Congressional Budget Office
Nonpartisan Analysis for the U.S. Congress

The Effects of Large-Scale Maintenance Actions on the Availability of the Air Force's Aircraft

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At a Glance

The Department of Defense often confronts decisions about whether to repair a piece of equipment (such as a ship, vehicle, or aircraft) to extend its service life or whether to replace it with a new piece of equipment. One important consideration is whether large-scale maintenance—such as an engine replacement or structural upgrade—would make the equipment more available for training or combat. As equipment ages, more parts tend to break, so the equipment tends to become less available. Large-scale maintenance might sometimes slow or reverse that decline.

This report examines the availability of six Air Force aircraft fleets after large-scale maintenance that has occurred since the mid-1990s. Although most aircraft periodically undergo heavy maintenance during their lifetime, the Congressional Budget Office focused on modifications that changed the aircrafts' Mission Design Series designation. Those types of changes usually focus on improving an aircraft's performance and reliability so as to keep it in the force for an extended time.

For the fleets that CBO examined, the agency found that the aircrafts' availability:

- Generally improved after four of the conversions (A-10A to A-10C, C-5B to C-5M, KC-135E to KC-135R, and KC-135Q to KC-135T); and
- Generally did not improve after two of the conversions (T-38A to T-38C, and T-38B to T-38C).

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Notes

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.

On the cover: A C-5B transport aircraft being converted to a C-5M. Photograph provided courtesy of Lockheed Martin Aeronautics Company and used with permission of the Air Force.

The Effects of Large-Scale Maintenance Actions on the Availability of the Air Force's Aircraft

In deciding whether to repair or replace equipment, the Department of Defense may consider how large-scale maintenance actions would affect the reliability of that equipment—that is, its availability to be used for training or combat. Availability tends to decline as equipment ages because more parts break, requiring increased maintenance. Large-scale maintenance, such as an engine replacement or structural upgrade, can change that trajectory by addressing problems with the equipment that are contributing to decreased availability.

This report focuses on one type of equipment: U.S. Air Force aircraft. It shows how large-scale maintenance actions undertaken by the Air Force that have changed the aircrafts' designated Mission Design Series (MDS) have affected the aircrafts' availability (as measured by the percentage of time they are considered capable of performing their missions). A change in an aircraft's MDS clearly indicates that a major modification—usually intended to increase the aircraft's capability—and associated maintenance have occurred. For example, some A-10A attack aircraft received weapons enhancements that resulted in those aircraft being redesignated as A-10Cs. Aircraft MDS changes are uncommon, but they enable the Congressional Budget Office to compare an aircraft fleet's performance before and after such a change in a straightforward way. (Aircraft can also undergo large-scale maintenance without a change in MDS; those modifications are not examined in this report.)

Typically, modification programs that result in a change in MDS also include changes to improve reliability because the upgraded aircraft are expected to remain in the force for an extended time. Reliability may be a secondary consideration, though, so an aircraft's modification may improve its capability without affecting its availability.

In most of the cases that CBO examined, aircraft were more available after the maintenance action than would be expected without it. CBO also analyzed flying hours per aircraft to see the effect of aircraft modifications on that metric, but the agency found no clear-cut pattern of changes in flying hours after a large-scale maintenance action.

MDS Changes That CBO Analyzed

The large-scale maintenance actions examined in this analysis were primarily oriented toward modifications that increase aircrafts' capabilities. The A-10As received targeting systems to improve their ability to employ precision munitions, C-5 transport aircraft and KC-135 tanker aircraft received new engines that improved their mission performance, and T-38 trainer aircraft received new avionics that are more like the avionics of modern combat aircraft that student pilots will eventually fly.

Some modifications made to increase capability can also be expected to improve availability. For example, new jet engines are typically more reliable than old ones. In addition, fixes to unreliable systems on aircraft that are not related to improving capability are often made concurrently. Nevertheless, large-scale maintenance actions do not necessarily improve aircraft availability.

Mission Design Series Changes That CBO Analyzed

MDS Change	Modifications Made	Dates of Work	Number of Affected Aircraft
A-10A to A-10C	Fire control system, smart bomb targeting	March 2008 to August 2012 (Mainly 2008 to 2010)	350
C-5B to C-5M	Reliability enhancement, engine replacement	February 2009 to August 2018 (Mainly 2014 to 2017)	49
KC-135E to KC-135R	Engine replacement	April 1996 to June 2005 (Mainly 1996 to 1997)	30
KC-135Q to KC-135T	Engine replacement, fuel tank upgrade	November 1993 to March 1996 (Mainly 1994 to 1995)	54
T-38A to T-38C	Avionics upgrades	August 1998 to August 2007 (Mainly 2003 to 2005)	370
T-38B to T-38C	Avionics upgrades	August 2001 to August 2006 (Mainly 2002)	86

The six MDS changes were made to four fleets: A-10 attack aircraft, C-5 transport aircraft, KC-135 tanker aircraft, and T-38 trainer aircraft.

CBO's Approach

For this analysis, CBO used monthly data (collected since October 1989) from the Air Force's Reliability and Maintenance Information System (REMIS). To analyze the performance metrics of the aircraft before and after the MDS changes, CBO adjusted the data in several ways, normalizing time before and after the MDS change and excluding data from the period when aircraft availability appeared to have been affected by the maintenance action itself. CBO then ran log-linear regressions to contrast how the aircraft would have performed without the modifications with how they actually performed after the modifications (for details, see the appendix). CBO plotted regression curves to depict the resulting best fit of the data. (Those curves appear as straight lines in the figures in this report because the ranges of values for the monthly availability rate for each aircraft type are narrow.)

