BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Why Some Weapon Systems Encounter Production Problems While Others Do Not: Six Case Studies

Experience has shown that new weapon systems regularly encounter great difficulties as they begin production, such as a high percentage of components that must be scrapped or reworked. These give rise to significant cost increases and schedule delays. Through an examination of six weapon system case studies, GAO found that such problems occur in programs where efforts to prepare weapons for production were insufficient. GAO found further that technical performance concerns, program management and staff, and funding and quantity instability greatly influenced these preparations during the weapons' development.

DOD has issued two directives which should improve production preparations in future programs. GAO makes recommendations on applying these directives to individual programs, to both improve production preparations and reduce the effects of other program influences on such preparations.

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON D.C. 20548

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To the President of the Senate and the
Speaker of the House of Representatives

This report describes the difficulties major weapon systems encounter as they make the transition from development to production, as well as their causes and effects.

We undertook this review to identify the causes of early production problems experienced routinely by weapon systems and to gain insights as to how they might be avoided in future weapon system acquisitions.

We are sending copies of this report to interested congressional committees; the Director, Office of Management and Budget; and the Secretary of Defense.

Charles A. Bowsher

Comptroller General
of the United States

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COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

WHY SOME WEAPON SYSTEMS ENCOUNTER PRODUCTION PROBLEMS WHILE OTHERS DO NOT: SIX CASE STUDIES

DIGEST

For many sophisticated weapon systems, the period after they begin production has proven to be as difficult as developing the weapon. Cost growth and late deliveries stemming from problems on the production floor have consistently impeded attempts to field new equipment. The additional time and money needed to produce the desired quantities of weapons routinely frustrate the budgeting and planning process. (See p. 1.)

The General Accounting Office (GAO) reviewed six weapon systems in depth to illuminate some causes of early production problems and to outline actions which could help minimize their occurrence in future programs. The programs reviewed were the Army's Copperhead projectile and Black Hawk helicopter, the Navy's High Speed Anti-Radiation Missile (HARM) and Tomahawk cruise missile, and the Air Force's F-16 fighter and Air-Launched Cruise Missile (ALCM). Development and procurement costs for these weapons shortly before the review began totaled over $70 billion. GAO's detailed work was conducted between January 1983 and January 1984. (See pp. 5 to 8.)

WEAK PREPARATIONS DURING DEVELOPMENT LED TO PROBLEMS IN PRODUCTION

The Department of Defense's (DOD) policy regarding production management states that production risks should be identified as early as possible, beginning with the first stages of development, and that these risks shall be reduced to acceptable levels before a production decision. The policy also states that production engineering and production planning should be done throughout full-scale development; voids in production technologies should be identified and addressed; and before proceeding into production, contractors should demonstrate the capabilities to produce within cost and schedule. Systems are prepared for production through a myriad of actions, which build continuously from the initial design until full production rates are obtained. (See pp. 2 to 5.)

In varying degrees, production preparations for the Copperhead, the Black Hawk, the Tomahawk, and the HARM programs were sporadic and underfunded and were largely compressed into the late stages of development and early production. As a result, these weapons encountered significant difficulties when production was attempted, which resulted in increased costs; delayed deliveries; and slower attainment of higher, more efficient production rates. On the other hand, production preparations for the F-16 and the ALCM were thorough and timely. Consequently, these two weapon systems entered production without delay and major cost increases. (See pp. 9 to 16 and 20 to 27.)

CONDITIONS OF THE DEVELOPMENT PHASE STRONGLY INFLUENCED PRODUCTION PREPARATIONS

Several conditions of these weapons' development phases directly affected the manner and thoroughness of their production preparations. These were:

--whether pressures to achieve technical performance requirements dominated the development phase,

--whether sufficient program management attention and staff resources were devoted to production concerns, and

--whether funding and quantity stability permitted early and serious consideration of production matters during the development phases. (See page 16 and pp. 30 to 41.)

THE COPPERHEAD AS AN EXAMPLE

The Copperhead illustrates the relationships between production experiences, production preparations, and factors influencing the preparations.

Production planning was started nearly 2 years after full-scale development began. By that time, the basic projectile design had already been established, leaving little room to introduce changes in the interest of producibility. Several untried production processes were not studied to see if they could produce components meeting specifications. Efforts to demonstrate production capabilities took place primarily after the production decision. Only one manufacturing technology project was completed by the time production began. Rather than phasing in production tooling and equipment gradually, all the tooling and equipment required for the full production rate of 700 projectiles per month were purchased up front. (See pp. 24 to 27.)

The Copperhead experienced significant production difficulties as a result of having to demonstrate most of its production capabilities in the production phase. For example, the process used to strengthen the projectile's steel control housing did not work as planned and required an additional machining process, among other measures, to produce the housing correctly. This was a new process which was not tried before production.

As a result of these and other production difficulties, actual manufacturing labor hours exceeded estimates by 50 percent. The contractor was able to deliver only about half of the 2,100 projectiles required under the first production contract. Unit procurement costs during the first years of production grew from $21,700 to $33,300 per projectile in constant fiscal year 1983 dollars. (See pp. 10 to 11.)

Key conditions during the Copperhead's development prevented production preparations from being more effective.

First, the Copperhead was a technical challenge--its sophisticated electronics and optics had to withstand the tremendous pressures of cannon launching. Technical concerns associated with this complexity and related technical problems, combined with the fact that the program's success depended on the projectile's technical performance, drew attention away from longer term production concerns.

Second, total planned production quantities dropped which led to a significant drop in peak production rates. Although 700 units per month had been planned throughout most of development, rates did not exceed 233 units per month through the end of 1984. This lower rate has proven inefficient for the sophisticated tooling purchased for much higher rates. Also, cost growth due to technical problems and funding delays reduced the number of projectiles built for testing and contributed to the low level of funding available for production preparations.

Third, according to representatives from the Army and contractor program offices, there were not enough production engineers during the development phase to properly prepare for production. (See pp. 33 to 38.)

MORE FAVORABLE CONDITIONS ENABLED A SMOOTHER TRANSITION TO PRODUCTION IN THE F-16 AND ALCM

While neither the F-16 nor the ALCM program has been free of problems in production, both programs met delivery schedules and built up to peak production rates as planned. (See pp. 15 and 16.)

Features of the F-16's and ALCM's development enabled a more balanced treatment of near-term technical concerns and long-term production concerns. These gave rise to strong production preparations by DOD and the contractors which reduced major production risks in development and met DOD's requirements for timeliness and thoroughness. Both programs experienced fewer technical difficulties than the other systems and had stable funding and production quantities, as well as production-oriented program offices at the service and contractor levels. Each program had sufficient resources to provide for substantial demonstration of production capabilities during the development phase.

Perhaps the key feature of the F-16 and ALCM programs was that each had unusual characteristics which provided the stimulus and proper environment for good production preparations. The goal of the F-16 program was to develop a low cost fighter. The low cost emphasis enabled the prime contractor to avoid risky design features and to develop a design which did not outstrip existing production capabilities. Further, once established, the design remained unusually stable due to the participation of four European countries in the program, which had to agree on any design changes.

The ALCM enjoyed the top national priority when the B-1 bomber program was first canceled. Consequently, strong emphasis was placed on meeting the fielding date and achieving the peak production rate on time. This was complemented by the competition between two contractors during ALCM's full-scale development, which stressed demonstration of production capabilities as well as technical performance. (See pp. 31 to 33 and pp. 37 to 40.)

PRODUCTION READINESS REVIEWS CAN BE USED TO HELP MANAGE PRODUCTION PREPARATIONS

How production readiness reviews--formal examinations required by DOD to assess whether a weapon is ready for production--were employed also distinguished the F-16 and ALCM from the other weapons reviewed. In these two programs, such reviews were conducted regularly during development; each review marked progress to date and identified areas for more work. In this manner, the reviews became tools for managing production preparations and facilitated reducing production risks.

In other programs, production readiness reviews were not begun early enough or conducted regularly to help manage production preparations. (See pp. 27 to 29.)

REVISED DOD POLICIES SHOULD IMPROVE PRODUCTION PREPARATIONS IN FUTURE PROGRAMS

DOD has taken an important step toward better preparing weapons for production in the form of two directives signed by the Secretary of Defense in January 1984. Together, they call for the balanced treatment of production preparations with other technical demands during development, increasing the consideration given to production preparations at major milestone decisions, and providing the funding and staffing to carry them out adequately. If successfully implemented, these initiatives should contribute substantially to ameliorating future production problems in weapon systems. (See pp. 42 to 43.)

CONCLUSIONS

On the basis of the six programs reviewed, GAO believes that specific actions should be taken by DOD and the services on a program-by-program basis which would help implement DOD's revised policies.

In those six weapons reviewed, the degree to which technical performance concerns could be balanced with production concerns was directly affected by (1) the technical requirements of the weapons, (2) the structure of competition between contractors during development, and (3) the weight given to production concerns at subsequent program decisions. To maintain balance between technical concerns and production concerns in future weapon system developments, DOD should pay particular attention to these elements which can stimulate or stifle the effectiveness and extent of production preparations.

During the course of development, several factors--in particular the design instabilities arising from a high technology design, changes in technical requirements, and quantity and funding fluctuations--can hamper production preparations. When the introduction of such factors is being contemplated in future programs, their effect on production preparations should be recognized and the production risks they carry explicitly assessed to enable better informed decisions to be made. When such factors cannot be avoided, actions should be taken to compensate for the attendant production risks, such as instituting a pilot production phase or building more slack into the production schedule.

In the six weapon programs reviewed, production readiness reviews were more effective when conducted at intervals during development to help manage production preparations. Although DOD instructions call for these reviews to be time-phased efforts spanning full-scale development, they were not conducted in this manner in all six programs. In future programs, DOD should ensure that production readiness reviews are employed as a tool for managing production preparations and that they are begun early and conducted regularly during development. (See pp. 44 to 46.)

RECOMMENDATIONS

On the basis of the six programs reviewed, GAO recommends that the Secretary of Defense take the following actions to help implement DOD's new directives and improve production preparations in future programs:

--When establishing those elements of a new weapon system development program which directly affect the balance between technical concerns and production concerns, such as technical performance requirements and the terms of competition, ensure that at the same time provisions are made to induce an adequate level of production preparations, to be conducted early and continuously throughout the weapon's development.

--Ensure that when contemplating decisions which have known production risks in weapon programs, such as those regarding requirements changes and funding reductions, decisionmakers explicitly assess these risks before making decisions. Where decisions of this type are necessary, take such compensating actions as are practical to lessen their effects on production. These actions could include instituting a pilot production phase; building more slack into production schedules to allow for problems; or having a two-staged production decision, both before entering production and again before going to a high rate.

--Employ production readiness reviews as a tool for managing production preparations to progressively reduce production risks, beginning early and repeating them at intervals during full-scale development.

DOD AND CONTRACTOR COMMENTS

DOD concurred in GAO's findings and recommendations. DOD believes the production initiatives described in the January 1984 directives are important and have received wide dissemination and emphasis through incorporation in the Defense Acquisition Improvement Program, implementation of the President's Private Sector Survey on Cost Control recommendations, and inclusion in the defense guidance on preparation of the annual defense budget. DOD officials believe they have made progress since the directives were issued. DOD officials realize that for the most part, the task of implementing the production initiatives through specific actions on future weapon systems, program-by-program, remains ahead. GAO's recommendations are aimed at such actions, to help implement the policies called for by DOD's directives and instructions.

DOD recommended that its two new directives, "Defense Production Management" (4245.6) and "Transition From development to Production" (4245.7) be included verbatim in the report. GAO agreed and included them as appendixes IX and X.

DOD suggested that the report highlight the benefit of concurrent development and production in some of the cases GAO studied since it provided more opportunity to attend to producibility matters early in development. GAO did find that initiating production preparations early and conducting them concurrently with other development activities enables more informed production decisions to be made and is consistent with DOD's requirements for production preparations. This point has been amplified in the report. However, this is not an endorsement of starting the production of units before they have been sufficiently and successfully tested.

DOD also suggested that some changes be made in the report in the interests of clarity and accuracy, which GAO has incorporated as appropriate.

Five of the six prime contractors commented on this report. They generally agreed with the report's overall conclusions and recommendations. They suggested some changes to the discussions of their respective weapon systems, and these have been incorporated as appropriate. (See pp. 47 and 48.)

Contents

ILLUSTRATIONS

ABBREVIATIONS

ALCM	Air-Launched Cruise Missile
DOD	Department of Defense
GAO	General Accounting Office
HARM	High Speed Anti-Radiation Missile

CHAPTER 1

INTRODUCTION

Experience has shown that for many, if not most, major weapon systems, the period after they begin production is a critical part of their acquisition. At this time, as actual production experience is accumulated, a realization often begins to emerge that weapons will be more difficult to manufacture and will command more time and effort than had been previously estimated. The greater production effort required ultimately leads to substantial cost growth and schedule slippage. Cost increases exceeding 50 percent during this period are not unusual. A second wave of increases occurs when the procurement of the weapons must be stretched out because the funding set aside is no longer sufficient to purchase the planned quantities at the increased costs. The additional time and money needed to produce the desired quantities of weapons routinely frustrate the budgeting and planning process. Weapon systems have encountered such disruptions in early production with some regularity, even though Department of Defense (DOD) regulations have called for weapons to be well-prepared for entering production. DOD has strengthened its regulations in this area, and these are discussed in chapter 5.

The cost increases and schedule stretch-out weapon systems encounter in early production are symptoms of specific production problems. Production problems have been discussed in reports by both DOD and GAO and include

--low yields (a high percentage of parts that must be scrapped or reworked compared with the number of good parts);

--increasing lead times needed to procure critical parts and materials;

--late availability of needed production facilities and equipment;

--difficulty in getting special tooling and test equipment to achieve the degree of accuracy required by component part specifications; and

--redesigns, which can require changes in tooling, test equipment, and/or manufacturing processes.

On the production line, these problems manifest themselves in parts shortages and in extra labor and machine time to rework parts to meet tolerances. Such problems result in more labor hours, more materials, longer delivery schedules, and cost growth.

MAKING A SMOOTH TRANSITION FROM DEVELOPMENT TO PRODUCTION IS CRITICAL TO WEAPON ACQUISITIONS

How well a weapon system makes the transition to production is critical to its becoming a successful acquisition. The transition to production encompasses a myriad of efforts, specified in DOD regulations, required to take a weapon system from the laboratory into full production rates. These efforts, or production preparations, span the development and production phases, and constitute a major determinant of a weapon system's production costs.

Preparing for production: requirements and tools

Ultimately, the intention of weapon system development programs is to have the system produced and deployed. Efforts to prepare a weapon for production, therefore, are critical elements of the development phase. According to DOD production management policy, production risks should be identified as early as possible, beginning with the first stages of development, and these risks should be reduced to acceptable levels before a production decision. The policy also calls for production engineering and production planning to be done throughout full-scale development; voids in production technologies to be identified and addressed; and before proceeding into production, contractors to demonstrate the capabilities to produce within cost and schedule.

Systems are prepared for production through a series of actions, which begin with initial design, and culminate when full production rates are attained. Ideally, these efforts build continuously, beginning with production planning and gradually phasing into demonstrations of the plans and needed capabilities. While DOD policy requires production planning and demonstration of production capabilities before a weapon enters production, it does not delineate the steps each program must take to do so. Instead, the specific production preparations to be employed are determined individually for each program.

Production preparation begins with planning the initial design so that it will be as easy as possible to produce. Once the weapon system design has been established, production planning proceeds with determining the facilities, tools, people, and procedures required to produce the weapon system according to that design. This involves determining how each part will be made and what it will be made of, identifying necessary production equipment and skills, determining the flow of parts and assembly sequences, determining the layout and sizing of facilities, and deciding how and when to inspect for quality. Production planning efforts can be directly or indirectly funded through the development contracts. In the Army, they have been historically aggregated under the term "producibility engineering and planning," a term which DOD had adopted in January 1984 regulations.

Design-to-cost, a DOD program which entails setting a unit production cost goal to be regarded equal in importance to technical performance goals, can also play a part in production planning, since it can serve as a vehicle for making trade-offs between the producibility and performance of a weapon system design.

Demonstration of production capabilities can begin under DOD's manufacturing technology program, where individual projects are undertaken by program offices to develop specific production capabilities. This is a logical extension of production planning, where gaps in needed production technologies, such as sophisticated tooling and new processes, can be identified. Through manufacturing technology, projects are undertaken to build a developmental prototype of the needed tool or process and to demonstrate, by making some parts, whether it can perform as required in production.

On a larger scale, several techniques can be used to demonstrate the ability of a production line to produce an entire weapon. Pilot production is funded through research and development and is usually done with a few top people with scaled-down tools. Only a small number of production prototypes are made in this manner to show the item can be produced as planned. In pilot production, manufacturing drawings and specifications and tools which are representative of those to be used in high rate production are used. Another technique involves initial production facilities whereby full-scale equipment and facilities are set up but can produce only at low rates. Rather than buying all the equipment needed for high rate production, only one of each needed machine is used to show that the line can work together to produce the weapon. Finally, low rate initial production can also be employed to provide demonstration of production capabilities. It is a concept whereby a conscious decision is made to keep the number of units produced each month substantially lower than the rates ultimately anticipated, to resolve production difficulties, and to reduce the risk of costly retrofits in the event of design changes. A separate determination is made by DOD or the services on whether to proceed into high rate or full production, where production of the maximum number of units per month planned for the system is attained. Since each of these techniques involves the production of complete units, usually only one approach or a combination of two is employed in a single program.

A final DOD mechanism that plays an important part in preparing systems for production is the production readiness review. This is a methodical examination of a program to verify whether the production design, planning, and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, or cost or other criteria. The review itself does not reduce production risks but rather identifies them. It is conducted at contractor facilities by a team of service representatives knowledgeable in production techniques and is intended to be a time-phased effort which spans full-scale development.

The labels applied to the above mechanisms are not as important as the timing and actual conduct of the activities described.

The transition to production and its role in the acquisition cycle

Although properly described as a phase, the transition is not a discrete phase in the typical weapon system acquisition cycle. This cycle as described in DOD directives and instructions is depicted below.

Weapon System Acquisition Cycle

Milestone 0	Milestone 1	Milestone 2	Milestone 3
Concept exploration	Demonstration and validation	Full-scale development	Production and deployment

Time →

Typically, a weapon system has taken 8 to 12 years from its inception to the deployment of the first units to the field. Production continues for several years thereafter until the inventory is filled. Each of the four acquisition phases is preceded by a senior management review either at the service or DOD level, which determines whether the system should proceed to the next phase. For some programs, management departs from this sequence of phases, such as compressing development into fewer phases or combining early production with full-scale development. For example, in the Black Hawk program, development consisted of a single competitive phase followed by production. In the ALCM program, the full-scale development program included 2 years of pilot production.

The first three phases are developmental. In concept exploration, alternative system concepts are identified and evaluated. Usually, little if any hardware is fabricated. Then, several alternative weapon concepts may be selected to proceed to the demonstration and validation phase, where a few hardware articles are fabricated to see whether they can perform as expected. When this phase has been successfully completed, one or more alternative systems proceed to full-scale development, where several hardware articles are made and undergo numerous tests to mature the design and to ensure that it meets the system requirements. Some long-lead-time items and early production units may be authorized in this last phase of development. In the fourth phase, the weapon system is produced in increments until the full production rate is reached, which ideally is sustained until all units are produced.

The period where the transition to production occurs cannot be clearly discerned from these acquisition phases. In fact, the transition overlaps the development and production phases. As discussed earlier, DOD directives and instructions call for production preparations to begin very early in development, even before full-scale development, and to gradually increase throughout the development phases. The transition phase continues into production, until it is demonstrated that the facilities, equipment, and people can produce the weapon system in the quantities and of the quality needed.

The link between the transition to production and cost estimating

Production is by far the phase when the most funds are expended in weapon acquisitions, amounting to several times the amount spent in the development phases. As such, production costs constitute the major portion of acquisition cost estimates. Accurate cost estimates depend upon accurate forecasts of key production factors, such as labor hours, material costs, facility capabilities, production yields, and production schedules. Since the activities which constitute a system's transition to production, in large part, determine these factors, a well-planned and well-executed transition is a prerequisite to making good weapon system acquisition cost estimates.

OBJECTIVES, SCOPE, AND METHODOLOGY

Our review was conducted on the premise that the cost growth and schedule slippage which often surface after major weapons begin production result primarily from some basic production problems. Several studies by DOD, the services, and GAO have discussed the issue of weapon system cost growth upon beginning production and have noted the presence of production problems, such as those noted on page 1. These studies were conducted primarily through a broad examination of many weapon systems. We adopted the case study approach to complement these broad studies so that we could identify some of the specific causes of the production problems encountered by these weapons and to gain insights as to how they might be avoided in future weapon system acquisitions.

We analyzed six weapon systems in depth to determine how well they had been prepared for production, as well as their subsequent experiences in early production. Essentially, we considered a smooth transition to production to be one where a weapon did not encounter major problems in production, evidenced by little or no cost growth and little or no slippage in meeting scheduled production deliveries. For the most part, those production problems experienced by the weapon systems we reviewed have been resolved. While we did pursue reasons why production preparations were or were not thorough in each program, we did not question whether decisions to delay or reduce such preparations in favor of other program priorities were proper. Rather, we focused on the effects such decisions had on each weapon's transition to production.

