[86]

This connection between development and production delays and overall cost growth should be of paramount concern for both USAF budget and combat personnel. As shown in Figure 1, there was a 1 to 1.05 normalized relationship between unit schedule delay and unit cost growth in fighter development programs during the 1970s, 1980s, and 1990s.[b]

This connection continued into the 1990s and 2000s with the development of the USAF and Navy's premiere fighter programs, the F-22 and the F-18E/F. While the F-22 has been plagued with schedule and cost overruns, the F-18E/F program met its major program milestones on schedule and has, as a result, seen negligible cost growth (Figure 2). A measurable amount of



DCG = Developmental Cost Growth

DSG = Developmental Schedule Growth

Figure 1. Relationship of Developmental Cost and Schedule Growth[87]

this schedule-driven cost growth results from inflation factors in the contractor's pricing, although it is certainly exacerbated by parts obsolescence costs, systems engineering inefficiencies, and subcontractor parts availability. These inflation factors affect both labor and material costs (e.g., with a mere 3 percent inflation, one hour of labor costing $100 in 1999 will cost $109.27 in 2002). SAIV endeavors to control them both by demanding schedule adherence.

These past program delays and cost overruns have led to increased publicity and, as a result, more congressional scrutiny. Beginning in the 1960s, Congress began to take a keen interest in defense procurement. In 1961, zero percent of the defense acquisition budget required specific

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[b] The AV-8B was a modification program versus a new development program and was treated as a dummy variable.

congressional line authorization. This involvement grew to 70 percent in 1967 and finally to 100 percent in 1983.[88] However, this justifiable "crusade for reform" is obscured by a resultant political peddling of influence, as industry and politicians attempt to extract the maximum monetary benefits for their regions. This practice has become even more prevalent as the number of Washington DC lobbyists has doubled since 1999 to over 34,000, with over $2.4 billion in gifts being dolled out.[89] As a result, Congress continues to delve deeper into DOD micromanagement.

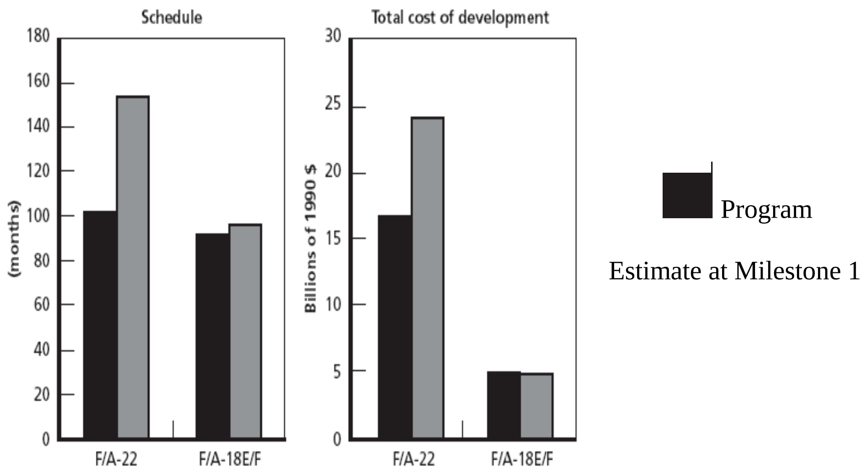


Figure 2. Relationships of Fighter Program Schedule and Cost Growth[90]

Congressional meddling, combined with the DOD's inability to execute programs on time, has required the DOD to avert program cancellation by rebaselining or stretching out programs. This practice started during the late 1960s and accelerated in the 1970s. As a result, the average length of production runs for DOD fighters grew from 9.4 years in the 1950s to over 18 years in the 1980s.[91] Indeed, today 60 percent of the DOD's major programs have had multiple baselines, with the F-22 having an astounding 15.[92]

This practice of extending programs lengthens production runs and causes substantial unit cost growth. It is a symbiotic relationship that reduces buying power and results in fewer combat aircraft. To point, the B-2 bomber's first flight was originally scheduled for late 1987 but did not occur until July 1989, due to a wing redesign that cost the program a year and caused a major program rebaselining.[93] In the end, the USAF bought just 21 of a planned 132 B-2s at over $1.1 billion a copy.[94] While the B-2 is a recent example of rebaselining leading to unit cost growth, diminished buying power, and the fielding of operationally-constrained "low density/high demand" assets, Table 2 indicates that similar concerns exist in the near future.

