U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Fatigue Management Programs for Airplanes with Demonstrated Risk of Catastrophic Failure Due to Fatigue

Date: 4/29/08

Initiated by: AFS-300

AC No: 91-82

Change:

1. PURPOSE.

a. This advisory circular (AC) provides guidance on developing and implementing a Fatigue Management Program (FMP). An applicant may develop an FMP as one method to address the unsafe condition that arises when the Federal Aviation Administration (FAA) has determined an airplane type design has an unsafe condition associated with a demonstrated risk of catastrophic failure due to fatigue (hereinafter referred to as demonstrated risk). An FMP incorporates damage-tolerance based inspections or a part replacement/modification program to mitigate the demonstrated risk. An FMP also incorporates inspections based on service history and engineering judgment to address the broader risk posed by potential cracking of other fatigue critical structure in the airplane. The FAA may mandate an FMP by Airworthiness Directive (AD) only in cases in which the FAA has determined that airworthiness action is necessary to address an unsafe condition. The FAA may also approve an FMP as an alternative method of compliance (AMOC) to an AD.

b. This AC provides guidance for actions once the FAA determines that an AD is necessary to address the unsafe condition associated with a demonstrated risk. Existing FAA guidance supports development of damage-tolerance based inspection programs for transport category airplanes to look proactively for potential cracks. Such guidance includes AC 91-56B, Continuing Structural Integrity Program for Airplanes, and AC 25.571-1C, Damage Tolerance and Fatigue Evaluation of Structure. These existing ACs do not describe all the actions that should be used to address a demonstrated risk.

c. This AC is not mandatory and does not constitute a regulation. It describes an acceptable means, but not the only means, for maintaining the continued operational safety for airplane type designs that have a demonstrated risk. However, if you use the means described in this AC, you must follow it in all important aspects. In this AC, we use terms such as “must” or “require” only in the sense of ensuring applicability of a particular method of compliance when you use a specific acceptable method of compliance described herein.

2. CANCELLATION. This AC cancels AC 91-60, The Continued Airworthiness of Older Airplanes, dated June 13, 1983.

3. RELATED REGULATIONS. Refer to the following Title 14 of the Code of Federal Regulations (14 CFR) sections, as applicable.

a. Design approval holder responsibilities for reporting of failures, malfunctions and defects included in part 21, § 21.3.

b. Certification procedures for instructions for continued airworthiness (ICA) and airworthiness limitations included in part 21, § 21.50.

c. Certification procedures for changes to type designs included in part 21, § 21.93.

d. Requirements for Supplemental Type Certificates (STC) included in part 21, § 21.113.

e. Small airplane requirements for strength and deformation included in part 23, § 23.305.

f. Small airplane requirements for fatigue, fail-safe, and damage-tolerance evaluations included in part 23, §§ 23.571, 23.572, 23.573, 23.574, and 23.627.

g. Small airplane requirements for inspections and ICAs included in part 23, §§ 23.575, 23.611, and 23.1529.

h. Transport category airplane requirements for strength and deformation included in part 25, § 25.305.

i. Transport category airplane requirements for fatigue and damage-tolerance evaluations included in part 25, § 25.571.

j. Transport category airplane requirements for ICAs included in part 25, § 25.1529.

k. AD requirements included in part 39.

4. DEFINITIONS. The following definitions apply for this AC:

a. Accident. An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and the time all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

b. Applicant. An applicant is any interested party, including the design approval holder (DAH), who is developing a fatigue management program.

c. Damage-Tolerance Based Inspection. An inspection based on consideration of the crack growth and residual strength characteristics of the structure, the physical access to the structure, and the inspection method reliability. The inspection should provide a high probability of detecting fatigue cracking before the residual strength degrades below a specified value.

d. Demonstrated Risk of Catastrophic Failure Due To Fatigue.

(1) An airplane type design has a "demonstrated risk of catastrophic failure due to fatigue" when:

- An airplane has experienced a catastrophic failure due to fatigue and the same scenario is likely to occur on other airplanes in the fleet,
- Airplanes of the type design have a service history that indicates a significant likelihood of catastrophic failure due to fatigue in the fleet, or
- Fatigue testing of the type design indicates a significant likelihood of catastrophic failure due to fatigue in the fleet.

(2) For the purpose of this AC, the term "demonstrated risk of catastrophic failure due to fatigue" will be referred to as "demonstrated risk."

e. DAH. A holder of a type certificate (TC) or STC issued under part 21.

f. Fatigue Critical Structure. A structure that is susceptible to fatigue cracking that could lead to a catastrophic failure of an airplane. This would typically include airframe primary load carrying elements subjected to repeated tension dominated loading. Examples include, but are not limited to:

- Joints or splices of tension dominant load path, e.g. lower spar caps, skins, stringers, fittings, bolts, etc;
- Maximum tension bending moment location on the wing and horizontal tail;
- Fuselage carry-through structure area similar to the above items, as applicable;
- Areas in primary wing load path where other loads are introduced such as engine or landing gear attachments;
- Wing strut attachments – both ends;
- Empennage attach areas; and
- Pressurized fuselage skins, frames, and longerons.

(1) For airplanes designed for high negative g loads (such as acrobatic category), joints, splices, and maximum compression bending moment locations on the wing and horizontal tails may also be fatigue critical.

(2) For some designs, control surface and flap hinge fittings and their attach structure may be fatigue critical. If there is no documentation, such as that normally provided at time of certification, to show these areas are *not* critical to safe flight, you should consider them.

g. FMP. An FMP is a set of maintenance actions whose purpose is to prevent catastrophic failure due to fatigue. An FMP becomes mandatory if the FAA incorporates it into an AD to address an unsafe condition. The FAA may also approve an FMP as an AMOC to an AD. The maintenance actions may include the inspection, modification, or replacement of fatigue critical structure. As a minimum, for the purposes of this AC, an FMP must:

(1) Address the structural elements involved in the unsafe condition. Applicants should base inspections or a part replacement/modification program on comprehensive damage-tolerance or fatigue evaluations. The applicant may limit the scope of the detailed evaluation to the structural elements directly involved in the unsafe condition.

(2) Include provisions for proactive inspection of other likely fatigue critical structure in the airplane. An applicant may base these inspections on service history experience and engineering judgment.

h. Fleet. For the purposes of this AC, a fleet is all airplanes of the same type design.

i. Incident. For the purposes of this AC, an incident is an occurrence (other than an accident) associated with the operation of an aircraft that affects or could affect the safety of operations. This includes in-service findings reported according to § 21.3.

j. Residual Strength. The strength capability of a structure after fatigue, corrosion, or a discrete source has damaged the structure. The residual strength capability includes consideration of static strength, fracture, and stiffness.

k. Service History Based Inspection. An inspection based on qualitative information derived from experience with the same or similar structure. Although directed at a likely fatigue critical site, the applicant does not typically quantify or validate the inspection's effectiveness.

l. Safe-Life. The number of events, such as flights, landings, or flight hours time in service, during which there is a low probability the strength will degrade below its design ultimate value due to fatigue.

m. Unsafe Condition. For the purposes of this AC, an unsafe condition is fatigue cracking that either resulted in a catastrophic failure or without intervention could result in a catastrophic failure.

5. APPLICABILITY.

a. This AC is applicable to:

- Small airplanes certificated to part 23 or predecessor regulations,
- Transport category airplanes certificated to part 25 or predecessor regulations, and
- Airplanes certificated in the primary and restricted categories.

b. The following may use this AC to develop FMPs:

- DAHs,
- Applicants for STCs,
- Applicants for AMOC to ADs,
- FAA aircraft certification engineers, and
- FAA Designated Engineering Representatives (DER) or delegated organizations.

6. RELATED PUBLICATIONS (current editions).

a. ACs.

(1) AC 21-40A, Application Guide for Obtaining a Supplemental Type Certificate, dated September 27, 2007.

(2) AC 23-13A, Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes, dated September 29, 2005.

(3) AC 25.571-1C, Damage Tolerance and Fatigue Evaluation of Structure, dated April 29, 1998.

(4) AC 43-4A, Corrosion Control for Aircraft, dated July 25, 1991.

(5) AC 91-56B, Continuing Structural Integrity Program for Airplanes, dated March 7, 2008.

b. Orders.

(1) FAA Order 8110.4C CHG 1, Type Certification, dated March 28, 2007.

(2) FAA Order 8110.54, Instructions for Continued Airworthiness: Responsibilities, Requirements, and Contents, dated July 1, 2005.

(3) FAA Order 8900.1, Flight Standards Information Management System (FSIMS), dated September 13, 2007.

c. Others.

(1) Best Practices Guide for Maintaining Aging General Aviation Airplanes, Appendix 1 — Aging Airplane Inspection & Maintenance Baseline Checklist for Airplanes Without a Type Specific Checklist, dated September 2003. An electronic version is available at http://www.faa.gov/aircraft/air_cert/design_approvals/small_airplanes/cos/aging_aircraft/media/aging_aircraft_best_practices.pdf.

(2) Commercial Airplane Certification Process Study, An Evaluation of Selected Aircraft Certification, Operations, and Maintenance Process, FAA, March 2002.

(3) DOT/FAA/CT-93/69.1 and DOT/FAA/CT-93/69.2, Damage Tolerance Assessment Handbook, Volumes 1 and 2, dated October 1993.

(4) FAA and Industry Guide to Product Certification, Second Edition, dated September 2004.

(5) General Aviation Manufacturers Association's Specification No. 2, Maintenance Manual.

(6) Nondestructive Evaluation (NDE) Capabilities Data Book, W.D. Rummel and G.A. Matzkanin, Nondestructive Testing Information Analysis Center (NTIAC), Texas Research Institute, Austin, Texas.

7. BACKGROUND.

a. In the early 1980s, because of concerns about the continued airworthiness of older airplanes certified to the Civil Air Regulation (CAR) 4b fail-safe requirements, the FAA began issuing ADs mandating damage-tolerance based structural inspection programs. The intent of the programs mandated by these ADs was to prevent unacceptable degradation of the structural integrity of the affected airplanes and thus to assure long-term continued operational safety of the fleet. These programs were proactive in that they addressed potential fatigue that could develop into an unsafe condition.

b. There have been airframe fatigue-related accidents and incidents that have required certain follow-on actions to maintain the continued operational safety of the fleet. Except for the requirement to report failures, malfunctions, and defects in § 21.3, no specific regulation or guidance exists to assist an applicant on what actions to take following a catastrophic failure due to fatigue or an in-service finding of fatigue cracking. Consequently, the FAA has worked on a case-by-case basis with applicants, owners, and operators to determine the actions needed to maintain the continued operational safety of these airplanes.

c. Reactively, to address a known unsafe condition that is likely to occur on other airplanes of the same type design, the FAA has mandated actions that deal with the specific unsafe condition. These actions typically include inspections, repair, or replacement of specific primary structural parts. However, in-service experience and fatigue test data have shown that actions to address one unsafe condition and extend the operation of a model fleet allowed a second unsafe condition to develop. Therefore, occurrence of fatigue in one critical part may be a precursor to fatigue in other critical structure and should be addressed proactively.