Our interest in the difficulties major systems encounter in making the transition stems from our October 1981 report, in which we analyzed the procurement profiles of 14 major Army weapon systems and found a clear pattern of cost growth once the systems began production.[1]

We tried to choose as case studies weapon systems that were in production long enough to determine whether their transitions to production had been smooth. We selected 6 weapon systems, of the approximately 60 major weapons being reported in Selected Acquisition Reports. To permit a comparison of the experience of the Army, the Navy, and the Air Force, we selected for our case studies weapons procured by each service. We also made a conscious attempt to select weapons with both positive and negative production experiences to shed more light on what can be done about production difficulties.

The weapons we selected and their prime contractors were:

Weapon system	Lead service	Prime contractor
Black Hawk helicopter	Army	Sikorsky Aircraft Division, United Technologies Corp.
Copperhead projectile	Army	Martin Marietta Orlando Aerospace
Tomahawk cruise missile	Navy	General Dynamics Corp., Convair Division[2]
High Speed Anti-Radiation Missile (HARM)	Navy	Texas Instruments, Inc.
F-16 fighter	Air Force	General Dynamics Corp., Fort Worth Division[2]
Air-Launched Cruise Missile (ALCM)	Air Force	Boeing Aerospace Co.

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[1] Budgetary Pressures Created by the Army's Plans to Procure New Major Weapon Systems Are Just Beginning (GAO/MASAD-82-5, Oct. 20, 1981).

[2] The Convair Division is located in San Diego, Calif., and the Fort Worth Division is located in Fort Worth, Tex. Each has its own facilities and people.

While not ideal selections in every respect (for example, the Black Hawk and the F-16 have been in production for over 6 years and the Navy and Air Force missiles are jointly managed), they met our essential criteria of being in production long enough to have actual experience; representing all three services; and collectively providing examples of both positive and negative production experiences. The six weapon systems are described in appendix I. The cost and quantities discussed in the report for the HARM represent only the Navy portion of the program.

Acquisition costs of these six weapons--which include development and procurement costs--as estimated in mid-1982, just before we began our work, totaled about $74 billion. These costs and associated quantities are shown below for each of the weapons.[3]

Weapon system	Acquisition cost (millions)	Quantity
Black Hawk	$ 7,732.5	1,107
Copperhead	1,619.5	44,666
Tomahawk	11,777.8	3,994
HARM	2,585.6	7,057
F-16	41,981.1	1,985
ALCM	8,135.0	4,348
Total	$73,831.5	

We conducted most of our work at the service commands where the program offices for each of the six systems were located. These included the Army Aviation Research and Development Command (St. Louis, Mo.), the Army Armament Research and Development Center (Dover, N.J.), the Naval Material Command and Naval Air Systems Command (Arlington, Va.), and the Air Force Aeronautical Systems Division (Wright-Patterson Air Force Base, Ohio). In addition, we visited the prime contractors for each system and key subcontractors on four of the six systems. We held numerous discussions with representatives of the program offices, development commands, service headquarters, the Office of the Secretary of Defense, and contractors to reconstruct the production preparations for each program, as well as early production experiences. The information we gathered from contractors was obtained primarily through discussions with contractor officials during visits to their facilities. We discussed these matters with DOD representatives on location at each production facility. We also analyzed

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[3]The figures shown here are intended to illustrate the magnitude of these programs. These figures may vary from those discussed later in the report because these later discussions center, for the most part, around time frames other than mid-1982.

numerous documents on each system, including contracts, contractor performance reports, production readiness reviews, cost studies, test reports, decision memorandums, and Selected Acquisition Reports. We reviewed DOD and service regulations and directives. We toured each prime contractor's production facilities, where we observed each weapon being fabricated and assembled.

In addition, we discussed the circumstances and processes for taking a large commercial product from development to production with two major commercial producers--the Ford Motor Company, Dearborn, Michigan, and the Boeing Commercial Airplane Company, Seattle, Washington. Because these firms develop products to meet a forecast market (rather than a defense need) and their sales depend on customer preferences (again, in contrast with defense), their incentives for preparing major items for production seem in general to be stronger than those for weapon programs. While these firms generally do not deal with technical risks as great as those DOD faces, their approaches to production preparations help define what is possible under more favorable circumstances. This, in turn, can help illuminate areas of comparatively greater production risks in DOD programs.

Our review was performed in accordance with generally accepted government auditing standards. The review was initiated in January 1983, and fieldwork was completed in January 1984.

STRUCTURE OF THE REPORT

In chapter 2, the details of the six weapons' production experience are presented, as well as what we believe to be the general underlying causes for the experiences, both positive and negative. These causes are discussed in greater detail in the next two chapters; chapter 3 covers how well each system was prepared for the production phase, and chapter 4 recounts some of the external factors which help explain the adequacy of production preparations. In chapter 5, we discuss what actions DOD has taken to improve the transition of weapons to production. In the last chapter, we present our conclusions and recommendations, as well as DOD and contractor comments.

CHAPTER 2

PRODUCTION EXPERIENCES ARE DIRECTLY AFFECTED

BY DEVELOPMENT PHASE ACTIVITIES

Two of the six weapons reviewed had relatively smooth transitions to production. The remaining four encountered, in varying degrees, more difficult problems in production, evidenced by cost growth and schedule delays.

Weapon systems which avoided major problems in production enjoyed a development phase in which design, planned procurement quantities, and funding were relatively stable. In these programs sponsors provided sufficient resources, and management showed a balanced concern for both technical performance and production by infusing the program management staff with enough production-oriented personnel. These conditions enabled timely and specific actions to be taken by DOD and the contractors to prepare the systems for production so that a minimum of problems occurred in early production.

Conversely, the four systems which had more difficult problems in early production went through development phases which were characterized by design, funding, and quantity instability, which led to a concentration of resources on technical design problems to the detriment of production preparations. As a result, they were not well-prepared for the production phase. According to DOD, several conditions of the defense and aerospace industry at the time intensified these difficulties in making the transition to production. A period of strong growth in commercial aerospace production placed increased demand on material and machining equipment manufacturers which substantially increased lead times for critical items and led to shortages. These effects were compounded by labor shortages and strikes in the labor force during the same time period.

FOUR OF SIX WEAPONS REVIEWED HAD DIFFICULT TRANSITIONS TO PRODUCTION

The Copperhead projectile; the Black Hawk Helicopter; the Tomahawk cruise missile; and, to a lesser extent, the HARM missile, encountered substantial problems in early production. While each of the four systems had production start-up problems unique to the weapon, production of the weapons, in general, turned out to be much more difficult and complex than had been anticipated in development. These problems derived largely from having to do basic production line planning, ready facilities and equipment, and demonstrate the ability to produce the weapon--in short, to conduct production preparations--in the production phase. As discussed in chapter 1, production preparations should be conducted throughout development to identify production requirements and to resolve difficulties before production begins.

In the Copperhead, Black Hawk, and Tomahawk programs, early production problems drove costs up and delayed initial deliveries. In several instances, production contracts had to be modified to reduce quantities to be delivered. Higher costs were reflected in proposals for later production contracts which, together with the reduction in scope of earlier contracts, caused the total production quantities to be stretched over a longer period. Stretch-outs, in turn, caused a secondary wave of cost increases as production efficiencies decreased and the fixed cost of keeping production facilities operating longer increased. The HARM program also encountered problems in production which led to cost increases, but these were discovered in late full-scale development, during pilot production.

All four programs experienced slower buildups to full rate production than planned. In addition, each program, reacting to production problems and their effects, required restructuring, including altering production rates, reducing quantities, or introducing additional sources in the production phase to help contain cost growth.

Copperhead

On the first Copperhead production contract, actual manufacturing labor hours exceeded estimates by some 50 percent, due primarily to problems in producing the steel case that houses the projectile's control section. In production, Martin Marietta tried to initially machine a softer steel and then attain the casing's needed strength through a heat treatment process. However, the housings became distorted under the heat and failed to meet tolerances. Metallurgical analyses had to be done on each lot of housings, and another loop of machining after the heat treatment was added. Problems also occurred with Copperhead's control actuator base, part of the mechanism which operates the projectile's wings and fins. The two complex special purpose machines which the actuator base manufacturer, Chandler Evans, purchased could not accurately cut grooves and drill holes in the aluminum base. The base eventually had to be sent from the production line to several craft shops for machining. Costs for the actuator base increased fourfold as a result.

Cost growth and schedule slippage marked the Copperhead's entry into production. Several factors, including technical problems, contributed to this experience, but problems on the production line were a major cause. Copperhead's unit procurement costs have increased from $21,700 to $33,000 in constant fiscal year 1983 dollars since production began in 1979.

Costs and quantities on the first two production contracts are shown below.

	Original price	Final cost	Planned quantities	Actual quantities
	----(millions)---			
First production contract	$ 62.7	$ 70.7	2,100	1,114
Second production contract	72.3	109.8	2,100	2,624
Total	$135.0	$180.5	4,200	3,738

On these contracts, signed in late 1979 and late 1980, the Army was to receive 4,200 projectiles for $135 million. Total production quantities planned at that time were 110,236 projectiles. Martin Marietta was able to produce only 1,114 of the 2,100 projectiles called for under the first contract, yet the contract price increased. Roughly half of the remaining projectiles were made up during the second contract but at substantial cost. The remaining quantities were deferred until the third production contract, which was signed in early 1982. Together, the first two contracts ended up costing $45 million more than originally estimated, while yielding nearly 500 fewer projectiles than planned.

Production deliveries fell behind from the start, and the buildup to full rate production was consequently slowed. By March 1983, when deliveries from the first two contracts were to be completed, actual deliveries were 1,475 projectiles behind. In 1982, the Congress deleted funding for procurement of additional projectiles and called for termination of the program. While the program was later restored, its experiences in production very nearly caused its cancellation.

Black Hawk

In producing the Black Hawk, Sikorsky experienced parts shortages, excessive reworking of parts, and excessive material usage. Sikorsky was forced to do assembly out of sequence and to adopt alternate fabrication and machining methods. Manufacturing and quality control hours actually spent on the first three production contracts totaled to 160,300 hours, over 50 percent more than the estimated 104,200 hours. This greater production effort was needed for the following reasons:

--In production many aircraft components were changed from metals to composites (materials formed by imbedding filaments, such as boron or graphite in a plastic-like epoxy medium), materials Sikorsky was inexperienced with.

--Sikorsky encountered difficulties in qualifying a subcontractor to build transmission components and subsequently in building the components itself for the first two production lots.

--Fabrication and delivery of production tools by Sikorsky and some of its vendors were late, as were deliveries of forgings and castings from vendors.

--Basic weaknesses in production control existed. For example, some parts reaching the production line did not match drawing requirements and the production schedule was inaccurate.

Since entering production, Black Hawk costs have increased from $3 million to $5 million per helicopter (in constant fiscal year 1983 dollars). Costs increased steadily in the production phase due to the problems discussed earlier and did not settle down until fiscal year 1982. These costs reflect the procurement of all aircraft components, including government-furnished equipment, such as the engines. As such, they reflect more than the airframe costs Sikorsky was responsible for. Our discussions center around the airframe, as its production experience was the main driver in the program.

When the Army awarded the first Black Hawk production contract in fiscal year 1977, it was planned that production would peak at 15 aircraft per month and procurement of all 1,107 helicopters would be completed in 9 years. Actual production costs exceeded ceilings on the first two contracts. By May 1979, Sikorsky had fallen nine aircraft behind schedule because of fabrication and assembly difficulties. Consequently, the third contract was reduced from 129 to 92 aircraft, and yet contract costs increased from $222 million to $260 million. In the fourth year, fiscal year 1980, planned production was also reduced from 145 aircraft to 94. Though the Army had planned to buy 345 Black Hawks in the first 4 years, it was able to buy only 257 and had to pay a higher price.

In late 1979, driven by production costs, late deliveries, and the need to keep annual funding requests affordable, the Army reduced the planned peak production rate from 15 to 8 aircraft per month and stretched the procurement of the 1,107 helicopters over 14 years rather than 9 years. In addition to the substantial cost increases this stretch-out caused, costs increased again significantly in late 1980 and early 1981, when follow-on contract proposals were prepared based on actual production cost experiences. Cumulatively, it was these increases which accounted for the unit cost increase from $3 million to $5 million.

Tomahawk

The initial layout of the Tomahawk's manufacturing and assembly processes caused work to be performed out of its normal station on the production line. Poor quality control over materials led to additional rework on the production floor and spending additional time repeating tests and inspections in the final assembly area. For example, tolerance differences in the wing doors, inlet covers, shrouds, and small parts were discovered in final assembly, when the components did not mate well and had to be remachined to fit together. In addition, production facilities were scattered around the San Diego, California, area. In early production, fabrication, machining, assembly, and finishing processes for the fuselage midsection took place at three separate locations, requiring each midsection to travel some 31 miles from start to finish and to be transported between locations six times. In addition to requiring increased material usage, these problems caused missiles to spend an inordinate amount of time repeating the final check-out and assembly steps in production.

Together, technical and manufacturing difficulties in the Tomahawk program led to schedule slippages, cost increases, and a major restructuring. Because of the difficulty General Dynamics was having in building quality missiles that would perform properly in testing, the planned 2-year pilot production line--covering fiscal years 1978 and 1979--was not established so that additional test missiles could be built. Although in fiscal years 1980 and 1981 the Congress funded production of more missiles than DOD requested, planned annual production quantities have been continually reduced since then. The fiscal year 1982 production quantities were reduced from 88 to 61 missiles, and planned fiscal year 1983 quantities of 120 missiles and 1984 quantities of 312 were reduced to 51 and 124 missiles, respectively. Full rate production decisions for the missile variants were delayed until problems revealed in testing were resolved. In 1982, production rates were restricted to 4 to 6 missiles per month and to 10 to 12 per month in 1983 due to production-related problems, far below the projected full rate of 25 missiles per month. In February 1984, the rate restrictions were lifted.

These decisions on quantities and production rates were part of a major program restructuring which took place in late 1982. The restructuring was the result of an external study of the program which, after identifying both technical and management problems, concluded that an additional $313 million was needed to stabilize the program. Technical problems cited included the quality control difficulties discussed above and numerous design changes being made in production. Regarding program management, the study noted that the DOD program office staff devoted to technical management was relatively small given the demands of the several missile variants. The savings from quantity reductions provided some of this funding, while the remainder was obtained through reprogramming. In addition, the study concurred in the Joint Cruise Missile Project Office's decision to establish McDonnell Douglas (the navigation/guidance associate contractor) and General Dynamics/Convair (the air vehicle associate contractor) as competitors for production of complete missiles in an effort to control future cost growth.

While substantial cost growth occurred during Tomahawk's entry into production, it cannot be readily discerned from a comparison of unit costs, as a result of other program changes. During early 1982, estimated cost growth on the order of $0.7 billion to $1 billion, due to program restructuring and other reasons, was offset by savings the Joint Cruise Missile Project Office expected from introducing additional sources. Whether these savings will actually be realized remains to be seen. Moreover, program quantities jumped more than sixfold by 1982, from 644 to 3,994 missiles, which also lowered unit costs. Finally, the program estimate was reduced another $1 billion in December 1982 as a result of revised inflation estimates ($600 million) and additional savings expected from second sourcing ($400 million).

HARM

During pilot production in 1980 and 1981, Texas Instruments found the HARM missile's microwave circuit boards, the heart of its sophisticated seeker, to be much more labor intensive to produce than originally planned. The circuit boards' complex circuit paths required more intricate artwork and etching on the production line than anticipated, which, together with difficulties in soldering and manually attaching foil to the board components and manually screening the circuit boards, caused low production yields on the circuit boards and consequent high scrap rates. In addition, the missile seeker required extensive calibration and testing in a special sound chamber, which initially amounted to 200 hours per missile. Eventually, Texas Instruments was able to reduce the testing to 48 hours per missile. Besides driving labor hours up, these difficulties also necessitated a higher ratio of more expensive engineering hours to production labor hours. Several major HARM subcontractors also experienced difficulties producing components of sufficient quality.

Since the HARM entered low rate production in late 1980, unit costs have increased from $186,000 to $258,000 in constant fiscal year 1983 dollars. The unit cost increases would have been higher had not additional sources for some of the production been selected.

A combination of factors accounted for the cost increase. In addition to the increased costs from the production experiences discussed above, design changes emanating from ongoing tests and evaluations resulted in cost increases during the same time frame. According to Texas Instruments, software difficulties were also a major contributor to production delays and increased costs. Finally, while Texas Instruments informed the Navy in March 1981 that HARM production costs had increased on the basis of these experiences, the Navy did not update its cost estimate to reflect the increases until late 1982, pending the results of a major cost study it conducted. By then, Texas Instruments had increased wage rates several times, which magnified the amount of the increase reported by the Navy.

It should be noted that a major contributor to both the design and production problems encountered during the HARM's transition to production was a decision in 1977 by DOD to significantly expand HARM's performance requirements. This is discussed in greater detail in chapter 4.

After the cost increase was recognized by the Navy, the Defense Systems Acquisition Review Council, convened to approve the HARM's entry into high rate production, deliberated for several months over whether to bring on another prime contractor to compete with Texas Instruments for HARM production. The Congress had already provided funds for initiating the second source. In March 1983, the review council approved high rate production by Texas Instruments as the sole source because (1) it concluded that the savings to be derived from a second sourcing would not offset its costs given the quantities of missiles to be produced and (2) Texas Instruments had proposed a fixed price for several years of HARM production. In addition, the Navy initiated development of a low cost seeker which may eventually replace the current HARM seeker.

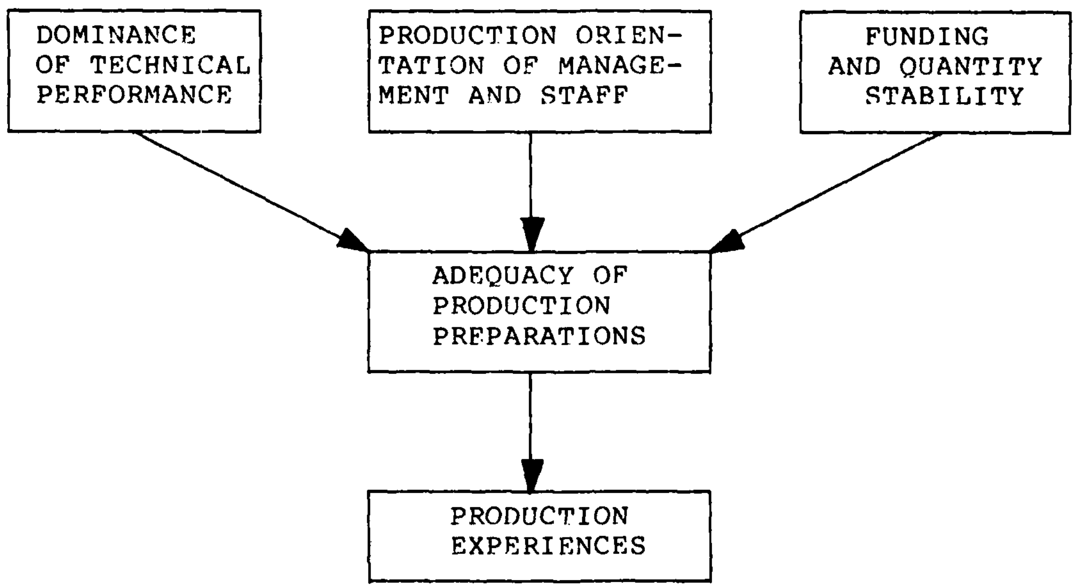
THE F-16 AND AIR-LAUNCHED CRUISE MISSILE: RELATIVELY SMOOTH TRANSITIONS

The F-16 fighter and the ALCM experienced fewer production start-up problems than the other systems. However, neither program was free of such problems, as evidenced by the mild cost increases in both programs' production. The F-16 experienced a 6-percent cost increase in late 1979 because the Air Force decided to reduce the production rate. Boeing and its subcontractors have had some problems in early ALCM production, such as rework and difficulty meeting part tolerances, reflected in a cumulative 17-percent unit cost increase (in constant dollars) since production began in 1980. However, both programs have met delivery schedules and have built up to peak rates as planned. In fact, ALCM achieved a peak production rate of 40 per month ahead of schedule. Neither has had production problems serious enough to have contracts modified to allow procuring lower quantities, nor have they required restructuring because of production experiences. ALCM unit costs increased substantially in late 1982 as a result of terminating the ALCM program in favor of an advanced design. These increases stem from the termination rather than production problems.

The contractors for the cruise missile engine and radar altimeter, critical subsystems common to both the Tomahawk and the ALCM, experienced relatively smooth transitions to production with one exception. Honeywell and Kollsman, developing competing radar altimeters, each had early designs which were too complex to produce within cost and schedule thresholds. While Kollsman has yet to make its design economically producible, Honeywell was able to redesign its product and produce at substantially greater rates than planned. Williams International has produced the engines on time and within projected costs and, at the direction of the service program office, brought on a second producer of engines so that desired production rates could be maintained.

SEVERAL KEY FACTORS STAND OUT IN EXPLAINING PRODUCTION EXPERIENCES

In the six weapon programs, several factors, shaped primarily by the development phases, surfaced consistently as reasons why early production problems did or did not occur. The chart below depicts these factors.



