EUROPEAN AND U.S. AIRCRAFT DEVELOPMENT STRATEGIES

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December 1971

P-4748

PREFATORY NOTE

The following statement was prepared for the Committee on Armed Services, United States Senate, and was presented on December 7, 1971. It summarizes work performed under the aegis of the Weapon System Acquisition studies program at Rand and draws on research performed by several colleagues, notably Giles K. Smith, Alvin J. Harman, and Susan Henrichsen. Detailed reports on much of the research have been separately published, particularly in RM-6269, *A Methodology for Cost Factor Comparison and Prediction,* August 1970; RM-6072, *System Acquisition Experience,* November 1969; and R-733, *System Acquisition Strategies,* June 1971. A complementary study by Arthur J. Alexander, R-589, *R&D in Soviet Aviation,* November 1970, is also highly relevant.

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Throughout the 1960s the Department of Defense and the individual Services made determined efforts to limit the extent of cost growth that occurs between the start of a major weapon system development program and the point at which systems are delivered to and used by the Armed Forces. For the most part, such efforts have concentrated on devising new contractual approaches and on a variety of management reforms.

Major U.S. system acquisition programs of the 1950s frequently had outcomes substantially different from those anticipated when development began. In a comparative sense, the prediction and control of program outcomes in the 1960s did not significantly improve over the previous decade. Cost, schedule, and system performance tended to deviate somewhat less from estimates during the 1960s largely because typical programs of that decade were marked by less ambitious technical goals and were somewhat shorter than in the 1950s. Nevertheless, in the 1960s major programs in all three Services experienced an average cost growth of about 40 percent (a figure discounted for inflation and for changes in the quantity of items purchased); schedule slippages of about 15 percent; and weapon system performance that characteristically deviated by about 30 percent from original specifications.

In general, it appears that changes to system specifications imposed after programs had begun accounted for about half of cost

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growth; that unforseen, and in some cases unforseeable, engineering difficulties encountered in the course of development accounted for at least an additional one-third; and that the native imprecision of cost estimating processes was responsible for the residual 15 to 20 percent. This analysis and the supporting studies indicated that improvements in the cost estimating process could reduce the differences between initial cost predictions and cost actually experienced. However, because most cost, schedule, and performance shortfalls appear to be attributable to factors other than estimating inaccuracies, it seemed evident that fundamental changes to the system acquisition process would be necessary before substantial improvements could result.

The evidence indicates that if program planners can make explicit allowances for the degree of state-of-the-art advance sought in a weapon, initial cost estimates can be made much more accurate. The difficulty, of course, is finding a way of measuring, quantitatively, the real scope of technical advance sought in a new weapons program. That is a problem of analysis, of methodology, and it probably can be solved. It is a very important problem, because examination of many individual programs and groups of programs suggests that there is a strong correlation between the extent of technical advance originally sought in a weapons development program and the subsequent tendency of that program to increase in total cost. Nevertheless, cost estimation improvements of that sort would only reduce the frequency of unpleasant surprises caused by unanticipated cost growth and would do fundamentally little to reduce the cost of the system acquisition process.

Examination of various "non-standard" R&D programs in this country and abroad indicates that two fundamental aspects of the way weapons are developed and procured in this country offer particularly attractive opportunities for improvement. Each of two changes represents an attempt to cope with the substantial technical uncertainties involved in R&D, and the inevitable revisions that occur in military hardware programs after development has begun.

The first change is to separate the development phase of weapon system acquisition from the subsequent production phase, both sequentially and contractually. Such an adjustment should appreciably reduce the incidence of very expensive production-line changes that are often caused by technical problems discovered late in the development program, but after the serial production of weapons for the services has begun. Such evidence as is available suggests that a sequential, incremental acquisition strategy would not appreciably increase the time needed to progress from the start of development to the first true operational capability of a weapon. If weapon production begins before the development process is substantially complete, before technical uncertainties have been largely identified or reduced, and before decisions on the operational requirements for the weapons themselves have been finally verified and validated, program costs will almost certainly be higher than anticipated--and higher than necessary.