Schedule delays also cause parts obsolescence issues, particularly in computer hardware. According to Moore's Law, computing power doubles approximately every 18 months – a

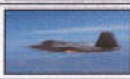
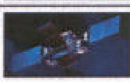
Program		Initial investment	➡ Initial quantity	Latest investment	➡ Latest quantity	Percent unit cost increase
Joint Strike Fighter		$183.6 billion	2,866 aircraft	$198.6 billion	2,457 aircraft	26.2
F/A-22 Raptor		78.4 billion	648 aircraft	73.1 billion	279 aircraft	116.5
Evolved Expendable Launch Vehicle		14.9 billion	181 vehicles	27.8 billion	138 vehicles	143.8
Space Based Infrared System High		3.9 billion	5 satellites	9.9 billion	5 satellites	149.9

Table 2. Examples of USAF Acquisition Programs with Diminished Buying Power[95]

significant concern for development programs that stretch out for decades. As an example, the B-2's computer architecture dates from 1984 when the first Macintosh computer was introduced; it was outmoded well before the bomber reached Initial Operational Capability (IOC) in late 1993. The B-2's microprocessors, used for critical flight management, stores management, and threat locating functions, utilize the military versions of the Intel 286 processor with merely 512KB of RAM. They are now operating at 90 to 99 percent dynamic memory capacity and simply cannot support several of the B-2's future planned enhancements.[96]

Similarly, the F-22 program office is already addressing parts obsolescence issues through massive buys of 10-year old components while trying to find new vendors to produce and satisfy out-year spare parts requirements.[97] This programmatic and funding concern is compounded by the effects of dependent technology, found in the parallel development of the F-22 and F-35, where Lockheed is relying on gains in one program to be integrated into the other. As a result, F-22 parts obsolescence issues have already delayed F-35 development.[98]

Finally, schedule delays are depriving combat forces of fielded systems. These delays have the dual effect of reducing immediate threat response capability while robbing users of baseline systems on which to rapidly insert emergent technologies such as data linked imagery or satellite target cueing. Recently, a fielding delay of the B-1B bomber's latest software upgrade deprived US Central Command of a significant capability in the GWOT. Sustainment Block 10, which included the ability to carry and employ the 500-pound GBU-38 Joint Direct Attack Munition (a preferred weapon due to its GPS-aided accuracy and low collateral damage radius), was initially scheduled to be released in mid-2004 and utilized during Afghanistan and Iraq election support. However, due to development delays, not only was this enhancement not available for either election but it is yet to be fielded.[99] This is merely one of an untold number of acquisition delays diminishing battlefield capability. USAF operators are used to making tradeoffs in employing weapon systems; however, they simply can't do this without possessing the hardware to begin with.

The USAF can no longer allow schedule delays to devastate its budgeting process, force manpower cuts, and shrink the number of fielded systems in attempts to pay for weapon systems cost overruns. It leads to a perception of low-density/high-demand specialization, which hurts USAF credibility in the joint arena. Defense Secretary Rumsfeld stated, "low-density/high-demand is nothing more than a euphemism for saying, 'Our priorities were wrong, and we didn't buy enough of what we need.'"[100] Whether schedule delays instigate cost growth or cost growth drives re-baselining and resultant schedule delays, SAIV provides the opportunity to control the interrelationship between the two. At a minimum, SAIV will drive discipline in delivery schedules—the programmatic element the war-fighters in the field really care about.

A Historical Perspective of Schedule Driven Programs—They Can Work!

Primary emphasis on RDT&E completion, production delivery, and IOC dates is not an entirely new concept to the USAF acquisition community. It has historically, however, usually received secondary attention to other programmatic variables. During the Cold War, operational performance was prime as USAF doctrine relied on technological superiority to deter the Soviet Union's overwhelming numerical advantage. In the 1990s, after the Gulf War victory and the dissolution of the Soviet Union, the acquisition community responded to "peace dividend" downsized budgets by shifting its focus to cost.[101] Program managers began extending schedules and trading off performance in efforts to maintain programs within cost. These attempts at using cost as an independent variable contributed to many of the massive delays and cost overruns addressed earlier. Yet, during and before these time periods, several schedule-driven programs fielded their systems on time. Analysis of these programs suggests using SAIV would help provide the USAF timely combat capability while assisting delivery within prescribed budgets.

The initial period of aircraft innovation occurred between 1904, the year after the Wright Brothers' first flight, and 1914. Aviation pioneers in the US and Europe produced spectacular advances in performance and, by the start of World War I, aircraft had already reached top speeds of nearly 130 miles per hour. The British, Germans, and French rapidly transferred new technology into weapon systems, with companies competing to field their products first. As the war progressed, these countries developed the first true combat aircraft (both fighters and bombers) in brisk succession.[102] This innovation continued at a blistering pace as five generations of fighter aircraft were developed while the European combatants struggled to gain and regain air superiority over the trenches.[103] WW I was merely the first instance of combat spurring rapid aircraft development and production.