As discussed in chapter 1, production preparations consist of a series of concrete actions taken in development to gear up for production. Systems which were not well-prepared for production encountered serious production problems. The production preparations of the six weapons reviewed are discussed in detail in chapter 3. Conditions which prevailed during the systems' development greatly affected the adequacy of production preparations, particularly to the extent that

--the pressures to achieve technical performance dominated the development phase;

--program management, from both the services and the contractors, demonstrated an appreciation for production preparations and devoted adequate staff to those efforts; and

--funding and quantity stability permitted early and serious consideration of production matters during the development phases.

Clearly these factors are interrelated. For example, a design employing advanced technology is more likely to encounter performance problems which take management attention and resources to solve. The attendant cost increases can cause funding cuts in other areas and often give rise to procurement delays and quantity reductions. We did not assess the propriety of the decisions made in these programs, nor are we asserting that individually any one factor is the primary cause of production problems. Rather, we found that in the development phase, conditions existed which definitely affected production experiences, particularly in that they drew attention and resources away from production preparations. Collectively, these conditions help explain why some systems were better prepared for production than others. Chapter 4 discusses the environmental factors of the six weapons reviewed in detail.

Not all production problems can be explained in terms of these factors. Indeed, even under the best of circumstances, not all problems can be foreseen or prevented; other problems are unique to the particular weapon system. However, the four factors presented above did largely explain how the six weapons fared in production and underscore the fact that many production problems have systemic causes originating in the development phase.

Why some weapons had serious production problems and others did not

The table below identifies the factors which caused production problems in the six weapons reviewed.

	Copperhead	Black Hawk	Tomahawk	HARM	ALCM	F-16
Production preparations were inadequate	X	X	X	X		
Development environment						
Technical performance dominated development	X	X	X	X		
Program management and staff lacked sufficient production orientation	X	X	X			
Funding and quantities were unstable	X		X	X		

The Copperhead's production problems stemmed from several causes. Although several actions were taken during development to prepare the system for production, they were, in general, underfunded and were too late to be effective. Instead, the technical difficulty of launching the electronically and mechanically sophisticated projectile from a cannon dominated development. This, coupled with the fact that the program experienced several funding cuts and planned procurement quantities were cut by two-thirds while it was still in development, made large investments in production planning impractical.

While the Black Hawk enjoyed reasonable quantity and funding stability, it too had serious problems in production. This can be traced to the Army's heavy emphasis on technical performance, coupled with inadequate attention to the contractors' production capabilities during the extremely competitive development phase. These incentives led the contractor to assemble a design-and-marketing-oriented program management and staff. Consistent with this emphasis, the Army provided very little money for production preparations. In addition, a major redesign by the contractor in the production phase, induced by a weight reduction incentive in the contract, all but negated what production preparations had been made.

Technical and quality control problems, evidenced by numerous test failures, were prevalent throughout the Tomahawk's development and early production. As with the Copperhead and the Black Hawk, the design was not stable. Efforts to help prepare the Tomahawk for production were reduced to put more effort into solving technical problems revealed in flight tests. The service program office staff, jointly serving both the ALCM and the Tomahawk, had an aggressive approach toward readying for production, but General Dynamics' program management at the time did not fully appreciate the missile's extensive production requirements and experienced difficulty responding to DOD actions and recommendations. General Dynamics noted that there was no single contractor responsible for integration of the missile components and that the service program office did not have adequate staff to act as the integration agent. In addition, program funding and quantities fluctuated throughout development and early production, making General Dynamics reluctant to streamline its facilities and operations for production.

The interaction of factors influencing the HARM's production experiences is less clear. The basic HARM design of the early 1970's required great strides in microwave circuitry to achieve desired performance, and its complexity has substantially increased since then as DOD has required greater frequency coverage and maneuverability of the HARM. Production preparations, while not ignored or shut out, were deferred until very late in development because of technical pressures and a very tight development schedule. Technical problems prompted the Congress to delay production for a year, which enabled Texas Instruments to do some last minute production preparation. Ironically, had technical problems not caused two program delays, providing time for production preparation, the production problems experienced may well have been greater.

In contrast, when the F-16 program began, the F-16's performance requirements were very flexible and did not, on the whole, represent great performance improvements over existing fighter aircraft. Rather, the main goal of the program was to build a low cost fighter which, combined with the agreements with four European countries to purchase and coproduce the aircraft, created a very stable design and program environment. In addition, advanced technologies were proven out before full-scale development which kept design risks low. These conditions, together with sound production preparations by both the Air Force and General Dynamics, largely explain the F-16's smooth transition to production.

Despite some technical challenges and a tight schedule, the ALCM experienced a comparatively smooth entry into producton. With the cancellation of the B-1 bomber in the late 1970's, fielding the ALCM became the top defense priority. This ensured an unusual level of program stability and all but guaranteed sufficient funding. This stability, coupled with a strong production staff, provided an environment for a balanced treatment of technical and production issues during development. Demonstration of production capabilities was a major element in the competition between Boeing and General Dynamics and in source selection. The stability of the program and the priority accorded production preparations were matched by Boeing's willingness to make substantial capital investments in production facilities and to aggressively manage subcontractors. In addition, the safety net of having two suppliers for major components enabled schedules to be met even when some producers ran into trouble.

CHAPTER 3

WEAPONS NOT WELL PREPARED FOR PRODUCTION

ENCOUNTERED SERIOUS START-UP PROBLEMS

The F-16 and the ALCM fared better in production than the other four weapons reviewed because they were better prepared to enter production. This means much more than technical maturity. In these two programs, a series of production planning actions, including producibility studies, production line and factory layouts, and tooling purchases, were carried out in development, coupled with some demonstration that capabilities and resources needed to begin production were present. These activities constituted a transitional phase, whereby the custom fabrication of development prototypes was gradually converted to a production line--a process which began well in advance of the production phase. Thus, the transition was not automatic; it took a series of deliberate concrete actions.

In varying degrees, production preparations for the Copperhead, the Black Hawk, the Tomahawk, and the HARM were sporadic and underfunded and were largely compressed into the very late stages of development or deferred until production had started. In several cases, the methods, equipment, and people used to produce the weapons differed substantially from those used to build development units. The production start-up problems discussed in chapter 2 derived largely from having to do basic production line planning, ready facilities and equipment, and demonstrate the ability to produce the weapon in the production phase.

The timing of the production preparations on these systems provided some insights into concurrency, which refers to conducting development and production activities at the same time.[1] To the extent that beginning production preparations early in development is considered concurrency, it facilitated the transition to production in programs such as the F-16 in that production preparations were more timely and thorough and that major gaps between the fabrication of development and production hardware were avoided. Concurrency had negative consequences in the Tomahawk and Black Hawk programs, where significant development activities slid into the production phase and were disruptive to production efforts. Copperhead, on the other hand, had little concurrency but encountered major production problems. This is not an endorsement of starting actual production before development units

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[1] Specifically, concurrency is the overlap in time between the development of a weapon system and its production. In a nonconcurrent program, development is completed before production begins. In a concurrent program, production is started while development is still under way.

have been sufficiently and successfully tested. Rather, the key lesson learned is that production preparations are proper development activities and conducting them concurrently with other development activities enables more informed production decisions.

PRODUCTION EXPERIENCES ARE DIRECTLY RELATED TO ADEQUACY OF PREPARATIONS

Both the F-16 and the ALCM had production planning efforts which began early and were sustained through development. Consistent with DOD policy on production management, in both programs, these efforts were coupled with some demonstration of production capabilities on developmental hardware before production began. Production planning and demonstration were totally integrated and nearly indistinguishable from the development effort itself, and provided an orderly transition to production.

Production planning for the Copperhead, the Black Hawk, the Tomahawk and to a lesser extent, the HARM, was not sufficient to forestall significant production difficulties. In each case, such planning did not start early in development where, according to DOD, the greatest opportunities to identify problems and reduce costs exist. Instead, production planning was treated as optional and fell prey to technical pressures. Production preparation had a minor role in the development phases of these programs. In the Black Hawk, Copperhead, and Tomahawk programs, we found no gradual transition from development to production as efforts to demonstrate production capabilities were pushed off into the production phase. This caused difficulties in converting production plans into the fabrication of real tools, facilities, and hardware in the production phase. Thus, a great deal of learning took place on the first production units, and production capabilities were demonstrated on the production line where the impact of problems was greater and opportunity to avoid them was less. The HARM did have a pilot production phase in development which forestalled major manufacturing problems in the production phase. Difficulties did arise in pilot production due to design instability and lack of early production planning, and their effects were later compounded by Navy cost estimating difficulties.

In addition, at the time of the production decisions for the two weapon systems that had thorough, timely production preparations--the F-16 and the ALCM--much more was known about key production factors than in the other four programs, where preparations were less extensive. This is because in addition to readying weapons for production, production preparations generate key production information, such as detailed drawings, line layouts, manufacturing processes, labor hour estimates, machine times, rework levels, scrap levels, lead times, and test and inspection procedures. This suggests that for the Copperhead, the Black Hawk, the Tomahawk, and to a lesser extent the HARM, the decisions to produce were based more on achievements in development than on whether production capabilities had been established and production requirements for the weapons were well understood. The less that was known about the weapons' production requirements and capabilities, the less their production costs could be predicted accurately. This was borne out to some extent by the significant production cost increases experienced in the Copperhead, Black Hawk, Tomahawk, and HARM programs.

The production preparations of the F-16 and Copperhead programs are discussed below to illustrate the relationship between each weapon system's production experience and the extent to which such preparations were carried out in each. Clearly, environmental factors such as the F-16's technical maturity, emphasis on low cost, and program stability made its extensive production preparations possible, whereas less favorable conditions impaired the Copperhead's production preparations. (See chapter 4.) The production preparations in the other four programs are discussed in appendix II.

Extensive preparations made to produce the F-16

Production preparation on the F-16 began in mid-1972, some 5 years before the planned production decision. The first 2 years of this effort were funded by the contractor. A production planning team representing design, manufacturing, industrial engineering, materials, and quality assurance disciplines developed manufacturing descriptions, assembly schedules, and factory layouts. Over 30 producibility studies were conducted. All this occurred before development prototypes were built.

One of the key outcomes of these efforts was the aircraft's modular design which made it easier and cheaper to produce. This meant building the fuselage in several vertical sections and stuffing these sections with needed wiring and components before mating them together. Fuselages of previous aircraft were built up as units, and workers had to crowd around each fuselage to install components and assemblies. The F-16's modular design permitted setting up numerous separate work stations, with one worker per assembly. In addition to reducing congestion, the modular design made the interior of the aircraft much more accessible and enabled testing to be done before major sections were mated. Although the first two advanced development prototypes were built in a nonmodular fashion, all eight full-scale development aircraft were built modularly.

In addition, the contractor's production planning and design-to-cost efforts complemented each other. The aircraft's production risks were reduced by minimizing sophisticated components and materials, while the strong production planning enabled the production cost goal to be achieved. As discussed in chapter 4, a major factor in the F-16's successful production planning was the great amount of design flexibility early in the program, together with an unusual degree of design stability which prevailed during full-scale development.

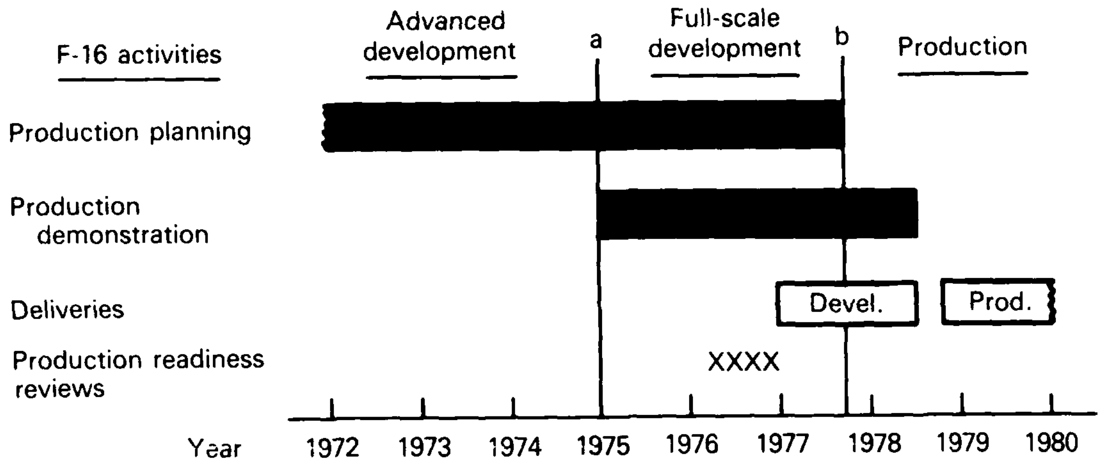
Complementing this production planning was a gradual development and demonstration of production capabilities which began with prototype aircraft and continued with early production aircraft. With each succeeding prototype aircraft, General Dynamics used production methods more closely resembling fabrication methods that would be used to build production aircraft. This continued to the point where the last two development aircraft were fabricated and assembled in the same manner as the first production aircraft.

Of great benefit to F-16 production was the fact that General Dynamics was operating a government-owned plant that could already produce the F-16, although some plant modernization was needed. In November 1974, when the contractor submitted its full-scale development proposal, the contractor had drawn up plans to modify the factory layout, purchase new equipment, and refurbish some old equipment. In addition, some 21 new machines were bought. Perhaps most important from a transition-to-production standpoint was the fact that these machines were gradually phased in over a 3-year period, during which time both development and production aircraft were being fabricated with the same people and in the same plant. The key to the smooth introduction of these machines was that the contractor had adequate facilities to produce the aircraft from the start. While the new and refurbished machines were being proven out, the contractor continued to build the parts with the old equipment. The old equipment was not retired until the replacements were fully proven.

Noteworthy in the F-16's entry into production which underscored the gradual transition from development was the fact that no break occurred between the fabrication of development aircraft and production aircraft. Deliveries between December 1976 and June 1979 are shown below.

	12/76	3/77	6/77	9/77	12/77	3/78	6/78	9/78	12/78	3/79	6/79
Development aircraft	1	1	1	1	1	1	2				
Production aircraft								2	3	7	9

The sequence of the production preparations leading up to the F-16's production decision is shown in the following chart. Point (a) indicates the full-scale development decision, while point (b) indicates the production decision.

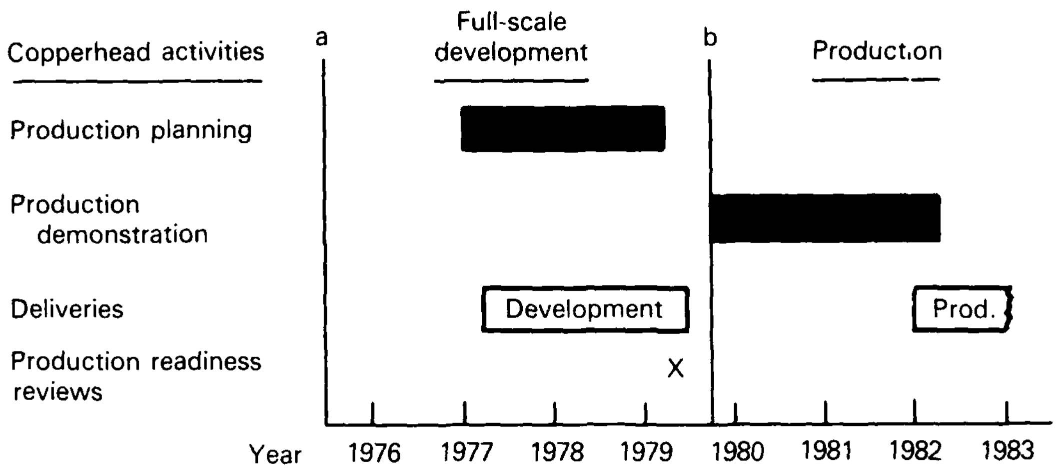


As the chart illustrates, at the time of production decision production planning was complete, production capabilities were developed and demonstrated, and incremental production readiness reviews were held with the benefit of actual hardware fabrication. Clearly, the demands of the production phase were understood before the decision to produce was made.

The production preparations carried out on the F-16 program are similar to the practices followed by the Boeing Commercial Airplane Company and the Ford Motor Company on commercial products. In both firms, production preparations begin very early in development, where multidisciplinary teams are established to ensure the new product designs are producible and that needed production capabilities exist. In fact, even though these commercial programs in general deal with lower technical risks than most weapon programs, both firms initiate production preparation some 4 to 6 years before the production phase begins. Production risks are resolved in the development phase. For example, when Ford introduced its nonmetal bumpers and Boeing its composite control surfaces, both also maintained production of metal versions of these components until the new materials proved themselves in testing and production. The commercial firms also attempt to avoid a gap between development and production by fabricating prototype hardware on production or pilot production facilities, particularly late in development.

<u>Weaknesses in the Copperhead's production preparations led to production difficulties</u>

Although several production planning mechanisms were used in the Copperhead program, production planning was not started until about halfway through full-scale development, and production capabilities were not demonstrated until production actually began. This is illustrated below in a chart showing the timing of Copperhead's production preparations. As with the F-16 chart, point (a) refers to the full-scale development decision, and point (b) refers to the production decision.



Production planning on the Copperhead program did not begin until nearly 2 years into full-scale development. By that time, it was too late to affect the projectile's producibility and the planning effort was relegated primarily to documenting its design and necessary production processes. Some production problems which, according to the contractors, stemmed from inadequate production planning included the following:

--Tolerances for some projectile components were unnecessarily rigid and not producible.

--Processes were later found unnecessary, such as filling holes for circuitry wires in printed circuit boards with glue, which caused excessive rework in the event that a circuit board did not meet all specifications.

--Electrical component testing time was excessive due to a design which did not adapt easily to test equipment.

--Electrical wires were too thin to be produced in a production environment without excessive breakage.

Evidenced by the inability of some key manufacturing processes to produce quality Copperhead components, the production planning effort did not provide for enough production process studies to ensure that planned processes would produce components meeting specifications. For example, for the control housing, such studies could have identified heat-treating as a production risk and a candidate for a demonstration project before production. The same is true for the control actuator base. In addition, no process studies were funded for the two complex machines which the subcontractor, Chandler Evans, needed to produce the base because the subcontractor did not receive any funding for production planning until late in development, when it was drawing up a proposal for production facilities. As discussed on page 10, the inability of these machines to accurately produce the base eventually led to a fourfold increase in the component's cost.

To meet the design-to-cost goal, Martin Marietta redesigned the Copperhead. While the redesign was viewed as an improvement, it increased development and production risks, ultimately leading to cost increases. For example, in advanced development, steel control housings were formed from a very hard steel and then machined. While machining the hard steel was expensive and time consuming, it was proven and constituted a low risk. In an effort to reach the cost goal, Martin Marietta decided to start with a softer steel, machine it first, and then harden it through a heat-treating process. This was an unproven process, and Martin Marietta experienced costly difficulties with it in production, as discussed on page 10.

Like production planning efforts, manufacturing technology projects were too little and too late to avoid major production problems. One project was completed by the time production began, while critical opportunities for additional projects were missed. The failure of production planning efforts to identify candidates for demonstration was a major factor. Neither the control housing heat-treating process nor the control actuator base machines were demonstrated through manufacturing technology projects.

Larger scale efforts to demonstrate production capabilities before committing to high rate production also fell short of resolving potential problems before production. In December 1977, the Army awarded Martin Marietta an initial production facilities contract. Although theoretically such a contract is a device to get just enough equipment to produce at low rates, this contract called for Martin Marietta to buy and set up all the equipment and special purpose machines to sustain the full production rate of 700 per month. No phase-in of new equipment occurred as over 2 years had elapsed since development projectiles had last been fabricated. When Martin Marietta and Chandler Evans attempted a prove-out run of some 37 projectiles, problems necessitating scrap and rework were encountered because many new and special purpose machines were being tried for the first time.

Top officials of Martin Marietta's Copperhead program office now believe that the wholesale introduction of such complex high rate equipment was a mistake. Moreover, the 37-projectile run did not prove out all key processes, as several components were made from development tooling or were parts left over from test projectiles. Also, the projectiles were not completed until after the production decision. Once again, the control housing illustrates the problem. Full-scale development housings were made by a subcontractor from the hard steel. Rather than trying the soft steel process in-house on the 37 projectiles, Martin Marietta used leftover housings made by the subcontractor. The first time Martin Marietta tried the new process in-house was in production. This incomplete demonstration of production capabilities led to substantial underestimates of production labor hours--actual labor hours expended under the first contract alone exceeded estimated hours by 35 percent. This also lessened the quality of information on which to base the production readiness review. This review is discussed in more detail on page 28.

The Copperhead experienced a gap between development and production rather than a smooth transition. It entered low-rate production in late 1979. Although ostensibly a tool to phase into production, this initial phase was mandated because the projectile was not meeting reliability requirements in testing, not because of production concerns. The Secretary of Defense constrained production to 200 projectiles a month until reliability goals were met. Moreover, a gradual entry into production was not really achievable given the many high rate and special purpose machines already in place and the critical processes as yet untried. When production began in late 1979, deliveries of the 37-round prove-out had not started and some 2-1/2 years had intervened since the full-scale development projectiles had been fabricated and delivered.

