



U.S. Department
of Transportation

**Federal Aviation
Administration**

Office of the Administrator

800 Independence Ave., S.W.
Washington, D.C. 20591

September 30, 2019

The Honorable Peter A. DeFazio
Chairman, Committee on Transportation and
Infrastructure
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

Enclosed is the report to Congress on airline and passenger safety as requested in the FAA Reauthorization Act of 2018 (Public Law 115-254, Section 328). The Act directs the Federal Aviation Administration (FAA) to submit a report on Airline and Passenger Safety no later than 180 days after enactment (April 3, 2019). The report addresses the average age of commercial aircraft owned and operated by United States air carriers; the overall use of planes, including average lifetime of commercial aircraft; the number of hours aircraft are in flight over the life of the aircraft and the average number of hours on domestic and international flights, respectively; the impact of metal fatigue on aircraft usage and safety; and a review of contractor-assisted maintenance of commercial aircraft; and a reevaluation of the rules on inspection of aging airplanes.

The report is late due to the impact of the Government furlough on the work schedule. The FAA was unable to complete the report in a timeframe that allowed submission by the statutory due date.

We have sent identical letters to Chairman Wicker, Senator Cantwell, and Congressman Graves.

Sincerely,

A handwritten signature in black ink that reads "Steve Dickson".

Steve Dickson
Administrator

Enclosure



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Office of the Administrator

800 Independence Ave., S.W.
Washington, D.C. 20591

September 30, 2019

The Honorable Maria Cantwell
Committee on Commerce,
Science, and Transportation
United States Senate
Washington, DC 20510

Dear Senator Cantwell:

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The Honorable Roger Wicker
Chairman, Committee on Commerce,
Science, and Transportation
United States Senate
Washington, DC 20510

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September 30, 2019

The Honorable Sam Graves
Committee on Transportation
and Infrastructure
House of Representatives
Washington, DC 20515

Dear Congressman Graves:

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Administrator

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Federal Aviation Administration
Aviation Safety

Report to Congress:

Airline and Passenger Safety

FAA Reauthorization Act of 2018 [P.L. 115-254] – Section 328

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1.0 Executive Summary

This report is submitted pursuant to Section 328 of the FAA Reauthorization Act of 2018 (the Act). The Act requires the FAA submit a report to Congress on airline and passenger safety. The report includes commercial aircraft usage data, the impact of metal fatigue on aircraft usage and safety, a review on contractor assisted maintenance of commercial aircraft, and a re-evaluation of the rules on inspection of aging airplanes.

2.0 Legislative Mandate

Section 328 of the Act requires:

- (a) REPORT.—Not later than 180 days after the date of enactment of this Act, the Administrator shall submit to the appropriate committees of Congress a report on airline and passenger safety.
- (b) CONTENTS.—The report required under subsection (a) shall include—
 - (1) the average age of commercial aircraft owned and operated by United States air carriers;
 - (2) the over-all use of planes, including average lifetime of commercial aircraft;
 - (3) the number of hours aircraft are in flight over the life of the aircraft and the average number of hours on domestic and international flights, respectively;
 - (4) the impact of metal fatigue on aircraft usage and safety;
 - (5) a review on contractor assisted maintenance of commercial aircraft; and
 - (6) a re-evaluation of the rules on inspection of aging airplanes.

3.0 Actions Taken to Address Mandate

3.1 Commercial Aircraft Usage Data

While Section 328 requests usage data for all commercial aircraft owned and operated by United States (U.S.) air carriers, the FAA notes that Section 328 later focuses on the rules on inspection of aging airplanes. The aging airplane inspection rules are only applicable to airplanes operated under Title 14 of the Code of Federal Regulations (14 CFR) Parts 121 and 129 with a maximum passenger capacity greater than 30 or payload capacity greater than 7,500 lb. In order to provide Congress with a complete data set applicable to the subject, the FAA provides usage data below for all U.S. commercial aircraft as requested, including airplanes operated under 14 CFR part 135, and for the subset of those airplanes to which the aging airplane rules are applicable. The FAA further breaks these down by passenger vs. cargo operations, as the usage is different between the two types of operations.

3.1.1 Average Age

The average age of all commercial aircraft owned and operated by United States air carriers is shown in Table 1.

Table 1. Average age of all commercial aircraft owned and operated by United States air carriers as of November 30, 2018.

Type of Operation		Average Age (Years)	Average Age (Flight Cycles)	Average Age (Flight Hours)
All Air Carrier Aircraft¹		17.1	15,310	30,000
Part 121 Airplanes with Max Pax >30 or Payload > 7500 lb.²	All	13.5	18,151	37,380
	Passenger	12.2	18,260	36,460
	Cargo Only	22.3	17,264	44,854

1. Commercial aircraft owned and operated by United States air carriers includes operations under parts 121 and 135. This includes, for example, air taxi, air charter, sightseeing/tourist, skydiving charters, air ambulances, airline passenger and cargo operations.
2. Certain aging airplane inspection rules are limited to part 121 and 129 airplanes with a maximum passenger capacity greater than 30 or pay load capacity greater than 7,500 lb.

3.1.2 Airplane Usage

Section 328 requests information on the overall use of planes and the average lifetime of commercial aircraft. The FAA tracks airplane usage for commercial airplanes, however, the FAA does not retain the date at which airplanes are declared “retired” by their owners. Therefore, the FAA cannot calculate an exact lifetime age in calendar years for each airplane that has reached the end of its life. Based on the usage data the FAA tracks for each commercial airplane, the FAA can provide a range of typical airplane lifetimes used in passenger and cargo operations, and can provide retirement statistics in terms of flight cycles and flight hours for airplanes that have been removed from service.

Table 2 shows the average last-recorded age in flight cycles and flight hours for U.S.-owned airplanes used primarily in commercial service whose owners have declared the airplanes “retired.” Figures A1 and A2, provided in Appendix A to this report, show the distribution of the last-recorded age for these retired airplanes. The spread of the distribution is very wide, as many factors affect an airplane owner’s decision to retire an airplane. The decision point to sell, retire, or replace an airplane differs across companies. The following are some of key factors in this decision:

- Maintenance costs.
- Noise levels.
- Fuel consumption.
- Loss of consumer demand.
- Regulation changes.
- Shifting operator business plans.
- Operating costs.

Therefore, a company generally decides to retire, sell, or replace an airplane long before metal fatigue becomes a driving factor.

Figures A3 and A4, in Appendix A, provide the age as of November 30, 2018, in calendar years of every passenger airplane and every cargo airplane, respectively, that are

operating under part 121 and subject to the aging airplane rules. From these charts, it is apparent that typical lifetimes as measured in calendar years are between 22 and 34 years for passenger airplanes and between 36 and 52 years for cargo airplanes.

Calendar years, however, are not the important factor for metal fatigue in airplanes. Metal fatigue is a function of repeated (cyclic) load, so the number of flight cycles and number of flight hours are the important factors when considering airplane lifetime. Figures A5 through A8 provide the number of accumulated flights and flight hours as of November 30, 2018, for passenger and cargo airplanes operating under part 121 and subject to the aging airplane rules. These charts show that the typical lifetime usage in terms of flight cycles and flight hours is not very different between passenger and cargo airplanes, even though cargo airplanes, on average, are operated over a longer span of calendar years. Passenger airplanes on average experience more flights per day than cargo airplanes.

Table 2. Average last-recorded age as of November 30, 2018, of all U.S.-owned airplanes primarily used as passenger or cargo airplanes and declared "retired."

Type of Operation		Average Age (Flight Cycles)	Average Age (Flight Hours)
All Passenger and Cargo Aircraft		36,401	57,374
Airplanes with Max Pax > 30 or Payload > 7500 lb.	All	37,064	59,264
	Passenger	37,884	58,437
	Cargo Only	33,502	62,859

Section 328 requests the number of hours aircraft are in flight over the life of the aircraft. As every airplane model is designed for a different lifetime, in order to view meaningful data on flight hour lifetime, one should look at each airplane model individually.

The oldest airplanes in use in the part 121 cargo fleet are the Boeing Models DC-9, DC-10 and 727-200. Figures A9, A10, and A11, in Appendix A, provide the current age in flight hours and flight cycles for each of these airplanes in service under part 121 as of November 30, 2018. These figures also show the limit of validity of the engineering data that supports the structural maintenance program (hereafter referred to as LOV) for each of these models (see section 3.4.3 of this report for more information). The LOV is the age in flight cycles, flight hours, or both, at which these airplanes must be removed from service.

The oldest airplanes in use in the part 121 passenger fleet are the Boeing Models 767-200 and 767-300. Figures A12 and A13 in Appendix A provide the current age in flight hours and flight cycles for each of these airplanes in service under part 121 as of November 30, 2018, and also show the LOV for these models.

Section 328 requests the average number of hours on domestic and international flights, respectively. The FAA does not distinguish between flight hours spent in U.S. airspace and flight hours spent outside U.S. airspace when collecting flight hour usage data. The FAA has no means to estimate the ratio of time spent inside vs. outside the U.S. This information does not affect the useful life of an airplane.

3.2 Impact of Metal Fatigue on Aircraft Usage and Safety

Section 328 requests information on the impact of metal fatigue on aircraft usage and safety. While metal fatigue affects all categories of aircraft and the FAA applies fatigue-assessment rules to all categories, the aging airplane inspection rules referenced in section 328(b)(6) apply only to transport category airplanes (those airplanes certified to the airworthiness standards of 14 CFR part 25). In this section of this report, the FAA will discuss the requirements for inspection of aging airplanes, and the rules for transport category airplanes that support those requirements, and will not discuss rules applicable to normal category airplanes (small airplanes), rotorcraft or engines, because those categories of aircraft are not subject to the aging airplane rules.

