



INSTITUTE FOR DEFENSE ANALYSES

**An Application of Cost-Effectiveness Analysis
in a Major Defense Acquisition Program:
The Decision by the U.S. Department of Defense
to Retain the C-17 Transport Aircraft**

W. L. Greer, Project Leader

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Abstract

This case study illustrates the traditional approach to cost-benefit analysis and acquisition decisions within the Department of Defense (DoD). It specifically discusses decisions made in 1993-95 regarding the C-17 strategic airlifter program. It also includes a discussion of events leading up to the study, the analytical approach taken, the study participants, critical points in the analyses, decisions reached, and lessons learned.

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1. Introduction

The C-17 Globemaster II aircraft has been one of the more successful military transportation assets in history. It provides rapid delivery of cargo or passengers almost anywhere in the world, including to some remote airfields. Currently it is flown by the U.S. Air Force's Air Mobility Command (AMC) and by the Armed Forces of several other countries, including the United Kingdom's Royal Air Force, the Royal Australian Air Force, the Canadian Force's Air Command, NATO, and the Qatar Emiri Air Force. The United Arab Emirates has ordered C-17s and many other countries are exploring the possibility. In addition to its transoceanic strategic lift capability, the C-17 can also perform tactical airlift, medical evacuation, and airdrop missions. It played a significant role in moving goods, vehicles, and personnel during Operation Enduring Freedom in Afghanistan, and Operation Iraqi Freedom in Iraq, continues to support ongoing operations in both countries, and has contributed to emergency relief operations around the world. It is widely considered a success story.

But that wasn't always the case. The program came very close to being cancelled in the early 1990s. Key decisions made around that time serve as a useful example of the valuable role of cost-effectiveness analysis in major defense investment decisions. This section describes cost-effectiveness analyses that informed the decision to retain the C-17 program and serves as a case study in how such assessments assist decision-makers in general. The focus is on the analyses, but just as important, it provides insights into how these analyses were received and used to make the decision to invest in the C-17.

The analyses depicted here are drawn from documents^{1,2} prepared by the Institute for Defense Analyses (IDA) for the Department of Defense (DoD). Studies such as these were referred to at that time as Cost and Operational Effectiveness Analyses (COEAs), currently called Analyses of Alternatives (AoAs). These studies include many of the basic considerations of cost and effectiveness analysis discussed in this book.

¹ W. L. Greer, et al., IDA Report R-390, *Cost and Operational Effectiveness Analysis of the C-17 Program*, Institute for Defense Analyses, December 1993.

² J. M. Bexfield, et al., IDA Document D-2688, *C-17 COEA Case Study*, Institute for Defense Analyses, September 2001.

A. Background

In the 1970s, the U.S. Air Force launched a plan for a new cargo aircraft to carry most of the largest equipment the Army needed (e.g., tanks, large tracked and wheeled vehicles, and Patriot batteries) into small remote airfields – many with runways shorter than 3,000 feet. Although at the time airlifters existed that could carry large equipment (the C-5) and land in small airfields (the C-130), no existing airlifters could perform these tasks simultaneously.

In December 1979, the DoD initiated the Cargo-Experimental (C-X) competition for a new strategic airlift aircraft. The C-X was to be an aircraft that could deliver a full range of combat equipment over intercontinental distances; operate from a 3,000-foot runway; possess survivability features; have excellent reliability, maintainability, and availability; and have a low life-cycle cost. Early in 1980, the DoD issued the request for proposals (RFPs) for the new C-X Program. Boeing, Lockheed Martin, and McDonnell Douglas responded. After reviewing the various designs, in August 1981 the DoD selected the aircraft design proposed by McDonnell Douglas.³ The winning design incorporated many features already demonstrated on the YC-15, a McDonnell Douglas aircraft that had been developed and flight tested in the 1970s. This chosen design was later designated the C-17. Because of the earlier testing of the YC-15, it was viewed as a program with low development and cost risk.

In addition to carrying large cargo and landing in small airfields, the C-17 was also designed to back up and turn in a small radius, thereby optimizing the use of limited ground space. It was also designed to conduct troop and cargo airdrops, replacing the aging C-141s that previously conducted those missions. It was an aircraft for all missions.

In 1982, the DoD conducted a large transportation assessment, the Mobility Study, that established the air mobility requirements at that time, based on perceived wartime needs. To meet these requirements, the U.S. Air Force determined that 210 C-17s were needed. These requirements were codified in the 1983 Air Mobility Master Plan. Largely because of cost rather than effectiveness considerations, the number 210 was subsequently reduced by the Office of the Secretary of Defense (OSD) to 120 during the 1990 Major Airlift Review. Thus the number of C-17s under consideration in the early 1990s was 120.

Several complicating issues arose at that time. The earlier assessments of low development and cost risk proved wrong. Costs for the C-17 continued to rise, and the

³ McDonnell Douglas was subsequently merged with the Boeing Company in 1997.

several aircraft delivered for testing did not demonstrate the reliability and performance expected. Static wing loading tests revealed that the wings failed at lower loads than predicted, forcing even higher costs to strengthen them. Lockheed Martin, manufacturer of the C-5 and C-141, made an unsolicited proposal in 1991 to upgrade and extend the life of the C-141s at a cost that appeared lower than that of the troubled C-17 program. An added complication and a renewed sense of urgency was presented when it was found that C-141s had developed a large number of microscopic cracks in the wing structures – a condition that temporarily grounded the entire C-141 fleet until repairs could be made.

This raised a number of questions for DoD: Should it continue with the C-17 program despite escalating costs and lower performance than desired? Should it cancel the C-17 program and extend the life of C-141s, continuing with wing repairs until a new C-X design was chosen? Or should it investigate other alternatives? These were the issues confronting Congress and the DoD in 1993 and are the topics of this case study.

Congress mandated that the DoD conduct an independent assessment of the C-17 program and report its findings to the appropriate Senate and House Armed Services Committees. The legislation further restricted Fiscal Year (FY) 1994 spending on the C-17 until such a study was completed. After reviewing the expertise and capabilities in several Federally Funded Research and Development Centers (FFRDCs), the OSD selected IDA to conduct the study. IDA completed its study in 1994. The findings were used by the DoD and duly reported to the congressional defense committees.

Table 1 summarizes the history of the C-17 program up to the point at which analyses were conducted to determine whether to go ahead with the program.

So what decision was made? Once the cost-effectiveness analyses were in hand, the OSD approved the 120-aircraft C-17 program in 1995. But the road to this decision point was not an easy one. It required numerous analyses, the main one of which is the cost-effectiveness case study summarized in this section.

At the end of this section, we also summarize more recent decisions affecting the C-17 program.

Table 1. C-17 Decision Timelines

Year	Events
1970s	<ul style="list-style-type: none"> • Air Force decided new cargo aircraft, C-X, was needed to carry heavy and large Army equipment into austere airfields.
1981	<ul style="list-style-type: none"> • McDonnell Douglas selected to build C-X, called C-17.
1982	<ul style="list-style-type: none"> • Mobility Study published, calling for more airlift capability.
1983	<ul style="list-style-type: none"> • USAF Airlift Master Plan estimated that 210 C-17s needed to meet needs identified in Mobility Study.
1990	<ul style="list-style-type: none"> • Major Airlift Review reduced C-17 requirement from 210 to 120.
1991	<ul style="list-style-type: none"> • Lockheed Martin proposed C-141 Service Life Extension Program (SLEP).
1992	<ul style="list-style-type: none"> • Joint Staff issued report, concluding that C-17 is more cost-effective than either new C-5 or C-141 SLEP. • Joint Staff issued Mobility Requirements Study.
1993	<ul style="list-style-type: none"> • Problems with aging C-141s continued. • C-17 exhibited engineering problems and cost increases. • Congress restricted FY94 C-17 spending pending further study. • DoD asked IDA to conduct COEA on C-17 program.
1994	<ul style="list-style-type: none"> • IDA completed C-17 COEA. • COEA sent to Congress after OSD review. • Additional DoD studies were authorized.

B. Organizations Involved

In 1993 strong views existed on the C-17 program. Proponents for the C-17 resided, among other places, within the AMC and at McDonnell Douglas. Detractors included Lockheed Martin, manufacturer of competing aircraft like the C-5 and C-141, and the Boeing Corporation, manufacturer of the commercial 747 and 767 aircraft, other potential competitors to the C-17. Numerous subcontractors were also interested in the outcome. Senior OSD officials were responsible for generating objective, unbiased analysis to support the Secretary of Defense on whether to continue the C-17 program. The Secretary was interested in a study that sorted through the claims and placed alternative courses of action in perspective. The report would be delivered to the Defense Acquisition Board (DAB), the OSD board that recommends acquisition actions to the Secretary of Defense, who, after review, would propose it to the House of Representatives and Senate defense committees. The study needed to be independent, clear, and able to withstand intense scrutiny.

The IDA study team consisted of experts in airlifter operations, computer modeling and simulation, aircraft and engine design, and cost estimating. The study team engaged

in frequent interactions with aircraft and engine manufacturers, USAF operational commands, the AMC, the USAF Air Staff, the Joint Staff, and OSD.

C. Methodology

The approach taken in this study consisted of the following steps:

- Identify the alternatives (fleets of aircraft to replace C-141s and upgrade strategic-lift capability).
- Establish airlift requirements (criteria and attributes).
- Estimate effectiveness of each alternative in the airlift mission (measures of effectiveness).
- Estimate the total ownership cost, sometimes referred to as the life cycle cost, of each alternative.
- Arrange the cost and effectiveness information to facilitate decision-making. Some steps (costing and determining effectiveness) were performed concurrently.
- Perform sensitivity analyses as needed.

1. Identify Fleet Alternatives

The alternatives were initially selected to have equal lift capability, as measured by one of the common capacity measures used in the airlift community: million ton-miles per day (MTM/D).⁴ When divided by the distance an airlifter must fly from the United States to the theater of interest, the MTM/D is a rough measure of the steady-state rate of delivery of cargo to the theater, provided sufficient infrastructure and parking spaces are available, including en route and in-theater. Since the infrastructure and parking assumptions are rarely satisfied, fleet-wide MTM/D offers only a partial approach to identify comparable alternative fleets of aircraft that offer similar airlift capability. More detailed analyses further differentiate among the alternatives.

2. Establish Airlift Requirements

The requirements for airlift were taken from the *Mobility Requirements Study* (MRS).⁵ This study, completed by the Joint Staff and OSD, identified the type and

⁴ For each primary authorized aircraft (PAA) in the fleet, this is the product of the average cargo carried, the average block speed, the wartime utilization rate of the airlifter (average number of hours per day it is flown), and a “productivity factor” to account for empty cargo bays on return missions. Information for this calculation can be found in Air Force Pamphlet 10-1403, *Air Mobility Planning Factors*, USAF Air Mobility Command, December 2003, (most recent).

⁵ *Mobility Requirements Study*, Joint Staff J-4, 1992.

tonnage of cargo and troops that were to be moved by air (as well as by land and sea) per day. Cargo was identified by a commodity code and by dimensions that allowed it to be sorted into three conventional cargo categories called outsize, oversize, and bulk.⁶ The MRS established lower limits for acceptable cargo delivery rates that would meet medium-risk criteria in warfighting simulations. The final cargo delivery schedule is referred to as the Time-Phased Force Deployment Data (TPFDD).

3. Estimate Effectiveness of Each Alternative

The effectiveness analysis involved estimating for each alternative fleet of airlift aircraft how much cargo and how many troops from the TPFDD were delivered to the theater within a fixed period of time. To make these estimates, the study used a detailed simulation of the aircraft loading, aircraft movement, and cargo flow. The specific models used were the Airlift Loading Model (ALM) for loading, the detailed simulation model Mobility Analysis Support System (MASS) for airlift movement and cargo flows, and the Airlift Cycle Analysis Spreadsheet (ACAS) for more aggregate but faster assessments of cargo and passenger movement. The use of a detailed model (i.e., MASS) along with a more aggregate one (i.e., ACAS) is a common approach that balances study resources and time with precision in results. Calibration of ACAS to specific MASS results allowed ACAS to be used in rapid sensitivity excursion analyses. Comparisons of ACAS runs with MASS runs for these same sensitivity excursions showed no loss in precision for using the significantly faster ACAS. The primary output of MASS and ACAS used in the report was the total cargo tonnage, separated into the three categories of bulk, oversize, and outsize cargo, delivered in 30 days by each alternative fleet.

4. Estimate Costs

The study team also provided cost estimates including the development, procurement, and the annual operations and support (O&S) costs for each airlifter in each alternative fleet. Total life cycle costs over a 25-year period were then estimated for each alternative. Information from the C-17 Program Office, contractors, and OSD was used

⁶ Bulk cargo is carried on standard USAF 463L pallets and is transportable by all airlifters. A pallet holds bulk cargo measuring no more than 104" x 84" x 96". Oversize cargo is larger than the pallet dimensions and consists typically of wheeled vehicles. Oversize cargo is larger than a single pallet but less than 1,090" x 117" x 105". All oversize cargo can fit on a C-141 (or larger aircraft). Outsize cargo is the largest of these three, fitting only on C-5s and C-17s.

to arrive at independent cost assessments, all conducted in accordance with standard costing methods.⁷

An attempt was made to make the alternatives as comparable as possible in all other measures. Specifically, all alternatives were sized to be capable of a brigade-size airdrop. All alternatives possessed comparable intra-theater tactical airlift capabilities. Since the C-17s could also substitute for C-130s in tactical airlift roles when in theater, the study argued that mixed fleets with C-17s need not have as many C-130s for comparable overall strategic and tactical capability as those without them. Adjustments were made to the C-130 fleet size needed for each alternative, with corresponding adjustments in the associated O&S costs.