Inventories shown are based on data in REMIS. Not all of the aircraft in those inventories are in active service, however.

Normalized Timelines

For the fleets CBO examined, the dates on which individual aircraft changed their MDS designation were spread over several years. For example, the A-10A with tail number 78-596 had its designation changed to A-10C in July 2008, whereas the designation for tail number 78-685 was switched in February 2011. To analyze aircraft performance before and after the change, CBO created a timeline: The month when the designation changed was set equal to zero, months preceding month zero were assigned negative numbers, and months following month zero were assigned positive numbers. So, for example, month 12 for tail number 78-596 was July 2009, and month 12 for tail number 78-685 was February 2012. To determine fleetwide aircraft availability, CBO then aggregated the performance of all converted A-10Cs in each aircraft's month 12.

Buffer Zones

The large-scale maintenance actions that resulted in MDS changes were time-consuming processes spanning several months or longer. CBO found no set criteria for when an aircraft's designation was changed relative to when it entered or exited a depot for maintenance. The change might occur three months into a year-long maintenance action or in the last month of an 18-month modification. However, performance metrics showed marked decreases in the months surrounding the change in designation. To prevent those decreases near month zero from affecting the results of its analysis, CBO set up a buffer zone of values around that month and excluded those months from the analysis.

Buffer Months Associated With MDS Changes

MDS Change	Buffer Months
A-10A to A-10C	-8 to +5
C-5B to C-5M	-19 to +3
KC-135E to KC-135R	-7 to +2
KC-135Q to KC-135T	-7 to 0
T-38A to T-38C	-10 to +7
T-38B to T-38C	-5 to +1

CBO excluded data from the buffer months to prevent its analysis from being contaminated by the maintenance action itself.

Results

CBO defines an aircraft's availability rate as the percentage of time that the aircraft is coded as being mission capable while possessed by an operational unit (that is, not in a depot or storage status). The way availability changed after the large-scale maintenance actions CBO examined was not uniform. For some fleets, average monthly availability initially jumped after the modification and declined thereafter. Other fleets showed a lessening of the effect of aging—in other words, their availability continued to decline, but more slowly than was observed before the modification. Two conversions, both involving T-38 trainer aircraft, were associated with no apparent long-term improvement in the fleet's average monthly availability.

To summarize those findings, CBO compared availability rates with and without the maintenance action. Specifically, the agency compared actual availability rates averaged over two periods (36 months to 47 months and 84 months to 95 months after the maintenance action, as measured by CBO's normalized timeline) with the estimated rate if the trajectory of each aircraft's availability had simply continued. (Numbers in the table may not sum to totals because of rounding.)

Aircrafts' Actual and Estimated Availability After the MDS Change, Averaged Over Selected Periods

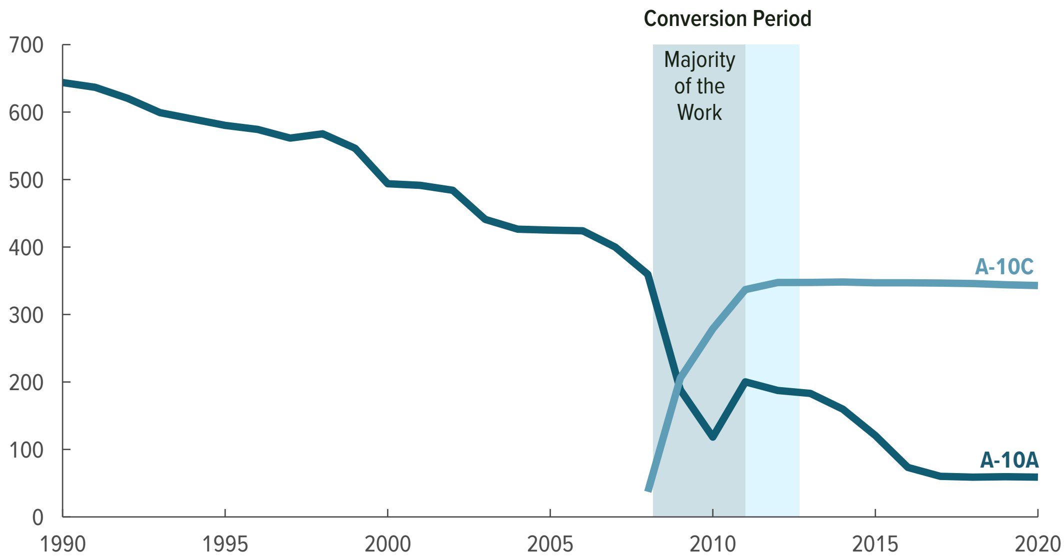
MDS Change	Actual Availability (Percent)	Estimated Availability Without Maintenance (Percent)	Estimated Change Caused by Maintenance (Percentage points)
		Average From 36 Months to 47 Months After MDS Change	
A-10A to A-10C	63	53	10
C-5B to C-5M	50	43	7
KC-135E to KC-135R	50	53	-2
KC-135Q to KC-135T	71	46	25
T-38A to T-38C	72	71	2
T-38B to T-38C	72	75	-3
		Average From 84 Months to 95 Months After MDS Change	
A-10A to A-10C	54	49	5
C-5B to C-5M		Not Applicable	
KC-135E to KC-135R	64	48	16
KC-135Q to KC-135T	69	34	35
T-38A to T-38C	66	69	-4
T-38B to T-38C	68	75	-7

The A-10, C-5, and KC-135 conversions were associated with long-run increases in aircraft availability. (CBO's data on the C-5M conversion did not extend beyond the third full year.) Estimates of changes in availability may have been affected by factors other than the maintenance actions.