3.2.1 Metal Fatigue

Structural fatigue damage is progressive and is the degradation of a material subjected to repeated structural loads. This can happen because of normal operational conditions and design attributes or because of isolated situations or incidents, such as material defects, poor fabrication quality, or surface damage, such as corrosion pits, dings, or scratches. Fatigue damage can occur in small areas or structural design details, in large areas, or in multiple elements at the same time, such as adjacent frames or stringers (multiple element damage). Figure 1 shows an example of a typical fuselage skin, frame and stringer configuration with fatigue damage in the fuselage frame. Figure 2 shows an example of fatigue damage at multiple locations in a rivet line of a lap splice joining two large skin panels (multiple site damage). Without intervention, fatigue cracks will grow, and can eventually compromise the structural integrity of the airplane. Fatigue damage is increasingly likely as the airplane ages, and is certain if the airplane is operated long enough without any intervention.

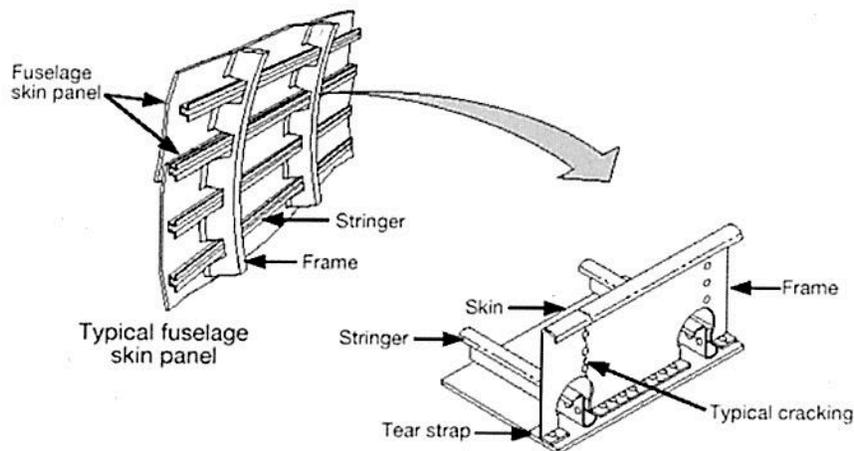


Figure 1. Illustration of a typical fuselage frame and stringer configuration with fatigue damage in the fuselage frame



Figure 2. Fatigue damage in a lap splice joining two large skin panels (multiple site damage)

The aerospace industry has long recognized that fatigue of metallic structure is a significant threat to the continued airworthiness of aircraft. This is because even small fatigue cracks can significantly reduce the strength of airplane structure, and fatigue cracks grow longer with repeated application of load. For over 60 years, the airworthiness standards for certification of new transport category airplanes have addressed fatigue. The FAA adopted these airworthiness standards to prevent catastrophic failures due to fatigue throughout the anticipated operational life of the airplane. These standards have evolved over the years and have changed as the relevant knowledge base has increased. This knowledge includes service experience, specific incidents and accidents, and technological advances in design, analysis, testing, manufacturing, and inspection of airplanes. Section 3.4 of this report summarizes the history of the FAA's fatigue management strategies and associated requirements. Section 3.4 also provides a summary of major metal-fatigue related accidents.

3.2.2 Requirements

FAA regulations for transport category airplanes include specific requirements intended to preclude catastrophic failures due to fatigue. These regulations mitigate the strength-reducing effects of fatigue regardless of why or how it manifests itself.

3.2.2.1 Damage-Tolerance and Fatigue Evaluation of Structure

For transport category airplanes, 14 CFR 25.571 requires applicants for design approvals to evaluate all structure that could contribute to catastrophic failure of the airplane with respect to its susceptibility to fatigue, corrosion, and accidental damage. The applicant must establish inspections or maintenance actions as necessary to avoid catastrophic failure during the operational life of the airplane based on the results of these evaluations.

3.2.2.2 Airworthiness Limitations and Maintenance Review Board Report

The Airworthiness Limitations section (ALS) is a mandatory section within the Instructions for Continued Airworthiness (ICA) that contains requirements for the maintenance essential to the continued airworthiness of an aircraft, engine, or

propeller. Airplanes certificated to part 25 amendment 25-54¹ and later will have an ALS specifying those items with mandatory replacement or inspection times and related structural inspection procedures approved under § 25.571. On certain existing airplanes and all new airplanes, whose application for a type certificate was after January 14, 2011, the ALS includes an LOV.² Operators may not fly an airplane beyond its LOV unless an extended LOV is approved.

Maintenance instructions contain information that includes recommended periods for cleaning, inspection, adjustment, testing, lubrication, degree of inspection, applicable wear tolerances, and recommended work necessary for each part of the airplane and its engine auxiliary power units, propellers, accessories, instruments, and equipment to provide for continued airworthiness of the airplane. Air carriers typically use the Maintenance Review Board (MRB) Report, and its associated requirements, to develop instructions for maintenance programs. The MRB contains the initial minimum scheduled maintenance and inspection requirements for a particular transport category aircraft and on-wing engine program.³

3.2.2.3 Operator Requirements

Section 91.403 requires an owner or operator of an aircraft to maintain that aircraft in an airworthy condition. In addition, it requires those persons to comply with a manufacturer's maintenance manual or instructions for continued airworthiness that contains an ALS with mandatory replacement times, inspection intervals, and related procedures specified in that section. Alternatively, an owner or operator may comply with operations specifications that contain inspection intervals and related procedures set forth in a program that has been approved by the Administrator under part 121 or 135 or § 91.409(e).

3.2.3 Impact on usage

If an airplane is properly maintained, theoretically it could be operated indefinitely. However, structural-maintenance tasks for an airplane are typically added to the maintenance program as the airplane ages and the likelihood of structural damage increases. A point is reached in an airplane lifetime at which confidence in the effectiveness of structural-maintenance tasks is not sufficient for continued operation. Maintenance tasks for a particular airplane can only be determined based on what is known about that airplane model at any given time; from analyses, tests, service experience, and teardown inspections. Damage detection before the damage reaches critical dimensions is the ultimate control in ensuring continued operational safety of airplanes. When timely damage detection is uncertain, then structural modification or retirement of structure or airplane is necessary to ensure the continued airworthiness of airplanes. Routine and non-routine maintenance essentially make up the two categories of maintenance for addressing metal fatigue.

1 Final Rule, Airworthiness Review Program; Amendment No. 8A: Aircraft, Engine, and Propeller Airworthiness, and Procedural Amendments, Amendment 25-54, Federal Register, 45 FR 60154, September 11, 1980.

2 Final Rule, Aging Airplane Program: Widespread Fatigue Damage, Amendments 25-132, 26-5, 121-351, 129-48, Federal Register, 75 FR 69745, November 15, 2010.

3 Advisory Circular (AC) 121-22C, Maintenance Review Boards, Maintenance Type Boards, and OEM/TCH Recommended Maintenance Procedures, FAA: August 27, 2012.
http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%20121-22C.pdf

3.2.3.1 Routine maintenance

Airframe manufacturers develop routine (scheduled) maintenance as a result of the damage-tolerance evaluation required by 14 CFR 25.571. Those mandatory maintenance instructions are in the ALS of the ICA, and are essential to the continued airworthiness of transport airplanes. In addition to these required actions, the airframe manufacturer, along with operators, develop a baseline maintenance program that operators will use throughout the operational life of the airplane. This program is typically established based on the MRB. Over time, operators may adjust the baseline maintenance program based on service experience in their own fleet. Figure 3 depicts the inspection and maintenance philosophy for an airplane model. While metal fatigue is a primary concern, the figure shows other damage threats that need to be addressed by an operator's maintenance program.

A routine maintenance program allows operators to plan for an airplane to be out of service to inspect and repair structure if cracks are found. As shown in Figure 3, directed inspections for metal fatigue typically occur much later in an airplane's life. The tasks associated with these inspections are generally more complex and require longer maintenance visits to accomplish due to inspection access complexity, the quantity of items operators need to inspect, and the corrective actions necessary if cracks are found. Based on this, an operator will develop a schedule for these maintenance tasks accounting for the increased scope of work.

Manufacturers often develop structural repair manuals (SRM) to provide operators with generalized repairs to correct any damage found during an inspection task. If cracking is found to exceed the damage described in the SRM, operators will typically need a specialized repair to return the airplane to service. This may cause a delay in returning the airplane to service. Besides repairing airplane structure, maintenance visits often entail replacement or modification of structure. Replacement and modification actions proactively address metal fatigue when inspections are no longer reliable.

Based on today's requirements, the last action a transport category airplane owner will do is retire an airplane at or prior to it reaching the LOV. The vast majority of airplanes are currently retired well before the LOV. These retirements are typically for economic reasons unrelated to metal fatigue considerations.

