Skip all front matter: Jump to Page 1

Reducing Long-Term Costs While Preserving a Robust Strategic Airlift Fleet

Options for the Current Fleet and Next-Generation Aircraft

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Summary

This document presents the results of a cost-effectiveness analysis to determine the best way to recapitalize the USAF intertheater (strategic) airlift fleet. The USAF intertheater airlift fleet consists of C-5s and C-17As. As of 2010, there were 111 C-5s in the inventory; as of 2012, there will be 221 C-17As.[1] Three versions of the C-5 were produced: the C-5A; C-5B; and two special-mission aircraft, C-5Cs.[2] The C-5 fleet is currently undergoing a modernization program to upgrade its avionics, engines, and other components. After an aircraft undergoes this Reliability Enhancement and Reengine Program (RERP), it is designated a C-5M. One C-5A and seven C-5Bs have undergone this upgrade and are now so designated. As of fall 2010, the USAF had 59 C-5As,[3] 42 C-5Bs, two C-5Cs, and eight C-5Ms. The current USAF plan for the

[1] U.S. Department of Defense and U.S. Transportation Command, "Mobility Capabilities and Requirements Study: Executive Summary," 2010. There has been one C-17A hull loss, and one C-17A operates as part of the NATO Strategic Airlift Capability (SAC) bringing the total aircraft in inventory down from 223 to 221. (Pacific Air Forces, "Excutive Summary: Aircraft Accident Investigation, C-17A, T/N 00-0173," Joint Base Elmendorf-Richardson, Alaska, July 28, 2010; the Ministry of Defence of the Republic of Bulgaria, et al., *Memorandum of Understanding Concerning Strategic Airlift Capabillity*, September 2008.)

[2] The C-5Cs were built early in the production run of the C-5As. For our purposes, we considered them equivalent to C-5As and therefore simply count them as C-5As before they are RERPed and as C-5Ms after they are RERPed.

[3] The National Defense Authorization Act for Fiscal Year 2012 authorized retirement of additional aircraft to reduce the C-5A fleet to 27 (Public Law 112-81, National Defense Authorization Act for Fiscal Year 2012, December 31, 2011), and the Air Force is seeking to retire all C-5As ("Air Force Requests C-5 Retirement Authority, Predicts $1 Billion in Savings," *Inside Defense*, March 16, 2012). In light of these developments and the ongoing debate, we conducted a sensitivity analysis to look at this very issue. We found that the results

C-5 fleet is to implement the RERP upgrade on all the C-5Bs and to retire 22 of the C-5As. Note that a RERP does not affect the service life of the aircraft. The resulting fleet will consist of 37 C-5As and 52 C-5Ms (one of which is an upgraded C-5A, two of which are upgraded C-5Cs, and the rest are upgraded C-5Bs). This fleet is sufficient to meet the demands of Mobility Capabilities and Requirements Study 2016 (MCRS-16) Case 1.

This reasearch was undertaken because of concerns that much of the current fleet is reaching the end of its service life in the next few decades and concerns about a budgetary spike that would result from the need to recapitalize. For nearly a decade, as a result of overseas contingency operations, the C-17As have flown significantly more hours than they did before September 11, 2001. The availability of the C-5s—especially the C-5As—has been an ongoing and significant problem affecting the capability of the airlift fleet. In future years, the aging of the current fleet will mean that some recapitalization actions will have to be taken.

We examined a broad range of potential aircraft alternatives and considered a number of permutations of USAF plans for the current fleet, including a reduced requirement and retirement of all C-5As, to determine how best to recapitalize this fleet. The analysis included both the net present value life-cycle cost (NPVLCC) and annual funding profiles of the options considered. Conclusions and recommendations are based on both of these measures.

Current Fleet Retirement Schedule

We projected the retirement schedule for the current fleet to determine when new aircraft would need to be added to retain the required capability.[4] The baseline retirement schedule was determined using each

presented in the document are not sensitive to C-5A retirements, and the overall conclusions are independent of these retirements.