5. Arrange Cost and Effectiveness Information to Facilitate Decision-Making

Finally, once cost and effectiveness measures were estimated for all alternatives, a way of displaying them simultaneously to help decision makers quickly sort out favorable ones from less favorable ones was developed. As discussed earlier, *this step is crucial in any study of this type, since it establishes the framework for the decisions that must ensue. Such a framework must be free from biases (or must clearly identify biases that would otherwise be hidden) but must emphasize the critical issues. The organization of the cost and effectiveness results is vital to the utility of the analyses.* Examples will be provided later.

⁷ Costs also addressed contract claims that McDonnell Douglas had made as well as penalty charges associated with terminating the C-17 line short of then-contracted production levels.

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2. Alternatives

Alternatives refer to the alternative fleets, each made up of a number of different types of aircraft. This section first discusses the different types of aircraft in the alternative fleets, and then describes the composition of the alternative fleets, i.e., how many of which types of aircraft are in each. Figure 1 provides a schematic of the aircraft under consideration to indicate the relative sizes and capacities of these airlifters. Capacity is significant for determining how much each airlifter can carry, and size proves important for airbases with restricted space or facilities.

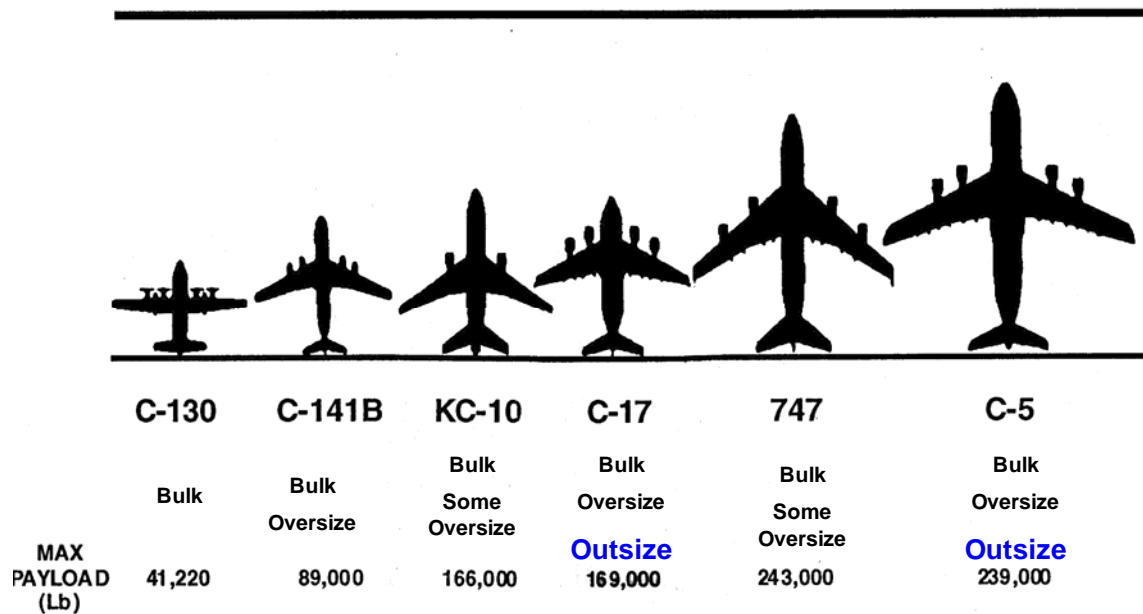


Figure 1. Aircraft Size and Capacity Comparisons

The military aircraft types considered in the study included: C-5A, C-5B, KC-10A, C-17, C-5B+, C-141, C-Y, Militarized 747-400F, and Militarized 767-300F. In addition, aircraft from the Civil Reserve Air Fleet (CRAF) that can be called up for duty to transport troops and bulk cargo during war conditions were also incorporated into fleet mixes. Each is discussed briefly in turn.

A. Core Aircraft Types

The 1993 core airlift fleet is summarized below. These aircraft would remain in the fleet no matter which new airlifter program is selected and are referred to as members of the core fleet, common to any alternatives.

1. C-5A/B

At the time this study was conducted in 1993, 76 C-5As and 50 C-5Bs were in the total aircraft inventories of the active, guard, and reserve fleets.⁸ The operating costs and the utilization rates are slightly different for the two types, but they carry the same payloads the same distances. These are the largest airlifters possessed by the U.S. Air Force. Each C-5 can take off or land with a maximum payload of nearly 120 tons, although that is not the typical load carried. At the time the study was conducted, the average cargo weight carried by the C-5s was 68.9 tons (these estimates are updated frequently by AMC, so more current numbers should be used in future studies), with a block speed⁹ of 423 knots. C-5s can carry very heavy or very large outsize cargo, such as M-1 Abrams tanks, Patriot battery radars, or CH-47 helicopters. They can also carry smaller oversize cargo, such as wheeled vehicles [5-ton and smaller trucks, M-2 Bradley or Stryker vehicles, or High-Mobility Multipurpose Wheeled Vehicles (HMMWVs)]. And, of course, the C-5 can also carry palletized bulk cargo such as ammunition, supplies and food, and troops.

2. KC-10A

The KC-10 is a dual-purpose aircraft. It serves as the largest airborne tanker in the fleet and as a cargo carrier. For purposes of this study, AMC estimated that 23 of the KC-10s would be dedicated to cargo missions. A single KC-10 can lift 83 tons of cargo, although it can carry only a fraction of oversize cargo and cannot carry any outsize cargo. The average payload assumed was 41.7 tons, and the aircraft moves with a 445-knot block speed.

3. CRAF

The Civil Reserve Air Fleet (CRAF) consists of a number of different aircraft owned and operated by various airfreight companies such as Federal Express (FedEx), and commercial passenger airlines such as United Airlines and American Airlines. The

⁸ In 2010, a total of 111 C-5s are in the USAF inventory. Of these, 49 are C-5Bs.

⁹ Block speed is the distance flown by an aircraft divided by the time spent once blocks are removed from the aircraft wheels and it taxis down the runway until it lands and comes to a complete stop with blocks again in place.

CRAF program was initiated in 1952 to provide on-call transportation assets in emergencies. These companies contract to provide aircraft and crew during specified wartime conditions in return for a guaranteed market share of DoD's peacetime airlift.¹⁰ There are three stages of wartime CRAF conditions. The Commander U.S. Transportation Command (USTRANSCOM), with the concurrence of the Secretary of Defense, has the authority to activate each stage.

- Stage I – minor operations – a pre-set number of commercial aircraft on 24-hour notice. Stage I has only been used a few times, such as in 1990 to support Operation Desert Shield deployments to Southwest Asia and in 2003 to support Operation Iraqi Freedom.
- Stage II – theater war – additional aircraft are released for more serious emergencies. Stage II has also only been used once, for Operation Desert Storm.
- Stage III – national emergency or two-theater war – even more aircraft made available. This stage has never been used. Nonetheless, this is the stage assumed for this study when supporting two nearly simultaneous major wars abroad.

B. Proposed Aircraft Types

Proposed aircraft types represent various alternatives that compete to augment the core fleet. These alternatives include proposals to extend the life of and/or replace the C-141. This section first reviews a program to extend the life of the C-141s and then introduces a variety of new aircraft alternatives.

1. C-141 Service Life Extension Program (SLEP)

The C-141, which can carry oversize and bulk cargo, was scheduled for retirement because of its age and because outsize cargo carriers were thought to be more useful to the airlift fleet of the future. To maintain the C-141 in the fleet would have required a Service Life Extension Program, or SLEP. The biggest cost items in the C-141 SLEP were to re-wing the aircraft and add a new cab top to replace serious corrosion damage. The maximum payload for the C-141 is nearly 45 tons, although the average cargo carried is 27.5 tons at a 410-knot block speed.

¹⁰ *Issues Regarding the Current and Future Use of the Civil Reserve Air Fleet*, U.S. Congressional Budget Office, October 2007.

2. C-Y

The C-Y is a hypothetical new replacement airlifter for the C-141. The C-Y would have modern off-the-shelf engines and avionics, but would carry the same load as the C-141. It was used in the analyses as a potential replacement for the C-141 as each C-141 reached its terminal fuselage life span at 45,000 flying hours, a point reached before the end of the 25-year period of the analysis. Thus two acquisition and operating costs are associated with the C-141 SLEP: the cost of SLEP itself plus the cost of the replacement airlifter when the C-141 reaches the end of its operational life.

3. C-17

The C-17 is smaller than the C-5, but larger than the C-141. The C-17 can carry outsize cargo, but not as much as a single C-5. The C-17 requires about as much room at an airbase as does the C-141, which is important when airbase space is limited. It can also operate from shorter runways than can the C-5, affording an opportunity to use more airfields in theater and en route. The C-17 can take off and land with a maximum payload of 85 tons, although the average payload assumed in the study was 48.3 tons (again, check recent AMC sources for more recent data). The C-17 block speed was estimated at 423 knots.

4. C-5B+

This is a new aircraft proposed as an alternative to the C-17. It is identical to the C-5B except that new GE CF6 engines would be used to reduce the high noise and pollution levels associated with the C-5 TF39 engines. The study assumed the same performance as the C-5B. Part of its cost involves a re-start of the C-5 manufacturing line at Lockheed, since the current C-5 line has been shut down.

5. Militarized 747 and 767

A different approach to replacing C-141s would be to purchase commercial aircraft, such as Boeing 747-400s or 767-300s, modified (militarized) to handle some oversize as well as the traditional bulk cargo.¹¹ Unlike the CRAF, these aircraft would be owned and operated by the U.S. Air Force. The 747s were estimated to be able to carry 73.1 tons each on average, while each 767 could carry 44.2 tons. Both aircraft types can fly at 445-knot block speeds. Two different commercial derivatives were used to explore whether

¹¹ Bulk cargo would be no problem in the commercial non-militarized version, since that is what CRAF carries. The nature of the militarization would be to strengthen the floors to handle higher pressure points (such as under the wheels of fully loaded 5-ton trucks) and possibly to modify the doors to permit wider cargo or equipment to be loaded from the side.

large or small options might be best. As will be seen in the results, the larger 747s were significantly more cost-effective than the 767s.

When the study began, militarized commercial aircraft were not included as candidates to replace the C-17. Some within the Air Force objected that these commercial (militarized) aircraft could not carry outsize cargo and only limited amounts of oversize cargo and therefore should not be considered candidates to replace the C-141. But since the C-141 SLEP was an option as a replacement for the C-17, and C-141s cannot carry outsize cargo, logic and fairness dictated that these militarized commercial derivatives be included. This inclusion turned out to play a crucial role in the decisions made, as will be demonstrated. *It also underscores the importance of not prematurely eliminating alternatives, and including as broad a range as possible, since a wide selection of alternatives can help highlight important variables to include in the analysis.*

C. Alternative Fleets

A total of 26 alternative fleets were considered¹² in the preliminary analysis illustrated in Table 2. The numbers in the table indicate how many aircraft of each type were included in each alternative. Each entry consists of two numbers, separated by a diagonal line. The larger number represents total aircraft inventory (TAI); the smaller number represents the primary aircraft authorized (PAA).¹³ Each of the alternatives, identified with a numerical label ranging from 1 to 26, was designed to have the capacity to deliver 52 MTM/D.

¹² A considerable number of additional alternatives were added later in the study, not all of which had a capacity of 52 MTM/D, but these were introduced after the more powerful comparison displays (to be shown later) were developed. At that point, equal MTM/D became an interesting but marginally useful criterion. Actual performance in realistic scenarios became the more important gauge. But to start the analyses, IDA first focused on these 26 equal-MTM/D alternatives.

¹³ The TAI entries indicate how many new aircraft are to be procured; the PAA values are the numbers available to deliver cargo and troops in the scenarios studied and the numbers used in O&S costing estimates.

Table 2. Alternatives with 52 MTM/D Capacity

Categories	Alternative Number	Numbers of Aircraft (TAI/PAA)				
		C-17	C-141 SLEP	C-5B+	747	767
One-Aircraft Alternatives	1	120/102	----	----	----	----
	2	----	263/225	----	---	----
	3	----	----	102/87	---	----
Two-Aircraft Alternatives with Reduced Numbers of C-17s	8	94/80	58/49	---	---	---
	9	94/80	---	21/18	---	---
	10	94/80	---	---	18/17	---
	11	94/80	---	---	---	30/28
	25	70/60	108/92	---	---	---
	26	70/60	---	42/36	---	---
	18	70/60	---	---	34/32	---
	22	70/60	---	---	---	56/53
	23	47/40	160/137	---	---	---
	24	47/40	---	62/53	---	---
	21	47/40	---	---	49/47	---
	17	47/40	---	---	---	83/78
	4	26/20	212/181	---	---	---
	5	26/20	---	82/70	---	---
	6	26/20	---	---	66/63	---
7	26/20	---	---	---	108/103	
Two-Aircraft Alternatives with No C-17s	12	---	136/116	49/42	---	---
	13	---	136/116	---	40/38	---
	14	---	136/116	---	---	65/62
	15	---	---	49/42	42/40	---
	16	---	---	49/42	---	69/66
	19	---	---	---	32/30	83/79
Illustrative Three-Aircraft Alternative	20	47/40	93/79	---	21/20	---

Note: All alternatives also contain a core fleet of 109 (PAA) C-5A/Bs, 23 KC-10s, and numerous CRAF. With Stage III CRAF, all alternatives provide 52 MTM/D capacity.

The entries in Table 2 represent additions to the core fleet. As indicated in the note at the bottom of Table 2, each alternative also includes the then-current core fleet of C-5s, KC-10s, and Stage III CRAF forces. The alternatives are sorted into sets of categories, called One-Aircraft Alternatives, Two-Aircraft Alternatives with Reduced Numbers of C-17s, Two-Aircraft Alternatives with No C-17s, and an Illustrative Three-Aircraft Alternative. Alternative 1 has 120 C-17s; all other alternatives have fewer, or no, C-17s.