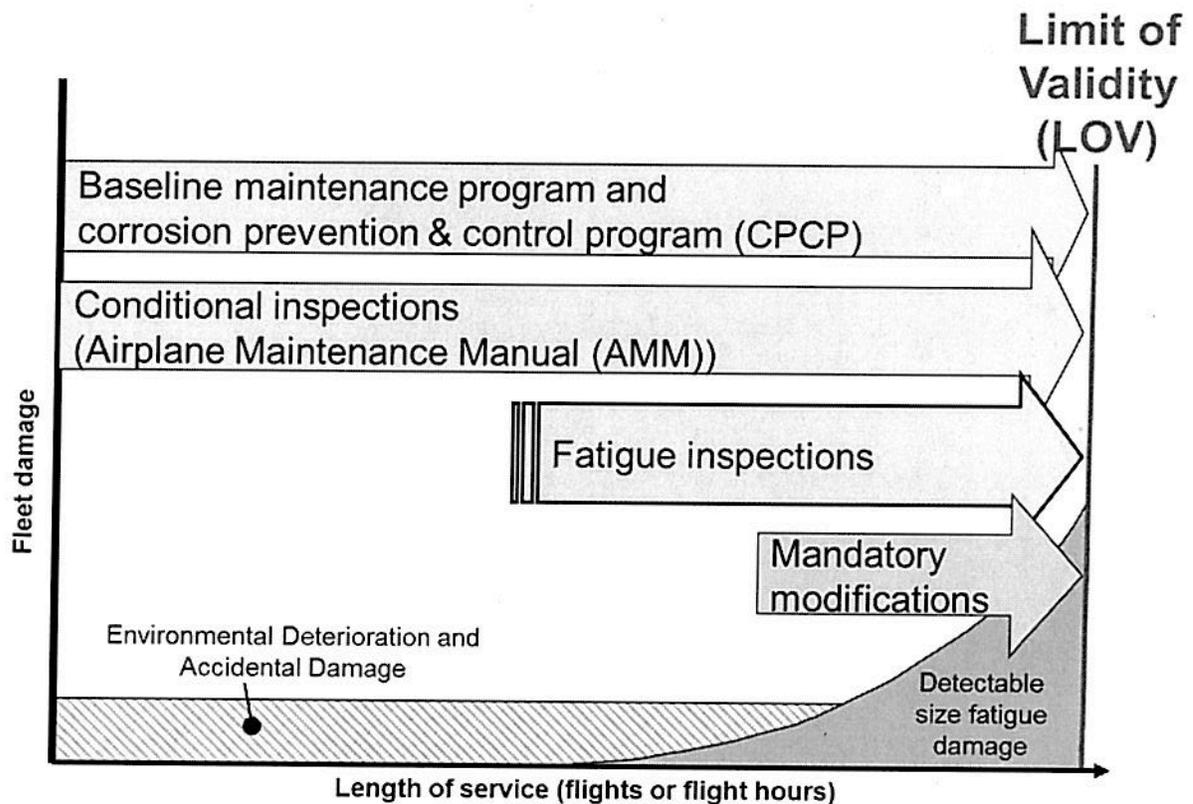


Figure 3. Inspection and Maintenance Philosophy over an Airplane Lifetime

3.2.3.2 Non-routine maintenance

While routine maintenance is planned to address metal fatigue, many factors can influence fatigue crack nucleation and growth earlier than expected, such as accidental damage, corrosion, or higher than anticipated loads. Airplane maintenance crews have found cracking outside of routine maintenance, and any crack detected in primary structure must be repaired prior to further flight. This unexpected downtime for repair can have a financial impact on airline operations due to lost revenue, as well as the additional maintenance and repair costs. Unexpected cracks detected in one airplane may also lead to an airworthiness directive⁴ to inspect for similar cracks in other airplanes of that type.

3.2.4 Impact on safety

Fatigue damage to a metallic structure occurs when the structure is subjected to repeated loads, such as the pressurization and depressurization that occurs with every flight of an airplane. Over time this fatigue damage results in cracks in the structure, and the cracks may begin to grow at the same time and eventually link together into larger

⁴ The FAA's airworthiness directives are legally enforceable rules. The FAA issues an airworthiness directive when an unsafe condition exists in a product (aircraft, engine, propeller or appliance) and the condition is likely to exist or develop in other products of the same type design. Refer to 14 CFR Part 39, [Airworthiness Directives](#).

cracks. Widespread fatigue damage (WFD) is the simultaneous presence of fatigue cracks at multiple structural locations that are of sufficient size and density that the structure will no longer meet the residual strength requirements of § 25.571(b).⁵ Structural fatigue characteristics of airplanes are understood only up to the point where analyses and testing of the structure are valid (the LOV as discussed in Section 3.2.2.2). With the Widespread Fatigue Damage rule, the FAA recently prohibited operating the larger transport category airplanes beyond that point for several reasons.² One reason is that WFD is increasingly likely as the airplane accumulates a larger number of flight cycles, and is certain to occur if the airplane is operated long enough. Another is that existing inspection methods do not reliably detect WFD because cracks are initially very small and may then link together and grow rapidly.

3.3 Contractor Assisted Maintenance of Commercial Aircraft

On March 4, 2015, the FAA issued a final rule regarding air carrier contract maintenance to amend 14 CFR 121.368, 121.369(b)(10), 135.426, and 135.427(b)(10).⁶ The new rules require affected air carriers to develop policies, procedures, methods, and instructions for performing contract maintenance that are acceptable to the FAA, and to include them in their maintenance manuals. These rules will ensure consistency between contract and in-house air carrier maintenance, and enhance the oversight capabilities of both the air carriers and the FAA.

The rules also require that air carriers provide to the FAA a list of all persons with whom they contract performance of their maintenance. The FAA needs this information to be complete and readily available in order to determine the extent to which maintenance providers are performing their work according to the air carrier's maintenance manual, and to plan surveillance of air carrier maintenance programs.

Additionally, FAA is developing and testing new internal processes, which will result in more accurate risk assessments and efficient targeting of its inspection resources for surveillance activities.

Enhancements to the FAA Flight Standards Service (FS) safety oversight model, Safety Assurance System (SAS) have been developed and implemented. These enhancements provide an interface both for new contract maintenance regulations, and internal FS surveillance processes.

3.4 Re-evaluation of the Rules on Inspection of Aging Airplanes

3.4.1 History of FAA's metal fatigue management strategies

There are three fundamental fatigue management strategies the FAA historically recognized as acceptable approaches to preventing catastrophic failures due to fatigue. They are commonly referred to as safe-life, fail-safe and damage-tolerance. A brief description of each follows.

5 After sustaining a certain level of damage, the remaining structure must be able to withstand certain static loads without failure (i.e. residual strength). In the context of WFD, the damage is a result of the simultaneous presence of fatigue cracks at multiple locations in the same structural element (i.e., multiple site damage) or the simultaneous presence of fatigue cracks in similar adjacent structural elements (i.e., multiple element damage).

6 Final Rule, Air Carrier Contract Maintenance Requirements, Amendments 121-371 and 135-132, Federal Register, 80 FR 11537, March 4, 2015.

3.4.1.1 Safe-Life

The strategy that is commonly referred to as "safe-life" involves proactive part replacement or modification when the probability of having a crack which could reduce the strength of the part is relatively low. Typically the average time to an acceptable fatigue state is determined and the time is reduced by a safety factor to establish a "safe-life" when the part must be removed from service. The factor used corresponds to the desired reliability that parts will be retired by replacement or modification before detectable fatigue cracks are present.

Successful application of the safe-life strategy requires an accurate estimate of the time required to initiate a crack. However, crack initiation is very difficult to analytically model with confidence. Consequently, safe-life substantiation heavily relies on comprehensive testing starting at the small test specimen level and concluding with full-scale structure. The resulting maintenance action is mandatory retirement of the part by removal or modification at a specified time in service regardless of condition. Today, the fatigue safe-life approach is used only if the damage-tolerance approach is impractical.

3.4.1.2 Fail-Safe

The strategy that is commonly referred to as "fail-safe" involves achieving a design where fatigue cracking will be obvious during normal maintenance and operation before the required strength is lost. Successful application of the fail-safe strategy is dependent on achieving a design that will reliably self-annunciate its cracked state at any time during its operational life prior to the strength dropping below the minimum required level. Once the damage size is determined, the fail-safe substantiation is typically performed by static analyses supported by fail-safe static testing of structure with artificially induced damage.

Use of the fail-safe strategy eliminates the need for any dedicated maintenance actions (e.g., retirement of the structure at predetermined times or special in-service inspections). It is a "business as usual" strategy, and normal maintenance and operational practices are deemed sufficient for maintenance of safety.

3.4.1.3 Damage-Tolerance

The strategy that is commonly referred to as "damage-tolerance" involves detection of fatigue cracks before the strength drops below a specified level. Unlike fail-safety, there is no supporting premise that the fatigue cracking will become obvious before it reduces the strength below the required level. The inspections required may vary from visual (to detect large, easily visible cracks) to relatively onerous non-destructive inspection (NDI) requiring specialized equipment and qualified technicians (to detect cracks not visible to the eye). For each part of the structure the failure of which could contribute to a catastrophic failure, a damage-tolerance evaluation must be performed and crack growth and residual strength characteristics quantified. Based on the results of the evaluation, an inspection method and inspection interval is determined that will result in crack detection with sufficient reliability and confidence before the required strength is lost.

Successful application of the damage-tolerance strategy is dependent on many factors. First and foremost, all fatigue-sensitive areas needing inspection must be properly identified and the most likely fatigue cracking scenario at each area established. Next, crack growth and residual strength must be accurately determined. While determination of a structure's fatigue safe-life with full-scale testing is not only possible but expected (as discussed in Section 3.4.1.1), determination of crack

growth and residual strength characteristics of a structure by full-scale testing is not practical for a number of reasons. Therefore, those characteristics are determined primarily by analysis supported by small test specimen and component tests. The detection capability of the selected inspection method must be well understood and the inspection requirements clearly documented. Lastly, the inspection requirements must be understood by the cognizant technician and the inspection must be accomplished as and when required. The damage-tolerance assessment results in mandatory inspections defined in the ALS.