After a relatively stagnant period in the interwar years, the mid-1930s witnessed a burst of aircraft development and production. Stimulated by nearly $100 million a year in aviation research, the US commercial airline industry rapidly built several new models of high-performance passenger aircraft.[104] These new technologies were soon applied to military aircraft (principally transports and bombers) as commercial companies competed to deliver the Army Air Corps aircraft in minimum time. Highlighting this drive for delivery was Boeing's development of the B-17 Flying Fortress, which progressed from concept to first flight in less than 12 months.[105]

Dramatic advancements in both technological capability and production determination continued during WW II as developers exploited the enormous increases in performance made possible by turboprop and jet engines.[106] For example, despite its quantum increase in performance, the renowned P-51 Mustang was developed in only 120 days.[107] Also notable was the development and production of the first operational turbojet aircraft, the German Messerschmitt Me-262, which progressed from design to first flight in approximately eighteen months.[108] Perhaps most remarkable is the design and prototype of the P-80, the first US jet fighter to go into service. Lockheed agreed to build the P-80 with a strict requirement of delivery 180 days after contract award, and its astonishing delivery in only 143 days stands in stark contrast with today's decades-long aircraft development cycles.[109]

The late 1940s and early 1950s also saw a number of technologically advanced USAF weapon systems produced in minimal time. The B-52 bomber, conceived in 1946, was developed, redesigned several times due changing USAF requirements, prototyped, and flown in less than six years. Its nuclear weapon-capable, high-altitude, high-subsonic, intercontinental design was a generational advance in integrated avionics, aircraft materials, and propulsion systems.[110] The bomber's development was expedited by its official DOD designation as a BRICKBAT[c] category S program, which directed B-52 delivery milestones a "highest national priority."[111] Next, the Korean War was instrumental in promoting intense competition in supersonic technology, leading to the development of six new aircraft that became known as the "Century Series" fighters. From their contractual authorization between mid-1951 and 1953, the complex F-100 series fighters achieved numerous aviation firsts, with all reaching IOC within five years.[112] Ironically, the rapid fielding of these technological advances was accomplished without the benefit of today's computer-aided design, computational fluid dynamics, and information cyber-networking.

The 1957 Russian launch of Sputnik created a firestorm in the defense acquisition community. For the first time, America's perception of technological superiority was challenged. The ensuing race to launch satellites and men into space elevated schedule to the primary programmatic driver for a number of USAF and NASA programs. Chief among them was the development and fielding of ICBMs, with a stated program goal of realizing IOC within six years. The Minuteman missile program benefited from this management focus and went from contract award to delivery to Strategic Air Command in four years.[113] Similarly impressive, the hypersonic SR-71 spy plane, with its 80,000-foot plus service ceiling, radar absorbing material, and revolutionary use of titanium, proceeded from contract award to flying operations in less than five years.[114] It is evident that if provided the right incentives, the defense industry can field technological breakthroughs in a responsive manner.

Historical analysis, however, yields one notable exception to schedule-driven success. The 1960s' C-5 Galaxy program had specific operational constraints, the foremost being total aircraft weight, and a specific schedule milestone of IOC in 1969. The program, utilizing a soon

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[c] BRICKBAT refers to those DOD programs designated by the President as being of the highest national priority. BRICKBAT programs are listed in a classified DOD document called the Master Urgency List.

discarded "total procurement package" strategy,[d] was plagued with delays and cost overruns as Lockheed speciously reduced weight by using thinner wing boxes.[115] These structures proved to be grossly insufficient, leading to massive cost overruns, a delayed IOC, and, ultimately, a $250 million government bailout.[116] Lockheed was never held accountable for its broken contractual requirements, an issue SAIV's contract provisions would fix.

Although not prevalent in today's acquisition programs, examples of contractually-mandated schedule adherence do exist. The F-22 System Program Office is using schedule as the primary driver for its December 2006 spiral-2 software update. The program is on schedule for delivery to Air Combat Command and is one of the few procurement highlights of the Raptor program.[117] The USAF's Small Diameter Bomb (SDB) program has used schedule adherence even more extensively. The SDB program office received direct guidance from former USAF Chief of Staff General John Jumper mandating asset availability to the Combat Air Forces in 2006. The program office developed a "Schedule is #1" rallying cry and awarded contracts with incentives for key milestone completions such as hardware delivery for operational test. As a direct result, the SDB program has met all of its original baseline cost and schedule estimates.[118]

Finally, Unmanned Aerial Vehicle (UAV) programs have utilized schedule-driven strategies to rapidly insert technology into the GWOT battlefield. Responding to a USAF request, Lockheed designed and delivered the Desert Hawk UAV to US Central Command in only 127 days. The cost of the six drones, a laptop-based control system, and the support equipment totaled a reasonable $400,000.[119] Similar rapid technology development and insertion has occurred in the integration of new sensors and Hellfire missiles on selected Predator UAVs. The acquisition community's responsiveness to these schedule-compelled programs provides optimism towards the more prevalent use of SAIV in the future.