The Copperhead's experiences in production contrast with Boeing and Ford's practices on commercial products in that neither company gambles with unproven technologies or processes in production. Both use the same fabrication methods in development that they use in production, although not necessarily with high rate tools. The lesson to be learned from this is that using the same processes on both development and production units is a lower risk approach than introducing a different fabrication method in production. When the latter is unavoidable, the fact that it constitutes higher risk should be recognized and would indicate a need to take action to reduce these risks, such as conducting a manufacturing technology project or allowing additional time in the production schedule for potential problems.

EFFECTIVENESS OF PRODUCTION READINESS REVIEWS VARIED CONSIDERABLY

Production readiness reviews, perhaps the most visible tool used by DOD in preparing weapons for production, were applied quite differently in the six weapon programs. In some cases, the reviews were used to manage the development of production capabilities to reduce risks, and in others they were viewed as a gate to pass through before entering production. The effectiveness of production readiness reviews depended on the quality of production information available, which in turn depended on the adequacy and timeliness of production preparations. The reviews were not always carried out as time-phased efforts which span full-scale development, as required by DOD regulations.

A good contrast exists between the ALCM and the Copperhead regarding how production readiness reviews were employed.

When the ALCM entered full-scale development in late 1977, the joint Navy/Air Force program office had developed a strategy to manage production preparations and reduce production risks through the production readiness review process. To do this, the full-scale development contract required Boeing to develop production plans and demonstrate capabilities before the production decision. The program office used this as a basis for conducting four incremental production readiness reviews, each of which concentrated on a particular facet of production readiness, marking the progress Boeing made on its plans and demonstrations. The four reviews were conducted between September 1978 and December 1979, during which time Boeing conducted its producibility studies, introduced the large castings on development prototypes, and was in the midst of pilot production.

In this manner, production readiness reviews became a vehicle for managing production preparations which progressively reduced production risks. The active production preparations generated much information for the reviews, and the reviews themselves were integral to the preparations. The program office followed up the production readiness reviews in the production phase with two reviews in December 1980 and August 1981 devoted to planning for full rate production. The project office's employment of incremental production readiness reviews was perhaps even more successful with Williams International, supplier of both sea-launched and air-launched cruise missile engines. Largely through this process, Williams grew from basically a research-oriented firm to a solid producer of the sophisticated engine with new production facilities before entering the production phase.

For the Copperhead, a single production readiness review was conducted in March 1979, 6 months before the production decision. At the time, fabrication of development prototypes had finished and very little production tooling was in place. Even the limited fabrication and assembly of the 37 prove-out rounds had not yet started. The review team chief noted that on one hand the review was too early because there was very little to base an assessment on and, on the other hand, too late because there was not enough time to reduce risks substantially before production. (Honeywell officials expressed a similar view on the cruise missile radar altimeter, where only paper designs were available for the production readiness reviews in which the producibility problems were not evident.) The Copperhead production readiness review was of limited benefit to smoothing the program's transition to production. As with the other production preparations for Copperhead, the production readiness review became an isolated activity, not part of an integrated approach to production.

The experiences of the other four systems bear out the relationship between the effectiveness of production readiness reviews and such factors as how they are employed and timed and what information is available when they are held. In the F-16 program, four incremental reviews were held before production, much like in the ALCM program. Production readiness reviews were not required at the time of the Black Hawk's development, and attempts by the Army to assess production readiness were thwarted by the lack of production preparations and the aircraft's redesign in production. The joint service program office conducted production readiness reviews on the Tomahawk missile in the same manner as it had on the ALCM. The prime contractor's program management at the time had difficulty responding to the production concerns raised through the reviews due to the managerial demands posed by developing the four missile variants simultaneously in the Tomahawk program. (See p. 53 for more detail on the missile variants.) One review was held prior to the HARM's low rate production decision, before pilot production deliveries and producibility efforts had begun. In commenting on this report, Texas Instruments stated that two production readiness reviews had been held during development. However, the Navy maintains only one such review was held before production, and we found evidence of only one review before production.

CHAPTER 4

PRODUCTION READINESS IS INFLUENCED BY DOMINANCE OF TECHNICAL CONCERNS, PROGRAM STABILITY, AND STAFF ORIENTATION

Conditions of a weapon's development phase can shut out or render ineffective the concrete, timely actions which must be taken to prepare a weapon system for production. While it is difficult to quantify these conditions, concerns over technical performance in the Copperhead, Black Hawk, Tomahawk, and HARM programs led to a deemphasis on production preparations. Production preparations were also hampered by varying degrees of design instability, fluctuations in funding and quantities, and in some cases a lack of production orientation on the part of program management and staff. In contrast, the F-16 and the ALCM programs received balanced treatment of technical performance concerns and production concerns and enjoyed greater stability than the other four programs.

The dominance of technical performance concerns was caused by technical requirements which necessitated great advances in technology and by relying primarily on technical performance to measure program success. For example, achieving Copperhead's strenuous performance requirements, being critical to the program's success, commanded most of management's attention and resources. Production preparations in this case did not figure prominently in program decisions or concerns. Competition during Black Hawk's development had a similar effect on production preparations as it concentrated almost exclusively on technical performance.

During the course of development, the design instabilities arising from high technology designs, changes in technical requirements, quantity and funding fluctuations, and the resultant loss of a production orientation among management and staff made it difficult to carry out production preparations effectively. For example, a major increase in HARM's performance requirements midway through development contributed to production planning being done late in development. Technical difficulties in Tomahawk led to less demonstration of production capabilities in development than planned. Funding and quantity changes made prudent tooling and facility decisions difficult in the Tomahawk and Copperhead programs.

PRODUCTION PREPARATIONS SUFFER WHEN TECHNICAL PERFORMANCE DOMINATES DEVELOPMENT

The Copperhead, Black Hawk, Tomahawk, and HARM weapon systems encountered more design instability and attendant problems than did the F-16 or the ALCM. Generally, this design immaturity existed because the weapon systems were pushing "state-of-the-art" technological limits from the outset which created more technical unknowns to be solved than in a program like the F-16, where more conventional technologies were involved. The Black Hawk's problems stemmed more from a nearly exclusive emphasis on technical performance and a major redesign which occurred in production, than from a high technology design. Requirements changes can also create design difficulties and were particularly troublesome where high technologies were involved. In general, where achieving performance requirements represented a difficult technical challenge or where problems were encountered in trying to meet performance goals, less emphasis during development was placed on preparing for production.

These trade-offs derive largely from the competing demands for limited research and development funds. When funding is cut or, more likely, when development problems drive up costs, there is a tendency to cut back on production preparations. Whether this is imprudent or unavoidable is not at issue in this report; rather when such efforts are reduced or pushed out of the development phase, more expensive production problems often result.

A critical factor in the F-16 and ALCM programs was that each had unusual circumstances which contributed greatly to program stability and balancing technical and production concerns. In addition to its low cost design, five nations were participants in the F-16 program, making it less prone to funding cuts and design changes. The ALCM program's stability derived in large part from the fact that it became the top defense priority when the B-1 bomber was first cancelled in the 1970's.

Design instability can degrade production readiness

In the six weapons programs reviewed, production preparations suffered or were made more difficult when

--the design represented a significant technical advancement;

--the design, evidenced by significant technical problems, required numerous changes; and

--performance requirements changed, particularly late in development.

The F-16 had an unusually low risk stable design with a pronounced emphasis on low cost. These characteristics of the program contributed greatly to the program's substantial production preparations in two ways. First, the concern over controlling the aircraft's costs helped to elevate the importance of production preparations in the development phase. This could be seen in the prominence given to producibility in conceiving the aircraft's design. Also, production preparations were critical to controlling the production costs and thus essential to the program's success. Second, the subsequent stability of the design provided a sound basis for production preparations which enabled them to build continuously, consistent with DOD policies.

From the outset, the goal of the F-16 program was to field a low cost fighter to complement the F-15, rather than a next generation fighter, which would exceed the F-15's performance. In fact, DOD believed that cost control was key to the aircraft's success and in awarding the competitive development contracts in 1972, stated that it favored cost containment over technology advances. As such, the F-16 had no preset performance requirements to reach. This design flexibility allowed for key tradeoffs between performance and cost which kept design risk low and paid great production dividends.

Several examples illustrate this. The existing F-15 engine was used, avoiding what is normally a major part of an aircraft's development. By designing the aircraft not to fly above the speed of Mach 2, high stresses and temperatures were avoided, which enabled 80 percent of the aircraft's metal parts to be made from aluminum rather than more costly hardened steel and titanium. Finally, the flight speed decision enabled the use of a fixed-geometry engine inlet, rather than a sophisticated variable-geometry inlet needed above Mach 2. This design enabled General Dynamics to produce an aircraft using, for the most part, conventional manufacturing methods which the contractor already possessed. The design did not outstrip existing production capabilities.

The F-16 did include advanced technologies, such as fly-by-wire flight controls and a blended wing/body aerodynamic design. General Dynamics proved these out in the advanced development phase so that they represented relatively mature technologies in full-scale development. This approach to new technology kept design risks to a minimum.

Once conceived, the F-16's design enjoyed a great deal of stability owing largely to the low risk design. Another reason why design changes were minimal was the fact that four European countries had decided to purchase the aircraft and participate in its production. All five (including the United States) agreed on a not-to-exceed price per aircraft, which served as an incentive to minimize design changes and to control costs.

The Tomahawk and the ALCM provide an interesting contrast in design stability and sophistication. Although not free of problems, the ALCM design was stable enough for the program to proceed into 2 years of pilot production and into high rate production without being disrupted by flight test failures. Flight test failures plagued the Tomahawk missile throughout full-scale development and continued into production. As a result, the planned 2-year pilot production line was not established so that more funding could be made available for redesigning efforts and building additional test missiles. Technical problems continued into production as numerous flight test failures occurred between mid-1978 and late 1981 which were serious enough to warrant temporary restrictions from additional flights until the problems were resolved.

The fact that several Tomahawk missile variants were being developed simultaneously was a major contributor to the Tomahawk's technical and quality problems and the weakened production preparations. Having to develop, test, and prepare the several missiles for production was a greater managerial challenge than that posed by the single ALCM version. In addition, the Tomahawk airframe had to fit in a torpedo tube and withstand high water pressures, which complicated its design and necessitated the use of forgings rather than castings. The design was further complicated by the first stage rocket booster, which was not required in the ALCM.

The HARM's sophisticated design, together with changing performance requirements, detracted from the missile's ability to enter production smoothly. The microwave circuit boards in the HARM seeker were pushing the state of the art and were completely new to the electronics industry when Texas Instruments won the advanced development contract in 1974. In January 1977, the Defense Systems Acquisition Review Council decided to double the missile's frequency coverage and increase its maneuverability against an updated threat. This required a complete redesign of the seeker, substantially increasing its complexity, particularly in the microwave circuitry and radio frequency receivers. Changes were also necessary in the missile's actuator. Even after this major redirection, the HARM's design continued to be unstable as several more redesigns occurred during pilot production. According to Texas Instruments officials, a major contributor to delays during pilot and low rate production was instability in the software, which controls the missile in flight.

The Copperhead represented a similar technological challenge whose attainment eventually led to a deemphasis on preparing for production. Unlike the F-16's performance requirements, the Copperhead's performance requirements were largely nonnegotiable --the sophisticated electronics and optics in the laser seeker had to survive the tremendous pressures of cannon launching. These stresses reached nearly 9,000 times the force of gravity, in contrast with missiles which experience well below 100 times the force of gravity during launch. Through its development, the Copperhead was plagued with reliability problems. These persisted and eventually caused one-third of the 144 test projectiles to fail. Many of these involved a plastic gyro, which had to be changed to titanium. These problems were compounded by cost growth due to technical problems and funding delays, which reduced the number of development projectiles, and by schedules which were compressed to preserve the fielding date.

After operational and special reliability tests yielded only 50-percent reliability, the Secretary of Defense limited the Copperhead's production rate to 200 per month (compared to a planned high rate of 700 per month) until reliability reached 80 percent. According to program officials, technical pressures associated with the projectile's sophistication and test problems, combined with the fact that program success depended on the projectile's technical performance, drew attention away from longer term production concerns. This was aggravated by the development cost growth discussed in the previous paragraph and the inability to obtain timely producibility engineering and planning funding in 1976.

As with the Copperhead and the HARM, technical performance dominated over production considerations during the Black Hawk's development phase. The competitive environment fostered by the Army during the Black Hawk's development and early production stressed performance and a shorter acquisition cycle, without a similar emphasis on production preparation. The competition between Boeing Vertol and Sikorsky for the multi-billion-dollar production phase was intense. The Army prepared well-defined technical performance specifications, and success in achieving them, in conjunction with production proposals, was to determine the winner of the competition. Evidenced by the small amount of funding the Army allotted for production planning, production capabilities were not a major factor in the competition. Sikorsky responded in kind to this environment by emphasizing research, development, and marketing, because these disciplines were more critical to winning the competition for the production contract than a production discipline. As a result, Sikorsky was not prepared for production when the Army awarded it the production contract. This contrasts with the ALCM competition where demonstration of production capabilities was conceived from the outset as an integral part of the development effort and figured prominently in selecting a contractor for production. In each case, the Black Hawk and ALCM contractors were responding to the demands placed on them through the competition conceived by the services. However, the ALCM competition created incentives for production preparations, where the Black Hawk competition did not.

The weaknesses in the Black Hawk's production preparations were compounded when Sikorsky redesigned the aircraft in production to save weight, among other reasons, making the aircraft more difficult to produce. In signing the production contract, Sikorsky agreed to reduce aircraft weight by nearly 300 pounds to meet the weight specification. In addition, the Army included a lucrative weight reduction clause that according to an Army cost study, could net Sikorsky $744 per pound of weight reduction per aircraft below the specification. As a result, the contractor redesigned the aircraft and reduced its weight nearly 750 pounds mainly by substituting titanium for steel and composites for fiberglass and aluminum. Examples include changing the sheet metal nose canopy and the aluminum cockpit frame to composites and the aluminum cargo door stiffeners and backing to kevlar. While lighter in weight, these materials were more difficult to produce because Sikorsky had little capability and experience to produce them. Developing the necessary production capabilities through facilities, tooling, and training caused production problems, and the redesign efforts put production behind schedule.

Sikorsky maintains that weight reduction was only one of several reasons for the redesign, including producibility, design improvements, and reliability and maintainability improvements. According to Sikorsky, the fixed ceiling prices on the early production contract motivated a "cost-effective productionization of the design." Further, the contractor stated that it did not realize a financial benefit from the weight reduction incentives in the first 3 program years.

FLUCTUATING QUANTITIES AND PRODUCTION RATES MAKE PREPARING FOR PRODUCTION DIFFICULT

Fluctuations in total quantities, peak production rates, and the buildup to those rates complicated production preparations in the Copperhead, the Tomahawk, and the HARM programs. These fluctuations made it difficult to accurately size the production facilities and select the most efficient production equipment. The F-16 and ALCM programs enjoyed greater stability which facilitated their production preparations, in that facility and tooling plans could be developed around reasonably stable production rates and total quantities. It is not unusual for weapon systems that experience technical problems and cost increases in development to encounter fluctuations in total quantities and production rates. Often, decisions to cut quantities or to slow production rates are predicated upon valid concerns over technical performance. Nonetheless, such decisions make sound production preparations difficult because the types of production equipment and sizing of facilities, as well as their scheduled phase-ins, depend largely on total quantities, peak rates, and the buildup to those rates.

Copperhead production quantities have dropped drastically since it entered full-scale development, to keep the total program affordable as unit costs increased. Initially, a production total of 132,650 projectiles was planned, which dropped to 110,236, 44,386, and 9,910 in 1977, 1980, and 1983, respectively, and eventually rose back up to 30,812. The quantity reductions alone caused procurement unit cost increases, as fixed costs, such as tooling and facilities, had to be spread over fewer units. Planned peak production rates have dropped along with the quantities. Although 700 units per month had been planned throughout most of the development phase, the Secretary of Defense initially limited the production rate to 200 per month because the projectile did not meet its reliability requirements. The monthly rate did not exceed 233 through the end of 1984.

Some sophisticated Copperhead tooling designed for the planned 700 per month rate has proven to be uneconomical for the actual rate of 200 to 300 per month. This was particularly true for the special purpose machines, which had difficulty making quality components in early production, as discussed on page 10. For example, the two four-spindle five-axis machines Chandler Evans purchased to produce the control actuator base were designed for 735 units a month and are not efficient for the current low rates. If the lower rates had been planned initially, the contractor likely would have opted to use a series of less sophisticated single-spindle machines, perhaps avoiding many start-up problems, as well as efficiently matching tooling capabilities with production rates.

The Tomahawk has experienced similar fluctuations in total and initial procurement quantities. The Tomahawk has lacked a stable quantity baseline both in total quantities and in the mixture of variants. The following table shows the wide variation in total planned production quantities as projected from each of five consecutive fiscal years.

Tomahawk Procurement Quantity Changes

Year	Land attack	Antiship	Total
1978	580	502	1,082
1979	-	251	251
1980	196	243	439
1981	443	201	644
1982	3,401	593	3,994

Perhaps most significant from a production standpoint is the increase in total planned production from 644 to 3,994 missiles. This occurred in 1982, after production preparations, such as tooling and sizing decisions, had been made and even after production had already begun.

In addition, funding cuts by both DOD and the Congress, aggravated by production cost increases, reduced annual production quantities from 88, 120, and 312 missiles in fiscal years 1982, 1983, and 1984 to 61, 51, and 124 missiles, respectively.

General Dynamics officials informed us that because of the uncertainty surrounding what production quantities and rates would be funded, they were reluctant to take steps to streamline production facilities and improve the efficiency of production operations earlier in the Tomahawk program. Inefficiencies in the Tomahawk's facilities early in production were discussed on pages 12 and 13.

The HARM program has also encountered some instability. Total production quantities as reported in fiscal years 1979, 1980, 1981, and 1982 were 6,467, 6,173, 7,057, and 7,955 missiles, respectively. Although the HARM was to begin production in fiscal year 1980 with 80 missiles, the Congress deleted funds for these missiles on the basis of technical problems disclosed during testing. The Congress did provide funds for initial production in fiscal year 1981, which amounted to a 1-year production delay.

The F-16's peak production rate remained stable at 15 aircraft per month until fiscal year 1982, when the rate was dropped to 10 per month anticipating phasing into production an improved version of the F-16. Similarly, total quantities were stable with a minimum buy initially set at 650 aircraft. This was increased once, in December 1976, to 1,388 aircraft, and it remained at that level throughout the F-16's transition to production. At the beginning of full-scale development in 1977, ALCM production quantities were set at 3,418 missiles as was a peak production rate of 40 missiles per month to be reached by October 1982. This quantity and rate baseline remained relatively stable until the program achieved the full 40 per month production rate. After that point, quantities were reduced significantly due to the ALCM being out of synchronization with the B-52 modification program and to the introduction of an improved cruise missile.

Quantity stability is only one variable affecting the transition to production. This is underscored by the start-up problems encountered by the Black Hawk despite a baseline of 1,107 helicopters, which never changed. This was not enough to overcome the effects of the minimal production preparations and the redesign (discussed on pp. 34 and 35 and pp. 57 to 59).

PROGRAM MANAGEMENT AND STAFF MUST BE PRODUCTION ORIENTED

Production-oriented program management and adequate production staffing during development by both the services and the contractors are critical to smoothing the transition from development to production. In programs where managers devoted more production staff and resources early in development, production preparations were solid and problems were overcome without disrupting the program. In programs such as the Black Hawk and the Tomahawk, where such a production orientation did not exist in development, production planning and demonstration efforts were minimal or had poor prospects for success. Generally speaking, weaknesses in production staffing and management attention occurred where technical concerns dominated development.

In the Black Hawk program, Sikorsky's management emphasized research and marketing skills during development, because these were most important to winning the production award. A production orientation was not a priority for the competition, and Sikorsky's management reflected this. Also, during the development phase and carrying over into production, Sikorsky experienced numerous turnovers in production management. Upper management in the company during that time had more experience in fixed-wing aircraft than in helicopters. It was not until 1980, after production problems were evident, that a new company president was able to bring in management experienced in helicopters and establish a production orientation.

Staffing in the Army program office also reflected the emphasis on technical performance. During the Black Hawk's transition to production, the program office had no formal production staff and had only one industrial engineer to handle all production responsibilities. The small amount of staff resources the program office devoted to production at that time left the office with inadequate production planning expertise, according to a program office production representative.

Representatives from the Army's Copperhead project office noted that the project office had few engineers with production background, and those which did had little impact because of the emphasis placed on design engineers to get the projectile to work. Martin Marietta program officials also believe they had an insufficient number of production engineers. At the height of development, the contractor had 150 design engineers and 15 production engineers, or a ratio of 10 to 1. The contractor in retrospect believes that a ratio of 3 to 1 would have been more appropriate. Chandler Evans also cited a lack of production engineers as a contributor to its production problems. During development, this subcontractor had six engineers on the program, none of whom were production engineers. This imbalance limited the exchange of information between design and production disciplines in development, a factor both contractors believe is critical to making an item producible.

