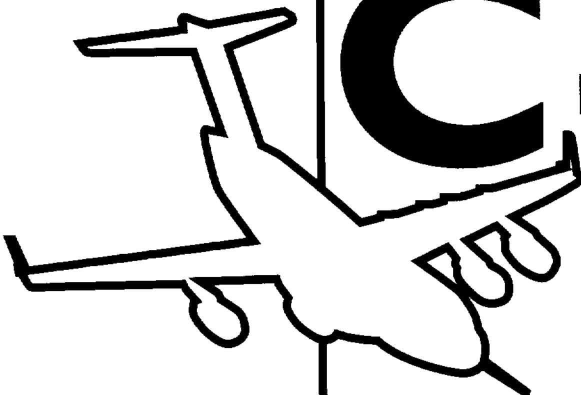
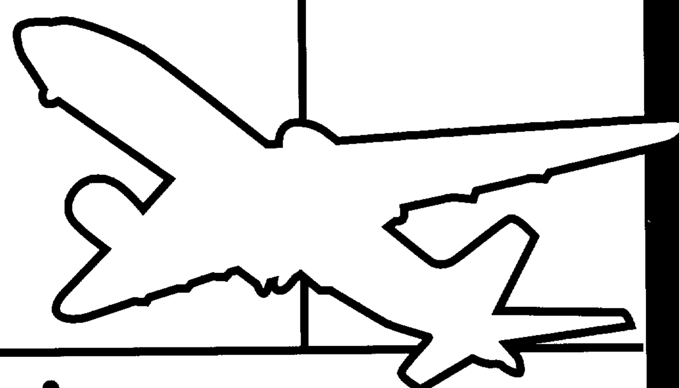
The DOD C-17 versus the Boeing 777





A Comparison of Acquisition and Development

A. Lee Battershell

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versus
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A Comparison of Acquisition and Development

by A. Lee Battershell

NATIONAL DEFENSE UNIVERSITY
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To those whose help, support,
and encouragement made
this book possible:

my family—the Battershells,
the Goodwins,
and the Arringtons—
and my boss, Jackie Crawford

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Preface

This study—a comparison of the Boeing and Department of Defense approaches to developing and producing an airplane—was undertaken to find out why the DOD approach results in development and production programs that span 11 to 21 years, while Boeing develops and produces planes in 4 to 9 years. The C-17 and 777 were chosen because both use similar technology levels.

Why *does* it take DOD longer than private industry to develop and produce a new plane? While there is no one answer, differences in commitment and focus are pervasive in each organization's management methods, technology philosophy, structure, mission, needs determination, and funding.

Boeing President Philip Condit emphasized in an interview with the author that while Boeing's latest transport plane, the 777, is phenomenal, it does not represent a technology breakthrough: "Designing the airplane with no mock-up and doing it all on computer was an order of magnitude change." The design process using CATIA—computer-aided, three-dimensional, interactive application—helped Boeing produce a better plane and reduce future costs. Boeing invested heavily in CATIA; completely reorganized its management approach, adopting a system of Continuous Quality Improvement (CQI); and used design-build teams composed of designers, builders, suppliers, and customers. CATIA allowed design-build teams to work together and identify problems before production; the teams could see how parts fit together and whether there was room to fit all the parts. Once everyone agreed on the approach and the design, Boeing committed to producing the 777.

Program management for the C-17 did not enjoy the same dedicated focus. Vacillation from the top in leadership and direction marred progress for the C-17 program, which began in the early 1970s as the Advanced Medium Short-Range Take Off and Landing (AMST) transport, a tactical plane primarily for short flights. Toward the end of the 1970s, leaders decided they really wanted a tactical plane with strategic capabilities (one that could travel longer distances), then decided they wanted a strategic plane, then refocused on a strategic plane with tactical capabilities that could carry more payload. Because DOD had already performed several tests on the tactical AMST to prove short take-off and landing capabilities, top leaders did not believe more testing was necessary for the strategic plane. Also, because top leaders knew exactly what they wanted, there was no reason for concept exploration, demonstration, and validation.

While leaders in the 1980s agreed the United States needed more strategic capability, they believed adding updated models of existing planes would provide the needed strategic airlift capability much sooner than the C-17. The U.S. Government purchased more C-5s from Lockheed and awarded McDonnell Douglas a low-level development contract, which essentially put the C-17 development on hold until 1985. After the government approved the C-17 for full-scale development, seven reorganizations within DOD and McDonnell Douglas, plus three significant labor turnovers, adversely affected C-17 development and production. In addition, both DOD and Congress continued to question whether the Air Force really needed the C-17.

As the reader will learn in the following chapters, the reasons it took DOD longer to produce the C-17 than it took Boeing to produce the 777 are many and complicated. The basic explanation is the difference in commitment and focus. The priorities of each presidential administration affected DOD commitment to the C-17. At lower levels, lack of policy direction and funding reflected a wavering commitment. Boeing viewed the 777 as important to its mission and remained committed throughout development. A stable management structure supported Boeing's constancy of purpose. Boeing made a concerted effort to determine what kind of airplane to build and researched the best methods to build it. Politics interfered with the DOD process to determine need and hindered its ability to stay focused on the C-17. In the end, strong leadership during the Clinton administration from General Ronald Fogleman, John Deutch, Under Secretary of Defense (Acquisitions), and Paul Kaminski brought the program to fruition.

The DOD C-17
versus
the Boeing 777

PART I

1. Introduction

In the time it has taken the Air Force to buy the C-17, Boeing has designed, tested, and produced the 747-400, 757, and 767, and has recently rolled out the new 777.

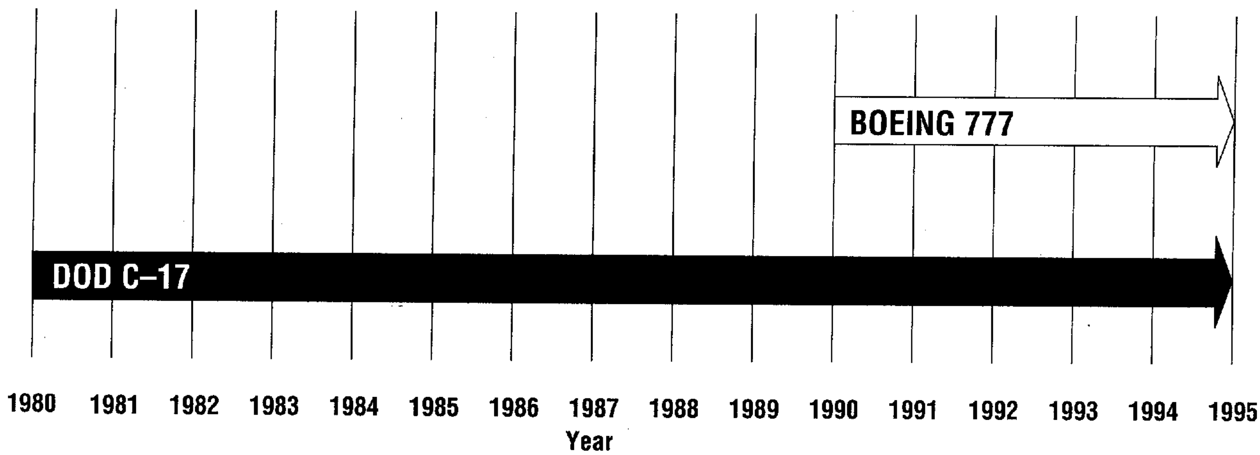
Senator Jeff Bingaman (D-NM)[1]

In 1995, two significant aircraft made aviation history as they lifted off runways in different parts of the country. One, the Boeing 777, a wide-bodied, two-engine passenger plane created by private enterprise, made its first commercial transoceanic flight in June 1995. The other, the C-17, a military cargo plane created by the Department of Defense (DOD), received initial operating certification in January 1995. Each aircraft exhibited innovative design and high-tech features, but neither boasted an unprecedented level of untried technology. They were similar in many ways—both intended to ferry passengers or cargo with appropriate ease from one point to another. Yet each of these aircraft had a unique story of development—one a straightforward narrative of almost 9 years, the other a complex, convoluted yarn spanning 24 years. Even after Congress approved funding, the C-17 time table was greater than the Boeing 777 (figure 1). This study compares and contrasts the histories of these two aircraft to determine why a private-sector company was able to develop and produce the 777 in significantly less time than the government took to develop and produce the C-17.

The 777 originated in the late 1980s during market research by the Seattle-based Boeing Company. To determine what the market would bear, Boeing solicited input from commercial airlines, asking them what they wanted in a new aircraft. Once Boeing determined the type of aircraft to build, the company set a timeline, initiated innovative development procedures, and then followed a set of guidelines to produce the aircraft.

The C-17 began in the early 1970s as the Advanced Medium Short Range Take Off and Landing (AMST)—a prototype for a tactical cargo airlifter. At that time, the Air Force was looking for a carrier to help upgrade its tactical cargo fleet. However, just as prototype testing reached completion, military leaders questioned the limited strategic aspects of the aircraft and began lobbying for an aircraft that included strategic capabilities. DOD created the C-17 in the AMST shadow—claiming short-takeoff-and-landing technology proved on the tactical AMST would work on the strategic C-17. Preliminary steps leading to the C-17 program started in the late 1970s. After heavy lobbying by President Carter and Defense Secretary Brown, Congress approved funding in 1980. Throughout the 1980s and early 1990s, the C-17 continued to experience erratic backing, technical problems, and contractual disagreements. Delays, cost increases, and questions of unethical management at DOD and McDonnell Douglas centering on the C-17 caused the public and

FIGURE 1. Development Timeline for the Boeing 777 and the DOD C-17 from Point of Approval* to Initial Operating Capability



*For the Boeing 777, approval was based on the date the Boeing board of directors approved the program. For the C-17, it was based on the date Congress voted funding.

Congress to question whether or not DOD could efficiently manage a major development program.

Problem

In the early 1990s, demands from the American public for more responsive government prompted Vice President Al Gore to initiate a national review to "make the entire Federal Government both less expensive and more efficient, and to change the culture of our national bureaucracy away from complacency and entitlement toward initiative and empowerment."[2]

In 1993, Secretary of Defense Les Aspin directed a review to identify savings and improve efficiency in DOD. In his final report he said:

> We must restructure our acquisition system to compensate for the decline in available resources for defense investment and to exploit technological advances in the commercial sector of our economy more effectively. . . . The existing DOD acquisition system is based on outdated management philosophies and organization structures. . . . There are so many hand-offs of responsibility for any one acquisition program that accountability is difficult, and the ability of any one person or organization to change the process is small.[3]

Many problems associated with the C-17 are directly or indirectly attributed to flaws in the acquisition process. This study will trace development of the C-17 in comparison with the Boeing 777 to discover differences in the process by:

- Summarizing the historical background of the Boeing company and DOD
- Analyzing and comparing the different approaches of Boeing and DOD to program management
- Examining the approach of Boeing and DOD to technology

- Comparing the organizational structure of Boeing and DOD to determine if, as many argue, the DOD structure encourages duplication and inefficiency
- Comparing the mission of the C-17 with that of the Boeing 777
- Investigating the ways DOD and Boeing determine need
- Comparing the steps Boeing and DOD followed to secure approval and funding for their programs.

Impact

Studies of acquisition over the past 25 years reveal that the DOD way of conducting business resulted in programs that spanned 11 to 21 years[4] and that by the time weapons systems are finally delivered, the technology is outdated.[5] Also, the lengthy time to develop weapon systems is directly linked to a doubling of the planned costs. Given this history, the C-17 case is not that unusual. If DOD continues using the same methods, costs will continue to climb. DOD must learn to maintain the superiority of the American military at less cost with more efficient methods. Therefore, whatever lessons we can learn from a comparison of the C-17 and the 777 can have a major impact.

Notes

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2. A Contrast in Backgrounds

[In] Desert Storm . . . *we had an advantage in people, an advantage in readiness, and an advantage in technology. . . . We need to preserve that part of the industrial base which will give us technological advantage, but we have to do it at a reduced cost and increased efficiency in procurement.*

William J. Perry, former Secretary of Defense[1]

The air combat and transport superiority the United States enjoys today is derived in part from efforts of pioneers such as the Wright brothers and from continuing joint ventures between private industry and the military. Private industry giants such as Boeing, McDonnell Douglas, Lockheed-Martin, Northrop, and many more worked hand in hand with the military to develop technology respected throughout the world.

The government influences Boeing's growth by its contracts with and the laws regulating the company and the contracting process. Government influence on commercial companies is important because DOD has no other way to build aircraft or any other defense system. Its strength as a national defense agency is derived in part from the health of its relationships with the commercial sector.

The Boeing Company

History

Incorporated under the name of Pacific Aero Products in 1916, Boeing changed its name to Boeing Airplane Company in 1917, when it built its first airplane—the B&W trainer, designed in 1914 by William Boeing and his friend, Conrad Westervelt, who was in the U.S. Navy. Ten years later, Boeing won the contract to carry the U.S. mail under its newly formed company, Boeing Air Transport, Inc. In 1928, Boeing bought Pacific AirTransport and took over routes along the Pacific coast. A year later, William Boeing and Frederick Renschler, president of Pratt and Whitney engine manufacturers, set up a holding company called the United Aircraft and Transport Corporation. The holding company bought Chance Vought, manufacturer of a Navy fighter-observation aircraft; Hamilton Aero Manufacturing Company and Standard Steel, propeller manufacturers; Sikorsky, Northrop, and Stearman, aircraft builders; Stout Airlines; and other businesses. It also established Boeing Aircraft of Canada, Ltd., and opened the Boeing School of Aeronautics in Oakland, California. In the 1930s, stringent antitrust laws caused Boeing to divest its airline and engine manufacturing subsidiaries and concentrate on building airplanes.

From the 1920s, when Boeing began carrying U.S. mail, until the 1980s, Boeing corporate development was strongly tied to its success in bidding for, winning, and successfully executing U.S. Government contracts (80 percent plus). In the 1980s, contracts with the government became less lucrative, and Boeing began to look for ways to increase the commercial side of its business; the 777 was a big step in that direction. In 1994, Boeing's commercial business represented 80 percent of its work; government business represented just 20 percent.

The 777

On April 9, 1994, Boeing rolled out its 22nd commercial airplane—the Boeing 777; two months later, on June 12, the aircraft flew its maiden flight. On May 30, 1995, the Federal Aviation Administration (FAA) certified Pratt and Whitney engines for extended twin-engine operations, and on June 7, 1995, United Airlines flew the first 777 commercial transcontinental flight.[2] That was approximately 5 years after the Boeing board of directors approved development of the 777, and almost 9 years after Boeing approved initial research for its new plane (figure 2).

The 777 was the first completely computer-designed aircraft, going from drawing board to production with no mockup. Even though Boeing used a fly-by-wire control system; advanced liquid-crystal flat panel displays; a two-way digital data bus; an aerodynamically efficient airfoil wing; two powerful thrust engines; and new composite materials in the 777, Boeing President Philip Condit did not consider these improvements breakthroughs:

> Fly-by-wire is interesting. . . . But if you step back, our autopilots are fly-by-wire and always have been. We've given it a little bit more authority [in the 777]. The 737 right from the start had what we called a stick steering mode in which you moved the control wheel to make inputs to the auto pilot. [These are] not an order of magnitude change. Designing the airplane with no mockup and doing it all on computer was an order of magnitude change.[3]

The Department of Defense

> Aerial transportation has revolutionized modern warfare. Through airlift, it has become possible to move troops and supplies directly and rapidly into the battle zone. Nevertheless, the potential advantages of airlift were neither readily apparent to many military leaders nor initially feasible, because of the technical limitations of early flying machines. As a result, the development of the U.S. military airlift system followed an evolutionary course.[4]

Military Air Transport History

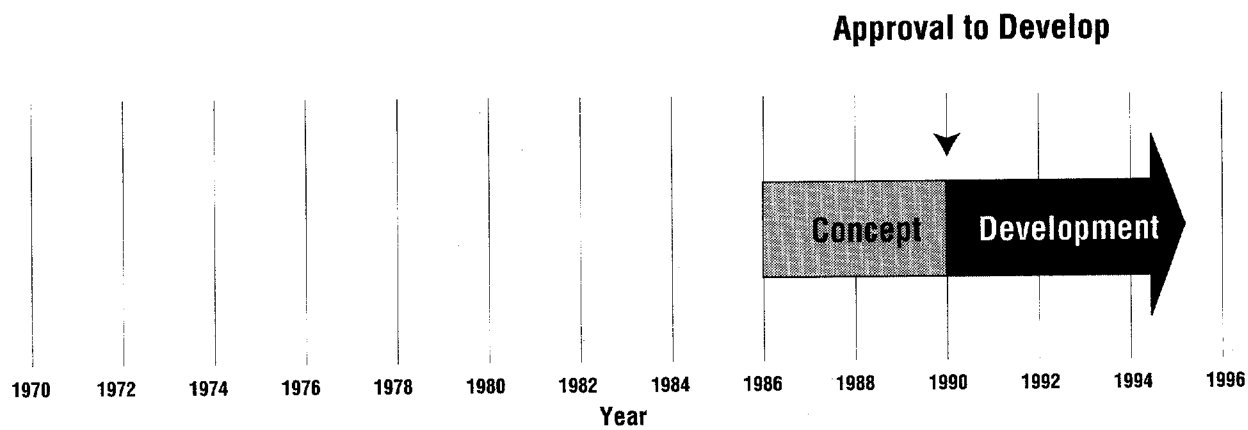
As early as World War I, the Army Signal Corps used airplanes to transport cargo and personnel. However, the military did not have a dedicated cargo plane until the late 1920s, when Douglas Airplane Company produced the first C-1. Before this, the Army used bombers and whatever else it had available for cargo. In 1995, the U.S. Transportation Command had 300 tactical and 552 strategic airlift assets that included but were not limited to the C-141 (226), the C-5 (118), and the C-17 (13).[5]

During World War II, airlift proved essential to deploy air, land, and sea forces. Units cut off by combat were either resupplied or withdrawn by air within hours. Vitally needed spares were moved in real time to restore combat capabilities. In the Normandy landings, air transports carried paratroopers over enemy defense lines to assault rear areas. In the closing days of the war, over 10,000 transport aircraft were in service.[6] Speaking to the 1947 National War College class, Major General Robert M. Webster, Commander of the Air Transport Command, stressed the importance of the transport service:

> I feel that we have come out of that war with an additional type, the transport plane, and that we should think in terms of bomber-fighter-transport—since they are all equally important—and they must be properly balanced to each other if we are to be prepared to conduct successful war operations.[7]

On July 26, 1947, Congress passed legislation creating an independent Air Force. Executive

FIGURE 2. Timeline for the Boeing 777, from Concept to Initial Operating Capability



order 9877, signed the same day, spelled out four missions for the new military department: strategic bombardment, air support of land retained forces, air defense, and air transport.[8] The new service proved its capabilities, from June 1948 to May 1949, when U.S. and allied military air carriers bypassed a Soviet blockade to transport over 2 million tons[9] of milk, flour, medicine, and other high-priority cargo to Berlin. The Berlin airlift took its toll, however, by pushing carriers beyond the miles recommended for safe flight. In June 1950, when the United States responded to the North Korean invasion of South Korea, the Military Air Transport Service (MATS) had to rely on commercial contractors to fly more than 40 percent of the missions on the United States- Japan shuttle.[10]

Both World War II and the Korean War confirmed the United States could not maintain enough airlift capability in its military to respond to wartime requirements. In 1950, the chairman of the National Security Resources Board requested a study of wartime airlift requirements. James H. Douglas, who chaired the study, recommended the government bear costs for commercial airlines to maintain 587 aircraft modified for military use. The modifications made the aircraft heavier, thereby increasing the operating expense for commercial airlines. The military agreed to assume additional costs to commercial airlines and inaugurated the Civil Reserve Air Fleet (CRAF) in 1952. Financial arrangements for CRAF evolved until, in the 1990s, rather than require the government to pay for added costs, carriers committed aircraft to CRAF in exchange for contracts to carry cargo during peacetime.

Beginning in 1963, congressional and military leaders began to debate whether to combine tactical and strategic resources. Those who were against consolidation argued if tactical resources were combined with strategic resources, the Air Force would neglect tactical resources.[11] Nevertheless, on August 29, 1974, Air Force Chief of Staff General David C. Jones announced consolidation of tactical and strategic military airlift under the Military Airlift Command (MAC), "to achieve better integration of overall airlift, strategic and tactical airlift assets."[12]

In 1986, the Packard Commission recommended a single unified command for all forms of transportation. The recommendations of the commission were incorporated into the Goldwater-Nichols Reorganization Act, passed during the Reagan administration. In 1987, President Reagan established the U.S. Transportation Command

(USTRANSCOM) to integrate global air, land, and sea transportation. Each of the service secretaries, however, had a high degree of control. During *Desert Shield* and *Desert Storm,* this control led to a breakdown in the unified command structure. As a result, in February 1992, Defense Secretary Richard Cheney designated the commander in chief of the Transportation Command as the single manager for defense transportation, thereby assigning all service transportation components to that command in war and in peace.[13]

On June 1, 1992, the Air Force deactivated MAC and created the Air Mobility Command (AMC). The AMC acquired tankers for refueling strategic aircraft in flight and relinquished control of tactical assets. AMC dissolved the 834th and the 322d Airlift divisions at Hickam Air Force Base in Hawaii and units at Ramstein Air Force Base in Germany and transferred all tactical C-130 fleets to PACAF and USAFE. Strategic assets such as the C-5 and C-17 remained with AMC. The new command's charter predicted "integration of airlift with tankers will better enable the Air Force to provide global mobility and reach while enhancing rapid response and the ability to operate with other services and nations."[14] The new reorganization effectively separated tactical and strategic assets once again.

DOD Acquisition Process

> Respondents think almost 50 percent of the annual defense budget is lost to waste and abuse . . . [and that] aerospace contractors are suspected of a proclivity towards fraud.[15]

The defense acquisition program provides DOD with the tools and supplies it needs to conduct day-to-day business, protect resources, and invest in infrastructure. Many, including Norman R. Augustine, president of Lockheed-Martin, believe the acquisition program is in need of radical reform.[16] Augustine attributes problems in the process to too many controls and regulations:

> The goal becomes one of complying with the regulations, not solving the problem. . . . It is ironic that when a truly important new system comes along, it is invariably pulled from the clutches of the acquisition process and afforded special treatment. Examples range from Vietnam-era gunships to the Trident submarine, [and] from the military space program to SDI and Stealth.[17]

How did the acquisition process become so cumbersome that a transport such as the C-17 takes 24 years to build? A general perception of corruption was certainly a factor. It created a wary Congress and public that cried for accountability. For example, in September 1995, the Justice Department took McDonnell Douglas to court for defrauding the United States by routinely mischarging labor costs on a number of DOD airplane contracts, including the C-17.[18] Other abuses have proven more onerous. After each bout of corruption, regulations, procedures, and more oversight were initiated as protection against further fraud. Additional regulations and procedures invariably extend acquisition timelines. Many waste and fraud reports accompanied defense spending in the 1980s. The press reported overruns of $1.5 billion for the Sea Wolf and $200 million for each B-1 airplane. There were stories of $400 hammers, $7,000 coffee pots, and criminal conduct by some defense contractors[19] With each scandal, Congress held widely publicized hearings and imposed more rigid controls and more oversight over the acquisition process. President Reagan referred to his inspector generals as "junkyard dogs" and encouraged them to root out fraud and abuse. Deputy Defense Secretary Frank Carlucci announced

32 initiatives for improving the acquisition process. Reforms made in the 1980s included the 1982 Prompt Payment Act, which required the government to pay interest on late payments; the 1984 Competition in Contracting Act, which reduced the number of exceptions for noncompetitive procurement; and the 1986 Goldwater-Nichols Reorganization Act, which consolidated parts of the military and initiated other changes to the acquisition process.[20]

During *Desert Shield/Desert Storm*, DOD tried with little success to raise the small-purchase threshold for contingency operations. Especially troublesome was DOD inability to purchase commercial items.[21] For example, Rear Admiral W. L. Vincent, in his *Report of the DOD Acquisition Law Advisory Panel*, reported a company could not sell an encryption radio to the government because it did not sell enough of the radios to the public and could not afford to provide the cost data DOD required. The Army required certification that the company was selling to the government at the lowest possible price. The company could not make such a guarantee because its products were priced on the open market. Because of the Army's inability to waive certification requirements, Japan bought the radios for Americans to use in *Desert Storm*.[22] Such absurdities helped convince an already wary public that the procurement system was ineffective. In the words of Senator Carl M. Levin (D-MI), the acquisition system is "an almost impossibly complex and unwieldy system for people who want to do business with the Federal Government."

Levin introduced S-1587, a 300-page bill to amend 200 separate procurement-related provisions of the U.S. Code for Acquisitions. The bill's stated objective was to streamline the acquisition process by eliminating or revising 300 of 600 laws, to facilitate government purchase of commercial products, and to improve the ability of small businesses to compete for contracts.[23]

After months of negotiations that melded provisions from S-1587, sponsored by Senator John Glenn (D-OH), and HR-2238, sponsored by Representative John Conyers, Jr. (D-MI), the Federal Acquisition Streamlining Act became law (PL-103-355) in October 1994. The act set the stage for rewriting the federal acquisition requirements. Senator William F. Cohen (R-ME) called attention to the need for such reform in his assessment of the acquisition system. In *A History of Government Contracting*,[24] James Nagle reported:

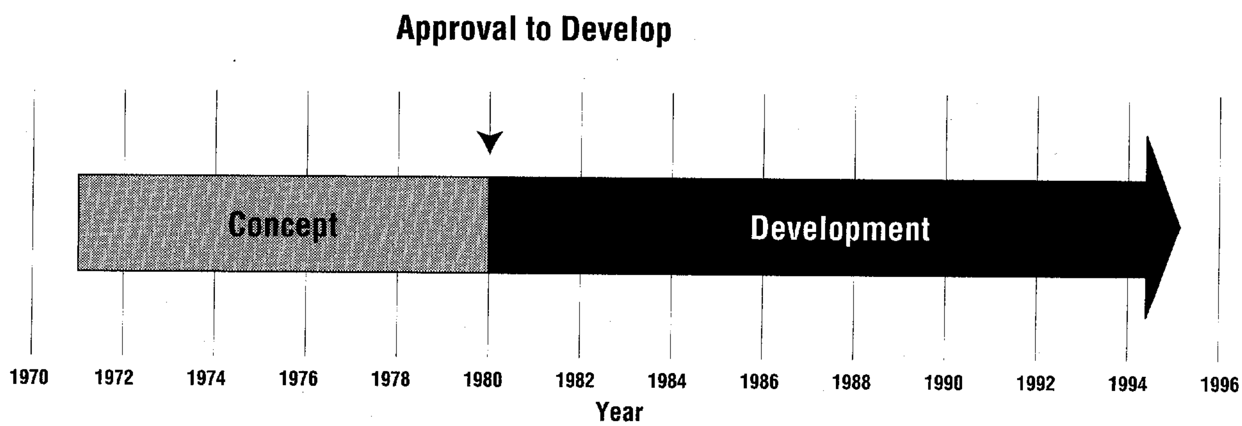
> If someone were asked to devise a contracting system for the federal government, it is inconceivable that one reasonable person or a committee of reasonable people would come up with the current system. That system is the result of thousands of decisions made by thousands of individuals, both in and out of government. It reflects the collision and collaboration of special interests, the impact of innumerable scandals and successes, and the tensions imposed by conflicting ideologies and personalities.[25]

How did the complexities of the DOD acquisition system affect the procurement problems of the C-17?

The C-17

On May 18, 1992, the C-17 made its first flight. On June 14, 1993, Charleston Air Force Base, South Carolina, received its first C-17.[26] Eighteen months later, on January 1995, General Robert Rutherford, USAF, commander of the Air Mobility Command (AMC), announced that the C-17 had achieved initial operating capability.[27] That was more than 14 years after Congress approved the C-X (1980) project, which developed the C-17, and more than 24 years after DOD began developing the AMST, the precursor of the C-17 (figure 3).