4 Two Air Force Materiel Command organizations supplied equivalent flight hours (EFH) data to us: Aeronautical Systems Center's C-17 Engineering Branch provided EFH for each

aircraft's current accumulated flight hours, their average severity, and a projection of future hours and severity for every aircraft to determine when that aircraft will reach a life-limiting constraint due to structural fatigue. For the C-5, different aircraft have different life-limiting components. Eight components are tracked to determine which component will be the life-limiter and when each C-5 will need to be grounded (or flight restrictions need to be imposed) based on the current flight limits.[5] In contrast, all C-17As have the same two potential structural problems: the aft fuselage and the upper wing skin. The problem with the aft fuselage of the C-17A is only a modest concern and will likely require a minimal fix that involves cold working of the rivet holes and other fairly well-understood procedures. As a result, the upper wing skin is considered the life-limiting component of the C-17A.

We projected the remaining years of life for each airframe to determine the number of retirements that could be expected each year through the life of the current fleet. Figure S.1 shows our projections through 2060. The figure shows that the C-17As are the first aircraft to reach end of life, starting in the mid-2030s. The C-5Ms then begin to reach their life limit and will be retired beginning at the end of the drawdown of the C-17A fleet. Since the C-5As are being flown just over 300 hours per year, these aircraft will not reach their structural life-limit for many years.[6]

We used this fleet drawdown as the baseline for our analysis. Permutations of this schedule, including different C-5A retirement dates, C-17A production rates, and RERP plans for C-5A and C-5B, were used to explore different cases to understand how the answer might

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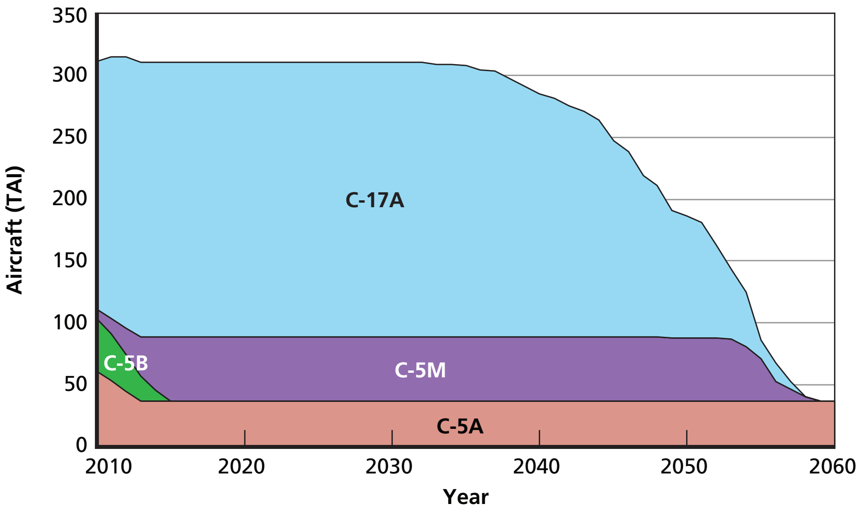
tail and other relevant information on the C-17A fleet (EFH data current as of June 30, 2010); and Warner Robins Air Logistics Center provided EFH data for each tail and other relevant information on the C-5 fleet (EFH data current as of October 26, 2010).

5 The eight components tracked for the C-5 include total pressure cycles, the upper aft crown, the inner wing upper, the inner wing lower, the outer wing upper, the outer wing lower, the horizontal tail, and the vertical tail.

6 This chart shows only life limits that are due to structural fatigue. It is likely that the C-5A will be retired for a reason other than structural fatigue at some point before the aircraft reach their structural limit, unless upgrades are done and, as a result, the C-5A begins to fly significantly more hours.

Figure S.1
Projected Retirement Profile of Current Fleet



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change under different circumstances and to understand the robustness of the answers.

Aircraft Alternatives and Fleet Options

We examined a broad range of potential aircraft alternatives. These represent a broad spectrum of aircraft types, including current-inventory aircraft, commercial-derivative aircraft, foreign military aircraft, and future-design aircraft incorporating a range of technology options and other fleet derivative aircraft. We considered 15 aircraft alternatives, shown in Table S.1. In addition to the aircraft shown in the table, we also considered a service-life extension program (SLEP) for the C-17A.