A second fundamental change would be to conduct the initial R&D for a new weapon in a highly austere manner, concentrating first on demonstrating system performance, and deferring more expensive tasks of detailed production design and reliability demonstration until both the technical and the requirements uncertainties have been very substantially reduced. In essence, that implies a policy of prototyping many, if not most, weapons, and of comprehensive testing before a final production configuration is adopted. Well structured demonstration and test programs will usually identify most technical problems at costs substantially below those incurred in U.S. weapons development programs of the recent past. Further, austerity in the initial phases of system development should in many instances permit the conduct of multiple and parallel development projects--if that is desirable--with two highly valuable consequences. First, in many instances the Services would not have to decide prematurely which of several attractive alternatives to proceed with; second, in many instances true competition in cost, schedule, and weapons performance could be maintained much farther into the weapons R&D process than has been practicable until now.

In the end, it is abundantly clear that any general system acquisition policy should incorporate a very high element of planning, policy, and management flexibility. Policies or approaches that are appropriate to one program may be totally unsuitable for another, even if they have surface similarities. In some instances, a requirement may be so obvious or a threat so blatant that weapons development must be started, regardless of high technical risk or uncertain cost. But such occasions have been relatively uncommon in recent years. The normal mode of acquiring major weapon systems during the 1970s and thereafter should very probably be based on an incremental acquisition strategy, the exceptions being determined by such special considerations or circumstances as may arise.

In an era of steady or even of declining real budgets, the consequence of spending a great deal more money than has originally been planned in a given weapons acquisition program tends to be a reduction in the quantity of items ultimately made available to the Services. Characteristically, during the 1960s the total funding requirement anticipated at the beginning of a weapons acquisition program has been exceeded only modestly. When development costs and productions costs prove to be higher than anticipated, a reduction in production quantities is a more common response than an increase in total program funding. The undesirable consequences of such a practice are obvious.

Not entirely unrelated to the question of how weapons acquisition has been conducted in this country in recent decades is how other major powers manage their weapons acquisition process. The Russians are, of course, a particularly interesting case. But the experience of three West European countries--France, Sweden, and Great Britain--which maintain aircraft industries, and today are developing and producing modern military aircraft, is worth considering.

First, it is important to appreciate that the general level of technology available to and exploited by European aircraft builders is not significantly inferior to the level of technology achieved by major American firms and required by our Armed Services. Certainly, there are performance differences, structural differences, requirements differences, and configuration differences between, for instance, European fighter aircraft and those characteristically used in the United States in the past 10 or 15 years. But, in general, the current products of European aircraft technology are not heavily dependent on either American research and development or American experience, and the products of the better European aircraft factories exhibit no striking inferiorities when compared to similar American aircraft. Dissimilarities exist, and in some cases they may be extremely important, but they do not appear to be much greater than the differences among various models of American combat aircraft of the 1960s. The most notable difference between typical European and American operational aircraft of 1971 is in the quantity and complexity of installed electronics equipment.

But two other differences are also significant. First, the development cost of many European military aircraft seems to be appreciably lower than that of generally comparable American aircraft, and that variation cannot be wholly explained in terms of lower labor costs. Second, the production cost of European military aircraft seems to be somewhat less than that of comparable American aircraft. Production cost differences are partly explainable in terms of lower labor costs, but not entirely. Fundamentally, the more attractive products of the military aircraft industry in France, Great Britain, and Sweden are characterized by simpler design, fewer production changes, and lower indirect costs. Taken together and considered as "program costs," development and production costs are plainly lower in France and Sweden than in the United States, and are probably at least as low in Great Britain. Perhaps as important is the fact that in many instances military aircraft development programs are carried out for only 10 to 30 percent more than the originally estimated cost, whereas in the United States development costs frequently exceed estimates by 50 to 80 percent. Nor is the time required to proceed from start of design work to first flight or the availability of a first operational article significantly longer in Europe than in the United States.

Such differences seem to be attributable to a different mode of aircraft development in Europe. Avions Marcel Dassault-Breguet, perhaps the best known aircraft builder in Europe, is a classic example, Dassault employs only about 12,500 people, but in the 1960s produced several versions of the Mirage fighter (and exported the bulk of the production to 13 foreign air forces), designed and produced a medium range supersonic bomber, developed and built in considerable numbers one of the best selling executive transports in the world, and produced prototypes of both vertical-takeoff and variable-wing-sweep fighter aircraft--together with prototypes of several advanced models of the basic Mirage. The prototype of the vertical-takeoff fighter was built and tested for about $6 million, after which a production prototype was constructed and flight tested for less than $25 million. Development costs of the variable-sweep Mirage G-8 appear to have totaled less than $30 million.

