CBO

Operating Costs of Aging Air Force Aircraft

Notes

Unless otherwise indicated, all years referred to in this report are federal fiscal years, which run from October 1 to September 30 and are designated by the calendar year in which they end.

All costs are expressed in 2016 dollars. The Congressional Budget Office used the gross domestic product price index to remove the effects of inflation.

Numbers in the text and tables may not add up to totals because of rounding.

On the cover: An F-16 aircraft undergoing maintenance at Hill Air Force Base, Utah, in May 2017. Photo by Derek Trunkey.

Contents

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Summary

As aircraft age, they generally become more expensive to operate. The rate at which those operating costs grow is important for setting operating budgets and for deciding when to replace aging systems. The faster costs grow as a system ages, the more funding will be needed to maintain existing aircraft and the sooner it becomes cost-effective to replace aging systems with new aircraft.

How Have Rates of Cost Growth Changed?

The rate of cost growth associated with the aging of Air Force aircraft has increased in recent years. A Congressional Budget Office report from August 2001 found that in the 1990s, operating costs typically grew between 1 percent and 3 percent annually in real terms (that is, after removing the effects of inflation).[1]

Recent growth in operating costs per flying hour has been greater than CBO calculated in its 2001 analysis.[2] For nine of the 13 aircraft fleets examined, CBO found real annual growth rates in operating costs per flying hour that ranged between 3 percent and 7 percent.

Why Have Rates of Cost Growth Changed?

Growth in the total Air Force budget during the 2000s appears to explain a considerable portion of the higher estimated annual growth rates in operating costs per flying hour beyond the growth rate intrinsic to the aging of the fleet. In other words, because the Air Force had more resources available, it was able to increase spending on aircraft operation and maintenance.

After accounting for the larger Air Force budget, CBO estimates that the real cost growth associated with aircraft aging generally ranged from 1.5 percent to 4.1 percent over the 1999–2016 period. That rate of growth is lower than the rate observed in the raw data but higher than the rate CBO estimated in its 2001 report.[3] One interpretation of those results is that the underlying intrinsic age effects remained roughly as they were in the 1990s and that changes in the size of the Air Force's budget lessened the observed growth rates in the 1990s and boosted them in the 2000s.

Background

Many studies have examined the extent to which operating costs increase as aircraft age.[4] An age effect might be thought of as an intrinsic rate at which aircraft become more expensive to maintain and operate as they age. Estimates of the age effect vary widely and often differ on the basis of the sample of data used, at least partly because the available data make it difficult to separate the age effect from other effects, such as changes in budgets and overall defense priorities.

Importance of Age Effects

Estimating the magnitude of aircraft age effects is important for at least two reasons. First, the Air Force wants to set budgets that are adequate, but not excessive, to maintain its aircraft. Second, the age effect is a key factor in deciding whether it is cost-effective to replace an aging system.

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1. Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment* (August 2001), www.cbo.gov/publication/13213. Operating costs include costs for crew, fuel, parts, and maintenance.

2. The 2001 report examined weapon systems across all branches of the armed services. This analysis focuses more narrowly on Air Force aircraft. An expanded analysis would require additional data that were not readily available.

3. Other factors besides aging, such as operating conditions and maintenance philosophy, could account for some of the cost growth. An evaluation of those factors is beyond the scope of this analysis, however.

4. See, for example, Logistics Management Institute, *The Relationship Among Cost, Age, and Usage of Weapon Systems* (January 2003); and Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment* (August 2001), Appendix B, www.cbo.gov/publication/13213.

Analysts use repair-replace models to compare the costs associated with continuing to maintain an aging system with the costs associated with a new system, including its up-front acquisition costs. Those costs are calculated by comparing the discounted cash flows and choosing the approach (repair or replace) that has the lower discounted present value (setting aside any differences in the systems' capabilities).[5] All else being equal, the greater the rate of growth in the operating costs of an existing system, the more likely it is to be cost-minimizing to replace that system.

Rather than viewing aircraft as having a single rate of growth in operating costs as they age, experts have developed a more nuanced three-phase model of a system's life cycle (see Figure 1). Early in the life of a fleet of aircraft, operating costs might be expected to decrease as technical problems are identified and solved and as the people and facilities that support the aircraft work more efficiently. Also, as more aircraft enter service, the fleet will experience economies of scale because the costs of infrastructure related to the fleet (such as facilities for training and maintenance) will be spread over more flying hours. At the midpoint of an aircraft's life, operating costs might be expected to be relatively stable in real terms as the size of the fleet stabilizes and as most systems and processes supporting the fleet have become well-established. As the fleet gets older, however, operating costs might be expected to rise because the aging aircraft would begin to require more maintenance. In that third and final phase, costs would rise at an increasing rate as a result of what are traditionally termed aging aircraft effects: structural fatigue, corrosion, diminishing availability of spare parts, and system obsolescence.

If the age effects are large enough, replacement of aging systems might be the preferred approach in repair-replace calculations. The reasoning is analogous to that used to decide when to buy a new car.[6] At some point in the car's life, continuing repairs might become so expensive that it would be more cost-effective to buy a new car that

should, at least for a while, require less maintenance. The rate of growth of operation and support (O&S) costs is a key factor in calculating the point at which replacement is optimal.[7]

Earlier Research

CBO's 2001 report estimated age-driven growth rates in aircraft operating costs using data from the 1990s and earlier.[8] In that analysis, CBO found that operating costs per flying hour increased by about 1 percent to 3 percent in real terms per additional year of aircraft age. The increase of 1 percent was for Air Force aircraft most similar to those analyzed in this report. Other studies using data from the same period either found no effect from aging or found growth rates with magnitudes similar to CBO's estimates.[9]

In the 2000s, however, actual operating costs per flying hour grew faster than the rates that one might have inferred from those earlier studies (including CBO's). Studies that used data from the 2000s estimated markedly larger age effects; for many types of aircraft, the real annual growth in costs per flying hour was between 4 percent and 6 percent in the 2000s.[10]

Data Used for This Analysis

For this analysis, CBO used data from the Air Force Total Ownership Cost (AFTOC) system, which captures all of the O&S spending associated with Air Force aircraft.[11] The O&S category of spending pays for the

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5.   A present value expresses a flow of past and future income or payments as a single amount received or paid at a specific time. The value depends on the rate of interest, known as the discount rate, used to translate past and future cash flows into current dollars at that time.