8. APPLICATION OF CERTIFICATION REQUIREMENTS TO UNSAFE CONDITIONS. The guidance included in this AC describes how applicants may apply the requirements in 14 CFR that address metal fatigue to address a known unsafe condition. These requirements include several approaches[1] for preventing catastrophic failure due to fatigue in new type designs. An applicant may successfully apply any of these approaches to an unsafe condition if the applicant understands:

- The intent of the design requirements,
- The underlying philosophy of the fatigue prevention approaches, and
- The safety issues posed by a known unsafe condition.

a. Safe-Life. For airplanes certificated using the safe-life approach, the safe-life of a structure is the number of events, such as flights, landings, or flight hours time in service during which there is a low probability the strength will degrade below its design ultimate value due to fatigue. The safe-life is a point in the airplane's operational life when the operator must replace, modify, or take the structure out of service to prevent it from developing fatigue cracks that can degrade the strength below its design ultimate value.

(1) An applicant can use the safe-life approach to address an unsafe condition by establishing a point in the operational life of the airplane when the operator must replace, modify, or take the structure out of service. If a catastrophic failure due to fatigue has occurred, or if an inspection finds cracks in-service, the safe-life of that structure likely has already passed. Based on service history, an applicant could establish a retroactive safe-life for the structure. Airplanes below the service history based safe-life could continue to operate until they reach the safe-life. For airplanes already at or beyond the service history based safe-life, the applicant could immediately replace, modify, or remove the structure from service or establish a schedule for completing these actions. To manage the risk, the FAA would coordinate any schedule with the applicant and consider:

- The number of airplanes used in commercial service,
- The risk of allowing operation beyond the service history based safe-life,
- The effectiveness of inspecting the structure,
- The residual strength characteristics of the structure,

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[1] For new type designs constructed with metallic structure seeking certification in the normal, utility, and acrobatic categories, 14 CFR part 23 allows the applicant to choose between the safe-life, damage-tolerance, and fail-safe design approaches. For new type designs in the commuter category or designs using composite materials, part 23 requires the applicant to use damage-tolerance, unless the applicant shows that damage tolerance is impractical. For transport category airplanes, 14 CFR part 25 requires the use of damage tolerance, unless the applicant shows that damage-tolerance is impractical.

- The availability of replacement parts, and
- Other relevant factors.

(2) For normal, utility, acrobatic, or primary category airplanes, any replacement or modified structure must comply with the current safe-life, fail-safe, or damage-tolerance requirements. For commuter and transport category airplanes whose certification basis includes damage-tolerance, any replacement or modified structure must comply with the applicable damage-tolerance requirements. For restricted category airplanes any replacement or modified structure must comply with the airplane category used for type certification under § 21.25.

b. Damage-Tolerance. For a new type design, the regulations include the damage-tolerance approach for preventing catastrophic failure due to fatigue. The damage-tolerance approach depends on directed inspection programs to detect fatigue cracks before they reach their critical size.

(1) Damage-tolerance allows a new type design to operate indefinitely until inspections detect cracks in the fleet (whereas a safe-life design requires replacing, modifying, or removing the structure from service at a set point in time, regardless of service history). If an inspection finds cracks in a damage-tolerant fleet, the FAA may determine that a demonstrated risk exists and require additional airworthiness actions, including more rigorous inspection requirements or fleet-wide replacement or modification of the structure.

(2) Cracking is a continued airworthiness issue because cracking usually reduces the strength of the structure below its design ultimate strength level. Service history has shown that the reliability of directed inspections is never sufficient to detect all cracks. As the number of crack reports increases, the likelihood that a number of airplanes in the fleet have undetected fatigue cracks also increases. Therefore, for areas where fatigue cracks are reported, the likelihood increases that a number of airplanes in the fleet will have strength below the design ultimate strength level. At some time during operation of the fleet, the likelihood that the strength of any given structure in a fleet is less than the design ultimate strength level becomes unacceptably high. The loss of design ultimate strength capability should be a rare event and the FAA does not knowingly allow the strength of airplanes to drop below the design ultimate strength level with any significant frequency.

(3) An applicant can use the damage-tolerance approach to address an unsafe condition. However, the applicant must understand that damage-tolerance based inspections may not provide a permanent solution, as explained in subparagraph (2) above, if we expect cracks to continue to develop in the fleet. In this case, the FAA will require the fleet-wide replacement, modification, or removal from service of the structure. The schedule for completing these actions for a structure with demonstrated damage-tolerant capability may allow a limited increase in operational life compared to the schedule for a structure with no directed inspection program or demonstrated residual strength capability.

c. Fail-Safe Design. A fail-safe design is a design that retains its required residual strength after a readily detectable failure or partial failure of a principal structural element. A fail-safe design typically consists of the fail-safe component or primary structural element, and a redundant or backup structural element(s), and/or crack arrest or crack containment features.

(1) The redundant structure provided by fail-safe design has sometimes prevented catastrophic failures. However, the FAA has documented cases in which a design thought to be fail-safe was not, and the design failed to prevent a catastrophic failure because the failure was not readily detected. AC 23-13A and the reference in paragraph 6c(2) identify several potential shortcomings of designs mistakenly thought to be fail-safe.

(2) Applicants can use the fail-safe design concept to evaluate the metallic structures of normal, utility, and acrobatic category airplanes. Prior to 14 CFR Amendments 25 45 and 23 48, fail-safe design was an option for transport category and commuter category airplane fatigue evaluation. Transport category airplanes certificated to Amendment 25-45 and subsequent, and commuter category airplanes certificated to Amendment 23-48 and subsequent, are damage-tolerant, but not necessarily fail-safe.

(3) Applicants who apply the fail-safe design approach to an unsafe condition should fully understand and address the potential shortcomings discussed in the documents listed in paragraph 6. An applicant should also understand that if we expect cracks to continue to develop in the fleet, which increases the likelihood that the strength of some airplanes' structure may deteriorate below design ultimate strength level, a fail-safe modification might not provide a solution to the demonstrated risk. In this case, the FAA will require the fleet-wide replacement, modification, or removal from service of the structure. As in the case of damage-tolerance, the schedule for completing these actions for a fail-safe design may allow a limited increase in operational life compared to the schedule for a structure with no demonstrated fail-safe characteristics.

(4) The FAA will require a special directed inspection program for any application of fail-safe design to address an unsafe condition. We cannot ignore that the original structure has a demonstrated risk. Therefore, the possibility exists that even with added redundant structure, cracking may continue to develop in the fleet. Applicants should develop an inspection program using the same methods as used in damage-tolerance to establish inspection thresholds and repeat intervals.

(5) For commuter and transport category airplanes whose certification basis includes damage-tolerance, any fail-safe modification of the structure must comply with the applicable damage-tolerance requirements.

9. OVERVIEW OF FATIGUE MANAGEMENT SYSTEM. In cases where accidents or incidents involve fatigue cracking, the FAA will act to determine if the type design (or supplemental type design) has a demonstrated risk. If the FAA determines that a demonstrated risk exists, the FAA may require maintenance actions to address the unsafe condition associated with the demonstrated risk. An FMP, as described in this AC, is one method applicants may use to address the unsafe condition associated with the demonstrated risk. This AC provides a means to address a demonstrated risk. It also provides proactive means to address the broader risk, which are inspections for cracks in other fatigue critical structure of airplanes of the same type design.

a. Figure 1 provides an overview of a fatigue management system. It depicts steps the FAA and applicants should follow when they suspect a risk of catastrophic failure due to fatigue. Appendix 1 describes in detail the steps the FAA will take to determine if a demonstrated risk exists. Paragraphs 10, 11, and 12 describe the actions needed once the FAA has determined that a demonstrated risk exists.

(1) In some instances, the FAA will mandate initial, short-term actions to provide short-term mitigation of the demonstrated risk and allow the fleet to return to service. These short-term actions often include operating limitations or immediate and short-interval inspections. The FAA often mandates these short-term actions with an emergency AD or immediately adopted rule (IAR) AD.

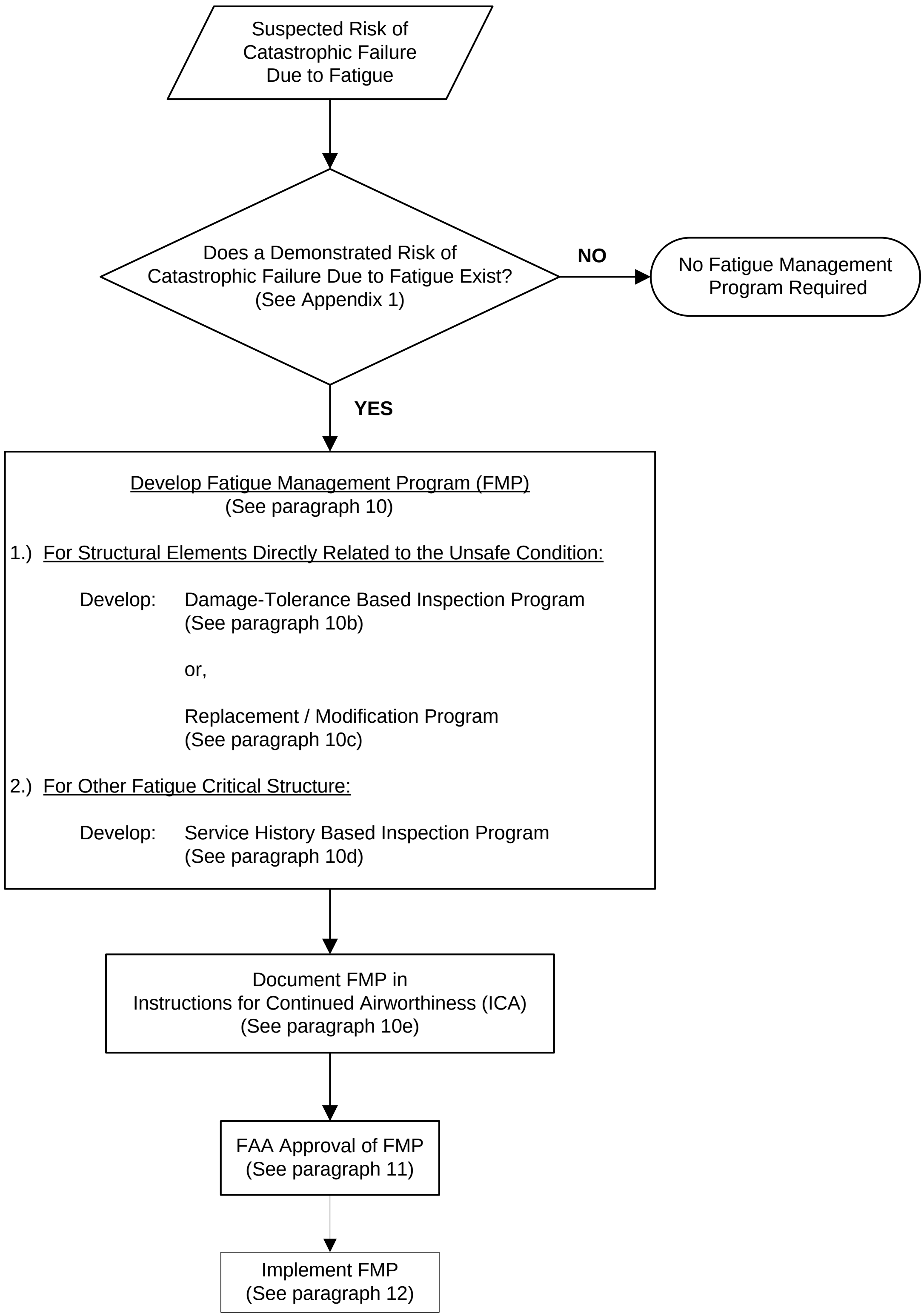
(2) In some instances, applicants may develop other interim actions and gain FAA approval after the FAA has issued an AD. Title 14 CFR §§ 39.19 and 39.21 permit an AMOC to an AD. In accordance with those regulations, if the interim actions adequately mitigate the demonstrated risk, the FAA may approve the interim actions as an AMOC to the AD. The Aircraft Certification Office (ACO) responsible for the AD will approve the AMOC by writing a letter to the applicant. The letter will stipulate all the specific requirements and limitations of the interim action. When properly coordinated between the ACO, interim action applicant, and appropriate Flight Standards District Office (FSDO), the combination of the AMOC approval letter and performance of the actions stated in the letter suffices as compliance with the AD.