Note that the One-Aircraft Alternatives involve only one new type of aircraft added to the core fleet. As already noted, Alternative 1 contains the full 120 C-17 fleet, as programmed at that time by the USAF. Alternatives 2 and 3 proposed replacement of the C-17 with a SLEPed C-141 fleet or a new-start C-5 fleet, respectively.

The alternatives that included a reduced number of C-17s proposed a number of different options including some C-17s in addition to one other aircraft. For example, Alternative 8 has 94 C-17s and 58 C-141 SLEPs. The smallest number of C-17s considered in this category was 26 C-17s, the minimum number already obligated to DoD under contract without incurring termination penalties.

The Two-Aircraft Alternatives with no C-17s include mixes of the C-141 SLEP, C-5B+, 747, and 767 aircraft, taken two at a time, that provide the same MTM/D as 120 C-17s.

The study also briefly examined a few three-aircraft alternatives, but it was felt that DoD would probably not embrace a program that called for three new airlifter types unless the results turned out to be dramatic. Although the results for these alternatives did not turn out that way, they served as a useful example for purposes of comparison.

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3. Key Inputs and Models

This section summarizes the important data and considerations needed for the analyses. It also points to the central role played by MASS and ACAS to develop measures of effectiveness, and the Cost-Oriented Resource Estimating (CORE) model for cost measures.

A. Scenarios and Delivery Requirements

The careful choice of scenarios is essential to any analysis, since this provides the context within which the system will be employed and a context for the evaluation of each alternative's effectiveness. The airlift analyses were conducted for two different types of scenarios: one massive and geographically distant, the other small, close, but intense. The selection of scenarios offers one of many opportunities for participants to influence a military cost-benefit analysis. Proponents and opponents of various alternatives can attempt to manipulate the scenarios in order to focus on features that show their solution to its best advantage. It is critical to guard against this kind of bias. *Scenarios must be selected to explicitly address all important features, since the purpose of the analysis is to provide objective and unbiased insights to the decision maker on how the system is likely to perform in critical scenarios relevant to national defense.*

In this case, the first scenario considered involved a concurrent, sequential deployment of forces from the United States to meet the needs first of a Major Regional Contingency (MRC)-East, and subsequently of a MRC-West.¹⁴ The designations East and West refer to the U.S. coast from which most of the airlifters would stage for the respective MRC operations.¹⁵ Over 550,000 tons of cargo was required within a 90-day period for both MRC scenarios.

The second scenario involved a Lesser Regional Contingency (LRC)¹⁶ that began with a brigade-size airdrop followed by air delivery of cargo and additional troops to the target country. In this second scenario, CRAF was not activated and the reserves were

¹⁴ Today the acronym MRC has been replaced by MCO (Major Combat Operation) and CC (Conventional Campaign), but the meaning is equivalent. We will use here the MRC notation used in the original 1993 study.

¹⁵ MRC-East refers to a theater in Southwest Asia, supported mainly by flights out of East Coast U.S. bases. Similarly, MRC-West refers to a theater in the Western Pacific with deployments from the western U.S. airbases. It was assumed that CRAF Stage II would be authorized at the onset of MRC-East, with Stage III activated when MRC-West deployments began.

¹⁶ Today LRC has been replaced by IW (Irregular Warfare) or a vignette from the SSSP, the Steady State Security Posture collection of lower intensity conflicts.

not mobilized. A total of 50,000 tons of cargo was required in 4 days, in addition to that delivered in the initial brigade airdrop. This case allowed the analytic team to test the robustness of the alternatives to very different requirements from those addressed by the MRCs.

The MRC scenarios dominated the analyses conducted. These scenarios required the full support of the airlifter fleet, including full augmentation by CRAF. Most of the analyses discussed in this paper refer to the first set of scenarios. It turns out that the LRC scenario added little to the insights obtained from the two MRC scenarios.

The airlift requirements from the Mobility Requirements Study (MRS) are summarized graphically in Figure 2 for two different time periods: 30 days and 90 days. Virtually all outsize and oversize cargo was required to be in theater within the first 30 days. There are only minor differences between requirements for 30-day delivery and for 90-day delivery in these categories. To meet continuing resupply requirements, the remaining bulk cargo in each case continues to build over time. This emphasis on rapid delivery of outsize and oversize cargo will become the basis of measures of (effectiveness) merit in the study.

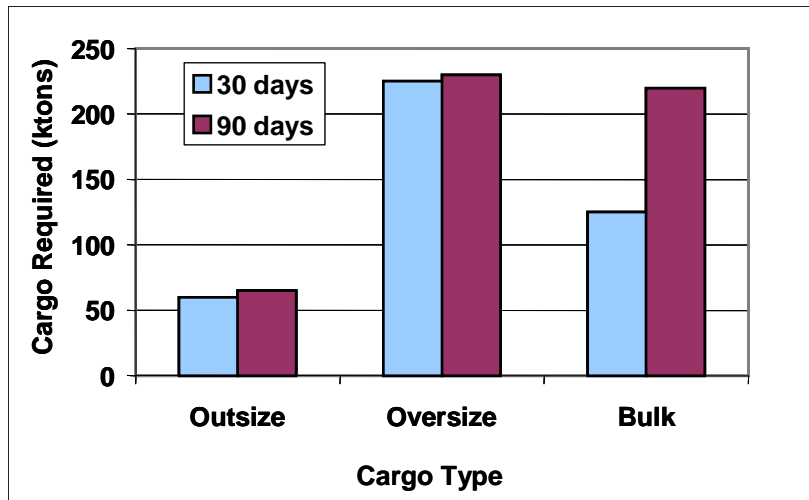


Figure 2. MRS Airlift Delivery Requirements for MRC-East and MRC-West Combined

B. Aircraft Characteristics

Several key aircraft characteristics are essential in determining load and delivery of required cargo. These are discussed in this section.

1. Range-Payload Relationships

Figure 3 summarizes the range-payload curves for each of the strategic airlifter types. The payload is limited at short flying distances (ranges) by the maximum cargo weight the aircraft can lift. The maximum range is defined where an aircraft carries its maximum fuel load at takeoff and no cargo. At intermediate distances, the range-payload relationship illustrated in Figure 3 depends on tradeoffs between cargo and fuel loads.

Once these relationships were established, they were used to determine the best refueling locations en route to allow an airlifter to carry as much cargo as possible. While actual operations would undoubtedly provide opportunities for in-flight refueling, payloads were assigned with the conservative assumption that the airlifter would have to use en route bases for refueling.¹⁷ As Figure 3 reveals, the 747 and KC-10 airlifters are the least constrained by the range-payload relationships.

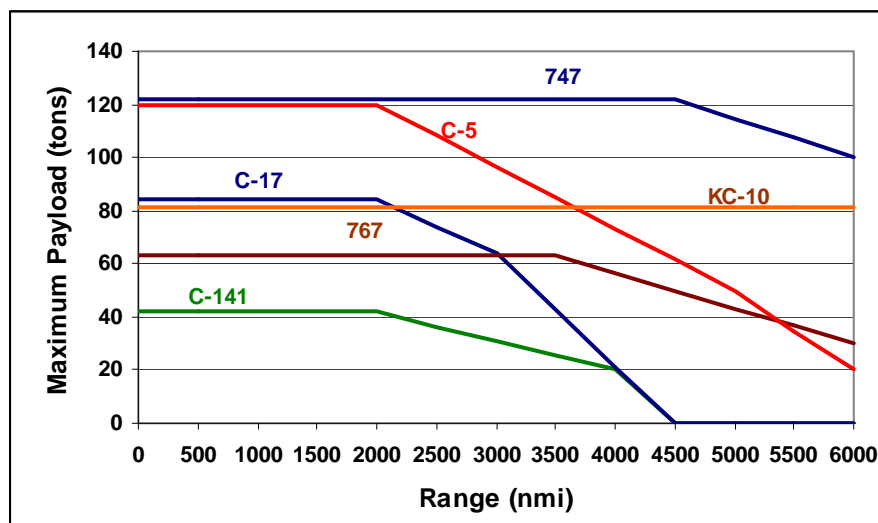


Figure 3. Range-Payload Curves for Airlifter Types

¹⁷ This assumption is further supported by the heavy demand for tankers to support fighter deployments to the MRC theaters as well as the potential for supporting combat aircraft employment during and following deployment.

2. Use Rate

Surge use rates¹⁸ are the upper limit in terms of flying hours that a fleet of aircraft can fly on any given day, applied to the first 45 days of operations. Table 3 reports surge use rates for each airlifter type analyzed. These numbers became major sources of disagreement as the study proceeded, resulting in sensitivity analyses using lower C-17 use rates and higher C-5B+ use rates. *While each excursion requires time and resources, the use of sensitivity analysis excursions to investigate key relationships and variables is one of the advantages of analysis. Sensitivity studies are usually conducted on a range of issues with priorities established by the key decision-makers. The need for sensitivity analyses excursions should be anticipated and built into study timelines.*

Table 3. Airlifter Surge Use Rates

Airlifter Category	Airlifter Type	Surge Use Rate (Hrs/Day/PAA)
Military	C-5A/B	11.0 (average)
	C-141 SLEP	12.5
	C-17	15.2
	C-5B+	12.5
	KC-10	12.5
Commercial Derivative	Militarized 747 or 767	12.5
CRAF	All	10.0

3. Maximum on Ground (MOG) and Ground Times

The space available at airbases is referred to as Maximum on Ground (MOG). It measures the maximum number of each specific type of airlifter that can be located at a given base to receive service at the same time.¹⁹ The values for each airlifter type were taken from a list of worldwide MOG allotments for each airbase. Table 4 summarizes MOG estimates for the airlifters analyzed at an aggregate theater-wide level. Note that the largest airlifters consume nearly twice the MOG space of the smaller ones. For

¹⁸ The use rate is the average number of hours per day that an aircraft flies. Its estimate depends on the amount of time it spends on the ground which, in turn, involves the mission capable rate, which is a measure of reliability. It is used in the models to place an upper limit on the amount of time an aircraft flies.

¹⁹ The MOG-value at each airbase is specified by aircraft type and is determined by the materiel handling equipment (MHE) available, fuel availability, and the number of service positions allotted to airlift (in-theater bases are often mostly occupied by fighter aircraft). Large aircraft may require more than one service position.

example, a maximum of 26 C-17 aircraft can be on the ground simultaneously in the East MRC Theater of operation.²⁰

Table 4. MOG Estimates Maximum Number of Aircraft on Ground Simultaneously (by Theater and Aircraft Type)

MRC Theater	C-17	C-141 SLEP, 767	C-5, KC-10, 747
East	26	26	15
West	24	20	11

Another important input is the ground time required to load and unload cargo and refuel aircraft. This reflects the amount of time each aircraft uses its allocation of MOG. Ground times vary by mission (en route refueling, on-load, off-load) and aircraft type. The C-5s had the longest ground times (3.75 hours on-load, 3.25 hours en route and off-load), especially when compared to 2.25 hours for en route, on-load, and off-load for the C-17 and C-141. Boeing’s commercial derivatives had the longest on-load times (4-5 hours) but the shortest en route times (1.5 hours).²¹

C. Loading and Transportation Effectiveness Analysis

The main models used for the estimates of how much cargo and how many passengers were delivered were ALM, MASS/AFM, and ACAS. These models are summarized briefly to give a sense of the assumptions used in the analysis.²² Further detail on each of the models can be found in Appendix A.

1. Airlift Loading Model (ALM)

The ALM was used to determine the average cargo payload carried by each aircraft in the fleet. The MASS/Airlift Flow Model (AFM) then used this result to simulate the transport. ALM used cargo from the entire TPFDD for these estimates. The cargo was differentiated according to 26 different categories called “commodities.” Each commodity could contain vehicles, pallets, and passengers (PAX). The sequence in which the aircraft were to be loaded had to be specified, as well as aircraft cargo storage dimensions, cargo door opening sizes, number of passenger seats, and maximum payload

²⁰ It suffices to show the difference in the number of spaces available for small airlifters as contrasted with larger ones. Detailed databases at the appropriate classification are maintained by AMC.

²¹ MOG was usually the most constraining at en route bases. En route MOG constraints may cause longer, less efficient routes to be used.

²² These models have subsequently evolved to more advanced versions, but it is important to know how they approached the transportation problem in 1993.

allowable by weight. Loading stopped when the weight limit was reached, or, more commonly, when cargo fully filled the cargo space in the aircraft.

2. MASS/AFM

The MASS/AFM was a large Monte Carlo simulation²³ that scheduled and executed each airlift mission, by tail number. It incorporated a great deal of realism, such as specific routes used, airbases with MOG limitations, times for loading and off-loading, and crew duty days. It used the ALM loading results along with the nature of the TPFDD cargo and PAX at individual airbases to load the cargo. Only that part of the TPFDD available at a specific base on a specific day (plus any undelivered leftover cargo from previous days) was available for loading. The output was tons delivered per day.

3. Airlift Cycle Analysis Spreadsheet (ACAS)

The ACAS model was a simplified approximation to the analyses produced by MASS/AFM and was used to conduct the large number of excursions needed in the study. It used aggregate data and aggregate MOG values, calibrated against MASS/AFM to give confidence, for these numerous excursions.

D. Cost Analysis

The total costs for the various airlifters were estimated from numerous sources and models. The study included both the acquisition costs for new aircraft (C-17, C-5B+, C-Y, 747 or 767) and for the C-141 SLEP, as well as 25-year operating costs. All costs were expressed in constant FY 1993 dollars and were discounted to net present value using the then-current standard discount factor of 4.5 percent per year. The Office of Management and Budget (OMB) changes the discount factor every year.²⁴ For cost-effectiveness analyses of Federal programs, OMB mandates the use of discounted dollars.

The study team used detailed cost information from numerous sources – the C-17 Program Office, airframe and engine contractors, and the OSD Cost Analysis Improvement Group (CAIG) – to arrive at its own independent cost estimates. Historical data trends were used to supplement these data sources when no data were available. In general, IDA cost estimates for the C-17 were somewhat higher than those of the Program Office, an issue that slowed progress during parts of the study while these differences were debated. The CAIG agreed with the IDA estimates, and these were the ones retained in the report.