These 15 aircraft included three current-inventory aircraft: the C-5A/B, C-5M, and C-17A. For the purposes of the effectiveness analysis, we assumed that the C-5A and C-5B have the same flight characteristics (but different availabilities). A C-17A derivative aircraft known as the C-17FE was also analyzed. The C-17FE is essentially

Table S.1
Aircraft Alternatives Considered

Current Inventory[a]	Commercial Derivative	Foreign Military	Future Design	Current Technology New Design[b]	Other
C-5A/B (Lockheed Martin)	C-767 (Boeing 767-300F)	A400M (EADS)	BWB-100++ (Boeing very advanced large blended-wing body)	C-84X (Identical to C-5M, but new design for costing)	C-17FE (Boeing C-17A narrow-body derivative)
C-5M (Lockheed Martin)	C-777 (Boeing 777F)	An-124 (Antonov)	BWB-100 (Boeing very advanced medium blended-wing body)	C-59X (Identical to C-17A, but new design for costing)	
C-17A (Boeing)	C-747 (Boeing 747-8F)	IL-76MF (Ilyushin)	SBW-75 (Lockheed Martin medium technology box wing)		

[a] C-5C aircraft are analyzed and counted as C-5A aircraft in this study.

[b] The C-59X and the C-84X have the same performance, weight, and characteristics of the C-17A and C-5M, respectively. These aircraft were considered new designs for costing meaning that a full R&D program would need to be executed without reliance on heritage designs.

a narrow-body C-17A with increased fuel efficiency and better short- and soft-field capabilities. The analysis considered three commercial-derivative freighter aircraft: the 767-300F, the Boeing 777, and the Boeing 747-8F. These aircraft are designated the C-767, C-777, and C-747, respectively, to highlight the fact that they are militarized aircraft based on their respective commercial counterparts. We also analyzed three foreign military aircraft: the European Aeronautic Defence and Space Company's A400M, the Antonov An-124-100M-150, and the Ilyushin Il-76MF. The An-124-100M-150 (denoted simply as An-124 in the table) is a commercial version of the An-124 fitted with Western avionics and is most similar to the C-5. The Il-76MF is a stretched variant of the Il-76 and most closely resembles the Boeing C-17A. We considered three new future-design aircraft: two blended-wing body (BWB) options from Boeing (the BWB-100 and the BWB-100++) and the Lockheed SBW-75 box-wing aircraft. These aircraft represent varying levels of technology—the BWBs represent a significant technological leap, while the SBW-75 represents a more modest technological advancement.

We also considered current-technology aircraft with the C-59X and the C-84X that have the same performance, weight, and characteristics as the C-17A and C-5M, respectively.[7] For the purposes of costing, the C-59X and C-84X were considered new designs, meaning that a full research and development program would need to be executed that would not rely on heritage designs. As a result, the learning curve would start at the beginning.

These aircraft alternatives represent a wide range of sizes, with maximum gross takeoff weights ranging from just over 300,000 lbs to nearly 1,000,000 lbs. Some of these aircraft alternatives cannot carry all the cargo that the current fleet of C-5s and C-17As can carry, specifically, what is commonly referred to as oversized and outsized cargo.[8]

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7 These options were developed for this study and the designation is simply based on maximum gross weight.

8 In this document, the term *oversized and outsized* is defined relative to a particular alternative. Specifically, for each alternative that is not capable of carrying all the cargo, all the cargo that cannot fit on that alternative is considered to be oversized and outsized. This study does

Examples of this type of cargo include helicopters; cranes; howitzers; 40-foot containers; low-bed semitrailers; and construction equipment, such as tractor scrapers, excavators, and graders.[9] Therefore, we considered both single-aircraft fleets and mixed-fleet options. The aircraft alternatives that cannot carry all the cargo must be paired with other aircraft to carry out the full requirement and therefore must be part of a mixed fleet. Other aircraft are capable of transporting all the cargo. These aircraft could be part of a mixed aircraft fleet or single-aircraft fleet. We examined these alternative fleets through a range of potential fleet retirement schedules and changes to the current plan, including extending C-17A production beyond 2012 and changes in the C-5 RERP program.

Methodology

The methodology we used was broadly similar to that for past recapitalization studies RAND Project AIR FORCE conducted for USAF.[10] This methodology had four major analytical pieces:

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not impose an artificial definition of this term, and each alternative is allowed to carry all the cargo that can fit in it.

[9] MCRS-16 examined the entire mobility problem and therefore moved much of the larger and heavier equipment by sea. The current study examines only the items that MCRS-16 identified as needing to move by air.

