United States General Accounting Office

GAO

Report to the Honorable Les Aspin, Chairman, Committee on Armed Services, House of Representatives

July 1991

B-2 PROGRAM

Trends in Manufacturing

GAO/NSIAD-91-211

GAO United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-243577

July 30, 1991

The Honorable Les Aspin
Chairman, Committee on Armed Services
House of Representatives

Dear Mr. Chairman:

This report presents manufacturing trend data on the B-2 bomber development and production and discusses the effectiveness of production management programs being implemented by contractors.

We are sending copies of this report to the Chairmen, Senate Committee on Armed Services, Senate and House Committees on Appropriations, Senate Committee on Governmental Affairs, and House Committee on Government Operations; the Secretaries of Defense and the Air Force; and the Director, Office of Management and Budget.

This report was prepared under the direction of Nancy R. Kingsbury, Director, Air Force Issues, who may be reached at (202) 275-4268, if you or your staffs have any questions concerning this report. Other major contributors to this report are Joseph C. Bohan, Assistant Director; Lionel C. Cooper, Jr., Evaluator-in-Charge; and Dale M. Yuge, Evaluator.

Sincerely yours,

Frank C. Conahan

Frank C. Conahan
Assistant Comptroller General

Executive Summary

Purpose

During the past several years, GAO has issued a series of reports on the B-2 stealth bomber program identifying causes of instability in the program, including manufacturing problems being encountered by the contractors. The objectives of this review were to determine the B-2 bomber's recent manufacturing progress and evaluate whether estimates to produce aircraft at planned production rates can be met. To meet the GAO objectives, GAO evaluated selected manufacturing indicators, including labor efficiency rates, manufacturing defects, changes to engineering drawings, work transferred to final assembly, and programs for production management.

Background

The B-2 aircraft combines conventional and state-of-the-art aircraft technology, such as special shaping and radar absorbing materials, and is designed to precise specifications needed to meet stealth requirements. Such factors make it a complex aircraft to develop and produce. Northrop Corporation, the prime contractor, is responsible for building one of the major sections and for final assembly of the aircraft. The Boeing and LTV Corporations are the major subcontractors responsible for building the other major sections.

The B-2 program began full-scale development in 1981 under a cost-plus-incentive-fee contract for six development aircraft. The Air Force began low-rate initial production concurrently with development efforts in November 1987 under a fixed-price-incentive-fee contract for five production aircraft. The Congress appropriated funds for five additional production aircraft in fiscal years 1989 and 1990.

Schedule slippages occurred early in the program primarily because of a major redesign of the aircraft, development taking longer than anticipated, and manufacturing problems. In February 1987, Northrop had planned to deliver all six development aircraft by the end of 1990. At the time GAO completed its review, two aircraft had been delivered, and aircraft number 3 was delivered on June 18, 1991. Since February 1987, Northrop's cost estimate to complete development has increased by $6.8 billion. Reductions in funding and the number of aircraft to be purchased have also delayed production. The most significant change was in April 1990, when the Secretary of Defense reduced the quantity of B-2s to be purchased from 132 to 75 aircraft because of the total costs and changing world conditions. In January 1991, the Air Force estimated the 75 aircraft would cost $63.7 billion.

The President's fiscal years 1992 and 1993 budget requests four aircraft and $4.8 billion in fiscal year 1992, and seven aircraft and $4.6 billion in fiscal year 1993.

Results in Brief

B-2 contractors are generally not meeting the manufacturing goals they established. They are continuing to experience significant problems in reducing labor hours, numbers of defects, engineering drawing changes and in completing work at major section assembly sites rather than transferring it to the final assembly site. Also, their production management programs are not fully effective. Because of these and other factors, they have frequently delayed their development and production plans, and costs have increased substantially.

To a large extent, the delays in delivery and cost increases attest to the problems caused by numerous engineering changes, new manufacturing technologies, and difficulties the contractors are encountering in manufacturing low observable aircraft that meet the precise tolerances of stealth requirements. These events caused instability in the B-2 program and resulted in significant increases in the labor and time required to produce the two aircraft that had been delivered at the completion of our review. Based on current efficiency rates, aircraft numbers 3 and 4 are also likely to significantly exceed their labor goals. The trend data on defects, engineering changes, and transferred work indicate that manufacturing stability still has not been achieved on the B-2 program, and disciplined and rigorous production management programs are not fully in place. Therefore, until the planning and manufacturing process becomes more reliable, there is a high risk that the contractors may not be able to achieve predicted efficiencies at planned, higher production rates.

Principal Findings

Manufacturing Problems and Trends

GAO's review of selected Northrop, Boeing, and LTV manufacturing trends shows progress is being made with each successive aircraft, but contractors are generally not meeting their goals and are continuing to experience significant problems. The manufacturing process is still maturing and considerable time is spent correcting defects and making engineering changes. Also, the contractors' production management programs are not fully implemented or effective in some significant areas.

Further, the B-2 is a complex and expensive program where the development aircraft are being manufactured to the precise tolerances identified for stealth requirements. This is important for test and evaluation and because five of the six development aircraft are to be delivered as part of the operational fleet.

Labor Efficiency Goals Not Being Met

Northrop, Boeing, and LTV are significantly reducing the number of production labor hours required to assemble each aircraft. For example, aircraft number 4 is projected to require about 750,000 fewer assembly hours than aircraft number 1. However, the contractors are generally not meeting their goals for improving labor efficiencies because the total number of hours to assemble each aircraft continues to be much higher than the goals set by the contractors. Assembly of aircraft numbers 1 and 2, which had been delivered at the completion of GAO's review, was completed in about 4.6 million production labor hours, exceeding the combined goal of about 3.3 million hours by 40 percent. Based on currently available data, the production labor hours needed to assemble the third and fourth development aircraft could be about 3.6 million hours, or about 30 percent higher than the combined goal of 2.8 million hours.

Contractors have not achieved labor efficiency goals because, in part, (1) programs for improving labor efficiency are not fully implemented and effective, (2) a higher-than-expected number of defects occur on each aircraft, (3) numerous changes are made to engineering drawings, and (4) work is transferred to Northrop's final assembly site rather than being completed as planned at Northrop, Boeing, or LTV.