²³ MASS/AFM has now been replaced at AMC by the Air Mobility Operations Model (AMOS).

²⁴ *OMB Circular No. A-94*, Office of Management and Budget (revised annually).

1. General

The basic approach was first to establish acquisition schedules and C-141 retirement schedules for all alternatives and to make assumptions regarding the active/reserve aircraft mix for airlift. The study team used the C-17 schedule programmed at that time by the U.S. Air Force, with C-141s retired at such a rate as to maintain a constant MTM/D capacity. Other airlift alternatives (C-5B+ and commercial derivatives) were acquired at rates consistent with their manufactures' capabilities, with the C-141s also retired at a rate to keep MTM/D constant.

All costs prior to FY 1994 were ignored. Only future expenditures were considered.

2. Acquisition

The study used the Air Force C-17 acquisition schedule, with a maximum acquisition of 16 per year. Historical cost data for the C-17 were used to generate a cost-learning curve to predict future costs for C-17s. Appropriate adjustments to historical trends were added as needed, such as the cost for extra weight to strengthen the wings and higher costs associated with more realistic engine estimates for all lots after the first ones. IDA estimated the full C-17 program acquisition cost at approximately \$23 billion, about \$3 billion over the Program Office estimate. In the end, the higher-cost IDA results were used in the report, with a comparison to the Program Office estimates included as an excursion.

At the time the study was conducted, 26 C-17s were under contract with long-lead funding. The U.S. Government would have incurred a cost penalty for breach of contract if it failed to buy 26 production C-17s. Thus alternatives with fewer than 26 C-17s were levied an additional cost associated with breaking the contract (\$1.5 billion).

Lockheed Martin Aeronautical Systems provided cost estimates for restarting the C-5 line as well as for refurbishing the C-141s in a C-141 SLEP. IDA used these and other historical Lockheed data and made adjustments as required. Examples of adjustments include adding hush kits to dampen the sound of the engines and adding extra material to the fuselage. The cost to restart the C-5 line was estimated at \$750 million. New C-5 engines were used to reduce noise levels below those mandated by the Federal Aviation Administration (FAA).

A recently completed Scientific Advisory Board (SAB) report had recommended that the weep hole cracks in then-current C-141s could be repaired and their life extended to 45,000 flying hours. When the C-141 reached its 45,000-flying-hour life limit, the SAB determined it had to be replaced, and the cost of a new C-Y replacement was imposed to include a \$3.5 billion development cost.

Boeing supplied basic cost data for the 747 and 767 commercial derivative aircraft. Production rates from 6 to 12 per year for military acquisition were used, based on Boeing production capabilities and competing markets for new 747 or 767 aircraft. An additional 20 percent of the acquisition price was added to account for reinforced floors and rollers and widened side doors, for an estimate of \$155 million for the militarized 747 and \$88 million for the militarized 767. Since these lines are open, no developmental costs were imposed. Over the course of the study, these same commercial derivative aircraft also became known as “non-developmental airlift aircraft.”

3. Operating and Support

The primary tool used to estimate O&S costs was the U.S. Air Force CORE model. This is the standard model used for O&S cost estimates in the cost community. Use of the model requires that the aircraft be sorted according to whether they are in the active, associate, or reserve fleets. It takes into account the number of flying hours per year, the cost of the fuel burned, the cost associated with the personnel needed (crew, maintenance), software costs, training costs, the cost of spares, and the cost of contractor logistics support.

O&S cost estimates from the U.S. Air Force CORE model for all the aircraft types are summarized in Table 5. The commercial derivative aircraft were assumed to have contractor logistics support, the cost of which was included in the cost estimates for alternatives containing commercial aircraft derivatives.

Table 5. Summary of O&S Costs per PAA

Aircraft	Number of Flying Hours per Year	CORE Cost Estimates (\$M/year/PAA)
C-17	1,427	10.8
C-5B or B+	660	9.49
C-5A	325	6.75
C-141 SLEP	1,178	7.72
747	900	8.08
767	900	4.98
KC-10A	550	4.62
C-130E/H	637	4.01

4. Initial Cost and Operational Effectiveness Results

This section summarizes the initial results presented to the Strategic Systems Committee (SSC) and to the Defense Acquisition Board (DAB) in August 1993, along with their reaction.²⁵ Throughout the early stages of the analyses, key decision makers were periodically apprised of the methodology, inputs, and results. Frequent meetings were held between the study team and working levels representing the interested DoD organizations. AMC was in continuous contact, providing all the MASS/AFM computer runs with inputs provided from IDA. *This is an essential part of any analysis, which is both a process and a product. Contact allows the analyst to understand the critical issues as viewed by the various players and decision makers, as well as to provide the decision makers with an opportunity to help guide the analysis.*

The initial cost and operational effectiveness results are summarized in Figure 4. These results were developed using cargo and equipment data specified in the airlift portion of the TPFDD files from the Mobility Requirements Study that had been completed the year before.

A. Initial Results

All 26 alternatives are displayed in Figure 4 according to their effectiveness (tons of outsize cargo²⁶ delivered in a 30-day period) and cost (FY 1993 25-year discounted life cycle cost). The numbers beside each symbol identify the alternatives. To assist with visual interpretation, alternatives that contain any C-17s contain a small black dot, those with any C-5B+ have a square, those with any C-141 SLEP have a triangle, and those with commercial derivatives such as 747s or 767s have an open circle. For example, Alternative 1 with only a small black dot includes only C-17s (120 according to Table 2). In contrast, alternative 18 contains both C-17s and commercial derivatives (70 C-17s and 34 747s according to Table 2) as indicated by the dark dot inside the larger open circle.

²⁵ The SSC provided a review of the study prior to presentation to the higher-level DAB. All offices represented in the DAB had representatives in the SSC.

²⁶ As noted earlier in Figure 2, virtually all the required outsize cargo must be delivered within a 30-day time period. This category of cargo differentiates best among the alternatives because of its criticality to the early stages of battle. Excursions (not shown here) at 20 days showed no new insights, so 30-day deliveries were displayed in the study.

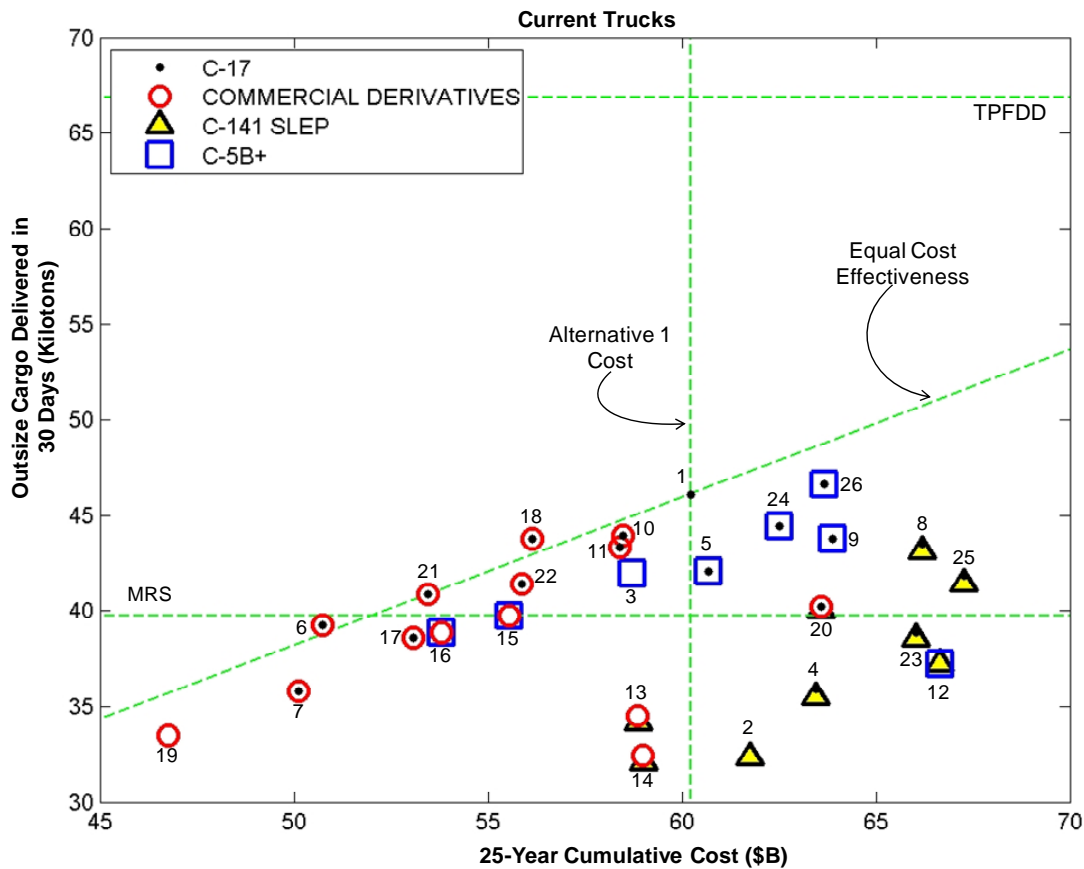


Figure 4. Comparison of Cost and Effectiveness of Alternatives with Current Trucks

For reference, the outsize cargo requirement of the 30-day scenario set by the MRS is shown as a horizontal dashed line. The vertical dashed lines shows the cost of the 120-C-17 Alternative 1, while the sloping dashed line indicates the locus of all alternatives that have the same cost-effectiveness (i.e., same slope or ratio of effectiveness to cost) as Alternative 1.²⁷

This chart clarifies several things. First, the C-141 SLEP alternatives (i.e., the triangles) appear to be among the worst candidates, both from a cost and from an effectiveness perspective. In order to make them more effective by adding either C-141

²⁷ As discussed elsewhere in this book, using cost-effectiveness ratios to evaluate alternatives is generally not appropriate and can in fact be very misleading without a budget constraint or fixed level of effectiveness.

aircraft or another aircraft that is part of the mix, additional costs would be incurred.²⁸ This seems to eliminate a whole category of alternatives immediately. Second, the mixes of C-17s and commercial derivatives (open circles with concentric black dots) appear to be close in cost-effectiveness. This catches our attention and elevates our consideration of militarized 747s and 767s. In particular the 747 appears the better of the two commercial derivatives. Finally, the C-5B+ (squares) alternatives appear slightly less cost-effective in all their mixes than the C-17 mixes, but run a close second. They cannot easily be dismissed from this chart.

The DAB was impressed with the potential for using commercial derivatives such as the 747 at lower cost than the C-17 program. The study team was tasked with examining several excursions and reporting back as soon as possible. At the same time, C-17 proponents perceived the results to be a threat to their program and reviewed the analyses in detail.

B. Changing Assumptions: Transportation of New Army Trucks

As often happens when unexpected results are presented, those most affected by the conclusion that commercial aircraft could be the most attractive alternatives began to search for flaws in the methodology and errors in the inputs. Hence they made a major discovery that seriously challenged the analysis to date. This discovery concerned the ability of commercial aircraft derivatives to transport new Army trucks.

The preliminary analyses had assumed current (meaning circa 1993) Army trucks (hence the subtitle in Figure 4 of “Current Trucks”) were to be airlifted. Actually, the Army planned to replace their 2.5- and 5-ton trucks with 10,843 new ones, members of the Family of Medium Tactical Vehicles (FMTV). Since trucks constituted a major component of the TPFDD, with thousands being airlifted to theater, the effect on the analyses could potentially be significant. These new trucks differed in two significant ways as far as air transportability is concerned: axle loads and truck height. Each is discussed next with its effect on transportability in the different alternatives.

The axle loads on some of the new trucks are much higher than those of the corresponding current trucks. These loads are so heavy, in fact, that a stronger reinforced floor would be needed on the militarized 747s to carry them. Thus additional costs for reinforcing commercial derivatives are necessary if these trucks are to be carried. Since

²⁸ These are examples of the Modified Budget Approach and the Modified Effectiveness Approach for cost-effectiveness comparisons in which neither cost nor effectiveness are initially constrained to be equal for all alternatives. These are described by Francois Melese in *The Economic Evaluation of Alternatives (EEoA)*, pp. 40-45, Naval Postgraduate School, January 2010.

the CRAF 747s are not reinforced, they cannot carry any new trucks at all, thus reducing their utility in moving some of the oversize cargo.

Even more significant is truck height. There are two versions of the new trucks: one designed for airdrop or low-altitude extraction by parachute, and the other for normal loading and unloading from a stationary airlifter. The difference is that the airdrop-capable versions have collapsible cab tops that permit them to be easily loaded through the nose of a 747; the others (the vast majority) have fixed, non-removable cab tops whose heights prevent the trucks from entering through the nose door. The nose door height cannot be changed because the 747s nose space is needed for cockpit and crew and therefore limits door height. The side doors would be tall enough, but not wide enough (without alteration). The new FMTVs would, however, fit through the doors of C-17s, C-5s, C-141s, and KC-10s.

The study team investigated possible ways to address this impasse. First, the Army could spend an additional \$700 per truck to ensure that all trucks have collapsible cab tops. This would ensure that they fit on 747's. The Army objected, not just on the basis of cost, but also on operational utility. The Army deliberately chose non-collapsible cab tops for the next-generation trucks to afford greater protection in chemical environments. Thus this solution did not seem reasonable. Second, if the cab tops cannot be changed, perhaps the 747 side doors could be widened. Boeing engineers estimated that the cost to widen the doors and provide additional roller reinforcements would be about \$10 million per aircraft. The materiel-handling equipment could raise the trucks to the appropriate height from the ground, and the trucks would have to maneuver with a sharp turn as they entered the fuselage. Thus, greater care in moving the trucks through the side doors would be needed, with some risk and longer loading times. But this seemed technically possible, so it, along with the extra costs entailed, became the new commercial derivative design: wider side doors with additional roller and floor reinforcements.