3.4.2 Evaluation of metal fatigue requirements prior to 1988

One of the first significant advances in the airworthiness standards occurred in March 1956, with the revision of the fatigue evaluation requirements contained in Civil Air Regulations (CAR) 4b.270.⁷ This revision added "fail-safe strength" as an option to the "fatigue strength" approach for addressing fatigue. This rule was adopted into 14 CFR part 25 in its original issue.⁸ Motivation for this change was the realization that precluding the occurrence of fatigue cracking might not always be possible and, therefore, as an option, the structure may be designed to survive cracking. The fatigue strength approach aims for a design where fatigue cracking is not probable within the operational life of the airplane. The fail-safe approach assumes that cracking could occur, but that a specified minimum strength could be maintained after a "fatigue failure or obvious partial failure." The efficacy of the fail-safe approach was not only dependent on the structure keeping the specified minimum strength with the fatigue damage present, but also on finding the damage during normal maintenance. As applied, the fail-safe approach emphasizes redundancy as opposed to fatigue performance, and inspectability is assumed and not quantified. The fail-safe option was the predominant approach chosen for most large transport category airplanes certified in the 1960s and 1970s.

The next significant change in the airworthiness standards for fatigue occurred in October 1978 with Amendment 25-45,⁹ when § 25.571 was revised to remove the fail-safe option entirely and establish a new requirement to develop damage-tolerance-based inspections wherever practical. The Hawker Siddley 748 and Dan Air, Boeing 707, accidents identified in Table 3 contributed to the FAA's adoption of this regulatory change. The motivation for this change was the recognition, based on mounting evidence, that the fail-safe approach that had been applied up to that point was not reliable and would not achieve the desired level of safety. Specific areas of concern with the fail-safe approach included loss of "fail-safety" with age. This was due to the increased probability of cracking in the structure adjacent to the fatigue failure, or obvious partial failure, and the lack of directed inspections and quantification of residual life with the assumed damage present. It was agreed at the time that more emphasis was needed on where and how fatigue cracking could occur in the structure, and on quantifying crack growth and residual strength characteristics. Such an approach includes knowledge of damage-tolerance characteristics and development of effective inspection protocols, such as where, when, how, and how often to inspect. Amendment 25-45 incorporated this approach for certification of new transport category airplanes.

7 Civil Air Regulations Final Rule, Miscellaneous Amendments Resulting from the 1955 Annual Airworthiness Review, Amendment 4b-3, February 7, 1956.

8 Final Rule, Recodification and new Part 25, Amendment 25-0, Federal Register, 29 FR 18289, December 24, 1964.

9 Final Rule, Fatigue Regulatory Review Program Amendments, Amendment 25-45, Federal Register, 43 FR 46238, October 5, 1978.

The same events and reasoning that drove the changes to airworthiness standards for new airplanes also influenced the strategy adopted to ensure continued airworthiness of the existing fleet. There was increasing concern about existing older airplanes that had been certified according to the fail-safe requirements of CAR 4b.270. Eleven large transport models were specifically identified as needing the most attention. The FAA published guidance for developing damage-tolerance-based inspection programs on May 6, 1981 in AC No. 91-56, Supplemental Structural Inspection Program (SSIP) for Large Transport Category Airplanes. The inspection requirements for these programs were documented in supplemental structural inspection documents (SSIDs) and mandated by airworthiness directives for the eleven aging model airplanes.

3.4.3 Evaluation of requirements from 1988 through today

The Aloha Airlines accident of 1988 was caused by fatigue cracking at multiple locations of a lap splice joining two large skin panels.¹⁰ Although that airplane had an SSIP that was mandated by an airworthiness directive, there were no special directed inspections for fatigue cracks at multiple structural locations. This was because industry believed that the link-up of multiple fatigue cracks in one skin frame bay would result in safe decompression by skin flapping and that the damage to the fuselage skin would be obvious by inspection or by the inability to pressurize the fuselage.¹¹ The accident was attributed, in part, to the aging of the airplane involved. This aging included the simultaneous presence of small fatigue cracks at multiple locations in the fuselage skin lap splice. Instead of being obvious, those cracks grew undetected. Then they linked up quickly to cause catastrophic failure of a large section of the fuselage.

That accident precipitated actions that culminated in regulations aimed at avoiding catastrophic failures from fatigue in existing and future airplanes. The FAA established a task force, later named the Airworthiness Assurance Working Group (AAWG), representing the interests of the airplane operators, airplane manufacturers, regulatory authorities, and other aviation representatives. The AAWG recommended establishment of an Aging Aircraft Program to address long-term airworthiness issues in airplane structure that result from aging. The AAWG also recommended that the program include an element for addressing fatigue cracking at multiple structural locations.

The April 1988 accident also precipitated Congressional legislation. In October 1991, Congress enacted Title IV of Public Law 102-143, the Aging Airplane Safety Act of 1991 (AASA). The AASA had two key elements:

- (1) It required "the Administrator to make such inspections and conduct such reviews of maintenance and other records of each airplane used by an operator to provide air transportation as may be necessary to determine that such is in a safe condition and is properly maintained for operation in air transportation."
- (2) It specified that an operator must be able to demonstrate, as part of that inspection, "that maintenance of the airplane's structure, skin, and other age sensitive parts and components have been adequate and timely enough to ensure the highest level of safety."

¹⁰ Aircraft Accident Report NTSB/AAR-89/03, Aloha Airlines, Flight 243, National Transportation Safety Board, June 1989, <https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR8903.pdf>.

¹¹ Flapping is a phenomenon that occurs in cracks in fuselage skin subjected to cabin pressure. When the two tips of a fatigue crack meet stiffened structure, the tips change direction and turn away from the stiffened structure, creating a U-shaped crack in the skin, which then would flap open when pressurized.

The SSIPs were revised to remove the methodology for classifying certain fatigue cracking in structures as "malfunction evident" or "damage obvious" and to include damage-tolerance-based inspections for those structures.¹² The FAA issued airworthiness directives in the 1990's to mandate those changes.

In 1998, the FAA amended § 25.571 (Amendment 25-96¹³) of the aircraft certification requirements for transport category airplanes to introduce requirements for WFD. As part of the certification process, § 25.571 requires full-scale fatigue test evidence to demonstrate that WFD will not occur before an airplane reaches its design service goal.

The FAA issued the Interim Final Rule on Aging Airplane Safety in 2002,¹⁴ the Aging Airplane Safety Final Rule in 2005,¹⁵ and the Damage Tolerance Data Rule in 2007,¹⁶ along with accompanying guidance material.¹⁷ The Aging Airplane Safety Final Rule, for airplanes operated under part 121 or part 129 with a maximum type certificated passenger seating capacity of 30 or more; or a maximum payload capacity of 7,500 pounds or more, requires the maintenance program for the airplane includes FAA-approved damage-tolerance-based inspections and procedures for airplane structure susceptible to fatigue cracking that could contribute to a catastrophic failure. These inspections and procedures must take into account the adverse effects repairs, alterations, and modifications may have on fatigue cracking and the inspection of airplane structure. The Damage Tolerance Data Rule is the design-approval-holder component that facilitates operator compliance with the Aging Airplane Safety Final Rule.

In November 2010, the FAA issued Amendments 25-132 and 26-5¹⁸ to require that design approval holders establish an LOV and demonstrate that WFD will not occur in the airplane before it reaches LOV. Under this change, we also added §§ 121.1115 and 129.115 in Amendment Nos. 121-351 and 129-48, to prohibit operation of an airplane beyond its LOV. Section 26.23 provides an option for any person to extend the LOV and to develop the maintenance actions that support the extended limit. Thereafter, to operate an airplane beyond the existing LOV, an operator must incorporate the extended LOV and associated maintenance actions into its maintenance program. The airplane may not be operated beyond the extended LOV. These amendments, which specifically address WFD, were intended to be the last element of the overall Aging Aircraft Program for structures.

While the efforts of the FAAs aging airplane program to address the adverse effects of metal fatigue in aging airplanes culminated in the issuance of the WFD rule, further activities have been chartered by the FAA to improve the regulations to ensure the

12 Advisory Circular 91-56B, Continuing Structural Integrity Program for Airplanes, FAA, March 7, 2008.

https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-56B.pdf

13 Final Rule, Damage-Tolerance and Fatigue Evaluation of Structure, Amendment 25-96, Federal Register, 63 FR 15707: March 31, 1998.

14 Interim Final Rule, Aging Airplane Safety, Amendments 119-6, 121-284, 129-34, 135-81, and 183-11, Federal Register, 67 FR 72725: December 6, 2002.

15 Final Rule, Aging Airplane Safety Final Rule, Amendments 119-6, 121-284, 129-34, 135-81, and 183-11, Federal Register, 70 FR 5518, February 2, 2005.

16 Final Rule, Damage Tolerance Data for Repairs and Alterations, Amendments 26-1, 121-337, 129-44, Federal Register, 72 FR 70486, December 12, 2007.

17 Advisory Circular 120-93, Damage Tolerance Inspections for Repairs and Alterations, FAA, November 20, 2007. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-93.pdf

18 Final Rule, Aging Aircraft Program: Widespread Fatigue Damage, Amendments 25-132, 26-5, 121-351, 129-48, Federal Register, 75 FR 69746, November 15, 2010.

highest level of safety. These recent activities, which will continue into the foreseeable future, will address improvements to the regulations, including but not limited to metal, composite, and hybrid structures, as well as new manufacturing methods and inspection methods. Much of this effort is being done in collaboration with other airworthiness authorities, airplane manufacturers, material suppliers, airline operators, and universities.

The previous efforts to improve damage-tolerance and fatigue airworthiness standards and advisory material have been more specific to transport airplanes constructed predominantly of metal, using skin-stringer-frame architecture. Today, the trend in industry is to use more composite and hybrid structures (i.e., structure that includes a combination of composite and metallic parts and assemblies) to improve the performance of transport airplanes. As a result, the damage-tolerance and fatigue airworthiness standards and advisory materials may not be adequate to address this trend. In 2015, the FAA tasked the Aviation Rulemaking Advisory Committee (ARAC)¹⁹ to evaluate and provide recommendations to revise the damage-tolerance and fatigue requirements part 25 and part 26, to address composite and hybrid structure, as well as address issues applicable to typical metallic structure.