FIGURE 3. Timeline for the DOD C-17, from Concept to Initial Operating Capability



The C-17 was the first Air Force transport to introduce a complete fly-by-wire system, an on-board inert gas generating system (OBIGGS), and head-up displays. It is the only DOD plane that combines into one plane the ability to carry outsize cargo, to airdrop cargo and personnel, to operate into and out of small austere airfields, and to provide significant maneuverability on the ground.[28] The C-17 has:

- The ability to back up on inclined surfaces, maneuver in close quarters, and park in small areas
- Built-in ramps for delivering cargo to airfields with no additional material-handling equipment
- Capability for extensive low-level operations to evade threats, and rapid-cargo offload capability for runways under combat conditions
- Operational flexibility to carry more types of cargo to more places under more threatening conditions than any other cargo plane the Air Force has in its military or Civil Reserve Air Fleet (CRAF) inventory.[29]

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3. Organization and Management

We trained hard . . . but every time we were beginning to form up into teams, we would be reorganized. I was to learn later in life that we tend to meet new situations by reorganizing . . . and a wonderful method it can be for creating the illusion of progress while producing confusion, inefficiency, and demoralization.

Attributed to Petronius Arbiter, A.D. 65

Although scholars have questioned whether Petronius, a first-century Roman satirist, is the source of this description of organization, it is often cited as a classic statement of the drawbacks of change for the sake of change. These words could easily be applied to the DOD C-17 program. However, if change or reorganization is initiated to accommodate dynamic forces in the environment or to achieve clearly defined objectives—as it was at Boeing—positive growth occurs.

Growth, as defined by B. J. Hodge and William P. Anthony, is part of the organizational cycle that includes birth, growth, maturity, deterioration, and death. Organizations can avoid deterioration and death by aptly managing change—deflecting threatening environmental changes and seizing opportunities that enhance objectives.[1] One of the keys to successful management is in identifying and defining what to change:

> Every company has two organizational structures: the formal one is written on the charts; the other is the living relationship of the men and women in the organization.[2]

Organization Theory

Throughout time, historians or analysts attempted to identify and define factors leading to organizational success. Adam Smith was a pioneer in defining and establishing parameters for organizations at the beginning of the industrial revolution. For example, Smith advocated labor specialization (production lines) and competition—specialization to speed production and competition to achieve balance and lower costs. From 1890 to 1930, the classical school—described by writer Frederick Taylor—added structure and span of control as essential elements to organization. In 1930, the behavioral school looked at motivation, communications, leadership, group dynamics, and human relations. In the 1960s, the systems and contingency schools, respectively, added environment and technological change (table 1).[3] Contingency theorist Joan Woodward writes:

> Different technologies imposed different kinds of demands on individuals and organizations, and these demands had to be met through an appropriate structure. Commercially successful firms seemed to be those in which function and form were complementary.[4]

Today, many organizations—including Boeing and DOD—are reorganizing under the W. Edwards Deming model, the so-called "Japanese style of management and organization." Because Deming is a statistical mathematician, one might suppose that science and math would form the theoretical foundations

TABLE 1. Evolution of Organization Theory

School	*Major Concepts*	*Theoretical Foundations*	*Primary Theorists*
Classical (1890-1930)	Division of labor, span of control	Engineering economics	Taylor, Mooney, Weber, Gantt, Gilbreth
Behavioral (1930-1960)	Motivation, communication, leadership, group dynamic, human relationships	Psychology, sociology, social psychology	Follett, Maslow, Herzberg
Systems (1960-1990)	Quantitative techniques, macro perspective, functionalism	Mathematics, engineering, computer science	Boulding, Kast, Forrester
Contingency (1965-1990)	Open systems, prescriptive approach, dynamic relationships	Sociology, industrial engineering, benchmarking	Woodward, Galbraith, Lorsch
Quality (1990-present)	Quantitative techniques, motivation, communication, group dynamics, customer/quality orientation	Statistics, industrial engineering, sociology	Deming

Source: B. J. Hodge and William P. Anthony, *Organization Theory: A Strategic Approach* (Boston, MA: Allyn and Bacon, 1991), with additions.

of his theory. However, Hodge and Anthony classify Deming as a behaviorist because "the essence of this approach is that people will work harder and with more of a sense of commitment if they have job security . . . and feel they have a significant part to play in decision making and group activity."[5]

Deming believes in replacing middle management with team leaders. Deming's teams are intended to encompass diverse skills to accomplish complex objectives. A plane-building team might include designers, manufacturers, analysts, marketers, and accountants. Under the Deming model, top management must communicate effectively with workers, and the entire team must focus on the customer. Deming lists 14 points for transforming western management (table 2). He also outlines seven deadly diseases and ten obstacles (tables 3 and 4) that deter the transformation process.[6] Several of these impacted the C-17 and the 777—especially lack of constancy of purpose, mobility of management, and insufficient or improper communication.

Constancy of Purpose

Constancy of purpose places the product and service of a company in a long-term perspective.[7] Because DOD objectives change to meet world circumstances faster than DOD can develop a system, it is difficult for DOD to consider its product and service in a long-term perspective. Boeing, on the other hand, is able

TABLE 2. Fourteen Points for Transformation of American Industry

1. Create constancy of purpose.
2. Adopt the new philosophy.
3. End dependence on inspection to achieve quality.
4. Stop awarding business on the basis of price tag.
5. Improve constancy.
6. Institute training on the job.
7. Institute leadership.
8. Drive out fear.
9. Break down barriers between departments.
10. Eliminate slogans, exhortations, and targets.
11. Eliminate quotas, management by objective, management by numbers, numerical goals; substitute leadership.
12. Remove barriers that rob management engineers and workers of pride of workmanship.
13. Institute a vigorous education and self-improvement.
14. Involve everyone in the transformation.

Source: W. Edwards Deming, *Out of Crisis* (Cambridge, MA: MIT Press, 1986).

to develop a corporate policy to support long-term objectives. The C-17 suffered many setbacks because of inconsistent, short-term perspectives. A good example is the tactical AMST that became a tactical plane with some strategic capabilities, then became a strategic plane, then later became the C-17 strategic cargo airlifter with some tactical capabilities—all because changing leaders had changing ideas. Conversely, the 777 benefitted from a corporate commitment based on long-term goals.

Mobility of Management

Typically, under a 4-year presidential system, top-level government managers are not in office long enough to embrace long-term goals. Noting that the average tenure of the secretary and the deputy secretary of the treasury is only 18 months, Deming asks, "How can anyone be committed to any policy when his tenure is only a few years?"[8] Changes in leadership at the presidential level impacted support for the C-17 as different defense secretaries expressed conflicting opinions on the worth of the program. Although corporate officers changed at Boeing during development of the 777, commitment to the program remained solid.

Communication

Bob Dryden, who ran the Wichita division of Boeing, said, "One of the things engineers don't learn in college is how to communicate. They know how to use slide rules and play with computers, but they don't talk to anybody."[9] Frank Shrontz, chief executive officer (CEO) of Boeing, recognized the value of improving management's ability to communicate with the work force and the value of communication among workers. His program manager, Philip Condit, made communications a top priority when he invited eight customer airlines to help set standards for the 777. To design and build the plane, Condit used teams that included mechanics and pilots as well as other relevant representatives. Each team member had to communicate frequently with other team

TABLE 3. Seven Deadly Diseases Western Culture Must Overcome to Achieve a Total Quality Organization

1. Lack of constancy of purpose
2. Emphasis on short-term profits
3. Evaluation of individual performance (merit rating or annual review)
4. Mobility of management; job hopping
5. Management by use of only visible figures
6. Excessive medical costs
7. Excessive costs of liability

Source: W. Edwards Deming, *Out of Crisis* (Cambridge, MA: MIT Press, 1986).

TABLE 4. Ten Obstacles Western Civilization Must Overcome to Achieve a Total Quality Organization

1. Hope for instant pudding (take a long-term perspective)
2. The supposition that solving problems, automation, gadgets, and new machinery will transform industry
3. Search for examples (instead of looking for a recipe for success, ask why the company was successful or not more successful)
4. "Our problems are different" (principles of quality are universal)
5. Obsolescence in schools (best way for a student to learn a skill is to go to work in a good company under masters—interns)
6. Poor teaching of statistical methods in industry
7. The unmanned computer
8. The supposition that it is only necessary to meet specifications
9. Inadequate testing of prototypes
10. "Anyone who comes to try to help us must understand all about our business"

Source: W. Edwards Deming, *Out of Crisis* (Cambridge, MA: MIT Press, 1986).

players and to keep lines open with management.

Management Focus

There are some fundamental differences in the way Boeing and DOD approach a program. Boeing emphasizes customer, schedule, and cost; DOD stresses technology. Boeing focuses on developing and manufacturing planes. DOD focuses on acquiring the tools it needs to uphold the national security strategy—the C-17 is one of many tools.

Once the Boeing board of directors agrees there is need for a product and approves program development, the CEO, the president, top executives, and the program manager remain sharply focused on developing and producing that product. If officers change, even at top levels, the program still follows the 3- to 5-year approved course. Within DOD, changing leadership, strategies, and policies contribute to lack of focus and inconsistent management practices. Each new U.S. president and DOD secretary bring a different view. In the years it takes to build a government plane, DOD may have several different security strategies combined with differing views from the top on how to implement those strategies. Few managers at the program level last the full length of a DOD development project.

Boeing and DOD each utilize a standard set of procedures for major development programs:

- The Boeing program takes 3 to 9 years and has three phases:
  - —Program definition
  - —Cost definition
  - —Production.
- The government program takes 11 to 21 years and, as of 1994, had five phases:
  - —Mission need
  - —Concept exploration and definition
  - —Concept demonstration and validation
  - —Engineering and manufacturing development
  - —Production.

It is not unusual for Boeing to deviate from its standard practices when developing a plane. As Boeing President Philip Condit explained, "We can and do shortcut any of the phases when it is to our customers' advantage. No two projects are exactly alike."[10] The military, likewise, will deviate from the norm when engaging in a long-term project. In the case of the C-17, DOD made incorrect assumptions regarding the maturity of its technology and eliminated two stages completely. Departures from standard development practices do not, however, always adversely affect development. In the case of the 777, deviations enhanced the process.

A factor present in the Boeing management process—and notably absent in DOD—is a high degree of focus coupled with constancy of purpose. Focus on the 777 riveted the attention of managers and workers at the Boeing Company for the better part of 9 years while the plane was in concept, development, and production. No such focus commanded the attention of DOD officers and personnel during the more than 20 years the C-17 was in concept and development.

The Boeing Company

> If you look back on Boeing's history and the six chief executives it has had, you'll find that in each case the right man was chosen at the right time. . . . Frank Shrontz [was] inheritor of his predecessors' legends and legacies. Just at a time when both legend and legacy seem frayed, he recognized that improving the ways management motivates and communicates with the work force, to achieve superior productivity, had become Boeing's top priority.[11]

After becoming CEO in 1987, Frank Shrontz realized management improvements were necessary if Boeing wanted to remain competitive in the market. Two improvements included better communications and eliminating nonvalue-added costs. Although Boeing offered long-term employment, stability, and numerous employee benefits, a 1989 strike proved the Boeing worker was looking for other incentives. Boeing had grown so fast in the 1980s that management lost touch with its workers. Employees sought respect and assurance that good performance would lead to career opportunity—for example, they asked for better training. Corporate officers saw in these demands a way to improve management. Management consultant Gary Jusela observed,

> I found Boeing to be a company of paradoxes. In some ways, it was the most loosely structured and informal system you'd ever want to see. But in other ways, it was very rigid, formalized and bureau-

> cratic. . . . One of the things that surprised me was that despite the senior officers having been here a long time, they showed an openness to looking for new ways. . . . They weren't blaming any of Boeing's shortcomings on the work force, the union, or anyone else. They were asking what management processes . . . weren't useful anymore.[12]

In 1988, Bert Welliver, Senior Vice President of Engineering and Technology, revealed during the previous year the company spent $2.5 billion on nonvalue-added costs. Most were design changes leading to costly production changes. If the company had not incurred the nonvalue-added costs, it could have claimed about $3 billion instead of $480 million profits for 1987.[13] Officers at Boeing recognized the company could not afford to operate the same way on the 777. The goal was simple: change organization practices to send a flawless design to the manufacturing plant. Along with personnel changes suggested by Jusela, Boeing would have to revamp its design and production processes. The importance of a good production for world markets is becoming increasingly important not only for Boeing but for America. As Peter Dressler of the Paradigm Design Studio in Philadelphia said,

> We're busy developing new stuff that [the Germans and the Japanese] . . . know how to put into production. . . . If we had more good, solid manufacturing and production engineers who were happy to make an elegant product that was serviceable, usable, manufacturable, and recyclable, we could knock everyone else's socks off.[14]

Boeing officers believed they could improve production by designing an airplane entirely on computer using a team approach, something no company had yet done. To do so, Boeing had to undergo massive changes—not only in the engineering process, but also throughout management. As Boeing prepared for these changes, Assistant General Manager Neil W. Standal explained, "Boeing is concurrently designing the system by which we are designing the aircraft."[15]

Boeing chose the computer-aided three-dimensional interactive application (CATIA) to design the 777 and implemented its version of total quality management—calling it Continuous Quality Improvement (CQI).[16] A French company, Dassault Aviation, developed and used CATIA to design fighter planes. CATIA described the geometry of every part, tube, and component in electronic terms and projected parts in a three-dimensional display. IBM and Boeing enhanced CATIA further, to detect parts that would not fit or function correctly, and created "CATIA man" to see how a person would fit into different areas of the plane. As part of an initiation exercise, nearly 100 top Boeing executives went to Japan to learn techniques in production and work-force motivation. Boeing extended its traditional 48-month development timetable almost a year to accommodate the new design and multifunctional team processes. According to Philip Condit, directing the 777 program turned into a people managing exercise:

> You know, I've got an undergraduate degree in mechanical engineering, a graduate degree in aeronautical engineering, a graduate degree in business administration, and now I find myself being a practicing psychologist because what I do ninety percent of the time is deal with people.[17]

CATIA enabled Boeing to use the teams that Deming recommended and to interact with its customers. The customers Boeing chose to contribute were: United Airlines, American Airlines, Delta Air Lines, British Airways, Japan Air Lines, All-Nippon Airways, Qantas, and Cathay Pacific. It also allowed better communication among designers and manufacturers.

Even though Boeing was undergoing the first real change since World War II in the way it built aircraft, in some ways it was returning to principles of earlier days. When the B-17 was designed, for example, engineers sat around a table and talked to each other. And because the manufacturing plant was directly below the design area, they were able to talk to workers when they felt the need. As the company grew, this high degree of integration and communication was lost. Yet, with CATIA, designers sat at computers—sometimes miles apart—and were able to view each other's work in 3-D and talk to each other. Parts labeled with the name and phone number of the responsible engineer made tracing problems through the computer network effortless.[18]

There were only two levels between the Boeing president and the 777 program manager (figure 4). Top ranking officers met daily to review status reports on every facet of the 777. When Boeing changed program managers on the 777, focus remained steady because there was continuous communication and constancy of purpose. In Condit's words,

> We all knew what we wanted in the 777. When I moved on from program manager to president [1992], Alan Mulally was the next program manager for the 777. He was there with me when we conceived the 777—so was Dale Hougardy who succeeded Alan [1994]. If, after I left, Alan decided to change the whole concept and design of the 777, we would have had problems. He didn't.[19]

Program Definition

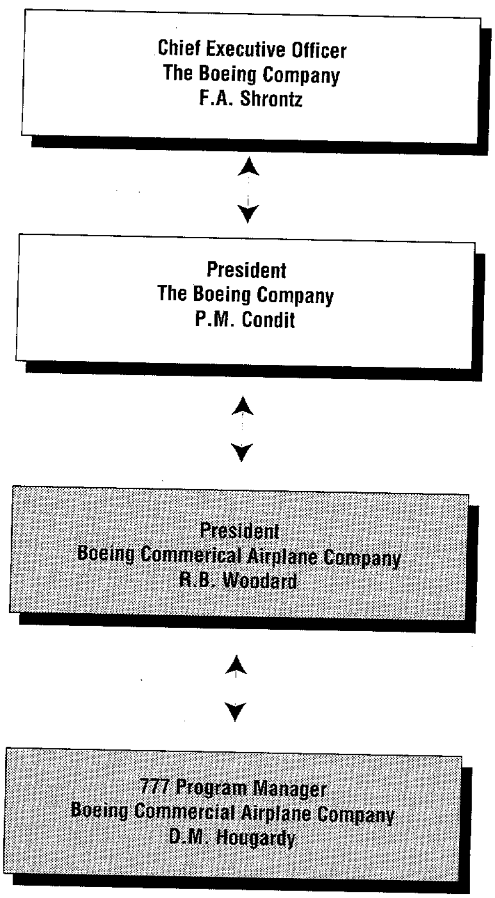
Boeing's early research revealed the company needed a plane to fill a gap in the market between the 767-200, which carried 218 passengers, and the 747-400, which carried 419 passengers. During early research, customers told Condit they did not want a lightweight plane of composites (already researched by Boeing) that would only carry 150 passengers. The plane they wanted—designed to carry 305 to 440 passengers—would replace aging McDonnell Douglas DC-10 and Lockheed L1011 airplanes. For reasons of economy and simple maintenance, the airlines expressed a need for a "family" of planes built around one basic model.[20] Boeing's innovative plan to produce the new aircraft included using the computer design program, CATIA, combined with intensive customer, manufacturing, and production input. According to Boeing's plan, customers would help define the plane and work with design-build teams—which included manufacturing specialists—to identify and solve problems before aircraft components reached the assembly line.

Cost Definition

Building an entirely new airplane was costly and constituted a bold step for Boeing when most airlines were choosing to buy derivatives. For example, the popular new Airbus A330/A340 was a derivative that combined a new wing with the A320 flight-control system and cockpit and the A300/A310 fuselage.[21] Nevertheless, Boeing was willing to face the costs of building a new plane to satisfy potential customers and to ensure long-term benefits for the company. Although Boeing considered building a 767 derivative—the 767X—the design-build teams initiated so many features that the idea of a derivative became highly impractical.

In order to assess costs of the program, Boeing first had to determine what it would include on the new plane. Outside representatives participated in the design process, adding features as they worked. Gordon McKenzie, from United Airlines, emphasized mission capability—range and payload—and insisted on cabin features with enough difference for passengers to notice. In

FIGURE 4. The Management Hierarchy of the Boeing Company, 1995



addition, McKenzie "stressed . . . reliability and maintainability of the airplane's design."[22]

The teams chose flat panels for the main digital displays instead of cathode ray tubes because the panels were half as thick, did not get hot, weighed less, and required fewer parts.[23] The fly-by-wire (FBW) technology performed stabilizing functions that permitted lighter wings and tail and called for fewer cables, pulleys, and brackets, making construction easier. The empennage (tail sections), made with carbon-fiber reinforced plastic weighed less than standard materials and cost less. Teams modified the electronics rack for better access and cooling and relocated the rotating beacon so mechanics could change the bulb from inside the aircraft.[24] Engine manufacturers designed powerful by-pass engines, allowing the plane to function with only two engines and thereby cutting operating costs.[25] In order to forestall anticipated problems with 777 avionics, the Boeing board approved funding early in 1990 for an Integrated Aircraft System Lab (IASL) to test the new system.[26] Boeing also built a new facility to produce composite materials at a lower cost for use in the tail sections and enlarged its manufacturing plant at Everett, Washington, to accommodate assembly of the new plane. As Boeing moved into the testing phase and began to incur problems with avionics technology, the board supported additional resources to solve problems threatening the delivery schedule.

Production

The final configuration of the 777 reflected input from four onsite customers and suggestions from 12 other customers that yielded more than 1,000 design innovations.[27] To make full use of CATIA, Condit organized the 777 teams in pyramids, with individual component designs at the bottom, subsystems in the middle, and the complete integrated 777 at the top.[28] Teams at the top incorporated all subteam efforts. There were approximately 238 design-build teams[29] in the pyramid—more than twice the number first envisioned for the process.[30]

Of course, there were initial growing pains. CATIA was not as user friendly as expected and required modifications before becoming fully operative. And because all the airplane parts were designed simultaneously, the parallel-processing system sometimes bogged down.[31] The complexity of communications among the many new design-build teams prompted Dale Hougardy, then vice president for operations, to remark:

> It requires an enormous commitment in terms of orientation to change a business

> practice as substantial as this. . . . We had to renovate procedures and practices. We spend lots of time communicating on a regular basis, because . . . [the process] needs constant nourishment.[32]

Although program managers changed several times during development of the 777, changes did not affect overall procedures and goals. In August 1992, Alan Mulally replaced Philip Condit as the 777 program manager and Condit went on to become president of Boeing. At this point, drawings were 25 percent complete and major assembly was to start in 5 months. Nevertheless, despite the leadership shift at a critical point, assembly began as scheduled.

The assembly process proved CATIA's worth almost immediately. Program Manager Alan Mulally described the surprise and excitement at Boeing:

> We knew the parts would be more accurate, and fit together better. What has surprised us all is that design-build teams, combined with digital design and customer airline knowledge, made the aircraft so much easier to assemble. We have learned much, and we're capable of doing things that were only visions a few years ago. Most importantly, we're building on this success, keeping it going, and learning how to do it more efficiently and faster.[33]

Later, on June 12, 1994, tears filled Mulally's eyes and cheers went up from the crowd as the first 777 lifted off Everett's Paine Field. Shortly afterwards, Dale Hougardy, vice president of Operations, became the new 777 program manager. Mulally was promoted to senior vice president of Airplane Development.

Even though Boeing's management transitions were smooth, the company experienced serious problems with avionics integration. Technology problems caused Boeing to inform the Federal Aviation Administration (FAA) that it would use "red-label" (software and hardware considered still in development) computers during its test flights. There were recurring problems in the Aeronautical Radio Inc. (ARINC) 629 database developed by Boeing engineer John Shaw, in the primary flight computer (PFC) developed by Avionics of London, and in the Aircraft Information Management System (AIMS).

When Hougardy took over as program manager in 1994, the 777 was still experiencing software problems. However, in April 1995, the FAA certified the 777 for extended twin-engine operations (ETOPS); on June 7, United Airlines flew the first commercial 777 from London to Washington. Bill Savery, former Chief of Engineering Operations, praised Boeing's tenacity in dealing with its avionics problems:

> It shows well the complexity and the problems we typically encounter in development programs. But it also shows Boeing['s] determination and initiative in developing work-arounds and recovery plans . . . to stick with the overall program goals—particularly completion of certification and delivery. Tremendous things can happen when you have dedicated, committed people who really want to make things happen.[34]

Summary

Although revitalization efforts were already underway at Boeing, a 1989 strike and extensive nonvalue-added costs presented a crisis at the company. Boeing committed to a new way of doing business, including a new structure and greater emphasis on communication.

Boeing officials followed the overall format of the program management plan but departed from previous development practices in several ways. The company involved more customers, suppliers, and maintenance personnel in concept and design; used computers for total design; and initiated integrated design-build teams. All three changes revolved around the use of CATIA. Recognizing all this would take time, Boeing purposely extended the period to build the 777. Figure 5 compares time required to produce and test the 777 to time required for other Boeing aircraft.

When Mulally and Hougardy became program managers, they continued the process Condit outlined at the beginning of the 777 program. Cross-functional design-build teams allowed engineers to use their talents more fully and reduced problems in production. Airline executives, mechanics, and pilots were made part of the design-build team early on and continued to make valuable suggestions throughout the process. All worked toward a common goal.

As Jeremy Main points out in *Betting on the 21st Century Jet,* changes at Boeing not only brought about a new commercial venture but also symbolized the company's willingness to adapt to change for the future.[35] Shrontz commented on the changes he helped introduce:

> I'm trying to change the culture, but not because I think this hasn't been a people-oriented company. Past management was dealing with different eras and change is a slow process—you just don't go from one approach to another overnight.[36]

The Department of Defense

> The current system is the result of a long accumulation of political weight on the side of complexity, redundancy, and oversight layers. It has become the vehicle for pursuing multiple political goals, often unrelated to those of procuring a weapon system, and these goals enjoy powerful constituencies. To rectify that balance will require the mobilization of an equal or greater weight on the side of change and reform.[37]

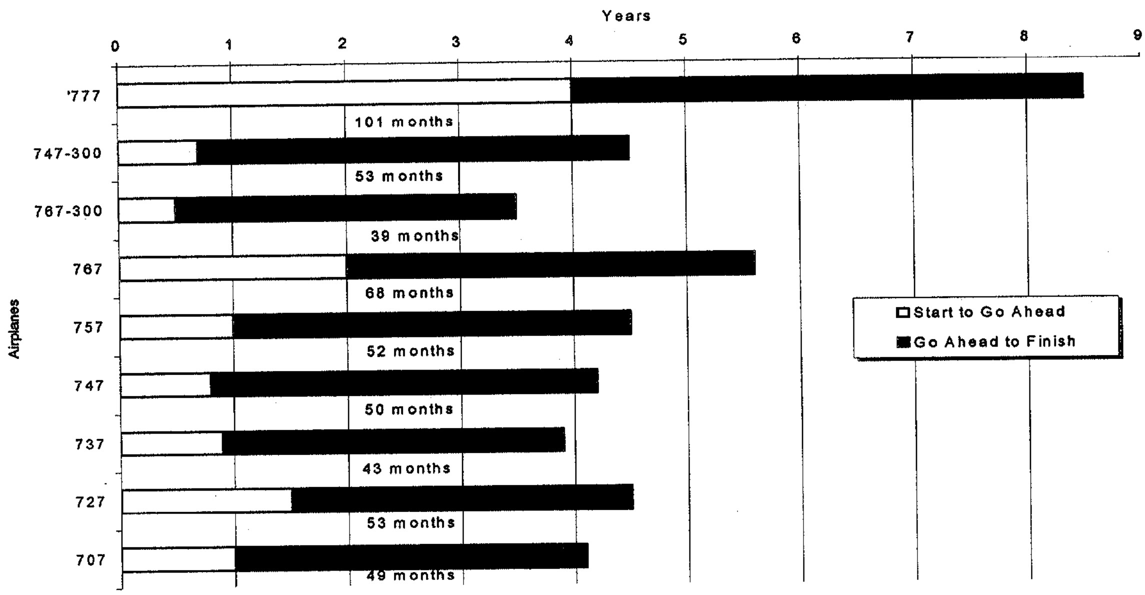
> Right now we have a process where parochial interests of the services rather than the joint mission are paramount. We need to shorten the distance between people at the top and bottom, we need to have a system that considers the joint mission, and we need to have program managers we know and trust. Right now we have all kinds of controls in place to make sure the program manager doesn't get us in trouble. Usually a [program manager] is selected for us. We don't know where he came from or how capable he is.[38]

Numerous studies show that DOD structure and rapidly changing top management contributed toward weapons that were over cost, behind schedule, and unable to meet mission requirements. These studies sometimes led to change at DOD, but too often changes were based on political elements and not on factors that would improve the acquisition system. The Carnegie Commission on Science, Technology, and Government calculated that overhead alone constitutes 40 percent of the DOD acquisition budget, compared to 5 to 15 percent in commercial enterprises.[39]

In the 1940s, each military department was responsible for its own program research, development, and acquisition. This independence resulted in duplication and inter- and intraservice competition for labor, plants, and material.[40] Efforts to combine the three separate services for a more unified acquisition met with varying degrees of success, and most merely added bureaucratic layers:

- In 1947, DOD created the Armed Services Procurement Act to standardize purchasing methods
- In 1958, President Eisenhower attempted to develop a more unified military structure through the joint chiefs of staff.[41]

FIGURE 5. Development Time for Boeing Commercial Models



Source: William Savery, former chief, Engineering Operations, The Boeing Company.