Comparing the ALCM and Tomahawk programs illuminates the role played by management orientation and staffing in preparing a weapon for production. The DOD joint cruise missile program office had a dedicated production team which was responsible for both the ALCM and the Tomahawk. The team, which originated with the ALCM program before the 1977 merger, had continuity, well-defined production objectives, and a strong voice in the program as evidenced by the production capabilities specified in development contracts, the incremental production readiness review process, and the importance of production capabilities in source selection. The team also hired consultants with years of production experience to help plan and conduct production readiness reviews. Yet, the ALCM had a relatively smooth transition to production while the Tomahawk encountered problems. Part of the explanation for this experience lies in the Tomahawk's having several variants and the program's design instability. However, another major factor was the production orientation and commitment of the ALCM contractor's (Boeing's) staff and the lack of a production discipline at General Dynamics during the Tomahawk's development.

Boeing's program management showed an appreciation for production during the development phase, which was reinforced by the aggressiveness of the joint Navy/Air Force production team. Boeing's production orientation was demonstrated by its committing itself to build a production facility dedicated to the ALCM, building development missiles with the large-scale castings to be used in production, and its strong and aggressive subcontract management. For example, when Wellman Dynamics (second source for the body castings) fell behind in deliveries, Boeing decided to increase Alcoa's production rate to help maintain production schedules. Boeing sent a multidisciplinary team to Alcoa and developed a plan with Alcoa to increase the production rate. The fact that Boeing had two sources for the large-scale castings was critical to Boeing's being able to maintain production even when one source had problems. Air Force program officials noted that a cooperative spirit existed between the service and the contractor, which led to quick resolution of problems.

During development and production of the Tomahawk, the contractor consistently experienced quality control problems. Although the government issued numerous formal requests for corrective action, General Dynamics did not respond to DOD's satisfaction. At one point, production was nearly terminated because the contractor had not yet taken actions to improve quality control. DOD assessments of General Dynamics' problems cited an overall lack of production discipline in management, as well as on the production floor. It was not until General Dynamics reorganized the program staff; brought in a new program manager with production experience; brought in a team of specialists; and improved communication between design engineers, production engineers, and assembly workers that corrective actions began to be taken. General Dynamics officials also noted that accountability for the production preparations for complete missiles was dispersed, as several contractors shared the responsibility rather than one having clear-cut control. An external study in 1982 of the program found that the DOD program office's technical staff was small in comparison with the technical demands of the several missile variants.

Experiences with the cruise missile engine and radar altimeter demonstrated how a production-oriented management and staff can overcome potential production problems. During advanced development, the joint cruise missile project office recognized that the engine was the missile's highest risk subsystem and was concerned that Williams International did not have the capabilities to reach desired production rates. Due to the responsiveness and commitment of Williams' top management to the program's requirements and its willingness to work with the program office in reducing risks, Williams expanded its facilities in development and educated a second contractor to produce engines. Williams officials also point to the close interaction between their design and production engineers as a key factor in achieving production readiness.

In the case of the radar altimeter, Honeywell and Kollsman each developed advanced designs which turned out to be too complex to produce within cost and schedule thresholds. Honeywell's production engineers worked along with its design engineers, and although not initially evident from the drawings, they were able to recognize the difficulty of producing the altimeter as soon as the first development prototypes were fabricated. This recognition, coupled with Honeywell's engineering strength, enabled the altimeter to be redesigned and made producible before production. Kollsman, on the other hand, did not have the depth in design and production engineering to make its design producible.

In the F-16 program, General Dynamics established a production planning team in advanced development, whose director became the head of F-16 production. In addition to running strong efforts in production planning, design-to-cost, and modernizing facilities, General Dynamics aggressively managed its subcontractors. As Boeing did with the ALCM, General Dynamics worked closely with the Air Force program office in recognizing and resolving problems at subcontractor locations. The Air Force program office also hired experts in aircraft production to help plan and conduct production readiness reviews.

THE DEVELOPMENT ENVIRONMENT FOR COMMERCIAL ITEMS FAVORS PRODUCTION PREPARATIONS

The development environment for new programs at the Ford Motor Company and the Boeing Commercial Airplane Company is in general more conducive to production preparations than in most weapon programs. In these two firms, programs enjoy balanced treatment of technical and production requirements, as well as a strong production orientation on the part of program management and staff. The lower technical risks involved in commercial programs and resultant design stability, as well as the broad base of production talent from which these two firms can draw staff and knowledge for new programs, contribute to this environment. In addition, the commercial market itself creates incentives for production preparations which are not necessarily present in weapon programs.

Because success in selling commercial products for a profit depends on the ability to produce within cost, the need to produce within cost establishes producibility as equal to other design considerations, such as technical performance. The price of these commercial products is as important to their success in the market as the features they offer. This cost discipline in turn holds other design considerations in check and fosters greater design stability. For example, in both Ford and Boeing, when a design change is considered, its longer term production and cost implications are weighed simultaneously and an informed trade-off is made.

Both Ford and Boeing try to keep program managers and staff responsible for new products together until after production begins, because in the commercial sector a program's success is not determined until production. In recent years, both firms believe they have made great progress in overcoming the dominance of design engineers over production engineers by making both disciplines equal in organizational structures and making both responsible for product designs. The design is not considered complete unless it has included all relevant disciplines and has been agreed to by both design and production groups. In Boeing, even program schedules cannot be approved unless all affected disciplines (including cost and sales) have input to the schedules and agree to them. This in turn produces commitment to the schedules.

Observations

It would be impractical for DOD to attempt to mirror the commercial development environment in its weapon programs in all aspects. Technical risks are normally greater in weapon programs, and design changes are often unavoidable, particularly when new threat information dictates the need for such changes. However, the environment for production preparations in commercial programs can help define an upper bound on what the most favorable conditions are. In this manner, commercial practices can help illuminate potential areas of production risk in weapon programs. Perhaps most important is the recognition that the demands of the market provide incentives for preparing commercial items for production which are not necessarily present in weapon programs. DOD can create and control such incentives in weapon system development programs when establishing performance requirements, structuring an approach for a weapon's development which includes the competition among contractors, and in weighing production concerns in subsequent program decisions. DOD's role in these areas and the resultant effects on production preparations were demonstrated earlier in this chapter, particularly in the F-16, ALCM, and Black Hawk programs.

CHAPTER 5

DOD POLICIES OFFER PROMISE

FOR BETTER PREPARING WEAPONS FOR PRODUCTION

The difficulties of getting weapons into production have commanded increasing attention in DOD, and DOD has taken several actions which hold the promise of better preparing weapons for production. Two directives issued by the Secretary of Defense in January 1984 are perhaps the most significant. Together, they call for the balanced treatment of production preparations with other technical demands, reinforced at milestone decisions, and embrace the Army's concept of producibility engineering and planning on a DOD-wide basis. These initiatives provide DOD policy guidance aimed at many of the systemic causes of production problems and if successfully implemented, should contribute substantially to ameliorating these problems in the future. The two directives are discussed in more detail below.

Directive 4245.6, entitled "Defense Production Management," a revision of an earlier directive, clearly states

> "It is DOD policy to plan for production early in the acquisition process and to integrate acquisition actions to ensure an orderly transition from development to cost-effective rate production."

Directive 4245.7, entitled "Transition From Development to Production," describes preparing for production as a technical discipline which must receive balanced treatment in development with other technical disciplines, such as performance and supportability. These directives appear in appendixes IX and X in the report.

Together these two directives call for the following actions for weapon acquisitions:

--developing a manufacturing strategy as part of the acquisition strategy and addressing manufacturing voids and producibility of concepts during concept demonstration and validation;

--making a comprehensive producibility engineering and planning program a requisite for full-scale development, containing specific tasks, measurable goals, and a system of contractor accountability;

--assessing production management and production status at each major milestone decision;

--adequately funding producibility engineering and planning, manufacturing technology, and facilities;

--employing pilot production lines, when necessary, to validate production readiness, manufacturing operations, and cost;

--conducting production readiness reviews in support of limited-production and full-production decisions;

--integrating factors affecting producibility and supportability during full-scale development and structuring the design and test cycle to provide a continuum in development, production, and operational support; and

--ensuring that an adequate number of technically qualified and competent people are committed to the program, while taking specific measures to train production personnel, including a defined career progression and extended assignments.

Other actions taken by DOD are discussed in appendix III.

These DOD directives provide sound guidance on when and how production preparations should be carried out in weapon systems. According to DOD officials, this guidance will provide the foundation for specific actions by DOD and the services to improve production preparations on a program-by-program basis.

CHAPTER 6

CONCLUSIONS, RECOMMENDATIONS,

AGENCY AND CONTRACTOR COMMENTS,

AND OUR EVALUATION

CONCLUSIONS

Our review of six weapon systems has shown that early production problems are largely the consequences of development actions and decisions. Production preparations in the four weapons which encountered production difficulties were not as thorough and timely as those in the two programs which had smooth transitions to production. Upon closer examination, technical pressures, insufficient resources, and other conditions of these four weapons' development phases in large part caused the inadequate production preparations.

Avoiding serious production problems on future programs will require aggressive employment of production preparations, which should begin before full-scale development. Such efforts should build continuously from producibility studies to gradual demonstrations of production capabilities during development. Production preparations, if they are to be successful, should be carefully timed to coincide with other development phase activities so that when critical development trade-offs must be considered, such as those regarding resource allocations, better informed choices can be made. Carrying out production preparations in this manner will require that they be put on a more equitable footing with technical performance considerations and be treated as an integral part of a weapon system development program. Adequate and timely preparations will require resources in the form of people, time, and money, which will be expensive to provide in development.

DOD directives support such an approach to production preparations. The two DOD directives published in January 1984 represent important contributions toward elevating the importance of production preparations in the development phase. These directives, if successfully implemented, should improve the production preparations in future programs and put them on a more equal footing with technical performance considerations. These directives should contribute substantially to ameliorating production problems in the future.

Overcoming transition-to-production problems and the cost growth and schedule slippage they cause will be a long-term challenge and will require sustained top level attention. Thus, the success of the DOD initiatives will also depend heavily on the support of DOD to fully fund timely and sustained production preparations in weapon programs and to determine a weapon's readiness for the production phase on the basis of demonstrated production capabilities.

We believe specific actions should be taken by DOD and the services on a program-by-program basis to help implement DOD's revised policies more uniformly on future weapon systems.

In the programs reviewed, the degree to which balanced treatment could be given to technical concerns and production concerns was directly affected by the technical requirements of the weapons; how competition between contractors was structured during development; and the weight given to production concerns at subsequent program decisions. To maintain balance between technical concerns and production concerns in future weapon developments, DOD should pay particular attention to these elements which can stimulate or stifle the effectiveness and extent of production preparations.

For example, the fact that demonstrated production capabilities were an important element in the ALCM's development competition and source selection stimulated a strong production planning and demonstration effort. In contrast, the strong emphasis on technical performance in the Black Hawk competition and source selection led to a deemphasis on production preparations in that program. Experience on the F-16 and Copperhead programs also underscored the effect technical requirements can have on giving balanced treatment to production preparations.

During the course of development, several factors--in particular the design instabilities arising from a high technology design, changes in technical requirements, and quantity and funding fluctuations--can hamper production preparations. In the HARM program, a very sophisticated initial design, coupled with a major increase in performance requirements, contributed to production planning being done late in development. Technical difficulties in the Tomahawk program resulted in less demonstration of production capabilities before the production decision than planned. The redesign of the Black Hawk in production rendered much of its production preparations up to that point obsolete. In addition, funding and quantity changes affected tooling and facility decisions in the Copperhead and Tomahawk programs.

When the introduction of such factors is being contemplated in future programs, their effect on production preparations should be recognized and the production risks they carry explicitly assessed to enable better informed decisions to be made. Where development conditions which preclude adequately funded or properly timed production preparations are found to be necessary, such as when an urgent need necessitates a performance requirement change or the use of highly advanced technology, actions should be taken to compensate for the attendant production risks. These could include instituting a pilot production phase; building more slack into production schedules to allow for problems; or having a two-staged production decision, both before entering production and again before going to a high rate. In any event, it is unrealistic to do little production preparation in development and to proceed to an ambitious production buildup without expecting major problems.

Although DOD instructions call for production readiness reviews to be conducted as time-phased efforts which span full-scale development, we found in the six weapons reviewed that they were not always conducted in this manner. In the ALCM and F-16 programs, production readiness reviews were conducted in intervals during development which facilitated the conduct of production preparations and thus became a positive tool for program managers. This proved a much more effective approach than conducting the reviews late in development, where they were of limited benefit to program managers. In future programs, DOD should ensure that production readiness reviews are employed as a tool for managing production preparations and that they are begun early and conducted regularly during development.

Finally, since production preparations generate critical production information for decisionmakers, such as labor hours, scrap and rework levels, and line layouts, more was known about their potential effect on the production of the F-16 and ALCM at the time of their production decisions than their possible effect on production of the other four weapon programs. DOD should explore ways to improve the quality of production information provided to decisionmakers, as well as a means to determine the quality of the information. One possibility would be enunciating key production assumptions, such as estimated labor hours, early in development and measuring demonstrated production capabilities against these. This would parallel the approach used for performance requirements, whereby specific values are stated early in development and progress in achieving those values is assessed on the basis of test results. Given their criticality to making good cost estimates, some steps need to be taken to elevate the importance of key production assumptions during development.

RECOMMENDATIONS

On the basis of the six weapons we reviewed, we recommend that the Secretary of Defense take the following actions to help implement the new directives and improve production preparations in future programs:

--When establishing those elements of a new weapon system development program which directly affect the balance between technical concerns and production concerns, such as technical performance requirements and the terms of competition, ensure that at the same time provisions are made to induce an adequate level of production preparations, to be conducted early and continuously throughout the weapon's development.

--Ensure that when contemplating decisions which have known production risks in weapon programs, such as those regarding requirements changes and funding reductions, decisionmakers explicitly assess those risks before making decisions. Where decisions of this type are necessary, take such compensating actions as are practical to lessen their effects on production. These actions could include instituting a pilot production phase; building more slack into production schedules to allow for problems; or having a two-staged production decision, both before entering production and again before going to a high rate.

--Employ production readiness reviews as a tool for managing production preparations to progressively reduce production risks, beginning early and repeating them at intervals during full-scale development.

DOD AND CONTRACTOR COMMENTS AND OUR EVALUATION

DOD concurred in our findings and recommendations. Its overall comments are included in appendix IV.

DOD believes the production initiatives described in the January 1984 directives (discussed in chapter 5) are important and have received wide dissemination and emphasis through incorporation in the Defense Acquisition Improvement Program, implementation of the President's Private Sector Survey on Cost Control recommendations, and inclusion in the defense guidance on preparation of the annual defense budget. DOD officials believe they have made progress since the directives were issued. For example, two services have already issued regulations to implement the directives, and DOD is readying for publication a detailed manual on reducing transition-to-production risks. DOD has also instructed its Production Engineering Services Office to get involved earlier in future programs.

In discussing our draft report and DOD's comments, DOD officials told us that they realize that the task of implementing the production initiatives through specific actions on future weapon systems, program-by-program, remains ahead. Our recommendations are aimed at such actions, to help implement the policies called for by DOD's directives and instructions.

DOD recommended that its two new directives, "Defense Production Management" (4245.6) and "Transition From Development to Production" (4245.7), be included verbatim in our report. We agreed and included them as appendixes IX and X.

Besides discussing its initiatives, DOD pointed out that systems experiencing a degree of concurrency in development and production had more opportunity for producibility matters to be attended to early in development than systems with gaps in the delivery of test and production items. DOD suggested that since concurrency in weapon system acquisitions is often considered undesirable, its positive influence in some of our case studies be illustrated. We did find that initiating production preparations early and conducting them concurrently with other development activities enables more informed production decisions to be made and is consistent with DOD requirements for production preparations. We have amplified this point in the report. However, this is not an endorsement of starting production before development units have been sufficiently and successfully tested.

DOD also suggested some factual changes be made in the report in the interest of accuracy, and we have incorporated these, as appropriate.

Five of six prime contractors commented on this report. They generally agreed with the report's overall conclusions and recommendations. Each contractor recommended changes to the discussions pertaining to its respective weapon system, and these have been incorporated, as appropriate. Their overall comments appear in appendixes V, VI, VII, and VIII. General Dynamics' Convair Division did not provide overall comments in writing, but as noted above, its detailed comments have been incorporated. Martin Marietta did not provide any comments on this report.

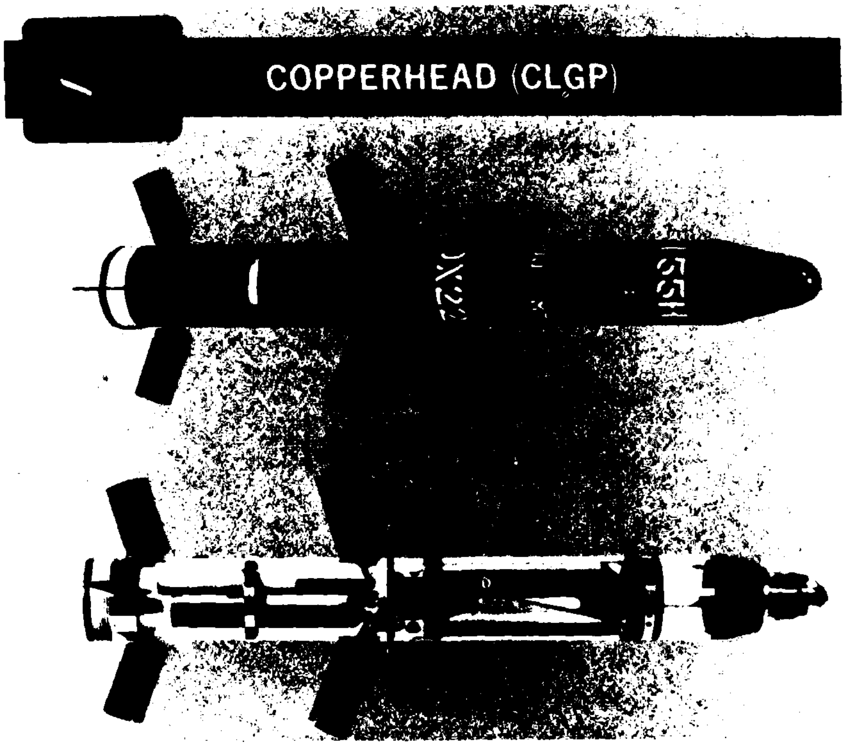
THE SIX WEAPON SYSTEMS REVIEWED

Following are brief descriptions of the six weapon systems reviewed.

COPPERHEAD PROJECTILE

The Copperhead, which has been in production since late 1979, is a laser-guided projectile which is fired from a 155-mm. howitzer.

Copperhead Projectile



Source U.S. Army

It was developed to provide a high probability of neutralizing or destroying moving or stationary targets, such as tanks. The projectile's laser seeker homes in on the energy reflected by focusing a laser beam on a target. The 138-pound 54-inch projectile includes 1,250 parts which must survive the tremendous forces of cannon launch as the acceleration causes the projectile weight to increase nearly 9,000 times. The stresses on the projectile's components require close tolerances for manufacturing and assembling the projectile, and this increases the potential for production difficulties. The projectile is composed of

--the guidance section, which includes optical components, a gyroscope assembly, and an electronics assembly;

--the payload section, which includes a warhead and fuze assembly; and

--the stabilization and control section containing, among other things, a control actuator assembly, which operates the projectile's wings and fins. This assembly includes a battery for electrical power, a gas bottle for control actuation, and actuator electronics.

Martin Marietta Aerospace, the prime contractor for the Copperhead, produces the guidance section and assembles the projectile. The Chandler Evans Company produces the control actuator.

BLACK HAWK HELICOPTER

The Black Hawk utility helicopter is designed to meet the requirements which grew out of the Army's experience with the UH-1 Huey in Viet Nam. It is being acquired to complement and eventually replace the UH-1.

Black Hawk Helicopter

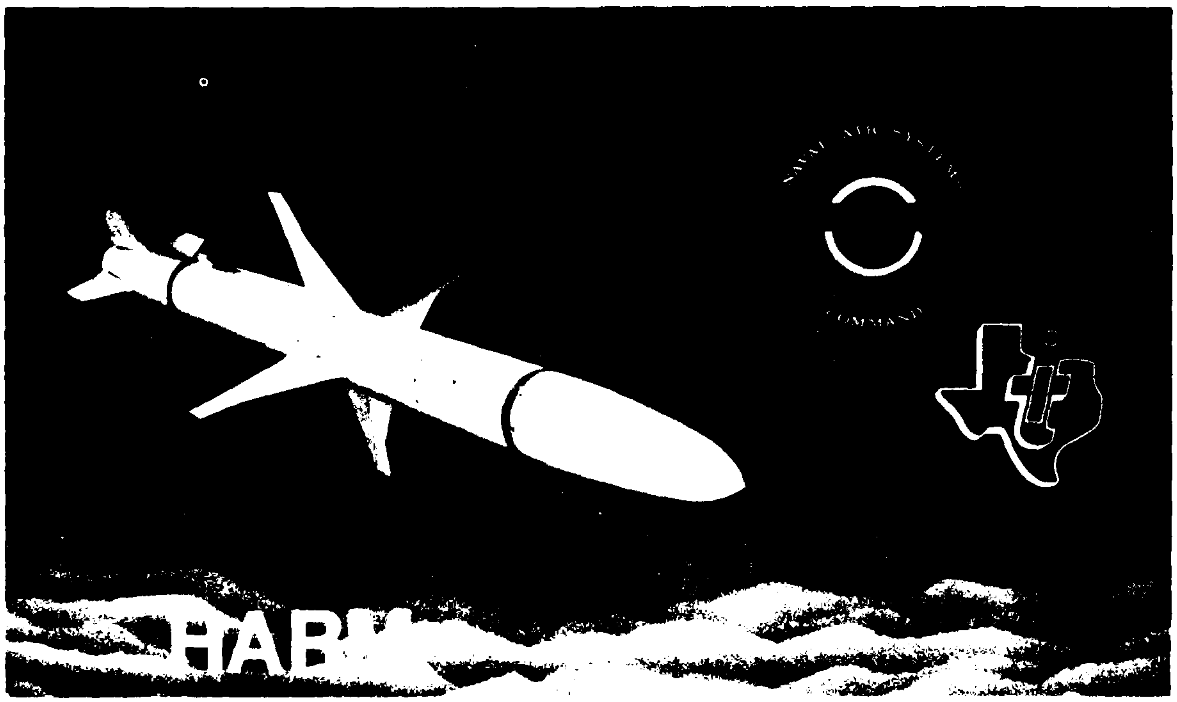
Source U S Army

The twin engine Black Hawk is used in the Army's air assault, air cavalry, and aeromedical evacuation missions. It was designed to be the Army's first true squad assault helicopter to transport troops and equipment into combat; resupply the troops while in combat; and perform the associated functions of aeromedical evacuation, repositioning of resources, and command and control. The basic UH-60A Black Hawk has been in production since December 1976 and has spawned several variants, including the Army Quick Fix (EH-60A), the Navy Sea Hawk (SH-60B), and the Air Force Night Hawk (HH-60D). Sikorsky Aircraft is the airframe prime contractor, and General Electric is the engine prime contractor.