The new trucks also affected CRAF. Civilian aircraft forced into service could not be expected to carry the new trucks because of the extra weight.

The results under the new assumptions are shown in Figure 5. The results assume either collapsible cab tops for the new trucks (FMTVs) or an extended side door for the Boeing 747.

Figure 5 is similar to Figure 4, except that it captures the fact that all alternatives will have lower delivery capabilities, since CRAF cannot carry the new Army trucks.²⁹

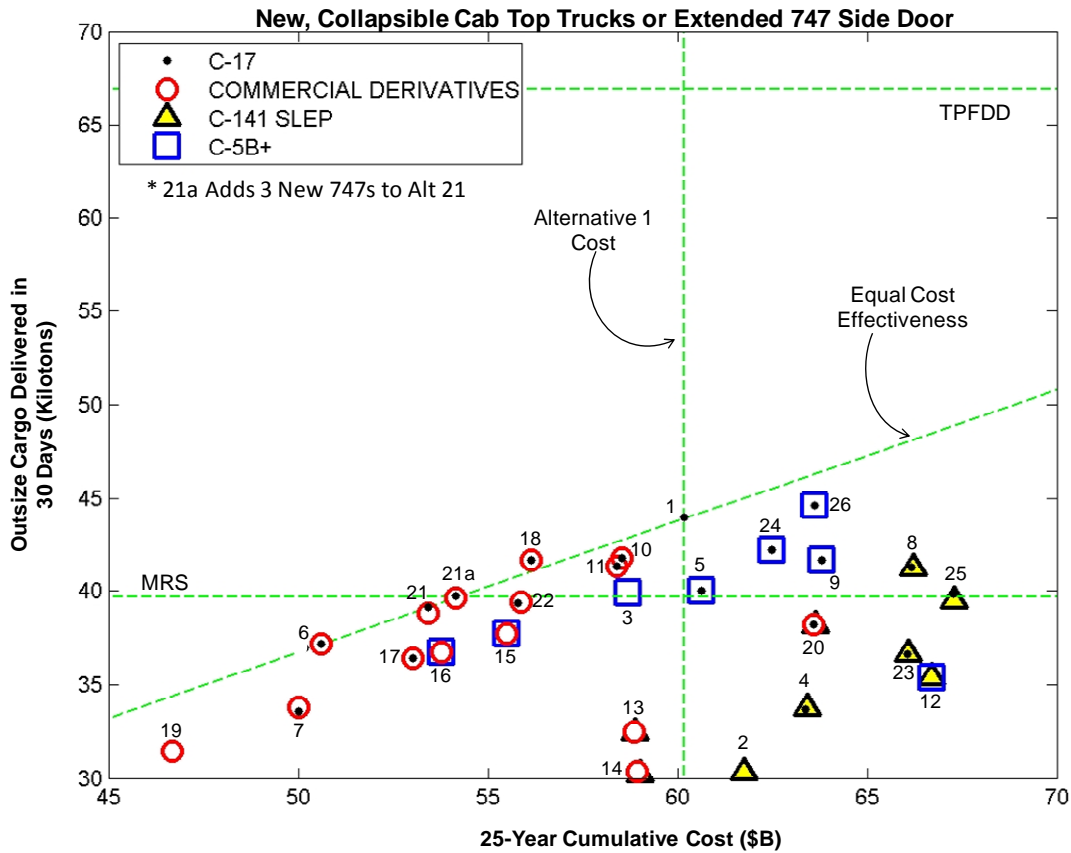


Figure 5. Comparison of Cost and Effectiveness of Alternatives with New Army FMTV Trucks

Figure 5 also contains a new alternative, Alternative 21a. This alternative was added after a second briefing to the DAB. At the DAB it was noted that, with only 3 additional 747s, Alternative 21 (with 47 C-17s and 49 747s) could be raised up to the MRS line and therefore meet the requirement and level the playing field.³⁰ With this,

²⁹ The reader may wonder how oversize cargo such as trucks can influence the rate of delivery of outsize cargo. The interaction is complex, involving a competition for space aboard aircraft that do carry outsize cargo (i.e., C-17s and C-5s), and between outsize cargo and oversize cargo. If no oversize trucks can be carried by CRAF, those same trucks begin to crowd out any outsize cargo that C-17s and C-5s would have otherwise carried, reducing their outsize delivery capability.

³⁰ This is identical to the Modified Effectiveness Approach described by Francois Melese, *EEoA*, op. cit., pp. 40-43, Naval Postgraduate School, p. 43, January 2010.

Alternatives 10 (with 94 C-17s), 18 (with 70 C-17s), and 21a (with 47 C-17s) could be seen as providing at least as much capability as demanded by the MRS, but at lower cost than Alternative 1 (with the programmed 120 C-17s). This chart reinforces the notion that there are less costly alternatives to the C-17 program, most involving militarized commercial derivatives.

Some decision makers wondered what the results would be if the new trucks could not be accommodated aboard militarized 747s. That was a fair question deserving an answer. Figure 6 summarizes results for that situation for a selected set of alternatives.

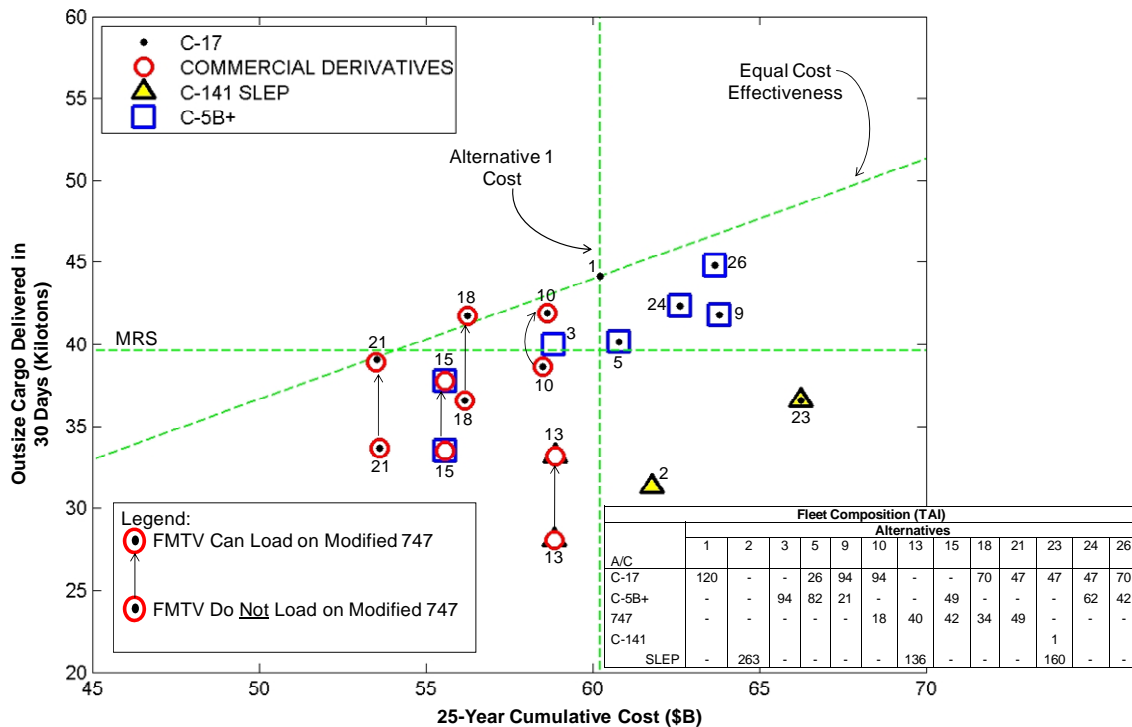


Figure 6. Comparison of Selected Alternatives with Different Assumptions about FMTV Loading on Militarized 747

As Figure 6 clearly illustrates, the viability of the commercial derivatives is critically associated with the ability to load the Army’s FMTV trucks onto the modified aircraft. Under these assumptions, the combined 747 and C-17 Alternatives 10, 18, and 21 that earlier had cost-effectiveness ratios similar to Alternative 1 (made up exclusively of C-17s), no longer do so and even fall below the minimum effectiveness MRS scenario line. If commercial 747 derivatives cannot be loaded with new Army trucks, then their effectiveness plummets.

5. Sensitivity Analyses of Other Underlying Assumptions

Additional analyses were conducted to gauge the sensitivity of the results to other assumptions. These are discussed here.

A. MOG and Use

The analyses presented so far include specific assumptions about the space available at en route and theater airbases and about utilization rates of aircraft. The space available for aircraft at airfields en route to a final destination is a function of the assumptions concerning other activities at those bases and in the theater and thus is subject to considerable uncertainty. The assumption regarding the utilization rates of aircraft depends on funding decisions and maintenance policies to provide specified levels of operational performance and could, in principle, be strategically altered. The study subjected both of these key assumptions to sensitivity analysis, to gauge the sensitivity of the results to specific assumptions and data inputs.

Although the values used in the study allowed for reasonably robust operating conditions, C-17 proponents cited less-than-ideal operating conditions as a key advantage of their aircraft. The C-17, with a MOG value close to that of the C-141, requires less space than the C-5 or 747. Since considerable subjectivity is inherent in the values used for any study, it seemed reasonable to explore how sensitive the results were to changes in this input. The study team thus considered the following three MOG conditions:

- Robust, corresponding to the AMC values used in previous charts
- Moderate, with conditions in MRC-East that approximated the 1990 Desert Shield MOG values
- Constrained, which included the moderate MOG for MRC-East just noted and reduced the MOG in MRC-West by removing airfields near the conflict border and reducing MOG elsewhere in the theater by 50 percent.

In all cases, as the MOG was reduced, the ability of the C-17 to land and take off on short airfields, to back up, and to take up less space than C-5s and the commercial derivatives made it more favorable. This is illustrated in Figure 7 for five of the alternatives. For clarity, only the most robust and constrained extremes are shown while the moderate MOG case lies in between.

Changes in the MOG have a powerful influence on the results. In the constrained case, none of the alternatives meet the MRS requirements, although Alternative 1 with

the most C-17s suffers less than the others with C-17s and other, more space-intensive airlifters. In terms of systems thinking, *this clearly points to the possibility of investing in adequate infrastructure to improve MOG as a new alternative that can be integrated with various combinations of aircraft. It also cautions against assuming lower cost alternatives always provide the best payoffs.*

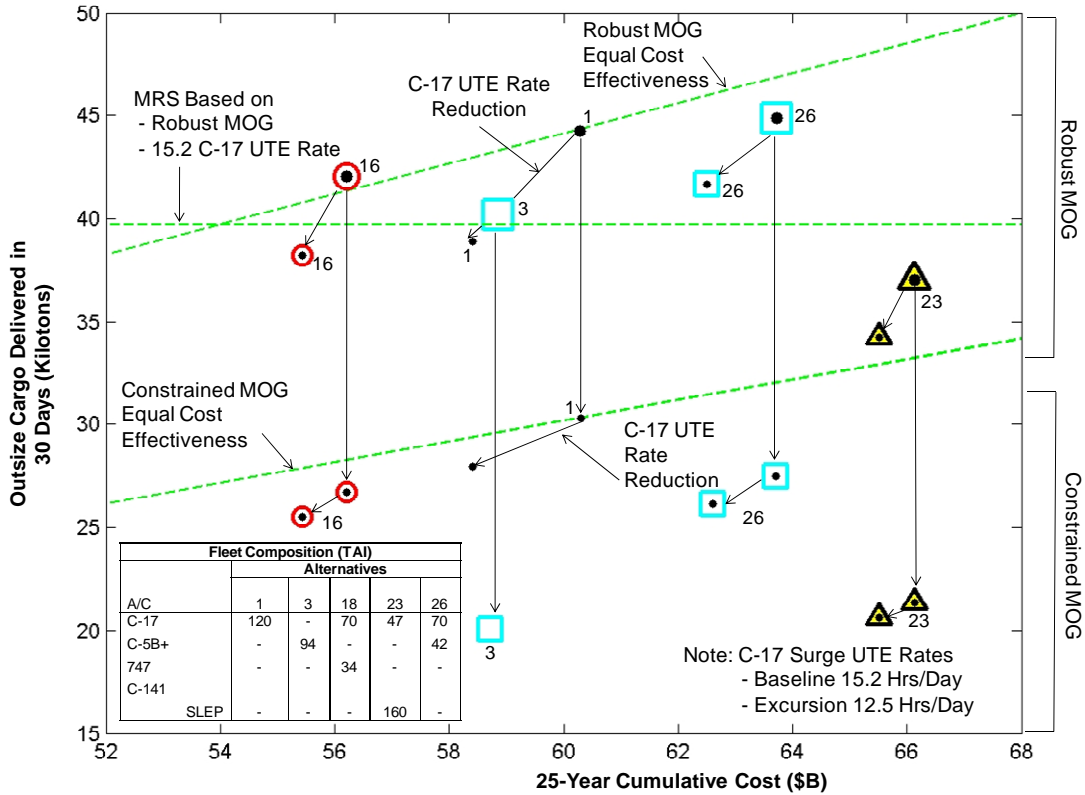


Figure 7. Impact of Reduced MOG and Reduced C-17 Use Rates

Another key assumption in the analysis was questioned by 747 proponents who objected to the application of the higher C-17 use rate. The basic analyses assumed a 12.5-hour-per-day use rate for the 747s and a 15.2-hour-per-day rate for the C-17s under wartime surge conditions. The use rate attainable by the C-17 was still unproven when the study was conducted, so some doubted it would exceed that achievable by commercial aircraft.