Successful examples of schedule-driven programs all share a collective USAF/contractor motivation to rapidly deliver quality weapon systems to the field. Whether this motivation came from wartime demands or competition-driven contract incentives, the defense industry has, in the past, demonstrated the ability to produce weapon systems of significant

[d] Total Procurement Package required simultaneous bidding for both the development and production stages as a means of preventing the winning contractor of the development stage from facing little or no competition during the second stage. It was found to be ineffective and the concept was abandoned in 1966.

complexity on strict development and production schedules. To correct the USAF's current troubled acquisition culture, the principle of SAIV aims to synergistically couple today's renewed defense emphasis with competitive programmatic incentives, thereby ensuring schedule adherence.

Debunking the Hollow Myths

> *… acquisition is not off track … We've got to put things in perspective. The Air Force and its contractors are developing complex machines and the environment we put [systems] into is very hostile and unforgiving …*

- Boeing Vice President George Muellner, September 2005[120]

Designating schedule as a first order driver requires dispelling some myths about past and present USAF acquisition programs. Chief among these is the assertion today's military weapon systems are too complex and multifaceted to adhere to disciplined procurement schedules. While it's true military aircraft have become more complex, the argument ignores the comparable increases in complexity of commercial systems and an analysis of military complexity versus the accelerated state of technology as a whole. Similarly, the assertion that schedule compliance can only be achieved when defense budgets are robust is unsupported. History indicates the ability of the defense industry to deliver systems on time has been largely independent of overall RDT&E outlays. Finally, some acquisition reformers have advocated increasing concurrency in development and production to solve schedule delays. While useful in some areas, concurrency has proven to be a catalyst for programmatic disaster in others.

Today's Air Force Systems Are Too Complex

As technological change has accelerated and the global economy has exploded in the last decade, the military has become less relevant as a driver of technology. In the mid-1980s defense R&D accounted for over 46 percent of the national investment. By 1997, however, it had diminished to 30 percent and it continues to decline today. Once the dominant buyer of microelectronics accounting for almost 70 percent of industry sales in the 1960s, the DOD now accounts for less than 1 percent of microelectronic sales and R&D.[121] This trend is particularly significant for the USAF, which has taken 15 to 20 years to field new systems like the B-2 and F-22. Excepting niche elements such as stealth (which, in itself, had been previously explored by the fielded F-117 fighter), many cutting edge technologies on the B-2 and F-22 at program start were merely commercially standard by the time they were delivered.

Historically, software development has been a problem area for military aircraft developers, consuming about 40 percent of the USAF's RDT&E budget. A 1999 study indicated the average software schedule overrun was 222 percent of the original estimate.[122] These overruns are commonly justified by stating that performance requirements for weapon systems are evermore demanding and thus cause greater reliance on software. As evidence, one could point to the fact software provided about 10 percent of an F-4's functionality in the 1960s but provides over 80 percent of an F-22's.[123] This evolution of software reliance is valid but neglects the reality that technology in the commercial sector has also evolved to rely extensively on complex software. While the F-22's integrated avionics has received publicity both for its touted complexity and its problematic in-flight shutdowns, it is largely comparable with the Eurofighter in the size of its flight program software (Table 3).

F-22:	2.2 million	Eurofighter 2000:	2 million
C-17:	1.3 million	Boeing 777:	4 million

Table 3. Operational Flight Program Software Lines of Code Comparison[124]

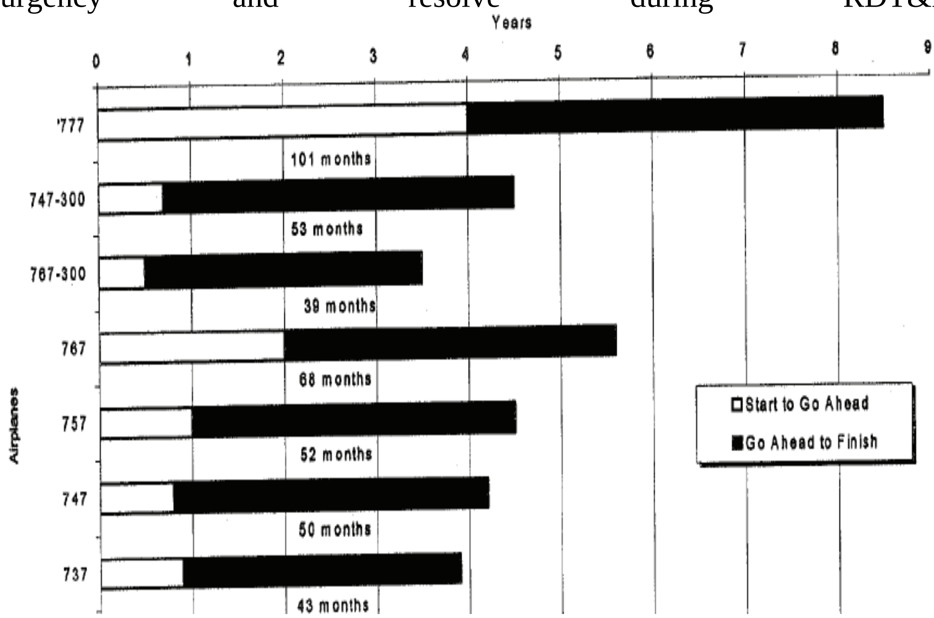
A comparison of the development and manufacture of Boeing's 777 and McDonnell Douglas's C-17, the most prominent outsized commercial and military aircraft of recent production, also reveals the fallacy of the military technological superiority argument. While the C-17 was certainly the most advanced strategic aircraft the USAF has produced to date, the 777 was similarly an order of magnitude increase in technology and design methodology.