- In the 1960s, Defense Secretary Robert McNamara introduced the planning, programming, and budgeting system to control allocation of resources.[42]
- In 1976, the Office of Management and Budget established acquisition guidelines for all government agencies.[43]
- In 1986, the Packard Commission made recommendations based on six underlying features that typified the most successful commercial programs: clear command channels; stability; limited reporting requirements; small, high-quality staffs; communications with users; and prototyping and testing.[44]
- In 1986, the Goldwater-Nichols Act codified most of the Packard Commission report and established the position of Under Secretary of Defense (Acquisition & Technology) under the Office of the Secretary of Defense.[45]

Almost all studies on military procurement recommend greater centralization, but, as Jacques Gansler noted, "The institutional resistance of the various services prevented many of the proposed changes from taking place."[46] For example, Defense Secretary Caspar Weinberger's resistance to the Packard Commission lessened the impact of the commission's recommendations. In 1989, Defense Secretary Richard Cheney authorized the study, *Defense Management: Report to the President,* which described how best to implement the commission's recommendations. Thomas McNaugher described the recommendations in *Defense Management Reform: For Better or for Worse?* as falling under the rubric "centralize, simplify, and stabilize."[47]

DOD fashioned its current organization and acquisition system after recommendations contained in the Packard Commission, the Goldwater-Nichols Act, and the Defense Management Review—all of which attempted to eliminate several layers of authority. That objective is exemplified in DOD Directive 5000.1:

> Each DOD component with acquisition management responsibilities shall maintain a streamlined chain of authority and accountability for managing major defense acquisition programs. . . . This chain of authority and accountability shall extend from a DOD Component Acquisition Executive through Program Executive Officers to individual Program Managers.[48]

DOD organization charts reveal that reform eliminated two layers of authority between the Secretary of Defense and the program manger for the C-17. However, five layers remained and the chain of command was not always straightforward (figures 6 and 7). Lieutenant Colonel Robert Saxer, USAF, pointed out serious problems in the DOD organizational structure in *Buying the C-17: A Case Study:*

> [although the program manager had a new boss] he was still dependent upon both ASC [Aeronautical Systems Center] and AFSC [Air Force Systems Command] for manning, administration, and functional staff support. . . . By eliminating the Air Force's senior acquisition general officer from the normal program reporting chain, a huge leadership void and a great deal of uncertainty were created. With a new organizational structure now in place, the issue of who would ultimately be held responsible and accountable for all AFAE [Air Force Acquisition Executive] and DAE [Defense Acquisition Executive] programmatic and policy decisions made throughout the life of a development program was now in question.[49]

Under the new system, service secretaries were excluded from the program chain of command. However, each secretary reported to Congress when a system was in jeopardy. Even though the services were restricted to supporting and advising, they were de facto responsible for program implementation. Thus, they retained a vested interest in acquisition. In addition, reforms added the positions of the Under Secretary of Defense (Acquisition & Technology), the service acquisition executives, and the Program Executive Officer. Reforms also included as players within the acquisition hierarchy the Joint Chiefs o f Staff (JCS) and, through them, the unified and specified commands.

A comparison of the DOD organization chart with Boeing (table 5) reveals that DOD has many more layers of management:

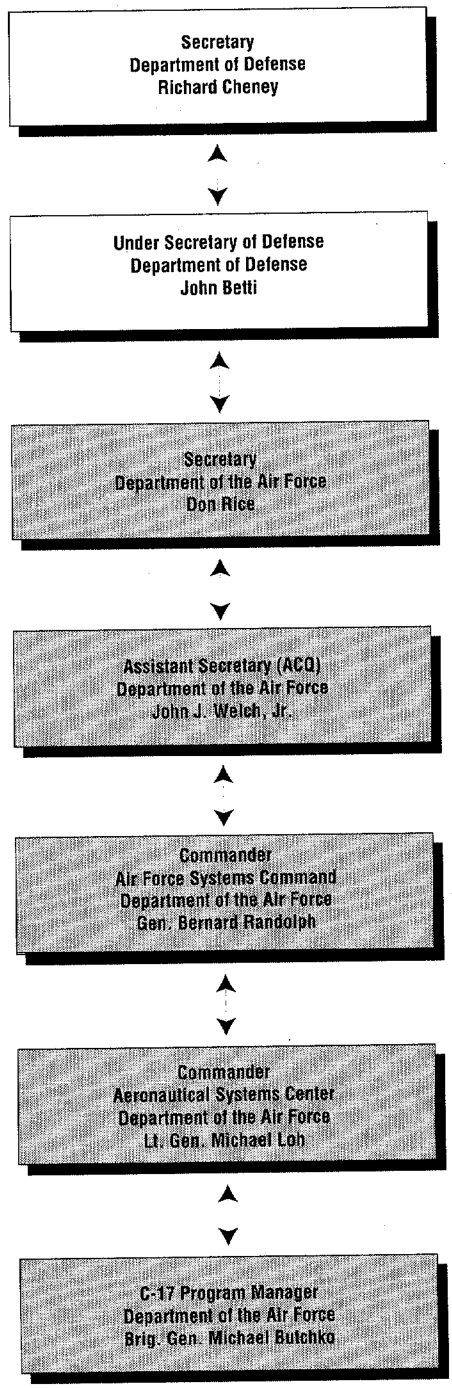
> [For the C-17] every major decision was viewed and reviewed by several levels. This contributed to the perceived lack of constancy and sense of confusion throughout. Decisions were probably much quicker at Boeing and very seldom reversed by the next layer. . . . [You] can't say that about DOD.[50]

Vacillation in leadership and direction marred C-17 program progress. Numerous managers headed the effort, many with differing views and some who openly disagreed on program principles and goals. Also, DOD eliminated two phases of its standard development program, combined two other phases, and invented one phase to cover the indecisive beginnings of the C-17.

President Jimmy Carter and Defense Secretary Harold Brown were convinced that DOD needed a strategic airlifter capable of carrying outsize equipment with short-take-off-and-landing (STOL) capability. They ignored congressional directives to build a *tactical* STOL aircraft and instead concentrated on promoting a *strategic* STOL aircraft.

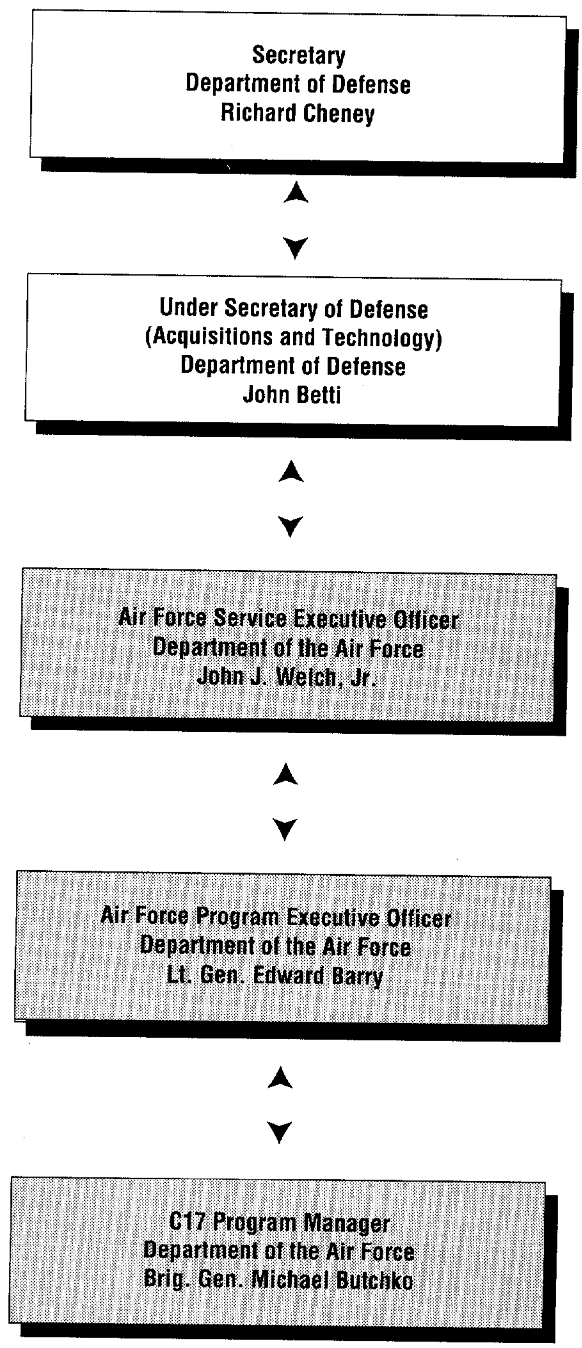
In 1979, Major General Emil Block, Jr., USAF, Chief of Staff, HQ MAC, formed a team to define a strategic mission need statement, develop a preliminary operational concept, and establish program management direction. Block completed the documents within 2 months and issued a statement of operational requirements January 23, 1980. Normally it takes DOD up to 2 years in the concept and

FIGURE 6. The Management Hierarchy of DOD, Before Reorganization, 1990



Source: Lieutenant Colonel Joseph D. Rouge, USAF, *C-17 Case Study: Major Players in Defense Acquisition* (Washington: Industrial College of the Armed Forces, National Defense University, December 30, 1995), 4.

FIGURE 7. Management Hierarchy of DOD After Reorganization, 1990



Source: Lieutenant Colonel Joseph D. Rouge, USAF, *C-17 Case Study: Major Players in Defense Acquisition* (Washington: Industrial College of the Armed Forces, National Defense University, December 30, 1995), 4.

TABLE 5. Organization Hierarchy for Boeing and DOD from Concept Through Development

	Years
CHAIRMAN, BOARD OF DIRECTORS/CEO	
THORNTON T. WILSON	(72-87)
FRANK A. SHRONTZ	(87-97)
PHILIP M. CONDIT	(97-present)
PRESIDENT, BOEING	
FRANK A. SHRONTZ	(87-92)
PHILIP M. CONDIT	(92-97)
HARRY C. STONECIPHER	(97-present)
PRESIDENT, COMMERCIAL AIRLINES	
DEAN THORNTON	(85-93)
B. WOODARD	(93-98)
ALAN MULALLY	(98-present)
VICE-PRESIDENT PROGRAM MANAGER 777	
PHILIP M. CONDIT	(86-92)
ALAN MULALLY	(92-94)
DALE HOUGARDY	(94-96)
RON OSTROWSKI	(96-present)

	Years
U.S. PRESIDENT	
RICHARD NIXON	(69-74
GERALD FORD	(74-77)
JIMMY CARTER	(77-81)
RONALD REAGAN	(81-89)
GEORGE BUSH	(89-93)
BILL CLINTON	(93-present)
SECRETARY OF DEFENSE	
MELVIN R. LAIRD	(69-73)
ELIOT L. RICHARDSON	(73-73)
JAMES R. SCHLESINGER	(73-75)
DONALD H. RUMSFELD	(75-77)
HAROLD BROWN	(77-81)
CASPAR W. WEINBERGER	(81-87)
FRANK C. CARLUCCI	(87-89)
RICHARD CHENEY	(89-93)
LES ASPIN	(93-94)
WILLIAM J. PERRY	(94-97)
WILLIAM S. COHEN	(97-present)
UNDER SECRETARY OF DEF (ACQ)	
DONALD A. HICKS	(86-86)
RICHARD P. GODWIN	(86-87)
ROBERT B. COSTELLO	(87-89)
JOHN A. BETTI	(89-90)
DONALD J. YOCKEY	(91-93)
JOHN DEUTCH	(93-94)
PAUL KAMINSKI	(94-97)
NOEL LONGUEMARE (Acting)	(97-97)
JACQUES S. GANSLER	(97-present)
ASST SECRETARY OF AIR FORCE (ACQ)*	
(SERVICE ACQ EXEC (SAE)	
DANIEL S. RAK (Acting)	(1986)
JOHN J. WELCH, JR	(87-90)
G. KIM WINCUP	(90-92)
DARLEEN A. DRUYUN (Acting)	(93-94)
CLARK G. FIESTER	(94-95)
DARLEEN A. DRUYUN	(95-present)
AIR FORCE PROGRAM EXECUTIVE OFFICER (PEO) TACTICAL & AIRLIFT PROGRAM	
MAJ GEN EDWARD BARRY	(90-91)
MAJ GEN ED FRANKLIN	(91-93)
BRIG GEN JIM CHILDRESS	(93-present)
SYSTEM PROGRAM DIRECTOR (MANAGER) C-17**	
MAJ GEN HARBOUR	(80-86)
COL THOMAS A. STOVER	(86-87)
COL V. STONE	(87-87)
BRIG GEN MICHAEL BUTCHKO	(87-91)
BRIG GEN KEN MILLER	(91-93)
BRIG GEN RON KADISH	(93-96)
BRIG GEN CHUCK JOHNSON	(96-present)
MCDONNELL DOUGLAS C-17 PROGRAM MANAGER	
MARVIN MARKS	(80-82)
J. D VAN DYKE,	(82-86)
ROBERT (BOB) CLEPPER	(86-90)
JOHN CAPELLUPO	(90-90)
DAVE SWAIN	(90-94)
DONALD KOZSLOWSKI	(94-present)

*Prior to 1990 the hierarchy included the Secretary of the Air Force.
**Prior to 1990 the hierarchy included the Commander Air Force Systems Command and Commander Aeronautical Systems Center.

development phase to develop documentation for a major weapons system, but Block's team, following Brown's direction, did not perform a standard or thorough investigation to identify need. Convinced that research and development on the AMST proved STOL technology adequately, Brown asked DOD to skip the demonstration and validation phase.[51]

Later, Defense Secretary Caspar Weinberger did not embrace Brown's plan for the C-17. Even though a congressional study identified a strategic airlift shortfall, Weinberger saw other options to improve the nation's airlift capacity. In 1981 Lockheed submitted an unsolicited proposal to Dr. Richard DeLauer, Under Secretary for Defense (Research and Engineering), offering to build 44 C-5s for $4.2 billion. Boeing also proposed to sell its 747 to the Air Force for $52 million each. Early in 1982, DOD announced Lockheed would build 50 C-5Bs to meet current needs for strategic airlift. Six months after the purchase, President Reagan announced an intent to preserve the C-17 program for procurement in the late 1980s to replace the C-130 and the C-141.[52]

In July 1982, Secretary of the Air Force Verne Orr authorized a truncated research and development program for the C-17, and the Air Force drew on fiscal year 1981 funds to award McDonnell Douglas a modest $31.6 million contract. The contract contained a clause allowing the government to restructure the contract if DOD decided to fully fund the program.[53] A development option provided for flight test articles with first flight in FY 1987; preparation for concurrent production; and completion of development beginning in FY 1988.[54] DOD and McDonnell Douglas decided not to use computer technology for design in order to avoid expenses such a technology would entail. The schedule would change many times in the ensuing years. McDonnell Douglas began concurrent development and production in 1988,[55] first flight occurred September 1991,[56] and the C-17 received initial operating capability certification January 1995.[57]

Program Managers

The DOD management system provides for two concurrent program managers or directors—one appointed by the military and one appointed by the contractor. The military manager ensures the contractor meets requirements, costs, and schedule; the contractor manager supervises subcontractors and builds and delivers the product. Both managers exercise tight control over technical decisions and matters affecting design, cost, and schedule.

When DOD awarded the truncated contract to McDonnell Douglas, Major General Elbert E. Harbour, USAF, was program manager for Air Force and J. D. Van Dyke was program manager for McDonnell Douglas. Over the life of the project, Air Force and McDonnell Douglas each assigned at least six different managers to the C-17 program. Command changes were often combined with restructuring. Unlike the Boeing team, new program managers were not always well acquainted with the C-17. And, unlike the Boeing team, which was focused and worked toward a common goal, the DOD and McDonnell Douglas teams often competed and worked at cross purposes.

The Air Force

Harbour became C-X program manager in 1980, an office under the Aeronautical Systems Division. A year later, reorganizations to the division gave Harbour the responsibility as Deputy for Airlift and Trainers[58] in addition to those he exercised as program manager for the C-X. When Harbour left in 1986, two officers took his place, covering a period of about 13 months—Colonel Thomas A. Stover, USAF, July 1986 to June 1987, and Colonel V. Stone, USAF, July to August 1987.[59] In August 1987, the Air Force designated the C-17 program as a separate office (ASC/YC) and appointed Colonel Michael J. Butchko (later Brigadier General) as System Program Officer (SPO).[60] Brigadier General Kenneth Miller, USAF, replaced Butchko in 1991,[61] and Brigadier General Ron Kadish, USAF, replaced Miller in 1993.[62]

When Butchko took command, he restructured the contract from schedule based to event based, pinning all future contract funding decisions on milestone events. For example, Lot 2, low-rate initial production option, could not begin until after successful completion of the December 1988 Mission Computer Critical Design Review. Butchko also rescheduled first flight from 1987 to 1990.[63]

McDonnell Douglas

Marvin Mark was C-X corporate manager from 1980 to 1981.[64] Van Dyke became general manager for the C-17 in May 1981, about 1 year before the Air Force awarded the low-level development contract to McDonnell Douglas.[65] Van Dyke remained manager until 1986. Robert Clepper succeeded Van Dyke and served until 1990. McDonnell Douglas Vice President John Capellupo held the position only a few months in 1990, until David Swain's appointment in that same year.[66] In 1993, Donald Kozlowski succeeded Swain.[67]

Reorganization and Employee Turnover

From 1981 to 1995, there were seven reorganizations involving DOD that affected C-17 development. McDonnell Douglas also underwent several reorganizations and three significant labor turnovers from 1981 to 1995.

Air Force combined the position of C-X program manager with that of deputy for airlift and trainers in 1980, allowing several programs to share resources for functions such as contracting, engineering, and manufacturing.[68] In 1984, the Air Force reorganized again in preparation for a milestone review and in anticipation of full-scale engineering for the C-17, this time to establish the C-17 program as a separate directorate:

> The basis of the concept [1984 reorganization] is the segregation of the total R&D and production/deployment effort into discrete areas or management centers. Each management center will be responsible for designated hardware/software items, the associated support tasks (logistics, technical data, training, R&M etc.) and appropriate schedule, cost and performance parameters.[69]

David Ward, who served as deputy director for the AMST program, ensured some continuity by remaining as deputy director for the C-17 program. However, when the C-17 went to full-scale development, many new people with no previous experience in the program were added to the Air Force office, including program managers.

When Stover and Clepper became program managers in 1986, McDonnell Douglas was just completing detailed engineering drawings in preparation for production. Although Boeing changed program managers at about this stage, Boeing's overall management procedures were designed to keep the 777 on track. Changes in the DOD command structure, combined with numerous changeovers, eroded the overall effectiveness of the program. By the time Butchko took over in 1987, McDonnell Douglas was experiencing major problems with its assembly schedule, which, by terms of the contract, threatened production funding. Within a year, two DOD-mandated reorganizations influenced management of the C-17 program—the realignment of the program reporting chain and a reordering of the plant representative hierarchy.[70]

Program Reporting Chain

Changes to the DOD acquisition process resulting from the Goldwater-Nichols Act and the Defense Management Review affected the reporting process for the program manager. When the Goldwater-Nichols Act required DOD to streamline the acquisition process, DOD added service acquisition executives responsible to the Under Secretary of Defense (A&T). However, because then Defense Secretary Caspar Weinberger did not favor the law, DOD did not seriously implement it. When Defense Secretary Cheney took office, he commissioned the Defense Management Review (DMR) to find out how best to implement the Goldwater-Nichols Act.

As a result of the DMR, in 1990 the reporting hierarchy changed dramatically. Butchko, the C-17 program manager, was responsible to the program executive officer (a new position), Major General Edward Barry, USAF, instead of to the Aeronautical Systems Center and the Air Force Systems Command. In addition, a merger of two Air Force commands (Air Force Logistics Command and Air Force Systems Command) into the Air Force Materiel Command changed the source and direction of the program manager's manning and staff support. In the new chain of command, the program manager was responsible to the program executive officer but was dependent on the Aeronautical Systems Center and the Air Force Materiel Command for manning, administration, and functional staff support. As Saxer points out, "With a new organizational structure in place, the issue of who would ultimately be held responsible and accountable for all . . . programmatic and policy decisions made throughout the life of a development program was now in question."[71]

Plant Representative

In the 1950s, the government established plant representatives to provide onsite inspections and administrative support for contract programs. Plant representatives historically reported to whichever service managed their program. In a 1990 reorganization, all representatives began reporting to DOD. At the time of the reorganization, Plant Representative Colonel Kenneth Tollefson, USAF, was experiencing serious problems with McDonnell Douglas and the military program manager. The problems worried Tollefson, but because he was not as well acquainted with the new command's hierarchy and support staff, he did not feel comfortable discussing his concerns.

The Contractor

When McDonnell Douglas won the C-X competition in 1981, it anticipated a streamlined, commercial-like development effort and designated its commercial division to develop and build the C-X. However, time and changing players brought about a traditional government-contractor arrangement characterized by tight controls and government oversight.[72]

In 1987, labor disputes and parts shortages began occurring at McDonnell Douglas. At the same time McDonnell Douglas began considering a Total Quality Management (TQM) system that, among other changes, called for reductions in middle management. From 1988 to 1989, McDonnell Douglas eliminated a full management layer at its headquarters[73] and all middle management at its production subsidiary, Douglas Aircraft.

Although McDonnell Douglas intended these changes to improve organization, methods the company used to bring them about created chaos in the C-17 program. For example, just as production began on the C-17 wing, Douglas Aircraft called 5,000 middle-management employees together on a Friday, fired them, then told them to reapply for a reduced number of management positions the following Monday.[74] The process of defining and filling new management positions took almost 6 months. People were often hired for inappropriate jobs, and workmanship on the C-17 reflected chaos in the plant. During production of the first 13 sets of wings for the C-17, there were 14 different wing-dock business managers. Over 90 percent of the nearly 900 structural mechanics were relatively inexperienced in aerospace. Repair and rework on the factory floor amounted to 40 percent of the man-hours on the first two C-17s and added about 4 percent to the aircraft cost.[75] Plant Representative Tollefson described the program management as "corporate suicide. . . . We would have to get a whole room full of people together to find out who was in charge of various operations."[76]

In June 1991, 1 month after the C-17 missed its scheduled maiden flight, Program Manager Miller pressured McDonnell Douglas to reorganize under a Process Variability Reduction (PVR) protocol Air Force developed. PVR separated the assembly process into subtasks and identified the areas associated with most problems. The PVR team included T. David Braunstein, Director of Process Integration at McDonnell Douglas; Jim Arnold, manufacturing system engineer, Air Force; and Jerry Guardado, Office of the Plant Representative.[77] In January 1992, McDonnell Douglas began restructuring to improve its production process. The program office identified critical problems, developed a strategic plan, and created working teams—adjustments similar to those incorporated at Boeing. David Braunstein, Director of Process Integration, described attempts to identify problems at McDonnell Douglas as "one of the biggest detective stories I've ever seen. We had to scour the whole process to learn how everything fit together and where the problem areas lay."[78] Careful analysis of the assembly process paid off with measurable signs of product improvement.

During 1993, labor disputes and rifts caused production slowdowns and overshadowed improvements in the McDonnell Douglas organizational structure. McDonnell Douglas moved workers from its ailing commercial sector onto the C-17 project, replacing workers with experience on the C-17. At this point, the Pentagon told McDonnell Douglas to resolve chronic problems or risk cancellation of the C-17 program. In December 1993, Secretary of Defense Les Aspin placed McDonnell Douglas on a 2-year probation to fix technical and financial problems. DOD delayed its commitment to buy more than 40 C-17s until it evaluated the company's performance in November 1995.[79]

In yet another reorganization, the company consolidated six defense and aerospace subsidiaries into two groups and moved the C-17 program from the Douglas Aircraft Commercial Office to the Aerospace Group. Vice Presidents John P. Capellupo and Kenneth A. Francis became responsible for running the two groups. Executive Vice President Herbert Lanese shared operational responsibility for the groups along with two other executive officers, John McDonnell and Gerald A. Johnston. A newly formed Office of the Chairman served as senior management council and policy-making body for the McDonnell Douglas government aerospace business. According to Anthony Velocci, "The company want[ed] to further lower the cost of producing its military and commercial products and improve quality across the board."[80]

Low-Level Research and Development

Traditionally, DOD does not have a low-level research and development phase. This "phase" was simply invented to keep the C-17 program alive until DOD decided if it wanted to produce the aircraft. During this period, McDonnell Douglas performed wind-tunnel testing, developed the thrust reverse, developed integrated avionics and flight control systems, and analyzed structural loads and sizing for primary structures.

Even though the low-level development phase lasted longer than the 15 months allocated for it, Congress allowed the program to continue. In fiscal year 1983, Congress approved the $26.8 million that DOD requested but demanded a study to justify the C-17 in light of recent C-5 and KC-10 purchases. In 1985, Congress appropriated the $123.3 million needed for an Engineering and Manufacturing Development (E&MD) contract, but the Defense Acquisition Board stalled the process by demanding a bottom-up analysis of the C-17 program requirements, scope, and content. Finally, on February 15, 1985, Defense Secretary Weinberger approved full-scale engineering development for the C-17.

Engineering and Manufacturing Development

> The E&MD tasks in the military and commercial sector are very similar. [They] include the detailed design engineering and development of manufacturing processes necessary to build an aircraft.[81]

Significant changes in the C-17 design complicated the early engineering and manufacturing development (or full-scale development) phase. The Air Force added built-in pallets and OBIGGS, raising the empty weight of the aircraft by 5,000 pounds. In order to accommodate the additional weight, the government renegotiated with McDonnell Douglas, agreeing to adjust the payload and range and change the landing gear. The Air Force then began a series of annual reviews to certify the company's ability to move from full-scale development to production. In September 1986, the Air Force certified McDonnell Douglas ready for production and rated the company highly as a manufacturer.[82] However, significant baseline changes and development caused production problems.

Concurrent Production and Development

The high degree of concurrency with many changes in design proved more trouble than the program could overcome. In October 1989, the Defense Acquisition Board reported production risks throughout the C-17 program. McDonnell Douglas had not resolved problems in airframe assembly, the mission computer, and the electronic flight control system. The Air Force responded by again changing the date of the first flight and moving certification for initial operating capability forward. Development costs had grown from $3.4 to $5.4 billion,[83] and by 1991, the Pentagon's Cost Analysis Improvement Group estimated the C-17 program could exceed its $6.6 billion ceiling price by more than $2 billion. At this point, arguments began between McDonnell Douglas and DOD over who should pay.

In December 1990, McDonnell Douglas submitted its request for test aircraft (T-1) completion certification—thereby asserting eligibility for much-wanted production contracts. However, Plant Representative Tollefson and Program Manager Butchko disagreed on whether McDonnell Douglas had really satisfied the milestone requirements. The relationship between the two disagreeing military officers greatly affected the C-17 program: "By the end of 1990, the relationship between Butchko and Tollefson was deteriorating rapidly. Each had an extremely strong personality, each was convinced they had the right answer for continuing problems."[84]

Other problems with the C-17 included unrealistic requirements and standards set too high from the beginning. According to Major General Frank E. Willis, USAF, MAC Deputy Chief for Requirements, "We in fact did find things that we would have been accused of gold-plating if we had paid money to develop them." An example was a 5-minute launch capability requiring complex avionics.

Another example was unrealistic payload requirements. When the Air Force finally conceded unrealistic payload requirements and lowered them, Congress demanded to know why and Defense Secretary Cheney ordered an explanation.[85] Senior DOD officials and members of the House Armed Services Committee began asking if the C-17 was another A-12,[86] the Navy airplane Secretary Cheney canceled for being over cost, over schedule, and unable to fulfill its mission. During testing in 1991, fuel leaks started to appear near the wing of the C-17. Some officials at McDonnell Douglas attributed this and other problems to lack of production discipline and out-of-position work. New command chains and work-team pyramids reduced the number of problems coming off the assembly line and cut overtime costs. McDonnell Douglas cut production time 31 percent, reduced out-of-position work to less than 5 percent, and improved rework and repair cost 60 percent.[87] In October 1992, a failed wing-strength test revealed McDonnell Douglas had erred in the wing design. Corrections increased the aircraft weight, thus decreasing the payload it could carry. Finally, after improvements in the assembly process and wing design, McDonnell Douglas was able to deliver the first C-17 to the Military Airlift Command at Charleston Air Force Base, South Carolina. It was the sixth C-17 off the assembly line. This aircraft, the first equipped with dual hydraulic actuators to retract the nose-wheel landing gear, was almost a year late and required a waiver from the original delivery requirements.[88] Fogleman, who received the C-17s and who was responsible for certifying them, then faced another kind of problem.

> I was looking at the potential of . . . six different kinds of airplanes in my first squadron . . . the fact that the first five airplanes that came off the production line . . . all had slightly different configurations I could live with that until we started . . . [certifying for] initial operating capability, then I wanted all 12 of those airplanes, if possible, to have the same configuration, and if not I didn't want more than two different configurations.[89]

Numerous changes and concurrent production resulted in several versions of the same aircraft. Before agreeing to certify the C-17, Fogleman demanded they be made identical.