In October 2018, ARAC submitted its first recommendation report on this tasking, addressing the integration of composite structure in damage-tolerance assessment. ARAC continues to develop recommendations for some follow-on actions, and anticipates completion of those recommendations in 2020. The pending ARAC recommendations will address structural damage capability, assessment of structural bonds, and damage-tolerance methods for establishing repeat inspection intervals.

Aside from the FAA's ongoing efforts to improve the airworthiness standards, the FAA continues to conduct extensive research with respect to emerging manufacturing technologies and materials. This includes, but is not limited to, additive manufacturing, composites, and hybrid structure. Also included are emerging inspection methods and technologies for both metallic and composite structures. Several of these efforts are being coordinated with certain universities, airplane manufacturers, and material developers/suppliers. Extensive testing of new materials, design concepts, manufacturing methods, and inspection methods are ongoing. This research does not only benefit industry at large, but it also in many cases supports the FAA's review of and improvement to the airworthiness standards, including guidance material developed to support applicants' compliance with the standards.

3.4.4 Summary of metal-fatigue accidents over time

Table 3 lists major transport airplane accidents that were attributed to metal fatigue damage, some of which resulted in changes to the airworthiness standards. Following the 1988 Aloha Airlines accident and subsequent rule changes to implement the FAA Aging Airplane Program, there have been no accidents attributed to fatigue damage that indicated faults in the FAA's approach to metal-fatigue for transport category airplanes. The 1992 El Al fatigue failure in the engine mount and subsequent engine separation occurred due to shortcomings in the fail-safe design concept, which the FAA removed from the rules in 1978. The new Boeing Model 747 engine mount design installed after the accident met the later damage-tolerance requirements of § 25.571. The 2002 China Airlines accident was attributed to an improperly engineered repair, and could not be prevented by any revised or new U.S. regulatory requirement.

¹⁹ Notice, Aviation Rulemaking Advisory Committee—New Task, Federal Register, 80 FR 4029, January 26, 2015.

4.0 Conclusion

Today, as a result of the continued improvements in the FAA regulations, combined with the collaboration efforts with other regulatory agencies and the aircraft industry at large, effective maintenance programs have been developed by airplane manufacturers and implemented by airline operators. The current regulations require a robust multilayered approach to ensuring the continued airworthiness of aging airplanes. These improvements are reflected in the positive airplane safety record over the past 15 years.

Table 3. Transport category airplane accidents attributed to metal fatigue damage in airplane structure.

Year	Airplane Model	Cause	Regulatory Changes
1956	de Havilland Comet (2 catastrophic accidents)	Fatigue cracking initiating at window corners, leading to fuselage breakup	Fail-safe requirement added to § 4b.270 of the Civil Aviation Regulations
1976, 1977	Hawker Siddley 748 Dan Air, Boeing 707	Fatigue cracking leading to failure in wing and horizontal stabilizer	Fail-Safe requirement not adequate. Damage-tolerance requirements added to § 25.571
1979	American Airlines DC10	Failure of engine mount due to fatigue cracking. Guidance on executing certain critical maintenance tasks not clear	Added § 25.1529, Instructions for Continued Airworthiness
1985	Japan Airlines 747-100	Fatigue failure in aft pressure bulkhead, attributed to an improperly engineered repair	No changes. The repair was not compliant to existing rules.
1988	Aloha Airlines 737-200 (failure occurred at over 80,000 flight cycles)	Explosive decompression caused by fatigue damage and disbonding of fail-safe straps. Also attributed to improper maintenance that led to corrosion.	FAA Aging Airplane program initiated. Elements of program: <ul style="list-style-type: none"> • Airworthiness directives to mandate inspections and modifications • Repair assessment guideline rule • Damage-tolerance inspections for repairs and alterations • Full scale fatigue test requirement • WFD assessment with LOV
1992	EI AI 747-200F	Engine separation due to failed engine strut. Failure was the result of fatigue damage in fail-safe (double-barreled) fuse pins.	No changes. The original design was certified prior to incorporation of damage tolerance requirements.
2002	China Airlines 747	Fatigue failure in aft pressure bulkhead, attributed to an improperly engineered repair.	No changes. The repair was not compliant to existing U.S. rules.

Appendix

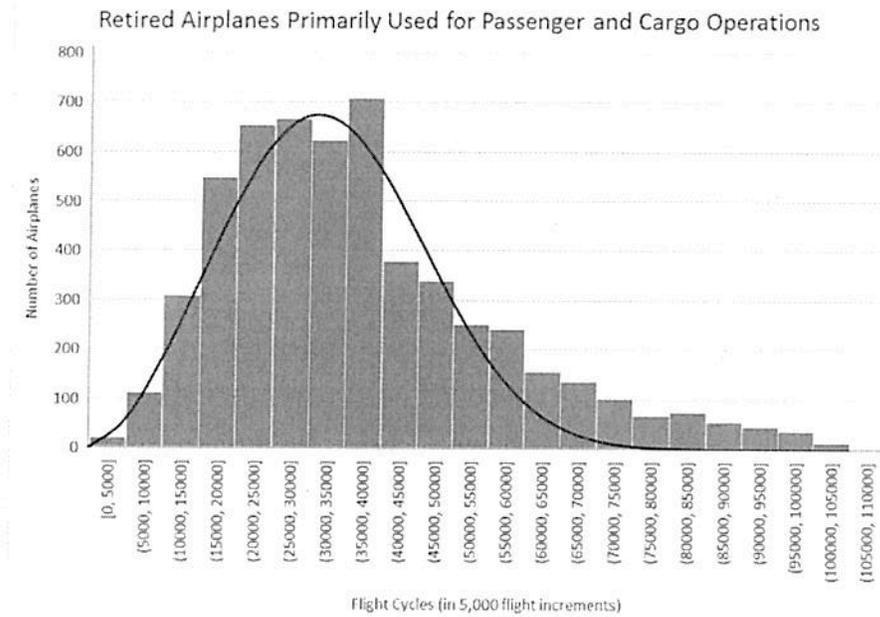


Figure A1. Age Distribution in Flight Cycles of Retired Airplanes Primarily Used for Passenger and Cargo Operations

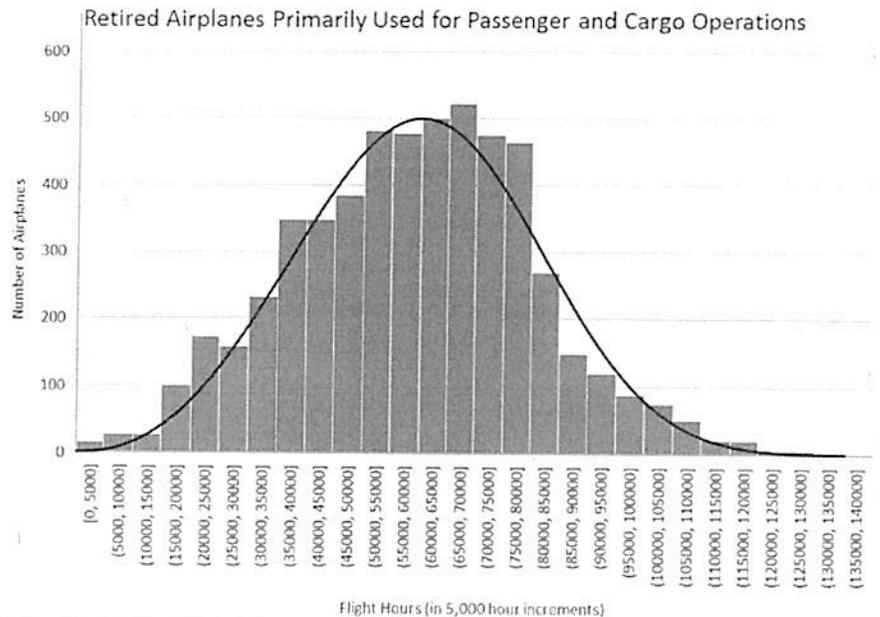


Figure A2. Age Distribution in Flight Hours of Retired Airplanes Primarily Used for Passenger and Cargo Operations

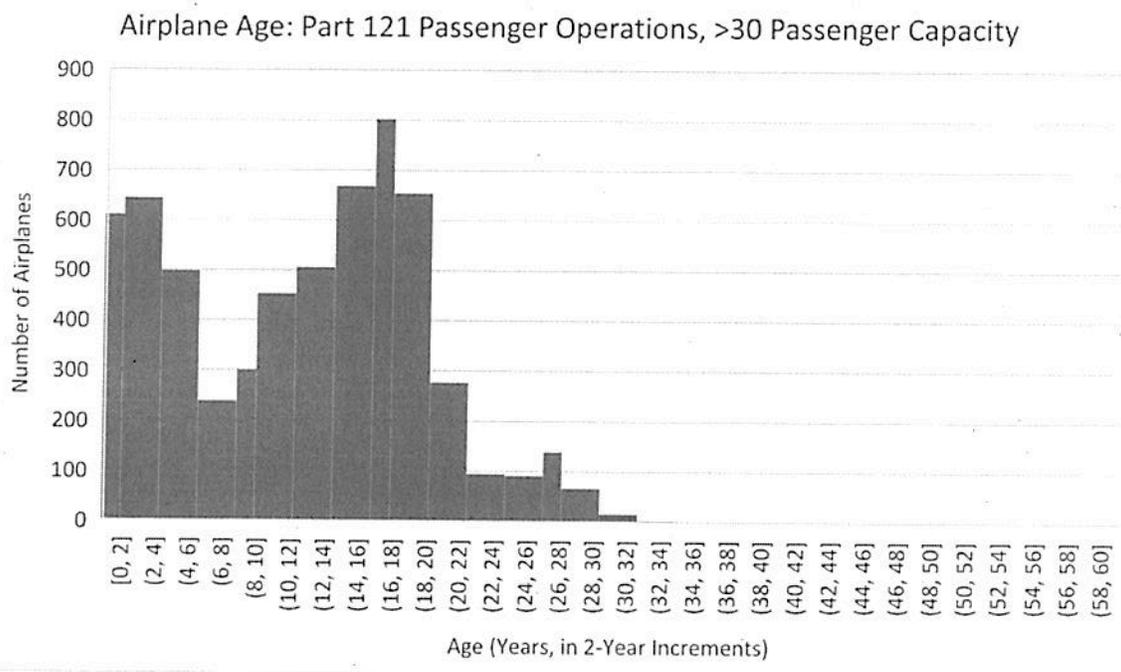


Figure A3. Airplane Age in Calendar Years for In-Service Airplanes with Maximum Passenger Capacity Greater than 30, in Part 121 Passenger Operations