6.   RAND, *Investigating Optimal Replacement of Aging Air Force Systems* (2003).

7.   Ibid., p. 6; Logistics Management Institute, *The Relationship Among Cost, Age, and Usage of Weapon Systems* (January 2003); and Victoria Greenfield and David Persselin, "How Old Is Too Old? An Economic Approach to Replacing Military Aircraft," *Defense and Peace Economics*, vol. 14, no. 5 (2003), pp. 357–368.

8.   Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment* (August 2001), www.cbo.gov/publication/13213.

9.   See, for example, Logistics Management Institute, *The Relationship Among Cost, Age, and Usage of Weapon Systems* (January 2003).

10.   See, for example, Edward G. Keating and Mark V. Arena, "Defense Inflation: What Has Happened, Why Has It Happened, and What Can Be Done About It?" *Defense and Peace Economics*, vol. 27, no. 2 (April 2016), pp. 176–183.

11.   See "Air Force Total Ownership Cost (AFTOC)," https://aftoc. hill.af.mil; and Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment* (August 2001), Box 1, p. 8, www.cbo.gov/publication/13213.
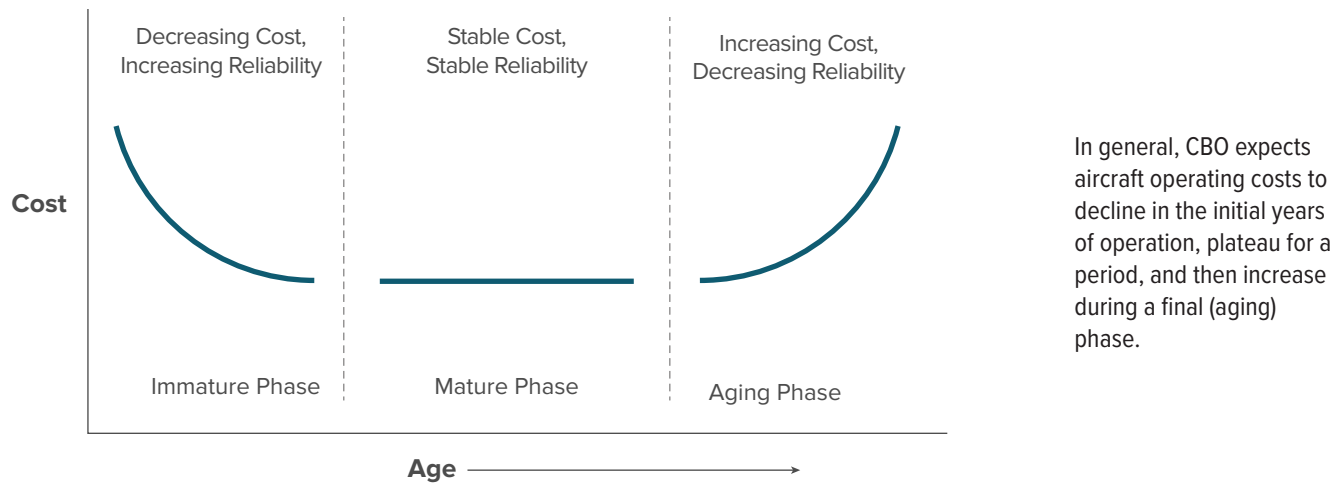
Figure 1.

A Theoretical Model of an Aircraft's Life Cycle Applied to Its Operating Costs

Source: Congressional Budget Office based on K.R. Sperry and K.E. Burns, *Life Cycle Cost Modeling and Simulation to Determine the Economic Service Life of Aging Aircraft* (October 2001).

Three types of aircraft analyzed in this report were in the decreasing cost (immature) phase, whereas most other aircraft examined in this report were in the increasing cost (aging) phase.

costs of military and civilian personnel as well as weapon system maintenance and installation support. AFTOC tracks annual operating costs by aircraft system across different cost categories (including personnel, parts, engineering support, and maintenance) by aircraft type. In 2017, the total Air Force budget was $168 billion, $76 billion of which was for O&S; about $42 billion of that O&S spending was reported in AFTOC and attributed to aircraft and other systems.

CBO examined AFTOC data for 13 large fleets of aircraft from fiscal years 1999 through 2016. (All costs are expressed in 2016 dollars to remove the effects of inflation.) Consistent with the approach taken by other researchers, CBO normalized annual O&S costs for each aircraft for the total flying hours the fleet accumulated in that fiscal year. In other words, CBO examined trends in annual O&S costs per flying hour for each fleet of aircraft.