HIGH SPEED ANTI-RADIATION MISSILE

The HARM is a Navy/Air Force program with the Navy as the lead service. It has been in limited production since February 1981.

High Speed Anti-Radiation Missile (HARM)



Source: Texas Instruments Corp.

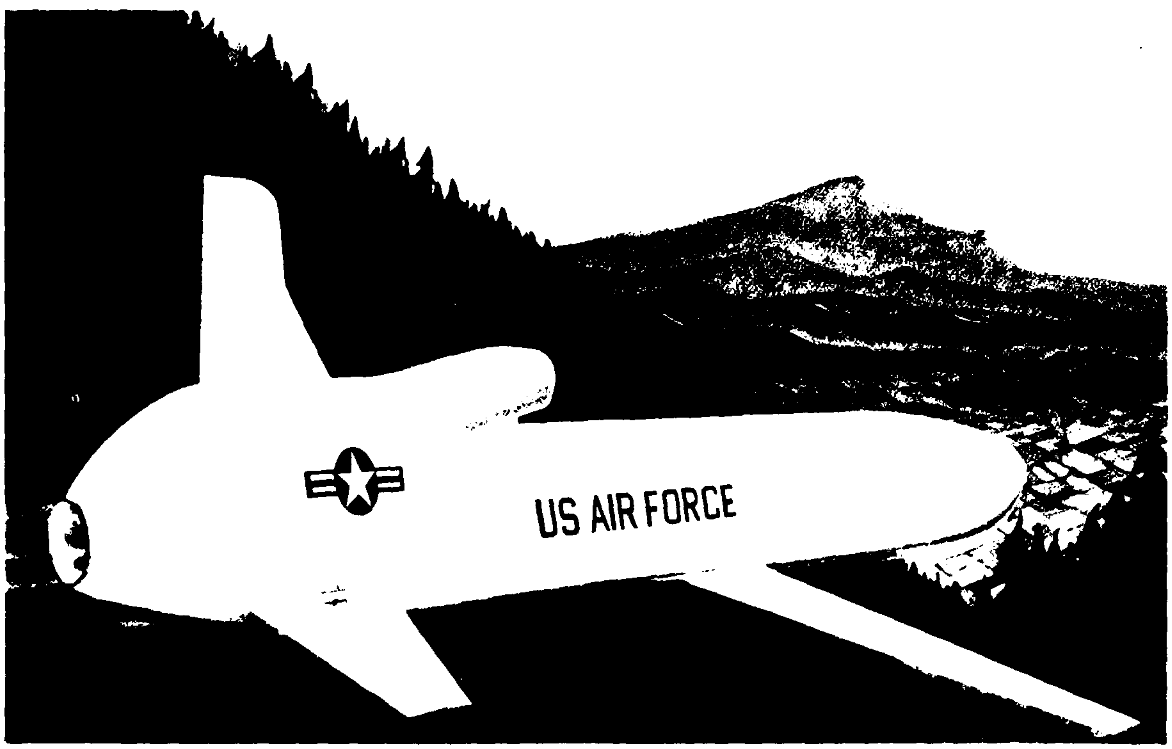
The missile is a defense suppression weapon capable of destroying or rendering inoperative elements of an enemy air defense radar network. The HARM is intended to be an improvement over the existing Shrike and Standard antiradiation missiles. The improvement will allow HARM to counter current threats and most of those expected throughout the 1980's. The HARM avionics, in conjunction with the radar warning equipment aboard the aircraft, is designed to detect, identify, and locate enemy radars and pass target information to the missile. The missile is intended to handle a broad range of radar frequencies. Initial deployment of the HARM will be with the Navy A-7E and Air Force F-4G aircraft.

The missile is composed of a guidance section, a warhead, a rocket motor, and a control section. Texas Instruments, the prime contractor, produces the sophisticated guidance section and assembles the complete missile.

AIR-LAUNCHED AND TOMAHAWK CRUISE MISSILES

The Air Force's ALCM and the Navy's Tomahawk missile are essentially small pilotless vehicles that, when launched, fly subsonic low-altitude paths to their targets, guided by preplanned routes stored in on-board computers. Each missile consists of a fuselage, foldable wings, tail empennage, a small turbofan engine, and a guidance and control unit. While the ALCM is launched from a B-52 aircraft, the Tomahawk can be launched from a torpedo tube or from surface launchers mounted on ship decks and land. Hence, the Tomahawk also has a rocket motor for initial launch before converting to cruise flight, which the ALCM does not need.

Air-Launched Cruise Missile



Source U S Air Force

Tomahawk Cruise Missile

Source: U.S. Navy

The ALCM has only one version, which delivers a nuclear device. The Tomahawk, on the other hand, has four variants, including a nuclear land attack variant and three variants with conventional warheads--one for land targets, one for enemy ships, and one ground-launched variant for land targets.

The ALCM and Tomahawk programs are closely related. Each had separate beginnings in the late 1960's and early 1970's and, in 1977, both programs were brought under a Navy/Air Force cruise missile project office for full-scale development. In addition, competition for the air-launched mission was established between a modified version of the Tomahawk built by General Dynamics (Convair Division) and the ALCM built by Boeing. Boeing won the ALCM competition, and in 1980, the ALCM air vehicle reverted to Air Force program management. General Dynamics developed and produces the Tomahawk. Both cruise missiles share variants of the same engine built by Williams International and the radar altimeter built by Honeywell. These major subsystems, as well as all guidance and control sections, are still managed by the joint project office. Both the ALCM and Tomahawk entered production in 1980.

F-16 AIRCRAFT

The F-16 is a lightweight single-engine highly maneuverable fighter aircraft being produced for the Air Force, four North Atlantic Treaty Organization countries, and other foreign countries. It has been in production since October 1977.

F-16 Fighter

Source: General Dynamics Corp.

The F-16 serves in both air-to-air and air-to-ground mission roles, and both single- and two-seat models of the F-16 aircraft are built. General Dynamics (Fort Worth Division) is the prime contractor for the F-16. The F-16 is powered by a Pratt & Whitney F100 engine, the same engine used in the F-15, and uses a Westinghouse radar. The fighter is armed with one internal 20-mm. cannon and six Sidewinder infrared missiles. The F-16 complements the F-15 in the air superiority mission and supplements the F-4, F-111, and A-10 in the air-to-surface role.

PREPARATIONS FOR PRODUCING THE ALCM, THE TOMAHAWK, THE BLACK HAWK, AND THE HARM

ALCM

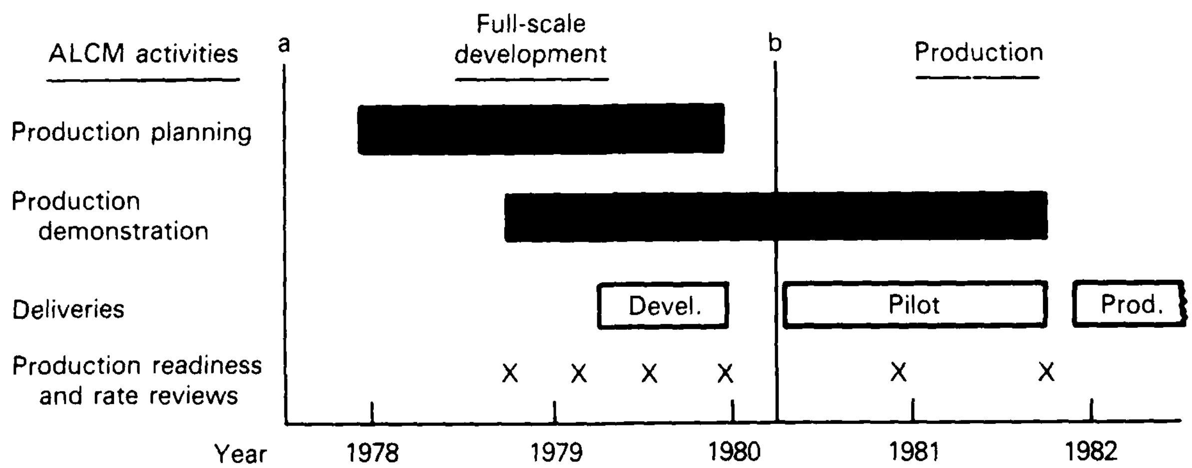
Like the F-16, the ALCM's transition to production was characterized by integrated production planning and demonstration, which began at the outset of full-scale development and continued into production. Production planning was done basically through provisions in the full-scale development contract, which called for Boeing to prepare a production plan for the missile, to compare its production requirements with Boeing's existing capabilities, and to develop and demonstrate new capabilities it was lacking before beginning the production phase. Once established, the production plan was used often, was frequently updated, and served as the basis for the production readiness reviews by the contractors and the joint program office representatives.

Beginning in late 1977, when DOD decided that ALCM's full-scale development phase would involve a competition between Boeing and a General Dynamics Tomahawk modified for air launching, Boeing conducted 92 design-to-cost studies which resulted in savings of $95,000 per missile. In addition, Boeing conducted 40 producibility studies during the period. As a result of these studies, Boeing decided to make the fuselage from a few large castings rather than numerous forgings. Drawing from a manufacturing technology project on an earlier program, Boeing changed its design from a 28-piece forging to a 4-piece casting. In addition, the cast fuselage sections needed little machining compared with the forgings, which reportedly cut production costs by 30 percent. Apart from the fabrication, having to join only 4 sections rather than 28 sections offered less opportunity for faults or sections not meeting dimension requirements and produced considerable cost savings.

This sound production planning was followed by a gradual development and demonstration of production capabilities. Four developmental missiles were built with the cast structure, and 3 of the 10 competitive flight tests were conducted with cast missiles. Concurrent with the flight test program were 2 years--fiscal years 1978 and 1979--of pilot production. This involved the fabrication and assembly of 24 missiles (12 in each year) to validate production plans, to demonstrate the ability to produce a quality end item, and to help form the basis for source selection. Boeing built all 24 pilot production missiles with the large cast sections.

As a result of production planning efforts, Boeing in February 1979 decided that a new dedicated production facility was needed to produce the ALCM in needed quantities. Boeing gradually phased in the production facility in a manner similar to the way it introduced castings. The new facility was under construction during the latter part of the pilot production program and was completed in time to assemble the first production missiles. In addition, the contractor maintained its ALCM pilot production manufacturing capabilities and capacity in its other plants until the new facility was fully proven. In this manner, Boeing was able to employ new machines and methods without the trauma associated with the wholesale introduction of new production facilities.

The chart below portrays the timing of the development activities relevant to preparing the ALCM for production. Point (a) refers to the full-scale development decision while point (b) refers to the production decision.



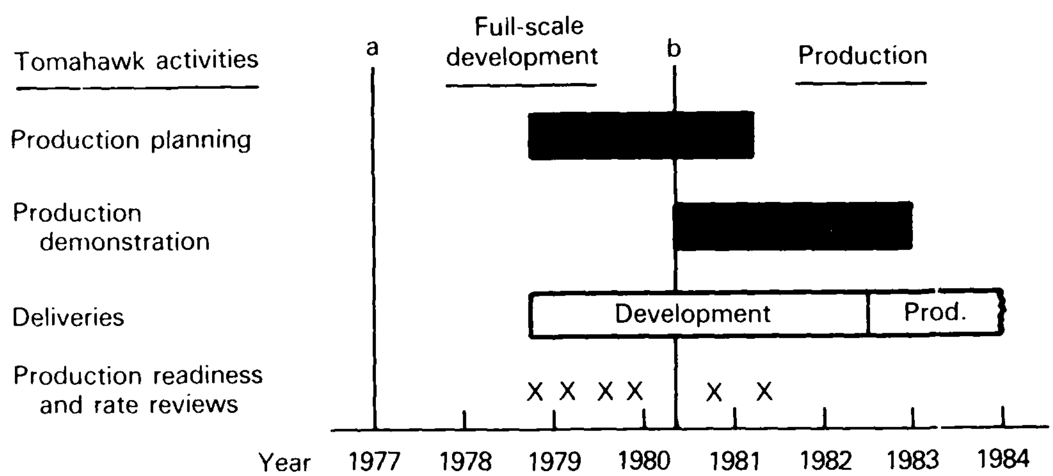
As with the F-16, at the time of the production decision, hardware was being made by production people and equipment and four incremental production readiness reviews had been conducted on the basis of plans and demonstrated capabilities. Also, deliveries of development hardware continued into the production phase, and production deliveries began with no line interruption.

TOMAHAWK

The Tomahawk's production planning and demonstration effort suffered as planned activities were reduced in scope as a result of test failures and quality problems. As in the ALCM program, a production plan was to be established for Tomahawk early in full-scale development which would be updated periodically and would form the basis for the production readiness reviews. However, General Dynamics program officials at the time concentrated almost exclusively on technical problems and, being overcome with the demands imposed by developing several missile variants simultaneously, did not meet production planning needs. This lack of front-end planning can be seen in the basic nature of some of the Tomahawk's production problems, such as the poor flow of parts on the production floor.

Perhaps the biggest blow to the Tomahawk's production preparations was reorienting the pilot production phase to an effort to build more test missiles. As in the ALCM program, 2 years of pilot production were planned for the Tomahawk in fiscal years 1978 and 1979. However, because of the Tomahawk's testing problems, a pilot production line was not established. Instead, more test missiles were built, which involved more hand labor and lacked the production disciplines of a true pilot production line. As a result, the program missed the opportunity to identify production problems through demonstration of hardware.

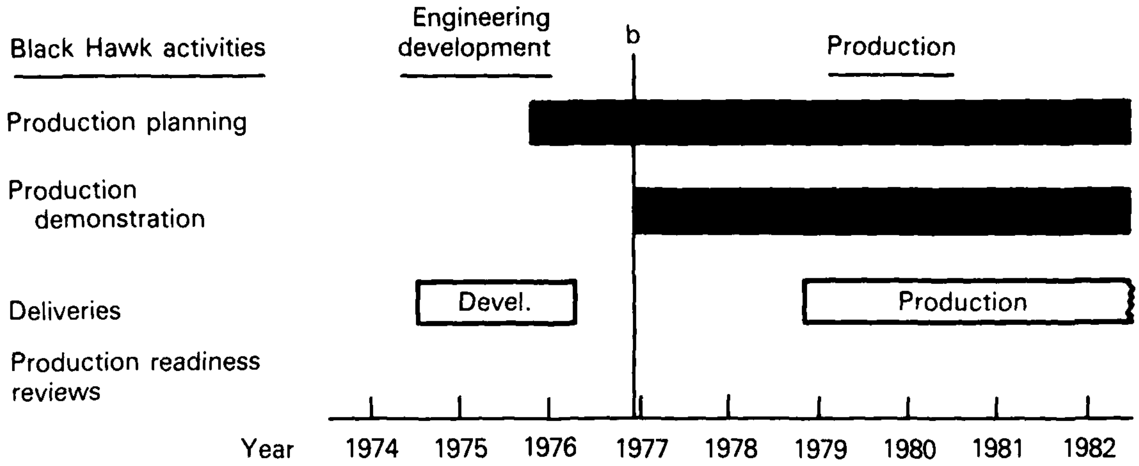
The timing of these development activities is shown below. As can be seen fewer production preparations had been conducted by the time of the Tomahawk's production decision than in the F-16 or ALCM programs. Point (a) refers to the full-scale development decision while point (b) refers to the production decision.



BLACK HAWK

Very little production planning occurred while the Black Hawk was in development, and that which eventually was done became disconnected from the design actually produced. Similarly, the development and demonstration of production capabilities were deferred to the production phase, occurring concurrently with the fabrication of first production units.

The timing of development activities relevant to preparing the Black Hawk for production is shown on the next page. Point (b) refers to the production decision.



Although competitive development began in August 1972, producibility engineering and planning did not begin until September 1975, a little over a year before the production award. This was a limited effort designed to identify long lead items and to "plan the plan." Earlier, the Army had decided not to fund more extensive production planning efforts for both competing contractors so it would not have to discard later the planning done by the losing contractor. The Army awarded limited producibility engineering and planned contracts in September 1975 and, in December 1976, awarded a more comprehensive second phase production planning contract to Sikorsky, which won the competition for production. Thus, the bulk of production planning was done concurrently with the production of aircraft.

Producibility engineering and planning became decoupled from the production helicopter. As a result of a major redesign in production to reduce the Black Hawk's weight, among other reasons, 700 metal components were changed to composite materials. Production planning, however, was aimed at producing the development design, not the new design. Thus, while the contractual producibility engineering and planning did generate some benefits, they were quite limited because they were too late and benefited the wrong aircraft. Design-to-cost efforts met a similar fate because they had been aimed at how the development aircraft would be fabricated and were not applied to the design actually produced.

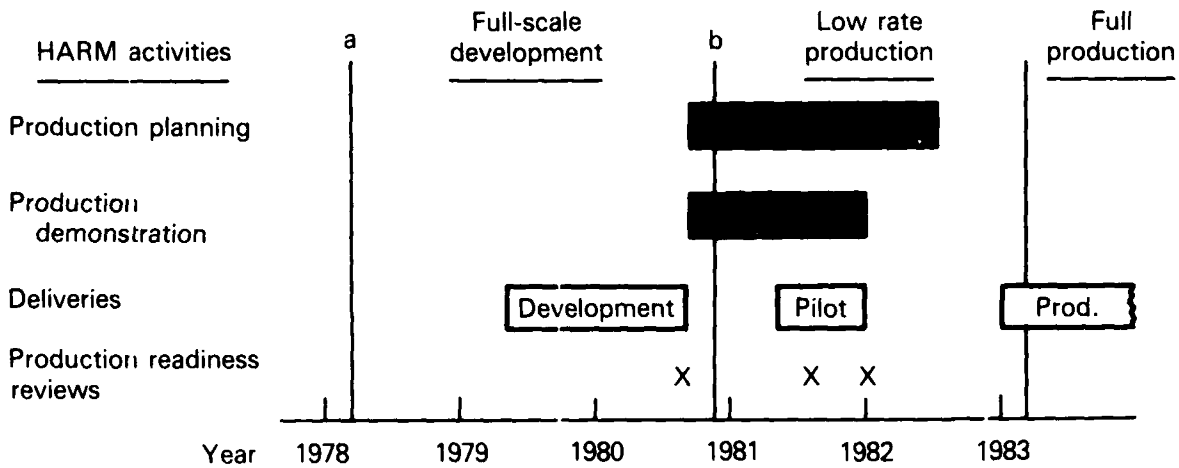
Production capabilities were not demonstrated before Sikorsky began production. One manufacturing technology project was conducted but was discontinued prior to implementation on the Black Hawk. Sikorsky had decided to reopen competition among all of its subcontractors and vendors in production, so no production capabilities had been developed by the suppliers. The Army funded an initial production facilities contract to Sikorsky, but not until production began.

The Army also dropped its plans for a low rate initial production phase. Instead, the program proceeded on a faster buildup to full rate production, which exacerbated the problems resulting from lack of production readiness.

HARM

The HARM's production preparations were made in the late stages of full-scale development. Pilot production did make for a transition to production, although substantial producibility and production planning efforts followed the pilot phase. Changes deriving from the sophistication of the design also complicated the pilot production effort. However, the revised production cost estimates based on the pilot experience were not recognized by the Navy until after low rate production had begun.

While the HARM's production preparations in some respects were more substantial than those in the Copperhead, Black Hawk, and Tomahawk programs, they were not as timely and integrated as those in the F-16 and ALCM programs. The timing of the HARM's production-related activities is shown below. Point (a) refers to the full-scale development decision, while point (b) refers to the production decision.



At the time of the low-rate production decision in November 1980, production capabilities were demonstrated to a lesser extent than in the F-16 and ALCM programs, as early pilot production missiles were not built in a production environment. Delivery of these missiles did not begin until after the decision. In addition, production planning and manufacturing technology efforts took place after the initial production decision. The production readiness review conducted just before the initial decision did not have as much production information available as the two reviews conducted after the decision. On the positive side, the low rate initial production phase did provide a much more accurate production picture for the full rate decision in March 1983.