b. Figure 1 also outlines the basic actions an applicant should take to develop an FMP. The purpose of an FMP is to prevent future catastrophic failures due to fatigue and to maintain the type design strength and stiffness of the airframe throughout the operational life of the airplane. As shown in Figure 1, there are two main components to an FMP developed in accordance with this AC.

(1) Damage-Tolerance Based Inspections or Replacement/Modification of the Structural Elements Directly Related to the Unsafe Condition. Applicants should base this portion of the FMP on a comprehensive fatigue or damage-tolerance evaluation. The applicant may limit the scope of the detailed evaluation to the structural elements directly involved in the unsafe condition.

(2) Service History Based Inspections of Other Fatigue Critical Structure in the Airplane. The applicant should establish proactive inspections of other likely fatigue critical structure if fatigue management actions do not already exist. These inspections address the broader risk affecting a type design. The applicant may base the inspections on service history and engineering judgment and not necessarily complete a comprehensive fatigue or damage-tolerance evaluation.

FIGURE 1. OVERVIEW OF A FATIGUE MANAGEMENT SYSTEM



c. For some airplane type designs, certain fatigue management actions such as component life limits, life-extending modifications, or supplemental inspection programs (SIP) may already be in place to maintain the continued operational safety of these airplanes. Applicants should reassess the effectiveness of these actions given that their actions did not adequately predict the unsafe condition. This reassessment should examine existing maintenance requirements and limitations to determine their adequacy based on the information learned from the unsafe condition.

d. Paragraph 10 describes in detail the FMP development process. Applicants should document the FMP maintenance actions in the ICA.

e. Paragraph 11 explains the approval of an FMP and the coordination needed for those approvals.

f. Paragraph 12 discusses FMP implementation. The operator accomplishes implementation of the FMP by following the instructions prescribed in the ICA.

10. DEVELOPING AN FMP. This paragraph describes the development of an FMP. The flowchart in Figure 2 outlines the decisions and actions an applicant should follow when developing an FMP.

a. Components of an FMP. Any FMP proposed by an applicant should include each of the following components:

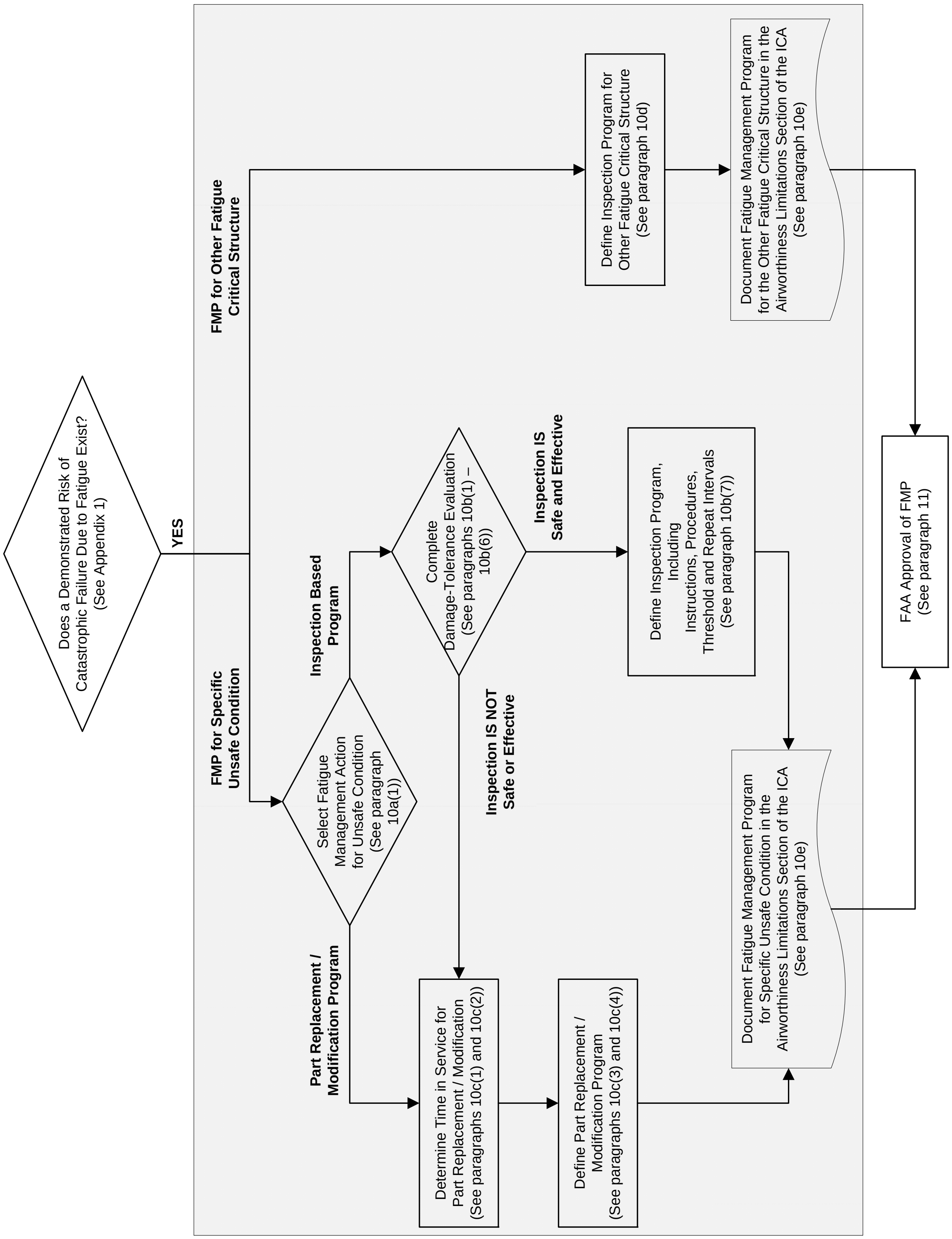
(1) Damage-Tolerance Based Inspections or Replacement/Modification of the Structural Elements Directly Related to the Unsafe Condition.

(a) The applicant may limit the scope of this component of an FMP to the structural elements directly involved in the unsafe condition. An applicant may propose an inspection program or a part replacement/modification program to address the demonstrated risk. An applicant should base any inspection program on a damage-tolerance evaluation of the affected structure. They should base the time in service for a part replacement/modification (effectively a safe-life) on a fatigue analysis or crack growth analysis. Any part replacement/modification program should demonstrate compliance to the applicable regulations. This includes any subsequent inspection requirements. Any proposed program should incorporate the lessons learned from the service history that led to the FAA's determination of a demonstrated risk.

(b) The applicant may select the type of program (inspections or part replacement/modification) to address the unsafe condition. Generally, the FAA will issue an AD requiring the selected program to address effectively the demonstrated risk. In addition to the effectiveness of an FMP, an applicant should also consider the practicality of each potential inspection and part replacement/modification program. An applicant should consider:

- Availability of parts needed for a replacement or modification program;
- Availability of qualified facilities, mechanics, and necessary tooling to complete the part replacement or modification;

FIGURE 2. DEVELOPING AN FMP



- Risk of damaging surrounding structure during part replacement or modification;
- Complexity of inspection program, including inspection method and potential modification of structure to gain access to inspection sites;
- Availability of qualified nondestructive inspection (NDI) inspectors and proper equipment;
- Burden of repetitive inspections and associated reporting;
- Risk of damage to structure when performing inspections – usually damage to fastener holes when removing and reinstalling fasteners; and
- Preference of operators. Some operators may prefer an inspection program while others may prefer a one-time fix by either replacing a part or modifying structure.

(2) Service History Based Inspections of Other Likely Fatigue Critical Structure. This component of an FMP includes inspections of other likely fatigue critical structure in the airplane. The purpose of this component is to proactively identify other fatigue critical locations and inspect for indications that may be precursors to an unsafe condition. An applicant may base these inspections on service history experience and engineering judgment. The applicant directs the resulting inspections at likely fatigue critical sites. These types of inspections have been successful detecting cracking before an incident. However, an applicant does not typically quantify or validate the inspection's effectiveness.

b. Damage-Tolerance Based Inspection Programs. In considering a damage-tolerance based inspection program to address the unsafe condition (paragraph 10a(1)), an applicant should complete a damage-tolerance evaluation. A thorough damage-tolerance evaluation will determine the critical crack size, the detectable crack size, and the interval (in number of flights or flight hours time in service) during which the crack grows from the detectable crack size to the critical crack size. AC 25.571-1C and the reference listed in paragraph 6c(3) provide additional information on performing a damage-tolerance evaluation.