A-10A to A-10C Conversions

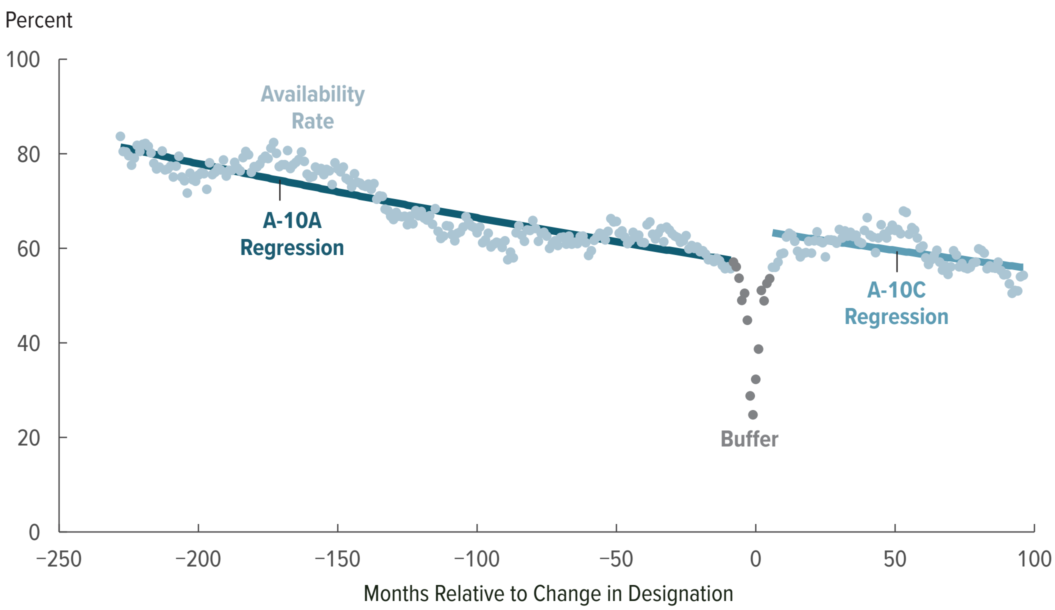
The Air Force converted 350 A-10A attack aircraft to A-10Cs between March 2008 and August 2012. (Most of that activity occurred in 2008, 2009, and 2010.) Those conversions, termed Precision Engagement, primarily focused on enhancing the aircrafts' capability by improving the fire control system and including smart bomb targeting. (If those weapon systems had not been operating correctly, the aircraft would not have been able to fly certain types of combat missions.) A modest number of unconverted A-10As remain in the fleet, although none have flown since 2010. After the conversion, availability of A-10 aircraft increased by about 6 percentage points.

Average Number of Aircraft, by Fiscal Year



Most of the remaining fleet of A-10As has been converted to A-10Cs.

Fleetwide Average Monthly Availability Rate



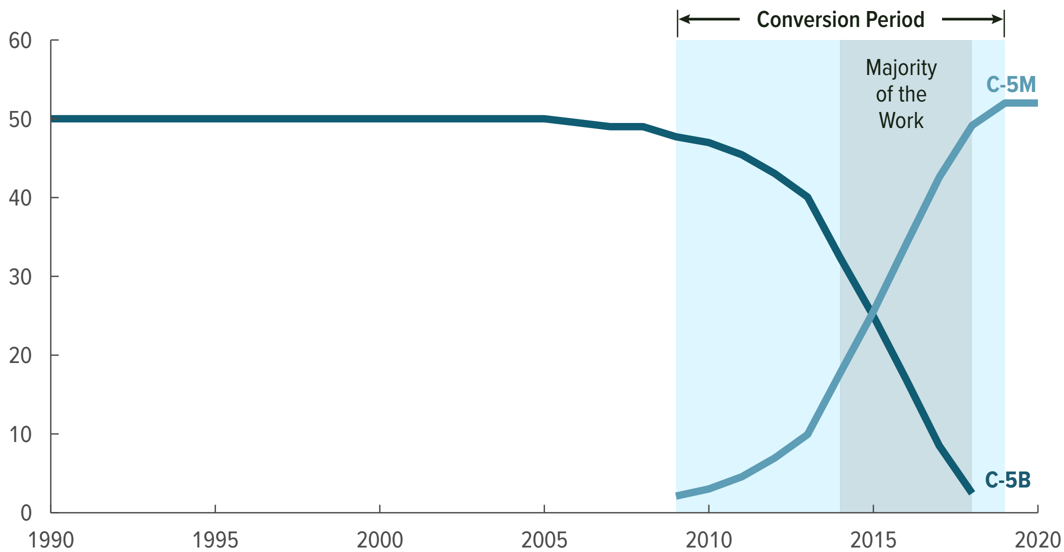
Availability improved immediately after the A-to-C conversion and then declined at approximately the same rate it had been before the conversion, CBO estimates.