The two aircraft, both of which reached IOC in 1995, are remarkably similar in levels of technological innovation. The C-17, the first USAF transport to introduce a complete fly-by-wire system, includes heads-up displays and a short takeoff and landing capability (STOL).[125] The 777, Boeing's first fly-by-wire aircraft, used composite materials extensively and was equipped with a two-way digital data bus and advanced liquid-crystal displays. The first completely computer-designed aircraft, the 777 was also the first US two-engine aircraft to immediately receive extended-range twin engine operations (ETOPS) certification.[e] Yet, despite these similarities, the C-17 took six years longer to field than the 777 and cost over $80 million more per copy.[126] A key distinction between the programs was Boeing's profit-driven motivation to develop and deliver aircraft on schedule to fulfill requirements of its first 777 customer, United Airlines.[127] While McDonnell Douglas received cost payments

[e] Federal Aviation Administration ETOPS certification allowed the twin-engine 777 to fly up to three hours from the nearest airport - key to lucrative flights such as from the mainland to Hawaii and from Japan to Singapore. The FAA usually restricts aircraft to one hour for their first year.

and profit on the C-17 during its development, Boeing recognized no income or profit during the 777's RDT&E.

Similar results are revealed when comparing the 53-month development of the $21million per copy Boeing 747 and the 87-month development of the $50 million per copy Lockheed C-5 Galaxy, both of which achieved IOC in 1970 (Figure 3).[128] Again the distinction is clear. On government contracts, most contractors not only receive funding to cover their costs during overruns but also continue to receive their contract profit percentages. Thus, while USAF contractors tend to stay in RDT&E longer and are practically rewarded for doing so, the commercial aircraft industry is demonstrably motivated to get out of the RDT&E phases and into aircraft production. As a result, one must ask if development "complexity" is just a convenient excuse for the defense industry's lack of urgency and resolve during RDT&E.



C-17 Globemaster: 14+ Years (179 months) C-5 Galaxy: 7+ years (87 months)

Figure 3. Comparisons of Military vs. Commercial Aircraft Development[129]

Schedule Adherence Only Occurs During Defense Funding Surges

A common myth attempts to tie periods of rapid aircraft development and delivery to surges in defense spending. While military spending has fluctuated from year to year, the long-term pattern in "constant" dollars adjusted for inflation has been surprisingly stable, excepting the early

1940s of WW II.[130] This is especially true for USAF RDT&E expenditures, as illustrated in Figure 4.

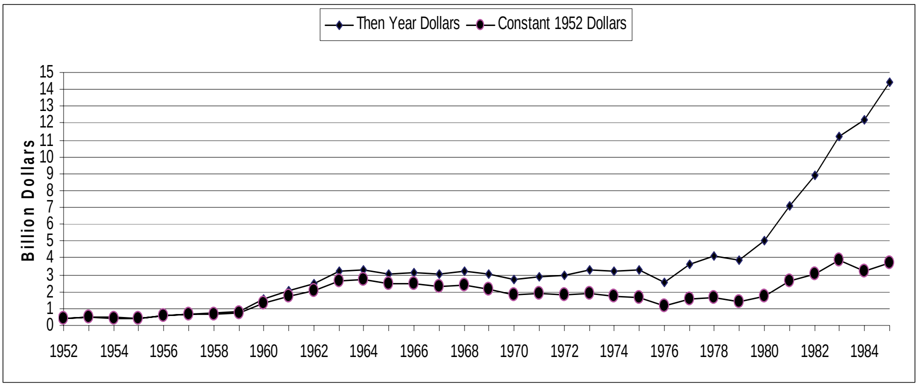


Figure 4. USAF RDT&E Budget Authorizations[131]

As shown, the successful fielding of the Century Series fighters in the early 1950s and the development of the ICBM fleet in the late 1950s and 1960s were largely independent of significant development funding outlays. In addition, the huge funding increases of the 1980s' Reagan defense build-up did little to motivate industry performance, as evidenced by numerous C-17 program delays and the Navy's cancelled A-12 program. Moreover, while USAF *production* funding did surge significantly during the Korean and Vietnam wars, RDT&E funding did not significantly increase during any of the major post-WW II conflicts. During these periods, it was competition and the possibility of large production contract profits, not appreciably larger outlays in development funding, which drove aircraft companies to rapidly develop, prototype, and produce new designs.