AFTOC data provide costs per flying hour over time by weapon system. For most Air Force systems, that time series essentially shows how the system's costs per flying hour have changed as the system has aged. If a fleet has a fixed set of aircraft, then age and time are perfectly

correlated: The fleet ages one year every year. But fleets are continually undergoing changes in their composition (most commonly because some of the aircraft are retired, but also because new aircraft are added). For the 13 aircraft types that CBO examined, fiscal year and average fleet age were closely related, making it difficult to disentangle age effects from time trends.
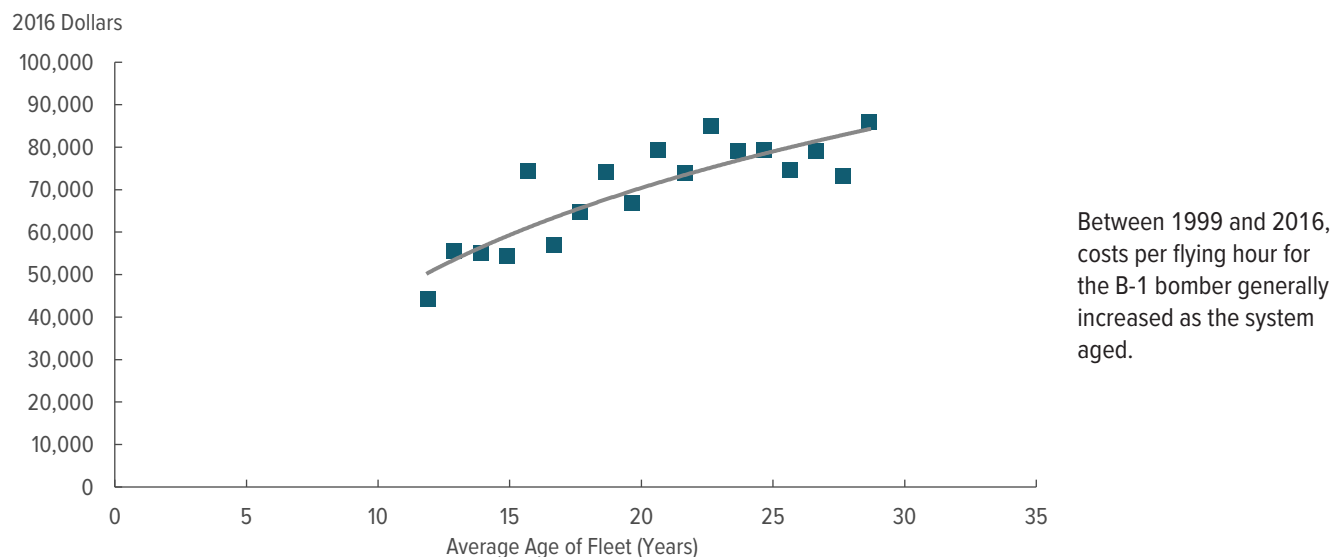
Estimating Operating Cost Increases Associated With Aging

In this analysis, CBO used two approaches to estimate the cost growth associated with aircraft aging. The first approach used the simple model employed by other studies, including CBO's 2001 analysis. That approach measured the correlation between annual operating costs per flying hour (the dependent variable) and the age of the fleet (the independent variable). The second approach added the size of the total Air Force budget (in constant dollars) as an independent variable.[12] Including the total Air Force budget allowed CBO to evaluate the possibility that more money was spent on aircraft

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12. The appendix describes both models in more detail.

Figure 2.

A Simple Model of Costs per Flying Hour as a Function of Aircraft Age for the B-1 Bomber

2016 Dollars

Between 1999 and 2016, costs per flying hour for the B-1 bomber generally increased as the system aged.

Source: Congressional Budget Office, using data from the Air Force.

The simple model shows costs rising at about 3 percent per year of age.

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maintenance because funding was available rather than just because the aircraft were aging.[13]

Estimating Age Effects Using the Simple Model
To replicate the findings of recent studies, CBO started with the simple model, which looks for a correlation between operating costs per flying hour and the average age of the fleet. CBO's analysis of the B-1 bomber fleet illustrates that approach. AFTOC data from 1999 to 2016 for that fleet show that real operating costs per flying hour generally increased as the fleet aged (see Figure 2). Because the B-1 fleet has not had any new aircraft since the 1980s, the youngest average fleet age occurred in fiscal year 1999 and the oldest in fiscal year 2016. Using the simple model, CBO found that the B-1's operating cost per flying hour grew at an annual

real rate of 2.9 percent (see the solid curve in Figure 2). CBO used that simple model to estimate the age-related growth for all 13 of the aircraft fleets it examined.

Aircraft Whose Costs Increased With Age. For nine of the 13 aircraft fleets examined (including the B-1), CBO found real annual growth rates in O&S costs per flying hour that ranged between 2.7 percent and 6.8 percent (see Figure 3).[14] To display those results, CBO used the average age at the midpoint of the years in the observed data (typically 2007 or 2008) for each system, because it was typical of the age of the aircraft fleet over the period that CBO examined.
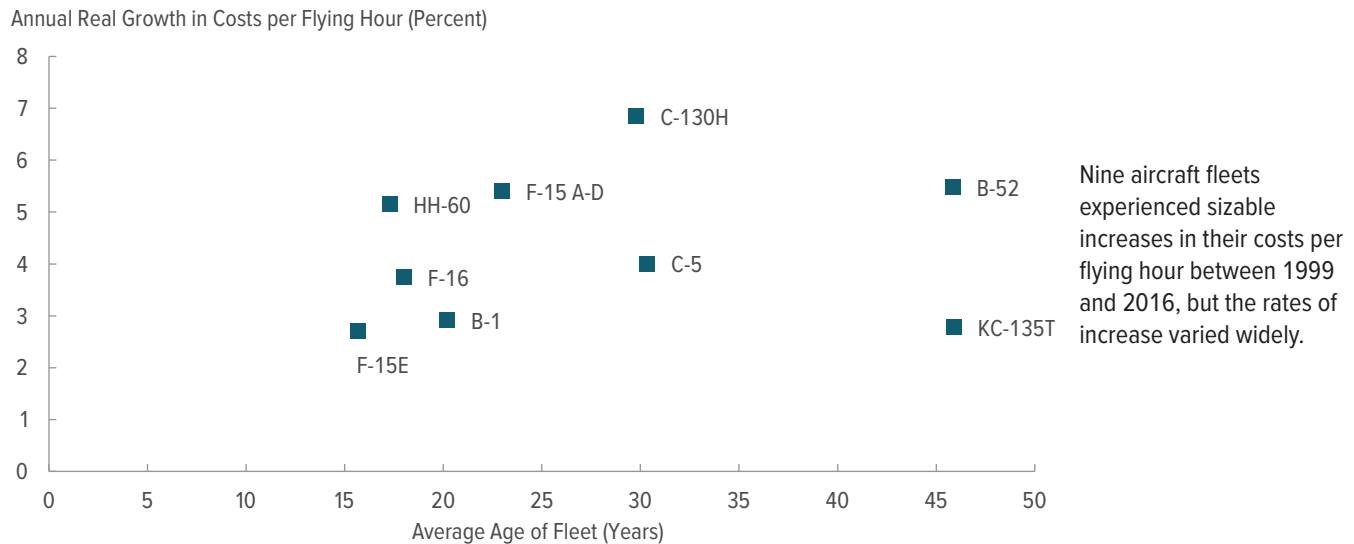
The growth rates that CBO found—even the ones that were relatively small—suggest that costs per flying hour grew sizably for those nine aircraft fleets. If compounded over many years, even relatively low real growth rates can have a large effect on costs. For example, an aircraft with 3 percent real growth in operating costs per flying hour (a rate similar to that estimated for the B-1) would

