ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 17 (2011) 258 – 269

Procedia Engineering

www.elsevier.com/locate/procedia

The 2nd International Symposium on Aircraft Airworthiness (ISAA 2011)

Analysis of Airworthiness Requirements on Amdt.25–132 of Limit of Validity to Preclude Widespread Fatigue Damage

XIE Jian*, LU Yao, HE Pei

Aircraft Airworthiness Institute China, China Academy of Civil Aviation Science and Technology, Civil Aviation Administration of China, ChaoYang District XIBAHE BEILI No.24A, Beijing, 100028, China

Abstract

This article introduces innovatory changes and background to inspections of WFD for transport category aircraft which have resulted in the amendment 25-132 of limit of validity (LOV), also indicates a proactive approach which should be taken to address WFD before WFD occurs. With regard to the amendment to regulations on WFD issued by FAA, this article analyzes and interprets the actions of the design approval holder(DAH) and the related compliance methods, focusing on the applicability of the new regulations to WFD and on the methodologies and processes for performing aircraft WFD evaluations which include the determination of inspection start points(ISP) and structural modification points(SMP), the establishment of limits of validity (initial limits and extended limits) , the establishment and revision of airworthiness limitations and Airworthiness Limitations section(ALS), the compliance for part 121 and 129 operators under new regulations, etc. Then a number of new research directions are presented in this article for domestic civil aircraft structure damage tolerance design and analysis for the present and the future.

Keywords: limit of validity; Amdt.25-132; airworthiness; widespread fatigue damage; damage Tolerance; transport category aircraft; ISP; SMP

* Xie Jian. Tel.: 86-10-64481172; fax: 86-10-64481171.
E-mail address: xiejian@mail.castc.org.cn.

1877-7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.10.027

1. Introduction

With the gradual increase in time of civil aviation aircraft in operation, aircraft structural fatigue damage problem is increasingly prominent. On November 15th 2010, the FAA issued the amendment 25-132[1] of limit of validity to prevent WFD for transport category aircraft, on January 13th 2011[2] and January 10th 2011[3] issued corresponding advisory circulars.

The airworthiness certification standards to fatigue damage have been made several significant revisions. One of the first significant changes in the airworthiness standards occurred in March 1956, with the revision of the fatigue evaluation requirements contained in Civil Air Regulations (CAR). This revision added "fail-safe strength" as an option to the "fatigue strength" approach for addressing fatigue 4b.270. Another significant change in the airworthiness standards for fatigue occurred in October 1978 with Amendment 25-45[4], when § 25.571 was revised and § 25.573 was deleted. This change involved removing the fail-safe option entirely and establishing a new requirement to develop damage-tolerance-based inspections wherever practical. In 1998, the FAA amended § 25.571 (Amendment 25-96) [5,18] of the aircraft certification requirements for transport category airplanes. Under this amendment, we introduced the term widespread fatigue damage (WFD) into § 25.571.

The latest significant change in the airworthiness standards for fatigue occurred in November 2010 with the issuance of Amendment Nos. 25-132 and 26-5[6] when the FAA revised § 25.571 and added §§ 26.21 and 26.23. FAA adopted these amendments to require that DAHs must establish a LOV of the engineering data, stated as a number of total accumulated flight cycles or flight hours or both, that supports the structural maintenance program and must demonstrate that WFD will not occur in the airplane before it reaches LOV. Under this change, FAA also added §§ 121.1115 and 129.115 in Amendment Nos. 121-351 and 129-48, to prohibit operation of an airplane beyond its LOV.

The purpose to issue the amendment 25-132 is that the DAH must establish a LOV or an extended LOV for their aircrafts to prevent WFD by adding contents in regulations. DAHs are required to identify and develop maintenance actions showing that such actions are necessary to prevent WFD before the airplane reaches the LOV. If necessary, DAHs are required to establish ISP and/or SMP for WFD evaluation, aircraft operators affected by new regulations also are required to bring LOV and using information of necessary maintenance actions to WFD into the maintenance program. Aircrafts are prohibited of use beyond the LOV, except that operators bring this LOV and necessary using information supporting ELOV into the maintenance program, approved by airworthiness authorities.

This article analyses and interprets actions of DAH and corresponding compliance methods in the amendment 25-132,focusing on WFD evaluation and applicability of new regulations to precluding WFD for transport category aircraft, also on methods and procedures of establishing ISP,SMP,LOV and ELOV. This article is intended to provide technical support to airworthiness certification of ARJ 21 and C919 relating to applying ATC or STC of aircraft, also intended to put forward new directions of structural damage tolerance design, analysis and experimental verification for civil aircraft in china.