Increased Concurrency Leads to Faster Schedules

The defense industry has attempted, at times, to reduce program schedules by utilizing concurrent development practices. Here, typically serial activities such as development, testing, and production become varying degrees of parallel activities. This procedure was used successfully on rocket development in the late 1950s but became problematic in the 1960s when applied to large integration projects such as the C-5 and F-111.[132] It was resurrected in the 1980s when the Soviet threat was paramount and was justified on the basis of getting weapon systems to the field quickly to counter the USSR.

This over-reliance on concurrency, however, led to several major program delays and cancellations, such as the A-12, and the fielding of hollow weapon systems. For instance, the B-2 program used concurrency throughout its acquisition cycle, but its use systematically intensified as the program's engineering, manufacturing, and development (EMD) phase increasingly slipped and overlapped into its developmental testing phase. Concurrency problems arose again later as setbacks in production caused considerable manufacturing work to be accomplished after B-2s were delivered to the Air Force for operational testing. In fact, the first B-2 delivered required about 230,000 hours of additional manufacturing work at the test site.[133] Unfortunately, the end result of the B-2's concurrency initiative was that the program concurrently experienced difficulties during development, testing, and production which contributed to its rebaselining and, ultimately, a reduced number of fielded aircraft.

The B-1B bomber program was planned and executed as a 100 percent concurrent program. After the Reagan administration restarted the cancelled B-1A program in 1981, B-1B RDT&E and production were launched at the same time.[134] It turned out the aircraft was not ready for production, however, and the B-1B endured years of costly modifications to its flight control software and defensive avionics systems. As these post-production integration problems dragged on, the aircraft soon gained the reputation as a weapon system not ready for combat.

After these programs, the Pentagon realized using concurrency to develop highly technically integrated systems was too risky; thus, it has been reluctant to use concurrency on the F-22 and F-35 programs. The issue continues to arise, however, as continual F-22 and F-35 development delays drive desires to use concurrency as a panacea to get schedules back on track. A better method is to apply SAIV to incentivize schedule adherence and discipline from the onset and to eliminate the delays that ultimately compound across a program's lifetime.

Schedule as an Independent Variable Implementation

> *…The Chief of Staff said he is down on acquisition programs whose costs continue to rise 'exponentially' with no end in sight and he's willing to cancel programs if they can't be brought under control … If a program shows no sign that it can be managed, his impulse would be to kill it.*

- General Michael Moseley quoted at the American Enterprise Institute, October 2005[135]

A fundamental cause of schedule and cost overruns is the USAF's familiar practice of awarding contracts largely on the basis of lowest bid cost. As a result, contractors often perceive the need to bid low to obtain contracts and underestimate the cost and schedule requirements of a program. This phenomenon is particularly insidious in the defense industry, where there are quasi-monopolies and reliance on competition is often limited to the initial bidding and contract award process. Additionally, the intervals between major orders often cause losing companies to abandon specific areas of defense or drive consolidation, especially since the complexity of systems make entry costs high. The 1993 to 1999 reduction of major fighter, bomber, and helicopter contractors from twelve to five is partial evidence of this effect.[136] Reduced competition means less incentive to deliver systems on time, while fewer major programs actually induce contractors to suckle on existing programs for as long as possible. SAIV provides the incentives and penalties needed to ensure a new paradigm of competition—competition against the calendar—and consists of three main elements.

1. Incentives for positive contractor performance
2. Penalties for poor contractor performance
3. "Time and technology assured" development … the five year test

Incentives for Positive Contractor Performance

Ensuring schedule adherence begins during contractor selection where increased emphasis must be placed on proposals with shorter periods of performance, particularly given the relationship between program length and cost growth. Next, the type of contract selected should motivate contractors to optimize performance while ensuring the maximum degree of budgetary stability. Fixed price contracts are often appropriate where performance standards are well defined; most production contracts utilize this pricing methodology. Cost reimbursement contracts are frequently used where goods and services can only be defined in general terms or when complex or unique systems require a specific level of performance.[137] RDT&E contracts use these "cost-plus" contracts extensively. In both cases, profit is usually based on a set percentage of the fixed price or projected cost. Thus, there are few mechanisms in place, particularly in cost reimbursement programs where the government habitually pays cost overruns, to reward or penalize contractor performance.

Incentive contracts, which represent only about four percent of the DOD's contracting, provide one means to reward contractors for on time or early delivery.[138] Defense contractors are generally not fond of incentive contracts, particularly ones with quantitative requirements such as schedule milestones or number of systems delivered, due to their exacting standards. They often prefer award fee mechanisms which are largely based on more nebulous factors such as "management responsiveness."[139] SAIV-based incentive contracts, however, will drive discipline into the schedule by helping ensure original program timelines are accurate, which in turn would enable the budgeting process and production phasing to be more accurate as well.