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13. Spending more on aircraft maintenance may be reasonable and appropriate. Some researchers have argued, for instance, that the Air Force underinvested in spare parts during the 1990s. Also, some costs—such as those for military and civilian compensation—have been growing faster than inflation because of pay raises and increased health care costs. See Congressional Budget Office, *Costs of Military Pay and Benefits in the Defense Budget* (November 2012), www.cbo.gov/publication/43574. Spending more on those categories may be necessary just to maintain the same level of performance among aircraft.

14. Those results are consistent with the findings of other studies that used data from the same period. Small differences are a result of other studies' using different samples and restricting their analyses to maintenance costs (a subset of O&S costs).

Figure 3.

Estimates of Aging Effects Using the Simple Model for Aircraft Fleets Whose Costs Increased With Age

Annual Real Growth in Costs per Flying Hour (Percent)

Nine aircraft fleets experienced sizable increases in their costs per flying hour between 1999 and 2016, but the rates of increase varied widely.

Source: Congressional Budget Office, using data from the Air Force.

Average age is the age of each fleet at the midpoint of the time series that CBO analyzed (typically 2007 or 2008), so those fleets are nine or 10 years older in 2018 than the age indicated on the horizontal axis. These growth rates are representative of the third phase (decreasing reliability and increasing cost) depicted in Figure 1.

The simple model measures the correlation between cost per flying hour and age.

be 80 percent more expensive to operate at age 30 than at age 10. And an aircraft with consistent 7 percent real growth in costs per flying hour, which is the rate CBO estimated for the C-130H cargo aircraft, would be almost four times more expensive to operate at age 30 than at age 10. (Because CBO estimated real growth rates for each of type of aircraft, its results exclude inflation-driven cost increases that would cause all costs to increase each year in annual budgets, which are presented in nominal dollars.)

Aircraft Whose Costs Declined With Age. Although operating costs per flying hour increased with age for most of the aircraft CBO examined, four of the aircraft experienced declining costs per flying hour (see Figure 4). Three of those aircraft—the C-17 cargo aircraft, RQ-4 surveillance aircraft, and F-22 fighter—were less than 10 years old for most of the observation period, so the negative age effect is consistent with the first part of the theoretical system life cycle. As those aircraft enter into middle age and beyond, one would expect that their costs per flying hour would stabilize and later increase as illustrated in Figure 1.

The fourth aircraft—the U-2 surveillance aircraft—is a different case. Although it is older, that aircraft was used more as the 1999–2016 period progressed and appears to have experienced economies of scale in costs per flying hour. The U-2's cost per flying hour decreased because its operating costs did not rise as rapidly as its annual flying hours increased.[15]

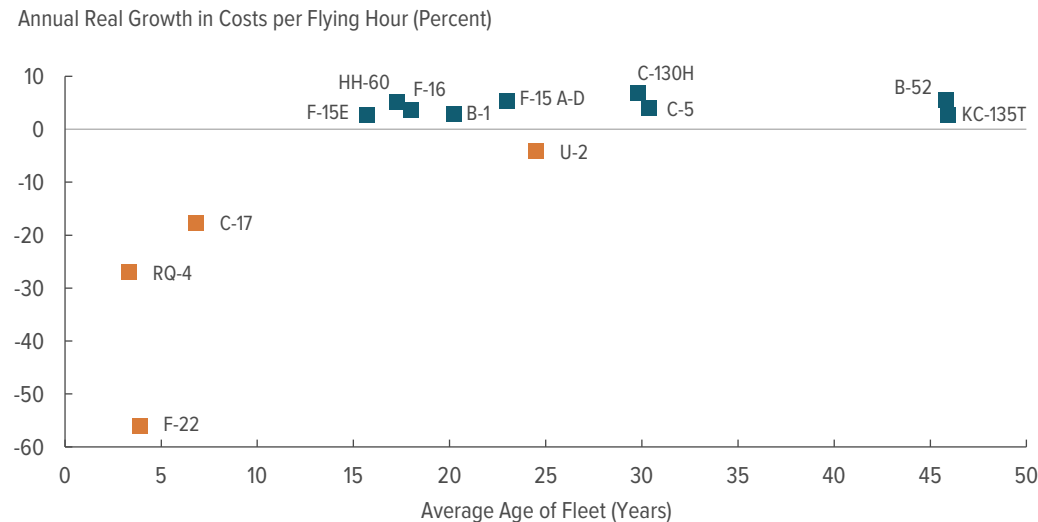**Estimating Age Effects Using the Model That Accounts for the Size of the Total Air Force Budget**
Using the simple model, CBO's results for the 1999–2016 period—real annual growth in aircraft operating costs mostly between 2.7 percent and 5.5 percent—match the findings of recent studies that used data from the same period.[16] CBO's and others' estimates suggest a much greater effect from aging than that found in earlier studies, including CBO's 2001 report (which found rates

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15. The C-17 also experienced considerable increases in annual flying hours per aircraft over the 1999–2016 period (peaking in 2010).