C-5B to C-5M Conversions

The Air Force modernized all 49 of its C-5B transport aircraft through the Reliability Enhancement and Re-Engining Program. That program replaced the C-5B's original engines with commercial engines that provide more thrust, comply with current noise and pollution standards, and need less maintenance. Upgrades were also made to the landing gear and the electrical, hydraulic, fuel, fire suppression, and pressurization systems. Upon completion of the program, the aircraft were redesignated as C-5Ms.

The C-5 aircraft were generally more available after the conversion, reversing what had been an age-related decline in availability.

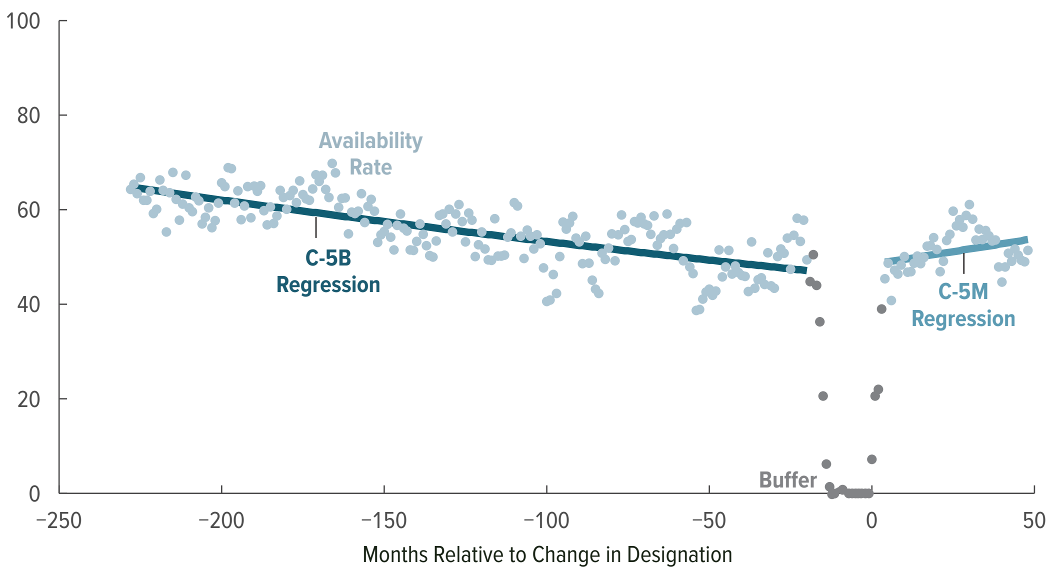
Average Number of Aircraft, by Fiscal Year



The C-5M inventories shown include one aircraft converted from a C-5A and two converted from C-5Cs. Those three aircraft were not included in the availability analysis.

Fleetwide Average Monthly Availability Rate

Percent

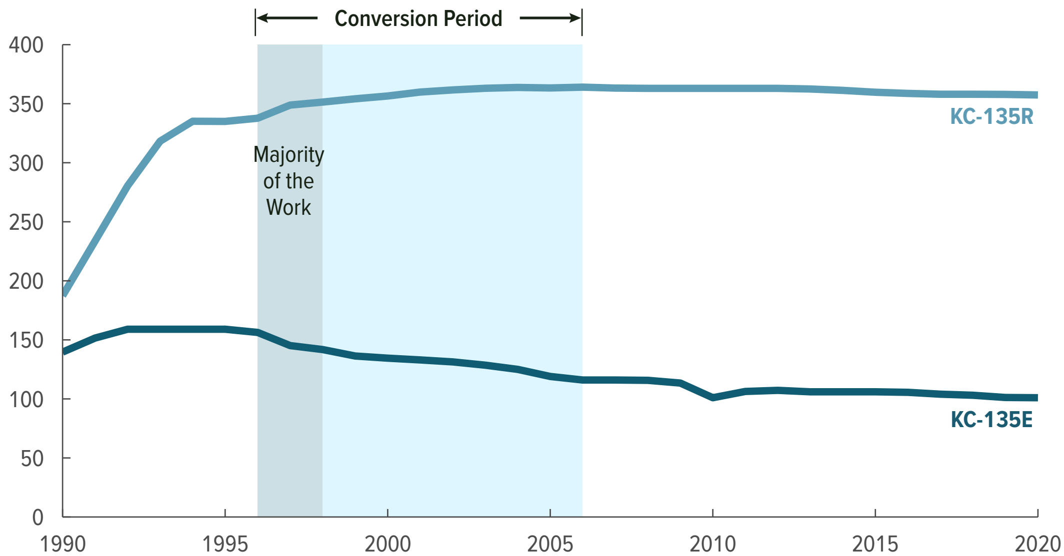


Availability increased by an estimated 7 percentage points in the third full year after the B-to-M conversion.