Manufacturing Defects

Manufacturing defects are expected during fabrication and assembly but should decrease as workers gain experience and the aircraft design stabilizes. As expected, the number of defects decreased on each successive aircraft, but was larger than anticipated. Defect rates, as a percentage of production labor hours, improved for Northrop during 1990, as compared to 1989. At Boeing, where two major sections are manufactured, the defect rates increased in 1990. Defect rates in 1990 were affected by the discovery that incorrect fasteners were being installed at Northrop, Boeing, and LTV. The problem resulted in a reinspection of completed and in-process aircraft.

Changes to Engineering Drawings

Engineering drawings are the basis for all parts, tooling, and manufacturing plans. Through December 1990, Northrop, Boeing, and LTV released about 23,500 aircraft hardware engineering drawings. These were many more drawings than planned, and many were released much later than planned. Most of these drawings were released in 1988 and prior years, with only about 1,900 released in 1989 and about 1,800 in 1990.

Many changes to drawings are still occurring: a total of 122,700 changes through August 1990, including 29,500 in 1988 and over 22,000 in 1989 and 1990. A number of changes each year are minor and correct document errors; however, most of the changes in 1989 and 1990 were made to improve producibility, correct deficiencies, and reduce weight.

Work Transferred to Final Assembly Plant

The contractors' inability to complete work on the aircraft's major sections before shipping them to final assembly continues to be a problem. Estimates of the work to be transferred decrease with each aircraft, but individual aircraft goals for the amount of work to be transferred have increased each year. For example, on aircraft number 3 estimates of transferred work increased from 3,712 planned hours of production labor in 1988 to 7,153 planned hours in 1991, an increase of 93 percent. The planned hours are in "standard hours"—the time it should take a trained worker under ideal conditions to complete the task. Northrop estimated it would require about 401,000 actual production labor hours to complete that work based on Northrop's projected labor efficiency rates.

The transfer of work is required even though schedule extensions have lessened the need to transfer work. Several schedule changes between February 1987 and December 1990 provided 11 to 24 months of additional time for the contractors to complete work on the major sections before shipment to the final assembly site.

Production Management Programs

Northrop, Boeing, and LTV have made progress in establishing programs to identify problems and to take corrective actions. However, significant weaknesses remain. The schedule for developing production labor standards has slipped as aircraft delivery dates have slipped. Work measurement and quality assurance programs have been established, but they are not yet fully effective in identifying and correcting problems.

Furthermore, until recently, insufficient emphasis was placed on tool proving. To avoid production problems, the Department of Defense (DOD) requires that critical manufacturing tools be proven for accuracy prior to being used in production. In May 1990, after some delays, Northrop submitted a corrective action plan for tool proving, which was accepted. As of March 1991, Northrop said it was about 15 percent complete with tool proving, LTV was 63 percent complete, and Boeing was 92 percent complete. Air Force B-2 program officials said that they are satisfied that the contractors now have acceptable plans in place.

Recommendations

GAO is not making recommendations in this report.

Agency Comments

In its oral comments on a draft of this report, DOD agreed with GAO's findings in the report. However, it believes that the criteria GAO used to measure progress are more appropriate to aircraft in the production phase of a program rather than for evaluating the initial manufacturing effort of six B-2s being built under the development part of the program. DOD also disagreed with GAO's conclusions that the contractors may not be able to achieve predicted efficiencies at the planned, higher production rates unless the planning and manufacturing processes become more reliable.

GAO recognizes that the B-2 program is a unique program. As indicated in this report, the B-2 is a complex and expensive program where development aircraft are being manufactured to the precise tolerances needed to meet stealth requirements. Further, the development aircraft, unlike in prior aircraft programs, are being built on production or hard tooling. For these reasons, GAO believes that criteria, such as those used in production contracts, are critical to the program. GAO believes that after nearly 10 years of experience and development contract cost estimates of $18 billion, most of which has been spent, the criteria are relevant indicators for judging current progress and problems in development and initial production efforts. GAO's concern that the contractors may not be able to achieve predicted efficiencies at planned, higher production rates results from the continuing problems the contractors have had in meeting their cost and schedule estimates and manufacturing goals.

Contents

Figure

Abbreviations

DOD	Department of Defense
DPRO	Defense Plant Representative Office

Introduction

The B-2 bomber is a flying wing, four engine aircraft with two crew members and provisions for a third. Intended to be a long-range, multi-role bomber, it is capable of penetrating Soviet air defenses at high and low altitudes. The B-2 program has been in the full-scale development stage since 1981. The first B-2 aircraft was delivered from the production line in November 1988, and its first flight occurred in July 1989. The second B-2 was delivered and made its first flight in October 1990; the third B-2 was delivered in June 1991.