Figure 7 also illustrates the effect of a smaller use rate for the C-17. The reduced use rate was assumed to be 12.5 hours/day – the same as the assumed use rates for the

C-5B+ and the militarized commercial derivatives. The smaller use rate reduced effectiveness and also cost (because of fewer flying hours per year associated with such a lower use rate). The overall effect was noticeable but was not nearly as dramatic as that seen in the MOG assumption excursions. While it was reasonable for the study team to be skeptical about such a large projected use rate for an unfinished aircraft, deviations from that projection did not dramatically affect the cost-effectiveness measures for the C-17. Interestingly, subsequent tests 2 years after this original study validated the 15.2 hours/day value, rendering the arguments moot. *However, study teams can never know these things in advance and are well served to look carefully at all key assumptions that could influence the results.*

B. Assuming Airlift Capability Other Than 52 MTM/D

After the first DAB meeting in August 1993, there was a growing sense on the part of some decision makers that commercial derivatives in conjunction with some number of C-17s might be the best program. When the initial results were briefed to the DAB, additional airlift capability assumptions were requested. These cases were developed to determine how few C-17s might be acceptable if that program was reduced from the 120 aircraft originally assumed in Alternative 1.

IDA was asked to assess how well a number of new alternatives would fare. The result of one set of analyses is summarized in Figure 8. In this case, 10 new alternatives are introduced, with MTM/D values ranging from 46 up to 55. An attention to cost was also used to make virtually all the new alternatives no more costly than Alternative 1. Figure 8 illustrates cost and effectiveness measures for Alternative 1, mixes of C-17s and commercial derivatives, and mixes of C-17s and C-5B+s. Since by the time the DAB was expected to reach its decision it was expected that 40 C-17s would already be delivered or under construction, many of the new alternatives included 40 C-17s, and none involves fewer than that number. As Figure 8 shows, the set of mixes of C-17s with commercial derivatives is roughly equal in cost-effectiveness to Alternative 1 with exclusively C-17s. Moreover, for roughly the same budget, the commercial and C-17 mixes are well above the effectiveness of the C-17 and C-5B+ mixes.³¹ This chart confirmed the sense derived from earlier charts that the mix of C-17s and commercial derivatives might have merit – provided they could carry the new Army trucks.

³¹ This is an example of the Fixed Budget Approach described by Francois Melese in *EEoA*, op. cit., pp. 33-35, Naval Postgraduate School, January 2010.

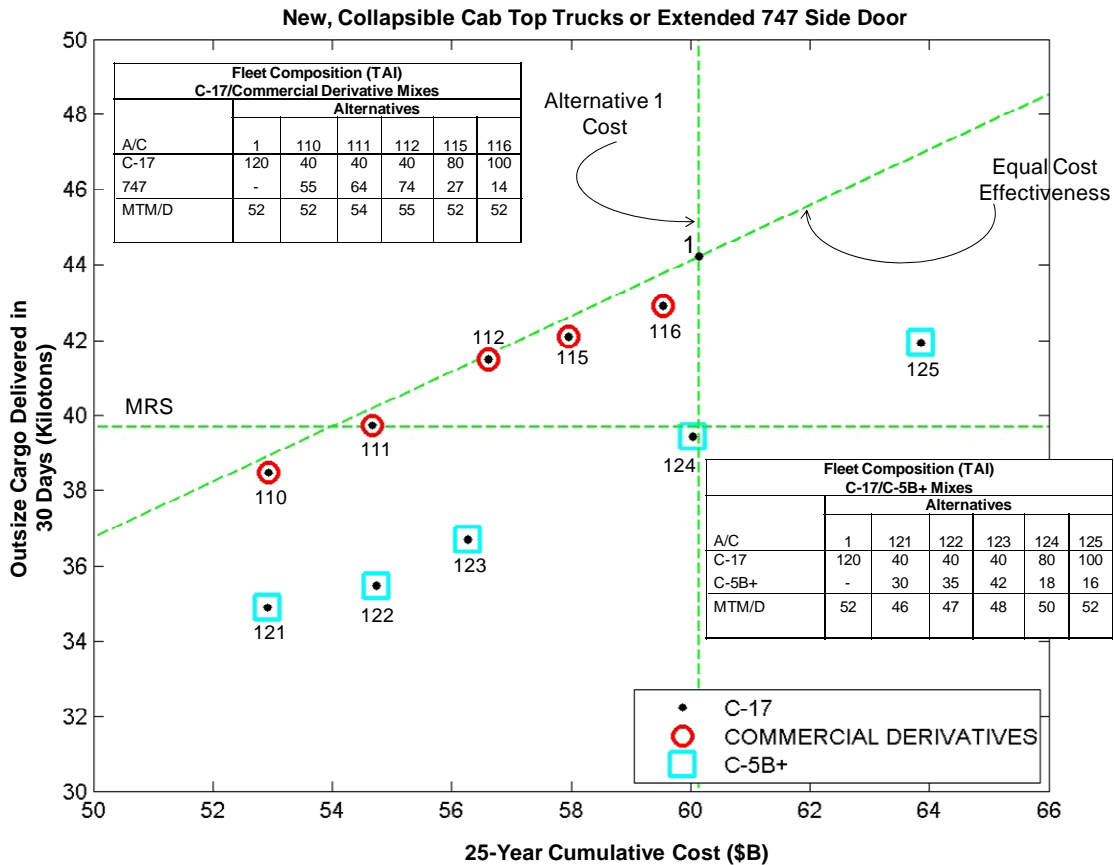


Figure 8. Cost and Effectiveness Comparisons of New Alternatives

Some decision makers felt that a fleet size capable of generating a transportation capability of 52 MTM/D was too small. After all, the C-17 program had been born when the requirement was 66 MTM/D. As previous charts have shown, all alternatives fell significantly below the effectiveness demanded by the TPFDD line. Thus IDA was subsequently asked to examine the possibility of alternatives that generated higher MTM/D. Figure 9 summarizes the results of two different sets of alternatives: those with 52 MTM/D and those with 59 MTM/D, a value with historical roots when new airlift programs were initiated several years prior to this study period. The 59 MTM/D alternatives are all identified with the prefix “E” on the chart. It is interesting that the same frontier line observed earlier still carries over to these higher MTM/D cases.

Namely, all alternatives fall on or below the equal cost-effectiveness ratio line that runs through Alternative 1, within statistical uncertainty.³²

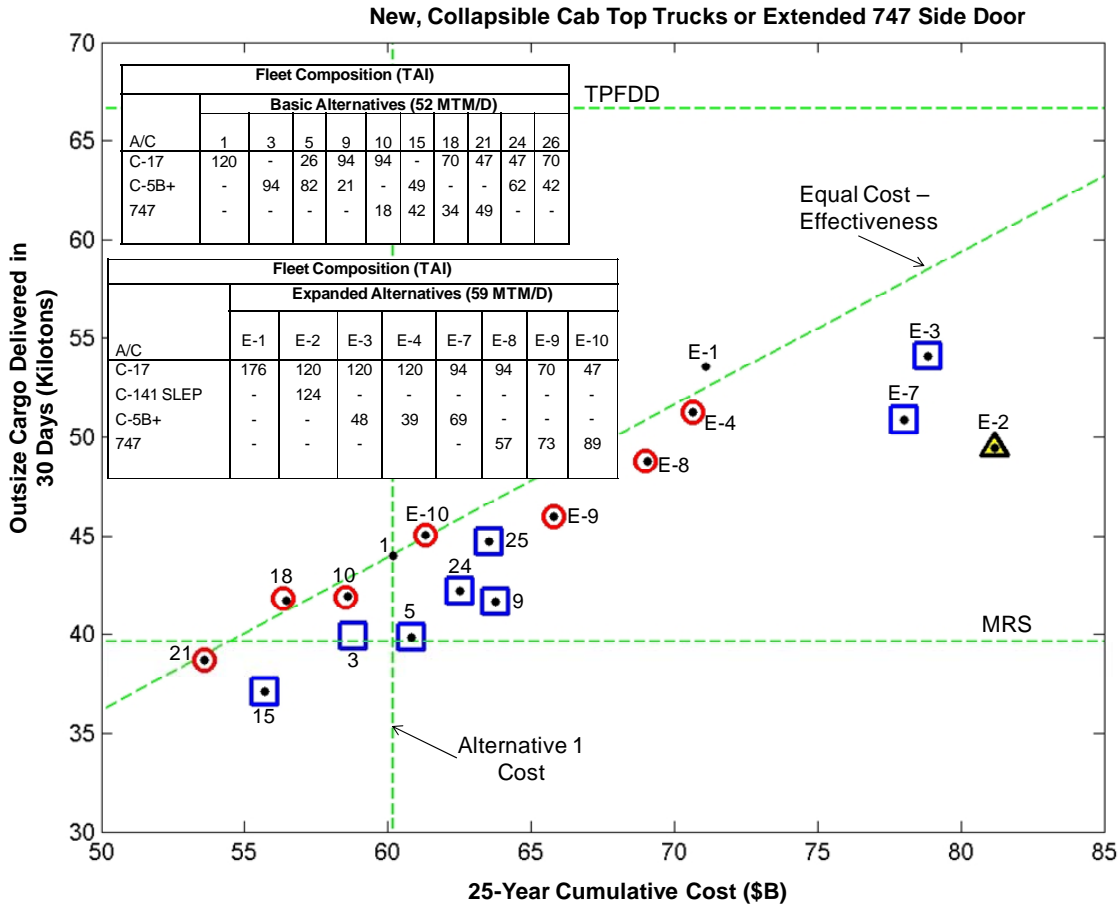


Figure 9. Comparison of 59 MTM/D Expanded Capacity Alternatives with the Nominal 52 MTM/D Alternatives

C. Another Scenario: LRC-Short

The foregoing analyses assumed two different MRCs. However, there may be a need for forces to meet lesser regional contingencies (LRCs). The one selected for analysis was LRC-Short, involving sustained airlift to a relatively close theater (short range, hence the name Short), following an airdrop on Day 1. The baseline assumption is that all major airbases are seized by the airdropped troops and are available for

³² The use of cost-effectiveness ratios can be misleading unless the analyses are constructed under the same budget or same effectiveness frameworks [Melese, *EEoA*, op. cit., pp. 17-20, 2010]. In this case, the use of a common effectiveness framework, i.e., same MTM/D, confers meaning.

operations. Since the MRC cases showed MOG to be a critical input, the study also examined an excursion in which 50 percent of these same airbases are unavailable.

Figure 10 summarizes the results for LRC-Short. In this case, the effectiveness measure is the total cargo delivered (not just outside) in 8 days after the initial first-day airdrop. The 25-year total cost is the same as before. The 4-day TPFDD is used for purposes of comparison, although it has not been achieved even in 8 days by any alternative.

A comparison of the amount of cargo delivered for robust (baseline) MOG conditions and for a 50-percent loss in airfields shows the same general results that appeared before in the case of the MRC scenarios: alternatives with C-5s and 747s suffer a greater reduction in capability than those with C-17s when MOG is constrained. Those with the C-5B+ seem to suffer the greatest reductions.

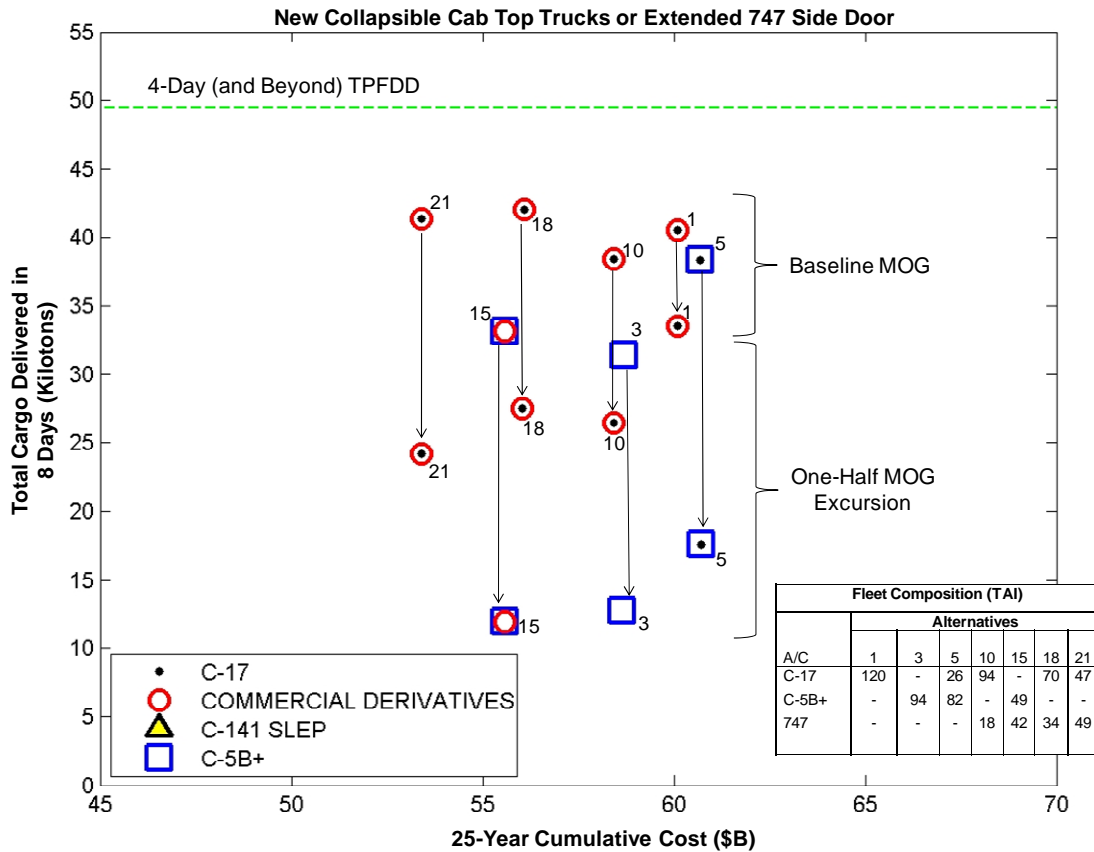


Figure 10. Comparisons of Alternatives in LRC-Short

D. Cost Excursions

All the sensitivity analysis excursions discussed to this point principally focused on different effectiveness assumptions including scenarios, use rates, MOG, and the composition of alternatives. The cost estimates included in the study represented the best estimates generated by the cost team. While there are many uncertainties in the details, one that became obvious to the DAB was the yearly acquisition cost assumptions for each of the alternatives.