16. That range was calculated by dropping the highest and lowest growth rates for aircraft in the mature or aging phases (see Table A-1 on page 12).

Figure 4.

Estimates of Aging Effects Using the Simple Model for Aircraft Fleets Whose Costs Declined With Age

Annual Real Growth in Costs per Flying Hour (Percent)

Between 1999 and 2016, some newer Air Force fleets experienced declining costs per flying hour as they aged.

Source: Congressional Budget Office, using data from the Air Force.

Average age is the age of each fleet at the midpoint of the time series that CBO analyzed (typically 2007 or 2008), so those fleets are nine or 10 years older in 2018 than the age indicated on the horizontal axis. These growth rates are representative of the third phase (decreasing reliability and increasing cost) depicted in Figure 1.

This figure adds the four aircraft with negative growth in operating costs to the nine aircraft with positive growth in costs shown in Figure 3. Three of those additional aircraft types are relatively new, and their declining operating cost is consistent with the first phase (increasing reliability and decreasing cost) depicted in Figure 1. (The declining portion of Figure 1 is consistent with the negative growth rate for the newer aircraft depicted here because Figure 1 shows cost per hour but this figure measures growth rates.)

The simple model measures the correlation between cost per flying hour and age.

between 1 percent and 3 percent; the increase of 1 percent was for Air Force aircraft most similar to those analyzed in this report). Those earlier studies used the same basic analytical method but with data from the 1990s.
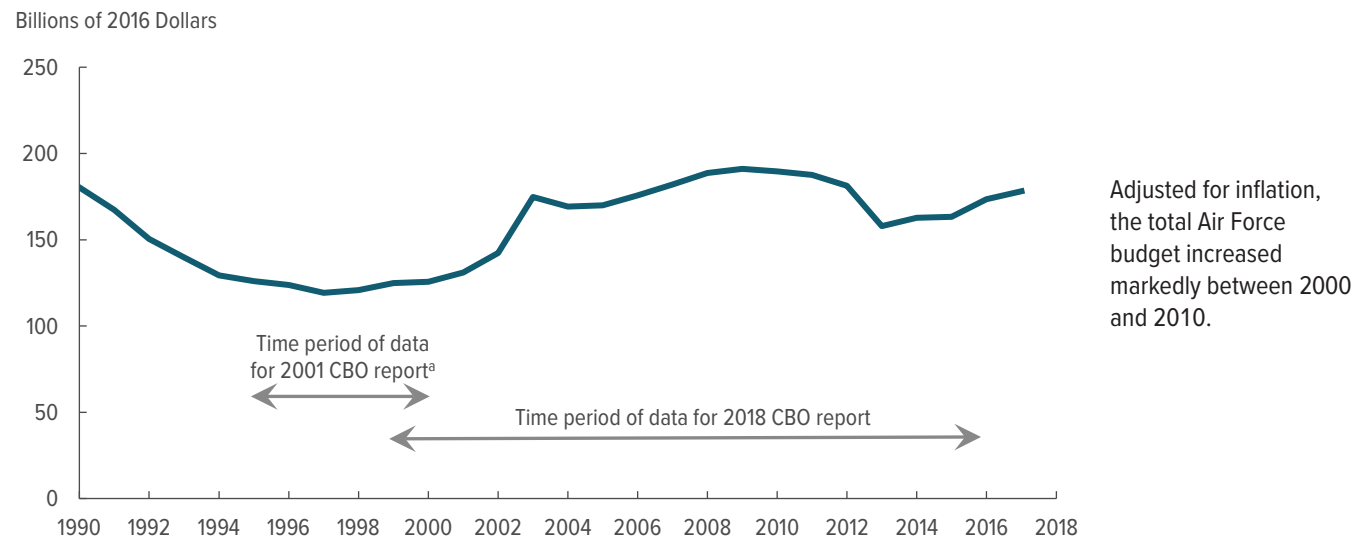
CBO looked for factors that might reconcile the divergent findings between the earlier studies and the more recent ones. A key difference between the two periods was the total Air Force budget, which increased considerably in real terms during the 2000s after relative stability in the mid-to-late 1990s (see Figure 5). One possible explanation for the different rates of growth in operating costs per flying hour is that the Air Force had the budgetary resources in the 2000s to perform more maintenance on aircraft. Increased spending on aircraft maintenance as a policy response to larger budgets is a very different cause for rising costs per flying hour than age effects intrinsic to aircraft. Perhaps the intrinsic age effects remained the same in the 2000s as they were in

the 1990s, but the higher funding levels allowed for more maintenance.

To test that hypothesis, CBO created a model that included the inflation-adjusted size of the total Air Force budget as an additional explanatory variable. That enhanced model has a tighter fit to the observed data (compare the results for the B-1 in Figure 6 and Figure 2). The estimated growth rate attributable to aging is slower, because part of the growth that was associated with age is now associated with changes in the budget. In the case of the B-1, the size of the total Air Force budget explains about one-third of the observed cost growth. The estimated age effect for the B-1 declined from 2.9 percent per year to 1.9 percent per year, an age effect much closer to the midpoint of those in CBO's 2001 analysis. In addition, the flattening of the B-1's cost curve in Figure 6 corresponds with the flattening of the total Air Force budget after 2010 (as shown in Figure 5).

Figure 5.