When Kadish became program manager in 1993, the Air Force and McDonnell Douglas began serious discussions on the pace of C-17 flight testing. McDonnell Douglas preferred to conduct a 1-year fast-paced program similar to those followed in the commercial sector. The Air Force demanded a slower paced, 3-year program, such as it used at Edwards Air Force Base in California. Under the latter standards, testing would continue through 1994 or 1995.

Throughout 1993, the media reported problems and excesses of the C-17 program. DOD disciplined top officials for improprieties. Decreasing payload requirements and an apparent lack of baseline configuration caught the attention of Congress. A Defense Science Board evaluation revealed outdated design methods and numerous changes had contributed to production delays. Also, rumors surfaced that McDonnell Douglas planned to file a $1.35 billion claim against the Air Force for rescoping the project.[90] The C-17 program suffered yet another setback when the Air Force established a Nondevelopmental Airlifter Alternative (NDAA) Program Office to determine the capabilities and costs of commercial aircraft alternatives to the C-17.[91]

Congress combined fiscal year 1994 funding for the C-17 with sealift programs and called for a bottom-up review of DOD airlift requirements before releasing fiscal year 1995 funds.[92] As Donald Kozslowski assumed the job of program manager for McDonnell Douglas in early 1994, Under Secretary of Defense (A&T) John M. Deutch brokered an agreement with McDonnell Douglas. DOD agreed to relax design specifications, provide money for computer assisted design/computer assisted manufacturing system, and purchase another 12 C-17s for a total of 40. McDonnell Douglas agreed to drop its legal claims, invest more money in the program, and improve its management.[93] The government made it clear that additional orders of the C-17 were dependent upon program performance and an NDAA analysis in November 1995.[94]

Summary

DOD deviated from its management model by skipping phases 2 and 3 (concept exploration and demonstration and validation) and combining phases 4 and 5 (full-scale development and production). DOD eliminated steps 2 and 3 because officials believed the AMST prototype proved technology for the C-17. DOD invented the low-level development phase to preserve the contract and funds Congress had already approved. Combining the last two phases led to concurrent production, which resulted in several different versions of the same aircraft.

Once the C-17 program got underway, several reorganizations, both at DOD and at McDonnell Douglas, disrupted command lines and adversely affected the program. The decision not to use computer-assisted design methods hindered development processes. McDonnell Douglas contributed to delays when it produced a defective wing design and allowed gross inefficiencies in production. When development costs began to soar, the government and McDonnell Douglas argued over who should pay. Technical difficulties, uncertain funding, and management problems created a volatile atmosphere between the military and its contractor as well as among principals in each sector.

Even though the DOD structure produced numerous inefficiencies, the greatest delays in the C-17 program can be traced to changing views in the White House. The influence of the DOD highly mobile top governors is not conducive to what Deming calls constancy of purpose. Beginning in the Nixon administration and continuing through the Reagan administration, the presidents' points of view and their defense secretaries greatly influenced the C-17. Officials in the Nixon and Ford administrations supported the tactical AMST. Top brass under Jimmy Carter put a lid on the program and lobbied hard for the C-17. Under Reagan, leaders first supported purchasing alternate aircraft (C-5B), and only later supported the C-17. Lobby power probably did more to hinder or speed the C-17 process than any other single influence. Without support, the program floundered. With it, it flourished. The C-17 program began to turn around in 1994 only after DOD established more realistic standards and high-level officials at DOD and at McDonnell Douglas began supporting the program more actively.

Comparison

- Boeing's organizational focus was to enhance development and manufacturing of the 777. Reorganizations at Boeing did not detract from the 777 development and production. DOD focus was to improve its organizational effectiveness. Reorganizations—both at DOD and at McDonnell Douglas—disrupted command lines and adversely affected the program.
- Boeing's organization and consistent focus allowed officers to view the 777 from a long-term perspective. DOD organization and changing leadership caused DOD officers to view the C-17 from a 4-year perspective.
- Boeing's cross-functional design-build teams, built around CATIA, allowed engineers to use their talents more fully and reduced problems in production. The defective McDonnell Douglas wing design, gross production inefficiencies, and the DOD decision not to use computer-assisted design methods hindered development processes.

- Boeing's management remained committed to the 777 throughout its 9-year program. Presidents and defense secretaries differed on their commitment to the C-17 and its precursor, the AMST, over the 24-year program.

Commitment

After board go-ahead on the 777, Boeing began finalizing design, preparing detailed engineering drawings, and gearing for production. When unexpected problems occurred with design, avionics, and the flight control system, Boeing directed appropriate resources to solve the problems. When DOD received approval and funding for the C-17 from Congress, it placed orders for a different type of plane (the C-5B) and put the C-17 on hold 4 years. When problems with design, avionics, and flight controls caused costs to exceed the ceiling price, McDonnell Douglas and DOD argued over who was responsible for the costs. Once the C-17 program began, Congress supported the program with yearly appropriations. However, when the program could not overcome its development problems, Congress began withholding procurement funds.

Focus

Once Boeing received approval to build the 777, program managers remained focused on what they needed to produce it. The four 777 program managers worked for the 777 program before their promotion to program manager. Conversely, the Air Force set unrealistic goals for its program and managers often came to the program with major responsibilities in other areas or with no C-17 experience. After DOD received approval to enter the engineering and manufacturing development phase, the program missed major milestone dates. McDonnell Douglas used less experienced technicians on the C-17 program, assigning the more experienced technicians to other projects. Fogleman described problems in C-17 management:

> I think the fundamental problem started . . . in the beginning. We allowed the aircraft to be overspec'd unnecessarily. . . . In the very beginning, McDonnell Douglas did not have a first team on the C-17 . . . Then, just about the time we had the go ahead to start producing, then McDonnell Douglas commercial business started to drop off. So they rolled this commercial work force into the C-17 factory and displaced the people they had trained in the C-17. And that cost us in terms of quality. That was an institutional disaster.[95]

As the program progressed, the government and McDonnell Douglas became embroiled in funding arguments. Neither DOD nor McDonnell Douglas was able to maintain the kind of focus Boeing directed on the 777 development.

Flexibility

Boeing developed and used a computer-design program that allowed flexibility in its design and manufacturing processes. DOD and McDonnell Douglas chose not to use a computer program, an action which they believed would cut development costs. When Boeing experienced technical problems on the 777, it was able to apply resources, which included people and money. Conversely, funding constraints imposed by DOD or Congress restricted effective management of the C-17.

Constancy of Purpose

Although too many management layers and a cumbersome structure retarded C-17 development, nonsupportive attitudes passed on by leadership caused the most delays. The highly mobile leadership places DOD at a disadvantage when compared with the more stable private sector. Because corporations are better able to control personnel movement at the top, they are able to remain focused on goals—and maintain Deming's constancy of purpose. The 777 program moved forward even though some top managers changed because Boeing followed a board-approved course of action. The DOD course, though approved by Congress, was set aside in favor of purchasing alternative aircraft and later altered to include added enhancements such as OBIGGS and palletized ramps.

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4. Mission

Every organization decides what it expects to accomplish—its desired end, its mission. All assets of the organization must then be directed toward the specified goal. This chapter identifies the missions of Boeing and DOD and examines the functions of the 777 and the C-17 to determine if or how each product helped fulfill overall mission requirements. It also looks at mission to determine what effect it had on development time.

The Boeing Company

> To be the number one aerospace company in the world and number one among the premier industrial concerns in terms of quality, profitability and growth.[1]

Boeing was successful in its mission to become the "number one aerospace company in the world" because Boeing made an effort to understand its customers, was flexible in adapting to their needs, and was willing to commit to a product that would help customers retain their competitive edge. Referring to its customers, Boeing President Condit said,

> We cannot expect to be profitable unless we design and build the kind of equipment that gives them the competitive edge they need to grow and prosper. . . . In short, our efforts will continue to be customer-driven, not technology-driven.[2]

To fill a perceived commercial need, Boeing sought to build a new medium-sized airplane that would replace aging wide-body aircraft already on the market. Boeing brought potential customers into the initial marketing process and later recruited airline representatives to help engineers design the new airplane. Gordon McKenzie of United Airlines said, "Boeing started with a blank sheet of paper and said, 'Tell us what you want'."[3] By September 1990, Boeing knew the answer:

- A large twin-engine jet airplane carrying between 305 and 440 passengers
- A transport with a fly-by-wire control system, flat-panel liquid-crystal displays, graphite composite floor beams, six-wheel landing gears, and optional folding wing tips
- An airplane with a self-diagnostic maintenance system
- A family of 777s to share parts and standard features
- An airplane that would cost less to maintain.

After the board approved the 777, Boeing established a program office to develop, configure, design, validate, and provide definition to the product.

The 777

> The mission of the 777 is to provide safe and timely worldwide airlift of passengers and cargo in a cost effective manner. It must be comfortable and aesthetically pleasing for passengers. It must operate routinely on a fast-paced schedule with

> high mechanical reliability and minimum down-time. It must operate efficiently and effectively both in the air and into and out of crowded airfields. And it must have extended-range twin-engine operations (ETOPS) capability upon delivery to the customer.[4]

Distance, Timeliness, and Safety. Boeing's ability to deliver a twin-engine plane that could fly 305 to 440 passengers from 3,960 to 7,380 nautical miles (nm) resulted from the company's efforts to find the right design, materials, and propulsion. Thick, aerodynamic wings allowed the plane to fly higher and faster, and engines developed by Pratt and Whitney, General Electric, and Rolls Royce provided greater lift and distance at less cost. The combination of a large plane with only two engines constituted operating savings up to 40 percent over comparable four-engine models.[5] Boeing flew thousands of miles before delivering the first 777 to United Airlines to prove its plane could safely transport passengers around the world. During testing, the wings were stressed to the equivalent of more than 2.5Gs—as if the aircraft were pulled abruptly out of a steep dive. In every trial the 777 performed beyond expectations.[6]

Cost. According to Condit, "More and more, our airline customers describe their needs in terms of economics. The past two years, in particular, have convinced them that they can flourish only by becoming more efficient and flexible under pressure from an increasingly lean and competitive business environment."[7]

For both the airlines and the manufacturer, cost was a leading concern. Airlines wanted the best performing aircraft for the least cost; Boeing wanted the best manufacturing value for the least cost. Reflecting on his customers, Condit said,

> When jet airplanes first started operating across the North Atlantic, range was absolutely critical. The airplane that could fly nonstop from New York to Paris had a real advantage in the marketplace over the airplane that needed to stop in Shannon, Ireland. . . . To be able to go from New York to Tokyo nonstop rather than stopping in Anchorage, Alaska, was a competitive advantage.
>
> However, the world is only so big. Once you go halfway around, added range has no value.[8]

The 777 costs about $25.25 per mile to operate—including insurance, administration, and financing. The amount is similar for the MD-11 and Airbus A340-300X,[9] but on a per-seat basis, the 777 costs less to operate than these aircraft.

CATIA and design-build teams allowed Boeing to develop an early manufacturing plan and to identify numerous problems before the aircraft reached the production line. Factory rework was cut up to 80 percent; the body and wings of the 777 fit together without any rework. Dale Hougardy, the 777 program manager, described the difference in manufacturing planning that CATIA introduced:

> In the past, manufacturing was at the end of the pipeline. With [the 777] . . . from day one we started the manufacturing plan. The plan was developed as engineering matured. This is concurrent engineering in action.[10]

CATIA also allowed Boeing to transmit exact designs to subcontractors, who in turn were able to produce parts that came together perfectly on the factory floor.[11] Engine makers were able to design tubes, brackets, and troublesome externals so that different systems did not compete for the same space. In March 1994, CEO Frank Shrontz acknowledged the effect of streamlined assembly on costs:

> Cost-cutting has arrived. . . . One important indicator is that although our total sales are down, our margins are

improving, if you set aside development costs of the 777.[12]

Comfort and Aesthetics. United Airlines specified in detail how it wanted the interior of the new aircraft to look. For example, United insisted on overhead storage bins that followed a straight path, opening up the passenger cabin, rather than tapering to follow the fuselage contour.[13] The result is a spacious architecture that welcomes passengers with an open, airy cabin featuring high ceilings and graceful contours. Large windows and comfortable side walls provide clear views and more shoulder room. The 777 has the widest cabin in its class. Airlines can configure the 777 for high-comfort intercontinental or high-traffic regional markets with equal ease. Boeing received the Industrial Design Award for the interior of the 777 in 1992.[14] Digital entertainment and communication features allow airlines to offer a wide range of personal services, including telephones, digital sound and video systems, satellite movies, interactive video, and computer outlets.

Mechanical Reliability. The media reacted with enthusiasm, reporting quotes from United Airlines and Boeing representatives:

> On virtually every design point, we told Boeing to design in reliability and maintainability. The 777 has so much airline reliability input, we shouldn't see any in-service surprises.[15]

> There's a tremendous amount of expertise and methodology for cockpits, but not for maintenance . . . at the gate, in the hangar, [or] at the shop.[16]

In an effort to reduce mechanical problems, Chief Mechanic Jack Hessburg asked gate mechanics to troubleshoot by performing repairs on mock-ups in the presence of designers. The designers were able to observe the way mechanics operated and to see where improvements were needed—such as adding a latch to keep a door propped open or relocating a light for better visibility.[17] As a result of feedback from mechanics, designers lowered the height of the fuel panel for better accessibility and increased the size of push buttons so crews could open exterior panels without removing gloves. Boeing also wrote software for an on-board maintenance system that tells gate mechanics exactly what they will need to repair the aircraft before it lands.[18]

Not wanting to repeat service problems encountered on the 747-400, Boeing tested the 777 by flying it thousands of miles. During testing, Boeing engineers changed software to minimize false fire warnings that led to in-flight shutdowns and took similar steps with erroneous oil system indicators, which were responsible for about 19 percent of in-flight shutdowns. They also added electrical and hydraulic redundancy. Dedicated flight-test aircraft were flown through 1,000 cycles of simulated airline operations using the Pratt and Whitney PW 4084 engine—the equivalent of about 3 years of service.[19] In the end, Boeing delivered a plane with high mechanical reliability.

Extended-Range Twin-Engine Operations (ETOPS). The key consideration in any new technology is adding value for customers. In the case of the 777, service readiness and ETOPS certification at time of delivery were added values.[20] Traditionally, the Federal Aviation Administration (FAA) does not allow a twin-engine plane to fly more than 1 hour from an airport in its first year. Boeing wanted pre-delivery certification from FAA to fly the 777 up to 3 hours from the nearest airport—a key distance for lucrative flights over water, such as from the mainland to Hawaii or from Japan to Singapore.[21] To secure early ETOPS certification, beginning in 1994 Boeing flew five 777s with Pratt and Whitney engines on thousands of test flights.[22] Because of early certification, Boeing's first customer, United

Airlines, was able to schedule a transoceanic flight as its first official in-service flight.[23]

Corporate Quality, Profitability, and Growth. At the per-unit price of $116 to $140 million (depending on options), it will take Boeing some time to recoup the almost $7 billion estimated for development on the 777. However, because Boeing expects to produce a family of 777s for the next 30 to 50 years, initial development costs were considered as an investment in long-term growth. At the end of 1995, Boeing had 166 orders for 777s, including 22 for the Saudi Arabian state airline, Saudia—an order for which Boeing competed successfully against McDonnell Douglas. In 1994 and 1995, Boeing captured most commercial airline orders, with the 777 leading the way. If the 777 meets Boeing's expectations over the long term, income from it could exceed that of the lucrative 747. Boeing is already using CATIA and design-build teams on other planes—namely the F-22 and the B-2.

Summary

Did the 777 contribute to Boeing's mission "to be the number one aerospace company in the world and number one among the premier industrial concerns in terms of quality, profitability, and growth?" Indeed, at the end of 1995, Boeing was the number one commercial airplane manufacturer in the world, with the 777 leading the way. The 777 proved aesthetically pleasing to customers and fit a market need. The computer design system, coupled with design-build teams, helped produce a trouble-free airplane. Building the 777 brought Boeing not only an entirely new product but innovative design methods and a fresh corporate culture.

The Department of Defense

> Provide the military forces needed to deter war and protect the security of our country.[24]

How DOD fulfills that mission is spelled out in U.S. strategic policy. For 1995, the President's National Security Strategy read, in part,

> We must be able to credibly deter and defeat aggression by projecting and sustaining U.S. power in more than one region if necessary. . . . To do this, we must have forces that can deploy quickly and supplement U.S. forward-based and forward-deployed forces . . . as we demonstrated by our rapid response in October 1994 when Iraq threatened aggression against Kuwait.[25]

During the course of its development, the C-17 was redefined many times. It began as a tactical aircraft with a relatively short range and limited capacity and ended as an aircraft capable of carrying outsized equipment over long distances. Along the way, as it changed to meet changing military requirements, it had to compete for funds with any number of other weapons systems, including some with high profiles and appeal.

Nevertheless, in October 1994, the C-17 proved its worth to DOD when it flew the 7th Transportation Corp and its outsized cargo into Saudi Arabia on its first operational mission. General Ronald R. Fogleman used the C-17 in two sorties of 14-hour direct flights before General Robert Rutherford certified the plane for initial operational capability. General Fogleman based his decision to use the C-17 on faith in the new aircraft as well as concerns about the reliability of the C-5. In Fogleman's words, "It means giving the commander the assurance that when he uses that piece of equipment, it will get the job done on time. That's why we did it."[26]

The C-17

> Worldwide airlift of U.S. combat forces, equipment, and supplies . . . [and] adequate aerial delivery and airlift to execute the army's airland battle doctrine, the Marine Corps' air-ground task force operational doctrine, and the unified commands' joint operations concepts.[27]

To complete its mission, the C-17 had to perform several functions not normally required of commercial aircraft: airdropping cargo and personnel, air refueling, operating in and out of austere airfields and providing defensive actions; and operating routinely in low-threat environments, occasionally in medium-threat environments, and rarely in high-threat environment. The definitions for low, medium, and high threat are:

- Low threat: Small arms/automatic weapons, plus light and heavy optically aimed antiaircraft machine guns up to 12.7-mm equivalent weaponry.
- Medium threat: Low-threat weapons, plus optically aimed antiaircraft artillery heavier than 12.7 mm, and man-portable, shoulder-fired, surface-to-air missiles. A medium-threat area may include more sophisticated weapons employed in a dispersion pattern that makes avoidance possible with proper tactics and/or defensive equipment.
- High threat: Low- and medium-threat weapons, plus a dispersion pattern that denies avoidance and requires penetration. Without suitable defensive countermeasures, tactics, and force protection, this penetration involves a high probability of detection and attrition.[28]

In addition to performing radical maneuvers in a tactical environment, the C-17 had to:

- Transport large payloads over intercontinental distances without refueling; provide strategic and theater airlift via airland, airdrop, or the low-altitude parachute extraction system; and augment aeromedical evacuation, nuclear weapon transport, and special capabilities missions.
- Easily make transitions between delivery modes by allowing in-flight reconfiguration.

The major contributions of the C-17 to the present airlift system were long-range direct delivery and a design allowing delivery of outsize combat cargo and equipment (with operators) directly onto semipaved runways 3,000-feet long and 90-feet wide.[29] (The C-17 was not designed to land on unprepared runways, as was the C-130). Payload, range, STOL capability, airdrop, maneuverability, survivability, and versatility were major factors for C-17 customers.

Payload and Range. The 1980 request for proposal asked for a plane that could carry 130,000 pounds and fly 2,400 nautical miles without refueling. However, as already noted, DOD changed specifications of the C-17 several times, often in response to mission. The state of the world changed over time while the C-17 was in development, as well as the perceived needs of the military. Changes to the aircraft often brought a chain of technical and production changes that were both costly and time consuming to DOD and its contractors.

Maneuverability. The C-17 ground maneuverability is much greater than that of the C-141 or the C-5. Many pilots say the C-17 handles like the much smaller C-130. The C-17 backs up and turns 180 degrees in fewer than 90 feet. This maneuverability is helpful for offloading material and is especially important at congested airports.

Survivability. In 1985, when the Air Force re-negotiated its C-17 contract, it added OBIGGS to provide a nitrogen generation system that keeps oxygen vapors in the fuel tank area below 9 percent. The lower oxygen vapors allows the plane to avoid ignition when small arms fire hit the fuel lines. The addition of OBIGGS also meant the C-17 did not have to rely on liquid nitrogen supplies. OBIGGS could supply 50 pounds of nitrogen-enriched air to keep the fuel system inert for at least 48 hours. Adding OBIGGS allowed the C-17 to use more austere airstrips.[30]

STOL. STOL capability is especially important for cargo transports because it enables pilots to deliver supplies close to an area of need. Adding short-takeoff-and-landing requirements on the C-17 required the addition of a fly-by-wire system and other high-tech features.

Airdrop. Customers wanted the C-17 to airdrop heavy equipment, cargo, and personnel—all on the same mission. Personnel airdrops normally involve free-fall and static-line drops through paratroop doors or over the ramp, whereas equipment airdrops use a towplate with a drague/extraction parachute. To airdrop personnel and equipment together, the C-17 required special outfitting.

Versatility. Customers also wanted a transport capable of carrying large vehicles, rolling stock, palletized and nonpalletized cargo, outsized items, and aeromedical litters. When crews reconfigure a C-141 to carry palletized cargo, they must perform the change on the ground. At least two planes are needed: one to carry pallets for reconfiguring and one to carry the cargo. With the C-17, a single loadmaster can flip a reversible floor while it is in flight to reconfigure the aircraft. While the pallets increase aircraft weight, the increased capacity and versatility more than compensate for the added weight.

Impact of Changes. Costs rose for the C-17 in part because of numerous modifications requiring major changes to the wing and propulsion system. Some of these changes included the fly-by-wire system, OBIGGS, a built-in four-pallet ramp, and a defensive system. Fogleman expressed his concerns over the number of engineering changes on the C-17:

> We should somehow put a premium in every ECP [engineering change proposal] that goes on. If you are successful in shortening the development process, you're not going to have that many technology changes. You ought to take what you have, and maybe some reasonable threshold and you baseline it with that. And then you go build the baseline without a bunch of engineering change proposals. . . . We ought to build a block knowing that sometime down the road you're going to bring that whole group of airplanes back for an upgrade.[31]

McDonnell Douglas also complained about changes. The contractor alleged the Air Force had redefined the project and filed for $450 million in losses.[32]

In addition to added monetary costs, the changes caused delays in production. DOD missed numerous deadlines. The changes, their implied costs, and the delays caused military and congressional leaders to question the C-17 program. The government ordered at least five studies that questioned the DOD mission and asked if the C-17 fulfilled that mission.

Summary

The C-17 fits the DOD mission to provide military forces and fulfills President Clinton's 1995 National Security Strategy "to have forces that can deploy quickly and supplement U.S. forward-based and forward-deployed forces . . . as we demonstrated by our rapid response in October 1994 when Iraq threatened aggression against Kuwait." However, the way DOD achieved its mission was different in the early 1970s, and the mission of its developmental aircraft, the AMST, was tactical. By the late 1970s, DOD changed the mission of its development aircraft to strategic. Once it settled on the C-17, DOD continued to add features such as OBIGGS, palletized ramps, and a defensive system. McDonnell Douglas complained the changes caused delays and increased costs beyond contracted parameters.

Comparison

The 777 contributes to Boeing's mission "to be the number one aerospace company in the world and number one among the premier industrial concerns in terms of quality, profitability and growth." The C-17 fits the DOD mission to provide military forces to deter war and protect the security of our country, and it fulfills the 1995 National Security Strategy to have forces that can deploy quickly around the world.

The difference between Boeing and DOD is that at the time the Boeing board of directors approved the 777, Boeing's corporate leaders believed the 777 was key to remaining number one in the aerospace industry. At DOD, the C-17 was one tool among many to help support and defend the United States. From 1981 to 1995, the C-17 competed for resources with many other weapon systems in the DOD arsenal. Conversely, the 777 retained its number one focus during development at Boeing and faced little competition from other major development programs.

Of course, differing ideas on what DOD needed to support its mission affected the design of the C-17. For example, DOD focused on producing a tactical transport from 1971 to 1979. In 1979, it changed its focus to a strategic transport. Even after Congress approved its program, DOD vacillated over whether the C-17 was the right aircraft to meet its mission. At least five studies were ordered to determine whether or not the C-17 was appropriate. After DOD began developing the C-17, it modified the design—creating chain reactions involving weight and aerodynamics that proved costly to DOD and its contractor.

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5. Need

Need: a condition in which there is a deficiency of something . . . an urgent requirement of something essential or desirable that is lacking.

Webster's New World Dictionary[1]

Boeing performs extensive market and technology research to identify customer needs and to evaluate the company's ability to supply those needs. DOD determines its needs based on the President's national security objectives. Once the President defines the national security objectives, the Joint Chiefs of Staff (JCS) determine military objectives to support the president. The commanders in chief of the major military commands determine what personnel and equipment are needed to support JCS objectives. If the military departments do not have sufficient resources for the mission, the deficiency becomes a "need."

Prior to 1986, the service departments directed their requests for weapons systems to the Office of the Secretary of Defense (OSD). OSD considered and prioritized needs based on each department's ability to argue its need within the context of the overall DOD mission. As the Defense Science Board stated in its *Report of the Acquisition Cycle Task Force*, programs must have strong advocates to survive. With strong advocates, bad programs survive; without strong advocates, good programs can go by the wayside.[2]

The Boeing Company

> [Boeing needs] an airplane that can replace the aging McDonnell Douglas DC-10 and Lockheed L-1011 wide-bodies, and fill a growing medium-sized market between the 767 and 747.[3]

The airlines wanted to fine tune their fleets with a plane bigger than the 767 stretched, but smaller than a 747. They also wanted an entire family of planes built around one basic model to allow cost sharing on maintenance, parts, and training. By 1990, Boeing decided on the all-new 777. Looking back on the process, United Airlines Vice President of Operations James Guyette noted, "Boeing listened and responded to our needs." Guyette called the process concurrent design—a first in the commercial industry.[4]

The 747

Although Boeing accurately defined customer need in a timely manner for the 777, it did not always do so. For example, Boeing allowed a preoccupation with technology to influence 747 product development, and untimely need identification caused 747-400 production delays. CEO Bill Allen recalled the attitude at the time, "If the Boeing Company says we will build this airplane, we will build it even if it takes the resources of the entire company."[5] When the Boeing board approved development of the 747, Pan American World Airlines was the only U.S. airline interested in purchasing the aircraft. British Airways, Japan Air Lines, and others placed orders solely because they feared Pan American would gain an advantage in the world market. According to TransWorld Airline chief executive Charles Tillinghast,

> We were reluctant participants in the 747. But we couldn't afford to sit it out. Had we known that the DC-10 and L-1011 were coming along, we might have sat it out. We feared that it would go ahead and we didn't have the courage to stand aside.[6]

Boeing's marketing prowess and the worldwide need to "keep up with the Joneses" helped sell the high-tech 747, but not until after Boeing nearly went bankrupt.[7] According to Frank Kolk of American Airlines, the real need in the 1960s was for a twin-engine, wide-body, double-aisle aircraft capable of carrying 250 passengers 2,100 miles—a product that was 25 years in the future.[8] Boeing also had problems when it developed the follow-on to the 747—the 747-400

Late in the process Boeing learned that customers wanted more high-tech elements than anticipated. Customer demands for new features necessitated a succession of changes throughout the 747-400—resulting in overwhelming integration problems.[9] By soliciting customer ideas and defining the work statement of the 777 early, Boeing successfully avoided unexpected customer demands.

CATIA

CATIA helped Boeing determine exactly what customers wanted and needed. Because engineers could design on the screen before going to production, customers could see early on what they did and did not like. However, using a computer design system and inviting customers, mechanics, and engineers to participate required a cultural change at Boeing that was not easy to implement. Gordon A. McKenzie, the United Airlines representative, claims he spotted rolling eyes when Boeing engineers learned that United and All Nipon Airways were "snooping around."[10]

Summary

By October 1990, Boeing had completed its market analysis, selected the 777 configuration, and identified costs. Philip Condit presented his plan to the Boeing board of directors for permission to solicit orders from the airlines. As he described the process,

> What you would love to have is United, British, American, JAL, on the same day all raise their hand simultaneously and say we all want it. Then you know you've got a slam dunk. . . . The board says, if you can find three great big airlines who all want to buy 100 airplanes, you don't even have to come back. . . . United said, we'll go. We [went] back to the board, [and] said, 'We think there's broad enough market interest. . . . Can we have approval to proceed?' The answer was yes, thank goodness.[11]

From lessons learned on the 747, Boeing realized the importance of identifying customer need before the production process. Customers told Boeing they wanted a family of aircraft to save money on interchangeable parts, maintenance, and training. CATIA and innovative design teams helped customers define and express their needs to Boeing.