In the cost estimates shown earlier, each alternative was developed imputing the costs of efficient production-lines, independent of annual budgets. A more realistic approach would be to constrain all annual expenses over the 6-year period of the Future Years Defense Program (FYDP) to be no greater than those associated with the C-17 program itself, as expressed in the then-current C-17 Selected Acquisition Report (SAR). This would force many of the alternatives analyzed to stretch their acquisition profiles to remain under the spending cap.³³ To test how stretching out programs and the concomitant increases in acquisition costs would influence the outcome of the analyses, a sensitivity analysis was conducted. The results for selected alternatives are in Figure 11.

³³ The EEOA makes a clear distinction between the “lifecycle costs” or “price” of an alternative, its operational effectiveness (schedule and performance), and the resources (funding or budget) likely to be available for the overall program (p. 2).

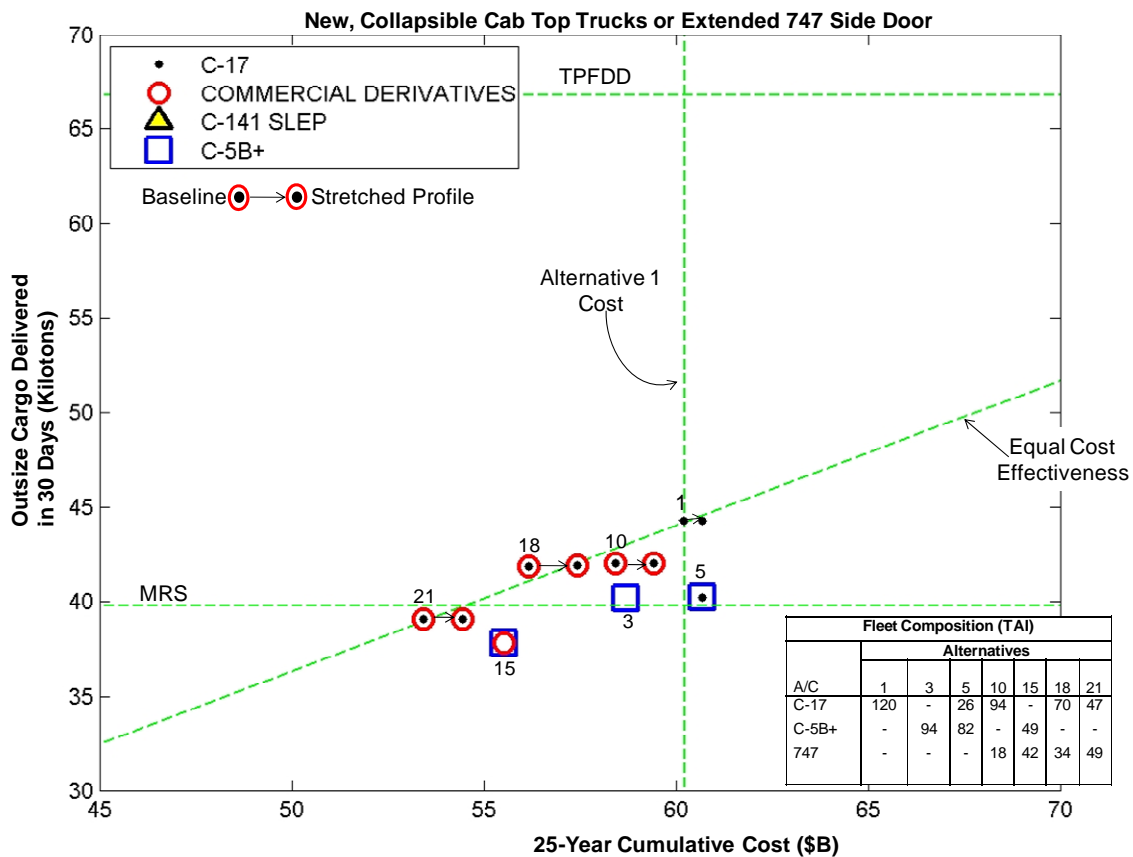


Figure 11. Effect of FYDP Stretch-Out on Alternatives in MRC

As Figure 11 shows, the alternatives with mixes of C-17 and commercial derivatives all increase in total cost by about \$1-2 billion. Alternative 1 also increases slightly, since the cost team did not feel that the full 120 C-17 program could stay within the cost caps of the C-17 acquisition budget. The C-5B+ alternatives do not increase in cost in this excursion, since the start-up time for the new C-5 line takes several years and removes it from competition with other aircraft types in those alternatives.

As the figure shows, even though total lifetime costs do increase if the SAR serves to limit near-term funding, the C-17/commercial-derivatives cases still dominate the cost-effectiveness comparisons.

The relative contribution from the different cost elements can be seen in Figure 12. Figure 12 also illustrates the effect of different discounting assumptions on the cost estimates. Two of the alternatives are compared in Figure 12: Alternative 1 with 120 C-17s, and Alternative 2 with no C-17s but with 263 C-141 SLEP/C-Ys instead. Figure 12 also illustrates the effect of discounting through two examples: no discounting, and the

baseline OMB-directed 4.5 percent discounting. Note the large effect of O&S costs that accrue over the 25-year life-cycle cost period for all alternatives. Discounting emphasizes near-term costs, which has a bigger effect (reduction) on long-term O&S cost estimates than on near-term acquisition cost estimates.

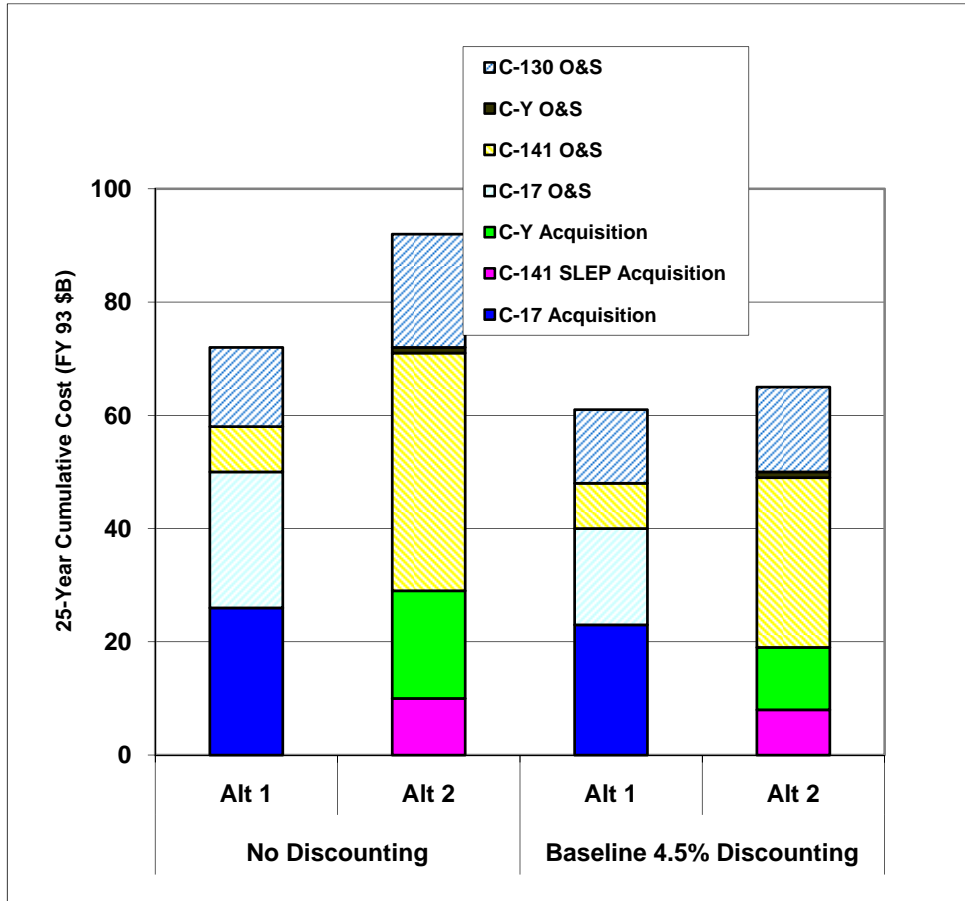


Figure 12. Effect of Discount Rates on Two Alternatives

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6. Reported Findings

The C-17 COEA reported the following findings, briefed to the DAB in November 1993. The findings incorporated several items reported in earlier briefings and added the sensitivity analysis excursions discussed in the previous section.

- The cost and performance of the planned C-17 alternative (#1) make it the preferred military airlifter. It is more resistant to airfield constraints (i.e., MOG) than the new C-5 and possesses a higher use rate. It is far superior in both cost and effectiveness to the C-141 SLEP.
- The next most attractive alternatives after the 120 C-17s would be mixes of C-17s and modified commercial aircraft with specially reinforced floors, and some concession for the height of new FMTV army trucks, such as wider side doors.
- If new Army trucks cannot be loaded on commercial derivatives, then the next most attractive alternatives to the 120 C-17 program would be mixes of C-17s and new C-5s.

A mix of commercial derivatives and some number of C-17s less than 120 became a serious contender to Alternative 1, the original/baseline 120 C-17 program, reducing the total cost. The study did caution that overall effectiveness could be compromised. The introduction of 747s would provide fewer aircraft for certain unique military operations such as airdrops, deliveries to remote and inadequate airfields, low altitude parachute extractions, and rapid off-loading of cargo while the airlifter is still moving down the runway (combat off-loading) with engines running. It also provided a fleet less well adaptable to limited MOG conditions. Nonetheless, its lower cost recommended it for more detailed consideration.

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7. The Rest of the Story: Ex-Post Decisions Subsequent to the Analysis

A. Decisions 1994-1995

The decision ultimately reached by the DAB in January 1994 was to place a cap on C-17 production at the 40 already under development and to establish a non-developmental airlift aircraft (NDAA) program to investigate the feasibility of acquiring and operating militarized commercial derivatives in lieu of C-17s. The analyses presented in the IDA study had a major impact. After the results of the NDAA study were available, a new decision would be made. The DoD also reached a financial settlement in 1994 with McDonnell Douglas over past claims, setting the stage for a clean slate and new decisions.

From February through May of 1994, the IDA analysts responsible for the study briefed Congressional staffers and the Government Accountability Office (GAO). In its report that same year,³⁴ the GAO favored the acquisition of 40 C-17s and 64 747s over the 120 C-17 case. In May 1994, the DoD formally released the IDA report to Congress in response to the initial congressional request for such a study.

In 1995 many events converged that influenced the ultimate decision. In January of that year, the C-17 reached its initial operational capability (IOC). It subsequently underwent formal reliability, maintainability, and availability (RM&A) testing in July, achieving the performance needed to support a 15.2 hours/year use rate. During the same year, the Air Mobility Command initiated, per OSD guidance, a study of NDAA options called the Strategic Airlift Force Mix Analysis (SAFMA).³⁵ The aim of that study was to determine the minimum number of C-17s acceptable and to provide industry with an opportunity to make proposals for NDAA competitors to the C-17. The request for proposals was released in March. Meantime, also in March, the Joint Staff and OSD released a new mobility requirements study to replace the older MRS used in the IDA C-17 COEA report. The new study was titled the Mobility Requirements Study Bottom Up Review Update (MRS BURU)³⁶ and established new cargo and troop lift requirements for the MRCs. This study provided the new delivery requirements for the SAFMA. SAFMA used essentially the same MASS model (updated) that IDA used 2 years earlier.

³⁴ *Airlift Requirements: Commercial Freighters Can Help Meet Requirements at Greatly Reduced Cost*, Government Accountability Office, GAO/NSIAD 94-209, July 1994.

³⁵ *Strategic Airlift Force Mix Analysis*, Air Mobility Command, 1995.

³⁶ *Mobility Requirements Study Bottom Up Review Update*, Office of the Secretary of Defense, 1995.

AMC conducted the SAFMA using C-17s and Boeing 747s, the only contractor-proposed alternative. Data from the C-17 RM&A as well as new lower price estimates from McDonnell Douglas for the C-17 were available. IDA played an auxiliary role in this process, providing an independent validation of the models and approaches taken, although the actual analyses were conducted by AMC as part of a proprietary source selection process.

In November 1995, the results of the RM&A and the SAFMA were presented to the DAB. At this meeting, it was decided to proceed with the 120 C-17 program and not acquire any militarized 747s.

Thus, in a lengthy set of decisions, OSD arrived back at the position it started from 2 years before: buy 120 C-17s. *However, something very significant had happened in the interim: the introduction of competition had compelled the C-17 manufacturer to reduce costs and improve performance in order to prevail. By revealing feasible alternatives, the IDA cost-effectiveness study contributed to what economists call a “contestable market.”*³⁷ *The threat of the entry of new competitors was sufficient to reveal efficiencies that reduced aircraft costs. The new restructured C-17 program was several billion dollars lower in total cost than the older one, a significant savings for the Government and its taxpayers.*

B. Decisions Post 1995

The C-17 program has prospered since the days of these early analyses. It has grown to nearly twice the size of the program discussed here and is now larger than the size of the original fleet envisioned in 1983 of 210 aircraft. Table 6 reports subsequent decisions made to augment the C-17 fleet from the original 120 aircraft to 223.

³⁷ William J. Baumol, John C. Panzar, and Robert D. Willig, “Contestable Markets: An Uprising in the Theory of Industry Structure: Reply,” *Amer. Economic Review* **73** (3), pp. 492-496, 1983.