Such low cost programs involve procedures and policies not usually favored in this country. With no exception, all of the "new" fighter aircraft developed by Dassault in the 1960s were based in large part on existing models. Changes were extensive: new wings, enlarged fuselages, different engines, very different electronic and armament equipment, and the like. But such changes were incremental, and all were extensively tested in prototype before being approved for production. The only program approximating American practices of the decade was the Mirage IV bomber, and in that case one conceptual prototype and three pre-production prototypes were built before a production configuration was approved, even though production preparations were begun before the prototype program had been completed.

Further, Dassault relies on very small design and prototype construction teams. In the 11 months between the start of detailed design and the first flight of the Mirage IV bomber prototype, the design staff never exceeded 85 engineers and draftsmen. During development of the Mirage III-V (vertical-rise fighter), the engineer-draftsman work force ranged from a high of about 30 to a low of about 10, supported by about 30 engineers and draftsmen from another French aircraft company.

Governmental control or monitoring of project progress is minimal. During development of the Mirage IV, which received more direct attention from the French government than any Dassault project before or since, only 40 government people were involved, and not all of them on a full-time basis. For the Mirage III, which has become the basic fighter of the French and several other air forces (including Israel), there were two full-time government project engineers, 15 to 20 part-time technical specialists, and five flight test specialists in the "program office."

Program documentation is minimal. In the variable-sweep Mirage G fighter program, a bi-monthly status report of 10 pages, in 10 copies, was the principal reporting document. It was supplemented by quarterly program summaries. For the vertical-rise fighter program (the Balzac/Mirage III-V), the statement of requirements was less than 15 pages long, and the formal Dassault proposal, including all drawings and reports, less than 16 inches thick.

In order to permit an early test of the feasibility of the technical concept, the original Mirage III prototype was taken out of storage and modified by the installation of lift-engines and control devices to produce the prototype of the first French vertical-rise fighter. A similar technique was used in prototyping the first French variable-sweep fighter. The fuselage of the original Mirage F-2 prototype was reconfigured and a wing-sweep device installed. The Mirage III-V vertical-rise fighter prototype flew nine months after approval of design start, and the Mirage III-G variable-sweep fighter prototype 16 months after design start.

Government project or program offices supporting fighter aircraft programs in France, England, or Sweden rarely contain more than 20 to 30 specialists; the ordinary government program office in the United States for a comparable program is staffed by at least five times as many specialists. The total of engineers, draftsmen, and experimental shop personnel engaged in such a European program rarely exceeds 700, and in only one recent instance has been as high as 950 (the Swedish Viggen fighter). In American experience, from two to ten times as many comparable specialists are employed. The technological and performance differences that distinguish European aircraft from comparable American aircraft are in no sense large enough to explain these striking differences in invested manpower resources. Only in the instance of a few multi-national aircraft development programs have the total staffs approached those commonly encountered in American experience--and only in those kinds of programs have costs approached the American norm.

In some part, the explanation lies in the fact that for nearly 10 years most European aircraft developers, and their governments, have been operating under severe budgetary constraints. Also, there simply are not enough aircraft engineers available in any West European nation to man a program of the sort that is normal in the United States. For practical purposes, the Europeans have compensated for this disparity in available resources by pruning away the redundancies of the development process.

In Western Europe, very few engineering personnel are engaged in the sort of data analysis that is common to American programs. The Swedes indulge rather more extensively than do the British or the French, but even in the development of such Swedish aircraft as the Viggen, the amount of work that is not immediately relevant to the task on hand is surprisingly small. True, some American management devices are widely used; both SAAB, the Swedish aircraft firm, and the British Aircraft Corporation rely on computerized progress evaluation techniques. But SAAB and BAC, in the Viggen and Harrier programs respectively, provide only about 10 percent as much computerized program coverage as is the U.S. practice.