(1) Evaluation Considerations. The damage-tolerance evaluation should consider the actual sites, cracking scenarios, and crack progression observed in the unsafe condition. Actual cracking scenarios can be complex, involve multiple sites, and at some point, include crack interaction.

(a) When using a damage-tolerance evaluation to determine the structure's residual strength and crack growth rate, the applicant should model the realistic cracking scenario. If the failure scenario includes cracks in multiple elements of a load path, or multiple cracks in one element, the applicant must evaluate that scenario to determine where, when, how, and how often to inspect for cracks.

(b) The damage-tolerance evaluation should not use an easily evaluated solution if it is not a representative scenario (for example, a handbook solution for a single crack growing from a hole when the actual scenario involves multiple cracks). Such an evaluation could result in an ineffective inspection program. However, in many cases, it may be acceptable to evaluate a conservative, but easier to analyze, scenario than the actual scenario. If an applicant uses such an approach, the applicant should explain and justify all simplifying assumptions.

(2) Critical Crack Size. The critical crack size is the size of crack that degrades the strength of the structure to the minimum strength required. The applicant should use fracture mechanics analysis, supported by test evidence, to determine the relationship between crack size and residual strength. The minimum strength requirements for determining the critical crack size are listed in (a) through (e) below.

(a) For airplanes certificated in the primary, normal, utility, acrobatic, and commuter categories, § 23.573(b), current amendment level, defines the residual strength requirement.

(b) For airplanes certificated in the transport category, § 25.571(b), current amendment level, defines the residual strength requirement.

(c) For airplanes certificated in the restricted category, the residual strength requirements should be consistent with the airplane category used for type certification under § 21.25.

(d) The FAA may require higher levels of minimum strength in instances of high probability of in-service cracking (several reports of cracks) or in airplanes with severe operational profiles such as aerobatics, aerial application, and low level survey.

(e) For an individual airplane with a known crack in the structure, the FAA may impose specific requirements before the FAA will allow further flight. See AC 23-13A for the FAA Small Airplane Directorate's policy for flight with known cracks in small airplane structure.

(3) Detectable Crack Size. The detectable crack size is the minimum size crack that an inspector can find reliably and repeatedly. For an inspection program to be effective, the detectable crack size must be sufficiently smaller than the critical crack size. An applicant should address, at a minimum, the following issues in determining the detectable crack size:

- What inspection methods are potential candidates for this specific application?
- What crack size is detectable using these candidate methods in this specific application?
- What is the probability of detection for the average inspector given the specific application? (See the reference in paragraph 6c(6) for information on probability of detection.)
- What qualifications will the inspector need to have? Will qualified inspectors be available?

- How accessible is the structure? In some cases, the inspector or mechanic may need to remove or modify the structure to gain access.

- Does sealant or paint cover the area? Can an inspector or mechanic easily remove the sealant or paint? Does the inspector or mechanic need to reapply the sealant or paint after the inspection?

- Will the inspector need to have fasteners removed to complete the inspection? If so, what is the potential for damaging the structure in this process?

- Will the fastener holes require additional reaming before inspection? Is the edge margin adequate? Will the reinstallation require special oversize fasteners?

(a) In addressing these and other related issues, the applicant is ensuring the average inspector can find a detectable crack with a high probability of detection.

(b) If the minimum detectable crack size is not sufficiently smaller than the critical crack size, an FMP based on inspections is not an effective option for addressing the unsafe condition. In this case, an applicant would have to pursue a part replacement/modification program as described in paragraph 10c of this AC.

(4) Crack Growth Life. Crack growth life is the interval (in number of flights or flight hours time in service) during which a crack grows from the detectable crack size to the critical crack size.

(a) An applicant typically determines the crack growth life based on a fracture mechanics-based crack growth analysis. However, in some cases, it may be possible to determine crack growth life by counting the striations on the fracture surface of the accident, incident, or test structure.

(b) If the crack growth life for the selected inspection method does not allow a sufficient interval between the time the crack reaches the detectable crack size and the critical crack size, inspections may not be a safe and effective method for addressing the unsafe condition. In some instances, an applicant may want to consider other inspection methods that may be able to increase the crack growth life by detecting smaller cracks. An applicant will often base their preference of inspection method on method sensitivity and cost versus inspection frequency. If the applicant cannot show the inspection program is safe and effective, then the applicant should pursue a part replacement/modification program as explained in paragraph 10c of this AC.

(5) Inspection Repeat Interval. The inspection repeat interval is typically a fraction of the length of time for the crack to grow from the detectable crack size to the critical crack size. Appendix 2 provides acceptable methods for determining the repeat inspection interval. It is the applicant's option to determine how complex or simple the analysis should be. The applicant may determine that a simple analysis using conservative assumptions and scatter factors produces an acceptable inspection interval. An applicant may also use a more detailed analysis to justify a longer inspection interval. The applicant should explain and justify all simplifying assumptions.

(6) Inspection Threshold. The inspection threshold is the time in service when the operator must perform the first inspection. The FAA has accepted several different methods for determining the inspection threshold. No matter what method an applicant uses, the applicant should always ensure that the thresholds are rational, given the accident, incident, or in-service findings. For example, if cracks are found in-service at 5,000 hours time in service, it is rational to set the inspection threshold at some time well before 5,000 hours, even if analysis produces a larger threshold.

(a) In many cases, "before further flight" may be the best inspection threshold to mitigate the demonstrated risk for the remaining fleet. In particular, if several airplanes in the remaining fleet have time in service greater than or similar to the airplane involved in the accident, incident, or in-service finding, immediate inspections may be the most appropriate inspection threshold.

(b) The applicant may determine the inspection threshold based on information learned from the airplane involved in the accident, incident, or in-service finding. Probabilistic methods, including Weibull analysis, allow an applicant to estimate the probability of a crack at a specific time in service. For small airplanes, the FAA's Small Airplane Directorate has accepted an inspection threshold corresponding to the time in service when the probability of developing a crack reaches 1-in-1,000.

(c) The applicant may determine the inspection threshold using a fatigue (stress-life or strain-life) evaluation. The applicant should correlate the results of the fatigue evaluation with the time in service of the airplanes involved in the accident, incident, or in-service findings. See AC 23-13A for guidance on performing small airplane fatigue evaluations.

(d) The applicant may also establish the inspection threshold based on crack growth. In this method, the applicant bases the inspection threshold on the time (divided by a factor) that a crack would grow from an initial assumed size to the time that the crack reaches the critical crack length. The reference in paragraph 6c(3) provides additional detail on the crack growth method.

(e) The applicant may also set the inspection threshold time in service to the time determined for the repeat inspection interval. For airplanes past this threshold, their first inspection should occur immediately.

(f) If situations occur when the fleet is beyond the threshold, the FAA expects inspection before further flight. However, the FAA may allow alternative interim short-term inspections on a case-by-case basis if there are extenuating circumstances.

(g) Ample literature is available that describes the details of any of the above analysis approaches. Whichever approach an applicant chooses, it is the applicant's option to determine how complex or simple the analysis should be. The applicant may determine that a simple analysis using conservative assumptions and scatter factors produces an acceptable inspection threshold. An applicant may also use a more detailed analysis to justify a longer inspection threshold. The applicant should explain and justify all simplifying assumptions.

(7) Define Inspection Requirements and Procedures. An applicant should document the inspection program in sufficient detail to support implementation of the program as an airworthiness limitation item. The inspection program documentation should include, but not necessarily be limited to:

- Reasons for the inspection, including applicable ADs and Service Bulletins (SB);
- Description of the inspection area, including illustrations depicting the inspection area, anticipated crack locations, probe/transducer placement, and crack signal;
- Instructions for preparing the inspection site, including required access, cleaning requirements, fastener removal, and safety (e.g., fuel tank purging);
- Description of inspection method; for example, dye penetrant, ultrasound, high/low frequency eddy current, visual, or magnetic particle;
- Required equipment, including any crack calibration standards used to calibrate inspection equipment;
- Calibration requirements;
- Required qualifications of inspectors;
- Accept/reject criteria;
- Repeat inspection interval (as determined in paragraph 10b(5));
- Inspection threshold (as determined in paragraph 10b(6));
- Reporting requirements; and
- Approval and revision status of the inspection instructions.

c. Part Replacement/Modification Programs. There are three reasons why an applicant may select a part replacement/modification program.

- Part replacement/modification may be necessary if a damage-tolerance based inspection program is not safe or effective.
- Part replacement/modification may provide a more efficient solution to the demonstrated risk than a damage-tolerance based inspection program.
- The applicant may desire a part replacement/modification program.

(1) An applicant must determine the time in service at which to accomplish the part replacement/modification, substantiate compliance to the applicable regulations, and develop detailed instructions for accomplishing the part replacement/modification. The applicant should be aware that by strengthening the location where the fatigue cracking occurred, the load path may change and transfer load to surrounding structure, creating a new fatigue location.

(2) Determine Time in Service for Part Replacement/Modification.

(a) The time in service for part replacement/modification is the point in the operational life of each airplane at which the operator must modify or replace the structure, regardless of condition. The applicant should establish the time in service to minimize the probability of having a crack initiate in the structure.

(b) For small airplanes, the FAA's Small Airplane Directorate has accepted a time in service corresponding to a probability of 1-in-1,000 of developing cracks in structure. The applicant typically uses a fatigue analysis correlated to in-service findings or a probabilistic analysis of all in-service crack findings to determine the time in service.

(3) Substantiation of Part Replacement/Modification. An applicant must demonstrate compliance to the applicable regulations for any replacement or modification of existing structure. Since the applicant knows the location is critical in fatigue, any part replacement or modification should demonstrate compliance to the most appropriate amendment fatigue regulations regardless of certification basis. In all cases, an applicant should establish a safe-life limit or develop a damage-tolerance based inspection program for both the modified or replaced structure and existing surrounding structure it affects.

(a) For small airplanes, Amendment 23-48 to §§ 23.571 and 23.572 are appropriate.

(b) For transport airplanes certificated prior to Amendment 25-45, use § 25.571 at Amendment 25-45.

(c) For transport airplanes certificated under Amendment 25-45 or later, use § 25.571 at the amendment level used for its TC basis.

(4) Instructions for Part Replacement/Modification. An applicant should document the part replacement/modification instructions in sufficient detail to support implementation as an airworthiness limitation item. Details of the mandatory actions include, but are not limited to:

- Development of service kit details,
- Determination of a part replacement/modification threshold and any part replacement/modification intervals, and
- Development of inspection and reporting instructions for structure prior to modification.

(a) Inspections and reporting instructions may be necessary as part of the service kit instructions or replacement procedures. One of the purposes of these inspections is to ensure that the modified structure is crack free. These additional instructions should provide detailed procedures to inspect for cracks in the affected parts (paragraph 10b(7) discusses inspection procedures). These instructions should also outline procedures for reporting the inspection findings to the applicant (and crack findings to the FAA).