2. WFD AND REVISE TO LOV

2.1. WFD AND LOV

In 1988, A USA Boeing B737-200[7,8] type of aircraft with 35493 hours/89090 cycles operation from ALOHA airline which was put into operation in 1969 had serious flight accident because of suddenly tearing and falling off of a piece of front fuselage skin whose length was about 18 inches caused by aircraft structure damage. FAA and NTSB later investigated and found that there were tiny cracks existed simultaneous in many rivets of lap joints in lacerated fuselage skin. The front fuselage skin was easily torn and fallen off under the function of fuselage pressurization and external aerodynamic with the size and density of these cracks. This aircraft structural damage was finally defined as widespread fatigue damage (WFD).

WFD is a condition that occurs when there is 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). 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 LOV. WFD which is general degradation of large areas of structure with similar structural details and stress levels may occur in a large structural element such as a single rivet line of a lap splice joining two large skin panels (multiple site damage). Or it may be found in multiple elements, such as adjacent frames or stringers (multiple element damage).MSD and MED can still simultaneously exist in the same area. MSD has the potential for strong crack interaction. In most cases, MED does not have the same potential for strong crack interaction (Fig. 1). Because the size of cracks contained in MSD and MED can not be detected reliably by existing method, if without intervention in advance, MSD or MED will develop to a state at a certain moment when structure can no longer support prescriptive residual strength of load.

In 2001, Aviation Rulemaking Advisory Committee (ARAC) [8] made a suggestion that a limit should be imposed to the validity of such maintenance program for large transport aircraft. Aircraft repairs, alternations and modifications (RAM) are required to be evaluated and methods should be provided for extended LOV of maintenance program. In 2003, ARAC suggested that a limit should be imposed to the validity of maintenance program for all new certificated Transport Category Aircraft. ARAC believed that the cognitive degree of fatigue feature of aircraft structure was limited by analysis and the quantity of tests, the inspections to maintenance program about structural fatigue should be established on the basis of above analysis and tests. Therefore, if these inspections are also planed to use beyond one time, more repairs, alternations and modifications are need to be replenished. Consequently, ARAC suggested that "a limit of valid to maintenance program" should be established to limit the usage of aircrafts. Once aircraft reaches this limit, operators may not use this aircraft except that a extended LOV and using information of any necessary maintenance activities are brought into maintenance program by operators.

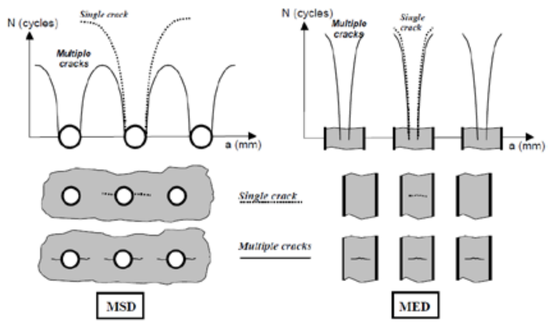

Fig. 1. Difference between MSD and MED Interaction Effects

Under the known condition that WFD may affect the flight safety, an active solution to WFD should be established in advance before WFD happens. This solution need a comprehensive analysis toward causes of WFD for the whole aircraft and need evaluations of repairs, alternations and modifications for aircrafts. Threat level toward aircrafts should be attained by these evaluations to change the current structure repair and structural changing methods. On April 18th 2006[8], FAA issued "Aging Aircraft Program:

Widespread Fatigue Damage, proposed rule" which aimed that WFD in Transport Category Aircrafts must be prevented by providing prior management to WFD. DAH was required to establish IOL or EOL for Transport Category Aircrafts based on comprehensive WFD evaluation of aircraft structural configuration to exclude WFD, also required to evaluate repairs, alternations and modifications of aircrafts to prevent WFD during above process. In January 2011, FAA adopted "limit of valid to maintenance program" recommended by ARAC.