The Department of Defense

> The bottom line is clear. America needs a new core airlifter to meet the requirements of America's national security strategy.[12]

The AMST

Unfortunately, America's security needs were not always so clear. In 1971, DOD commissioned Boeing and McDonnell Douglas to develop the AMST (Advanced Medium Short Take Off and Landing), a tactical cargo plane that could carry outsize equipment and take off and land on short runways. This plane grew into a much larger plane with greater capabilities, including some strategic features.

The need for the AMST originated with the Tactical Air Command, which needed to replace the C-130 with a plane that could carry outsize equipment directly to a battle zone. Although the Air Force had many C-130s in its inventory, the relatively small cargo-carrying capability of the C-130 limited its effectiveness. The C-5 could carry outsize equipment, but it could not fly close to battle zones.

In November 1972, the Air Force contracted with Boeing and McDonnell-Douglas to build prototypes for the AMST. The aircraft was to have a wide-body fuselage and the ability to carry a 27,000-pound payload on a 400-nm radius mission into and out of a 2,000-foot unimproved landing zone. The cargo compartment of the AMST was 68 percent greater than the C-130H, could deliver a 95 percent larger payload, and required about half the field length during landing and take-off.[13]

The C-17

After consolidation of the tactical and strategic military airlift commands in the mid-1970s, military leaders began asking if the Air Force could rework the tactical STOL aircraft into a strategic STOL aircraft. The Army still contended it needed a tactical aircraft with the ability to carry oversized and outsized equipment to forward points. However, the Air Force wanted strategic capability. The Chairman of the Joint Chiefs of Staff, General George S. Brown, asked, "Is it practical to have an AMST with a slightly higher box pick up much of the C-5 outsized load for Europe—with air refueling as necessary?"[14]

After much vacillation and a change in administration, the Air Force scrapped the AMST and initiated the C-X program. Major Charles L. Johnson reported on the prevailing views in *Acquisition of the C-17 Aircraft—An Historical Account:*

> A senior administration official (under Carter) . . . pointing at what he termed the almost unanimous opinion among pertinent government agencies [suggested] that the C-X program should be started now. He said it would be a mistake to prolong the agony of Boeing and McDonnell Douglas by giving the impression that the AMST (YC-14 and YC-15) intratheater STOL program is still alive under the guise of C-X. The White House's view of the requirement . . . centers on a highly fuel-efficient follow-on to the C-5 and the C-141. Further, advocates of the C-X optimized for long-range strategic (intertheater) airlift have the "political clout" in the executive branch and in Congress, and the supporters of intratheater.[15]

General Block led the joint task force of Air Force, Army, and Marine Corps representatives to define a new airplane that could perform both intertheater and intratheater airlift roles.[16] According to Block's planners, the new aircraft should:

- Carry outsize cargo
- Provide direct delivery to combat areas with a short field takeoff and landing requirements
- Refuel in flight.[17]

Justifying the new aircraft, Block pointed out deficiencies in the military's ability to carry outsize and oversized cargo: The C-5 could deliver battle tanks and other outsized cargo into only large, rear-area airfields, and the C-130 cargo-carrying abilities were limited.[18] The proposed aircraft, through aerial refueling, would have extended range and would help reduce ramp saturation at enroute bases and reduce overflight rights problems.[19]

In March 1980, General Block testified before Congress that his task force investigated a number of ways to meet the airlift requirements, including using more civilian airliners, buying more C-5s, and purchasing Boeing 747s for Air Force use. The task force concluded that these airplanes could not satisfy outsized cargo and other intratheater requirements:

> Based on operational experience, the Air Force believes that the C-5 does not have the capability to operate into small austere airfields. . . . The C-5 requires a runway width of 148 feet to turn 180 degrees [and] . . . taxiways 60 feet wide; it cannot back up and does not have adequate clearances for the obstacles normally associated with smaller, austere airfields. The Boeing 747 also has limitations because of its physical size and would require a considerable development effort to adapt it for outsized cargo. The cockpit must be raised, the nose door enlarged, the cargo floor strengthened and the landing gear made to kneel to facilitate loading. Even with kneeling, the cargo floor would be about 9 feet above the ground, and the aircraft would still have loading restrictions.[20]

Lockheed wanted to sell the C-5. At Lockheed's prompting during committee hearings, Congressman Richard Ichord confronted General Block with the 1967 mission statement for the C-5:

> Short field takeoff and landing ability will enable [the C-5A] to operate into short semiprepared airstrips. This would allow it to deploy combat forces directly from the U.S. and rear area marshaling points into objective areas using airdrop or airland techniques at semiprepared airstrips as far forward as the tactical situation requires.[21]

It became clear the Air Force had inflated C-5 performance standards to justify its purchase in light of recent C-141 purchases in the 1960s. Despite Lockheed's claims that wing modifications enabled it to operate in short semiprepared airstrips, the C-5 could not operate as stated. Yet, further studies to prove limitations of the C-5 did not convince Congress that DOD needed the C-17. Holding the Air Force accountable for past exaggerations, the House Research and Development Subcommittee voted 8 to 3 against funding the C-X for fiscal year 1981. After the hearing, Ichord wrote,

> The subcommittee did not believe that the C-X—a future system—was justified in the absence of relevant data or that this system should be supported in the absence of funds for the procurement of available sea and airlift assets that are needed to satisfy today's requirements. Beyond the matter or priority, the case for the C-X per se was not made to our satisfaction; and the DOD representatives who appeared before the full committee fell short of making the case for this aircraft.[22]

When Congress finally established funding for the C-X through a joint resolution in 1980, it also mandated the Secretary of Defense conduct a comprehensive study to determine overall U.S. military mobility requirements before initiating development of the aircraft.[23] Meanwhile, DOD selected McDonnell Douglas as the contractor for the C-X program in August 1981, causing William Gregory, editor-in-chief, *Aviaton Week & Space Technology,* to comment:

> Last year the Air Force completed a competitive source selection and chose Douglas to build its entry as the C-17 . . . What the winning contractor had won was the right to build an unfunded airplane.[24]

Throughout the hearing process, Congress learned that although DOD might need additional cargo planes, it didn't know how many it needed or what type. The Army did not consider the size implications of major equipment, nor how many items it needed to deploy with combat units. The Army also did not know how many airlift assets were already committed to the deployment of tactical fighters and airlift squadrons.[25]

Newly elected President Reagan and his defense secretary were not convinced DOD needed another strategic airlifter—especially since it already had the C-5. In 1982, DOD ordered 50 C-5Bs but allowed McDonnell Douglas to enter into a low-rate research and development contract while the new administration decided whether or not it really needed a C-17. In addition to the *Congressionally Mandated Mobility Study* completed in 1983, there were six additional studies and plans: *Airlift Master Plan* (1983), the *DSARC Bottom-up Review* (1985), *Major Airlift Review* (1990), *Mobility Requirements Study* (1992), *AMC Alternatives to Strategic Airlift* (1995), and *Optimum Mix of C-17s and Non-Developmental Airlift Alternatives* (1995).

Either Congress or DOD commissioned each study to determine if DOD needed the C-17 or—if it did—how many. The *Congressionally Mandated Mobility Study* (CMMS) recommended more airlift, sealift, and pre-positioning equipment—both ashore and afloat. The study also recommended increasing the airlift objective, by 20 million ton miles a day (MTM/D) for a total of 66 MTM/D, based on the threat of Soviet invasion and a NATO/Warsaw Pact conflict. At least one-half of the additional 20 MTM/D was for outsized cargo such as armored vehicles, self-propelled artillery, large helicopters, and other combat support vehicles requiring a C-5 or C-17.[26]

After the Berlin Wall fell in 1989, people began to question the need for a large military arsenal. In 1990, the *Major Airlift Review* (MAR) lowered airlift requirements to 48 MTM/D, and Defense Secretary Richard Cheney recommended reducing the number of C-17 purchases from 210 to 120.

However, *Desert Storm* in late 1990 and other regional conflicts caused the *Mobility Requirements Study* (MRS) to raise suggested payload requirements to 57 MTM/D.[27] LtCol Lockhart explained that the previously low 48 MTM/D requirement was really based on available funds and that the 57 MTM/D was not really meant as a standard:

> In the MAR decision, they didn't start with a requirement of 48 MTM/D. The perception was that they started with available dollars and found how many aircraft they could buy and backed into the 48 MTM/D. Further, the 57 MTM/D was never meant as a requirement in the MRS.[28]

Another study by RAND, *Finding the Right Mix of Military and Civil Airlift, Issues and Implications,* found that if DOD used a mixture of aircraft to include the Boeing 747-400, the KC-10, and the Lockheed C-5, DOD could save between $5 billion and $24 billion. In one approach, RAND estimated the total need for C-17s at 40. The RAND conclusion was based on the use of the C-17 for transporting outsize equipment and personnel and using other types of aircraft for less than outsized equipment (oversized and other).[29]

Both the MRS and the MAR study based their conclusions on the C-17 ability to carry 160,000 pounds 2,400 nm without refueling. Today, the requirement is for a 110,000-pound payload at a range of 3,200 nm. The AMC report states the Air Force needs at least 120 C-17 aircraft (or equivalents) to meet the DOD goal of handling two nearly simultaneous major regional conflicts.[30]

The C-17 is easier to handle, requires fewer crew members, and costs less to maintain than the C-5s and C-141s. The C-17 has less dependence on ground-handling equipment because of an in-flight reconfiguration feature. It is capable of performing airdrop missions for both cargo and personnel. On the other hand, the C-5 and the Boeing 747 carry more than the C-17 and travel further without refueling.

In November 1995, the *Non-Developmental Aircraft Alternative* (NDAA) study cited findings similar to those of the earlier RAND study: DOD could save at least $9 billion if it used a mix of C-17 and 747 aircraft. The Joint Chiefs of Staff expressed willingness to purchase a mix of C-17s and 747-400s. However, DOD decided to purchase the full complement of 120 C-17s because, as Under Secretary Paul J. Kaminski argued, even though a mix of 100 C-17 and 18 C-33 (Boeing 747) aircraft would cost less in life cycle costs, "It brought far less flexibility with it."[31]

Summary

Politics at all levels affected DOD ability to determine need for the C-17. Although the C-17 is now part of the DOD fleet, arguments continue on how many C-17s DOD needs to fulfill its mission. A November 1995 study concluded that the most cost-effective purchase would include a mix of C-17s and 747s. DOD decided to buy 120 C-17s because of the aircraft's versatility.

Comparison

- Boeing took 4 years to decide what kind of airplane it needed to build. DOD took 10 years, from 1971 to 1981, to decide what kind of airlift it needed to build.
- Boeing brought customers into the design process early and performed an intensive marketing study to determine what its customers needed. DOD did not perform a comparable market study until after Congress tied funding to a mission-need study.
- Boeing used early customer input to help eliminate late engineering changes, which can result in costly production problems. DOD and McDonnell Douglas made numerous changes to compensate for faulty wing design, payload, pallets, and landing gear, which caused costly production problems.
- Boeing listened to its customers and developed an overall plan for its next-generation aircraft. When Boeing's customers said they didn't want a 767X, Boeing built the 777. Conflicting priorities of different presidents and their defense secretaries influenced DOD internal priorities; DOD needs changed with changing administrations.
- Once Boeing defined customer need, outlined its plan, and gained board approval, support for the 777 program remained steady. DOD began with a need for a tactical airplane—as determined by the Tactical Air Command—and ended with a need for a strategic airlift as determined by the President. Congressional support vacillated.

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PART II

6. *Program Management*

A . . . [program] can be generally characterized as a set of interdependent activities or tasks, which are integrated to accomplish a specific set of goals and objectives within a specified time period.

A. J. DiMascio, The Project Cycle[1]

For Boeing, the approval process for development begins *before* the company identifies customer needs; for DOD, the process begins *after* DOD identifies customer needs. Boeing customers include airlines and major airplane leasing companies around the world; DOD customers include the nine commanders in chief (CINCs) and aircraft operators.

Approval for both Boeing and DOD revolves around development phases. As identified in chapter 3, the development phases for Boeing are program definition, cost definition, and production (figure 8). Phase names for DOD changed over the life of the C-17 project, but as of 1996 they were designated as mission need, concept exploration and definition, demonstration and validation, engineering and manufacturing development, and production and deployment. Although officially DOD does not count mission need, identifies concept exploration and definition as phase 0, and identifies production as phase IV, this study numbers the phases 1 through 5 to compare them more easily with the Boeing phases (figure 9).

Within each phase, there are milestones that require board or management approval. Two milestones in Boeing's cost-definition phase require board approval—one grants approval to offer the product to customers and the other grants approval to begin building. Other milestones require the approval of certain corporate officers. In the case of DOD, four milestones require Defense Acquisition Board approval. They are concept studies, concept demonstration, development, and production. In addition, DOD must obtain congressional funding approval for its programs each year.

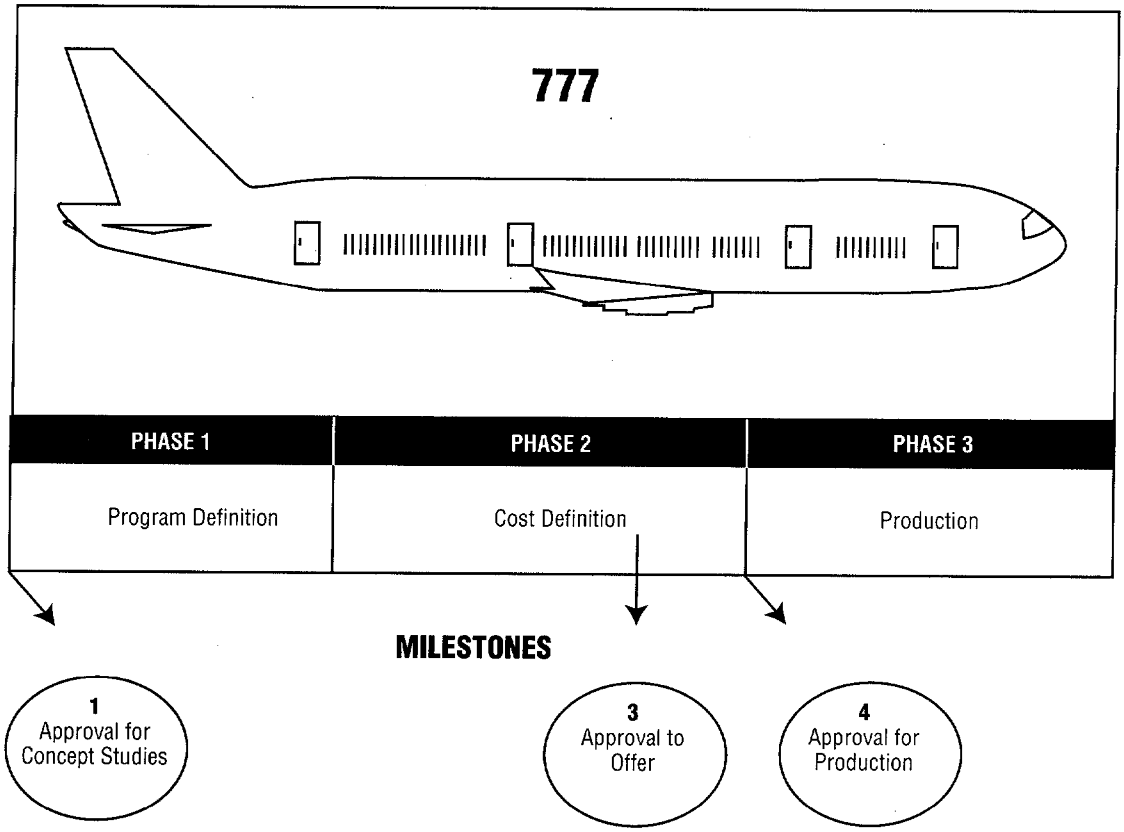
The Boeing Company

Philip Condit is quick to point out the company's written standards are only guidelines. Based on needs of its customer and/or lessons learned, Boeing may deviate from its standard corporate guidelines. It is important, however, to understand the basic format of Boeing's process in order to compare differences between approval for the 777 and the C-17.

Phase 1—Program Definition

During phase 1, Boeing studies the market and identifies a spectrum of designs, while focusing on customer mission requirements. After soliciting and analyzing input from key airlines, the company investigates technology, costs, and scheduling considerations to arrive at a configuration and preliminary design. The company then determines what personnel

FIGURE 8. The Boeing 777: Approval Milestones within Each Phase



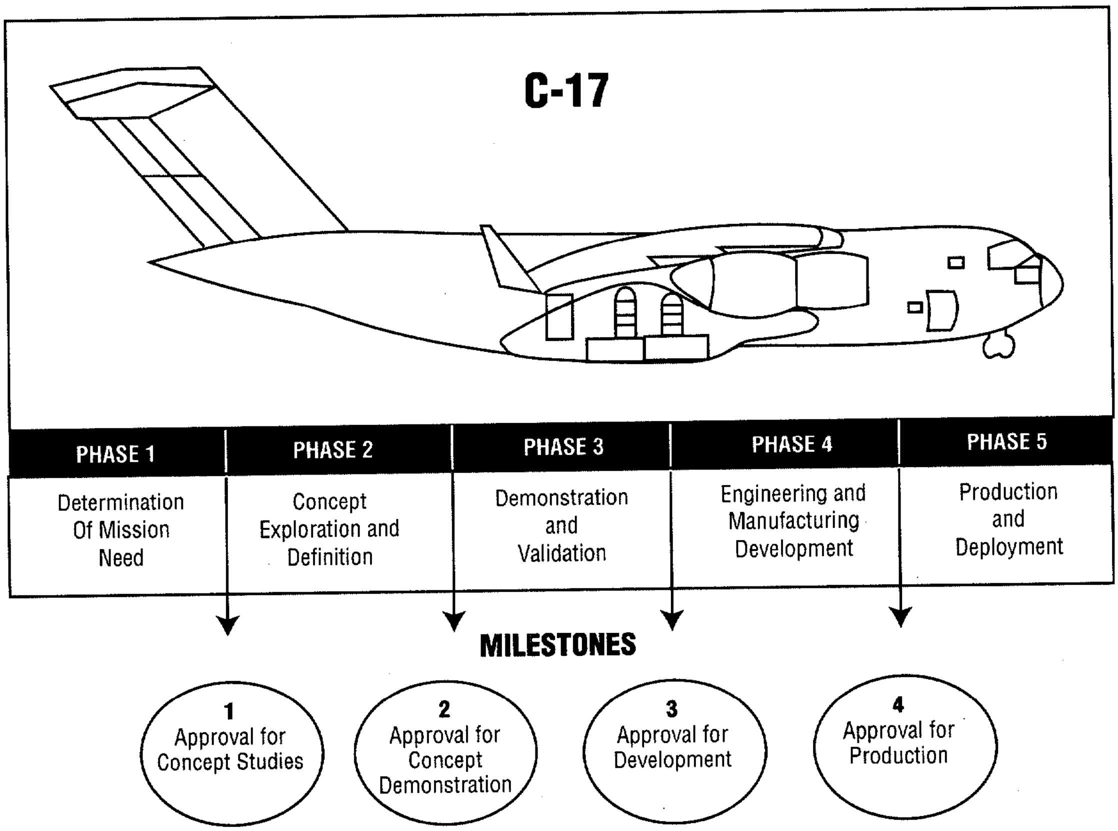
skills and facilities it will need to develop the proposed aircraft.

The CEO and one other corporate officer may begin the definition phase, which identifies the need for a product. Officers representing different Boeing departments then participate at well-defined milestones along the way. For example, 10 officers must approve the first milestone to begin program definition. They base their approval on written evaluations in five areas: market, strategy, product, innovation, and planning. Only three officers need to approve the second milestone, which evaluates the market and analyzes key mission requirements. At the end of phase 1, Boeing approves a baseline configuration for development and evaluation.[2]

Phase 2—Cost Definition (9 Milestones)

In this phase, Boeing bases approval on cost of resources and of time (figure 10). A team determines market potential by studying customer need, production requirements, and availability of resources. The Vice President, Customer Support, communicates with potential customers. Engineers and accountants analyze problems with technology and plot profit potential. They review the configuration to look for component compatibility and other potential problems. Boeing identifies the engines and suppliers; approves the price/market/cost relationships; approves authorization to offer; and approves engineering design go-ahead. A technology review determines if proposed technology is mature and how its use will affect scheduling.

FIGURE 9. The DOD C-17: Approval Milestones within Each Phase



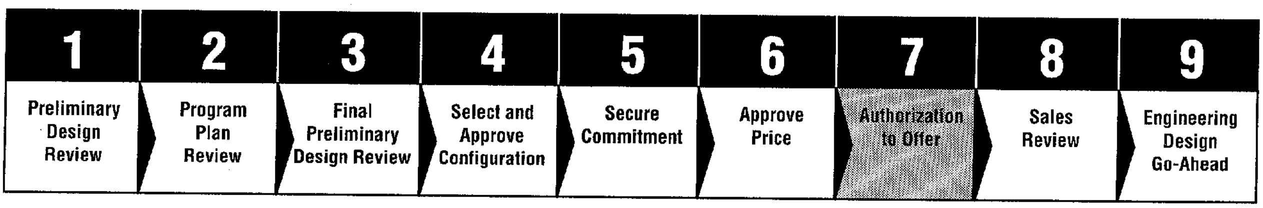
At milestone 4, when Boeing selects the airplane configuration, 12 departments participate in the process to approve technology and program development. Milestone 7, authorization to offer, requires approval from almost all departments before seeking board approval. At milestone 8, five officers study updated evaluations to determine if customer interest and orders are enough to continue. If the officers and the board approve the program, the board simultaneously authorizes funds and other corporate resources. Seven officers approve milestone 9, to begin a detailed engineering design. At this point, Boeing produces a schedule, budget requirements, engine contracts, configuration, design criteria, and resource requirements.

After the board agrees to offer the plane, officers contact customers for purchase. If customers support the plane with orders and a deposit, the board approves go-ahead and the plane enters production.[3]

Phase 3—Production

During early stages of the production phase, engineers establish the final airplane configuration and complete detailed designs. When the design drawings are 90 percent complete, Boeing begins manufacturing. The production phase is distinguished both by manufacturing and extensive ongoing testing. Boeing's standard test areas include air conditioning, avionics, landing gears, engines, flight controls, special instrumentation, and auxiliary power unit.[4]

FIGURE 10. Boeing Model for the Cost-Definition Phase (9 Milestones)



The 777

> In any earlier project, most of my time would have been spent solving technical and contracting problems. Now, I spend 70 percent to 80 percent of my time on people issues. It is phenomenally important to tell everyone what is going on, and I use every device I can get my hands on. These include orientation sessions, question-and-answer sessions, information sheets, and just a lot of meetings with everyone from customers to production workers.[5]

Boeing followed the standard development course for the 777 with some important variations. The company involved customers in the early stages, used CATIA, and used design-build teams to implement customer feedback and improve communication within Boeing.

The approval process was highly integrated because approving officers were incorporated into the design-build hierarchy. The hierarchy established direct communication lines between customers and engineers and between engineers and corporate officers. Corporate officers kept the board informed.

This knowledge flow enhanced the approval process in all ways. For example, although the board indicated it would grant automatic go ahead only after receiving 100 orders for the 777, when Philip Condit appeared before it with a purchase order for 34 planes, the board granted immediate approval for development. Potential airline customers believed Boeing had a well-thought out product that would sell, and their feedback inspired the board's decisiveness.

The board trusted its corporate officers. When Condit asked for almost a year longer than normal to prepare for production on the 777, it readily granted his request.

Summary

Boeing followed its standard course of approval for the 777, but with some important variations. Customers were consulted early to develop a product which had great market appeal. Boeing was able to make use of customer input through the use of computers and an effective design-build hierarchy, which kept management and the board informed of continuing customer interest as well as development progress.

The Department of Defense

DOD does not have a Board of Directors that provides approval, oversight, and funding functions. Instead, DOD has the Defense Acquisition Board (DAB) and Congress. DAB provides oversight and approves major acquisition development programs. An independent body, Congress, provides approval, oversight, and funding.

DAB members include the Under Secretary and Deputy Under Secretary of Defense (Acquisitions); the Chairman and Vice Chairman of the Joint Chiefs of Staff; the Director of Defense Research and Engineering (DR&E); the Component Acquisition Executives (CAE) of the Army, Navy, and Air Force; the Comptroller of DOD; the Assistant

Secretary of Defense for Program Analysis and Evaluation; the Director of Operational Test and Evaluation; and the Director and Chairman of the cognizant DAB Committee. DAB must approve a weapon system's progress before it can enter or exit a phase.[6]

Because the functions of Congress and DAB are independent, phase approval may not include funding. For example, DAB may approve a phase before Congress approves funds for that phase.[7] Conversely, large projects sometimes span several years between phases and DAB approval, while Congress approves funds yearly. As a result, Congress often has more influence over the development process than the DAB.

Phase 1—Mission Need

The request to validate a need, phase 1 (figure 9), can originate from many sources, including the commanders in chief, the Joint Chiefs of Staff, a service component, a separate operating agency, the OSD technology community, or a contractor. Usually the originator will define alternative solutions for mission need. Today, before a need leads to concept exploration, the Joint Requirements Oversight Council (JROC) must validate need. JROC members include the Vice Chairman of the Joint Chiefs of Staff, the Vice Chiefs of Staff for the Air Force and Army, the Vice Chief of Naval Operations, and the Assistant Commandant of the Marine Corps.[8]

Phase 2—Concept Exploration and Definition

Phase 2 is the "idea" phase and lasts 1 to 2 years.[9] Generally, the services award a contract for concept exploration to an outside source. By definition, a contractor's concept exploration is narrowly focused. For example, if the contractor is an aircraft manufacturer, an aircraft-related solution is likely. In this phase, often the contractor re-investigates security threats to the country, duplicating efforts the military already performed in phase 1. Even though the JROC evaluated several alternative solutions during the need assessment, the contractor again explores alternatives, determines costs, and establishes preliminary schedules.

A recent study, *Reengineering the Acquisition Oversight and Review Process,* recommended that DOD transfer the concept exploration and definition phase to the commanders in chief so end users can participate more actively in the creative process.[10] Since concept evaluation often duplicates work performed during phase 1, another solution would be to drop phase 2 entirely.

Phase 3—Concept Demonstration and Validation

The DOD demonstration and validation phase usually lasts 2 to 3 years, unless a prototype is included. With a prototype, the phase can last 5 years or longer. In phase 3, the contractor tests technical concepts identified in phase 2. The system program office (SPO) and contractor review system software and check materials for availability or limitations. Contractors may fabricate some hardware. Also, in this phase the SPO and contractors perform a comprehensive review of the project life-cycle, which includes reliability, availability, and maintainability:[11]

> The differences between the commercial and government sector are most distinct during the DOD demonstration and validation phase. Differences occur not in tasks and expenses but in timing and use of technology. The theme underlying the systemic differences is once again technological maturity. By the time the launch customer is secured in the commercial sector, D&V [demonstration and validation] for the initial configuration of that generation of aircraft is done. In the military sector, it has just begun.[12]

The SPO prepares an updated and expanded operational requirements document and a minimum set of alternatives, identifies funding sources, and reevaluates cost, budgeting, scheduling, and contracting. In 1979 the Air Force prepared a truncated study for the C-17 because the President and the Secretary of Defense felt that prior research on the AMST was justification enough for the program.