(b) If cracks are found, the FMP holder should make arrangements and subsequently develop instructions to provide for the return of removed parts (or the applicable portions of removed parts) to the FMP holder or the FAA for evaluation. In either case, the instructions should encourage maintenance facilities to return removed parts to the FMP holder for evaluation.

(c) Accurate inspection and reporting can facilitate further refinement of modification/replacement thresholds and intervals. This refinement may be beneficial where the original analysis was conservative, there are few or no Service Difficulty Reports (SDR), the FMP holder suspects anomalies exist, or where modifications and replacements are difficult, costly and time-consuming.

d. Inspections for Other Fatigue Critical Structure. The second component of an FMP is proactive inspections of other fatigue critical structure (see paragraph 10a(2)). Historically, fatigue cracking in another part of the structure follows fatigue cracking in one location of the airplane structure. This occurs because fatigue cracking is time in service related and a type design typically uses similar materials, construction techniques, and attention to fatigue detail throughout the structure. Although inspection or modification/replacement of a specific part or parts mitigates a demonstrated risk, continued operation allows more fatigue cycles to accumulate on other likely fatigue critical structure and may lead to another unsafe condition. To address this broader risk, an applicant should develop inspections for other fatigue critical structure as part of the FMP.

(1) Structures with Existing FMPs.

(a) For some airplane type designs, certain fatigue management actions such as component life limits, life-extending modifications, or an SIP are already in place to maintain the continued operational safety of that fleet. Applicants should reassess the effectiveness of the existing actions given that the existing actions did not adequately predict the unsafe condition being addressed. This reassessment should examine existing maintenance requirements and limitations to determine their adequacy based on the information learned from the unsafe condition.

(b) It may be necessary to adjust life limits, modification or inspection thresholds, or inspection intervals and reassess structure for other fatigue critical areas. This is particularly important for a structure with a safe-life limit. The DAH typically bases the limits on the most fatigue critical area in the structure. If modifications or replacements extend this limit, the applicant should show there are not other areas in the structure more limiting than the extended limit.

(2) Structures without Existing FMPs. For airplanes with no existing fatigue management actions, the applicant should, at a minimum, develop an inspection program for other fatigue critical structure. An applicant may base this portion of the FMP on service history and engineering judgment. The resulting inspection program provides some protection from future catastrophic failure due to fatigue. Directed inspections of probable cracking locations (beyond routine annual or other scheduled inspections) are always beneficial. These types of inspections have successfully detected cracking before an incident. However, they may not provide the same level of safety as a damage-tolerance based inspection program.

(3) Service History Review. In reassessing existing fatigue management actions or in developing new actions, an applicant should thoroughly review the type design's service history. A review should look for precursors such as repeated repairs, working or broken rivets, fretting, chafing, fluid or pressurization leaks, etc. Service history is an important aspect of setting up or adjusting any continued airworthiness program. Sources of service history information include:

- Existing mandatory actions, including ADs and the Airworthiness Limitations Section (ALS) of ICAs;
- Manufacturer's SBs;
- FAA SDR database;
- In-service findings reported according to § 21.3;
- Repairs that received field approvals;
- History of part replacement;
- Discussions with type clubs of the specific type design; and
- Discussions with repair facilities that maintain the specific type design.

(4) Typical Fatigue Critical Structures. At a minimum, an applicant should consider the following areas when developing the FMP component for other likely fatigue critical structure:

- Joints or splices of tension dominant load path, e.g. lower spar caps, skins, stringers, fittings, bolts, etc;
- Maximum tension bending moment location on the wing and horizontal tail;
- Fuselage carry-through structure area similar to the above items, as applicable;
- Areas in primary wing load path where other loads are introduced such as engine or landing gear attachments;
- Wing strut attachments – both ends;
- Empennage attach areas; and

- Pressurized fuselage skins, frames, and longerons.

(a) For airplanes designed to high negative g loads (such as acrobatic category), joints, splices and maximum compression bending moment locations on the wing and horizontal tails may also be fatigue critical.

(b) For some designs, control surface and flap hinge fittings and their attach structure may be fatigue critical. If there is no documentation, such as that normally provided at time of certification, to show these areas are not critical to safe flight, the applicant should consider them fatigue critical.

e. Documenting the FMP. The applicant should incorporate instructions associated with both components of an FMP into a document suitable for FAA approval and for use by maintenance personnel.

(1) If the airplane model has an ICA, the applicant should add the FMP to the existing ALS of the ICA. If the airplane model does not have an ICA (or an ALS associated with the ICA), then the applicant should write the FMP instructions in a document that contains pertinent information equivalent to the ALS portion of an ICA.

(2) Write instructions in plain English and provide clear and concise instructions for completing the tasks. The instructions should include, but not necessarily be limited to, the following:

- The type and the extent of inspection programs;
- Steps involved in part replacement or modification;
- Information describing the order and method of removing and replacing parts and any precautions necessary to facilitate inspection;
- Diagram of structural access plates, or how to gain access when access plates do not exist;
- Details for utilizing special inspection techniques, including procedures for these techniques;
- Identification of primary structure;
- All data on structural fasteners, such as identification and torque values;
- List of required special tools;
- Any necessary shoring, jacking, or other special handling requirements;
- Any subsequent required inspections; and

- Instructions for notifying the FMP holder of positive and negative findings for structure associated with the demonstrated risk and positive findings for other fatigue critical structure. Normally, the ICA will include a form specifying all pertinent information about the finding.

(3) Order 8110.54, Instructions for Continued Airworthiness, Responsibilities, Requirements and Contents, provides guidance about the content of an ICA or its equivalent. The reference in paragraph 6c(5) gives direction in the preparation of maintenance data for the maintenance of general aviation airplanes, including ICA.

(4) Paragraph 11 provides guidance regarding the approval process for documenting the actions associated with an FMP.

11. COORDINATION AND APPROVALS.

a. To address a demonstrated risk, the FAA may mandate an FMP. The FAA will only approve FMPs that address the demonstrated risk and only when we have issued or anticipate issuing an AD mandating an FMP. If approval is required, use the process explained in this paragraph.

b. When following the steps described in this AC, the applicant should communicate and coordinate with the cognizant FAA ACO and FSDO, as appropriate. These offices will coordinate with their respective Directorate and Aircraft Evaluation Group (AEG) offices when necessary. The FAA orders and ACs referenced in this paragraph describe roles and responsibilities depending on the method of approval needed for the specific application.

c. The process an applicant uses to get its FMP approved by the FAA varies according to whether the DAH or another applicant is seeking approval. The FAA encourages applicants to use the appropriately authorized designees to approve, or recommend for approval, the substantiating data. Because of the detailed engineering evaluation required to develop an FMP, the FAA will, in general, consider an FMP to be a major change to the type design (see § 21.93). The cognizant FAA ACO should coordinate with the appropriate Directorate to verify that the proposed FMP is a major change to the type design.

(1) If the DAH is seeking approval of its FMP, it typically documents the required actions in a SB, Service Letter, or similar document. These instructions should include a section that specifies the actions needed to mitigate the demonstrated risk and those actions that address other fatigue critical structure. If the affected model has an ICA, then the DAH should revise the ICA to incorporate the FAA-approved FMP. If the affected model does not have an ICA, the DAH should create an ICA and incorporate the FMP to implement it. As a part of the design approval process, when the DAH submits an ICA to the FAA, the ACO and the AEG review the ICA in accordance with FAA Order 8110.54. The DAH could also use the TC process to gain FAA approval of their FMP as an STC.

(2) If the applicant is not the DAH, the applicant should apply for an STC to gain FAA approval of the FMP (see § 21.113). The STC should include instructions similar to those normally contained in a DAH's SB. These instructions, which make up an ICA, should include a section that specifies the actions needed to mitigate the demonstrated risk and those actions that address other fatigue critical structure (new STCs require an ICA as part of a design change per § 21.50(b)). As a part of the design approval process, when the applicant submits an ICA to the FAA, the ACO and the AEG review the ICA in accordance with FAA Order 8110.54. AC 21-40A and FAA Order 8110.4 provide policy and guidance on the STC process.

(3) See paragraph 10c(3) for discussions regarding certification basis of modifications. The ALS of the ICA must be approved by the cognizant ACO. Appropriately authorized DERs or delegated organizations are expected to review and approve all technical aspects of the substantiating data and underlying technical changes per the applicable regulations in support of the STC process. These regulatory compliance findings will be to the agreed upon certification basis. Up-front planning should be in accordance with Partnership for Safety (PSP) or Project Specific Certification Plans (PSCP) developed between the FAA and the applicant at the beginning of the STC project. See the reference in paragraph 6c(4) for information regarding PSPs and PSCPs.

d. The FAA may sometimes issue an AD to mitigate the unsafe condition associated with the demonstrated risk before the DAH or other applicant has developed an FMP. In these cases, the applicant will submit their FMP to the cognizant ACO either as a method of compliance to the AD or as an AMOC to the AD. If found acceptable, the ACO will approve the FMP. Since only the FAA can determine if actions comply with an AD, ACO approval is the avenue toward granting a method of compliance for the AD. The manager of the cognizant ACO will grant approval with a letter to the applicant.

12. IMPLEMENTING AN FMP. Figure 3 illustrates the key elements of implementation discussed in detail below.

a. FMP Actions to Address the Demonstrated Risk.