2.2. REVISE TO LOV

Amdt.25-132 involves the federal regulations: part 25, part 26, part 121, part 129[1,9,10,11,12]. Section (a) (3) and section (b) in § 25. 571 about structural damage tolerance and fatigue evaluation are revised. § 25. 571(a)(3) added the content "The limit of validity of the engineering data that supports the structural maintenance program (hereafter referred to as LOV), stated as a number of total accumulated flight cycles or flight hours or both, established by this section must also be included in the Airworthiness Limitations section of the Instructions for Continued Airworthiness required by §25.1529". § 25. 571(b) added the content "an LOV must be established that corresponds to the period of time, stated as a number of total accumulated flight cycles or flight hours or both, during which it is demonstrated that widespread fatigue damage will not occur in the airplane structure. This demonstration must be by full-scale fatigue test evidence". The core of this revise to §25.571 is replacing "design service goal" with "limit of valid". LOV must be brought into ALS of ICA, this means that usage of new aircrafts which exceed LOV will be limited. Part 26 added section §26.21 and §26.23 about WFD for aging aircrafts, which list affected aircraft models and aircraft model exceptions, LOV must be established for aircrafts with a maximum takeoff gross weight greater than 75000 pounds and the guide of WFD must be established to evaluate repairs, alternations and modifications of aircrafts. Section §129.115 and §121.1115[15,16] are added about WFD toward operators, making some requirements of ALS to aircrafts subjected to and excluded from section §26.21.

3. ESTABLISHING A LIMIT OF VALIDITY AND A EXTENDED LOV

3.1. WFD EVALUATION RELATIVE TO LOV

The evaluation will vary from model to model and area to area on any given airplane structural configuration. The evaluation of the identified WFD-susceptible structure has two objectives:

(1)To predict when WFD is likely to occur.

(2)To establish additional maintenance actions, as necessary, to ensure continued safe operation of the airplane.

AC25.571-1D provides guidance for DAH to conduct WFD evaluation, to establish LOV/ELOV and to evaluate repairs, alternations and modifications of aircrafts, also provides guidance for affected aircrafts operators to bring LOV and ALS containing ALI into maintenance program.

WFD evaluation includes analysis, tests and reviewing data in service. $WFD_{(average\ behavior)}$ of aircraft should be determined by using reliable and conservative approach, precluding WFD is essential maintenance operation.

Evaluation process includes:

(1) Identifying a "candidate LOV"

(2) Identifying WFD-susceptible structure

(3) Performing a WFD evaluation of all susceptible structure

(4) Finalizing the LOV and establishing necessary maintenance actions

The flowchart of Fig. 2 expresses this evaluation process and actions which should be taken. WFD-susceptible structure may be the MSD or MED or both. All areas should be considered during evaluating WFD sensitivity of repairs, alternations and modifications for aircrafts. Supporting reason should be provided during inclusion and exclusion any area. APPENDIX 5 [3] provides some MSD or MED-susceptible structure figures.

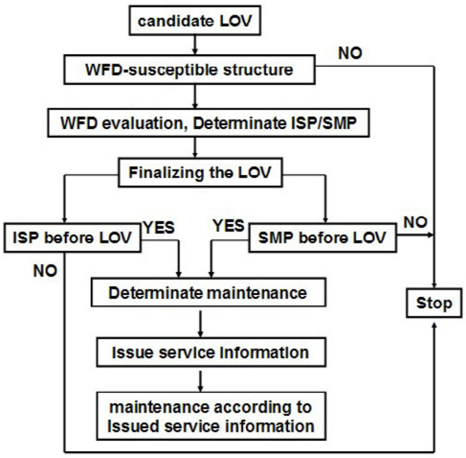

Fig. 2. Process for WFD

The fatigue process that leads to WFD is shown in Figure 3. This figure is applicable both to damage that occurs in MSD and damage that occurs in similar structure at more than one location (MED). For any susceptible structural area, it is not a question of whether WFD will occur, but when it will occur. In Figure 3, the "when" is illustrated by the line titled "WFD $_{\text{(average behavior)}}$," which is the point when, without intervention, 50 % of the airplanes in a fleet would have experienced WFD in the considered area. (Note that the probability density function for flight cycles or flight hours to WFD has been depicted for reference.) The WFD process includes this phase of crack initiation and a crack growth phase. During the crack initiation phase, which generally spans a long period of time, there is little or no change in the basic strength capability of the structure. The actual residual strength curve depicted in Figure 3 is flat, and equal to the strength of the structure in its pristine state. However, at some time after the first small cracks start to grow, residual strength begins to degrade. Crack growth continues until the capability of the structure degrades to the point of the minimum strength required by § 25.571(b). WFD average behavior should be estimated for each susceptible structural area. Such an estimate may be based on full-scale fatigue test evidence and analyses at a minimum, and if available, in-service history. In making this estimate, consider the following [2,3,13] :

(1)Initial cracking scenario. This is the size and extent of multiple location cracking expected at the initiation of MSD or MED.