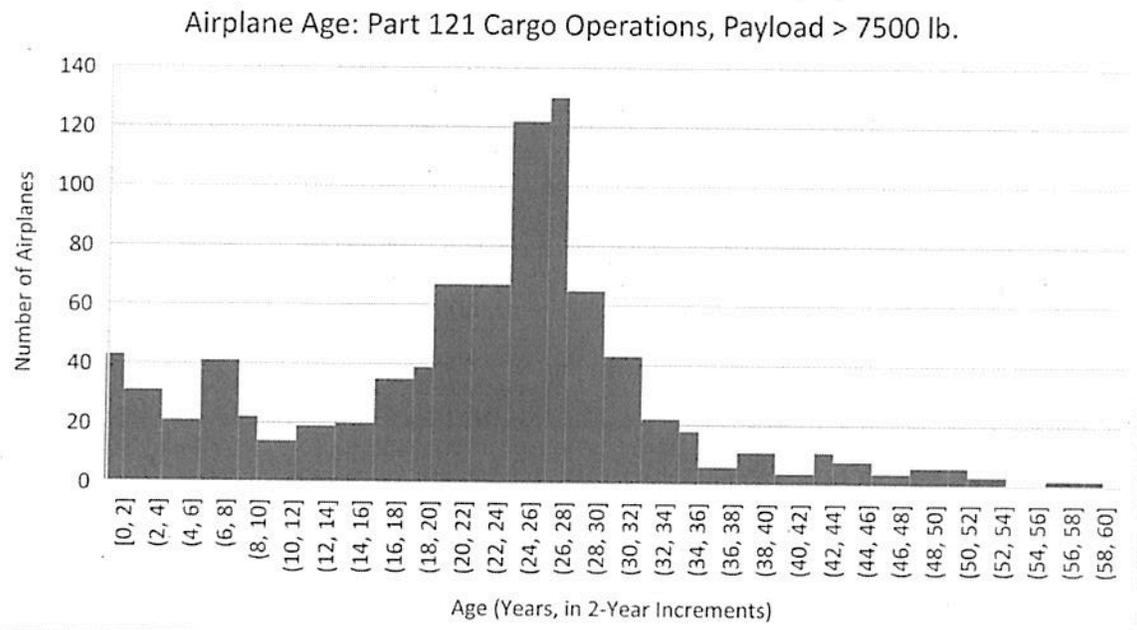


Figure A4. Airplane Age in Calendar Years for In-Service Airplanes with Payload Greater than 7500 lb. in Part 121 Cargo Operations

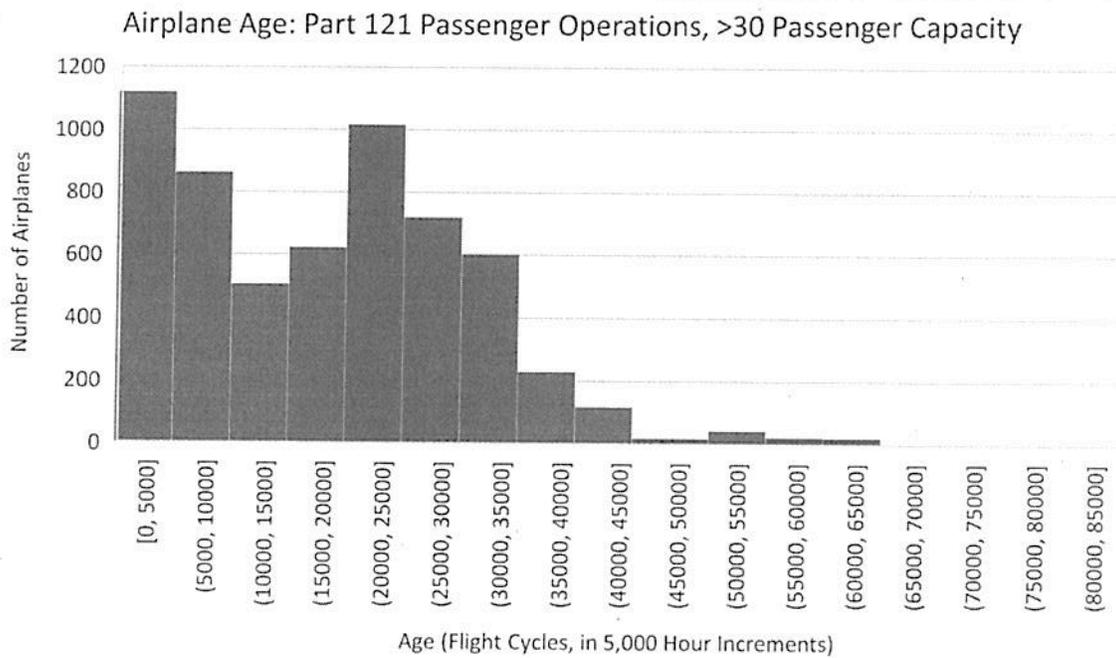


Figure A5. Airplane Age in Flight Cycles for In-Service Airplanes with Maximum Passenger Capacity Greater than 30, in Part 121 Passenger Operations

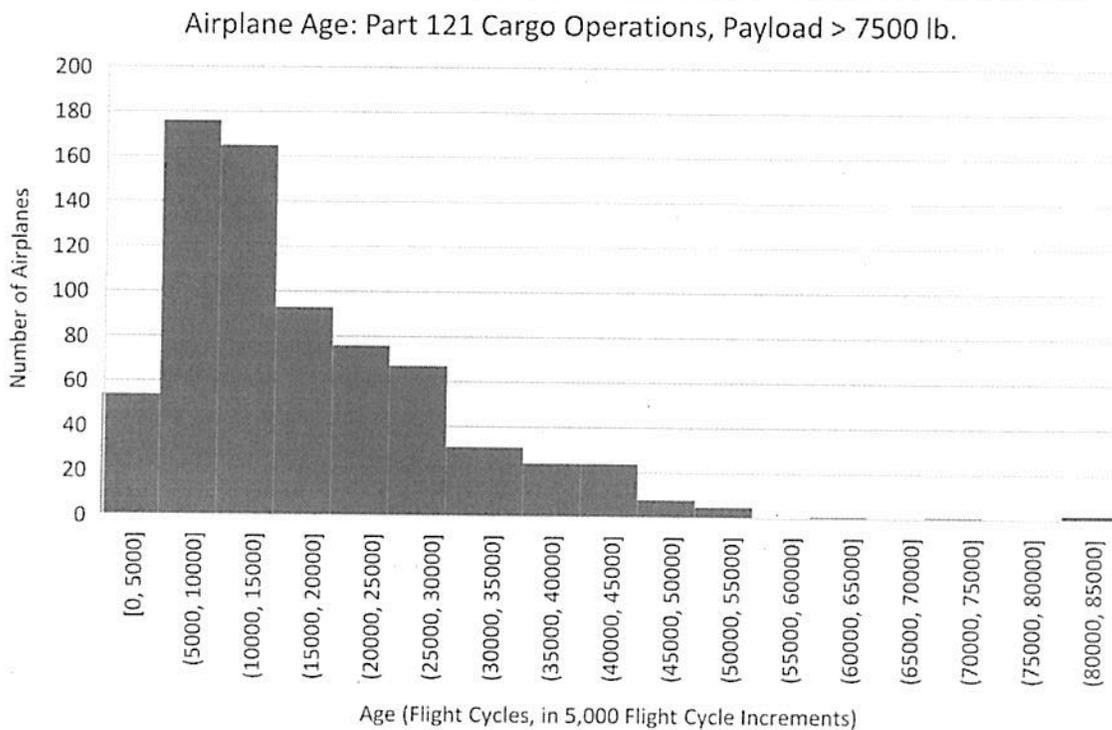


Figure A6. Airplane Age in Flight Cycles for in-Service Airplanes with Payload Greater than 7500 lb. in Part 121 Cargo Operations