KC-135E to KC-135R Conversions

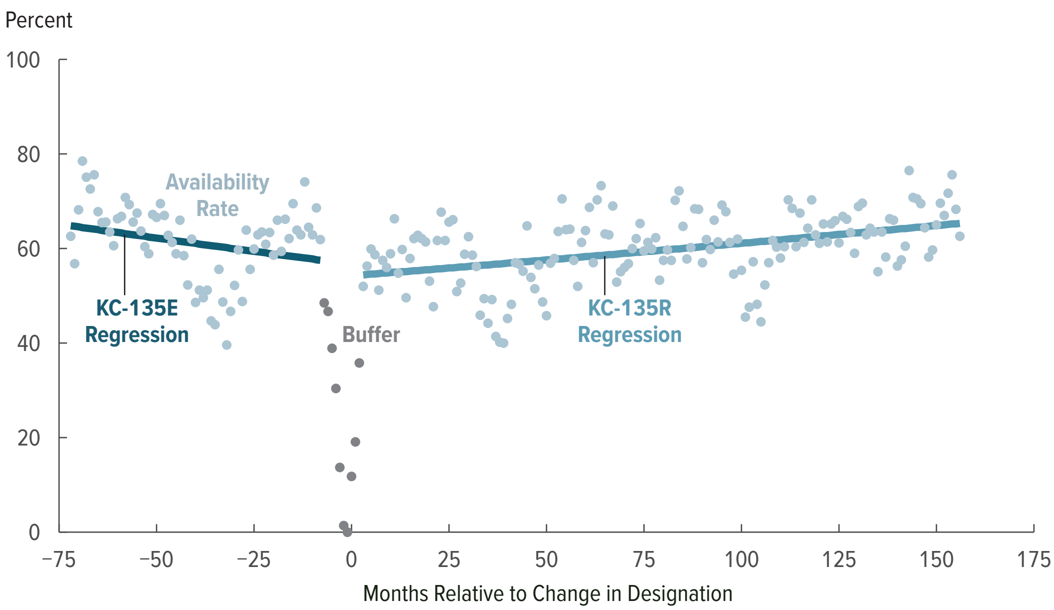
Between April 1996 and June 2005, 30 KC-135E tanker aircraft underwent engine replacement, which caused them to be redesignated as KC-135Rs. (An earlier conversion, from the original KC-135A to KC-135E, preceded the period for which CBO has data. The KC-135Es that were not converted to KC-135Rs were retired in 2009 but remain in the REMIS inventory.) The KC-135E-to-R conversions were concentrated in 1996 and 1997. Average availability rates for those aircraft (both before and after the conversions) have varied widely from month to month. Nevertheless, availability rates have trended upward since the aircrafts' change in designation, a marked departure from the rates' earlier downward trajectory.

Average Number of Aircraft, by Fiscal Year



Only a small portion of the KC-135E fleet has been converted into KC-135Rs. Most KC-135Rs were converted directly from KC-135As.

Fleetwide Average Monthly Availability Rate



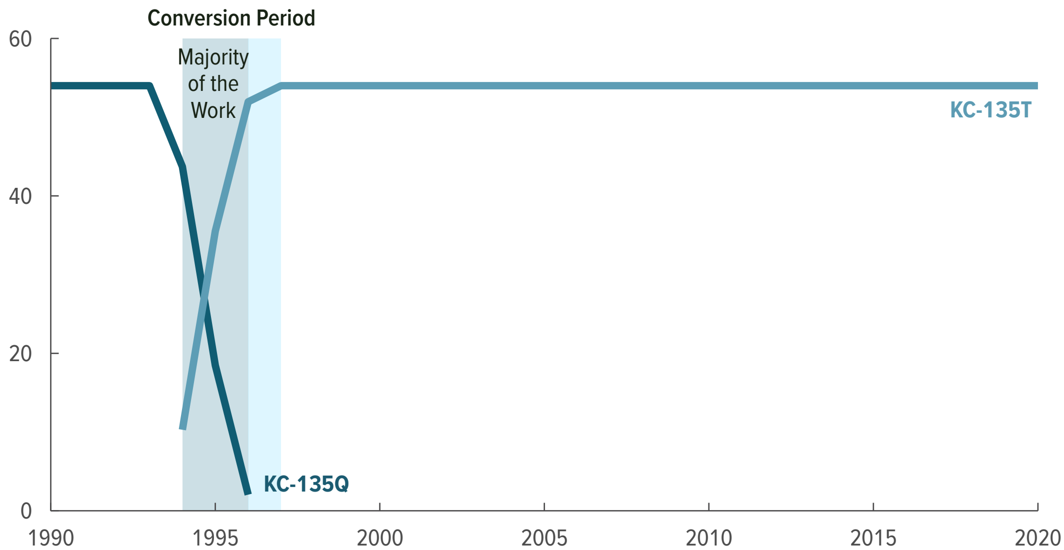
Availability generally improved after the E-to-R conversion compared with its trend before the conversion.

KC-135Q to KC-135T Conversions

Between November 1993 and March 1996, 54 KC-135Q tanker aircraft received new engines and upgrades to their fuel tanks for refueling other aircraft in flight. Those changes caused the KC-135Qs to be redesignated as KC-135Ts. (Starting in the 1960s, KC-135Qs had their internal plumbing modified to handle the special fuel used by the SR-71 Blackbird reconnaissance aircraft, but the SR-71 fleet has since been retired from the Air Force.)