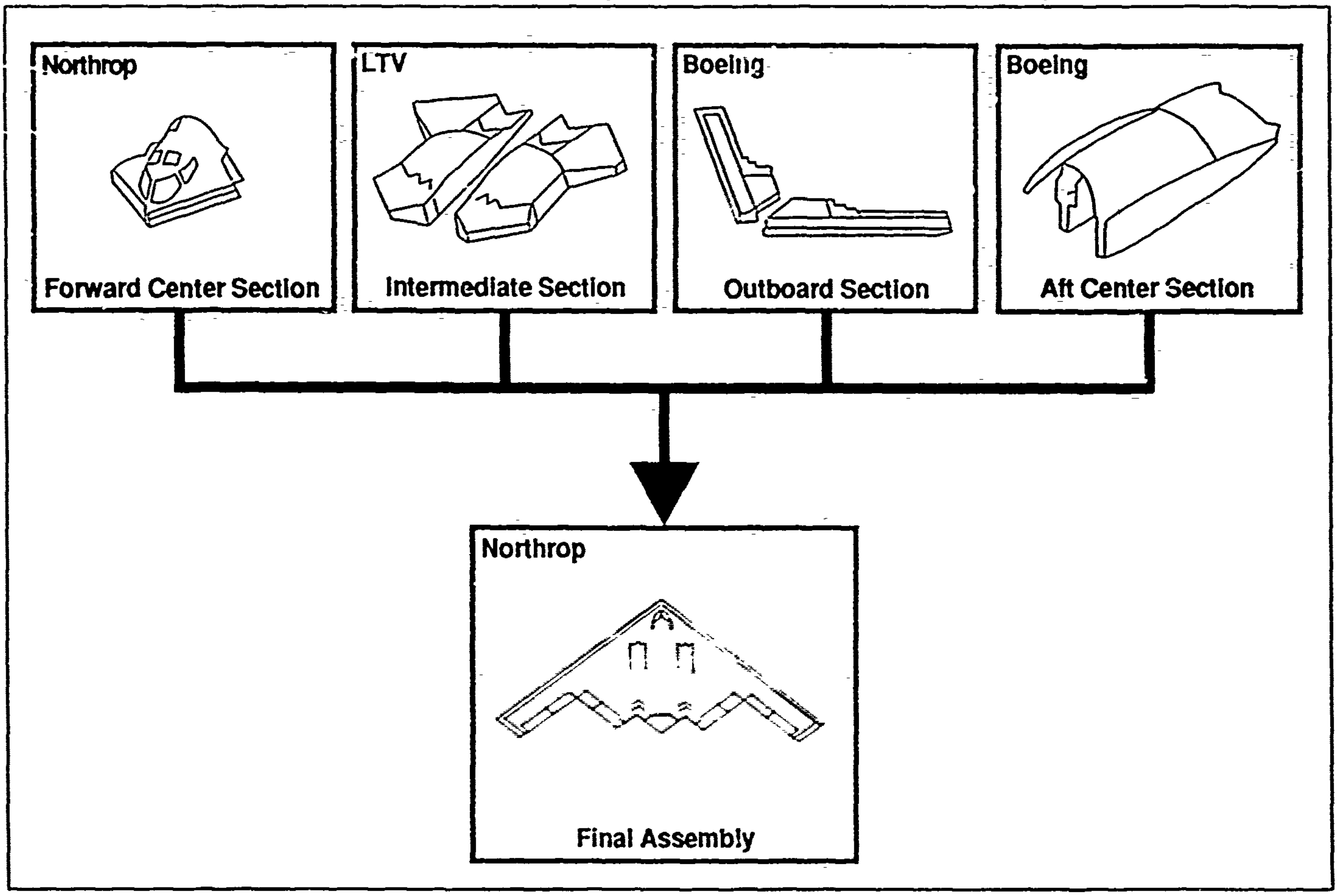
The B-2 bomber combines conventional and state-of-the-art aircraft technology and is designed to very precise specifications identified for stealth requirements. The design includes special shaping and use of radar-absorbing materials that are intended to reduce the radar cross section of the aircraft. These materials require new manufacturing technologies that are more challenging than those used on standard aluminum aircraft.

The B-2 bomber program is one of the most costly Department of Defense (DOD) programs. Its high development and estimated production costs have made it the subject of considerable controversy. In April 1990, the Secretary of Defense decided to reduce the number of aircraft to be procured from 132 to 75. The Secretary made the decision because of changing world conditions and the high costs of the B-2 and other defense programs.

Background

The program is managed by the Air Force B-2 System Program Office, Wright-Patterson Air Force Base, Ohio. The B-2 Division, Northrop Corporation, Pico Rivera, California, is the prime contractor and manufactures a major section of the aircraft. Major subcontractors include the Boeing Corporation, Seattle, Washington, and LTV Corporation, Dallas, Texas, which manufacture separate sections of the B-2 at their production facilities. Figure 1.1 shows the major sections of the aircraft manufactured by each contractor. Aircraft sections are shipped to the B-2 final assembly site in Palmdale, California, where Northrop is responsible for final assembly and systems integration.

Figure 1.1: Contractors Responsible for Manufacturing Major Sections and Final Assembly of B-2 Aircraft



Contracts Awarded

The Air Force began full-scale development in 1981 under a cost-plus-incentive-fee contract with Northrop for six development aircraft, two structural test articles, and tests and evaluation. Concurrent with development efforts, it began low-rate initial production under a fixed-price-incentive-fee contract with Northrop in late 1987 to manufacture five production aircraft.

Funds have been authorized for another five production aircraft—numbers 12 through 16. The Air Force is in the process of negotiating with Northrop for these aircraft, and B-2 officials estimated that negotiations will be completed by the end of summer 1991. Advanced procurement funding for five aircraft—numbers 17 through 21—was authorized through fiscal year 1990. The Air Force has granted Northrop authority to proceed with advance procurement efforts for these aircraft.

Program Changes During 1990

During fiscal year 1990, the program was restructured. The quantity to be acquired was reduced, schedules were extended, and new cost estimates were released. Subsequently, revised cost estimates recognized prior year funding shortages and additional costs due to cost growth and the need to further adjust the production schedule.

The Air Force had planned to buy 132 aircraft, with a peak production rate of 36 per year, for about $70.2 billion. In April 1990, the Secretary of Defense completed a major aircraft review of the B-2 and several other aircraft acquisition programs. He concluded that the B-2's total costs and the changes in world conditions allowed the pace and quantity of the program to be reduced. As a result, he proposed buying a total of 75 aircraft with a peak production rate of 16 per year by 1998. The 75 aircraft fleet is made up of 5 development aircraft that will be refurbished and 70 production aircraft. Also, the Secretary reduced the number of aircraft to be purchased in fiscal year 1991 from five to two aircraft. The revised estimate for the total cost of this program was $61.1 billion.

In July 1990, Air Force officials advised the Congress that the Secretary of Defense's changes to the program and prior unfunded requirements were not fully reflected in the $61.1 billion estimate. The Air Force's revised estimate, including the unfunded requirement and other adjustments, was $62.8 billion. In January 1991, the estimate was increased to $63.7 billion, reflecting a decision by the Air Force to extend production another year.

The President's fiscal years 1992 and 1993 defense budget submitted to the Congress on February 4, 1991, requested four aircraft and $4.8 billion in fiscal year 1992 and seven aircraft and $4.6 billion in fiscal year 1993.

Slips in Planned Delivery Schedules

The B-2 program has progressed slower than planned. Program delivery schedules have slipped a number of times since the start of the development program in 1981. Schedule slippages early in the program were due primarily to a major redesign effort, development taking more time than anticipated, and manufacturing problems. Between February 1987 and January 1991, schedule changes were made because of delays in delivering major sections of the aircraft to final assembly and delays in the final assembly process. Reductions to government funding and the number of aircraft to be purchased also affected schedules.