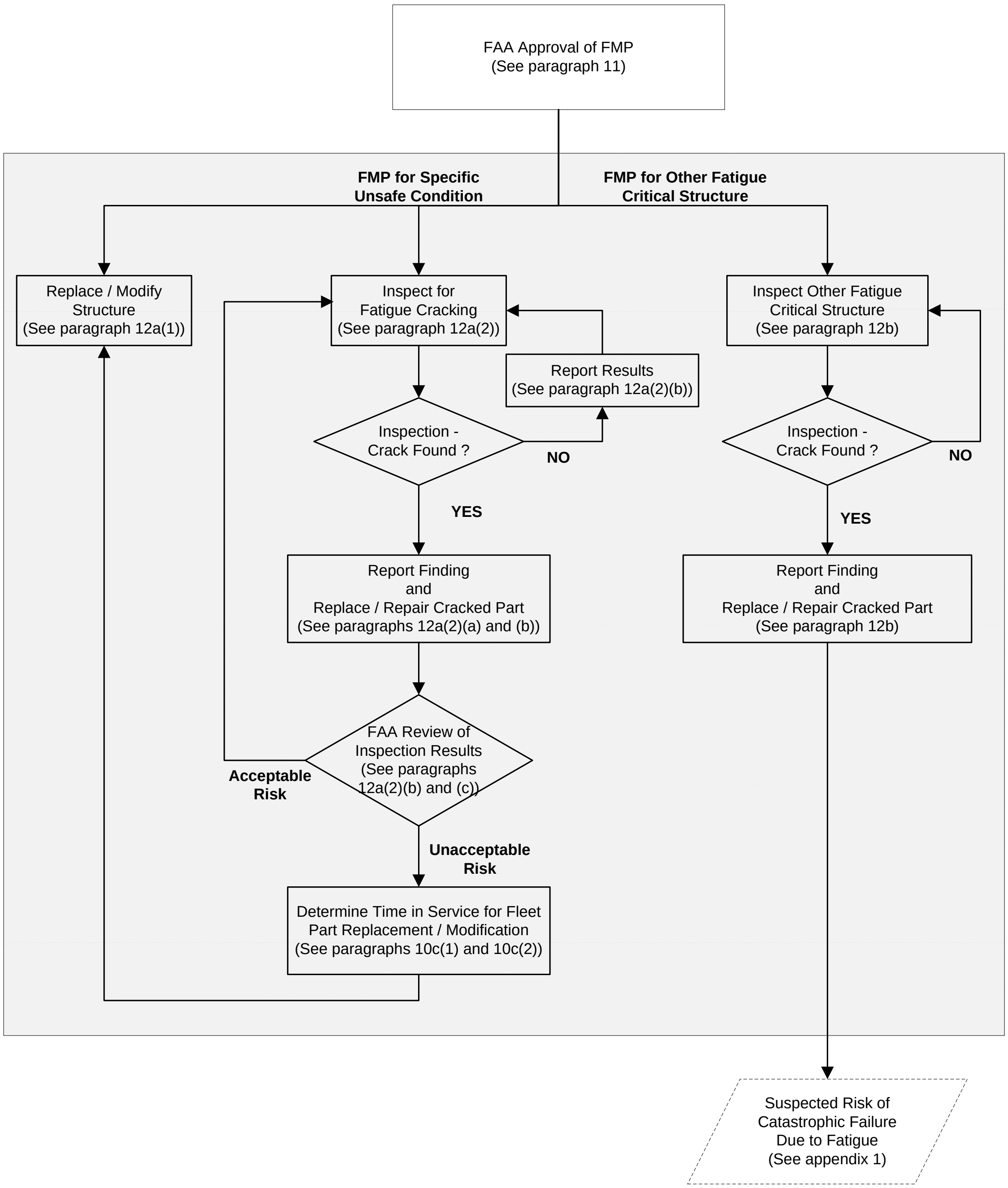
(1) Part Replacement/Modification. Perform part replacement/modification per the instructions included in the ICA.

(2) Damage-Tolerance Based Inspections. Complete inspections per the instructions included in the ICA.

(a) If the inspections detect fatigue cracking, repair or replace the cracked part per FAA-approved repair instructions.

(b) Typically, the FAA will include instructions in the AD for operators to report to the FMP holder both negative and positive crack indications along with the time in service on the aircraft inspected. Generally, an AD will also require that operators report to the FAA positive crack indications and time in service. History of inspection results provides data to measure the success of an inspection program. The FMP holder uses reports of cracks found and their sizes, negative inspection results, and the airplane time in service to assess the effectiveness of the inspection program. Damage-tolerance based inspections must have a demonstrated high probability of detection, so both positive and negative findings are statistically relevant to verify that the inspection method is as reliable as assumed. Report results per the instructions contained in the ICA.

FIGURE 3. IMPLEMENTING AN FMP



(c) If the inspection program finds a crack and verifies another occurrence of the unsafe condition, the FAA will assess the overall risk to the fleet if inspections were to continue. The inspections may continue if the FAA determines the risk level is acceptable. However, if the FAA determines that continued reliance on inspections poses an unacceptable risk level, then we will mandate termination of the inspection program and development of a part replacement/modification program.

b. FMP Actions to Address Other Fatigue Critical Structure. Generally, an AD will require operators to accomplish the established inspections for other fatigue critical structure per the instructions specified in the ICA. A crack found by these inspections would require evaluation as a suspected risk of catastrophic failure due to fatigue, as described in Appendix 1. The inspector should report positive inspection findings to the FMP holder and the FAA per the instructions contained in the ICA.

13. LIST OF ACRONYMS.

a. AC. Advisory Circular

b. ACO. Aircraft Certification Office

c. AD. Airworthiness Directive

d. AEG. Aircraft Evaluation Group

e. ALS. Airworthiness Limitations Section

f. AMOC. Alternative Method of Compliance

g. CAR. Civil Air Regulation

h. CFR. Code of Federal Regulations

i. CPCP. Corrosion Prevention and Control Program

j. DAH. Design Approval Holder

k. DER. Designated Engineering Representative

l. FAA. Federal Aviation Administration

m. FMP. Fatigue Management Program

n. FSDO. Flight Standards District Office

o. IAR. Immediately Adopted Rule

p. ICA. Instructions for Continued Airworthiness

q. NDE. Nondestructive Evaluation

r. NDI. Nondestructive Inspection

s. NTIAC. Nondestructive Testing Information Analysis Center

t. NTSB. National Transportation Safety Board

u. PSCP. Project Specific Certification Plan

v. PSP. Partnership for Safety Plan

w. SB. Service Bulletin

x. SDR. Service Difficulty Report

y. SIP. Supplemental Inspection Program

z. SRM. Structural Repair Manual

aa. STC. Supplemental Type Certificate

bb. TC. Type Certificate

ORIGINAL SIGNED by

James J. Ballough
Director, Flight Standards Service

APPENDIX 1. DETERMINATION OF DEMONSTRATED RISK OF CATASTROPHIC FAILURE DUE TO FATIGUE

1. Summary.

The Federal Aviation Administration (FAA) may suspect an airplane type design has a risk of catastrophic failure due to fatigue when fatigue may be a causal factor to an accident or incident, or after reports of in-service findings of fatigue cracks in flight critical structure. In an accident or incident, the FAA is a party to the National Transportation Safety Board (NTSB)[1] led investigation of the accident or incident. For reports of in-service findings of fatigue cracks, the FAA typically works with the design approval holder (DAH) to investigate the reports of cracking.

In both cases, the FAA works to determine whether the suspected risk is an actual demonstrated risk of catastrophic failure due to fatigue.

When the NTSB or FAA/DAH investigation finds that fatigue contributed to the accident, incident, or in-service finding, and that the unsafe condition is likely to develop on other airplanes of the same type design, the FAA may determine that a demonstrated risk exists. The FAA may then consider Airworthiness Directive (AD) action to maintain the continued operational safety of the fleet (see Title 14 of the Code of Federal Regulations (14 CFR) part 39, § 39.5).

2. Failure Investigation.

Failure investigations should look at the evidence from a broad perspective, including the conditions and circumstances surrounding the accident or incident. If partial or complete structural fracture(s) contributed to the accident or incident, the investigator[2] should determine if fatigue was a contributor and if it is likely to occur in other airplanes.

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[1] The NTSB is responsible for the organization, conduct, and control of all accident and incident investigations within the United States where the accident or incident involves any civil aircraft or certain public aircraft (see 49 CFR § 831.2(a)(1)). The NTSB may designate additional parties to accident or incident investigations. The NTSB limits these designated parties to those persons, government agencies, companies, and associations whose employees, functions, activities, or products were involved in the accident or incident and who can provide suitable qualified technical personnel to assist in the investigation (see 49 CFR § 831.11(a)(1)). The FAA is the only entity afforded the right to be a designated party in an accident or incident investigation.

The NTSB determines the probable cause of an accident and may also issue safety recommendations to address safety issues identified during the accident investigation. The FAA, based on the findings of the NTSB-led investigation and NTSB-issued safety recommendations, may make a determination that an unsafe condition exists and that airworthiness directive action is necessary to maintain the continued airworthiness of the airplane type.

[2] "Investigator" could be someone from the NTSB, the FAA, the DAH, or an owner's group. Typically, it is a combination of any or all of these.

a. Did fatigue contribute to failure?

The failure investigation will answer this question by considering the airplane loading at the time of the failure, usage and maintenance history of the airplane, and examining the fracture surfaces.

Accident and Incident Investigation. Airplane accidents result in many broken parts and therefore many fracture surfaces. Investigators will examine all fracture surfaces of primary structure for the mode of failure, including evidence of fatigue. An investigator can sometimes observe evidence of fatigue cracking in the field; however, a laboratory fractographic analysis should verify all potential fatigue damage sites.

Many fracture surfaces will indicate static overload resulting from the accident impact or flight loads. Examination of these fracture surfaces, including the failure direction (e.g., wing bending up or down), can assist in determining whether fatigue contributed to the failure.

Investigators will review all available airplane logs. The airplane usage and maintenance history may reveal that it was susceptible to the effects of fatigue.

Investigators will also study the conditions associated with the accident. A qualitative estimate of the loading at the time the failure occurred, as a minimum, can help determine if the airplane exceeded its design limits. Investigators will review the operating environment, including weather conditions, at the time of the failure. This information will help determine if the pilot was operating the airplane outside its design envelope or if turbulence or upset recovery maneuvers subjected the airplane to high loads. The investigator should also consider the flight phase and attitude at the time of the accident. For example, if the aircraft was in level flight in good weather, it is unlikely that the failure was due to static overload based on load considerations only.

In an incident, the fracture surfaces may not be accessible for examination. The investigator may need to rely on indications of deformation in primary load path as well as secondary load paths (e.g., ribs and stringers). In these cases, the investigator may excise the fracture surfaces from the airplane so that metallurgists can examine the fractures.

(Note: When the NTSB investigates accidents or incidents, it documents all of the above information to the greatest extent possible. If structural failure is a possible cause, the NTSB's metallurgists will thoroughly examine the fracture surfaces.)

In-Service Findings. In-service findings of failures or cracks are similar to an incident in that the fracture surfaces may not be easily accessible for examination. If the repair of the failed area removes and replaces the failed or cracked part, the investigator should obtain the removed part for examination.

Summary. Conclusively determining whether or not fatigue contributed to the failure is usually possible based on examination of fracture surfaces and consideration of the loads likely experienced during the accident sequence. If the investigation determines fatigue contributed to the accident, incident, or in-service finding, the investigation must then determine whether other airplanes in the fleet are likely to develop similar fatigue damage.

b. Is the Fatigue Cracking Scenario Likely to Occur on Other Airplanes?

If the investigation determines that fatigue contributed to the accident, incident, or in-service finding, then it is important to determine if fatigue is likely to occur on other airplanes in the fleet. An investigator can answer this question by performing a detailed investigation that identifies all fatigue cracking sites in the structure, the possible cause of the cracking, and how the cracks progressed.