(2) Final cracking scenario. This is an estimate of the size and extent of multiple location cracking that could cause residual strength to fall to the minimum required level (WFD condition), as shown in Figure 3.

(3) Crack growth. Crack growth predictions can be developed in two ways: analytically and empirically.

(4) Differences between MSD and MED. The differences between interaction effects for MSD and MED are illustrated in Figure 1.

(5) When assessing MSD, certain assumptions or methods may have a greater impact than others on the final outcome of the WFD evaluation [14].

(6) When considering MED in evaluation, interaction between cracks in different elements need not be considered.

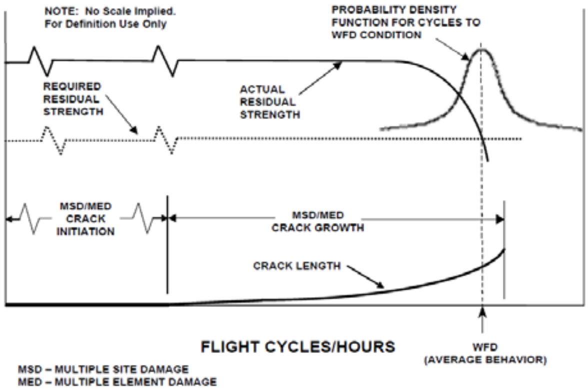

Fig. 3. MSD/MED Residual Strength Curve

3.2. ESTABLISHING SMP AND ISP

This gradual deterioration is a function of use and can be statistically quantified. The term WFD is used and can be statistically quantified. As depicted in Figure 3, WFD can never be absolutely precluded because there is always some probability, no matter how small, that it will occur. Therefore, modifying or replacing structure at a pre-determined, analytically-derived time stated in flight cycles or flight hours, minimizes the probability of having WFD in the fleet. Modification or replacement is the most reliable method for precluding WFD.

The point at which a modification is undertaken is referred to as the SMP and it is illustrated in Figure 4. The SMP is generally a fraction of the number representing the point in time when $\text{WFD}_{\text{(average behavior)}}$ will occur, and should result in the same reliability as a successful two-lifetime fatigue test. This level of reliability for setting the SMP is acceptable if inspections for MSD or MED are shown to be effective in detecting cracks. If the inspections are effective, they must be implemented before the SMP. The implementation times for these inspections are known as the ISP. Repeat inspections are usually necessary to maintain this effectiveness in detecting cracks. If inspections for MSD or MED are not effective in detecting cracks, then SMP should be set at the time of ISP. An inspection is effective if, when performed by properly trained maintenance personnel, it will readily detect the damage in question. The SMP should minimize the extent of cracking in the susceptible structural area in a fleet of affected airplanes. In fact, if this point is appropriately determined, a high percentage of airplanes would not have any MSD or MED by the time the SMP is reached.

The SMP may be determined by dividing the number representing the timing of when $\text{WFD}_{\text{(average behavior)}}$ will occur by a factor of 2 if there are effective inspections, or by a factor of 3 if inspections are not effective.

The ISP is determined through a statistical analysis of crack initiation based on fatigue testing, teardown, or in-service experience of similar structure. The ISP is assumed to be equivalent to a lower-bound value with a specific probability in the statistical distribution of cracking events. Alternatively, you may establish an ISP by applying appropriate factors (e.g., dividing by a factor of 3) to the number representing WFD average behavior.

The IWFD depends on the detectable crack size and the probability that it will be detected with the specific inspection method.

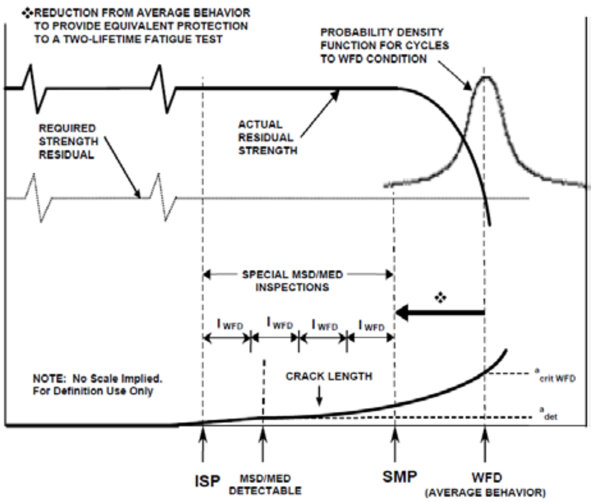

Fig. 4. MSD/MED Residual Strength Curve(including WFD Inspections)

3.3. ESTABLISHING AN LOV

New full centerline engine programs result in three regulatory Type Certificates: One is for EASA and As depicted in Figure 5, the process for establishing an LOV involves four steps:

(1) Identifying a candidate LOV for the airplane structural configuration. A recommended approach sets the “candidate LOV” equal to the design service goal. The final LOV would depend on both how well that design objective was met and the applicant’s consideration of the economic impact of maintenance actions required to preclude WFD up to the final LOV.