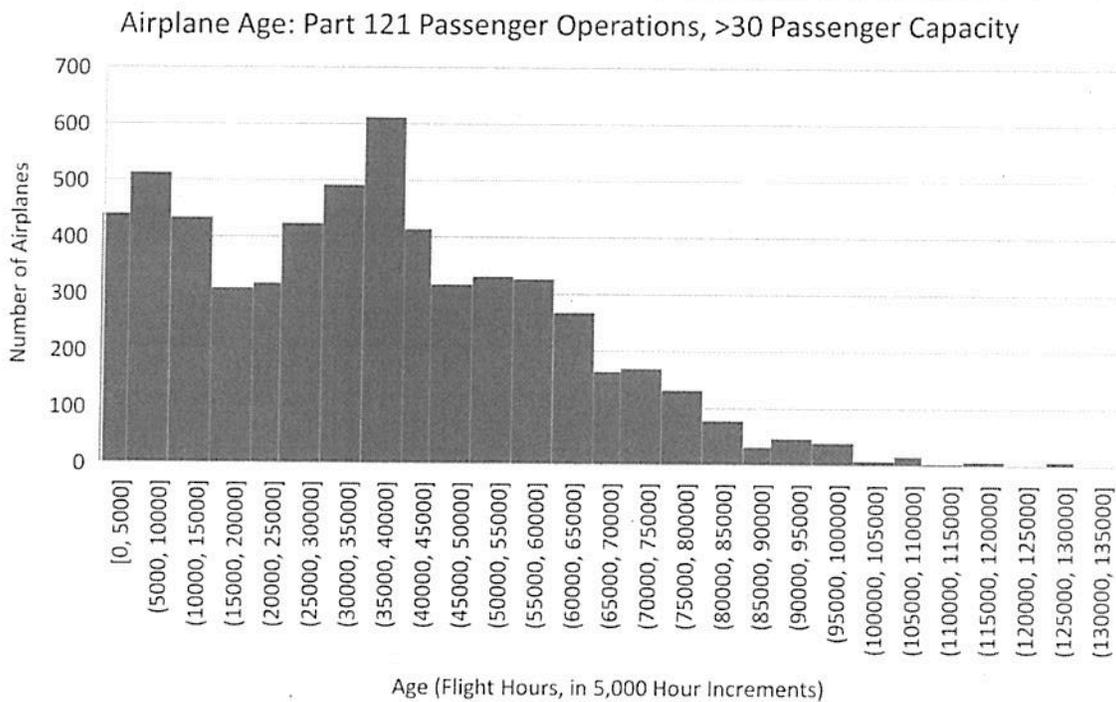


Figure A7. Airplane Age in Flight Hours for In-Service Airplanes with Maximum Passenger Capacity Greater than 30, in Part 121 Passenger Operations

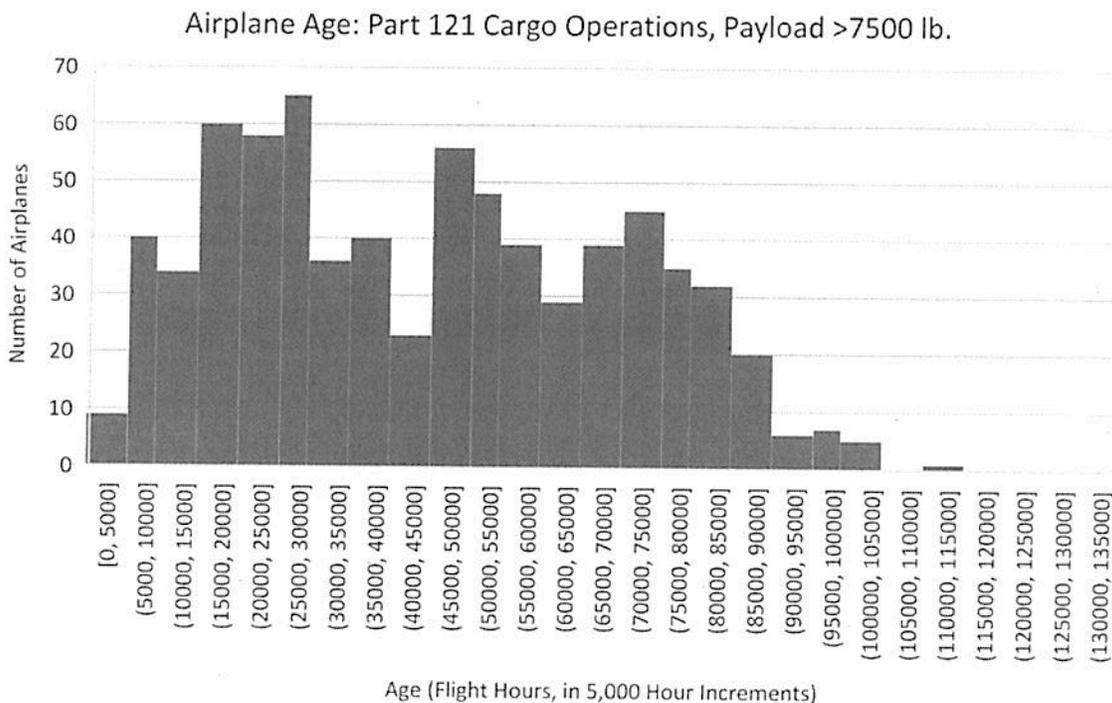


Figure A8. Airplane Age in Flight Hours for In-Service Airplanes with Payload Greater than 7500 lb. in Part 121 Cargo Operations

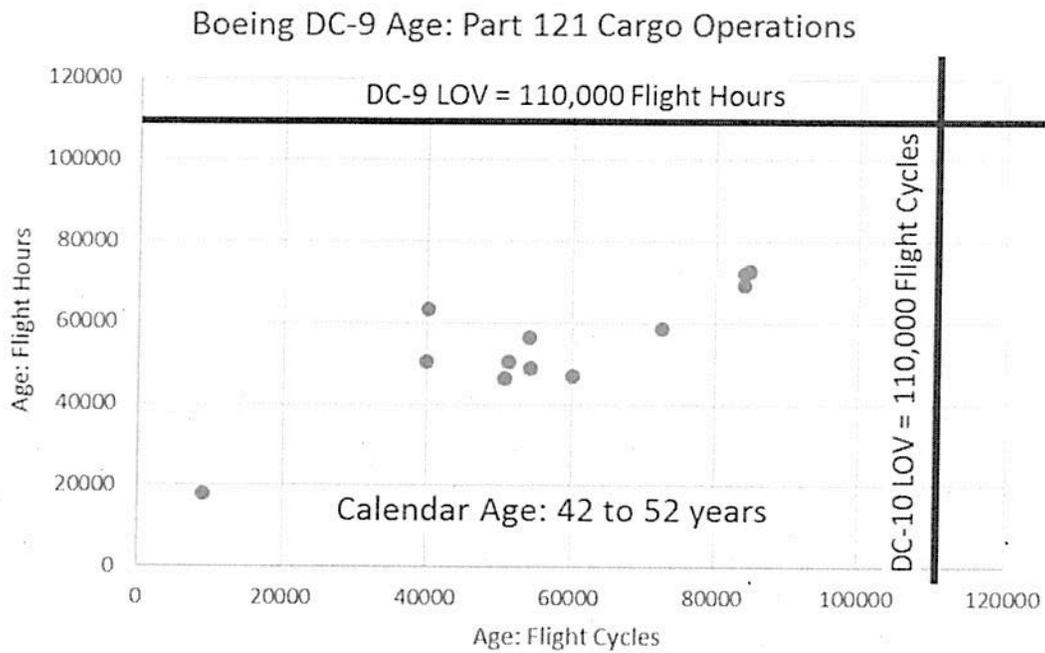


Figure A9. Boeing Model DC-9 Age in Flight Cycles and Flight Hours In-Service in Part 121 Cargo Operations

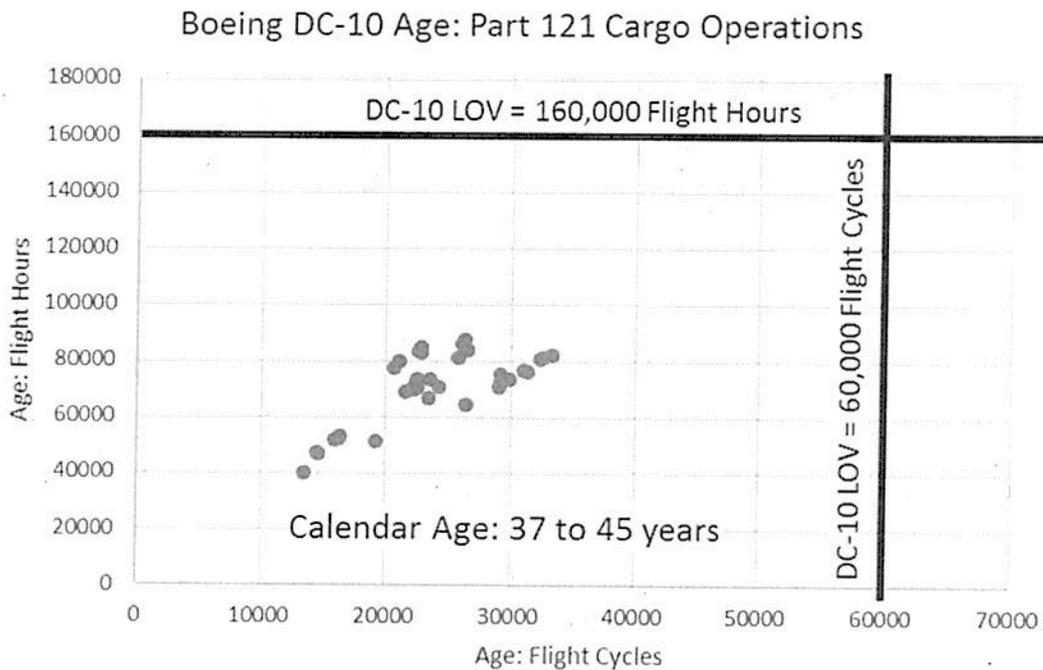


Figure A10. Boeing Model DC-10 Age in Flight Cycles and Flight Hours In-Service in Part 121 Cargo Operations