Site. In addition to the initial fatigue crack(s) identified, the failure investigation may find other fatigue cracking sites in the structure. This is often the case when cracking is due to normal fatigue (often called "fatigue wear-out"). For example, the general location of a failure may be the attachment of the wing at the wing root. However, signs of fatigue cracking could also exist at other locations in the same load path, such as at hole(s) in a spar cap, wing skin, or wing/stringer details. This would be an indication of fatigue wear-out and therefore likely to occur in other airplanes.

It is also possible that evidence of fatigue exists in other load paths. For example, the accident, incident or in-service finding may involve a fatigue crack in the attachment of the wing at the wing root. However, additional fatigue cracks may exist in other wing fittings further outboard, in the horizontal tail, or control surface attachments.

Identification of all sites of fatigue cracking can help determine the likely scenario that caused the cracking.

Scenario. An effort should be made to determine if there is any correlation between the fatigue cracking sites and the most fatigue critical area on the component under investigation. This requires some knowledge of relative gross area stress levels and physical details of the type design. If the observed cracks are in areas of high gross or local stress, it would be reasonable to expect that similar cracking would eventually occur in other airplanes in the fleet.

Anomalies. The investigator should evaluate the fatigue cracking sites to determine if they contain signs of physical anomalies not expected to occur in the rest of the fleet. These anomalies could be significant manufacturing or service-induced defects exceeding what would be expected or allowed to exist normally. One indication of an anomaly might be if the fatigue cracking site is in an area of relatively low stress while there are no sites identified in more highly stressed areas. If this is the case, the inspector should carefully examine the site(s) for evidence of tool marks, corrosion, accidental damage or other distress that could have precipitated the apparent premature cracking.

If corrosion is a likely causal factor, the investigation should determine if there are environmental conditions unique to this airplane. Service Difficulty Reports (SDR) should be searched for other similar occurrences. If a Corrosion Prevention and Control Program (CPCP) exists, it should be reviewed. AC 43-4A, Corrosion Control for Aircraft, is a good source for information regarding corrosion prevention, detection, and control.

On occasion, fatigue cracking occurs in one airplane of a fleet due to an anomaly. If demonstrated that the site and scenario observed are unique to the accident or incident airplane, there would be no need to develop a fleet wide FMP. However, the demonstration should include data from a survey of part or all of the fleet to validate the uniqueness of the condition observed. The survey should include an SDR search for other reported occurrences of cracking. Reports of similar cracking on other aircraft could confirm likelihood. However, you should not conclude that cracking is unlikely because of a lack of reports. Experience shows that in many cases cracking incidents go unreported. (Often repairs are made to cracked structure using the DAH published Structural Repair Manual (SRM) or standard repair procedures per AC 43-13. Although the damage causing the repair should be reported, it is often not.)

Summary. Historically, fatigue cracking found in service or test is later found in other airplanes in the fleet. Although singular fatigue cracking events do occur, they are rare. In making the final determination of whether or not the cracking is likely to occur in other airplanes, one should err on the side of caution. In most cases, discovery of fatigue cracking in an airplane identifies a fatigue critical detail in the basic type design. When this occurs, one should not ignore the warning.

3. FAA Determination of Demonstrated Risk

If the investigation finds that fatigue cracking contributed to the accident, incident, or in-service finding, and that it is likely to exist or develop in other airplanes of the same type design, the FAA may determine that a demonstrated risk exists. In these cases, the FAA would consider issuing an AD requiring mandatory actions to maintain the continued operational safety of the affected fleet. These actions would be included in an FMP to mitigate the demonstrated risk and proactively address the broader risk posed by other fatigue critical structure.

In some instances, the FAA will issue an AD mandating initial, short-term actions to provide short-term mitigation of the demonstrated risk and allow the fleet to return to service. These short-term actions often include operating limitations or immediate and short-interval inspections. The FAA often issues these short-term actions as emergency ADs or Immediately Adopted Rule (IAR) ADs. Information learned from these short-term actions, including inspection results, will help the FAA and the applicant to determine a long-term or permanent solution to mitigate the demonstrated risk.

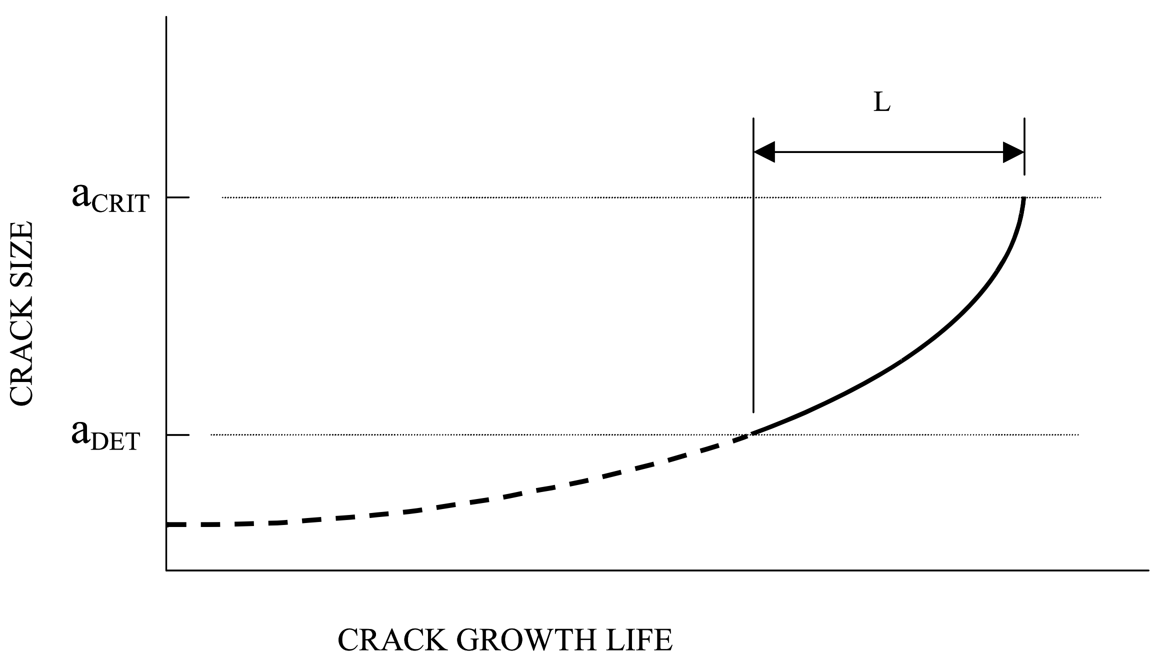
The investigation may find that fatigue cracking did not contribute or was a singular event not likely to occur in other airplanes of the same type design. In this case, a demonstrated risk does not exist, and the FAA will not issue an AD requiring an FMP.

APPENDIX 2. METHODOLOGY FOR DETERMINING REPEAT INSPECTION INTERVALS

The reliability of the repeat inspections should assure crack detection before the residual strength degrades below the required level. The inspection method chosen will define the initial detectable crack that will be used to perform the damage-tolerance evaluation. Once the initial detectable crack is defined, crack growth and residual strength assessments must be performed to determine the time for the initial detectable crack (a_{DET}) to grow to a size (a_{CRIT}) that would result in failure if the required residual strength loads were applied. These assessments could be performed analytically or by test; however, in most cases they are performed analytically using fracture mechanics methods. It is the applicant's option to determine how complex or simple the analysis should be. The applicant may determine that a simple analysis using conservative assumptions and scatter factors produces an acceptable inspection interval. An applicant may also use a more detailed analysis to justify a longer inspection interval. The applicant should explain and justify all simplifying assumptions. The resulting life for a_{DET} to grow to a_{CRIT} is used to set the inspection interval. This general process applies to both single and multiple load path structure regardless of the level of inspection (e.g., for complete load path failure or less than load path failure in a multiple load path structure). The details are discussed further below.

(A) Single Load Path Structure. The time for a detectable crack (a_{DET}) to grow to critical size (a_{CRIT}) in a structure is denoted as L in Figure 2-1. The inspection interval would be established as L divided by an inspection safety factor, K, of not less than 2.0. This provides two opportunities to find a crack once it has grown to a detectable size.

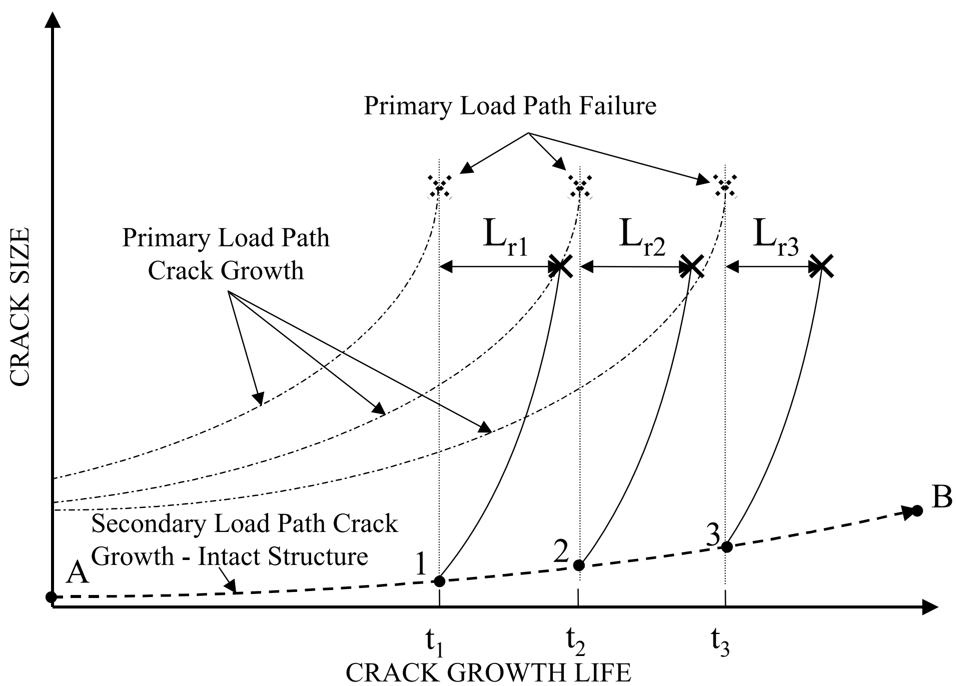
FIGURE 2-1. CRACK GROWTH IN SINGLE LOAD PATH STRUCTURE



(B) Multiple Element Structure. Depending on detectability considerations and residual life characteristics of the structure following a load path failure, it may be beneficial to take advantage of the redundancy of a multiple load path structure. On the other hand, the safety of a multiple load path structure can be managed without taking advantage of its redundancy. In this case each load path would be considered independently and inspection intervals established for each load path consistent with paragraph (A) above.