For example, major sections of aircraft numbers 3 and 4 were delivered to final assembly 10 to 18 months later than planned. Also in January 1991, Northrop's estimates of the time needed to complete final assembly of aircraft numbers 3 and 4 were 85 and 76 percent higher, respectively, than the estimates for these aircraft in February 1987.

In February 1987, Northrop was also planning that all six development aircraft would be delivered for testing by the end of 1990, but only two were actually delivered. Northrop delivered aircraft number 3 in June 1991. The remaining three development aircraft are scheduled for delivery in 1992. The 10 production aircraft are currently scheduled for delivery beginning with 2 aircraft in 1993 and 4 in each of the following 2 years.

Increases in Cost Estimates

Northrop's cost estimates for development and the low-rate initial production aircraft under contract have increased significantly. Between November 1987, when the low-rate initial production contract was awarded, and January 1991, the estimate to complete the low-rate initial production work increased by about $0.5 billion over the contract price. In a similar period, February 1987 to January 1991, Northrop increased the estimate to complete the development contract by $6.8 billion, to a total of $18 billion. Northrop identified these increases in its cost performance reporting to the Air Force. Additional increases to the low-rate production contract are expected due to contract cost growth and changes in schedule and plans for buying aircraft. The changes had not been placed on contract as of May 31, 1991.

Objectives, Scope, and Methodology

Since 1986, we have issued a series of reports on the B-2 program, including our first unclassified report in February 1990[1] identifying program schedule changes, cost estimate increases, and manufacturing problems being encountered by the contractors. These reports discussed other issues, such as a major redesign early in the program, without adjusting the schedule. This required the contractors to start manufacturing even though the design was not complete. The objectives of our review were to determine recent manufacturing progress and evaluate

[1] Strategic Bombers: B-2 Program Status and Current Issues (GAO/NSIAD-90-120, Feb. 22, 1990).

whether estimates for being able to produce aircraft at planned production rates can be met. To meet our objectives, we evaluated selected manufacturing indicators, including labor efficiency rates, manufacturing defects, changes to engineering drawings, work transferred to final assembly, and programs for production management.

In conducting our review, we examined Northrop's planned production delivery schedules and cost estimates and changes to these plans between February 1987 and January 1991. This period was selected because in February 1987 the Air Force anticipated that significant progress in completing the six development and five low-rate initial production aircraft would be achieved by the end of 1990.

We also examined calendar years 1989 and 1990 data for selected manufacturing indicators at Northrop, Boeing, and LTV, including labor efficiency rates, defect rates, changes to engineering drawings, and work transferred to final assembly. To determine whether contractors are complying with various Department of Defense standards for timely and effective production management, we examined reports of contractors' deficiencies, corrective actions planned, and the status of these plans.

We worked primarily at Northrop Corporation, B-2 Division, the prime contractor for the B-2 program. We visited Northrop's final assembly site located at Air Force Plant 42, Palmdale, California; Boeing Corporation, Defense and Space Group, Military Airplanes Division, Seattle, Washington; and LTV Corporation, Aerospace and Defense Company, Aircraft Division, Dallas, Texas. We also visited the B-2 System Program Office, Wright-Patterson Air Force Base, Dayton, Ohio, and conducted work at the Defense Plant Representative Offices, formerly the Air Force Plant Representative Offices, at the prime contractor and subcontractor locations.

We conducted our review from March 1990 to May 1991 in accordance with generally accepted government auditing standards.

Manufacturing Trends

Our current review of manufacturing trends shows progress is being made, but contractors are generally not meeting goals and are continuing to experience significant problems. Contractors are reducing the production labor hours needed to manufacture the aircraft, but not to the extent expected. The defects that occurred during the manufacture of aircraft numbers 1 to 4 have declined but are still numerous, and defect rates have not decreased as much as expected. The number of new engineering hardware drawings has leveled off, but a large number of changes to these drawings continue to affect manufacturing efficiency. Also, work transferred to the final assembly site from the contractors' major assembly facilities continues to be a problem.

Many factors have caused the companies to not meet the goals. According to Northrop officials, the manufacturing process is maturing and low efficiency results from nonstandard processes, parts shortages, transfer of work, and the concurrent development and production program. In addition, considerable time during final assembly was spent correcting defects and making engineering changes. As discussed in chapter 3, contractors' production management programs have not been fully effective in identifying and correcting problems in some significant areas. Another reason is that developing the B-2 is a complex and expensive process. According to Air Force officials, criteria have been established for measuring progress in development and early production that would normally apply to a more mature production program. Nevertheless, the program has been ongoing for nearly 10 years, and we believe these criteria are relevant indicators for judging progress and problems both in development and production.

Labor Efficiency Goals Not Being Met

Northrop, Boeing, and LTV are significantly reducing the number of production labor hours required to assemble each successive aircraft, but are generally not meeting the goals they set for themselves for improving labor efficiency (see table 2.2). Production labor hours identify labor that can be reasonably and consistently related directly to a unit of work being manufactured. For example, aircraft numbers 1 and 2 were assembled in about 4.6 million production labor hours, exceeding a combined goal of about 3.3 million hours by 40 percent. Aircraft numbers 3 and 4, based on current experience, will take about 3.6 million hours to complete, or about 30 percent higher than a combined goal of about 2.8 million hours (see table 2.2).

The failure to achieve labor efficiency goals is caused, in part, by programs for improving labor efficiency that are not fully implemented and effective, rework caused by a higher-than-expected number of defects on each aircraft, many changes to engineering drawings, and work being transferred to final assembly rather than being completed as planned at subcontractors' plants.

Production Labor

DOD policy requires major contractors to use work measurement programs to improve productivity and reduce manufacturing costs. DOD's experience has shown that where work measurement programs have been implemented and conscientiously pursued, excess manpower and lost time can be identified and reduced and other improvements can be made.

DOD guidance states that effective work measurement must be built on a credible foundation of standards. Accordingly, DOD policy requires major contractors and subcontractors to develop rigorous, engineering-based production labor standards to cover most of the direct labor to build each aircraft. These standards represent the time it should take a trained worker under normal circumstances to do an assigned task or group of tasks, such as drilling holes or installing parts. The standard times for some tasks can be seconds, so tasks are aggregated into standard hours required to build a part or complete a specified job. According to DOD, a sound standard hour base also establishes credibility in cost estimates, production schedules, performance reporting, and other areas.