The Air Force's Total Budget, by Fiscal Year

Billions of 2016 Dollars

Adjusted for inflation, the total Air Force budget increased markedly between 2000 and 2010.

Source: Congressional Budget Office, using data from the Office of the Under Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2018* (August 2017).

a. CBO's 2001 report used data from the Air Force Total Ownership Cost database from 1996 to 1999 on Air Force operation and support costs. It used additional data from 1986 to 1999 for Navy aircraft and budget data from 1976 to 1999. See Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment* (August 2001), www.cbo.gov/publication/13213.

For seven of the nine aircraft types for which CBO estimated that costs increased with age using the simple model, the effects declined using the enhanced model (see Figure 7 on page 9). The change was largest for the F-16 fighter: About 60 percent of its growth in costs per flying hour over time was no longer attributed to age after the size of the total Air Force budget was included in the analysis. But for the C-130, adjusting for budget totals had almost no effect. The only two aircraft for which inclusion of the total Air Force budget slightly increased the estimated age effect were the F-15E fighter and the KC-135T tanker.[17] (See the appendix for the results of CBO's analysis for each aircraft.)

Importance of the Results

Funding for operation and support has grown faster than inflation and as a share of the Department of Defense's (DoD's) budget for the past three decades. One area of

particular growth has been the costs of operating weapon systems, including military aircraft.[18]

Understanding the reasons for aircraft O&S cost growth is important for two reasons. First, projections of future O&S cost growth are a sizable component of DoD's budget projections. Policymakers would not want to overfund future budgets because of an overestimate of the effects of aging on aircraft (or underfund those budgets because of an underestimate).

Second, the estimated age effect is a key input to decisions about when it is cost-effective to replace an aging system. An exaggerated age effect would bias repair-replace models toward premature replacement of incumbent systems.
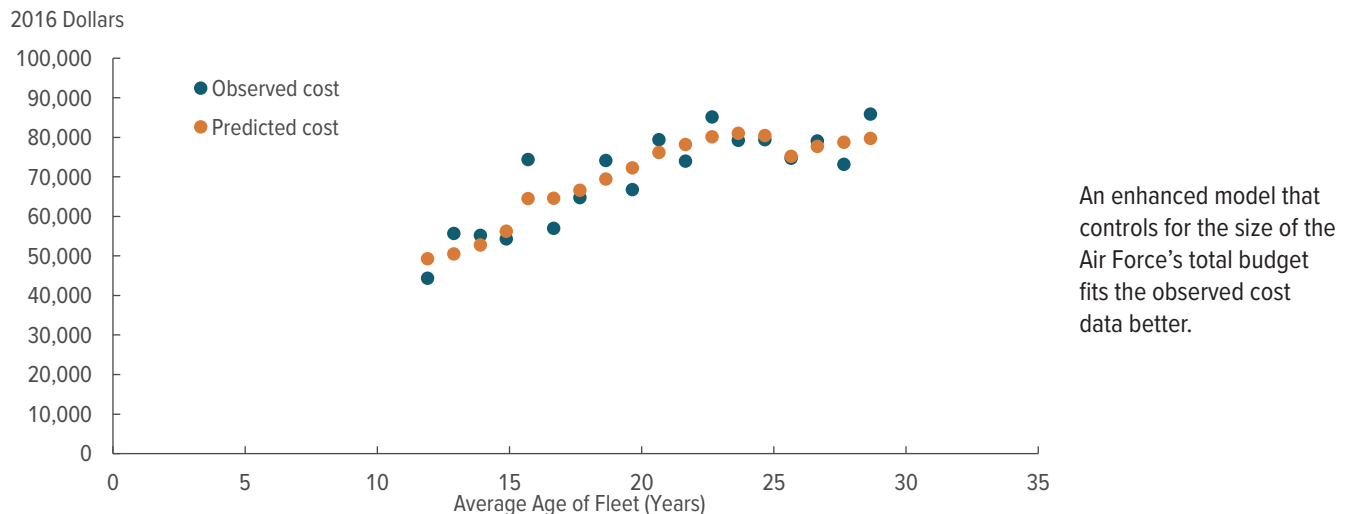
Whereas CBO's 2001 report found that operating costs generally grow at rates that are 1 percent to 3 percent above inflation as aircraft age, this report, which uses

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17. CBO's results for the KC-135T are lower than those estimated by RAND in 2003. For its analysis, RAND used monthly data from 1995 to 2003 (overlapping the annual data used here by four years).

18. Congressional Budget Office, *Trends in Operation and Maintenance Spending by the Department of Defense* (July 2016), www.cbo.gov/publication/51731.

Figure 6.

An Enhanced Model of Costs per Flying Hour as a Function of Aircraft Age for the B-1 Bomber

An enhanced model that controls for the size of the Air Force's total budget fits the observed cost data better.

Source: Congressional Budget Office, using data from the Air Force.

The flattening of the cost per flying hour corresponds to the inflation-adjusted decrease in the total Air Force budget after 2010 (shown in Figure 5).