Table 6. Summary of C-17 Acquisition Decisions through FY 2010

2002: 60 additional C-17s bought.....	Total 180
2005: OSD <i>Mobility Capabilities Study</i> ³⁸ shows no additional C-17s beyond 180 are needed.	
2007: 10 additional C-17s bought	Total 190
2008: 15 additional C-17s bought	Total 205
2009: IDA <i>Study on Size and Mix of Airlift Force</i> ³⁹ shows no additional C-17s beyond 205 are needed.	
2009: SecDef declares that no more C-17s are needed.	
2009: 8 additional C-17s bought	Total 213
2010: OSD/USTRANSCOM <i>Mobility Capabilities & Requirements Study</i> ⁴⁰ shows no additional C-17s beyond 213 are needed.	
2010: 10 additional C-17s to be bought	Total 223
(production through 2013)	
2010: Quadrennial Defense Review ⁴¹ indicates that no more C-17s are needed.	
2010: Subcommittee of Senate Homeland Security & Governmental Affairs hearings ⁴² on C-17 requirements, also affirmed that no additional C-17s are needed.	
2011: No additional C-17s in budget.	

The impetus for adding C-17s beyond the 120 initially approved came after the attacks on September 11, 2001, and the decision to strike back at al-Qaeda and the Taliban in Afghanistan. The austerity of Afghanistan and nearby airfields as well as those in Iraq supported the requests for additional C-17s.

Additional studies have continued to the present time, all addressing the issue of how many C-17s (and other airlift aircraft) are needed. Table 6 also summarizes the conclusions reached in those studies. The programmed number in 2011 is 223 C-17s.

³⁸ *Mobility Capabilities Study*, Office of the Secretary of Defense, 2005.

³⁹ William L. Greer, et al., *Study on Size and Mix of Airlift Force*, IDA Paper P-4425, Institute for Defense Analyses, February 2009.

⁴⁰ *Mobility Capabilities and Requirements Study-2016*, Office of the Secretary of Defense, 2010.

⁴¹ *Quadrennial Defense Review*, Office of the Secretary of Defense, 2010.

⁴² *Hearing on the Cost-Effectiveness of Procuring Weapon Systems in Excess of Requirements*, Senate Homeland Security and Governmental Affairs Subcommittee on Federal Financial Management, Government Information, Federal Services, and International Security, July 2010.

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8. Lessons Learned

There are several lessons to be learned from this study.

A. The Importance of an Open Process

The results were certain to be controversial to some interested parties, so it was necessary to maintain credibility and impartiality. The C-17 COEA benefited from a continuously open process, with frequent feedback and critical commentary as the study developed. The analysts were able to maintain their independence and objectivity throughout but made their results available to others as the study evolved. In this way, all parties had an opportunity to see how the results were evolving and to recommend alternative approaches, inputs, and/or sensitivities.

B. The Value of Competition

The emergence of a viable competitor to the C-17 and the willingness of decision makers to honestly consider this alternative created positive incentives for the C-17 manufacturers to meet and exceed their cost and performance objectives. Even though in the end DoD did not select the 747, its presence, looming as an alternative on the horizon, appears to have had a salutary effect on the C-17 program and the airlift capabilities of DoD. While this cannot be proven unequivocally, most observers of the decision process feel that the analysis encouraged implicit competition that may have saved the Government billions of dollars.

C. The Power of Sensitivity Analysis and Other Excursions

Every piece of data and every assumption in the analysis needs to be scrutinized to understand its effect on the conclusions. The problem must be clearly structured up-front and reviewed as the analysis proceeds from an independent and broader systems perspective to avoid overlooking important factors. Future Army trucks having trouble fitting in 747s is a good example. It is easy for analysts to become focused on the particular program – buy C-17s – while the effect of other programs that could have a profound effect – new rigid top trucks – are overlooked.

Another example is MOG. The infrastructure investments needed to improve airfield airlift capability could overwhelm the cost of the aircraft themselves. In fact an important tradeoff exists between improving airfields and lower aircraft costs, or improving aircraft so they can operate in more constrained airfields. These insights and the importance of changes in assumptions and input values can only be determined by a

robust set of alternatives and sensitivity analysis excursions. Not all of these can be foreseen at the start of a study, but time and resources to conduct sensitivity analyses must be included in the overall study plan.

Appendix A

Additional Details on Loading and Transportation Models and Acquisition Costs

The main models used for estimating how much cargo and how many passengers were delivered were ALM, MASS/AFM, and ACAS. These models are summarized briefly to give a sense of the assumptions used in the analysis.¹

A. Airlift Loading Model (ALM)

The ALM was used to determine the average cargo payload carried by each aircraft in the fleet. The MASS/AFM then used this result to simulate the transport. ALM used cargo from the entire TPFDD for these estimates. The cargo was differentiated according to 26 different categories called “commodities.” Each commodity could contain vehicles, pallets, and passengers. Examples include Air Force aircraft, Air Force support, Marine prepositioning, armored infantry, mechanized infantry, Combat Service Support (CSS), engineer, CSS medical, and ammunition. Pallets were of a common size and weight, but weight and dimensions differentiated the vehicles from one another. The sequence in which the aircraft were to be loaded had to be specified, as well as aircraft cargo storage dimensions, cargo door opening sizes, number of passenger seats, and maximum payload allowable by weight. The ALM then used user-selected rules for loading the aircraft (e.g., vehicles were sorted according to width, with the widest loaded first and pallets last for a given commodity code). Loading stopped when the weight limit was reached, or, more commonly, when cargo fully filled the cargo space in the aircraft. Most airlifters reached volume constraints before they reached weight constraints, as they do in real life. From these simulations, the analysts calculated the average payload carried by each aircraft type, detailed by commodity type, and by the cargo classes of out/over/bulk/PAX.

While ALM does an excellent job of estimating optimum average cargo loads, these loads are rarely achieved in actual operations. Differences in actual units, in the way cargo arrives at a port of debarkation and in the proficiency of the cargo loaders, often results in actual loads falling slightly below those predicted by the model. These

¹ These models have subsequently evolved to more advanced versions, but it is important to know how they approached the transportation problem in 1993.

inefficiencies can sometimes be noted during real exercises and operations. By establishing community agreement at the outset on the use of the same methodology for all aircraft, the study treated each alternative in a consistent manner.

B. MASS/AFM

The MASS/AFM was a large Monte Carlo simulation² that scheduled and executed each airlift mission by tail number. It incorporated a great deal of realism, such as specific routes used, airbases with MOG limitations, times for loading and off-loading, and crew duty days. It used the ALM loading results along with the nature of the TPFDD cargo and PAX at individual airbases to load the cargo. Only that part of the TPFDD available at a specific base on a specific day (plus any undelivered leftover cargo from previous days) was available for loading. User-selected priorities for loading out/over/bulk/PAX classes were considered for each airlifter. The Air Mobility Command analysts ran the simulations at Scott AFB with inputs from IDA. The primary outputs for the study were tons delivered per day by commodity type and class (out/over/bulk/PAX).

As with ALM, MASS/AFM may produce results that would be viewed as optimistic in real operations. For example, the inefficiencies that often exist with high levels of congestion at en route bases are not included (although MOG does limit the number of aircraft being serviced at the base). *Again, the decision makers and study team need to make reasonable assumptions and focus on the higher objectives of the study. If an assumption appears to have the potential for making a large impact on the results, sensitivity analysis may be required.*

C. Airlift Cycle Analysis Spreadsheet (ACAS)

The ACAS model was a simplified approximation to the analyses produced by MASS/AFM and was used to conduct the large number of excursions needed in the study. It used aggregate data and aggregate MOG values, calibrated against MASS/AFM to give confidence, for these numerous excursions.

D. Acquisition Costs

The study used the Air Force C-17 procurement schedule, with a maximum acquisition of 16 per year. It also used multi-year procurement arrangements to reduce uncertainty and cost. From the historical cost data for the C-17, IDA derived a cost learning curve to predict future costs for C-17s as more manufacturing experience is

² MASS/AFM has now been replaced at AMC by the Air Mobility Operations Model (AMOS).

attained. This stage was a delicate one, requiring the cooperation of McDonnell Douglas to supply competition-sensitive information with the understanding that only aggregate levels of detail would appear in the final report. Publishing a second proprietary document for use by the Government, while using the aggregate results in the COEA, attained the desired balance between a need for discussion of the methodology and a display of the aggregate results and the need to protect the legitimate interests of the source. Appropriate adjustments to historical trends were added as needed, such as the cost for extra weight to strengthen the wings and higher costs associated with more realistic engine estimates for all lots after the first ones. During the study, the C-17 Program Office disagreed strongly with the IDA estimates. The basic disagreement arose from different assumptions about the learning curves. IDA used data for the entire C-17 program, adjusting the first few low-cost lots for their later prices while the Program Office used later prices only. IDA estimated the full C-17 program acquisition cost at approximately \$23 billion, about \$3 billion over the Program Office estimate. In the end, the higher-cost IDA results were used in the report, with a comparison to the Program Office estimates included as an excursion.

At the time the study was conducted, three test C-17s (not counted as part of the 120) had been produced, an additional six production aircraft were undergoing operational test and evaluation (OT&E), and a total of 17 production aircraft had either been delivered or were in various stages of assembly at the Long Beach McDonnell Douglas facility. Moreover, aircraft through production number 26 were under contract with long-lead funding. Failing to buy 26 production C-17s would have incurred a cost penalty by the U.S. Government for a breach of contract. Thus alternatives with fewer than 26 C-17s were levied an additional cost associated with breaking the contract (\$1.5 billion).

Lockheed Martin Aeronautical Systems provided cost estimates for restarting the C-5 line as well as for refurbishing the C-141s in a C-141 SLEP. Again, only aggregate data appeared in the final report, with company-sensitive data relegated to the proprietary Government-use document. IDA used these data and other historical Lockheed data and made adjustments as required. Examples of adjustments include adding hush kits to dampen the sound of the engines and extra material to the fuselage. A recently completed SAB had recommended that the weep hole cracks in then-current C-141s could be repaired and their life extended to 45,000 flying hours. When the C-141 reached its 45,000-flying-hour life limit, the SAB determined it had to be replaced, and the cost of a new C-Y replacement was imposed to include a \$3.5 billion development cost.

For the C-5 restart, a cost to restart the line was imposed on any alternatives using C-5B+ aircraft. IDA estimated that \$750 million would be needed to restart the line in Marietta, GA. New C-5 engines were used to reduce noise levels below those mandated by the FAA.

Boeing supplied basic cost data for the 747 and 767 commercial derivative aircraft. Production rates from 6 to 12 per year for military acquisition were used, based on Boeing production capabilities and competing markets for new 747 or 767 aircraft. An additional 20 percent of the acquisition price was added to account for reinforced floors and rollers and widened side doors, for an estimate of \$155 million for the militarized 747 and \$88 million for the militarized 767. Since these lines are open, no developmental costs were imposed.

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Appendix C

Glossary

ACAS	Airlift Cycle Analysis Spreadsheet
AFB	Air Force Base
AFM	Airlift Flow Model
AFSAA	Air Force Studies and Analysis Agency
ALM	Airlift Loading Model
AMC	Air Mobility Command
AMOS	Air Mobility Operations Model
AoA	Analysis of Alternatives
CAIG	Cost Analysis Improvement Group
CAPE	Cost Assessment and Program Evaluation (formerly PA&E)
CC	Conventional Campaign
COEA	Cost and Operational Effectiveness Analysis
CORE	Cost-Oriented Resource Estimating
CRAF	Civil Reserve Air Fleet
CSS	Combat Service Support
C-X	Cargo Experimental
DAB	Defense Acquisition Board
DoD	Department of Defense
EEoA	Economic Evaluation of Alternatives
FAA	Federal Aviation Administration
FFRDC	Federally Funded Research and Development Center
FMTV	Family of Medium Tactical Vehicles

FYDP	Future Years Defense Program
FY	Fiscal Year
GAO	Government Accountability Office
HMMWV	High-Mobility, Multipurpose Wheeled Vehicle
IDA	Institute for Defense Analyses
IOC	Initial Operational Capability
IW	Irregular Warfare
JROC	Joint Requirements Oversight Council
LRC	Lesser Regional Contingency
MASS	Mobility Analysis Support System
MCO	Major Combat Operation
MHE	materiel handling equipment
MOG	Maximum on Ground
MRC	Major Regional Contingency
MRS	Mobility Requirements Study
MRS BURU	Mobility Requirements Study Bottom Up Review Update
MTM/D	million ton-miles per day
NDAA	Non-Developmental Airlift Aircraft
O&S	operations and support
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
OUSD (A&T)	Office of the Under Secretary of Defense (Acquisition and Technology)
PA&E	Program Analysis and Evaluation (now renamed CAPE)
PAA	primary authorized aircraft

PAX	passengers
PDM	Programmed Depot Maintenance
RFP	request for proposal
RM&A	Reliability, Maintainability, and Availability
SAB	Scientific Advisory Board
SAFMA	Strategic Airlift Force Mix Analysis
SAR	Selected Acquisition Report
SecDef	Secretary of Defense
SLEP	Service Life Extension Program
SSC	Strategic Systems Committee
SSSP	Steady State Security Posture
TAI	total aircraft inventory
TPFDD	Time-Phased Force Deployment Data
USTRANSCOM	U.S. Transportation Command

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Biography for William L. Greer

Dr. Greer is Assistant Director of the System Evaluation Division at the Institute for Defense Analyses (IDA), a non-profit Federally Funded Research and Development Center in Alexandria, VA. He specializes in air mobility cost and effectiveness analyses and has been involved in several recent large studies that address strategic and tactical airlift demands and the next-generation airborne tanker. Other work includes analyses of the Joint Strike Fighter, USAF long-range bomber force size requirements, ballistic missile defenses, and naval surface forces. Prior to working at IDA, Dr. Greer worked at the Office of the Secretary of Defense in the Pentagon, the Center for Naval Analyses in Alexandria, VA, and the Chemistry Department of George Mason University in Fairfax, VA. He has a PhD in chemical physics from the University of Chicago and a BA in chemistry from Vanderbilt University.

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