[10] We first evaluated options to recapitalize the USAF aerial refueling aircraft in the KC-135 Recapitalization Analysis of Alternatives, completed in early 2006. The results of that study were that the total cost of maintaining aerial refueling capability is insensitive to the timing of recapitalization and that, therefore, decisions about that timing should be made on other grounds, such as technical risk, some extra capabilities associated with new tankers, and the tightness of the overall U.S. Department of Defense budget in different times. See Michael Kennedy, Laura H. Baldwin, Michael Boito, Katherine M. Calef, James S. Chow, Joan Cornuet, Mel Eisman, Chris Fitzmartin, Jean R. Gebman, Elham Ghashghai, Jeff Hagen, Thomas Hamilton, Gregory G. Hildebrandt, Yool Kim, Robert S. Leonard, Rosalind Lewis, Elvira N. Loredo, Daniel M. Norton, David T. Orletsky, Harold Scott Perdue, Raymond A. Pyles, Timothy L. Ramey, Charles Robert Roll, Jr., William Stanley, John Stillion, Fred Timson, and John Tonkinson, *Analysis of Alternatives (AoA) for KC-135 Recapitalization: Summary Report*, Santa Monica, Calif.: RAND Corporation, MG-455-AF, December 2005, Not available to the general public; and Michael Kennedy, Laura H. Baldwin, Michael Boito,

- Determine the retirement profile of the current fleet.
- For each aircraft alternative or set of alternatives, determine the number of aircraft required to meet the strategic airlift requirement.
- Determine the yearly procurement for each alternative needed to meet the overall requirement, based on the retirement profile.
- Cost each fleet for each retirement profile.

The baseline retirement profile we used was discussed earlier. Other retirement profiles were considered as excursions.

The number of each aircraft alternative was calculated to meet the airlift requirement from the most recent requirement for organic strategic airlift, as defined in MCRS-16 Case 1.[11] In the MCRS-16 Case 1 scenarios, U.S. forces conduct two nearly simultaneous large-scale land campaigns and respond to three nearly simultaneous homeland defense consequence-management events with corresponding aerospace control levels and maritime awareness presence levels, which are concurrent with the land campaigns.

We modeled the actual cargo in this case and determined the cargo that could be carried based on the internal dimensions of each aircraft alternative. Cargo weight was used to calculate the average weight carried on each route to determine aircraft fuel burn, flight

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Katherine M. Calef, James S. Chow, Joan Cornuet, Mel Eisman, Chris Fitzmartin, Jean R. Gebman, Elham Ghashghai, Jeff Hagen, Thomas Hamilton, Gregory G. Hildebrandt, Yool Kim, Robert S. Leonard, Rosalind Lewis, Elvira N. Loredo, Daniel M. Norton, David T. Orletsky, Harold Scott Perdue, Raymond A. Pyles, Timothy L. Ramey, Charles Robert Roll, Jr., William Stanley, John Stillion, Fred Timson, and John Tonkinson, *Analysis of Alternatives (AoA) for KC-135 Recapitalization: Executive Summary*, Santa Monica, Calif.: RAND Corporation, MG-495-AF, 2006.

The second analysis was conducted as part of the USAF Intratheater Airlift Fleet Mix Analysis, completed in late 2007. The results of that study were that conducting a SLEP on the combat-delivery C-130E and C-130H1 models is less cost-effective than replacing them with new C-130J-30s with equivalent capability. See Michael Kennedy, David T. Orletsky, Anthony D. Rosello, Sean Bednarz, Katherine Comanor, Paul Dreyer, Chris Fitzmartin, Ken Munson, William Stanley, and Fred Timson, *USAF Intratheater Airlift Fleet Mix Analysis*, Santa Monica, Calif.: RAND Corporation, MG-824-AF, October 2010, Not available to the general public.

[11] U.S. Department of Defense and U.S. Transportation Command, 2010.

time, and any required refueling stops. For some aircraft alternatives, we note the amount of cargo that could not be carried because of size limitations. We computed the peak aircraft requirement for all alternatives and then computed an equivalency ratio relative to the C-5M for each aircraft alternative (for the cargo the alternative can carry) to make comparisons among aircraft straightforward. The final result for each aircraft alternative of this part of the analysis is (1) a "C-5M equivalency" and (2) a "C-5M residual." The C-5M residual is the number of C-5Ms required to carry the cargo that the alternative could not carry for size reasons.