In their work measurement programs, the contractors record how many standard production labor hours of work they have completed, or earned, compare it to actual production labor hours being charged, and report the results as a percentage of labor efficiency. If a contractor's actual hours equal standard hours, efficiency would be 100 percent; if two actual labor hours were needed for each standard hour, efficiency would be 50 percent.

Production Labor Efficiency Lower Than Estimated

Building the aircraft involves fabricating parts from raw materials, "subassembly" of parts into components and systems, assembly of major sections by Northrop, Boeing, and LTV, and final assembly by Northrop of the major sections and systems into the completed aircraft. Table 2.1 shows data Northrop provided on production goals and the percentage of labor efficiency achieved for different types of production labor.

Table 2.1: Labor Efficiency at Northrop, Goals Versus Actual

Figures in percent

	Goals	Actual
Fabrication	40.0	43.3
Subassembly	30.0	30.0
Major assembly	4.5	3.5
Final assembly	5.4	3.5

These figures are averages for the 6-month period ending June 1990.

The data show that efficiency goals were exceeded for fabrication and were being met for subassembly but were not being met for major and final assembly. With a 5.4 percent efficiency goal, Northrop expected to need about 18.5 production labor hours in final assembly to earn each standard hour. Because it was 3.5 percent efficient during the period, it actually needed 28.6 hours to earn each standard hour.

Northrop officials also said under the aircraft industry learning curves they had applied, they would not expect to achieve 100 percent efficiency unless 1,000 aircraft were produced. They project eventually achieving between 20 to 25 percent labor efficiency in major assembly and 9 to 11 percent labor efficiency in final assembly under the plan to buy 75 aircraft. This translates into a need for about 4-1/2 actual hours to complete each standard hour in major assembly and about 10 actual hours for each standard hour in final assembly.

The data the contractor reported to the Air Force under terms of the contract showed that higher numbers of production labor hours were needed to earn each standard hour from January through November 1990, particularly in final assembly. Northrop officials said these data included times charged for direct supervision and lead assembly workers that are included in reporting under terms of the contract but were not included in the data provided to us. For January through November 1990, for example, Northrop reported to the Air Force that final assembly was about 1.26 percent efficient and Northrop needed about 79.5 actual hours to accomplish each standard hour.

Northrop officials said that low efficiency in the beginning of a program results from nonstandard processes, part shortages, transferred work, concurrent development and production, and other factors. They said that higher efficiencies in fabrication and subassembly indicate a maturing of the manufacturing process, which has not yet occurred in final assembly. According to Northrop data, as of February 1991, 37 to 47 percent of the production labor hours on aircraft 1 to 3 during final assembly were used to correct manufacturing defects and make engineering changes.

Labor Inefficiencies Substantially Increase Production Labor Estimates

We reviewed Northrop, Boeing, and LTV data on goals and actual production labor hours needed for major and final assembly of aircraft numbers 1 and 2, which have been delivered. We also reviewed data on their goals and the hours they projected will be needed to complete aircraft numbers 3 and 4, then 90 percent and 83 percent complete, respectively, based on efficiency rates achieved through December 1990. The contractors' data are summarized in table 2.2

Table 2.2: Total Production Labor Hours Needed to Assemble Aircraft

Hours in thousands

Aircraft number	Goal[a]	Actual or estimate at completion	Difference	Percent
1	1,754	2,515	761	43
2	1,521	2,083	562	37
Total	**3,275**	**4,598**	**1,323**	**40[b]**
3	1,462	1,888	426	29
4	1,345	1,759	414	31
Total	**2,807**	**3,647**	**840**	**30[b]**

[a]This is a composite of goals established by Northrop, Boeing, and LTV for completion of their respective major aircraft sections and final assembly and not an overall B-2 program goal.

[b]This is the average percent.

Achieving the goals to complete aircraft numbers 3 and 4 would require improving efficiency rates. For example, the efficiency rate for final assembly of aircraft number 4 in November 1990 was about 3.6 percent. That rate would need to improve to about 4.2 percent for the same number of standard hours in order to meet the goal of 1,345,000 production labor hours. On aircraft number 2, interim rates were higher than the final rate but deteriorated as the aircraft neared completion and problems were identified that had to be corrected.

Manufacturing Defects

Significant numbers of manufacturing defects are being reported during assembly of each successive aircraft, resulting in considerable additional work (see table 2.3). A manufacturing defect is a condition or part on the aircraft that does not totally conform to an engineering drawing or specification requirements. In order of seriousness, a defective part may be used as is, used after minor or major rework, or scrapped. Manufacturing defects are expected during fabrication and assembly of an aircraft, but the quantity and severity should decrease as workers gain experience and the aircraft design stabilizes. Defect rates as a percentage of production labor hours at Northrop showed improvement during 1990, as compared to 1989. At Boeing the defect rates worsened in 1990 (see table 2.4).

Table 2.3 summarizes Northrop's projections of the defects at Northrop, Boeing, and LTV that are expected to occur during assembly of aircraft numbers 1 to 7. (Defects also accrue during fabrication of major sections of the aircraft at Northrop, Boeing, and LTV; however, fabrication defects are not recorded against individual aircraft.)

Table 2.3: Northrop Estimates of Assembly Defects (As of December 31, 1990)

Aircraft number	Estimated number[a] of defects at completion
1	141,600
2	131,000
3	117,600
4	95,200
5	90,300
6	80,200
7	71,200

[a]Northrop actually identified 122,700 and 113,100 assembly defects on aircraft numbers 1 and 2, respectively. Some types of defects were not recorded. Northrop has retroactively adjusted the totals up to 141,600 and 131,000, respectively. This adjustment made the data comparable for all seven aircraft.

Although the number of defects on each successive aircraft has decreased, it is still larger than expected. For example, for aircraft number 3 about 101,000 such defects were expected to occur, but the projection is now 117,600. Northrop officials said that the increase is due to a large number of engineering changes, a significant increase in inexperienced manufacturing personnel, and fastener problems. Also, aircraft number 3 represented a greater manufacturing challenge because it is the first aircraft that has an avionics unit installed that is representative of the production unit.