more recent data but the same simple model, finds considerably greater rates of O&S growth, exceeding 5 percent in real terms for some aircraft. If such elevated O&S cost growth persisted, the O&S budget for aircraft would rise far beyond historic norms, and buying replacement aircraft could appear to be more cost-effective for many systems.
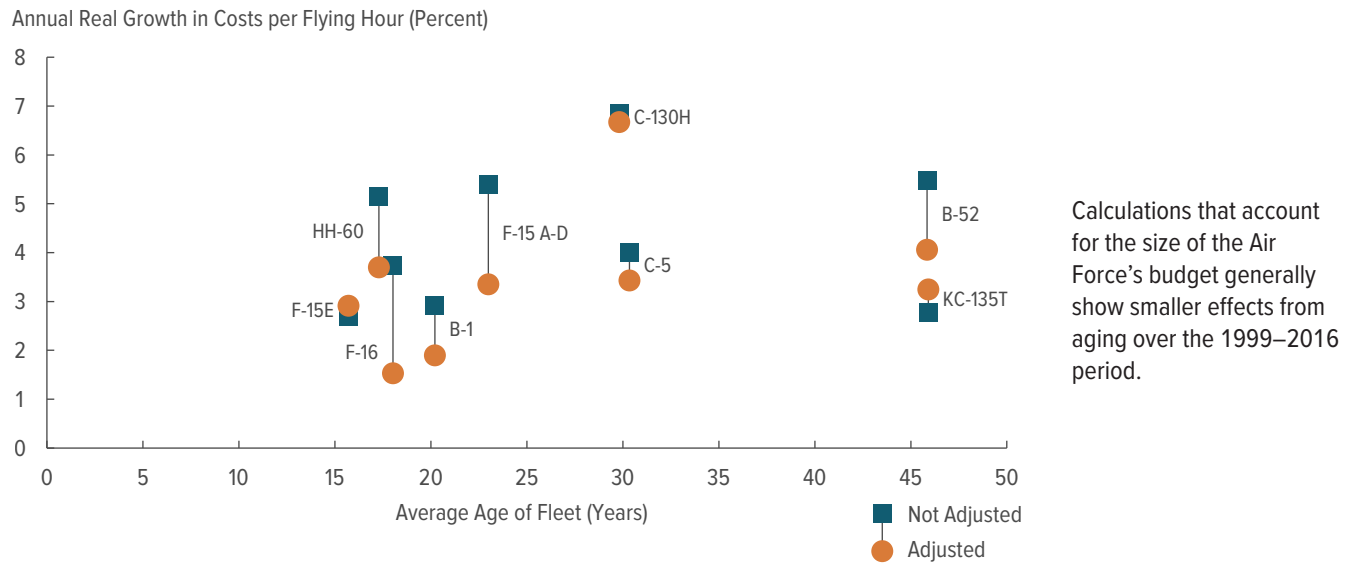
Such a scenario, however, may be unduly dire. CBO's analysis suggests that an aircraft's age is not the sole factor driving O&S cost growth. Although aircraft age is important and does appear to increase aircraft O&S costs, the size of the total Air Force budget also appears to affect cost growth. In particular, when the Air Force has more resources available, it tends to spend more to operate and maintain its aircraft. Such investments may be wholly appropriate, but they obscure underlying, intrinsic age effects. CBO's 2001 analysis used data from a period of comparative budget stringency, which resulted in lower estimates of growth rates in O&S costs than CBO found using more recent data, which generally covered a period of increasing Air Force budgets, resulting in larger estimated age effects. That means that the wide range of estimates on the effects of aging on aircraft operating costs may result in part from the budgetary environment and management decisions rather than differences in intrinsic age effects.

When CBO incorporated the size of the total Air Force budget in its analysis, the estimated age effect declined, falling from 2.7–5.5 to 1.5–4.1. (Those ranges were determined by dropping the highest and lowest growth rates for aircraft in the mature or aging phases.) That amount is still higher than the range CBO estimated in its 2001 report. Using that enhanced analysis, CBO found that aircraft age effects appear to be considerable but not as large as the rates suggested using the simple model. One interpretation that would make this report's findings consistent with those of the 2001 analysis is that the underlying intrinsic age effects between 1999 and 2016 remained roughly as they were in the 1990s, but the 2001 report's methodology underestimated those effects because it did not take into account the downward drift in the Air Force's budget in the mid-1990s.

If CBO obtained more comprehensive and complete data—specifically, cost and age data for individual aircraft over a longer period—its estimates would be more precise. Such data would allow CBO to estimate the effects of aging over the life cycle of aircraft under different budgetary regimes. Those data, however, were not readily available.

Figure 7.

The Effects of Adjusting for the Size of the Air Force's Total Budget on CBO's Estimates of Aircraft Aging

Annual Real Growth in Costs per Flying Hour (Percent)

Calculations that account for the size of the Air Force's budget generally show smaller effects from aging over the 1999–2016 period.

Source: Congressional Budget Office, using data from the Air Force.

Average age is the age of each fleet at the midpoint of the time series that CBO analyzed (typically 2007 or 2008), so those fleets are nine or 10 years older in 2018 than the age indicated on the horizontal axis. These growth rates are representative of the third phase (decreasing reliability and increasing cost) depicted in Figure 1.

Points denoted by squares are the results of the simple model, which does not account for budgetary effects; points denoted by circles are the results of the enhanced model, which adjusts the age effect for the size of the total Air Force budget. Average age is the age of each fleet at the midpoint of the time series that CBO analyzed (typically 2007 or 2008), so those fleets are nine or 10 years older in 2018 than the age indicated on the horizontal axis.

Appendix:
CBO's Analytical Approach

The Congressional Budget Office examined a wide range of Air Force aircraft to measure their operating costs over time. After some preliminary analysis, CBO narrowed its focus to 13 aircraft types for which the Air Force has large fleets.[1] For this analysis, CBO collected information from the Air Force Total Ownership Cost (AFTOC) database for the 1999–2016 period (the longest stretch for which consistent and comparable data are available).

CBO's Approach

CBO used two approaches to analyze the data.[2] The first approach used the method employed by other studies, including an earlier CBO study.[3] That approach, which CBO refers to as the simple model, looks for a correlation between operating costs per flying hour and the average age of the aircraft fleet. The simple model has this logarithmic form:

$$\ln\left(\frac{Cost_t}{FH_t}\right) = \alpha + \beta \times Age_t$$

where $Cost_t$ = annual operating cost in year t, FH_t = flying hours in year t, and Age_t = average age (in years)

in year t. Using data from AFTOC, CBO estimated the coefficients α and β for each aircraft fleet (see Table A-1). The coefficient β is the estimate of the annual growth rate in costs per flying hour as the age of the fleet increases.