Using our retirement profile for the current fleet and the C-5M equivalency and the C-5M residual, we could then compute the procurement profile (number of aircraft procured per year) for each alternative for the fleet to meet the Case 1 requirement for all years in this analysis. In the case of an alternative that cannot carry all cargo (i.e., has some C-5M residual), the aircraft in the current fleet will be able to carry the residual cargo for some time. However, as more retirements occur, a point will come when another large aircraft will need to be procured to carry this cargo. We then determined the total NPVLCC of each alternative fleet. The fleet that meets the requirement at the lowest cost is the most cost-effective alternative fleet. In addition, we performed a sensitivity analysis to ensure that the most cost-effective fleet is also a robust solution.

In addition to NPVLCC, we computed funding profiles for each year in the analysis. In many instances, large spikes in yearly spending may not be acceptable. We considered cases to smooth the funding profile and then determined how this affected NPVLCC.

Results

This analysis led to a series of conclusions. A highly advanced conceptual-design aircraft (specifically, a high-proportion composite BWB) is the most cost-effective option for all current fleet retirement profiles analyzed and for all sensitivities we varied. Under baseline assumptions, this option results in a cost savings of nearly $40 billion

(FY 2011) NPVLCC over a new-design C-5M aircraft. But this is a highly advanced aircraft, and its development presents a significant technological risk. Appendix C in the companion volume details this technological risk in terms of empty weight fraction, weight specific range, and percent composites.[12]

Absent a new, revolutionary aircraft design, we found that procurement of a commercial-derivative aircraft for bulk cargo followed by later procurement of an outsize and oversize cargo-capable aircraft is the most cost-effective option. This conclusion held even for the C-84X, the current-technology aircraft with the same performance as the C-5M but incorporating the cost of a full research and development program. Further, the commercial-derivative aircraft followed by the highly advanced aircraft (the BWB) is only slightly less cost-effective than procurement of a single-aircraft fleet consisting of the BWB alone. This strategy, therefore, provides a hedge against the technical risk of the advanced aircraft. The strategy also has the advantage of delaying the peak in annual procurement spending. The procurement bow wave, defined as a significant increase in annual expenditures due to research, development, test, and evaluation spending and initial procurement, can be delayed by 10 to 15 years in this case.

Continuing production of the C-17A at a low rate could delay and flatten the procurement bow wave. The idea here was to keep the production line open while getting a few aircraft per year and having the ability to increase production when required. We looked at two options: procuring two C-17As per year and procuring six C-17As per year. This option is inferior according to all measures of effectiveness we considered: Low-rate C-17A production has higher NPVLCC, earlier peak spending, and higher near-term cost.

We also considered the possibility of SLEPing the C-17A past the current service life. Since there are currently no SLEP options for this aircraft, we did the cost-effectiveness analysis parametrically, based on a 45,000 to 60,000 EFH SLEP, by determining the cost at which a SLEP would be cost-effective relative to the base case, procuring a new aircraft. SLEPing the C-17A is cost-effective if the SLEP cost is

12 Mouton et al., forthcoming.

between $35 million to 95 million, depending on the follow-on aircraft option that is available and chosen.

RERPing the C-5s is beneficial regardless of recapitalization strategy. Specifically, we found that RERPing the C-5Bs into C-5Ms is cost-effective. We also found that that RERPing a portion of the C-5A fleet would be cost-effective if the cost and resulting availability were similar to those for RERPing the C-5Bs.

To summarize these key findings:

- A highly advanced and mostly composite BWB was the most cost-effective future aircraft, although the most technologically risky.
- Absent a revolutionary new aircraft, a commercial-derivative aircraft for smaller cargo, followed later by a new-design military airlifter is the most cost-effective option.
- Keeping the C-17A line open at low production rates to reduce future research, development, test, and evaluation expenditures is not cost-effective and does not produce smooth spending profiles.
- A C-17A SLEP to extend the life from 45,000 to 60,000 EFH could be cost-effective.
- RERPing the C-5s, in particular the C-5B, is cost-effective. It may also be cost-effective to RERP a portion of the C-5A fleet.