As shown in table 2.4, Northrop's defect rates per 1,000 production labor hours were lower in 1990 compared to 1989, while Boeing's rates were higher in 1990 than 1989.

Table 2.4: Average Assembly Defects Per 1,000 Production Labor Hours

Manufacturing process	Labor hours		Number of defects		Average defects per 1,000 hours	
	1989	1990	1989	1990	1989	1990
Northrop						
Fabrication	386,800	340,500	25.340	22,085	65.5	64.9
Forward center assembly	543,600	469,000	28,142	21,109	51.8	45.0
Final assembly	786,900	1,695,900	63,402	128,088	80.6	75.5
Boeing[a]						
Aft center assembly	427,200	886,100	33,808	85,534	79.1	96.5
Outboard assembly	665,000	1,417,100	42,551	99,453	64.0	70.2

[a]Data for 1989 were available only for May through December.

In determining an average defect rate per 1,000 production labor hours, we needed to know the numbers of production labor hours and either the number of defects or defect rates each month. LTV officials told us that they could not readily identify the numbers of production labor hours for each month. Therefore, we could not develop comparable data for LTV.

Northrop and Boeing officials said that the severity of the action required to correct defects is important. Northrop officials said that a comparison of data for 1988 through 1990 shows reductions in the severity of defects with more being corrected through minor rework. Boeing officials said that, normally, 76 percent of its defects are classified as minor because the part can ultimately be returned to engineering drawing requirements. The balance, 24 percent, is identified as rejections and normally result in the part being repaired to less than the original requirements or scrapped.

We also reviewed data Northrop collected on its top five defects in 1988 and 1989 and through June 1990. The data show that although progress has been made in reducing some specific types of defects, other types continue, and new types have surfaced. For example, foreign objects were a major problem in fabrication in 1988 and 1989, but not in 1990, while hole drilling has been a major defect each year.

During 1989, the contractors identified a number of problems with the various fasteners used on all of the aircraft being assembled. Each manufacturer identified installation of incorrect fasteners as a major reason for increases in the numbers of defects during 1990. In response to the problem, the Air Force and the three contractors implemented a fastener control program to determine the extent of the defects, identify the causes, and take corrective action. The program resulted in a reinspection of completed and in-process aircraft. Over 85,000 fasteners were reinspected. Of these, the contractors identified over 11,000 incorrect fasteners and reworked over 5,100 to engineering requirements.

Engineering Drawing Changes

A large number of changes to hardware engineering drawings is contributing to manufacturing inefficiencies. Engineering drawings are critical to the manufacturing process because they must be released in time to prepare all parts, tooling, and manufacturing plans. The availability of engineering drawings, and changes to them, affect labor efficiency because work cannot be completed if parts are not available, do not fit, or do not work as planned. The number of drawings and changes to the drawings should decrease as the design matures.

Through December 1990, Northrop, Boeing, and LTV released about 23,500 aircraft hardware design engineering drawings. This was many more drawings than originally planned, and many were released much later than planned. However, most of these were released in 1988 and prior years, with only about 1,900 released in 1989 and about 1,800 released in 1990.

The contractors are making significant numbers of changes each year to the engineering drawings that have been released, as shown in table 2.5. The number of changes declined in 1989 as compared to 1988, but data for the first 8 months of 1990 show that about 15,129 changes were made. On an average monthly rate that would amount to about 22,700 for the year or about the same as the rate experienced during 1989.

Table 2.5: Total Changes to Engineering Drawings Through August 1990

	Calendar year				
Contractor	1984 to 1987	1988	1989	1990 (to Aug.)	Total
Northrop	18,060	12,802	9,736	7,374	**47,972**
Boeing	21,103	10,909	8,995	5,323	**46,330**
LTV	15,929	5,817	4,212	2,432	**28,390**
Total	**55,092**	**29,528**	**22,943**	**15,129**	**122,692**

Our review of Northrop data showed that a number of these changes each year are minor in that the changes correct errors in engineering parts lists and notes. However, they still present problems. Most of the changes in 1989 and 1990 were made to help reduce the weight of the aircraft, to make it more producible, or to correct deficiencies. Also, considerable time was spent in final assembly making engineering changes. Defense Plant Representative Office (DPRO) officials located at Northrop told us in February 1991 that the number of engineering changes and drawings being released was still a concern because of the impact on labor efficiency, the manufacturing process, and producibility of the aircraft. Both Northrop and Air Force program officials identified high numbers of engineering changes as an underlying cause for some of the labor efficiency and defect problems.

Work Transferred to Final Assembly

Northrop, Boeing, and LTV continue to have problems completing all scheduled work on their major sections of the aircraft prior to shipping the sections to Northrop's final assembly site. Northrop began transferring work from Boeing, LTV, and its own plant to the final assembly site in an attempt to accomplish the work and minimize the effects on aircraft delivery schedules. Transferring work to the final assembly site is inefficient because it forces workers to travel to the site to complete installation of the systems and disrupts the flow of work planned for final assembly. The elimination of work being transferred to final assembly as soon as practicable has been an objective of all the contractors.

Even though transferred work has caused problems, the situation could have been much worse. The need for the contractors to transfer work has been lessened by changes to scheduled delivery dates. Extending delivery dates reduces the need to transfer work by providing additional time for the contractors to complete major sections on the development aircraft before shipping them to final assembly. Several schedule changes made between February 1987 and December 1990 provided an additional 11 to 24 months.

The April 1990 program revision reducing the total acquisition from 132 to 75 aircraft further extended manufacturing schedules. For example, the delivery date of aircraft number 8 was extended by about 8 months. Nevertheless, in March 1991, Northrop predicted it would not be able to deliver aircraft numbers 3 through 11 without some additional transferred work, as shown in table 2.6.

Table 2.6: Estimated Standard Hours of Work Transferred to Final Assembly

Aircraft	September 1988	August 1989	June 1990	March 1991
1	18,620	19,431	19,431[a]	19,431[a]
2	14,211	15,031	16,360	16,028[a]
3	3,712	4,228	6,258	7,153
4	3,204	3,500	5,125	6,446
5	2,284	3,000	3,797	3,804
6	1,600	2,900	3,546	3,269
7	[b]	1,325	552	1,501
8	[b]	971	0	1,022
9	[b]	811	0	913
10	[b]	696	0	712
11	[b]	696	0	465

[a]Data for aircraft numbers 1 and 2 are final. Data for aircraft number 3 and beyond are contractor estimates.