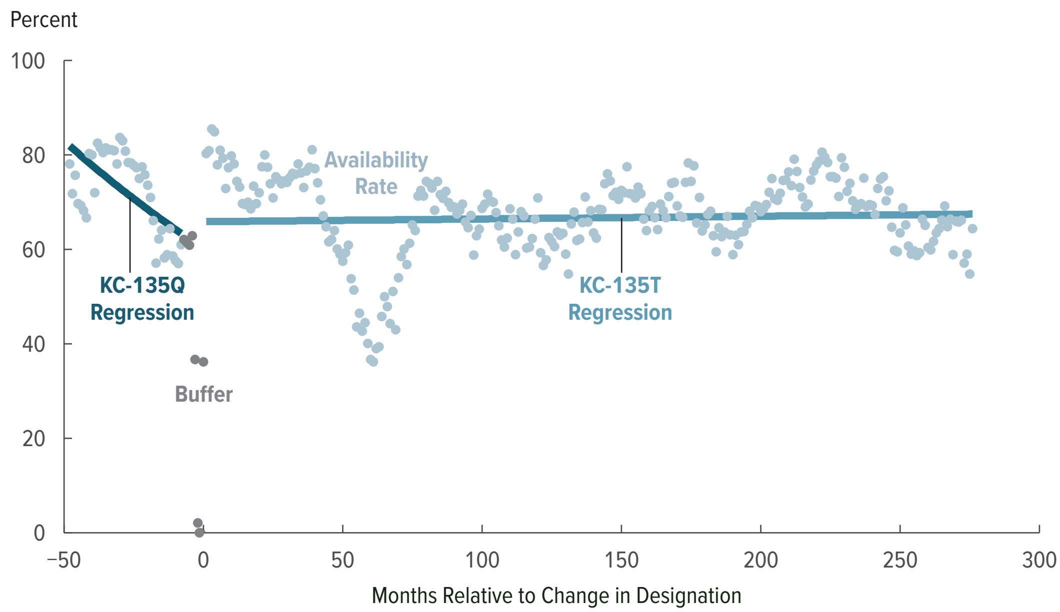
Availability of the KC-135Q fleet diminished sharply in the four years preceding the change in designation. (Data for that fleet were limited, so the drop may reflect a period of unusually low availability.) Right after the conversion, availability increased markedly, from about 60 percent to 80 percent. About five years later, availability declined again as the fleet underwent the Pacer CRAG (compass, radar, and global positioning system) avionics upgrade. Since then, availability of the KC-135T fleet has stabilized.

Average Number of Aircraft, by Fiscal Year



All KC-135Qs were converted to KC-135Ts.

Fleetwide Average Monthly Availability Rate

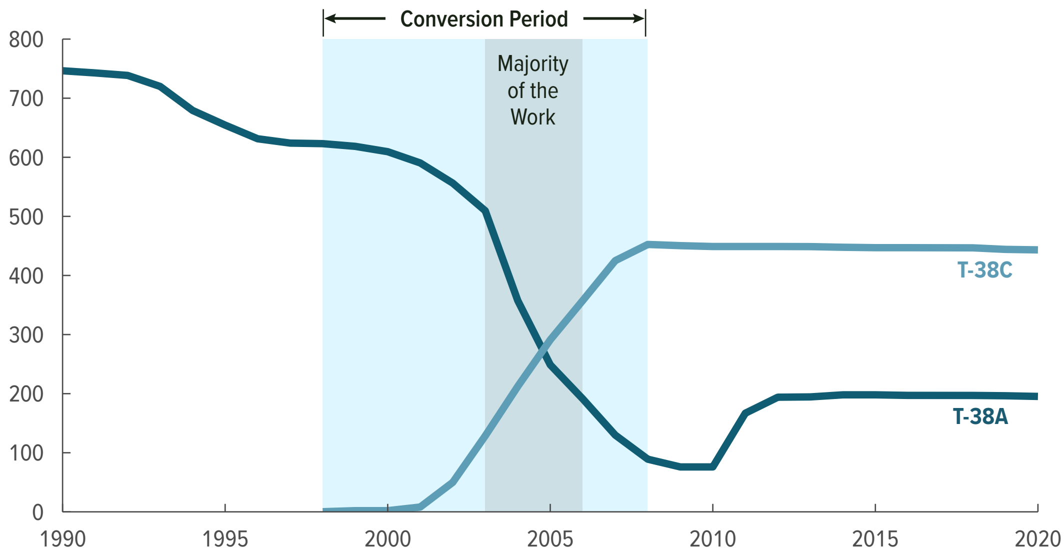


Rather than continuing to decline (as it had been before the conversion), availability of KC-135Ts has stabilized, oscillating around 67 percent. The large dip in availability around month 60 occurred during the aircrafts' avionics upgrade in the late 1990s.