A critical element of SAIV is making profit incentives high enough to compel performance. While typical profit percentages for both cost and fixed price contracts range between eight and twelve percent, it is essential for SAIV-driven contracts to have incentive fees sufficient to compel on time execution—approximately 20 percent for on time performance with graduated increases to 25 percent for early delivery. For instance, Lockheed would receive a nominal profit of 2 to 3 percent for a research and development contract with an incentive of an additional 18 percent for on time prototype delivery and 22 percent for a three-month early delivery. This would motivate a margin conscious contractor to focus his resources on areas of developing concern, including allocating company funds, if necessary, to meet incentive fee schedules.

The Santa Monica freeway repair following the 1994 Northridge earthquake serves as a model for this methodology. Potential bidders projected a completion time for their efforts and were informed that if work was completed after the established date, they would be penalized but if it was completed early, they would receive a bonus. The penalty/bonus incentive was set at $200,000 per day. The winning contractor, CC Meyers, made schedule adherence the key to its construction strategy by hiring extra crews, paying overtime, and chartering transportation for supplies. Although these measures extended CC Meyers $14.9 million cost budget slightly, the repairs were completed 74 days early, garnering the company a $14.5 million bonus. Because the state of California estimated that the freeway's closure cost Los Angeles' economy $1 million a day, the speediness of completion may have saved the state as much as $34 million.[140]

This freeway repair highlights another key to the incentive fee strategy—payments must be based on major milestone completions and not time-phased. Additionally, the current policy of allowing provisional incentive fee payments based on percentage of work accomplished must be eliminated.[141] Presently, contractors can receive 75 percent of the incentive fee if a program is on schedule at the 75 percent point, even if the program's highest risk is in the final 25 percent of the development. As the latter stages of a program usually focus on system integration, historically an area of delay, this time-phased approach is financially inconsistent with responsible systems engineering,

To enact these incentive procedures, the USAF will be required to budget in anticipation of the contractor meeting program milestones on schedule (or early if there is an early delivery consideration). As a result, the program office must ensure sufficient funds are available to cover the contingent liability created in any specific incentive fee period. However, with a change to acquisition law, a potential benefit exists if incentive fees are not awarded. It provides the USAF the opportunity to utilize a portion of the unused incentive funds as management reserve in other contract areas of the program, if necessary.

Penalties for Poor Contractor Performance

Utilizing SAIV methodology, late performance in itself would affect a company through lost incentive fees and profit. However, when incentives are coupled with a penalty instrument for late delivery, the USAF is fully equipped to stimulate contractor performance. The USAF should employ liquidated damages clauses as tools for this two-fold contractor motivation.

Liquidated damages are a little used provision of the Federal Acquisition Regulations (FAR). They may be used for services, research and development, and construction when "time of delivery or timely performance is so important the government may reasonably expect to suffer damage if the delivery or performance is not met." This performance schedule may be expressed "in terms of specific calendar dates or specific periods from the date of contract award." While not specifically punitive, liquidated damages compensate the government for "probable damages" in cases where an exact damage amount is difficult to prove, such as when research and development delays drive extensions or delays in subsequent program elements.[142]

The USAF must first establish the appropriate liquidated damages rate; two possible approaches are an inflation-based rate and a comparative rate. When utilizing the inflation-based rate, the USAF should adopt the higher of the producer price index (PPI) and the employment cost index (ECI)[f] rate.[143] This would help ensure the USAF receives consideration for worst case inflationary cost increases caused by contractor delay. The comparative rate codifies a relationship between historical cost and schedule delays of similar aircraft or products, such as the 1.05 to 1 delay relationship previously shown for fighter aircraft, and assesses damages based on this rate. (For this 1.05 to 1 relationship, the damage rate would be 5%). Table 4 gives an example of these rates applied to a $10 million, 48-month long fighter development program that is 24 months late, assuming a 2.0% PPI, a 2.2% ECI, and a 1.05 to 1 cost to schedule delay relationship. The USAF should utilize either inflation-based or comparative rate liquidated damages for its RDT&E contracts and could, in fact, look to recoup RDT&E liquidated damages on follow-on production contracts. Conversely, the inflation-based rate should be used for production contracts. Table 5 details a program with $200 million yearly purchases that is 24 months late and assumes a 2.2% PPI.

*Liquidated damages = (Delay Length) * (Program Cost) * (Liquidated Damage Rate)*
Inflation-based rate damage: (24 months / 12 months) * $10,000,000 * 2.2% = $ 440,000
Comparative rate damage: (24 months / 48 months) * $10,000,000 * 5% = $ 250,000
* Inflation rate uses 12 months as the basis for delay length while the comparative rate uses overall program length*

Table 4. Development Contract Inflation vs. Comparative Rate Damage Assessment

*Liquidated damages = (Delay Length) * (Program Cost) * (Liquidated Damage Rate)*
Inflation-based rate damage: (24 months / 12 months) * $200,000,000 * 2.2% = $ 8.8 million
*For production contracts, the yearly production value is the program cost variable *

Table 5. Production Contract Damage Rate Assessment

While canceling a program experiencing extreme cost and schedule overruns (done recently to the Army's $8 billion spy-plane program) sends an unmistakable message to the defense industry, it ultimately de-

[f] PPI measures changes in the wholesale prices of finished goods. ECI measures changes in wages, salaries and benefits for civilian workers (private industry plus state and local government).

prives the services of needed systems.[144] Assessing damages for unsatisfactory performance, even if they are merely credited via post-production support equipment or services contracts, provides the USAF its required assets, keeps the aerospace industry more viable, and demonstrates USAF resolve for better performance in the future.