Phase 4—Engineering and Manufacturing Development

In phase 4, the SPO evaluates project systems economy, efficiency, and effectiveness to determine if it is ready for production. The SPO also reevaluates need, checks mission critical computer resources, and reviews contractor capabilities. This phase ends with a plan that includes a manufacture-ready design, a comprehensive production plan, and logistic arrangements, such as details involving suppliers and equipment. Depending on the contract and design maturity, even though DOD cannot legally require it, some contractors commit their own resources, for reasons that include maintaining a project's momentum, retaining its workforce, and beginning production work. McDonnell Douglas committed resources at this stage of the C-17 development because problems during development caused it to exceed the contract ceiling costs.[13]

Phase 5—Production

The DOD production phase 5 is similar to Boeing's phase 3—managing the production line and delivery to customers.[14] It is in this phase the program faces costly rework if excessive changes were ordered or the design was improperly executed. In the military, if significant rework occurs, the system reverts to the development phase or undergoes a process known as production concurrency. The latter occurred in the case of the C-17, causing the first six aircraft to have different configurations. Even though the C-17 entered into a new phase from 1982 to 1985 called limited development, the major modifications for OBIGGS, palletized ramps, and new landing gear and problems with flight control systems, wing design, and avionics integration made concurrent development and production more challenging.

The C-17 program skipped the first three phases—mission need, concept exploration and definition, and demonstration validation. DOD argued need was already established. Indeed, numerous follow-on studies pointed to an airlift deficiency for the U.S. military. Also, many ranking officers in the military felt the AMST sufficiently proved technology for the proposed C-X program. Documentation the Air Force would normally prepare in these early phases was hastily patched together and presented to Congress as justification for the C-X program.

The C-17

> It doesn't matter what the military strategy is. Sometimes what counts is expediency, compromise, and getting it over with. To field any new major weapon system in today's environment requires sophisticated political skill, thorough analysis, and—perhaps most of all—tenacity. . . . In Washington, the battle is never over.[15]

Numerous advocates and detractors greatly influenced the C-17 development course. Even though Congress had approved the AMST program, President Jimmy Carter removed funding for it from his fiscal year 1979 budget—an action that killed the program and paved the way for the C-X program, which Carter believed in strongly. General Block began forming his team for the C-X program in 1979.

The C-X program was not universally supported. A 1980 letter from Assistant Secretary of Defense for Program Analysis and Evaluation Russell Murray to Secretary of the

Air Force Hans Mark questioned the capability of the C-X versus the C-5 and challenged figures the Air Force used. Murray wrote, "I hasten to add that I am not an advocate of the C-5 (yet), but merely its temporary public defender for lack of anyone else to play that role."[16]

Because many military leaders believed the AMST had proved technology for the C-X, they attempted to push the program through Congress without the normal preparation required for such a program. According to Barbara Westgate, "USAF leadership attempt[ed] to define a program on extremely vague guidance yet survive the scrutiny of Congress who wanted . . . a [mission need statement] and funding profiles providing great program detail."[17]

The inadequate documentation, coupled with conflicting testimony on military needs, led Congress to reject the proposal. After the House Armed Services Research and Development Subcommittee voted against the C-X, Defense Secretary Brown requested a full committee hearing. This effort to bypass the subcommittee's authority angered several members of Congress. When the full committee met, Brown failed to appear, sending instead a lower ranking delegation of civilian and uniformed personnel. Offended by this slight, the committee questioned the witnesses on technical matters beyond their capabilities and then voted against funding.[18] After intensive lobbying by both President Carter and Defense Secretary Brown, the joint committee finally approved $35 million to begin research and development if DOD adequately demonstrated it needed a new cargo plane.

With the January 1981 departure of Carter and Brown, the C-17 lost its greatest advocates. Although Reagan's mandate to rebuild the nation's defenses increased available funds, numerous other glamorous and politically visible weapon systems, such as the B-1, M-X, F-15, and F-16, competed with the C-17. Furthermore, support vacillated. In November 1981, the Army and Air Force Chiefs of Staff and the Marine Corps Commandant sent a strongly worded letter to Congress endorsing the C-17. Two months later, Richard DeLauer, Defense Under Secretary for Research and Engineering, and Frank Carlucci, Deputy Secretary of Defense, expressed doubts about the C-17. Following the recommendations of a special committee assigned to determine the nation's airlift needs, DOD purchased 50 C-5s to redress the immediate strategic airlift shortfall.

The Air Force decision to buy the C-5s angered Army officers who felt they were cut out of the decisionmaking process on a program affecting their mission. Secretary of the Army James R. Ambrose expressed his anger in a letter to the Air Force Secretary in February 1982:

> It is one more illustration of the likely and unreasonable fate of adequate airlift in the hands of an Air Force [that] has its hands full with the MX, B-1, ATM, satellites, etc. I continue to believe, and, indeed, with increasing strength, that the deployment situation for ground forces will not be straightened out until control of its destiny is given to the using service. To abdicate it in this way to such obvious and long enduring prioritization at the bottom of the list is perpetuating a scandalous situation.[19]

On July 16, 1982, President Reagan sent a letter to Representative Trent Lott, Minority Whip of the House:

> Our proposed airlift program currently before the Congress includes four related components. First, we intend to buy 50 additional C-5 aircraft to quickly reduce the critical shortfall in outsize capacity. Second, we will increase our air refueling/cargo capability by procurement of 44 KC-10 aircraft. Third, we will expand the civil reserve air fleet

> enhancement program, under which domestically owned carriers can be used in time of need. Finally, we plan to use available fiscal year 1981 funds in the C-X program to continue research and development on the C-17, thereby preserving the option of developing the C-17 for procurement in the late 1980s to provide outsize capability and be a potential replacement for C-130 and C-141 aircraft. We believe this combination of actions is required to develop the airlift capability we urgently require.[20]

In July, 1982, Air Force Secretary Verne Orr authorized award of a contract to McDonnell Douglas for a modestly paced research and development program. This $31.6 million development contract for work through September 30, 1983, preserved the original source selection contract for McDonnell Douglas.[21]

After 2 years of low-level development, the C-17 was ready for full-scale development. However, because DOD had just purchased several new cargo planes, Congress expressed reluctance to fund full-scale development for the C-17. The Senate requested a study to prove need. Only after the report satisfied Congress did it approve the $123 million requested in the 1984 presidential budget.

In the meantime, a milestone review for full-scale development presented to the Defense Systems Acquisition Review Council (predecessor of DAB) in November 1984 caused Chairman Richard DeLauer to request a bottom-up analysis of the C-17 program, to include requirements, scope, and content. Defense Secretary Weinberger approved full-scale development February 1985. Nearly a year later, on December 31, 1985, the Air Force finally approved a restructured full-scale development contract with McDonnell Douglas.

Summary

Kenneth E. McAlear captured the essence of difficulties the Air Force encountered in selling the C-17 within both DOD and Congress:

> The Air Force and the Military Airlift Command have simply not done an adequate job on Capitol Hill and within the Department of Defense in the last 10 years trying to justify a new airlift airplane. Shortcomings in solid airlift doctrine, analysis, political sophistication, articulate spokesmen, and bureaucratic infighting have all contributed to the failure.[22]

In the late 1970s, two high-powered advocates, President Carter and Defense Secretary Brown, overcame opposition for the C-17. However, President Reagan and Defense Secretary Weinberger had different views of how DOD should solve its airlift shortfall. Weinberger allowed the C-17 contract to proceed on low-level development in late 1982 but did not approve full-scale development until 1985.

Comparison

- Boeing performed an extensive cost-definition phase to compare customer wants with technology maturity, cost, and the price its customers were willing to pay. DOD did not initially fully evaluate alternatives for cost savings.
- Boeing's board of directors provides approval, oversight, and funding. After board approval, Boeing remained committed to the 777 throughout development. DOD provides approval and oversight and Congress provides approval, oversight, and funding. After DOD and Congress approved the C-17, both continued to vacillate on approval and funding.

- Boeing used a sophisticated computer design program to help facilitate communication among its integrated teams of engineers, customers, marketers, and production specialist. Early customer involvement helped eliminate last minute engineering changes that create costly production problems. DOD decided not to use a computer design program and made engineering changes that created costly production problems. Excessive changes caused the C-17 to undergo significant development problems even when it entered production.
- Boeing added almost a year to its development program because it needed more time to accommodate problems inherent in a new computer design program, highly computerized avionics, and a new organization approach. DOD used a highly success-oriented schedule because it believed the C-17 technology was mature and would not result in many problems.
- Boeing followed its standard development structure with some enhancements that brought customers into the design process and improved internal communications. The assurance that Boeing could sell the 777 gave the board confidence to add almost a year to its normal production process.

DOD did not follow its standard development structure for approval. It skipped phases 1 through 3. Support for the project vacillated under different presidents and funding was further threatened when Congress learned of problems with the program. There was no forethought given to extending time lines before the program began because military leaders believed technology would not present problems.

Notes

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17. Barbara Westgate, "Weapon System Jeopardy! The Answer is: The C-17" (thesis, Industrial College of the Armed Forces, National Defense University, Washington, 1995), 9.
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21. Ibid., 267.
22. McAlear, 33.

7. Technology Requirements and Problems

Technology must earn its way on to a Boeing plane. . . . In short, our efforts will continue to be customer driven, not technology driven.

Philip M. Condit[1]

Studies of DOD acquisition over the past 25 years reveal that DOD methods resulted in development programs spanning 11 to 21 years, and by the time the weapon systems were delivered, the technology was out of date. Not surprisingly, the length of time to develop systems was also linked to a doubling of costs.

Jacques Gansler warns against government preoccupation with technology without regard to cost. He believes that until DOD introduces affordability into its requirements and shifts from a *design-to-performance* approach to a *design-to-cost* approach, it will procure fewer and fewer weapon systems each year. Eventually, Gansler speculates, the United States will not have enough modern systems to present a credible defense posture.[2]

According to Gansler, technology has generally introduced improved performance, but "in the defense world, costs have risen along with performance." Comparatively, "commercial computers, televisions, and other items that use similar technology have improved dramatically in performance and gone down dramatically in price."[3]

The Boeing Company

> The 777 causes me to sit bolt upright in bed periodically. It's a hell of a gamble. There's a big risk in doing things totally differently.[4]

In the 1970s and 1980s, Boeing chose not to include the fly-by-wire system, flat-panel video displays, and advanced propulsion systems on its planes.[5] Even though the technology existed for these features, Boeing did not consider it mature enough for use in its commercial planes. Before going into production on any high-tech system, Boeing imposes Gansler's design-to-cost constraints. Evaluations of technology often include trade-offs of performance, technology, and manufacturing investments. In 1990, new features on the proposed 777 included:

- The fly-by-wire system
- Advanced liquid-crystal flat-panel displays
- A two-way digital databus patented by Boeing (Aeronautical Radio Inc., ARINC 629)
- Aerodynamically efficient wings
- Powerful thrust engines
- Composite materials in the airframe
- An advanced composite empennage.

Technical Problems

Although Boeing did not consider new features on the 777 as technical breakthroughs, design methods the company chose were on the leading edge of technology. Philip Condit referred to Boeing's computer design technology, which eliminated the mockup, as an "order of magnitude change." Of course, there were some startup difficulties associated with innovative design technology as well as with some of the new technology features on the 777—particularly with avionics.

Avionics Integration. Avionics cover a multitude of high-tech electronic devices found on modern aircraft;[6] on the 777 they include:

- The fly-by-wire system with ARINC 629
- The Aircraft Information Management System (AIMS)
- The Flight Management System (FMS)
- The Primary Flight Computer (PFC)
- Actuator Control Electronics (ACE).

The Fly-by-Wire System. This uses electrical signals rather than mechanical links to move airplane control surfaces such as the rudder and ailerons. It performs stabilizing functions that permit use of lighter tail and wings and reduces the need for cables, pulleys, brackets, and actuators. Because the system has fewer moving parts than standard systems, mechanical malfunctions are fewer. The system provides protection against inadvertent maneuvers and is easier to handle because of automatic compensation for gear, flap, and thrust changes.[7] However, because of the complex interactions between hardware and software, fly-by-wire is extremely difficult to build and test.

Although Boeing considered fly-by-wire technology mature, it could not assemble and integrate the fly-by-wire system until it solved problems with other components—the ARINC databus, AIMS, and the software coding. Problems with avionics began early on and continued throughout testing. For example, the rudder shut down because engineers had not anticipated how much the tail flexed when the rudder moved. To solve the problem Boeing had to rewrite computer codes to better control the ailerons, slats, and rudders.[8]

ARINC 629. The electronic highway along which the 777 computers exchange data, the ARINC 629 is an updated version of the ARINC 429 found on the C-17. ARINC 629 features one wire running the length of the aircraft to which every other computer is connected. Because all computers communicate with each other and with the central processing units along this system, ARINC had to be operational before Boeing could test its other systems. Early versions of the powerful, integrated ARINC circuit chips overheated and would not transmit data.[9]

Aircraft Information Management System (AIMS). Honeywell developed AIMS, the system that manages data exchange among most 150 processors on the 777. Departing from the fail-safe architecture of separate computer functions, Honeywell consolidated most of the 777 digital processing into two central computers. To keep a bug in one processing unit from corrupting other units, Honeywell partitioned the software, which required 18 preprogrammed application-specific integrated circuit (ASIC) chips. Developing these chips required a year longer than anticipated. Don Morrow of Honeywell admitted that the company "really underestimated what it would take to develop [AIMS]. . . . As a result, we went downstream a little farther than we wanted."[10]

Ada Software Language. DOD originally developed Ada, a single-standard software language, to cut costs for supporting more than 300 existing program languages and to provide greater portability for use in planes and other weapon systems. Ada prevents isolated faults from shutting down the entire system, protects against real-time bugs, has high host-target portability, and does not allow programmers to take shortcuts, which sometimes cause errors.[11] However, programmers for the 777 complained that early versions of the code were problematic and caused delays when developing the primary flight computer.[12] Boeing was the first company to use Ada in a commercial aircraft.

Primary Flight Computer (PFC). Three primary flight computers calculate precise adjustments in response to the autopilot and to the flight management computer that controls destination, course, and altitude. Boeing's contractors had problems writing software codes for the three computers and integrating codes with the ARINC databus.[13] Solving problems in the avionics system took over a year longer than Boeing anticipated. In order to maintain its schedule, Boeing flew test flights with uncertified computers; the FAA certified the 777 as safe only 1 month before delivery of the first plane to United Airlines.

Computer and Aircraft Design

> If Boeing's new approach to design works, the 777 will be an efficient, economic plane with a lot fewer bugs than new planes usually have. As a result, Boeing could save the millions it usually spends fixing design problems during production and after the plane has been delivered to the airlines.[14]

Boeing's decision to change design and production practices emerged as a means of cutting costs after analysis revealed primary cost drivers at the company were downstream changes (those made after development) and rework on the factory floor.

In the past, Boeing engineers were still designing when manufacturing began. They often made changes as problems came to light on the factory floor, on the flight line, or even after delivering the plane to the customer. For example, when Boeing delivered the 747-400 to United in 1990, it assigned 300 engineers to eliminate bugs undetected earlier.[15] United officials were dissatisfied with the late delivery of the 747 and with the costs sustained in rescheduling flights and compensating passengers for maintenance delays. Boeing wanted to avoid similar embarrassing and costly problems on the 777; the company's goal was to deliver a fault-free aircraft on time.

Startup problems with CATIA threatened Boeing's delivery schedule. According to Ronald A. Ostrowski, director of engineering, the challenge was to "convert people's thinking from 2-D to 3-D, [which] took more time than we thought. I came from a paper world, and now I am managing a digital program."[16] Instead of allowing the schedule to slip because of CATIA, Boeing increased human resources and spent the money necessary to overcome problems. Boeing probably spent $7 billion for research and development, although Boeing has not confirmed these estimates. Alan Mulally, Senior Vice President for Airplane Development, defended Boeing's upfront expenditures:

> In our business, it's very rare that you can move the end point. When you make a commitment like we made, . . . [customers] lay out . . . plans for a whole fleet of airplanes. . . . They will have plans to retire old airplanes. . . . It just seemed best to keep the end date the same and add some more resources.[17]

Boeing's decision to press forward with the new design technology proved worthwhile. CATIA-designed parts made in factories all over the world fit together with almost no need for rework. The wing assembly tool that Giddings & Lewis in Janesville, Wisconsin, put together and the world's largest C-frame riveting system wing assembly tool from Brotje Automation of Germany both ran with CATIA. In Kansas, Boeing's Wichita Division built the lower lobe (belly) of the 777 nose section; the skins of the airframe came from Japan.[18] Charlie Houser, product line manager at Wichita, described the process:

> CATIA and digital preassembly let us find areas of potential interference before we

> started production. The individual assemblies fit together extremely well, especially the passenger floor. . . . It went together smoother than any floor grid of any size that we've ever built in Wichita.[19]

Engines

Boeing chose three companies to supply engines for the 777: Pratt and Whitney, General Electric (GE), and Rolls Royce. The engines were described as:

> the largest and most powerful ever built, with the girth of a 737's fuselage and a thrust, or propulsive power, of between 71,000 and 85,000 pounds compared with about 57,000 pounds of the latest 747 engine. Key factors in this performance are new, larger-diameter fans with wide-chord fan blade designs and bypass ratios ranging from 6-to-1 to as high as 9-to-1. The typical by-pass ratio for today's wide-body jet engines is 5-to-1. Pratt and Whitney is furnishing the PW4000 series of engines, General Electric is offering the GE90 series and Rolls-Royce is offering the Trent 800 series of engines.[20]

Boeing's success in finding manufacturers willing to invest in new engine technology represented a significant shift in attitude toward technology development. Many American companies were unwilling to take leading steps in technology unless the government picked up the tab. For example, in the 1960s, GE would not take risks to develop a high-bypass jet engine for the 747. Yet, GE participated in a military program, the C-5A, where the government absorbed the costs to develop that same high-bypass technology.[21]

Boeing pushed propulsion technology on the twin-jet 777 because all airlines had expressed interest in reducing operating expenses. As Jerry Zanatta, director of flight test engineering pointed out, "Flying with two engines allows redundancy that a pilot wants in order to ensure safety of flight. Flying with more than two engines only increases fuel costs and operating costs unnecessarily."[22] Ultimately, if Boeing had not delivered the twin-engine 777, another company would have done so. Airbus now has a twin-engine plane (A330) that competes favorably with the 777.[23] For the 777, Pratt and Whitney and Rolls Royce built derivative engines by scaling up older designs. GE designed a completely new engine.

When the 777 lifted off on its first test flight in 1993, two balls of flame and smoke belched from Pratt and Whitney engines. The differences in the rates of thermal expansion between the interior components of the engine and the compressor case caused the casing to expand faster than the actively cooled interior engine components. To equalize the temperatures, Pratt and Whitney engineers changed the software commands directing the blade angle of the first four compressor stages. The engine worked perfectly on the second flight.[24]

Boeing also grounded a plane in May 1995, after a GE engine backfired in a spectacular display of flame and smoke. Improper airflow caused the backfire, which GE solved with methods similar to those used by Pratt and Whitney.[25] GE and its French collaborator, SNECMA, chose composite materials for the new engines because of their lighter weight and ability to withstand the extreme heat of high-compression engines—even though Rolls Royce had tried and failed to use composites in the 1980s.[26] In 1995, at the SNECMA engine test sight in Villaroche, France, bird-strike tests on the engine knocked out three blades. To solve the problem, GE made 40,000 computer calculations for stress on the blade. Within a few months, engineers redesigned a part which enabled the engine to withstand bird-strike tests.[27]

Summary

Boeing committed to an airplane that would serve its customers and ensure the company a place in the market for 50 years. The company was also committed to changing its design and manufacturing process. Given these commitments, Boeing's board and management focused on what they had to do to make it happen. When Boeing encountered problems in the design-build system and with avionics, it absorbed the costs and pushed forward to meet its delivery schedule.

The Department of Defense

> Technology on the C-17 was not as well defined as some would have us believe.[28]

> I was shocked in the fall of 1992 to discover that this airplane was being produced from paper, that they did not have a CAD/CAM system, that they had never had a CAD/CAM system.[29]

Secretary of Defense Harold Brown justified using a fixed-price contract to produce the C-17 because military leaders believed the technology for the C-17 was mature. AMST prototypes demonstrated short-field take-off-and-landing capability, and by the late 1970s, the hardware and software were considered off the shelf.[30] The Air Force's request for proposal stated, "Undue complexity or technical risk will be regarded as poor design."[31] After McDonnell Douglas won the contract, it wrote this low-risk technology theme into the C-17 technical planning guide:

> The C-17 systems are straightforward in design, are highly reliable, and represent current technology. For example, a version of the C-17 engine has been proven in commercial airline service since 1985. New-technology systems, like the on-board inert gas generating system (OBIGGS), are used only where they offer significant advantages over previous methods. . . . computer-controlled multifunction displays and head-up displays enable the aircraft to be flown and all its missions accomplished with a flight crew of only two pilots and one loadmaster.[32]

The technologies for the C-17 were not new, but the way technologies were applied was. The C-17 depended on a complex, integrated avionics system to reduce the crew to two pilots and a loadmaster. By comparison, the C-141 and the C-5 required as many as seven people to perform similar functions.[33] Introducing STOL to an aircraft designed to carry 5 times as much weight as the AMST involved major modifications to the "already proved" technology, including a new wing: "There is more technology in the wing than in any other part of an airframe. . . . Production schedules are keyed to wings."[34]

The AMST

In 1971, the Air Force contracted with both Boeing and McDonnell Douglas to build an AMST prototype that could fly a 400-nautical mile-radius mission, carry 27,000 pounds, and land on short runways using short takeoff and landing technology. Such an aircraft, in the words of General Paul K. Carlton, would be "a miniature C-5."[35] In 1975, the McDonnell Douglas YC-15 prototype successfully demonstrated powered-lift technology that met mission requirements.

In 1976, Air Force Chief of Staff General David C. Jones asked if a single derivative model of the AMST could be used in both a strategic and tactical airlift capacity.[36] Gordon Taylor and Gordon Quinn from the Aeronautical Systems Division at Wright-Patterson Air Force Base, Ohio, investigated the ability of the AMST to carry the M-60 Main Battle tank, weighing 110,000 to 117,000 pounds, with ranges of 2,000, 3,000, and 4,000 nautical miles. Taylor and Quinn concluded that using a derivative aircraft in routine strategic airlift would significantly increase both the weight and cost of the AMST. To restructure the AMST from a tactical to a strategic aircraft would require full-scale development (a larger wing, heavier structure, and different aerodynamics). Even in a non-STOL capacity, the wing, a major airframe component, would have to undergo considerable change.[37] In 1976, Brigadier General Phillip Larsen, USAF, Deputy Chief of Staff, Systems, Air Force Systems Command, wrote, "It would not be cost effective to incorporate a STOL capability in a strategic airlift derivative aircraft. . . . It would be necessary to increase . . . [the] YC-15 wing area 69 percent and gross weight 115 percent."[38]

On December 10, 1979, Program Management Directive R-Q 6131(3) formally canceled the AMST program. On that same day, Directive R-C 0020 (1) provided formal direction and guidance for full-scale engineering development of the C-X. This directive ordered that the C-X skip standard steps in the program process, most significantly, the phase for demonstration and validation, because "the new aircraft will use existing technology . . . since the Air Force had demonstrated and proved advanced technology concepts and operational utility in the AMST program."[39] This "phase omission" proved to be an error in the C-17 program process.

Changing Payload Requirements

The payload requirements for the C-17 changed at least five times over the course of its development. The 1981 request for proposal ordered a STOL plane that could carry a maximum payload of 130,000 pounds.[40] By the time the Air Force awarded the contract in 1982, it had raised the key payload requirement to 172,200 pounds for a 2,400-nm range.[41] In 1988, DOD decreased the payload to 167,000 to compensate for a palletized ramp and OBIGGS system that increased the weight of the aircraft by 5,000 pounds. In 1991, MAC commander General Hansford Johnson, USAF, reduced the payload requirement once again, to 160,000 pounds.[42] He reasoned that the kinds of equipment MAC needed to haul over essential routes—from West Coast bases to Hickam Air Force Base, Hawaii, and East Coast bases to Lajes Airfield in the Azores—did not require a plane with a 167,000-pound capacity. Johnson claimed the Air Force inflated the weight requirements during contract negotiations because McDonnell Douglas asserted it could build an aircraft that would carry 172,000 pounds for 2,400 nautical miles. He claimed reducing the payload to 160,000 pounds would better meet the needs of MAC:

> This was not a reassessment of requirements as much as it was a refinement of the original requirements. . . . McDonnell Douglas, in competing for the contract, offered more than what MAC needed. . . . All of us, being eager to do more, said sure, we'll write the specs at the higher level.[43]

When the C-17 was in the early stages of development, its payload requirement was 160,000 pounds. At this requirement and exercising STOL capability, the aircraft needed more powerful engines. Pratt and Whitney and Rolls Royce were capable of producing such engines, but John M. Deutch, Under Secretary of Defense (A&T) considered the change too costly. Deutch preferred to reduce payload specifications rather than change engines—especially since most agreed the C-17 payload requirements were set too high at the beginning.[44] General Fogleman asserted, "We didn't need a plane to carry a 172,200 pound payload then and we don't need a plane to carry 160,000 pounds now.

> The original requirement set in the early 1980s was for a 130,000 pound payload, the weight of an M-1 tank. This specification . . . was linked to the Cold War goal of transporting 10 Army divisions to Europe in 10 days, rather than dealing with the types of regional contingencies the Pentagon now is focusing on. . . . An

> absolute critical leg for us in this new world we are living in is how much can this airplane carry 3,200 miles. . . . So we established a 110,000-pound payload threshold at the 3,200-mile range which did not exist before.[45]

The C-17 program did not begin to overcome its technology problems until top military leaders such as Deutch and Fogleman focused realistically on C-17 requirements compared with customer needs. By January 1995, in a concerted effort to establish realistic requirements, DOD, Congress, and McDonnell Douglas agreed to decrease the payload and increase the range requirements.

Technical Problems

From the beginning, key players in the C-17 program underestimated the technical challenges of the project. Roger A. Panton, chief of engineering for the C-17, said, "Our primary technical problem with the C-17 was integration. We grabbed too much off the shelf and tried to put it together."[46] Off-the-shelf technology included a fly-by-wire system, advanced materials, engines, software, and a powered lift that the McDonnell Douglas YC-15 prototype demonstrated in 1975.

In a 1993 report, the Defense Science Board also cited lack of computer-aided design as a contributor to program difficulties.[47] Deutch added to this assessment some of the program's other weaknesses:

- Technical risks involved in flight test software and avionics integration
- Structural deficiencies in the wings, flaps, and slats
- Uncertainty of flight-test program requirements.[48]

Avionics Integration. Problems occurred when DOD changed from a manual flight system with electronic control to a quadruple-redundant electronic flight control system (fly-by-wire).[49] The change to the fly-by-wire became necessary when initial wind tunnel testing revealed pilots using a manual system could not prevent the aircraft from going into an unrecoverable stall during short-field landings at a slow, high-angle approach.[50] Introduction of the fly-by-wire system brought with it complex problems of computer integration similar to those experienced at Boeing.

Flight Control System. Shortly after McDonnell Douglas directed the Sperry Corporation to use the fly-by-wire system, Honeywell purchased Sperry. Honeywell reset the date for flight-qualified software to April 25, 1991, thereby extending delivery 4 years from the date McDonnell Douglas first ordered the system in 1987. Not satisfied with the extended delay, the Air Force Program Office convinced McDonnell Douglas that GE could deliver the fly-by-wire system. McDonnell Douglas ended Honeywell's contract in July 1989.[51] GE delivered its system for integrated testing October 1990.[52]

Mission Computers. The core of the C-17 avionics integration is the mission computers. Three computers receive information over the databus from on-board systems. The computers compare information, analyze data, perform calculations, and display information to the pilot and copilot. The displayed information includes functions a flight engineer normally performs, such as determining position and velocity, determining weight, calculating airdrop requirements, and gauging small airfield conditions.[53]

McDonnell Douglas awarded a fixed-price contract to Delco in July 1986 to develop the mission computer.[54] In August 1988, an independent review team—which included personnel from McDonnell Douglas, Hughes Electronics, and the Air Force—concluded Delco had not completed engineering requirements and McDonnell Douglas had not adequately defined those requirements. In July 1989, McDonnell Douglas terminated Delco's contract and assumed responsibility for managing the software.