The fundamental strategy used most widely in Europe, though not in all programs, calls for no substantial production commitment to be made until the basic development process has been completed, and proof of utility demonstrated by performance tests of a prototype article reasonably representative of the desired operational item. Such firms as Dassault, SAAB, BAC, and Hawker-Siddeley rely on permanent-cadre, highly skilled engineering shop fabrication groups to assemble prototypes to the same sorts of detailed specifications that are common in this country. Skilled shop personnel are substituted, in part, for the tooling and machining that is common in the United States.

Another element of the European design process that is extremely revealing is the pronounced reliance on early proof testing of engines, electronics equipment, and airframes. Production commitments ordinarily are delayed until both the performance and the probable durability of the subsystems have been appropriately demonstrated. Departures from such practices frequently have expensive consequences, even in Europe. The Swiss, for instance, decided some years ago to build a version of the Dassault Mirage III under license, to equip their air defense forces. But they also decided to alter the basic aircraft by incorporating an American-developed electronics system that had not been fully tested in the form the Swiss wanted, and which had not been flown in the Mirage at all. The resulting modifications to the basic aircraft, and the necessity of extending development testing to reconcile the new electronics with the airframe, delayed the program by more than a year and increased the real cost of each aircraft by about 80 percent (over original estimates). Thus the Swiss eventually produced an aircraft substantially different from the original Mirage III but not obviously so much better than the original as to justify the 80 percent cost differential. As has been the case for several American programs which have encountered similar problems, the eventual recourse of the Swiss was to reduce the quantity of aircraft actually built, so that in the end the Swiss air defense force obtained about 60 percent as many aircraft as it originally specified, but for somewhat more than the original program cost estimate. Neither the South Africans nor the Australians, who have also built versions of the Mirage III under license, encountered any large cost growth effects. But they did not significantly change the original design.

The small size of the development project staff is an important consideration in the European policy of proof testing systems before committing them to production. A lapse of several months between completion of a prototype and commitment to production makes it impractical, on economic grounds alone, to maintain a large project staff while testing proceeds. But a relatively small staff of highly skilled designers and fabricators can be usefully employed at many tasks, and in extreme cases can be "carried" for a considerable period at relatively slight cost. On the other hand, the existence of a large design staff, plus production capability common in this country, represents a source of pressure to move at once to the next stage of acquisition, be it final design or production, with less concern for whether the current development or test phase has been satisfactorily completed.

The delay for validation of performance has another effect: it permits rational and low-cost alteration of specifications to make actual performance correspond realistically to updated appraisals of threat. Further, cost-performance tradeoffs can be made most effectively during a development-test phase, before production configurations have been translated into production tooling and the like.

To return briefly to the Dassault case, one of the more interesting questions that arises from an examination of how Dassault operates is what explains the company's unusual record of success. Aircraft production work is inherently unstable; no firm in the western world, Dassault included, has been able to depend on a steady demand for continual production. The capacity of the French Air Force to absorb large numbers of fighter aircraft is limited by many factors, not the least being a tight budget and a national policy that also requires expensive investment in missile and nuclear weapons development. Yet the interest of the French Air Force in obtaining the most advanced aeronautical items Dassault can propose seems insatiable, and Dassault's capacity to create interesting options at low cost seems unlimited.

Dassault subcontracts a very large part of the manufacturing responsibility for the aircraft the company develops. It is a fundamental of company policy, partly impelled by the desire of the French government to spread the production workload as widely as possible over a relatively large French aircraft industry. But whereas most American companies seem to look on development as a necessary and unavoidable, but not particularly desirable prelude to production, Dassault seems to view production as a buffer work assignment that fills capacity not absorbed by development. Dassault is a development-oriented aircraft company; most American aircraft companies are production-oriented. The difference is more than interesting; it is potentially very significant.