"Time and Technology Assured" Development

To secure SAIV's success and alleviate concerns over complexity, the USAF must ensure a program's technology is mature enough to realize fielding within five years of the program's Milestone A decision. This assessment must occur prior to entering the Milestone B development phase. Programs whose technology is found to lack sufficient maturity would require further program and concept refinement. It is critical that this test be passed before advancing the program any further down the acquisition trail. A realistic fielding assessment would serve as a catalyst for SAIV's success by requiring better defined programs from the outset and adding increased fidelity to program schedule baselines.

This time and technology assured strategy, especially in today's environment of accelerating change, will require mechanisms to ensure technology is mature enough for incorporation into USAF weapons programs. The mandated use of open architecture systems will better facilitate computing power advances while the increased use of computer modeling should assist in earlier and more successful component integration. Increased funding in science and technology, through the Air Force Research Labs (AFRL) and the Defense Advanced Research Projects Agency (DARPA), will also be required to accelerate and mature technological advances. Overall, this early investment in maturing technology will reduce schedule risk and cost later.

To be sure, time and technology assured development is a major paradigm shift which may require the USAF to relax its "100 percent solution" mindset and accept that riskier technologies be fielded through a program's future spiral upgrades. The USAF recently acknowledged this, as Chief of Staff General Mike Moseley froze the design of the F-22 at its present configuration to reduce costs and allow for the funding of four additional airplanes.[145] The USAF should also expect a certain degree of requirements pushback and scrutiny from contractors as they attempt to better define what can be technologically assured. The benefits of this initiative are substantial, however, as it incentivizes contractors to focus on technologies that will actually be delivered within five years.

Conclusion

> *They [the Pentagon budget personnel] can almost live with the cost increase since I am guaranteeing the system's delivery on time. They seem to understand if it's not on time; the cost will increase anyway…*

Major Bill McGuffey, ASC/SDLGSSS, February 2006[146]

In promoting the use of Schedule as an Independent Variable, the USAF will rely on one of the basic principles of capitalism—competition engenders enhanced performance. SAIV explicitly links the contractor's schedule performance to profit and motivates it to compete against its sole competition … the government's timeline and calendar. The benefits of this approach are far reaching. It will provide the USAF more immediate combat capability, provide discipline and stability to the budgeting process, likely reduce total program costs, and possibly reduce Congress's vigorous involvement in the acquisition process.

SAIV is a comprehensive approach to ensuring schedule. It merges the incentives of profit with the contractual teeth of unsatisfactory performance penalties while stipulating technological maturity. Its five-year time and technology assurance strategy, combined with increased science and technology funding, will refine the USAF's technological fruits until they are mature enough to be delivered in a reasonable time period. This will help ensure the USAF builds more adaptive systems that are not immediately obsolete due to long acquisition timelines.

The stakes are high for the Air Force. The DOD currently has more than $1 trillion worth of major acquisition programs in development and production, with the USAF having the largest share.[147] The F-35 Joint Strike Fighter alone has a lifetime price tag of $240 billion. Of further concern, for the first time a single prime contractor will be involved in designing and developing a new aircraft to meet the manned fighter needs of three services for decades.[148] Looking back, if the F-22's baseline schedule had been measurably adhered to, the USAF would be currently receiving its 350th of 750 planned Raptors rather than celebrating a 3-month old IOC with 20-plus aircraft of a now-planned 183.[149] The USAF must act now to prevent becoming marginalized as a hollow service without any significant or relevant capabilities. SAIV provides the tools to do just that.

Glossary

AFRL	Air Force Research Laboratory
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
ECI	Employment Cost Index
EMD	Engineering, Manufacturing, and Development
ETOPS	Extended Range Twin-Engine Operations
FAR	Federal Acquisition Regulation
GPS	Global Positioning System
ICBM	Intercontinental Ballistic Missile
IOC	Initial Operational Capability
NASA	National Aeronautics and Space Administration
PPI	Producer Price Index
RAM	Random Accessed Memory
RDT&E	Research, Development, Test, and Evaluation
SAIV	Schedule as an Independent Variable
SDB	Small Diameter Bomb
STOL	Short Takeoff and Landing Capability
UAV	Unmanned Aerial Vehicle
USAF	United States Air Force

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