Because McDonnell Douglas failed to spell out language requirements to its software subcontractors, the C-17 evolved with software in almost every computer language known at the time.[55] GAO described the C-17 as "the most computerized, software-intensive aircraft ever built, relying on 19 different embedded computers incorporating more than 80 microprocessors and about 1.3 million lines of code." As late as 1995, Deputy Program Manager John Wilson said problems with the software were ongoing:

> This is a tough area. The C-17 System Program Office recognizes that additional throughput could be beneficial. Although the computer performs the basic mission, it is slow and does not have the throughput and user friendliness we would like. We are working the area.[56]

Wings. In September 1991, persistent fuel leaks around the wings held up delivery for nearly a month while technicians located the leaks and determined cause. Jim Berry, Vice-President and General Manager at McDonnell Douglas, attributed the fuel leaks to sloppy workmanship caused by lack of production discipline and unscheduled work.[57]

In October 1992, the C-17 failed a wing-strength test. Even though the Air Force had reduced the maximum payload requirements from 167,000 pounds to 160,000 pounds, the wings were still not strong enough to handle a full payload at the required 150 percent safety factor.[58] Causes of the failure were attributed to a computational error in the initial wing design and improper methods of determining compression stress. McDonnell Douglas repeated the error throughout the wing structure, further complicating correction procedures.[59]

The failed wing-strength test and fuel leaks cost McDonnell Douglas more than $1 billion, and modifications to correct them added 700 pounds to the weight of the aircraft.[60] A CAD/CAM system similar to Boeing's CATIA might have prevented both problems.

Summary

DOD and its contractor underestimated the scope of technological changes and their costs when they changed the mission of their aircraft from tactical to strategic. To meet changing weight requirements, McDonnell Douglas had to add computerized flight controls. Lack of experience and mismanagement of software contracts caused delays and increased costs to the project. A math error caused major problems in the wing, and sloppy work created fuel leaks.

Comparison

- Boeing evaluated technology carefully and took care not to push it further than the market required. DOD goldplated its payload requirements and pushed technology beyond the needs of its customers.
- Boeing required its subcontractors to use Ada to enforce discipline on its computer system. DOD allowed its contractors to use a number of noncompatible computer languages.
- Boeing used a computer to design its aircraft and built a new lab to integrate and test avionics. McDonnell Douglas designed the C-17 on paper.
- When Boeing encountered technical problems in CATIA and the fly-by-wire system, the company took immediate steps to correct them; Boeing remained committed to its delivery date and allocated resources to solve its problems. When DOD learned that McDonnell Douglas would miss its deadline, it curtailed funding and extended the delivery date.

DOD often takes so long to overcome technology problems that, by the time a weapon is complete, the technology is outdated. In *Affording Defense,* Jacques Gansler summarizes DOD methods: "The unreasonably long acquisition cycle leads to unnecessary development costs, to increased 'gold plating,' and to the fielding of obsolete technology."[61] Even though the C-17 is the most versatile cargo plane the United States has, DOD was not able to produce it until it solved major technology problems. Although Boeing began development of its plane several years after DOD began development of the C-17, it completed the 777 at about the same time as the C-17. Boeing used the same level of technology, and in some cases—as with computer design, flat-panel displays, increased propulsion, and advanced manufacturing process—it used higher technology.

Jacques Gansler illustrates the difference between the defense world and the commercial world by observing the practices of new engineers in each setting:

> A typical American engineering student (graduate or undergraduate) is taught how to design the "best system." Using computers, sophisticated mathematics, and all their engineering skills, these students set out to design systems that will achieve the maximum performance. If they enter the commercial world, they are taught that their designs should be modified to reduce the likely costs of production and operation. However, if they enter the defense world, they continue to use the design practices they learned in school, and cost-cutting becomes an exercise for the manufacturer.[62]

The military has learned some lessons from commercial developers. The F-22 and now the C-17 acquisition programs are using the integrated product team concept Boeing developed in its design-build process. Jay Kappmeier, general manager for the McDonnell Douglas C-17 support team, credits integrated teams for helping change the C-17 program from a failure to a success. He said that with integrated product teams, "Problems bubble up faster and they are resolved faster."[63] The F-22, the B-2, and the V-22 Osprey are all benefiting from CATIA and the strides Boeing made in composite manufacturing. However, *the military has not adopted the design-to-cost approach found in commercial industry*. For example, the F-22 faces more than one-half billion dollars in cost overruns in the design phase alone.[64]

When Dr. Kaminski became Under Secretary of Defense for Acquisition and Technology in 1994, he emphasized several initiatives to overcome problems enumerated in the C-17. One is using cost as an independent variable (CAIV). The CAIV initiative encourages program managers to work with users and decide, based on the mission, if program requirements are worth the cost. While he admits DOD has not completely adopted CAIV, he points to Army success with the SMART-T program, a program to develop a tactical communication terminal. Following the CAIV initiative, the Army program manager worked with users to change requirements and reduce costs from $790 million to $250 million.[65] In addition to CAIV, Dr. Kaminski also helped rewrite regulations to reduce acquisition cycle time and encouraged program managers to use modeling and simulation to better manage system engineering and integration risks.

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8. Funding

Budget instability, as Pentagon officials refer to it, is hardly unique to the Defense Department. Few businesses can predict sales in advance. . . . All employ approaches to budgeting [and funding] that leave options open for handling uncertainty.

Thomas L. McNaugher[1]

Both the government and private sectors must plan when funding large development programs, such as the C-17 and the 777, and both must consider fundamental fiduciary responsibilities to constituents. DOD has a fiduciary responsibility to provide the best defense for American citizens at the least cost to the taxpayer. The Boeing Company has a fiduciary responsibility to its stockholders and must remain competitive in the market.

According to Boeing President Philip Condit, not all decisions to improve competitiveness improve the bottom line in the short term:

> I sometimes make decisions that cost money rather than make money. In other words, if it costs to provide something to a client that will protect our market share and help provide future income for the shareholders, I will spend that money. Not every decision is for the immediate bottom line—some are for future bottom lines.[2]

Likewise, not all procurement decisions improve DOD ability to defend American citizens in the short term. Historically, DOD weapon-acquisition decisions determine defense capabilities 20 to 30 years in the future. To determine how to allocate assets, government and corporate officials must weigh current needs against future ones.

In addition to planning and budgeting for large development programs, government and business must properly account for how each spends development funds. Congress allocates funds for development based on DOD requirements in the yearly presidential budget. In business, corporate officers request development funds, which the board approves and allocates in the corporate budget. If government or a business spends money for development that was not allocated—by Congress or the governing body of the corporation—they are breaching a fiduciary trust. Government officials may incur an anti-deficiency violation (the government version of a misappropriation of funds); business officers may incur a fraud violation for misappropriation of funds.

The Boeing Company

Boeing funds research and development of commercial aircraft with resources that include investments, income from operations (airplane sales), or outside financing. Although Boeing customarily receives a deposit of 20 to 30 percent from customers when building a new airplane, such deposits do not cover development costs. When Boeing undertakes a major development program, financing it becomes one of the biggest challenges.[3]

Although Boeing sets aside money for large research and development projects, the company is not always able to predict research and development costs accurately.

For example, switching to a wider fuselage and incorporating improvements for stability caused the 707 to go far over budget in the 1950s. Likewise, costs soared on the Dash-80—which exceeded original estimates by $20 million. In the early 1970s, Boeing almost went bankrupt when the development costs on the 747 exceeded expectations.[4]

Boeing's experience in the early 1970s with the 747 caused George Weyerhaeuser, a member of the board, to warn Boeing, "You're never going to start a new airplane program with my approval unless you have a plan that shows you're going to get a decent return on investment."[5] Yet, by the late 1970s, the board was confident enough to authorize more than the net worth of the company on two new airplanes—the 767 and 757.[6]

Up until the 1980s, much of Boeing's business was government related. However, during the 1980s, military contracts became less profitable and Boeing began to give more thought to expanding its commercial business. In 1986, a blue ribbon commission suggested government regulations were becoming increasingly onerous and little profit potential existed in government contracts.[7] In keeping with the commission's findings, from 1988 to 1990, Boeing lost $95 million, $559 million, and $418 million in successive years on contracts with the Federal Government.[8]

Shronz recognized the need for change at Boeing. In January 1990, he combined six divisions dealing with defense and space activities into one defense and space division under Jerry King.[9] The new Defense and Space Group ended 1991 with a small profit,[10] and later, from 1992 to 1994, when fewer commercial sales and high R&D costs created a slump at Boeing, the group helped fund the 777 with its improved earnings.[11] Boeing also trimmed its work force as part of an overall effort to keep the company healthy and to meet its deadline for the 777.

Because of changes initiated by Shrontz, Boeing's commercial side grew. In 1992, the company's business was 80 percent with private industry and only 20 percent with the government.[12]

The 777

> This has all cost a bundle, but it's our investment in the future.[13]

The development costs of the 777 probably equaled those of the C-17. Joseph Ozimek, marketing chief for Boeing's commercial aircraft, described the 777 as "the world's most expensive privately funded commercial venture. The pyramids and the Manhattan Project were government funded."[14]

Boeing will not divulge exactly what it spent on development for the 777. However, by backing into financial information published by Boeing, experts estimated the costs at about $7 billion. Analyst Joseph E. Campbell (Lehman Brothers, Inc.) estimated Boeing spent $6.3 billion. Boeing's Japanese partners also spent money for research and development. The total probably equals the $7 billion plus spent on the C-17.[15] However, if the value of time is factored into the DOD program, the C-17 cost more.

When board members approved the 777, they set a course that would determine Boeing's primary revenues for the next 30 to 50 years. They anticipated high development costs and knew necessary management and production changes would be costly. John Mintz captured the spirit of Boeing's long-term objectives in *Betting It All On 777:*

> The making of the 777 is a tale of a $22-billion company reinventing itself for the 21st century. Building the 375-seat jet—the world's largest twin-engine plane—required a revolution inside Boeing. The company had to change how it finances new airplanes, how its engineers design them, how its test pilots check them out, how its marketers sell them.[16]

Financing. In an effort to spread financial risks and lessen development costs, Boeing entered into a risk-sharing arrangement with Mitsubishi Heavy Industries, Ltd., Fuji Heavy Industries, Ltd., and Kawasaki Heavy Industries, Ltd.[17] Risk sharing was new to Boeing. In the 1970s, Boeing secured loans from three major subcontractors—United Technologies, Northrop, and Rohr—but these loans were repayable under normal terms and conditions.[18]

Unlike traditional loan agreements, risk-sharing agreements are not repayable. In exchange for agreeing to subcontract work, the Japanese consortium contributed 20 percent of the airframe.[19] Although no one confirmed how much the Japanese contributed, Japanese development costs were estimated at anywhere from millions to billions.[20]

Boeing could not form a risk-sharing partnership in the United States because stringent antitrust laws prevent domestic teaming. Such laws complicated Boeing's ability to finance new airplane development, especially because Boeing's chief competitor, Airbus, formed a multicountry team to share development costs. The existing Airbus partnership, the anticipated high costs for the 777, and antitrust laws caused Boeing to look to Japan for partners. Japanese contractors provided about 20 percent of the 777 airframe, most of the fuselage body sections, in-spar ribs, and wing-to-body fairings. In return for these contracts, Japan's airlines promised to buy 777s.[21]

Design. To overcome traditional problems between design and production, Boeing introduced design-build teams and CATIA. Although these design innovations were costly in the short term, Boeing believed they would prove cost effective in the long term on later 777 models.[22]

Testing. Boeing bypassed the normal 2-year qualifying process for extended range twin-engine operations by extensive testing. The company invested $370 million in a new Integrated Aircraft Systems Laboratory adjacent to its headquarters, equipping it with full-sized 777 wing and tail assemblies and the airplane's entire computer system. Here, engineers tested individual parts, sub-assemblies, and integrated aircraft systems on the static bench and under simulated flight conditions.[23] Boeing also flew 777 test models the equivalent of 3 years of operation hours. When technology problems threatened certification, Boeing added more resources to overcome these problems. Boeing considered the high cost of early certification necessary to meet customer needs.

Marketing. Four decades ago Boeing decided to seek specific customers, aggressively support its products after sale, and look into the future for profits. Boeing introduced the 707, 727, 737, 747, 757, and 767 based on this strategy and in each case waited out profits, even though unforeseen events often caused some to doubt its efficacy.[24] For example, events resulting from the Persian Gulf War caused Dean Thornton, president of the Boeing Commercial Airplane Group, to question the success of the 777.

The Gulf War and a worldwide recession in the early 1990s caused air traffic to drop 3 to 4 percent. The traffic decline coupled with overbuying in the late 1980s caused airlines to order fewer planes. In 1992, the uncertain economy prompted Thornton to remark, " [The 777 is] not going to fail, but the degree of success is uncertain. It depends on the market."[25]

Nevertheless, as United Airlines representative Gordon McKenzi observed, "Even unprofitable airlines need to position themselves for recovery. You just can't wait until times are good [before ordering new planes] because of 4- to 5-year lead times [for airplane production]."[26]

Boeing experts believed noise control rules and aging aircraft would cause many aircraft retirements in the 1990s—about 300 per year—compared to about half that number expected from 2001-2010.[27]

Boeing began lowering prices so airlines would find it cheaper to buy new planes than to maintain their old ones. Condit plans to shave 25 to 30 percent from 777 prices by the year 2000.

One way of lowering prices is to decrease production costs. By 1998, for example, Boeing plans to reduce production time on narrow-body jets from 13 months to 6.[28] CEO Frank Shrontz also hopes to exceed a production rate of 300. This rate takes advantage of economies of scale for ordering tools and supplies and contributes to a lower break-even target. If Boeing can produce more planes, the economies of scale improve. Regarding his goals, Shrontz observed,

> I don't think we're in any danger of not achieving a break-even quantity for the program. We believe we will sell many more than 300 or 400, but giving you a time frame is difficult. For example, we almost canceled the 737 program early on, because we were only selling about one a month. Ironically, the 737 turned out to be our most successful program to date. We have the capability to build seven 777s a month.[29]

As of August 1997, Boeing had 325 orders for the 777.[30] If the 777 continues to enjoy record-breaking sales, Boeing will recoup investments much faster than the 7-year time frame set by the 707 for showing a profit.

> A good part of our future success on the commercial side of the business depends on [the 777]. We invested heavily in it with both dollars and talent. I think we picked a winner.[31]

Summary

Boeing changed its management structure and built the commercial side of its business when government contracts no longer made sense. To meet the funding challenges of the 777, Boeing committed corporate resources, found innovative, risk-sharing financing, and made necessary cuts at home. In keeping with its long-term marketing goals, Boeing committed to funding upfront costs and waiting out the first nonprofitable years of the 777.

The Department of Defense

> It is a telling fact of life in the defense business that firms and program managers make multimillion dollar investment decisions with only a vague sense of future funding levels. Private firms may not plan perfectly, of course, but they surely realize that they undermine the wisdom of their own R&D investments if they fail to provide funding stability to major projects. Meanwhile, other countries—France and Japan in particular—seem able to allocate even billions of dollars over periods of several years. In the United States, by contrast, the pursuit of the world's most sophisticated military technologies creeps forward to the tune of a ponderous annual budget cycle that leaves everyone guessing about next year's budget.[32]

In an effort to control spending, Congress allocates yearly funding for large projects such as the C-17. Thomas L. McNaugher of the Brookings Institution believes that this yearly funding raises costs of large projects and that, among other benefits, multiyear funding would help reduce staffs at the Defense Department and in Congress.[33] Jacques S. Gansler suggests that a multiyear budget would encourage more realistic cost estimates. Under the current system, program managers project increases into future budgets when funding is threatened in current years.[34] In *Affording Defense,* Gansler cites numerous studies that hold budget instability and changing requirements responsible for cost overruns of $15 billion a year at DOD.[35]

Both McNaugher and Gansler believe that full funding of approved government programs would produce plans that are more realistic and save money as well as time. As Alan Mulally, Senior Vice-President, Boeing, said, "If I had to compete for funding each year, it would add at least a year and a half to my program management time."[36]

The Congressional Process

Congress passes two yearly bills critical for funding: the authorization bill approves a DOD program, and the appropriation bill grants the money for it. Congressional approval does not always mean funding. For example, in 1978, President Carter removed funding for the AMST from the 1979 appropriation bill—an action that killed the program even though Congress had authorized (approved) it.

Not only does Congress appropriate large-project funds annually, but it establishes limits on how long the funds are available for the project. For example, DOD must obligate appropriated research and development funds (3600 funds) within 2 years. If DOD needs to purchase items that require a long lead-time, it must request procurement funds (3010 funds). Congress can require DOD to obligate procurement funds within a year.

Because DOD writes budget plans several years before Congress acts on them, it may not make sense to purchase long-lead items within the period set by Congress. For example, actual development time often lags behind planned progress. Yet, if a program officer decides not to purchase long-lead items within congressional parameters, the money must be returned and the allocation request repeated. Program managers are often inclined to make unwise purchases rather than risk their allocations.

Both DOD and Boeing are experienced players in the research and development business. The difference between the two is that Boeing usually devotes a full phase to cost definition and decides, in advance, the benefits of a program and how it will cover cost overruns—from sales or from outside financing, for example. DOD has only one source of support—Congress. DOD must argue the benefits of a program and identify costs while it is still in the very early stages of planning; it does not have a phase devoted solely to cost definition. George McAleer, acquisition professor at the Industrial College of the Armed Forces, captures the essence of the problem:

> You [come] up with the estimate . . . in the idea phase. . . . You say . . . $200 million dollars [to complete the program]. Then you get into [engineering and manufacturing development] several years later, and the $200 million has grown to $450 million. And there you are on Capitol Hill and you're saying, "Mr. Congressman the program has grown." And the Congressman says, "Colonel, you mean to tell me you don't know how to estimate within a 100 percent rough?" That's what the folks on the Hill will look at—the stupidity of major weapons acquisition from DOD.[37]

The Defense Acquisition Board

The Defense Acquisition Board (DAB) must approve any program such as the C-17. The program then enters the Planning, Programming, and Budgeting System (PPBS). As the name implies, the PPBS has three phases:

- **Planning.** The 9-month planning phase is the responsibility of the Under Secretary of Defense for Policy.
- **Programming.** The programming phase falls under the Assistant Secretary of Defense for Program Analysis and Evaluation. This office releases its Defense Planning Guidance in August of each odd-numbered calendar year. The services and defense agencies submit their program objective memoranda (POM) in April of each even-numbered calendar year.
- **Budgeting.** The budgeting phase is the responsibility of the Comptroller, who

combines information from USD(P), the POMs, and OSD. The Comptroller submits the final request to the Office of Management and Budget for submission to Congress as part of the President's Budget Request.[38]

A full PPBS cycle takes 24 months. Planners must factor this into any long-term government program along with the 8 months it normally takes Congress to pass funding legislation. Thus, budgeting and funding for DOD programs are both time consuming and costly. Many, including Jerry King, president of Boeing's Defense and Space Group, consider the funding process to be the number-one problem for DOD.[39]

Other Countries

France and Japan both set aside funds for an entire program once they decide on a major weapon system. The companies contracting with these governments enjoy more stable financing. In the United States, when a company like McDonnell Douglas contracts for a major development program such as the C-17, it must contend with unstable congressional financing. There are times when even incremental funding may not cover costs.

Impact on Contractors

DOD usually retains significant control over the development and production processes through progress payments to its contractors. Normally, progress payments cover most development costs. However, in fixed-price contracts, the contractor accepts risk for part of the development costs. Contractors are usually willing to accept fixed-price development contracts only if they (1) expect to make up losses in the production phase, (2) want to invest in new technology and allow the government to pay part of the costs, or (3) expect to make up costs through change orders. For the C-17, McDonnell Douglas hoped to make up losses in production.

The C-17

During fiscal years 1981-95, developing the C-17 cost U.S. taxpayers $5.6 billion. McDonnell Douglas funded an additional $1.7 billion—bringing the total C-17 development cost to $7.3 billion.[40]

Congress specifies the amount DOD must allocate for research and development and for production. It is illegal for DOD to spend money appropriated for production on research and development. Figure 16 shows how much the President requested and how much Congress funded for the C-17 during fiscal years 1981-95. Congress came closer to meeting DOD requests for development than it did for production.

Development Funding (3600). Support for DOD requests vacillated, but in the end, Congress funded most of the amount requested for development. In 1980, after the House initially rejected the C-17, Congress appropriated $35 million for fiscal year 1981 C-17 development—$46.3 million less than requested. In fiscal year 1983, Congress appropriated $60 million for the C-17, even though DOD did not ask for it because Congress believed the C-17 program needed funds in order to have a meaningful program. In fiscal year 1984, Congress met the DOD request exactly. In 1985, in addition to almost meeting the DOD budget request, Congress designated the C-17 a special interest program so DOD could not transfer money from the C-17 program without congressional approval. For 1987, DOD moved the delivery date forward 3 years and reduced its requests for money. Congress appropriated more. In January 1988 and 1989, because of budgetary restrictions, Congress deducted $100 million and $20 million from the C-17 program, but invited DOD to request reprogramming.[41] DOD chose not to do so.

Procurement Funding (3010). Funding did not go as well for procurement as it did for research and development. Congress

TABLE 6. Funding Schedule for Development—RDT&E (3600 Funds)
(dollars in thousands)

Fiscal Year	PBR*	CA**	Difference
1981	$81.3	$35.0	$46.3
1982	0	0	0
1983	0	60.0	60.0
1984	26.8	26.8	0
1985	129.3	123.3	6.0
1986	453.7	383.7	70.0
1987	612.3	650.0	37.7
1988	1,219.9	1,119.9	100.0
1989	961.7	941.1	20.6
1990	915.2	885.2	30.0
1991	541.1	541.1	0
1992	377.4	376.4	1.0
1993	210.3	180.8	29.5
1994	179.8	179.8	0
1995	221.5	190.2	31.3
TOTAL	$5,930.3	$5,693.3	$237.0

*PBR: President's budget request.
**CA: Congressional appropriation
Source: "Congressional Track Sheets," synopses of congressional authorization and appropriation history prepared by the Secretary of the Air Force (Acquisitions) for FY81-95 [Washington: Secretary of the Air Force (Acquisitions), undated].

appropriated $16.7 billion of the $21.7 billion DOD requested to produce the C-17 from fiscal years 1987-95—$5 billion less than DOD requested. The Senate Armed Services Committee expressed concern over Air Force requests for long-lead items suggesting that, "the Air Force may be planning for an unrealistic aircraft production rate."[42]

In 1987, three factors caused Congress to cut the C-17 budget: (1) the General Accounting Office (GAO) was performing an audit to determine if DOD really needed the C-17; (2) Congress wanted DOD to open competition for wing production rather than allow McDonnell to manufacture it; and (3) Congress wanted assurance from McDonnell Douglas it would assume upfront costs for production tooling.[43]

By 1989, when Congress began debating procurement funds for fiscal year 1990, the C-17 was in trouble. Members of Congress

TABLE 7. Funding Schedule for Procurement (3010 Funds)
(dollars in thousands)

Fiscal Year	PBR*	CA**	Difference
1987	$182.3	$15.0	$167.3
1987 ADVP†	35.0	35.0	0
1988	6,179.0	5,890.0	289.0
1988 ADVP	663.0	663.0	0
1989	904.1	900.1	4.0
1989 ADVP	998.7	1,000.0	1.3
1990	1,524.0	1,110.1	413.9
1991	1,704.5	400.0	1,304.5
1991 ADVP	204.3	60.0	144.3
1992 MOD††	1,618.0	0	1,618.0
1993	2,513.9	1,810.6	703.3
1993 ADVP	205.6	250.9	45.3
1994	2,072.8	1,935.8	137.0
1994 ADVP	245.5	245.5	0
1994 MOD	16.5	2.1	14.4
1995	2,472.9	2,168.6	304.3
1995 AVDP	189.9	189.9	0
TOTAL	$21,730	$16,676.6	$5,053.4

*PBR: President's budget request.
**CA: Congressional appropriation.
†ADVP: advance procurement for long-lead items.
††MOD: modification
Source: "Congressional Track Sheets," synopses of congressional authorization and appropriation history prepared by the Secretary of the Air Force (Acquisitions) for FY81-95 (Washington: Secretary of the Air Force (Acquisitions), undated).

voiced deep concerns about costs of production and shifting schedules:

> The first flight of the C-17 is officially scheduled for August 1990. Air Force testimony in March indicated that due to problems with electronic flight control systems, [the] first flight wouldn't occur before December 1990. In June, the makerof the flight control system advised the prime contractor that it was continuing to have problems and could not support the December 1990 date. The most ambitious schedule now puts first flight in

> the March-April 1991 time frame. The design of the flight control system is only 70 percent complete and additional problems are a possibility. . . . Under the Air Force's current plan, funds for 22 aircraft, or 10 percent of the total fleet, would be appropriated before the first flight. This situation is unacceptable to the Committee.[44]

Continuing changes in the schedule, technical problems, and inconsistencies in procurement needs all affected congressional appropriations. Defense Secretary Richard Cheney reported a reduced need for C-17s just as the Air Force appeared to contradict Cheney with directives to accelerate procurement. For fiscal year 1991, Congress deducted $1.3 billion from the C-17 production budget, and, for fiscal year 1992, Congress deleted $1.6 billion requested for modifications. The Appropriations Committee reported,

> The first test aircraft has not flown yet, much less the first production aircraft, which is still in final assembly. . . . The committee sees no need to begin this modification program when the first production aircraft has not been delivered.[45]

In 1992, the DOD Inspector General issued reports alleging that the government improperly paid McDonnell Douglas. In the same year, the C-17 failed a wing-strength test because of math errors by McDonnell Douglas. During congressional deliberation for FY 1993, Congress deducted $703.3 million and reduced the procurement from eight to six airplanes. It made similar reductions in fiscal years 1994 and 1995. In addition, Congress imposed the following conditions:

> The conferees directed that not more than $100,000,000 of fiscal year 1994 advance procurement funding may be obligated until the Secretary of Defense provides a report to the Congressional Defense Committees, which designates a production representative aircraft that incorporates fixes to the wing, flaps, slats, and landing gear. In addition, the report will identify the cost of retrofitting the first ten production aircraft with these deficiency corrections.[46]

The conferees also directed that the C-17 Lot VII engine advance procurement contract not be awarded until the Secretary of Defense provides the Congressional Defense Committees with a report on the consideration to be received by the government for any engines in Lots IV through VI which do not meet the specific fuel consumption requirements in the engine specifications found in the original contracts.[47]

Paying the Contractor

In January 1993, the DOD Inspector General reported a potential antideficiency violation because the government used production funds to pay for research and development. Inspector General Derek Vander Schaaf recommended "address[ing] the direct responsibility of the three senior Air Force officials present at the September 29, 1990, meeting for the improper payment through their intimidation of the [administrative contracting officer]." Inspector General Derek Vander Schaaf reported the officers improperly provided $349 million in financial assistance to McDonnell Douglas, improperly accepted the first test airplane as "assembly complete," and used their positions to bully others into submission.[48]

The C-17 contract between DOD and McDonnell-Douglas was a fixed-price incentive-fee contract. As of July 1991, the $6.6 billion contract ceiling price covered contract line items funded with both development and procurement appropriations. DOD needed to take extra care so it would not cause an antideficiency violation by paying more than $4.9 billion for development and $1.7 billion for the first six operational aircraft.[49]

To help finance work in progress, DOD agreed to pay McDonnell-Douglas progress payments equaling up to 99 percent of the contract price,[50] $4.45 billion for development [99 percent x $4.5 billion] and $1.68 billion for production (99 percent x $1.7 billion). Once payments for development exceeded $4.45 billion, DOD could not pay until McDonnell Douglas delivered the contracted item, such as the test airplane, in an acceptable condition. DOD paid monthly progress payments based on McDonnell Douglas' actual monthly costs and estimated costs to complete the contract. In July 1991, the estimate-at-completion (EAC) for development and Lots I and II was $7.3 billion.[51]

If DOD were aware of the $7.3 billion EAC, DOD would multiply the monthly invoiced amount by a loss ratio factor then further limit payments to 99 percent of the contracted price.[52] For example, a $6.6 billion contract ceiling price divided by a $7.3 billion EAC has a loss ratio of 90.4 percent. Because the contractor was responsible for any costs expected to exceed $6.6 billion, DOD used this procedure to ensure its contractors had sufficient funds based on contract progress, but did not receive the full amount until after acceptable product delivery. However, the procedure is based on the contractor providing correct estimates. As Ann McDermott points out in her report, "Implementing Public Law 101-510:"

> The longer contractors delay admitting overruns will occur, the longer they receive payments at the initial rate. In addition, the perception exists that the more sunk costs a program has, the less likely it is that the service or Congress will cancel the program. Since it may not be in the contractor's best interest to identify cost overruns early, it is imperative that program personnel carefully monitor contract cost and schedule information.[53]

Paying with the Correct Funds

Congress appropriated research and development funds for the test aircraft (T-1) and two nonflying test items—the "static" test vehicle and the "durability" test vehicle. Congress allocated production funds for the first four production aircraft, even though the Air Force planned to use them in the flight-test program.[54] *Neither the contract nor the legislation defined differences between research and development and production for items that were not readily linked to a particular aircraft.* Costs for the efforts in question fell into the category of "sustaining engineering." Sustaining engineering "ensure[d] that the system design was correctly and efficiently implemented during the system's production phase."[55]

By exercising procurement options in January 1988 (Lot I for 2 C-17s) and July 1989 (Lot II for 4 C-17s), the Air Force fully obligated its production funds. The contract (1) included a Limitation of Government Obligations clause allowing the program manager to obligate production (3010) funds for the full target price, (2) included a plan which set a minimum amount of RDT&E (3600) funding each fiscal year, (3) required McDonnell Douglas to continue performance on R&D effort as long as the government fulfilled its minimum funding requirements, and (4) required the contractor to separate production and R&D charges for billing purposes.[56]

In May 1990, McDonnell Douglas submitted a bill for $231.6 million based on an estimate-at-completion of $5.942 billion. The Administrative Contracting Officer (ACO) decided McDonnell Douglas understated its estimate-at-completion and refused payment until McDonnell Douglas provided updated estimates. On July 10, 1990, McDonnell Douglas submitted a revised estimate-at-completion of $6.414 billion. The ACO approved the payment but was able to pay only a portion of the bill because of insufficient R&D funds.[57]

When the ACO was unable to pay the McDonnell Douglas revised bill, he reviewed the accounting records to find out why there was a shortage of funds. When the audit revealed DOD overpaid from R&D funds, McDonnell Douglas insisted the Air Force split progress payments based on the ratio of production and R&D funds to total contract funding. The company stated, under the terms of the contract, if the Air Force refused to fund further development, McDonnell Douglas was not obligated to continue the project.[58]

Program Manager Major General Michael Butchko directed McDonnell Douglas to review records and determine if any sustaining engineering costs were erroneously charged to research and development rather than to production; McDonnell Douglas found it had repeatedly erroneously charged sustaining engineering costs to R&D. The Air Force then adjusted journal entries to redefine the transition point for sustaining engineering charges of $172 million—*moving them from development to production accounts*. In addition, improper acceptance of the test aircraft allowed McDonnell Douglas to liquidate $1.6 billion and receive an additional $16 million in production funds from the government. A Defense Contract Audit Agency (DCAA) audit approved the adjustments Butchko's office made even though DCAA considered the audit unusual and noted the transactions violated cost-accounting rules, which prohibit retroactive cost-accounting changes. To justify the changes, the DCAA wrote, "The final price paid is a cumulative redetermination of all CLINs [contract line item numbers]; the accounting change does not appear to have any cost impact to the government."[59]

Sustaining engineering costs proved difficult to allocate because they were never properly defined. Butchko chose not to exercise the option of requesting a ruling from GAO or asking the local oversight office to perform a technical review. Instead he requested a Defense Contract Audit review. The Defense Contract Auditor acquiesced to the program manager's desire to reclassify funds even though the transactions were improper.