Some other attributes of the Dassault technique are particularly interesting. The design staff is relatively unspecialized, as compared to American counterparts, and rewards do not ordinarily include promotion to management posts. Some Dassault designers have been doing essentially the same tasks for 20 years; one man has designed the wings of virtually all Dassault aircraft since 1950, for instance. Excellence of design is, in itself, a career goal. Further, rewards are not for innovation, for new ideas, but for simplicity and cost effectiveness in initial design. Dassault does not tolerate engineers who propose expensive or hard-to-produce parts, or who suggest costly "improvements" that may also require high cost operating or maintenance procedures. Once an operationally acceptable configuration has been demonstrated in flight test, most engineering personnel are withdrawn from the project and the task of preparing production drawings is entrusted to a minimal engineering staff backed up by highly capable draftsmen. The former are forbidden to make major changes; the latter lack the inclination and the ability. And in all instances the incorporation of uncertain, high-cost, or high-risk technology is discouraged. Proven items are preferred, even at a slight apparent loss in performance. In actuality, incremental improvements during production tend to offset any early performance losses. The initial Mirage IV bomber, for instance, had a flight performance about 10 percent below original expectations when first delivered, but later models overcame that deficiency and, in the view of the French Air Force, fully satisfied the essential operational requirement.

Two basic arguments have been advanced against American adoption of many of the most attractive elements of European aircraft development practice. The first is that too much time is spent in proceeding from design start to the availability of an operational item. The second is that the performance of, for instance, European fighter aircraft is inferior to that of contemporary American aircraft, and that if the Europeans attempted to achieve American performance levels, their costs would be as great as ours.

Neither of those arguments is wholly refutable. But neither is entirely relevant, either. As noted earlier, the time required by such firms as Dassault to proceed from design start to operational deployment is not longer than in American experience, partly because technological jumps are smaller (a consequence of evolutionary design trends), and partly because engineering problems and design changes in American programs often delay the availability of an operational item well past the date originally estimated. In a sample of European development programs recently examined, development schedules tended to be from 10 to 50 percent longer than *predicted* U.S. schedules for comparable aircraft, but only 10 to 20 percent longer than *actual* U.S. schedules. The difference represents schedule slips in American programs.

The second element, performance differences which favor American aircraft, is intricate. It is worth recalling that in many respects the performance attributes of American aircraft do not entirely match those predicted when program approval was granted. European aircraft are not exempt from such occurrences, of course. But in most European programs differences between originally anticipated performance and actual performance, where they occur, generally appear to have been chosen as alternatives to incurring higher costs than originally predicted. And except perhaps in electronics subsystems, the performance of European fighter aircraft such as the Mirage F-1, Viggen, and Harrier is not appreciably inferior to that of comparable U.S. aircraft (F-4, F-8, A-7, F-111, and so on). The Europeans have chosen not to develop certain types of highly-specialized aircraft and certain highly-specialized capabilities, often on grounds that they would not be worth their cost. But that is another matter. What they do develop is not inferior.

Examination of major DoD weapon system acquisition programs of the past 20 years, together with observations of European development programs and some non-standard American programs, has given a good indication of the sources of high system acquisition costs. Fundamentally, high system acquisition costs and cost growth both appear to arise from efforts to subdue difficult technology on highly compressed schedules, and from an apparent willingness to pay what is required to insure satisfaction of original (or even expanded) system performance goals. Another obvious and important contributor is the customary acceptance of optimistic assumptions about the long term predictability of technology and the cost of coping with it. Occasionally there may be valid reasons for urgency in satisfying originally specified goals, for incorporating new and more stringent performance requirements during a program, or for insisting on meeting originally conceived schedules. That such extreme urgency characterizes very many U.S. weapons acquisition programs is not evident, however.

Advocating more efficient and more economical system acquisition practices has been almost a tradition in this country for at least a dozen years. Efforts have been made to identify and eliminate the causes of inefficiency, but most such efforts have ordinarily been directed at refining management procedures and exercising better control over the activities of contractor organizations. Some variety of fixed-price incentive contracting has often been proposed as a device for impelling contractors to become more attentive to cost. But neither greater elegance of management procedures, nor readiness to force a major contractor into extreme financial difficulties has alleviated the fundamental problem. A strikingly different strategy for weapons acquisition may be the only long term solution.

Three aspects of the system acquisition process, as recently experienced in this country, deserve attention.

First, despite determined efforts to improve the outcomes of major acquisition programs by altering contractual approaches and introducing complex management reforms, recent programs have incurred cost, schedule, and system performance difficulties not greatly different from those characteristic of the 1950s.