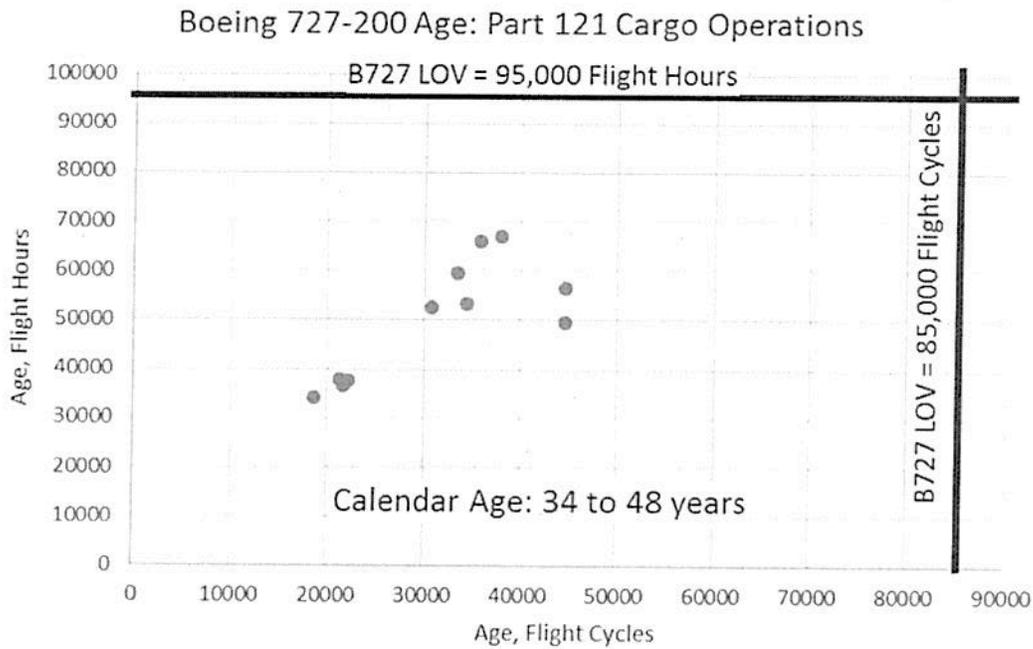


Figure A11. Boeing Model 727-200 Age in Flight Cycles and Flight Hours In-Service in Part 121 Cargo Operations

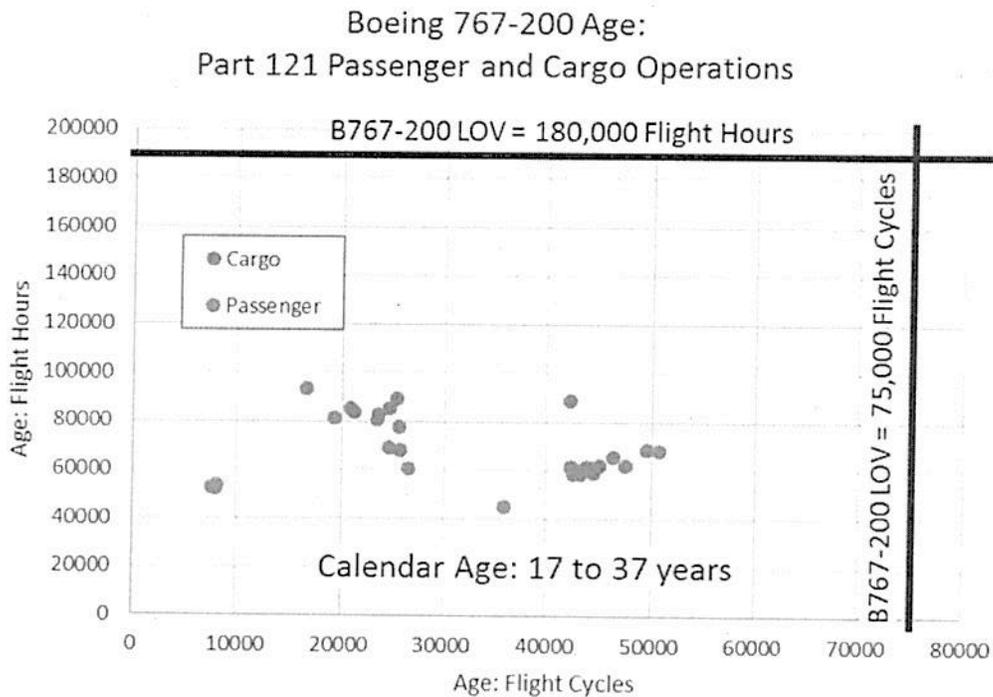


Figure A12. Boeing Model 767-200 Age in Flight Cycles and Flight Hours In-Service in Part 121 Passenger and Cargo Operations

Boeing 757-200 Age:
Part 121 Passenger and Cargo Operations

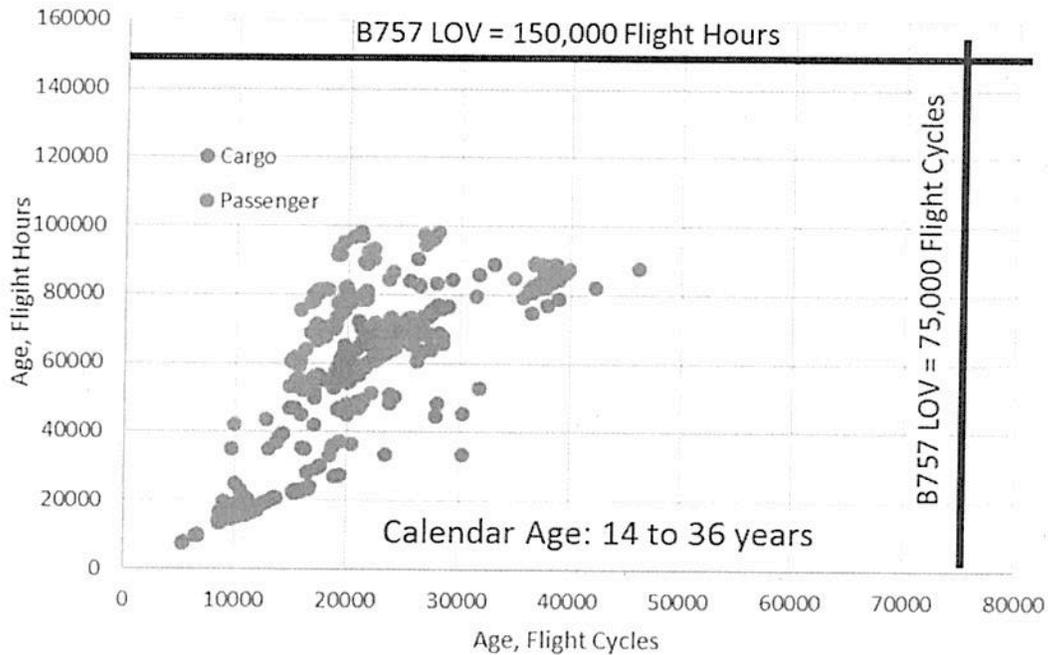


Figure A13. Boeing Model 757-200 Age in Flight Cycles and Flight Hours In-Service in Part 121 Passenger and Cargo Operations

Table A1. Certified Limits of Validity by Airplane Model as of November 30, 2018

Model	Limit of Validity	
	Flight Cycles (FC)	Flight Hours (FH)
Airbus		
A300 B2	60,000	65,000
A300 B4-100	57,000	76,000
A300 B4-200	57,000	118,000
A300 B4-600	55,000	107,000
A300 B4-600R, F4-600R, C4-600R	42,500	89,000
A310-200	45,000	105,000
A310-300	40,000	116,000
A318, A319, A321	48,000	60,000
A320-100	48,000	48,000
A320-200	60,000	120,000
A330-200 (non-enhanced)	40,000	130,000
A330-200 (enhanced)	33,000	100,000
A330-300 (non-enhanced)	44,000	126,000
A330-300 (enhanced)	33,000	100,000
A340-200 (non-enhanced)	26,000	128,000
A340-300 (non-enhanced)	31,000	156,000
A340-200 (enhanced)	20,000	100,000
A340-500/-600	16,600	100,000
A380-800	28,000	206,300
Boeing		
727	85,000	95,000
737-100/200 LN 1-291	34,000	34,000
737-100/200/200C LN 292 and on	75,000	100,000
737-300/400/500 LN 2566-3132	85,000	100,000
737-600/700/700IGW/700C/800/900/900ER	100,000	150,000
737-8/9	100,000	150,000
737-8LCA	28,000	67,000
747-100/200/300, SP, SR	35,000	135,000
747-400/400D/400F	35,000	165,000
747-8/8F	35,000	165,000
757-200/300	75,000	150,000
767-200/300	75,000	180,000
767-300F/400ER	60,000	180,000
777-200/200LR/300/300ER	60,000	180,000
777F	37,500	180,000
787-8/9/10	76,000	230,000
Boeing (Heritage McDonnell Douglas)		
DC-8	56,000	125,000
DC-9	110,000	110,000
MD-80, MD-90	110,000	150,000
DC-10	60,000	160,000
MD-10	60,000	160,000
MD-11	40,000	150,000
717	110,000	110,000
Bombardier		
CL-600-2D15/2D24 (CRJ705/CRJ900)	80,000	110,000
CL-600-2E25 (CRJ1000)	60,000	N/A
Fokker		
F28/F70/F100	90,000	N/A
Lockheed		
L-1011	46,000	N/A
L188	26,600	N/A
L382	75,000	N/A
Embraer		
ERJ 170-100/-200	80,000	80,000
ERJ 190-100	80,000	80,000