T-38A to T-38C Conversions

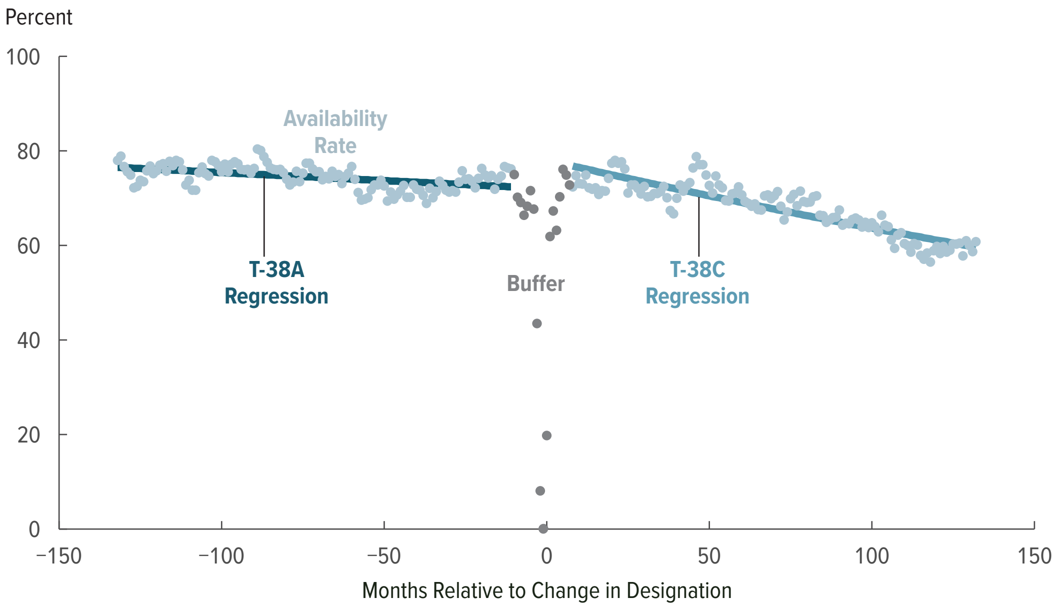
Over the nine-year period from August 1998 to August 2007, 370 T-38A trainer aircraft were converted to T-38Cs. Most of the conversions—which consisted primarily of avionics upgrades—occurred in 2003, 2004, and 2005. The conversions did not have the stated purpose of extending the T-38s' service life or improving their reliability. Nevertheless, the aircrafts' average availability rate increased immediately after the conversions. Since then, it has declined.

Average Number of Aircraft, by Fiscal Year



Most T-38As have been converted to T-38Cs.

Fleetwide Average Monthly Availability Rate

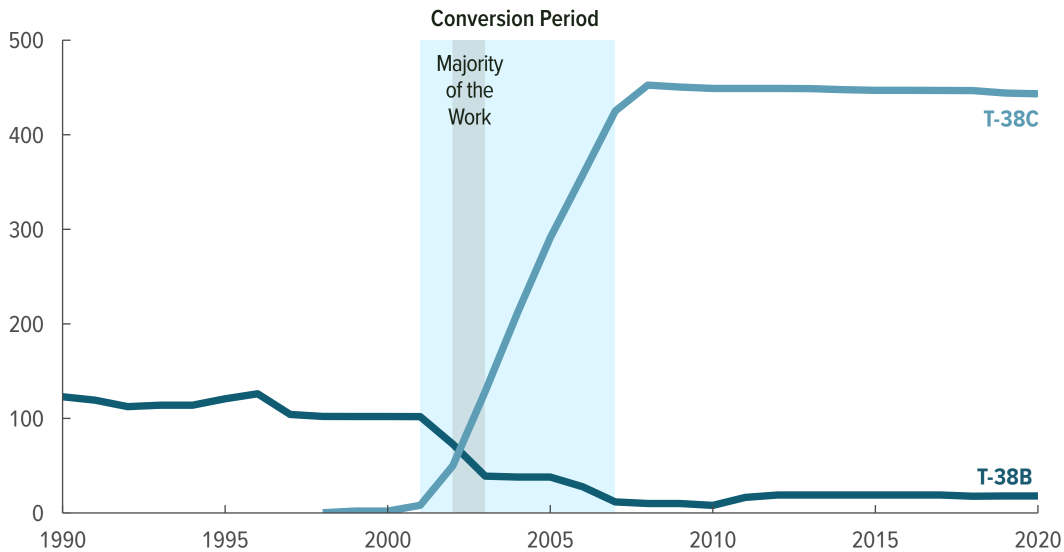


Although availability of T-38Cs increased initially after the conversion, it then declined—more quickly than availability of T-38As had been declining.

T-38B to T-38C Conversions

In the early 2000s (mainly 2002), the Air Force converted 86 T-38B trainer aircraft to T-38Cs. Similar to the A-to-C conversions, those B-to-C conversions consisted primarily of avionics upgrades. CBO found no evidence of improved availability immediately after the conversions, and the availability rate has trended downward since then.

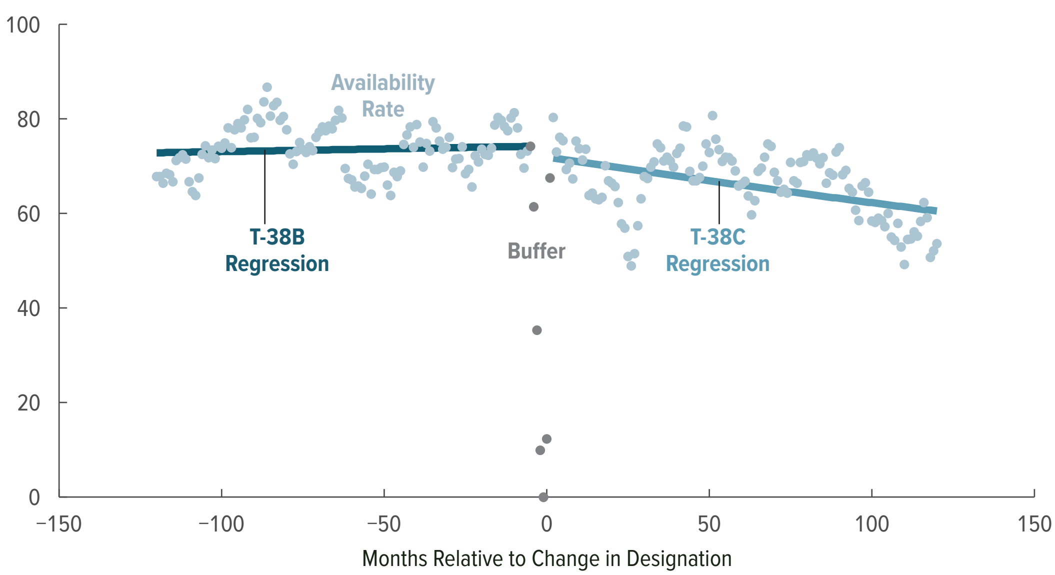
Average Number of Aircraft, by Fiscal Year



The Air Force retains a small number of T-38Bs.