The Navy did not fund a producibility engineering and planning effort on the HARM, and little was done by the way of producibility. In early production, a government team spent 6 months on-site at the contractor's facilities monitoring production and assisting in resolving difficulties. Schedules had been extremely tight since the HARM entered full-scale development, and the situation worsened when halfway through full-scale development, DOD decided to substantially increase the missile's performance requirements. One Texas Instruments official explained that time constraints forced short-cuts to be taken, one of which was to send "first cut" drawings to the model shops, without producibility studies or reviews.

The HARM program did benefit from a pilot production effort funded in fiscal year 1980. Texas Instruments had constructed a new facility at Lewisville, Texas, which it decided to use to assemble the HARM, and the pilot production of 45 missiles was intended to prove the facility out for production. During that time, the missile was undergoing numerous design changes based on development testing, which complicated the pilot effort. The 45 missiles produced in pilot production were not tooled early enough to provide a production environment. Metal parts were fabricated in model shops, while other components, including microwave circuit boards, were made with low rate production tooling and test equipment. The extent to which pilot production could be conducted was limited by the amount of early production planning. Nonetheless, pilot production provided a basis for making more realistic production estimates, as well as identifying areas where improvements could be made, such as in the manufacturing technology projects that followed. Several manufacturing projects were successfully completed but these were not funded until after production had begun.

Because of problems revealed in testing, production funding was delayed 1 year, which caused a 12-month gap from the time when pilot production was completed to the time when fabrication of production missiles began. This gap bought time for Texas Instruments to solve some of the pilot production problems and perform some producibility studies that had not been done previously. Initial production may have been much more troublesome had this gap not occurred. The HARM did undergo a low rate initial production phase of 80 missiles in fiscal year 1981, where some of the improvements generated by the pilot effort were applied.

OTHER DOD ACTIONS AND STUDIES TO

FACILITATE THE TRANSITION TO PRODUCTION

Several actions by DOD and the services have demonstrated a greater concern over the difficulties of getting weapons into production. DOD studies have cited various contributors to production problems, several of which we confirmed in the six weapons we reviewed. Recent DOD and service efforts reflect the findings of these studies. The Army's redefinition of producibility engineering and planning as including all production preparations up to low rate production is perhaps the most comprehensive attempt to improve the management and conduct of production preparations.

ADDITIONAL DOD EFFORTS TO IMPROVE THE TRANSITION TO PRODUCTION

DOD directive 4245.7, entitled the "Transition From Development to Production" was inspired by a Defense Science Board study on the transition to production. The directive authorizes further development and publication of the Board's preliminary guidelines on how to properly phase design, test, and manufacturing tasks to reduce production risks. The study, undertaken at DOD's request and culminating in an August 1983 report, identified several influences on weapons' production, many of which we saw in the six weapons reviewed. Among these are staffing; production planning; stability in funding and design requirements; and a preoccupation with system performance and fielding dates.

The study noted that the practice of establishing a single milestone decision as the point at which production begins perpetuates the misconception that the transition to production is an event, rather than a process which can span several years. The lack of an overall policy to the contrary was seen as reinforcing the view that production efforts do not begin until after the formal production decision.

The Board also called for developing a detailed production plan at the outset of full-scale development to be continuously updated until high rate production is achieved. This would make the transition an integral part of development.

Other actions by DOD in recent years have demonstrated a better understanding of the complex transition issue. Defense Acquisition Circular 76-43, issued in March 1983, calls for early production planning and addresses the government investment required to provide adequate facilities, economies of scale, and efforts to lower production costs. It also states that the capabilities of both prime contractors and major subcontractors to produce the end item in the required quantities and on time must be a major consideration in the full-scale development phase. It points out the importance of protecting producibility engineering and planning funds from being used for other development efforts. Several objectives of the DOD Acquisition Improvement Program emphasize preparing for production, particularly in stressing a producible design during full-scale development, contractors' production capabilities in source selections, and concentrated producibility engineering and planning efforts during development.

ARMY EFFORTS TO IMPROVE THE TRANSITION TO PRODUCTION

In late 1981, the Secretary of the Army established the Cost Discipline Advisory Committee to identify cost control problems in the Army's acquisition of weapons and to develop recommendations. In its December 1981 report, in addition to discussing other cost control issues, the Committee observed that

> ". . . one of the times when large cost growth has been reported is during the transition from development to production. Because the cost increase is occurring on most major programs, it appears to be systemic."

Upon reviewing four weapons in detail, the Committee found that production-oriented personnel were not made available to program offices early enough and that contractor production plans and producibility studies received little attention from source selection boards. It was further noted that after source selection, producibility efforts were not continued until just before production--too late to anticipate problems.

Pursuant to the cost discipline study, the Army is exploring ways to increase its production-oriented staff. In addition, the Army revamped its producibility engineering planning regulation. If successfully implemented, producibility engineering and planning will be a separate development contract item with its own costs and set of milestones. Producibility engineering and planning as redefined will encompass nearly all facets of production planning and demonstration, an approach which offers the promise of integrating the various efforts into a continuous building-block approach to the transition to production. The concept calls for a detailed production plan to be drawn up early, including fabrication plans, factory layouts, and equipment and personnel requirements. Manufacturing technology projects would not only be identified but would also be carried out under producibility engineering and planning. In addition, prototype tooling would be fabricated and a pilot production line would be set up to manufacture enough items to prove out the production processes.

The Army has taken other actions related to preparing weapon systems for production. In mid-1981, the Army Missile Command published a guide for getting missile systems into production which thoroughly treats the mechanisms available to aid in the transition, as well as when and how they should be employed. The guide also discusses key issues which affect the management of the transition, including the priority accorded technical performance, the acquisition strategy (or sequence of program events), the adequacy of resources applied to production preparations, the early identification of risks, and realistic cost and schedule thresholds. The Army has just begun budgeting for production risks under a program entitled Total Risk Assessing Cost Estimate for Production. This involves identifying and quantifying risks when a system makes the transition to production and adjusting estimated costs according to assessed risks. Finally, the Army has instituted a program management control system in an attempt to define a program baseline and track changes to it.

AIR FORCE AND NAVY EFFORTS

In February 1983, the Air Force completed a study of over 100 weapon programs which showed that systems today take longer and cost more to acquire than in the 1950's and 1960's. Although many factors were cited, the study singled out funding instability, requirements instability, and technical problems as the principal causes for cost growth and schedule stretch-out. Following this study, the Air Force embarked on a program called Project Cost, which pulls together some 200 Air Force actions in the areas of weapon affordability, stability, and management. Perhaps the most important of these, as they relate to the transition to production, is program baselining. It is an attempt to establish the scope of a weapon program in terms of requirements, schedule, and cost in order to highlight and assess the impact of program changes. Although holding the promise of improving program stability, the Air Force is having difficulty in getting all interested parties to agree on an initial baseline.

The Navy's most significant effort in this area has been in support of the Defense Science Board study. In addition to chairing the study task force, the Navy contributed the analysis showing that the transition to production is erroneously perceived as a single event, rather than a phase. The Navy is incorporating this position in its acquisition regulations.

In addition, the Navy funded a study of the production readiness review process, whose results were reported in August 1981. The study found that the key to avoiding cost overruns and schedule slippages was to do production planning as early in a program's life cycle as possible. This requires production planning to be adequately funded and staffed and specifically included in development contracts' statement of work. According to the study, production personnel were in short supply or were nonexistent at program offices and production readiness reviews were viewed as isolated evaluations rather than as one element in a continuous production planning effort. Contractors were also cited as not adequately staffing for production because of a heavy research and development orientation on the part of many contractors and their unwillingness to make commitments to production because they were unconvinced that the production phase would be funded.

The study concluded that the acquisition process as defined by DOD regulations focused more on policy rather than providing guidance on underlying production requirements to the program manager. It called for a reorientation of the acquisition process so that substantial funding of production planning would be provided during development, perhaps starting before full-scale development, even if such a practice necessitated terminating lower priority programs. The study also recommended that contractors be required to prepare production plans before full-scale development so that their ability to produce and their performance on prior production efforts could be assessed during source selection.

THE UNDER SECRETARY OF DEFENSE

27 SEP 1984

RESEARCH AND ENGINEERING

(AM)

Mr. Frank C. Conahan, Director
National Security and International
Affairs Division
U.S. General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548

Dear Mr. Conahan:

This is the Department of the Defense (DoD) response to the General Accounting Office (GAO) draft report, "Preparing Weapon Systems for Production: Can We Afford Not To Do It?," July 1984, GAO Code 951718, OSD Case 6573. The Department agrees with the report findings concerning conditions existing during the 1982-1983 survey and review period.

DoD concurs in the report's recommendations and is pleased that the report describes with approbation the production initiatives being implemented by the Office of the Secretary of Defense (OSD) and the Military Departments. These initiatives are described in two new directives, DoDD 4245.6, "Defense Production Management," and DoDD 4245.7, "Transition from Development to Production."

The policy and procedures contained in these documents have been provided wide dissemination and emphasis through incorporation in the Defense Acquisition Improvement Program, implementation of the Grace Commission recommendations and inclusion in the Defense Guidance on preparation of the annual defense budget. GAO's report describes the purpose and content of these DoD directives; however, it would be useful to include them verbatim. Copies are enclosed together with a distribution memorandum signed by the Secretary of Defense on January 19, 1984.

There is one finding from this survey that both the DoD and GAO staffs consider particularly valuable. This finding concerns program overlap or "concurrency"--a condition generally considered high risk and undesirable. Significantly, the systems surveyed, which had a degree of concurrency in development and production, had fewer problems than those with gaps between delivery of test and production end items. The point to be observed here is that concurrency in the schedule forced producibility engineering and planning to be conducted early in the development rather than waiting until the design had been completed.

The lesson concerning concurrency warrants greater emphasis in the report. There is a discussion of program phasing on page 38 which could be expanded to illustrate the essential contribution of early production preparatory activities to a smooth transition from development to production. While the report should not be an advocate of concurrency, it should not miss the opportunity to clearly evidence the necessity of a fully integrated design effort from the outset. DoD strongly recommends such a section be inserted in the report.

The opportunity to review this report is appreciated. It is gratifying to note the cooperation and constructive relationship that exists between the two organizations on this area of critical importance to the materiel acquisition process. The report author, Mr. Paul Francis, has agreed to serve on a panel of a government-industry producibility conference sponsored by NSIA this fall. The Department looks forward to such occasions for jointly delivering this vital message.

Sincerely,

James P. Wade, Jr.

Enclosures

James P. Wade, Jr.
Principal Deputy Under Secretary of Defense for Research & Engineering

GAO note: Not all of DOD's comments are reproduced here, but the comments in their entirety are available upon request.

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

North Main Street
Stratford, Connecticut 06601
(203) 386-4000

24 August 1984

Mr. Frank C. Conahan, Director
National Security and
International Affairs Division
United States General Accounting Office
Washington, D. C. 20548

Dear Mr. Conahan,

In response to your letter of 30 July 1984, we have reviewed your draft report, "Preparing Weapon Systems for Production: Can We Afford Not To Do It?". Comments relative to specific items contained therein are included as an attachment to this letter.

In addition to these comments, we offer for your consideration several factors which had a major bearing upon the effectiveness of planning actions by Sikorsky during the period of transition from full scale development to production.

- Material lead times for Lot I aircraft encountered the effects of a boom in commercial aerospace production. Specifically, demand strained available capability among manufacturers of precision forgings, forgings, castings, and raw material. Commodity lead times were often extended by 100% or more.

- The effects of peak demand in the industry not only had an impact on material, but also on the acquisition of new machining equipment. Fourteen major pieces of machining equipment, ordered in 1978 and 1979, experienced an average slippage to planned availability of 4.6 months.

- Significant labor disputes occurred among subcontractors in the 1979-80 timeframe. The most notable of these strikes was at the Speco Division of the Kelsey Hayes Corporation, an alternate source for tail, intermediate and main transmissions. The strike impacted gearbox availability to such a degree that continuation of aircraft deliveries in accordance with the contract schedule was no longer possible.

- The crash of a prototype aircraft (S/N 73-21650) on 19 May 1978. This event led to incorporation of critical design fixes and delayed the start of production by three full months.

The BLACK HAWK Program today is one which the Army and Sikorsky can be justly proud. Sikorsky is delivering aircraft ahead of schedule and, due in large part to the multi-year procurement of BLACK HAWK, at a lower price than in preceding years.

24 August 1984

We are in the concluding stages of negotiations for a second multi-year procurement. These negotiations will result in a further price reduction for BLACK HAWK airframes from Sikorsky.

Much can and has been learned from the BLACK HAWK experience. There is a positive story to be related and this aspect is understated in the draft report. From the Contractor's perception, the following are among the key lessons learned:

- The efficiency with which production start-ups occur is often the result of the degree of balance achieved between difficult technical and performance requirements concurrent with a rapid build-up of production deliveries to achieve ultimate rate. To minimize this conflict, we suggest a phased implementation of selected design objectives in lieu of current practice under which full implementation of the technical specification is attempted on the first and all subsequent units. This approach will simplify the control of factors which most often result in negative cost and schedule performance.

- We continue to demonstrate throughout the BLACK HAWK Program, the positive effects of competitive sources of supply as a means of reducing product cost. It is, therefore, our recommendation that early in the life cycle of the program, alternate suppliers be developed in order to heighten competition and achieve a resultant benefit on price. This, of course, places an added burden on the Government to provide additional funding for multi-source qualification in the initial stages of procurement. We believe the payback to be most significant.

- We believe that industry involvement in the requirements formulation stage of a program is not only desirable but necessary. This involvement may take the form of early tradeoffs of significant cost drivers in the proposed specification. Such action would provide timely evaluation of mission goals and lead to design of effective approaches to reduce production costs.

Sikorsky appreciates the opportunity for this review and requests your support in incorporating these comments in the final report. If there are questions regarding these or related issues, please do not hesitate to contact this office.

Very truly yours,

UNITED TECHNOLOGIES CORPORATION

William A. Minter
Vice President
BLACK HAWK Program
SIKORSKY AIRCRAFT DIVISION

ndn
Enclosure

[GAO note: [illegible] reproduced here, but [illegible] available upon request.]

TEXAS
INSTRUMENTS

28 August 1984

United States General Accounting Office
National Security and International Affairs Div
Washington, D C. 20548

Attention: Frank P. Conahan, Director

Dear Mr. Conahan:

We appreciate the opportunity to review and comment on your draft report, "Preparing Weapon Systems for Production." We realize that preparing such a report that accurately captures the history of each of these programs must have been a major task. Our involvement in the HARM program is first hand and we sometimes forget pertinent facts that truly portray our history.

The enclosure of comments is, to the best of our ability, an accurate statement of the events that occurred during the transition to production. We recognize also that those who may be associated with the program, outside of TI, may have an entirely different view of the situation.

I hope that our comments assist you in finalizing your report and if we can be of further assistance, please do not hesitate to call.

Regards,

Charles J. Rieke

st

INTRODUCTION:

Your draft report "Preparing Weapon Systems for Production: Can We Afford Not To Do It?" appears to be well written and generally accurate. Texas Instruments agrees that additional emphasis should be placed upon production preparation while a weapon system is in development. Responsibility for adequate production planning must be shared by the contractor(s) involved, DoD, and Congress. Too frequently, as was the case with HARM, performance requirements are changed during development, too great an emphasis is placed upon performance at the expense of production planning, and acquisition funding and quantities change dramatically from year to year.

Congress can be one of the biggest impediments to proper production planning. Not only does a weapon system have to go through the DoD's annual PPBS cycle with the attendant annual perturbations, but it must also struggle through the four defense advisory committees (HASC, SASC, HAC and SAC) with all the associated pork barrel politics. One committee will want to cancel the program, the next will add to DoD's request, while the next uses the fate of one program as a bargaining chip for another.

It appears that the source of program cost data used in your report is the SAR. SAR data may be better than none at all when trying to track cost estimates for a program, but from our vantage point, SAR estimates and subsequent contractor actual costs do not always track each other. Prior to the Nunn Amendment and the problems associated with a program breaching the Nunn thresholds, seemingly little importance was placed upon the SAR. In the case of HARM, there was absolutely no direct contractor involvement in formulation of the SAR data. Only after the cost increase referred to in your report was Texas Instruments given any insight at all as to the HARM SAR and its content. The Navy and Air Force compiled SAR data based upon a limited amount of actual cost history and applied their own learning curve assumptions to derive total estimated program cost. Contractors should have an opportunity to present their own cost estimates for production that would be subject to DoD modification. Thus, a combination of DoD and contractor estimates would be the basis of the SAR, rather than what seems now to be primarily DoD estimates only.

Your report's description of HARM's development and early production history seems to be generally accurate. It is easy for us to get defensive on these issues because so many of us have been personally and professionally committed to the success of HARM for so long. Now that HARM is in full production with the production rates increasing from the current 25 per month to the planned 300+ per month, we are very proud of our factory, our production capability, the steadily decreasing prices, and the outstanding performance of HARM in operational use.

It is true that during the development of HARM, the planned procurement was delayed, stretched, and reduced. These changes were caused by a variety of factors, not the least of which were the Congressional funding cuts. There were problems during "pilot production" (FY80 Procurement) in which TI produced 45 missiles for use in the Navy's OPEVAL and the Air Force's IOT&E; however, by the time we were in "initial production" (FY81 Procurement), we were able to deliver the required 80 tactical missiles on schedule and within budget. We are now in full production delivering 25 missiles per month. With production problems seemingly behind us, both the Navy and Air Force have accelerated their procurement plans to take full advantage of our production capabilities.

Currently there is a request from DoD to Congress to use already available FY84 funds to procure an additional 207 missiles and at the same time increase production capacity from 65 per month to 110 per month. This request has been under review by the four advisory committees for several months. One committee approved the full request, another approved part of it, while yet another tied its fate to resolution of the FY85 authorization bill, which may remain unresolved until sometime in FY85. Here is a case where available funding could and should be used to increase the capacity of the HARM factory, but for political reasons the decision lingers. Already the program is forced to keep production rates flat for FY82/FY83. Congressional funding cuts during the battle over single vs. dual source resulted in the 30 per month rate being maintained for all of the FY83 production, rather than a more efficient ramp-up.

In your report on page 36 you refer to "total production quantities" in FY79-82. Your quantities reflect only half of the planned procurement. As a joint USN/USAF program, there were similar amounts for the other service. The total procurement has varied from 14,000 to 21,000 to 17,000 over the years.

In summary, it appears that your report is a good one. It makes a very valid recommendation: increased production planning is required during the development phase of a weapon system. This increased emphasis must be made by all parties concerned: contractors, DoD, and Congress.

Specific references are included as clarifications to improve the readers understanding of specific situations.

GAO Notes:

1. The page reference above has been changed to correspond to that in the final report.
2. The detailed portion of Texas Instruments' comments is not reproduced here, but the comments in their entirety are available upon request.

BOEING AEROSPACE COMPANY

SEATTLE, WASHINGTON 98124

EDWARD J. RENOUARD
ALCM PROGRAM MANAGER

August 14, 1984

Mr. Frank C. Conahan, Director
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

Thank you for giving me the opportunity to review and comment on your draft report "Preparing Weapon Systems for Production: Can We Afford Not to Do It?" Overall, the report is well organized and provides valuable insight into problems and cost growth experienced on weapon systems in the transition from development to production. Your report should contribute significantly to enabling the Government to acquire more defense capability for fewer taxpayer dollars expended.

Submitted for your consideration are some suggested changes and additions that I feel clarify pertinent ALCM information. The underlined portion of the paragraph contains the proposed changes.

Again, I would like to express my appreciation for the chance to review firsthand your findings on our program. If I can be of further assistance please contact me.

Sincerely,

E. J. Renouard

Attachments

[GAO note: The detailed portion of Boeing's comments is not reproduced here, but the comments in their entirety are available upon request.]

GENERAL DYNAMICS
Fort Worth Division
P. O. Box 748, Fort Worth, Texas 76101
(817) 777-2000

24 August 1984

United States General Accounting Office
National Security and International Affairs Division
441 G Street, N.W.
Washington, D.C. 20548

Attention: Mr. Frank C. Conahan

Subject: Draft Report Titled, "Preparing Weapon Systems for Production: Can We Afford Not To Do It?" (Code 951718)

Dear Sir:

General Dynamics has received subject draft and reviewed as requested. Generally, we feel it is an excellent report of F-16 program history and we are quite pleased with the way you have presented the program. We can certainly appreciate the purpose of your report since we did strive to accomplish preparation for F-16 production essentially in accordance with the objectives and management methodology which you set forth. We at General Dynamics are proud of our achievement and believe that timely detail planning and preparation for production is a must. To paraphrase your report title: "How Can We Afford Not To Do It?"!

General Dynamics and the Air Force entered the F-16 program with the firm conviction that production planning and preparation for production must be accomplished during the development phase. Accordingly, General Dynamics and the Air Force developed most of the detail planning during the YF-16 prototype phase (comparable to Demo and Validation phase of the Acquisition Cycle) with considerable emphasis on the transition from development to production. USAF management (ASD and Hq USAF) were both very supportive of the production planning efforts by providing consultation services and "lessons learned" experiences and funding of the efforts in 1974 prior to Full Scale Development authorization. These efforts contributed greatly to successful plans and preparation for transitioning the F-16 Program from development to production.