When taking advantage of redundancy in a multiple load path structure there are two scenarios: when the inspection is for a completely failed load path, and when the inspection is for a cracked but not completely failed load path. In either case, the remaining life of the secondary load path after primary load path failure (L_r) is used to determine the inspection interval. Consistent with this, the resulting intervals are only valid out to the time that the cumulative fatigue damage and/or crack growth in the intact structure is accounted for. This issue is illustrated in a crack growth context in Figure 2-2.

FIGURE 2-2. DECREASING RESIDUAL LIFE IN SECONDARY LOAD PATH WITH TIME FOR MULTIPLE ELEMENT STRUCTURE



As shown in Figure 2-2 and described in paragraph (B)(1)(i), crack growth in the secondary load path from an initial crack will proceed along curve A-B as long as the primary load path remains intact and load redistribution is negligible. However, at the time of primary load path failure, loading on the secondary load path will increase due to load redistribution and crack growth will accelerate (e.g., subsequent growth from point 1, 2, or 3 depending on if the failure occurs at time t_1, t_2 or t_3). Note that the amount of residual life, L_r, in the secondary load path has an inverse relationship to the time at which primary load path failure occurs. For example, L_{r3} is less than L_{r2} because the longer crack growth life of the primary load path means that a crack in the secondary load path will have also grown longer and thus have a shorter remaining crack growth life once the primary load path fails. This must be taken into account whether inspection is for a complete load path failure or not as discussed below.

(1) Inspection for Complete Load Path Failure. If a failed load path is easily detectable and the residual life and strength of the remaining structure is sufficient, this approach may be optimum. Analysis or tests as described in the following paragraphs can be used to determine the inspection interval.

(i) Evaluation by Analysis. Figure 2-3 illustrates an example of multiple load path structure for which a completely failed load path is easily detectable. The inspection interval is based on the life of the secondary load path (L_r) after primary load path failure at time N_F. Consistent with this, damage accumulated in the secondary load path prior to primary load path failure must be accounted for in the analysis. In order to do this within the context of a crack growth analysis it is necessary to assume some initial crack, of size a_i, exists in the secondary load path at time zero. This initial crack size should be representative of a normal manufacturing quality. Analytical crack growth in the secondary load path accumulated prior to an assumed primary load path failure is accounted for by calculating the amount of growth, (Δa_i), between time zero and N_F. Load redistribution that may occur prior to N_F should be considered. The residual life, (L_r), then becomes the time for a crack of size $a_i + \Delta a_i$ in the secondary load path to grow to critical size assuming a complete primary load path failure has occurred (i.e. "failed" condition loads used – all load now carried by the secondary load path). It should be noted that the calculated time of primary load path failure, N_F, would also represent an upper limit of applicability for any repeat inspection period based on L_r. This is because if the primary load path failed shortly after N_F the time for the assumed crack in the secondary load path to grow to its critical size is less than L_r. (The analyst's selection of L_r and N_F requires judgment based on a balance between a reasonable inspection interval and reasonable period of applicability of the inspection. A longer N_F will result in a shorter L_r and vice versa.) Based on the above,

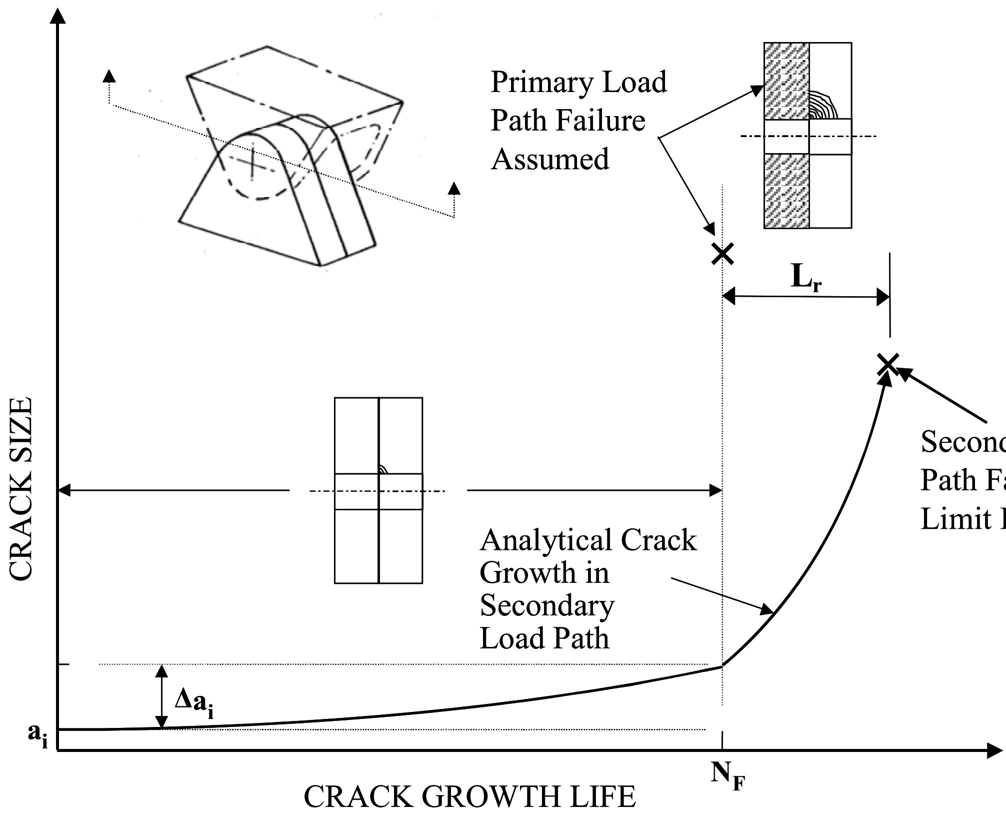
$$\text{Inspection Interval} = L_r/K$$

$$\text{Inspection Interval Period of Applicability} = N_F/L_{SF}$$

(Inspection safety factor, K, should normally be 2.0 or greater)

(Life safety factor, L_{SF}, should normally be 1.0 to 2.0 depending on the overall conservatism in the analysis)

FIGURE 2-3. MULTIPLE LOAD PATH STRUCTURE ANALYTICAL EVALUATION TO SUPPORT INSPECTION FOR A COMPLETELY FAILED LOAD PATH



(ii) Evaluation by Test. Figure 2-4 illustrates some key points if an inspection for a complete load path failure is to be developed based on testing. The inspection interval is based on the test demonstrated residual life (L_r) subsequent to load path failure. Because the residual life decreases with the time accumulated prior to a load path failure as previously discussed, there will be a period of applicability for the L_r and it will be dependent on the time at which a load path failure is simulated, (N_D).

The test article should consist of as-manufactured production parts. Representative "well" condition loading should be applied for some predetermined period of time, (N_D). At the end of this period the load path that is to be inspected for complete failure should be disabled (e.g. saw cutting, attachment(s) removal, member removal) to simulate its failure. The test should then be restarted with a representative "failed" condition loading. (Note that the external loads may be the same as for the "well" condition if the member failure simulation results in the correct "failed" condition internal load redistribution.) The test should continue until the desired residual life has been achieved or to the time at which the secondary load path can no longer support the required residual strength loads, whichever is less, (N_0). Based on the above, Demonstrated residual life = $L_r = N_0 - N_D$

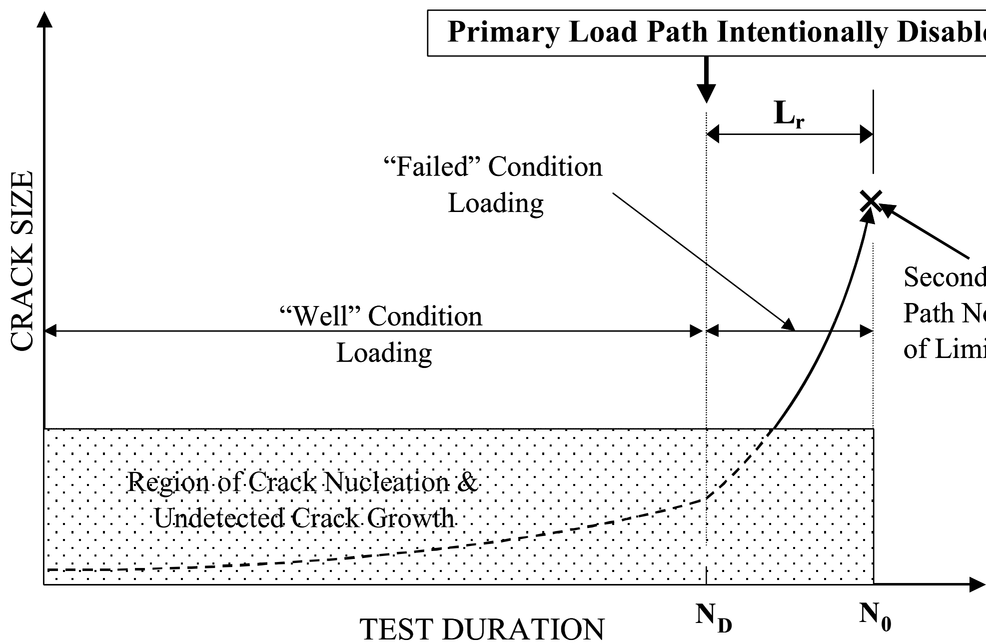
Inspection interval = L_r/K

Inspection Interval Period of Applicability = N_D/L_{SF}

(Inspection safety factor, K, should normally be 2.0 or greater)

(Life safety factor, L_{SF}, should be 2.0 for test)

FIGURE 2-4. MULTIPLE LOAD PATH STRUCTURE EVALUATION BY TEST TO SUPPORT INSPECTION FOR A COMPLETELY FAILED LOAD PATH



(2) Inspection for Less Than a Complete Load Path Failure. Inspection for less than a load path failure may require special nondestructive inspection (NDI) procedures but will result in longer inspection intervals. Figure 2-5 illustrates how inspection intervals could be established on the basis of crack growth and residual strength evaluation.

In this case, the inspection interval is based on the life of the secondary load path (L_r) subsequent to primary load path failure at N_F plus the time (L_P) for a detectable crack (a_{DET}) in the primary load path to grow to critical size under in-service loads. The determination of L_r is the same as discussed in paragraph (B)(1)(i) above. Based on the above, Inspection Interval = $(L_P + L_r)/K$

Inspection Interval Period of Applicability = N_F/L_{SF}

(Inspection safety factor, K, should normally be 2.0 or greater)

(Life safety factor, L_{SF}, should normally be 1.0 to 2.0 depending on the overall conservatism in the analysis)

FIGURE 2-5. MULTIPLE LOAD PATH STRUCTURE ANALYTICAL EVALUATION TO SUPPORT INSPECTION FOR LESS THAN A FAILED LOAD PATH