Avoiding an Antideficiency Violation

Antideficiency violations are based on violations of "the color of money." The program manager must distinguish money assigned for research and development (3600) from that designated for procurement (3010). Rather than mix appropriated funds, the responsible agency must ask Congress for approval to reprogram or request additional funds. Butchko planned to go to Congress until he learned if he re-allocated sustaining engineering charges to production instead of R&D, he could free money to pay R&D costs.

The argument centered on whether the engineering drawings for sustaining engineering work were 90 percent complete. Colonel Kenneth Tollefson of the resident Defense Procurement Representative Office did not believe they were. Normally, the resident representative (Tollefson) would perform the technical review, but Butchko overruled Tollefson.[60] Butchko then ignored an opportunity for review from the General Accounting Office. Later reports cited "failure to take reasonable steps to ensure adequate evaluation of the 1990 proposal" as basis for the violation. The 1990 proposal redefined and reclassified sustaining engineering to production rather than R&D.

On April 29, 1993, Secretary of Defense Les Aspin dismissed Butchko and disciplined two other generals—Lieutenant General Edward Barry (program executive officer) and Brigadier General John Nauseef (principal assistant to the Deputy Chief of Staff)—and a civilian, Albert Hixenbaugh (contracting officer). The defense secretary directed that none of the four "be assigned to work in the acquisition management area" and stated,

> The defense acquisition system operates on the principle of centralized policy-making and decentralized execution. At the heart of the system is the need for accountability at all levels. If the system is to work, then those charged with responsibility for the management of billion-dollar systems must perform to the highest standard.[61]

DOD and McDonnell Douglas conducted more than six reviews to evaluate the accounting procedures for the C-17 and to revisit actions of Butchko and others. Several of these reviews produced contradictory conclusions. One report found while "certain management decisions were questionable . . . [they] are clearly within a range of acceptable management discretion."[62] Another report stated Butchko knew or should have known precisely what actions to take and he recognized the impropriety of his actions. However, the same report found no criminal liability because there was no evidence he or any other government official had knowingly or willfully violated the law. Investigators concluded their report with a disclaimer:

> While we understand and accept the need for the rules regarding the proper expenditure of appropriated funds, we cannot help but wonder whether this whole process has focused thousands of man-hours of effort on a very small problem not warranting that type of response.

Summary

DOD depended primarily on Congress to fund development based on contracted costs for the C-17. Since actual costs exceeded the contracted amount, McDonnell Douglas funded approximately $1.7 billion of the $7.3 billion.

Congress funded most of the requested development costs and long-lead procurement on an annual basis even though it questioned the wisdom of Air Force's purchasing long-lead items because "the Air Force may be planning for an unrealistic aircraft production rate." And it often questioned whether DOD really needed the C-17. However, when McDonnell Douglas experienced problems with avionics and manufacturing, both DOD and Congress withheld procurement funds and DOD extended product delivery dates. Arguments arose between DOD and its contractor over who should pay for the C-17 development. Ensuing funding violations resulted in disciplinary actions against program management officials.

Yearly funding competition, arguments between DOD and its contractor, and funding violations detracted focus from developing and producing the C-17.

Comparison

- Boeing lined up resources to pay for the 777 development—including some innovative risk-sharing arrangements with Japanese manufacturers. DOD depended on Congress to fund the C-17.
- Boeing committed funds to develop the 777 upon board approval. The 777 program manager did not have to fight for funds after board approval. Even after DOD and congressional approvals, the C-17 was subject to annual DOD and congressional funding reviews and highly dependent upon program manager interaction with the contractor and funding authorities.
- When Boeing had problems with the design process and the 777 avionics, it committed resources that included funds to overcome the problems. When DOD experienced problems with avionics, DOD and Congress withheld funds and extended delivery dates.

- Boeing and its risk-sharing partners agreed on financing for the 777 development and production. Arguments between DOD and its contractor over who should pay for the C-17 development and funding violations detracted focus from developing and producing the C-17.

In the 1980s, Boeing began to see the disadvantages of relying on government contracts for profit and took steps to develop its commercial side that included the 777. The 777 was conceived within the guidelines of Boeing's marketing strategy, which encompassed long-term profitability. Boeing carefully lined up resources to pay for the 777 development—including some innovative risk-sharing arrangements with Japanese manufacturers.

DOD commitment to the C-17 was not so straightforward, and like many large programs, it was subject to annual congressional funding reviews. Many feel this yearly funding process adds time and costs to DOD programs.

Congressional funding for C-17 research and development was initially fairly consistent. However, in the mid-1980s, when troubles in the C-17 program became public, Congress responded by cutting procurement funds and demanding studies to examine DOD needs. Boeing, on the other hand, met adversity with increased resources.

Both Boeing and DOD must separate costs for research and development from those for production. Each organization has mechanisms to classify uncertain items—DOD can request clarification from GAO and Boeing can request clarification from the IRS. DOD methods violated the law, and the numerous studies to determine accountability in the wake of the anti-deficiency scandal detracted focus from the C-17 project.

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PART III

9. *Critique*

Why did the C-17 take so much longer to develop than the 777? The answer—to some degree—is found in each organization's methods of management, selecting technology, organization, mission, needs determination, and funding. Under stable leadership and unwavering board support, Boeing approached 777 development with commitment, focus, and flexibility. On the other hand, the C-17 fell under the influence of the White House, and the DOD mobile internal leadership contributed differing views of management as well as different levels of competency. DOD support wavered, its structure lacked flexibility, and its leadership failed to remain focused.

Program Management

Both the government and Boeing have standard procedures for developing aircraft. Boeing followed procedures fairly closely, whereas DOD skipped several important steps in its standard process. Boeing tracked the market in arriving at a comprehensive plan for development. DOD had no comparable plan and frequently questioned the efficacy of its own program.

The C-17 began with mixed blessings during the Carter years—when support for an airlifter with strategic capabilities overrode backing for a tactical airlifter. C-17 advocates pushed the program through Congress without the equivalent of a comprehensive "market study," and skipped other steps in the normal acquisition process. Because DOD frequently changed plans, setting goals became unrealistic. Weight requirements, for example, were changed several times—either to accommodate add-ons or mission adjustments. Technical difficulties accompanied the changes, and not surprisingly, DOD failed to meet deadlines. Congress responded predictably by ordering studies, adjusting funding, or demanding other forms of accountability.

Because the C-17 cycle time was so long, there was a loss of accountability and resolve as people came and went and organizations changed. Personnel changes often brought significant shifts in program direction. Program managers' actions frequently reflected the unsettled relationship and disagreements between McDonnell Douglas and the government—straining relationships in all directions. The government unnecessarily complicated the contract by combining development and procurement funds in the ceiling price and failing to define sustaining engineering, which allowed managers to make improper payment decisions. Major changes in the DOD command structure blurred command lines at critical times and interfered with managers' ability to function. The leadership of DOD, though highly competent at times, was not consistent.

In contrast, Boeing followed its standard course for development but with several important modifications. The company solicited more than usual customer input, initiated entirely new design procedures, and extended its timeline to accommodate innovations and reorganization. Boeing's plan followed a carefully laid course and was not affected by personnel changes. Shifts in management—including the position of program manager—went smoothly. Boeing kept lines of communication open and encouraged a high degree of communication among designers and engineers. The new CATIA design-build teams incorporated customers, mechanics, and other end users into the design process.

Selecting Technology

Some people believe that a high level of technology may account for the long-term nature of DOD programs; however, this was not necessarily the case for the C-17. For example, the C-17 was not equipped with complex systems found in a fighter or a bomber. In fact, the technology used on the C-17 was tested and proved on the prototype of the C-17, the AMST.

The military, however, did not use the tested technology exactly as it was used on the AMST. For the C-17, the short-take-off-and-landing capability required developing a new wing design and installing a fly-by-wire system. DOD added OBIGGS, a new defensive system, and rotating cargo pallets. Requirements changed as the international situation changed, allowing requirements to creep and, in some cases, such as increasing payload capability beyond needs, requirements became gold plated.

DOD and McDonnell Douglas chose not to use a CAD/CAM system in order to cut upfront costs. While the CAD/CAM systems were not as sophisticated during early C-17 development as when Boeing designed the 777, such a system clearly would have helped C-17 development. With a CAD/CAM system, designers could better manage design modifications as requirements and technology changed over the long development time. McDonnell Douglas' lax management of software controls resulted in myriad computer languages, which made the system inefficient and testing unnecessarily complex. Because the cycle was so long, mature technology in the beginning of the program became obsolete technology by the end.

Problems with technology were compounded by disagreements with its contractor. When DOD reduced the number of aircraft it planned to purchase, it also reduced incentives for its primary contractor to make up in production what it lost during development. McDonnell Douglas responded by taking its most experienced technicians off the C-17 program—technicians whose skills were needed to coordinate the complex computer systems.

Although Boeing prefers to stay on the leading edge of technology to remain competitive, the company *does not use untried technology* on its commercial airplanes. In the case of the 777, several features were new, but technology for them was mature. Boeing took several steps to prevent technical problems from holding up the program. The company used CATIA, a technological troubleshooter, it imposed discipline on its software languages, and it built high-tech labs for testing the wing and tail assemblies. When Boeing encountered problems, namely in its design system and integration of its fly-by-wire system, it increased resources to resolve the problems in a timely manner.

Organization

Numerous studies have held the DOD acquisition system responsible for inefficiencies. In keeping with efforts to reform, DOD has undergone several reorganizations—some of these taking place while the C-17 was in development. DOD reorganizations, intended to streamline the acquisition system, disrupted lines of command for program managers and added layers of management to the C-17 program. McDonnell Douglas also attempted reorganization, but the company's methods—such as eliminating whole layers of management and firing and rehiring workers in inappropriate jobs—disrupted production and caused other serious problems on the C-17, such as fuel leaks.

Complicating development still further were parochial interests of the services and commands causing one to ask who the C-17 customer was—the Army, the Air Force, the commands, the commanders in chief? The letter from the Army Secretary to the Air Force Secretary expressing dissatisfaction with the Air Force decision to buy the C-5 is one example. Another is the Mobility Air Command efforts to sell Congress the CX program while the Air Force Systems Command tried to push the AMST plane.

During C-17 development, first the Mobility Air Command then the Air Force Chief of Staff lobbied hard to reduce the C-17 troublesome, gold-plated payload requirements. One could argue the C-17 is no different than the variety of customers Boeing faces. In both cases, there is a determination process that derives basic requirements for the aircraft from known customer needs. Problems with late customer add-ons definitely impacted 747-400 timely development. The difference for the 777 was Boeing's concerted effort to use integrated teams allowing designers to identify both customers and customer needs earlier in the process. Its cost-definition phase helped Boeing determine if cost and technology maturity would allow it to meet customer needs. Continued competition from airline manufacturers helped motivate Boeing to build a support organization and development processes to decrease costs and increase quality. For the C-17, when realistic requirements and the threat of competition were introduced, the program turned around. Introducing integrated teams helped facilitate recovery.

No doubt, extra layers of management and midprogram restructuring slowed C-17 development. However, the greatest detriment to efficiency was a lack of constancy of purpose. The organizational structure of DOD renders it subservient to the views of the current administration and subject to a highly mobile leadership. These factors make focusing on a long-term program problematic, if not impossible.

Boeing's organizational structure is more stable and characterized by fewer layers than that of DOD. Also, Boeing thoroughly evaluated its structure before embarking on the 777 program. Cost-benefit studies and lessons learned from other programs suggested changes in methodology as well as changes in management. Boeing hired an outside consultant to direct changes in corporate management and devised a revolutionary design-build pyramidal system to improve design methods. A highly sophisticated computer system facilitated the process.

Mission

The DOD mission is further defined in the national strategic policy of the United States and is thus subject to the interpretation of each president. What is needed to fulfill the DOD mission is characteristically debated in the White House, on the Hill, and in the Pentagon. The C-17 competed with numerous other weapons systems for its place in the United States arsenal, and its mission evolved despite ever-changing policy. Most notable was the transition from tactical airlifter to one of strategic capabilities. This mission difference necessitated significant modifications and did much to prolong the program.

Boeing envisioned the 777 as an important part of its mission to become number one in air and space in the world. Using direct market research—asking potential customers—

Boeing determined a need for a cost efficient, medium-sized plane to replace aging aircraft in the market. Research also told Boeing that airlines were interested in a family of airplanes that would share parts and reduce maintenance training. Boeing was willing to undergo heavy costs to build a trouble-free aircraft; certify it for early, extended twin-engine operations; and assure the aircraft met its promised delivery date. The company regarded the aircraft—and its family—as a long-term investment supporting the company mission.

Needs Determination

Congress and DOD ordered numerous studies to help define DOD overall needs—these "market studies" often came in mid-development and helped to define, finally, the C-17 mission and configuration. During the 1980s, leaders did not embrace the C-17. Throughout the 1990s, military leaders continued to argue over how many C-17s were needed and whether to purchase alternative aircraft such as the 747.

Lessons learned on the 747-400 taught Boeing the necessity of correctly assessing need. With the 777, Boeing determined early on that customers wanted enough new features to justify building an entirely new aircraft. To forestall late add-ons, the company used a highly sophisticated computer system, keeping customers in the design loop throughout development.

Funding

A large, long-term development program—such as the C-17—must be approved by Congress. After initial approval, the program appears as a line item in the president's budget where it must survive the yearly Congressional scrutiny. When the C-17 began to miss deadlines and encountered other problems, Congress responded with demands for accountability and reduced funding.

Although DOD normally follows strict guidelines on expenditures allocated for development versus production, the C-17 was in development and production at the same time. This concurrence, in combination with improperly defined contract terms, blurred allocation lines. In 1992, the DOD Inspector General found several officers guilty of inappropriate behavior and potential anti-deficiency violations for misappropriation of funds. The incident lent an aspect of scandal to a program already plagued with problems. Numerous investigations followed the citations, further detracting from the program.

Because McDonnell Douglas was operating under a fixed-price contract, the company expected to sustain certain losses in the development stages of the C-17. It hoped to make up the losses on lucrative production contracts. However, as costs mounted, the company objected—claiming the Air Force had rescoped the contract with its many changes. McDonnell Douglas also felt the impact of smaller than anticipated orders for the C-17. These factors in combination caused McDonnell Douglas to threaten the government with legal action and to take other measures that slowed C-17 production. Even though McDonnell Douglas ultimately absorbed most development cost overruns, Congress took them into account when it reduced procurement funding for the C-17.

The Boeing system for funding is much simpler. The board guarantees financing when it grants approval for a project. However, when profit returns are several years down the road, financing a large development program is not easy—even for a large, healthy corporation like Boeing. Boeing financed the 777 from internal resources and from unique risk-sharing agreements with Japanese companies. When commercial sales were down, or Boeing felt financial pressures, the company took whatever money-saving steps it needed, including personnel cuts.

Approval

Even though DOD projects must undergo initial approval by the Defense Acquisition Board, Congress exercises powerful yearly control when it considers annual appropriations for the program.

In the case of the C-17, political factors intervened to influence approval for the DOD program. Congress first approved the AMST program to satisfy DOD needs for a tactical airlifter. However, President Carter removed the line item for the AMST from his presidential budget in order to pave the way for an airlifter with strategic capabilities. Although Congress objected to the paucity of documentation supporting the C-17 program, it eventually approved the program heavily lobbied by President Carter and Secretary of Defense Brown. President Reagan vacillated over support of the C-17. First he supported the purchase of alternative aircraft (to fill immediate needs) and then he supported the C-17 as a replacement for aging aircraft in the U.S. fleet. However, as the C-17 neared full-scale development and the program fell behind schedule, Congress began to question the Air Force's ability to manage its program, demanded studies to determine need, and withheld funding.

For the 777, Boeing followed its normal approval process—with certain important modifications. In order to prepare for production and to establish a realistic timetable, corporate officers asked the board for approval to extend the standard timetable by almost a year. Because Boeing had learned hard lessons from the late delivery of its 747-400, the company placed a premium on a dependable schedule. The board's decision to grant the extra time and then, later, to uphold the schedule when technical difficulties arose, demonstrated the company's commitment to the 777. Boeing's hierarchy of design-build teams included approving officers and facilitated a step-by-step process of development.

Commitment

The priorities of each presidential administration affected the DOD commitment to the C-17. At lower levels, lack of policy direction and funding reflected a wavering commitment. Boeing viewed the 777 as important to its mission and remained committed throughout development. Boeing's constancy of purpose was supported by a stable management structure.

Focus

Boeing made a concerted effort to determine what kind of an airplane to build and researched the best methods to build it. Politics interfered with the DOD process to determine need and hindered its ability to stay focused on the C-17. In the end, strong leadership assigned during the Clinton administration brought the program to fruition.

Flexibility

Political influence, the annual funding process, and out-of-date design tools all limited DOD flexibility. Boeing's hierarchy of design-build teams kept Boeing informed of customer needs and corporate managers informed of technical difficulties. When problems arose, Boeing responded quickly and decisively.

Conclusion

Although actual costs for the C-17 and the Boeing 777 were similar, when time is factored in, the C-17 cost more. As Bruce Smith, *Aviation Week* reporter, said, "The C-17 transport is a good example of what happens when the challenges of a major military aircraft program are underestimated and the development phase of the program drags on for too many years."

Paul Kaminski, former Under Secretary for Acquisitions and Technology, recommends, among other things, more research before committing to production. He developed new initiatives to mitigate some of the problems encountered in the C-17 program. Examples include initiatives to reduce acquisition cycle time, to use modeling and simulation so program managers can better manage system engineering and integration risk, and to view cost as an independent variable so program managers can work with users to decide if the requirement is worth the cost. If DOD were to truly centralize acquisition and development under the DOD structure and focus on its primary customers, the commanders in chief of the unified commands, it could simplify the acquisition process. If Congress joined with DOD in providing full funding for major acquisition projects, the programs might enjoy greater stability. Under such a system, DOD would be compelled to choose its needs more selectively.

Future studies should assess how Dr. Kaminski's initiatives might have solved the problems identified in the C-17 program, and compare the C-17 with at least one program that encompasses the new initiatives. If new initiatives such as these prove to be successful, they should be considered for application throughout DOD, as they might well prevent other programs from taking 24 years to produce workable weapons systems.

Glossary

A&T	acquisition and technology
ACO	administrative contracting officer
AFAE	Air Force acquisition executive
AIMS	aircraft information management systems. Manages data among the computer processors.
AMC	Air Mobility Command
AMST	advanced medium short take-off and landing
ARINC	Aeronautical Radio Incorporated. The ARINC 629 is an electronic highway along which computers exchange data.
ASC	aeronautical systems center
ASD	aeronautical systems division
ASD(PA&E)	Assistant Secretary of Defense for Program Analysis and Evaluation
ASIC chips	application-specific integrated circuit chips
CAD/CAM	computer-aided design/computer-aided manufacturing system. An object is designed with the CAD component of the system, and the design is translated into manufacturing or assembly instructions for specialized machinery.
CAE	component acquisition executive
CAIV	cost as an independent variable
CATIA	computer-aided, three-dimensional, interactive application
CEO	chief executive officer
CINC	commander in chief
CLIN	contract line item number
CMM	Congressionally Mandated Mobility Study
CONG AP	congressional appropriation
CQI	continuous quality improvement
CRAF	Civil Reserve Air Fleet
C-X	cargo transport research
D&V	demonstration and validation
DAB	Defense Acquisition Board
DAE	defense acquisition executive
DCAA	Defense Contract Audit Agency
DMR	Defense management review

DOD	Department of Defense
DODI	Department of Defense Instruction
DODIG	Department of Defense Inspector General
DDR&E	Director of Defense Research and Engineering
DSARC	Defense Systems Acquisition Review Council
ECP	engineering change proposal
empennage	tail assembly of an airplane, consisting of vertical and horizontal stabilizers and including the fin, rudder, and elevators
ETOPS	extended twin-engine operations
FAA	Federal Aviation Administration
fly-by-wire	a system of electrical signals rather than mechanical linkages to move airplane control surfaces such as the rudder and ailerons
FSED	full-scale engineering development
GAO	General Accounting Office
inertial upper stage	the upper stage of a space ship that is self-contained and uses automatic instruments to guide along a preassigned course using the laws of accelerated motion and gravitation
IRS	Internal Revenue Service
JCS	Joint Chiefs of Staff
JROC	Joint Requirements Oversight Council
LOGO	limitation of government obligations
MAC	Military Airlift Command
MAR	major airlift review
MATS	Military Air Transport Service
mockup	a full-sized replica of a structure or apparatus used for experimental purposes
MRS	Mobility Requirements Study
MTM/D	million-ton miles a day
NDAA	non-developmental airlift alternatives
OBIGGS	onboard inert gas generating system. This nitrogen generation system keeps oxygen vapors in the fuel tank area below 9 percent. The lower oxygen vapors allow the plane to avoid ignition when small arms fire hits the fuel lines.
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
PA&E	program analysis and evaluation
PBR	President's budget request
PEO	program executive officer
PFC	primary flight computer
POM	program objective memorandum
PPBS	Planning, Programming, and Budgeting System

PVR	process variability reduction. An Air Force developed system used to identify production problems associated with C-17 assembly.
R&D	research and development
R&M	repair and maintenance
SAF(AQ)	Secretary of the Air Force for Acquisitions
SAM	surface-to-air missile
SDI	Strategic Defense Initiative
SPO	system program office
STOL	short take-off and landing
TAC	Tactical Air Command
TQM	total quality management
USD	Under Secretary of Defense
USD(P)	Under Secretary of Defense for Policy
USD(PA&E)	Under Secretary of Defense for Program Analysis and Evaluation
USTRANSCOM	U.S. Transportation Command

About the Author

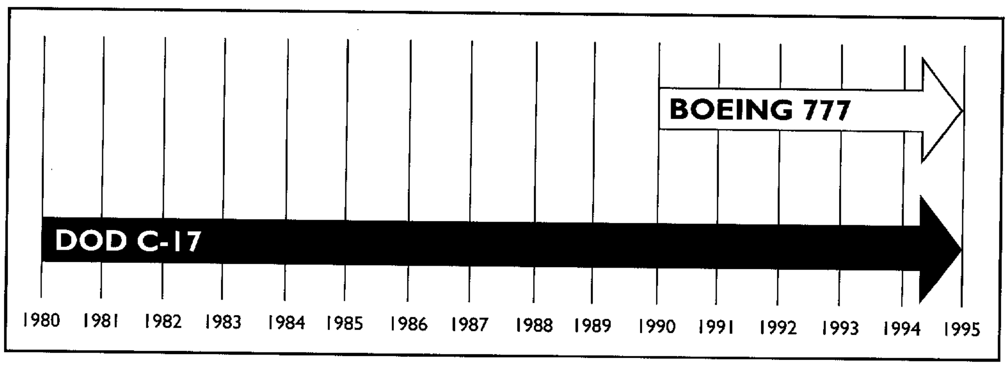
A. Lee Battershell is a Certified Acquisition Professional Program Manager and Acquisition Professional Financial Management Comptroller. She is currently on the staff of Battershell and Company, Certified Public Accountants, in Kent, Washington. Prior to her current position she served on the board of directors of the Association of the Industrial College of the Armed Forces, and the Industry Conference Board, Washington. Research for this book was conducted while the author served as a Research Fellow at the Industrial College of the Armed Forces.

Ms. Battershell retired in 1997 as Director, Policy, Oversight, and Systems, Air Force Audit Agency. During her 31 years of government service she served in various positions for the Departments of Defense, Air Force, State, and Treasury. She authored several pamphlets and articles, including "Acquisition Alerts for Program Managers" and "Technology Approach: DOD versus Boeing, A Comparative Study."

In addition to many performance awards, Ms. Battershell received the Federal Woman of the Year Award and the Outstanding Civilian Career Service Award. She holds a Master of Science in National Resource Strategy from the Industrial College of the Armed Forces, National Defense University, a Bachelor of Science in business from California State University, Sacramento, and a certificate from the Defense Acquisition University Senior Acquisition Program Course. At present she is completing her Master of Science in business from Central Michigan University.

The DOD C-17 versus the Boeing 777

Why did it take the Pentagon three times longer to develop the C-17 Globemaster III than it took the Boeing Company to produce the 777—planes with similar capabilities and technology? This striking comparison led the author of *The DOD C-17 versus the Boeing 777* to conclude that: "Boeing made a concerted effort to determine what kind of airplane to build and researched the best methods



to build it. Politics interfered with the DOD process to determine need and hindered its ability to stay focused on the C-17." As this work by a talented acquisition professional reveals, "differences in commitment and focus are pervasive in each organization's management methods, technology philosophy, structure, mission, needs determination, and funding."

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