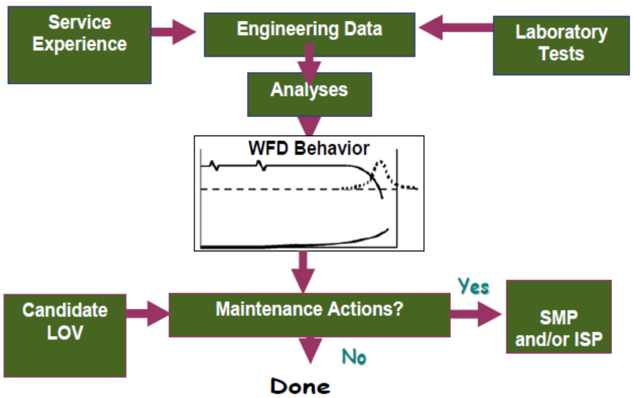

Fig. 5 WFD Evaluation for Each Susceptible Structure

(2) Identifying WFD-susceptible structure. For this evaluation example, it was determined that the airplane structural configuration had six areas with WFD susceptible structure. The applicant should establish criteria that could be used for identifying what structure is susceptible to WFD based on the definitions of MSD, MED, and WFD, when developing the list of structure susceptible to WFD. The applicant should also provide supporting rationale for including and excluding specific structural areas.

(3) Performing a WFD evaluation of each of the six areas of WFD-susceptible structure to determine whether there are ISPs and SMPs for the candidate LOV identified. This allows evaluation of the candidate LOV. Figure 6 shows the WFD behavior for one WFD-susceptible area. The figure also shows three different candidate LOVs. Candidate LOV1 is at a point that occurs significantly before the $WFD_{(average\ behavior)}$ line. This LOV won't require any maintenance actions. Candidate LOV2 occurs before the $WFD_{(average\ behavior)}$ line, but closer to it. As a result, inspection will need to start before the LOV. Although candidate LOV3 occurs before the $WFD_{(average\ behavior)}$ line, with this LOV the probability of WFD in the fleet is unacceptable and an inspection and subsequent modification or replacement is required before the airplane reaches LOV3. Note that for LOV2 and LOV3, if inspections were determined to be unreliable, then the SMP would occur at the point on the chart where the ISP is. Using this example, this decision process needs to be repeated for all six WFD susceptible areas.

(4) Finalizing the LOV. Once all susceptible areas have been evaluated, the final step is to determine where to establish the LOV that you will propose for compliance. Figure 7 shows the results of the WFD evaluation of the six WFD-susceptible areas. As shown, there are inspections and modifications or replacements that must be performed over time to preclude WFD. Any LOV can be valid as long as it is demonstrated that, based on its inherent fatigue characteristics and any required maintenance actions, the airplane model will be free from WFD up to the LOV.

The example in Figure 7 includes three LOVs that could be proposed for compliance.

(i) LOV1: Maintenance actions are not required to address WFD.

(ii) LOV2: Inspection and modification or replacement of area four are required to address WFD.

(iii) LOV3: The DAH may propose an LOV that is greater than LOV2. However, as shown in Figure 7, that would result in more maintenance actions than identified for LOV2. Operators would be required to perform maintenance actions in four out of the six WFD-susceptible areas. Areas 1, 2, and 4 would have to be inspected prior to the LOV. Areas 3 and 5 would be free from WFD maintenance actions. Area 4 would be required to be inspected and modified, and then the modification would be required to be inspected prior to the LOV. Area 6 would require only modification prior to reaching the LOV because it was determined that inspections in this area would not be reliable.