To assist you in finalizing your report we offer some suggestions as follows, which we hope you will find helpful.

1. Considerable advanced technology was involved in the design and manufacture of the two prototypes. For example, there were several "firsts" for the F-16.

   - A fly-by-wire flight control system.
   - Increased "G" capability cockpit (30° seat angle) with full hemispheric visibility.
   - Controlled vortex lift.
   - Blended wing/body aerodynamic design.
   - Relaxed static stability horizontal tail.
   - Automatic variable wing leading edge camber.
   - Production graphite composite empenage surfaces.

[GAO note: The detailed portion of General Dynamics' comments is not reproduced here, but the comments in their entirety are available upon request.]

To: Mr. Frank C. Conahan
24 August 1984

5. (Continued)

wing to assure that precise placement of the leading edge vortex over the wing planform required some 40 separate wind tunnel models for development of this technology alone. The fly-by wire flight control system was certainly a high risk system in development requiring channel quadra-redundancy in the electronic computer and a new concept in servo-actuators. The leading-edge automatic variable camber which resulted in electronic computer programmed hydraulic actuation that operates without pilot input was also a high risk item. The fact that these systems functioned as planned is a tribute to the homework and dedication of the F-16 design teams. We do not think that high technology/high risk innovations used on the F-16 should be minimized.

We want to reiterate that the GAO has developed an excellent report and believe it will be a valuable tool for planning future weapon systems for production. We are most pleased to be a part of this effort and appreciate being requested to participate in the review of your proposed report.

If there are any questions regarding the above, please contact R. W. (Bob) Whiting at (817) 777-4234).

Sincerely,

E. Earl Hatchett
Division Vice President-Finance

Attachment: F-16 Contract Demonstration Milestones

THE SECRETARY OF DEFENSE

WASHINGTON, THE DISTRICT OF COLUMBIA

19 JAN 1984

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
ASSISTANT SECRETARY OF DEFENSE (COMPTROLLER)
ASSISTANT SECRETARY OF DEFENSE (INTERNATIONAL SECURITY POLICY)
ASSISTANT SECRETARY OF DEFENSE (MANPOWER, INSTALLATIONS, AND LOGISTICS)
ASSISTANT TO THE SECRETARY OF DEFENSE (ATOMIC ENERGY)
DIRECTOR, PROGRAM ANALYSIS AND EVALUATION
DIRECTOR, DEFENSE COMMUNICATIONS AGENCY
DIRECTOR, DEFENSE LOGISTICS AGENCY
DIRECTOR, DEFENSE NUCLEAR AGENCY
COMMANDANT, DEFENSE SYSTEMS MANAGEMENT COLLEGE

SUBJECT: DoD Directive 4245.7 "Transition from Development to Production"

Attached is a new Directive that is intended to maintain a high degree of technical balance in our acquisition process. Too often in the past, when faced with funding and schedule constraints, we have compromised the technical integrity of our programs by deleting or deferring vital program elements that contribute to system performance, producibility, and supportability. We have added unintentionally to the life cycle cost and postponed effective operational capability dates by pursuing development programs which do not yield producible designs and supportable configurations in a timely manner.

This Directive sets forth policy aimed at ensuring that our programs, once established, are continued on a sound technical basis. A high degree of managerial discipline is needed at all levels to ensure this policy is instituted.

This Directive authorizes the development and use of DoD 4245.7-M, a "Transition" manual to aid in structuring technically sound programs, assessing their risk, and identifying areas needing corrective action. Refinement and coordination of this manual will take a period of time. The Deputy Chief of Naval Material (Reliability, Maintainability, and Quality Assurance) is the proponent of this manual and has produced a preliminary document "Solving the Risk Equation in Transitioning from Development to Production." Pending development and publication of the DoD 4245.7-M in the DoD publication system, this preliminary document should be used as general guidance.

Attachment
a/s

APPENDIX IX

January 19, 1984
NUMBER 4245.7

USDR&E

Department of Defense Directive

SUBJECT: Transition from Development to Production

References:
(a) DoD Directive 5000.1, "Major Systems Acquisition," March 29, 1982
(b) DoD Instruction 5000.2, "Major System Acquisition Procedures," March 8, 1983
(c) DoD Directive 5000.3, "Test and Evaluation," December 26, 1979
(d) DoD Directive 4245.6 "Defense Production Management," January 19, 1984
(e) DoD 5025.1-M "DoD Directives System Procedures," April 1981, authorized by Directive 5025.1, October 16, 1980

A. PURPOSE

This Directive:

1. Consistent with references (a) through (d) consolidates established policy, prescribes procedures, and assigns responsibilities on the application of fundamental engineering and technical disciplines in acquisition programs to expedite the transition from development to production.

2. Authorizes the publication of DoD 4245.7-M, "Transition from Development to Production," consistent with DoD 5025.1-M (reference (e)).

B. APPLICABILITY

This Directive applies to the Office of the Secretary of Defense, the Military Departments, the Organization of the Joint Chiefs of Staff, and the Defense Agencies. As used herein, the term "DoD Components" refers to the Military Departments and the Defense Agencies.

C. POLICY

1. It is DoD policy to ensure that fundamental engineering principles are followed and that relevant technical disciplines are applied in the development and production of defense systems, support equipment, and modifications. The policies and procedures contained in this Directive and in references (a) through (d) shall be supplemented in their implementation by a formal program of risk evaluation and reduction.

2. Emphasis shall be placed on maintaining program technical balance. Implementation of this policy shall be consistent with, but not subordinate to, funding, schedule, and other constraints.

D. PROCEDURES

1. Acquisition programs shall be subjected to a rigorous, disciplined application of fundamental engineering principles, methods, and techniques in general accordance with DoD 4245.7-M. Elements of program risk shall be identified and assessed throughout the acquisition cycle. The program's acquisition strategy shall feature provisions for eliminating or reducing these risks to acceptable levels.

2. The guidance contained in DoD 4245.7-M shall be used in and tailored to individual acquisition programs to:

a. Make standard the technical approach and establish a framework that all programs must embrace.

b. Identify fundamental tools, engineering methods, and other material that will be useful at the working level.

c. Provide a checklist and criteria for program review to ensure that proper attention is given to technical areas that typically introduce risk and are known to be critical to success.

3. DoD 4245.7-M shall be used also as source material for orientation, indoctrination, and classroom training in the technical disciplines stated therein.

4. Factors affecting producibility and supportability shall be integrated fully during full-scale development. The design and test cycle shall be structured to provide a continuum in development, production, and operational support.

5. The modernization and improvement of industrial facilities shall be supported actively and encouraged by innovative arrangements.

6. Acquisition program manning and personnel development programs shall ensure that an adequate number of technically qualified and competent people are committed to the program.

E. RESPONSIBILITIES

1. The Under Secretary of Defense for Research and Engineering (USDR&E), as chairman of the Defense Systems Acquisition Review Council (DSARC), and in coordination with the other members of the DSARC, shall:

a. Ensure compliance with this Directive when evaluating and making programmatic decisions on acquisition programs.

b. Develop, publish, and maintain DoD 4245.7-M, consistent with DoD 5025.1-M (reference (e)).

APPENDIX IX

2. The <u>Heads of the DoD Components</u> and their program managers shall

a. Structure and execute acquisition programs in accordance with this Directive and document compliance at milestone decision points

b. Program and protect the upfront funding for design, test, production planning, and support planning activities that is necessary to begin sound development programs leading to efficient transitions to production.

c. Take specific measures to train and assign technically qualified production personnel in key positions including a defined career progression, extended assignments, line management involvement in recruitment, and the application of sound and innovative management approaches.

3 The <u>Commandant, Defense Systems Management College</u>, shall review the policies and procedures set forth in this Directive and in DoD 4245.7-M and incorporate the material in College curricula.

F. <u>EFFECTIVE DATE AND IMPLEMENTATION</u>

This Directive is effective immediately. Forward one copy of implementing documents to the Under Secretary of Defense for Research and Engineering within 120 days.

Caspar W. Weinberger

CASPAR W. WEINBERGER
Secretary of Defense

APPENDIX X

January 19, 1984
NUMBER 4245.6

USDR&E

Department of Defense Directive

SUBJECT: Defense Production Management

References:
(a) DoD Directive 5000.34, "Defense Production Management," October 31, 1977 (hereby canceled)
(b) DoD Directive 5000.1, "Major System Acquisitions," March 29, 1982
(c) DoD Directive 4245.7, "Transition From Development to Production," January 19, 1984
(d) DoD Instruction 4200.15, "Manufacturing Technology Program," July 14, 1972
(e) through (l), see enclosure 1

A. PURPOSE

This Directive replaces reference (a) to update policy, procedures, and responsibilities for production management in the Department of Defense during the acquisition of defense systems and equipment.

B. APPLICABILITY AND SCOPE

1. This Directive applies to the Office of the Secretary of Defense (OSD), the Military Departments, and the Defense Agencies (hereafter referred to collectively as "DoD Components") for the acquisition of major systems as defined by reference (b).

2. Production management of system programs not defined and designated as major system acquisitions also shall be guided by the provisions of this Directive.

3. The principles contained in this Directive apply to all defense materiel programs.

C. DEFINITIONS

Terms used in this Directive are defined in enclosure 2.

D. POLICY

It is DoD policy to plan for production early in the acquisition process and to integrate acquisition actions to ensure an orderly transition from development to cost-effective rate production.

APPENDIX X

E. PROCEDURES

1. Points of contact selected by heads of DoD Components shall develop internal policy and procedures to implement this Directive and shall coordinate production management activities.

2. Emphasis shall be placed on application of fundamental engineering principles and relevant technical disciplines during development and production. Assessment of production risks shall be made throughout the acquisition process. These assessments shall be formalized through industrial resource analyses (IRAs) and production readiness reviews (PRRs). Risks shall be reduced to acceptable levels in accordance with DoD Directive 4245.7 (reference (c)).

3. A manufacturing strategy shall be developed as part of the program acquisition strategy. Manufacturing voids, deficiencies, and dependencies on critical foreign source materials shall be addressed concurrently with concept demonstration and validation through the use of manufacturing technology projects (DoD Instruction 4200.15, reference (d)), or other means. The producibility of each system design concept shall be evaluated at the full-scale development (FSD) decision point to determine if the proposed system can be manufactured in compliance with the production cost and industrial base goals and thresholds.

4. Contractor past performance (to the extent that it has a bearing on the concept involved), production management capability, quality history, and the potential to execute the production program shall be among those factors included in the contractual solicitations and evaluated thereafter in the source selections.

5. A comprehensive producibility engineering and planning (PEP) program is a requisite for entering FSD. PEP programs shall be conducted throughout FSD and shall contain specific tasks, measurable goals, and a system of contractor accountability.

6. A quality program in accordance with DoD Directive 4155.1 (reference (e)) shall be conducted throughout acquisition and deployment. Industrial preparedness planning shall be integrated effectively with production management and production planning under DoD Directive 4005.1 (reference (f)). Determinations of priorities and allocations shall be within the framework of DoD Component delegation of authority, consistent with DoD Instruction 4400.1 (reference (g)).

7. The Office of the Under Secretary of Defense for Research and Engineering (OUSDR&E) shall maintain visibility of production management matters throughout the acquisition process for all major programs. Production decisions under consideration at a Defense Systems Acquisition Review Council (DSARC) or OSD program review shall be supported by an independent OSD assessment of production readiness in addition to an evaluation of the findings of a formal PRR. PRRs shall be planned and conducted by the DoD Components in accordance with DoD Instruction 5000.38 (reference (h)) to confirm:

a. The stability and producibility of the design.

APPENDIX X

b. Progress toward meeting reliability and maintainability characteristics.

c. The adequacy of supporting manufacturing technology.

d. The refinement of manufacturing methods, techniques, and processes.

e. The suitability of manufacturing, cost, and quality assurance control provisions.

8. An acquisition may not proceed into production until it is determined that the principal contractors have the physical, financial, and managerial capacity to meet the cost and schedule commitments of the proposed procurement. An assessment shall be made of the contractors' capabilities to meet surge (peacetime) and mobilization (declared national emergency) requirements and their commitments to participate in the DoD industrial preparedness production planning program under DoD Directive 4005.1 (reference (f)).

9. Competition, value engineering, tailoring of specifications and standards, design-to-cost, cost benefit and trade-off assessments, preplanned product improvements, multiyear procurement, industrial modernization incentives, and other techniques shall be used, as appropriate, to reduce production, operating, and support costs. Standardization, commonality, and interchangeability shall be promoted throughout the acquisition cycle to reduce lead time and life-cycle cost.

10. Technical data packages shall be developed and proven by means of production demonstration and configuration audit, consistent with competition, component breakout, and reprocurement objectives.

11. Continued emphasis shall be placed on life-cycle cost reduction during the production phase through the use of contractual incentives and other means.

12. Production management planning and implementation shall include provisions for measuring progress in meeting design-to-cost and life-cycle cost commitments.

13. Selection of contracts and subcontracts requiring contractor cost and schedule management systems to comply with the DoD Cost Schedule Control Systems criteria shall be made in accordance with DoD Instruction 7000.2 (reference (i)). When a contractor or subcontractor is not required to comply with the criteria, the Cost Schedule Status Report approach to performance measurement set forth in DoD Instruction 7000.10 (reference (j)) normally shall be used.

14. Production engineering and management shall include those actions that are required to maintain a capability to produce materiel for the operation and maintenance of equipment after the production phase is complete. The planning for these post-production activities shall start during the development phase.

15. <u>Program Milestone Reviews</u>. Production management shall be addressed specifically at each program milestone decision point in the major system acquisition process in accordance with DoD Instruction 5000.2 (reference (k)).

APPENDIX X

a. Milestone I - Demonstration and Validation. Production feasibility of candidate system concepts shall be addressed and areas of production risk defined. Manufacturing technology needed to reduce production risk to acceptable levels shall be identified. Preliminary goals and thresholds for production cost shall be formulated. Preliminary goals and thresholds for industrial base capability shall be formulated based on an IRA.

b. Milestone II - FSD. The producibility of the design approach shall be confirmed and production risk determined acceptable. The FSD phase shall include provisions to attain producibility of the production design using cost-effective manufacturing methods and processes. Resource requirements for PEP, long-lead procurements, critical materials, labor skills, facilities, equipment, and limited production shall be identified and programed. The capability to meet production unit cost, schedule, and surge requirements shall be confirmed at the prime and key subcontract levels.

c. Milestone III - Production and Deployment. Production decisions shall be supported by an assessment of the program readiness for production, based on a formal PRR. The PRR shall include assessing the results of PEP and manufacturing technology activities. Plans and provisions for accomplishing cost reduction during production shall be described.

F. RESPONSIBILITIES

1. The Under Secretary of Defense for Research and Engineering shall have production management responsibilities including:

a. Developing directives and issuing instructions, consistent with DoD 5025.1-M (reference (l)), relating to production management, production readiness, production priority, and industrial preparedness.

b. Evaluating the production management activities of the DoD Components in major systems acquisition and other programs to ensure consistent application of production management policy and principles.

c. Providing guidance for the research programs for the development of defense-related manufacturing technology.

d. Exercising policy and operational control of the DoD Product Engineering Services Office, OUSDR&E, in its mission of providing assistance to DoD Components on production management matters and conducting independent assessments of producibility and production readiness of major programs throughout the acquisition cycle.

e. Ensuring that funds budgeted for manufacturing technology, value engineering, facilities, and industrial preparedness within the Department of Defense are adequate.

2. The Under Secretary of Defense for Research and Engineering in the role of the Defense Acquisition Executive shall:

a. Review the production management, engineering, and planning provisions of the System Concept Paper (SCP) or Decision Coordinating Paper/Integrated Program Summary (DCP/IPS) and other programing documents.

b. Assess the status of production management at the DSARC.

c. Ensure adequate funds are budgeted in the FSD phase for producibility engineering and production planning.

d. Ensure adequate funds are budgeted for dual sourcing and competition when appropriate.

e. Review the production management status of existing domestic or foreign systems and equipment being considered for DoD adaptation and use.

3. The Assistant Secretary of Defense (Manpower, Installation, and Logistics) (ASD(MI&L)) shall review production planning provisions incident to meeting post-production materiel support requirements.

4. The Heads of the DoD Components, and their program managers, shall:

a. Plan, program, budget, and execute production management in compliance with this Directive.

b. Establish a production management point of contact.

c. Conduct a vigorous manufacturing technology program in cooperation with other DoD Components, federal agencies, and the private sector.

d. Conduct manufacturing assessments relating to major systems acquisition programs.

e. Make appropriate contacts with and delegations of authority to cognizant contract administration activities.

f. Ensure that consideration is given to the producibility of proposed concepts during the demonstration and validation phase.

g. Ensure that program funding and schedule reduce production risk through manufacturing technology and producibility engineering and planning activities.

h. Integrate industrial preparedness planning and IRAs into the production management of defense systems.

i. Conduct production planning to meet materiel requirements for the post-production period.

j. Conduct PRRs in support of limited-production and full-production decisions. These reviews may include participation by consultants, other DoD Components, and attendance by OSD representatives.

k. Ensure that system contractors develop and pursue effective production plans and that system contractors impose the same requirement on their subcontractors.

l. Employ pilot production lines, when necessary, to validate production readiness, manufacturing operations, and cost and to provide production articles for test and evaluation.

m. Plan and fund continuous cost-reduction activities during the FSD and the production and deployment phases (including dual sourcing, competition and component breakout).

n. Measure and report design-to-cost status during FSD and later cost experience during production.

o. Exercise surveillance over contractor production operations using the services of the cognizant contract administration office to identify variances from the production plan and cost in time to direct remedial action.

p. Present the program production management status to the DSARC or Service System Acquisition Review Council ((S)SARC)), or both, at program milestone decision points I, II, and III.

q. Provide production engineering and production management training for program manager staffs and other technical personnel involved in the acquisition of defense systems.

G. EFFECTIVE DATE AND IMPLEMENTATION

This Directive is effective immediately. Forward two copies of implementing documents to the Under Secretary of Defense for Research and Engineering within 120 days.

CASPAR W. WEINBERGER
Secretary of Defense

Enclosures - 2
1. References
2. Definitions

APPENDIX X

REFERENCES, continued

(e) DoD Directive 4155.1, "Quality Program," August 10, 1978
(f) DoD Directive 4005.1, "DoD Industrial Preparedness Production Planning," July 28, 1972
(g) DoD Instruction 4400.1, "Priorities and Allocations - Delegation of DO and DX Priorities and Allocations Authorities, Rescheduling of Deliveries and Continuance of Related Manuals," November 16, 1971
(h) DoD Instruction 5000.38, "Production Readiness Reviews," January 24, 1979
(i) DoD Instruction 7000.2, "Performance Measurement for Selected Acquisitions," June 10, 1977
(j) DoD Instruction 7000.10, "Contract Cost Performance, Funds Status and Cost/Schedule Status Reports," December 3, 1979.
(k) DoD Instruction 5000.2, "Major System Acquisition Procedures," March 8, 1983
(l) DoD 5025.1-M, "DoD Directives System Procedures," April 1981, authorized by DoD Directive 5025.1, October 16, 1980

APPENDIX X

DEFINITIONS

1. Industrial Resource Analysis (IRA). A discrete analysis of industrial base capabilities conducted to determine the availability of production resources required to support a major system production program. These resources include capital, materiel, and manpower required to accelerate to and maintain full production rates and respond to surge and mobilization requirements. IRA includes the results of feasibility studies, producibility analyses, and manufacturing technology program assessments.

2. Producibility. The relative ease of producing an item or system. This is governed by the characteristics and features of a design that enable economical fabrication, assembly, inspection, and testing using available production techniques.

3. Producibility Engineering and Planning. The production engineering tasks and production planning measures undertaken to ensure a timely and economic transition from the development to the production phase of a program.

4. Production Engineering. The application of design and analysis techniques to produce a specified product including:

a. The functions of planning, specifying, and coordinating the application of required resources.

b. Performing analyses of producibility and production operations, processes, and systems.

c. Applying new manufacturing methods, tooling, and equipment.

d. Controlling the introduction of engineering changes.

e. Employing cost control techniques.

5. Production Feasibility. The likelihood that a system design concept can be produced using existing production technology while simultaneously meeting quality, production rate, and cost requirements.

6. Production Management. The effective use of resources to produce, on schedule, the required number of end items that meet specified quality, performance, and cost. Production management includes but is not limited to industrial resource analysis, producibility assessment, producibility engineering and planning, production engineering, industrial preparedness planning, post-production planning, and productivity enhancement.

7. Production Readiness. The state or condition of preparedness of a system program to proceed into production. A system is ready for production when industrial resource capacity, completeness and producibility of the production design, and the managerial and physical preparations necessary for initiating and sustaining a viable production effort have progressed to the point at which a production commitment can be made without incurring unacceptable risks to the thresholds of schedule, performance, cost, or other established criteria.

APPENDIX X

8. Production Readiness Review. A formal examination of a program to determine whether the design is ready for production, production engineering problems have been resolved, and the producer has accomplished adequate planning for the production phase.

9. Productivity Enhancement. The use of contract incentives and other techniques to provide the environment, motivation, and management commitment to increase production efficiencies.