[b]Data are not available.

It is not clear whether improvements in efficiency or the program schedule extensions have had a greater impact on the expected decreases of transferred work. To the extent it is the schedule extensions, transferred work may continue to be a problem in the future if aircraft delivery schedules based on significant improvements in producibility are to be achieved.

The transferred work hours identified in table 2.6 are in standard production labor hours. Therefore, the number of actual production labor hours that will be required to complete this work will depend on contractors' labor efficiency rates. For example, Northrop estimated in March 1991 that the transferred work of 7,153 standard production labor hours for aircraft number 3 will require about 401,100 actual production labor hours to complete, or about 56.1 hours to earn each standard hour.

Production Management Programs Are Not Fully Implemented and Effective

Major contractors are required to have programs and systems that implement production management in disciplined and rigorous ways, provide evidence of effectiveness, and take timely action to identify causes and meaningful corrective actions when problems are identified. Progress has been made at Northrop, Boeing, and LTV in establishing the required programs and systems. However, the contractors' efforts are not fully effective yet, and progress has been less than expected in some significant areas.

Development of Engineering-Based Labor Standards

As discussed in chapter 2, DOD's guidance calls for contractors to establish a credible foundation of production labor standards. When in place, such standards will more fully identify the production labor required to build and produce the product. However, the schedule for Northrop, Boeing, and LTV to develop these standards has been tied to aircraft delivery dates and has slipped as these dates have slipped. In our opinion, not establishing standard hours could be contributing to contractors' difficulties in estimating labor efficiency goals, production schedules, and costs.

DOD policy requires major contractors to develop rigorous, engineering-based production labor standards to cover most of the direct production labor needed to build each aircraft. Called Type I, these standards identify the amount of time required to complete tasks, and the standards must be auditable and repeatable. Under DOD requirements, at least 80 percent of the standards used by Northrop, Boeing, and LTV in the B-2 program must be Type I. The purpose of 80 percent Type I coverage is to encourage contractors to develop a standard hour base that is credible and supportable by rigorous engineering studies. DOD considers the extent of coverage with Type I standards to be a measure of the soundness of the work measurement system. DOD also provides for Type II standards, which are standards that do not meet the criteria for Type I. DOD guidance allows the use of Type II standards initially, but contractors must develop schedules for converting to Type I coverage.

Northrop, Boeing, and LTV have identified a total of about 199,500 standards for the B-2 program. In order to meet the contract requirement (80 percent), the contractors will need about 160,000 Type I standards. As of January 1991, the contractors had a total of 96,900 Type I standards in place. Boeing had 48,800 or 77 percent of its requirements for Type I standards in place, Northrop had 29,000 or 38 percent, and LTV had about 19,100 or 32 percent in place. The more the contractors can achieve the 80-percent Type I standards, the better defined the work will be.

Northrop's low-rate production contract originally required that the 80-percent coverage of direct labor with Type I standards be achieved by early 1990. However, this was tied to a planned aircraft delivery date and, as the delivery date for the aircraft slipped, the date for having Type I standards in place has slipped. In March 1991, Air Force officials said they expect the Type I standards to be in place by the third quarter of 1992.

The Air Force program office said they allowed the contractor to tie Type I implementation to aircraft deliveries because expending labor developing these standards, while the design was undergoing constant change, was not cost-effective. They said a more stable environment was needed for conversion to Type I standards.

Correcting Labor Efficiency Problems

DOD guidance states that during development, emphasis should be placed on developing and implementing the technical and management tools, techniques, and processes necessary to support effective work measurement systems during production. Northrop, Boeing, and LTV have established such work measurement programs, but the programs are not yet fully effective in identifying and assessing problems and taking corrective actions.

As of April 30, 1991, DPRO officials at Northrop were still seeking improvements to these contractors' work measurement programs in such areas as the accuracy of data being reported, support for labor efficiency goals, and the adequacy of analyses and corrective actions where there are significant variances between goals and actual hours. For example, in a letter of concern to Northrop in July 1990, these officials observed a long-standing lack of improvement in the quality of variance analysis being done and said that comparing effectiveness of current reports against ones written in 1986 showed little improvement. They said most analyses were expressed in general terms and lacked sufficient detail to be useful to management and did not identify root causes. The proposed corrections did not indicate what actions were needed to prevent problems from recurring. Northrop provided a detailed corrective action plan in September 1990 showing how and when it would improve the effectiveness of their analyses. Improvements were also being called for in Boeing and LTV work measurement programs. The

Air Force said that it is working with the DPRO and each of the contractors to make sure work measurement systems are effective. In April 1991, the DPRO noted some improvements but said effective implementation is still a problem.

Correcting Manufacturing Defects

DOD policy requires Northrop, Boeing, and LTV to establish programs that identify quality problems and take timely corrective actions. Corrective actions include, at a minimum, determining the extent and causes of defects, analyzing trends, introducing required improvements, and monitoring effectiveness.

According to Northrop and DPRO officials, these programs at Northrop, Boeing, and LTV collect and analyze data, establish some targets, and assign corrective action teams to resolve significant defect problems. However, the programs have not achieved a level of effectiveness acceptable to the DPRO. For example, the contractors had not established targets to initiate corrective action investigations based on large numbers of defects identified. In September 1990, DPRO officials indicated that Northrop has been slow to act on these problems and called for an effective corrective action plan by Northrop to address chronic problems in manufacturing. By April 1991, Northrop had revised its procedures to require the investigation of chronic manufacturing problems. However, it was too early for the DPRO to determine the effectiveness of these procedures.

Furthermore, DPRO officials at Northrop have reported finding increasing numbers of defects. In December 1989, they said the increased deficiency rate indicated that inspection and manufacturing departments were performing with a lack of attention to product integrity and ignoring a "build it right the first time" methodology. In May 1990, they reported that although Northrop had agreed to a major corrective action plan, the plan had yielded poor results, and Northrop had failed to meet certain milestones. Northrop reported in June 1990 on corrective actions taken, including issuing new procedures and instituting needed training. DPRO officials said in October 1990 that they would continue to monitor Northrop's defect rate and assess the effectiveness of its corrective actions. In March 1991, Northrop officials said that, as one measure of progress, they had eliminated a backlog of delinquent corrective actions evident in 1989 and 1990.