The second approach, which CBO calls the enhanced model, adds the size of the total Air Force budget as an independent variable. The enhanced model has this form:

$$\ln\left(\frac{Cost_t}{FH_t}\right) = \alpha + \beta \times Age_t + \gamma \times Budget_t$$

where $Budget_t$ = the Air Force's total obligational authority (the total amount of funds available for obligation in a given year, regardless of when they were appropriated, obligated, or expended) in year t.

CBO estimated the coefficients for each aircraft fleet (see Table A-1). The coefficient β is the estimate of the annual growth rate in costs per flying hour attributed to aging, and the coefficient γ is the annual growth rate attributed to the total Air Force budget.

Limitations of This Analysis

CBO's analysis was constrained by the data that were available. Because of those limitations, CBO was able to analyze aircraft only over the 1999–2016 period. Ideally, having access to data from before 1999 could have improved CBO's estimates of the effects of Air Force budgets on increases in costs per flying hour by covering more periods of large and small budgets. In addition, CBO could examine only general trends in aircraft operating costs because AFTOC reports fleet averages, not data for each aircraft. If data were instead reported for individual aircraft, then CBO could have obtained more accurate estimates of cost growth for each aircraft type.

A more complete data set also would have provided more data points and more independent variation of age and time (because the analysis would have included

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1. CBO examined data for these aircraft: the B-1 and B-52 (bombers), the C-5, C-17, and C-130H (cargo aircraft), the F-15A-D, F-15E, F-16, and F-22 (fighters), the HH-60 (helicopter), the KC-135T (tanker aircraft), and the RQ-4 and U-2 (reconnaissance aircraft). CBO treated the F-15E as distinct from the F-15A-D because of significant design differences. In addition, the analysis was restricted to the C-130H and the KC-135T because, for other variants of those aircraft, either the number in the fleet was too small or some other changes were occurring (such as upgrades from one variant to another).

2. CBO also considered using other models that included additional independent variables—in particular, the age of the aircraft squared (to test if the age effect increases at the end of an aircraft's life), the mission capable rate (a measure of how often an aircraft is ready for missions), and the fleet's flying hours. Those other coefficients were usually small or insignificant, leading CBO to use the models discussed here.

3. Congressional Budget Office, *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment* (August 2001), www.cbo.gov/publication/13213.

Table A-1.

Regression Results for the Simple and Enhanced Models

Aircraft	Estimated Coefficient for the Simple Model (Standard Error)		Estimated Coefficient for the Enhanced Model (Standard Error)		
	Intercept	Age	Intercept	Age	Air Force Budget[a]
Aircraft in the Aging Phase					
B-1	10.55 **	0.029 **	10.13 **	0.019 **	3.94 **
	(0.10)	(0.005)	(0.13)	(0.004)	(1.00)
B-52	8.47 **	0.055 **	8.25 **	0.041 **	5.52 **
	(0.33)	(0.007)	(0.26)	(0.007)	(1.54)
C-130H	8.44 **	0.068 **	8.37 **	0.067 **	6.51 **
	(0.10)	(0.005)	(0.18)	(0.006)	(1.39)
C-5	9.88 **	0.040 **	8.83 **	0.034 **	7.61 **
	(0.21)	(0.007)	(0.40)	(0.006)	(2.54)
F-15 A-D	8.94 **	0.054 **	8.53 **	0.034 **	5.92 **
	(0.14)	(0.006)	(0.14)	(0.006)	(1.16)
F-15E	9.93 **	0.027 **	10.01 **	0.029 **	3.10 *
	(0.13)	(0.008)	(0.14)	(0.010)	(1.65)
F-16	9.11 **	0.037 **	8.21 **	0.015 **	8.38 **
	(0.18)	(0.010)	(0.23)	(0.009)	(1.59)
HH-60	9.22 **	0.051 **	8.58 **	0.037 **	5.63 *
	(0.16)	(0.009)	(0.27)	(0.009)	(2.07)
KC-135T	8.36 **	0.028 **	8.43 **	0.032 **	-1.82
	(0.25)	(0.005)	(0.25)	(0.006)	(1.45)
U-2	8.36 **	-0.041 **	11.98 **	0.034 **	-2.88
	(0.25)	(0.007)	(0.24)	(0.008)	(1.84)
Aircraft in the Immature Phase					
C-17	18.83 **	-0.177 **	8.79 **	-0.099 **	-6.42
	(0.08)	(0.011)	(1.10)	(0.015)	(1.83)
F-22	15.05 **	-0.561 **	29.83 **	-0.744 **	-83.00 *
	(0.79)	(0.176)	(5.90)	(0.162)	(32.63)
RQ-4	12.28 **	-0.273 **	3.35	-0.349	51.76
	(0.68)	(0.188)	(7.14)	(0.395)	(36.58)

* = p value of less than 0.1; ** = p value of less than 0.01. The p value is the probability of observing a coefficient at least as large as the one listed in the table if the true coefficient is zero (assuming all other model conditions are met).

The simple model measures the correlation between an aircraft's cost per flight hour and its age. The enhanced model controls for the size of the Air Force's total budget. The dependent variable is ln(Cost/flying hour).

a. Calculated in millions of 2016 dollars.

some younger and some older aircraft for each year). That type of study could take into account individual conditions and specific mechanical problems to provide a more accurate analysis. Furthermore, a data set that encompassed a longer time period (both the 1990s and the 2000s) would have allowed CBO to better estimate age effects in different budgetary environments and at various points in an aircraft's life cycle.

A final caveat is that the type of regression analysis CBO used in this report can only measure observed correlations and cannot prove causation. Other variables that were not observed could have caused some of the cost increases.

About This Document

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September 2018