Second, although some advantage could arise from improvements in cost estimating methods and the application of techniques that would permit the earlier identification and correction of cost growth trends in individual programs, it does not appear that *substantial* improvements in the outcomes of system acquisition programs can be anticipated from such devices alone.

Third, major system acquisition programs that departed in many respects from the pattern ordinarily observed in defense procurements of the 1960s have had surprisingly good outcomes, proved reasonably predictable with respect to cost, performance, and schedules, and have been appreciably less costly in terms of total resources expended than comparable programs carried through according to the generally accepted precepts of system acquisition in the United States.

From these premises, it is possible to proceed to a set of principles applicable to a wide variety of systems that may be required during the next decade. Those principles represent a sharp departure from the policies common in the 1960s, in which, usually, a single, major authorization decision was made, followed by a highly compressed program that required starting series production well before development was actually complete.

An alternative acquisition strategy, appropriate to present budgetary constraints, levels of technical knowledge, and weapons requirements, could be characterized in these terms: (1) *incremental acquisition*, based on a sequence of decision points and a succession of development and production phases, and (2) pronounced *austerity* in the early phases of development. These are not new principles, and they actually are being applied in some current DoD programs.

Incremental acquisition would require separating the development of systems from their subsequent production. Further, it would depend on completing those aspects of system development required to demonstrate the performance potential of a system before addressing such issues as are involved in verifying the reliability and maintainability of the system. Thus, the initial design and development phase should not include elaborate efforts to resolve maintainability, reliability, and similar issues unless there is a reasonable assurance that the system, as then conceived, has an achievable performance that is relevant to current and anticipated needs.

The assumption underlying "concurrent" programs is that careful advance planning, thorough analysis, and extensive pre-program design work will compensate for the difficulties that have troubled earlier programs. But in any program marked by a considerable degree of technical uncertainty--and that is often characteristic even of programs that seem technically straightforward when they are proposed--it is extremely unlikely that planners can anticipate the precise nature of future difficulties and offset them. Careful analysis and planning in advance of program approval must not be abandoned, of course. But planners must not delude themselves into believing that abstract analysis, however comprehensive, will resolve technical, scheduling, or cost uncertainties, and that acquisition programs will thereafter proceed toward completion without encountering difficulty and without almost inevitably being subject to change in both general goals and small details.

Austere initial development seems an important element in any incremental acquisition strategy. Conducting an acquisition program in discrete phases, with pauses deliberately and systematically introduced between the phases, would encourage realistic reassessment of program objectives and costs. To be fully effective, such a policy must be based on tightly constraining program resources. Large programs, employing many thousands of people, resist change and are difficult and costly to slow or redirect, however desirable change or redirection may be, because of the enormous institutional pressures for proceeding in accordance with an original schedule, particularly if production commitments exist. After a system design has demonstrated satisfactory performance and the need for the system has been reverified, it is reasonable to proceed to the next phase, with considerable confidence that most of the essential changes have been identified and most of the major surprises have occurred.

During development, the desired product is information, and only information. Hardware is merely a means of acquiring the information needed to proceed to another phase. Moreover, during development it is essential to purchase only that information relevant to the problem then being addressed. Irrelevant information is inevitably expensive and frequently worthless. It is unlikely, for instance, that spare parts consumption rates and maintenance requirements can be accurately calculated before test articles are in hand and test experience has been accumulated. Making such calculations is costly. Acting on them before they can be validated is very costly.

The feasibility of conducting successful development programs under austerity principles has been amply demonstrated, both in the United States and abroad. Two major classes of benefits are obvious. One is that the direction and goals of small, relatively cheap acquisition programs can be changed quickly and inexpensively in response to the appearance of unanticipated technical problems or changes in requirements. Another is that initial austerity in development makes possible the funding of multiple, competitive sources during early development phases and gives the military buyer a better chance of getting what he really needs.

The general adoption of a strategy of incremental acquisition and a policy of austere initial development seems almost certain to result in lessened cost growth and lower acquisition costs. The predictability of schedule and system performance outcomes seems almost equally certain to improve. As noted earlier, such an approach may not be entirely suited to all major system acquisition programs. Threats may arise that will require the acceptance of uncertain program outcomes, including costs. Concurrency may be the only recourse. But experience of the last decade suggests that few programs are so driven by a dominant threat that they must rely on that recourse.