Fleetwide Average Monthly Availability Rate

Percent



Since their conversion, T-38Cs have been less available than CBO estimates they would have been otherwise. Before the conversion, availability of T-38Bs had neither a positive nor a negative trend.

Appendix: Methodology

This appendix provides the regression results for the aircraft conversions discussed in the body of the report (see Table A-1).

All of the regressions took this form:

$$\ln(\text{Availability Rate}) = \alpha + \alpha_{Post} \times I_{Post} + \beta \times \text{Month} + \beta_{Post} \times I_{Post} \times \text{Month}$$

Months preceding the conversion (which is known as month zero, or the month in which the aircraft's Mission Design Series designation changed) are denoted with negative numbers, and months following the conversion are denoted with positive numbers. I_{Post} is an indicator variable set equal to one for months after month zero and equal to zero for months before it. Months in the buffer zone around each conversion were omitted from the estimation. The unit of observation is each fleet's monthly average availability rate, which is the percentage of time that the aircraft is coded as being mission capable while possessed by an operational unit. The number of observations refers to the number of months of data used in the regression; it is not related to the number of aircraft in each fleet.

If $\widehat{\alpha}$ denotes the regression's estimated intercept and $\widehat{\beta}$ denotes the regression's estimated value on the month variable, in month T_{Pre} preceding the conversion, the estimated availability rate would be $e^{\widehat{\alpha} + \widehat{\beta} \times T_{Pre}}$. For a month T_{Post} after the conversion, the estimated availability rate would be $e^{\widehat{\alpha} + \widehat{\alpha_{Post}} + (\widehat{\beta} + \widehat{\beta_{Post}}) \times T_{Post}}$. In that formulation, if the estimated $\widehat{\alpha_{Post}}$ coefficient was statistically significantly different from zero, the estimated availability rate changed after the conversion. If the estimated $\widehat{\beta_{Post}}$ coefficient was statistically significantly different from zero, the estimated slope of the availability curve changed after the conversion.

Table A-1.

Regression Results

Coefficient	Estimate	Standard Error	T Statistic
	A-10A to A-10C (Observations: 311, R squared: 0.8389)		
α	-0.56674	0.00679	-83.409
α_{Post}	0.11766	0.01283	9.169
β	-0.00159	0.00005	-31.451
β_{Post}	0.00023	0.00020	1.152
	C-5B to C-5M (Observations: 254, R squared: 0.5141)		
α	-0.78168	0.01380	-56.655
α_{Post}	0.05912	0.03222	1.835
β	-0.00153	0.00010	-15.250
β_{Post}	0.00363	0.00100	3.609
	KC-135E to KC-135R (Observations: 219, R squared: 0.1438)		
α	-0.56673	0.03560	-15.920
α_{Post}	-0.04417	0.04089	-1.080
β	-0.00186	0.00081	-2.303
β_{Post}	0.00305	0.00084	3.647
	KC-135Q to KC-135T (Observations: 317, R squared: 0.0741)		
α	-0.50588	0.05471	-9.246
α_{Post}	0.08895	0.05713	1.557
β	-0.00640	0.00180	-3.553
β_{Post}	0.00648	0.00180	3.596
	T-38A to T-38C (Observations: 247, R squared: 0.8165)		
α	-0.32724	0.00701	-46.715
α_{Post}	0.08002	0.00967	8.271
β	-0.00046	0.00009	-5.194
β_{Post}	-0.00158	0.00012	-12.930
	T-38B to T-38C (Observations: 234, R squared: 0.3611)		
α	-0.29715	0.01752	-16.960
α_{Post}	-0.03160	0.02397	-1.318
β	0.00016	0.00025	0.653
β_{Post}	-0.00160	0.00034	-4.727

Data source: Congressional Budget Office, using data from the Air Force. See www.cbo.gov/publication/57258#data.

About This Document

This Congressional Budget Office report was prepared at the request of the Ranking Member of the Senate Armed Services Committee. In keeping with CBO's mandate to provide objective, impartial analysis, it makes no recommendations.

Edward G. Keating, David Arthur, John Kerman (formerly of CBO), and Annie Rabbane (formerly of CBO) prepared the report with guidance from David Mosher. Robert Carter and Joshua Wolfson, visiting fellows at CBO from the Air Force, assisted. Justin Falk and Sarah Sajewski provided assistance, and Adam Talaber fact-checked the report. Timothy Conley of the RAND Corporation and J. J. Gertler of the Congressional Research Service provided comments. (The assistance of external reviewers implies no responsibility for the final product, which rests solely with CBO.)

Jeffrey Kling and Robert Sunshine reviewed the report. Christine Bogusz was the editor, and R. L. Rebach was the graphics editor. An electronic version is available on CBO's website (www.cbo.gov/publication/57258).

CBO continually seeks feedback to make its work as useful as possible. Please send any comments to communications@cbo.gov.

Phillip L. Swagel
Director
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