Northrop also reported in January 1990 that it had reviewed Boeing's corrective action process and had identified some improvements and a number of continuing concerns. At that time, Boeing was revising its corrective action process. In October 1990, the DPRO at Boeing reported that the new corrective action process was not complete or operating efficiently and was confusing and complicated. In February 1991, the DPRO reported that they were still concerned.

Air Force program officials said in March 1991 that the contractors have made many changes and enhancements over the last year. They said improvements have been made in data gathering methods so that recurring defects and different defects with the same root cause (e.g., chronic manufacturing process problems) can be more easily identified. Other improvements have been made, and the Air Force expects corrective actions to be more effective in 1991.

DOD Requires Critical Tools Be Proved Prior to Use in Production

To avoid production problems, DOD requires that critical manufacturing tools be proven for accuracy prior to being used in production. These tools include production jigs, fixtures, tooling masters, templates, patterns, and devices used to inspect other tools and parts. Other tooling that may pose significant risk to production or has not been proven satisfactory is also to be considered for verification, testing, proofing, or demonstrations to provide confidence that tooling will not adversely affect quantity production. According to DPRO officials at Northrop, tool proving must be rigorous and demonstrate that the tool is safe, can produce the part to the required dimensions and will repeatedly produce the same part.

Unlike other aircraft programs, B-2 development aircraft are being built using production, or "hard," tooling; essentially, the tooling is maturing as the aircraft is being developed. Development aircraft would normally be built using "soft," less expensive tooling that could more easily be changed as the aircraft design matures. Northrop said the design of the B-2 tooling was accomplished with 2- and 3-dimensional computer graphics, which provided electronic checking of all designs. In addition, they said each of about 8,200 designed tools was inspected by Northrop's quality assurance office and, where required, checked back to the master tools. Both they and the Air Force B-2 program office decided from the beginning to build all aircraft, even development vehicles, using full-rate production tools because of the requirements for precision in stealth products.

In November 1988, the DPRO notified Northrop that the B-2 program procedures for tool proving were not adequate. Northrop submitted a corrective action plan, but in December 1989 the DPRO expressed concern to Northrop about its lack of progress in establishing a sound tool proving procedure. It observed that based on production schedules at that time, nine aircraft would be through assembly before the initial phase of the agreed to tool proving effort would be completed. In May 1990, the DPRO also completed a major tooling review. It informed Northrop that its review of a sample of 133 interchangeable parts revealed many problems directly related to poor or missing tools or the production of bad parts.

DPRO officials said the lack of progress was due to a Northrop management position that the tools in the program were generally accurate and any problems identified could be fixed on a case-by-case basis. Therefore, Northrop did not require its employees to systematically prove tools.

However, when new Northrop managers were assigned for operations and manufacturing in mid-1990, they agreed to prove all tools necessary to meet DOD requirements. In May 1990, Northrop submitted a revised corrective action plan for tool proving. It recognized its tool proving procedures did not satisfy DOD requirements and that it was not adequately controlling tool proving of major subcontractors. Northrop subsequently revised its tool proving procedures, which the DPRO accepted.

As part of the plan, Northrop agreed to use its new procedures to prove 421 tools of the type the major review found to have problems. It identified about 3,200 tools that need to be proven at Northrop. DPRO officials said that major jigs will not be proved for some time and not until after a number of additional aircraft have been produced. They said the goal is to have Northrop prove all 3,200 tools on the list by the time rate production of about 1 aircraft per month begins. In August 1990, the DPRO at Northrop informed its counterparts at Boeing and LTV of efforts to implement tool proving, saying that Northrop would be tasking the subcontractors to become very serious about tool proving as a means of controlling scrap and rework, ensuring quality, and reducing production costs.

Northrop officials told us that they reviewed Boeing and LTV written procedures for tool proving guidelines in August 1990. Although they did not test any tool proving actions, they considered the subcontractors' programs to be adequate. According to Northrop in March 1991, it was 15 percent complete with tool proving, LTV was 63 percent complete, and Boeing was 92 percent complete.

Air Force B-2 program officials told us that they are fully satisfied that Northrop, Boeing, and LTV now have acceptable tool proving plans in place.

Conclusions, Agency Comments, and Our Evaluation

The manufacturing trend data we examined show that Northrop and its major subcontractors have been unable to meet their goals and continued to experience problems in reducing production labor hours, numbers of defects, engineering drawing changes, and work transferred to the final assembly site. These data indicate that the contractors have not achieved the manufacturing stability they had hoped to achieve by now.

The contractors have established production management programs to identify and correct these types of problems. However, the programs had not been fully implemented at the time of our review and the contractors' had made less progress in implementing them than DOD expected. Therefore, we believe that until the manufacturing trends and the production management programs become more reliable, there is a high risk that Northrop and its major subcontractors will not be able to achieve predicted efficiencies at the planned, higher production rates.

DOD Comments and Our Evaluation

We provided a draft of this report to DOD and solicited written or oral comments. Although we did not receive written comments, DOD officials told us that they generally agreed with the findings of the report. However, they stated that the criteria we used to measure the contractors' progress were more appropriate to aircraft in the production phase of a program than for evaluating the initial manufacturing effort of the six B-2s being built under the development part of the program. The officials disagreed with our conclusion that the contractors may not be able to achieve predicted efficiencies at the planned higher production rates unless the planning and manufacturing processes became more reliable.

The B-2 program is unusual in many ways. For example, the development aircraft are being built using production, or hard, tooling. In other aircraft programs, this kind of tooling is not used until the production phase. In addition, most of the B-2 development aircraft are being manufactured to precise tolerances needed to meet stealth requirements because they are intended to be a part of the operational fleet. Also, the contractor and the Air Force use the production indicators described here to demonstrate manufacturing improvements and to identify problem areas that need attention. After nearly 10 years of experience and a development contract cost estimate of about $18 billion, we believe the manufacturing criteria used are relevant indicators for judging current progress and problems in development and initial production efforts. We believe that our concerns about the risk involved in any DOD assumptions that Northrop and its major subcontractors will be able to achieve predicted manufacturing efficiencies are well supported by the problems they have had in meeting their cost and schedule estimates as well as manufacturing goals.