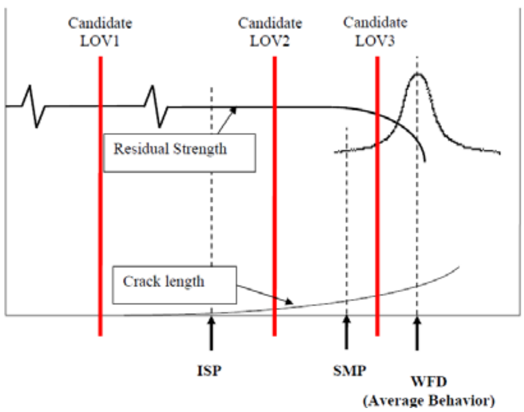

Fig. 6 Comparison of WFD-Susceptible Structure to Airplane LOV

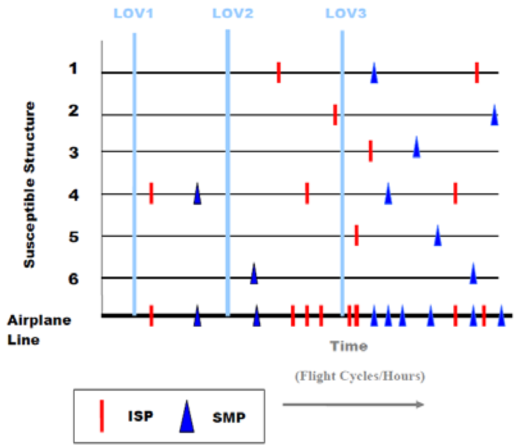

Fig. 7 Airplane Maintenance Actions

3.4. ESTABLISHING A EXTENDED LOV

The requirements for extending an LOV are the same as those for establishing the initial LOV except for the differences noted in Table 1 below.

Any person may apply to extend an existing LOV established under § 25.571, § 26.21, or § 26.23. The applicant must demonstrate that WFD will not occur in the airplane up to the proposed extended LOV. The applicant should consider the age (flight cycles or flight hours or both) of high-time airplanes relative to the existing LOV to determine when to begin developing data to extend it. Because the data is likely to include additional full-scale fatigue testing, the applicant should allow sufficient time (e.g., four years) to complete such testing and to submit the compliance data for approval. An extended LOV is a major change to the type design of an airplane. Thus any person applying for an extended LOV must use the processes for an amended type certificate (ATC) (subpart D of 14 CFR part 21) or supplemental type certificate (STC) (subpart E of part 21). An extended LOV may also include specified maintenance actions, which would be part of the new LOV approval. Extended LOVs, along with any required maintenance actions for the extended LOV, would be incorporated into the ALS.

Table 1 Differences between LOV and Extended LOV

	§ 26.21 (Initial LOV-*required*)	**§ 25.571 (Initial LOV-required)**	**§ 26.23 (Extended LOV-*optional*)**
LOV Establisher	DAH	Applicant	Any Person
Affected Airplanes	MTGW > 75,000 lbs	All Transport Airplanes	Airplanes with an LOV
Considered Configuration	Configuration at Effective Rule Date	Configuration of production airplane	Configuration at Approval Date of Extended LOV
Maintenance Actions	AD	Placement in ALS	Placement in ALS

Time that Unpublished Service Information is due	By Date Indicated in the Binding Schedule	By Date of TC Approval or Delivery of the First Airplane or Issuance of a Standard Certificate of Airworthiness or Date of lov Approval	By Date of Approval of the Extension
Compliance Plan	Yes per § 26.21(d)	Not Required by §25.571	Not Required by § 26.23

4. ESTABLISHING AND REVISING ALS

The ALS of the ICA is required by part 25, Amendment 25-54 (September 11, 1980) and later. Airplanes certificated to Amendment 25-54 and later will have an ALS specifying those items with mandatory replacement or inspection times and related structural inspection procedures approved under § 25.571. Before 1980 those airworthiness limitations had been contained in chapter 5 of the airplane maintenance manual. Under § 26.21, a DAH with airplanes that do not have an ALS must create one and include the LOV. If an airplane does have an ALS, the DAH must revise it to include the LOV. Any new ALS and any ALS revision must be submitted to the FAA Oversight Office for review and approval.

Only DAHs may revise the ALS of the ICA for their airplanes. Anyone else adding limitations must do so in the form of a supplement. The extended LOV, along with any service information that supports it, must be incorporated into the ALS. Type certificate holders would do this in the form of a revision, and other persons would add a supplement. Service information documented in the ALS or any supplement to it becomes airworthiness limitation items.

Unlike § 26.21, for Airplanes with TC Applied for After January 14, 2011, subject to § 25.571 which applies to all transport category airplanes, the FAA may issue a design approval for an airplane model before full-scale fatigue testing has been completed. The DAH would establish the LOV after completion of this testing. Operators may operate such airplanes while the DAH is performing the fatigue testing. To do this, they must incorporate into their maintenance program the ALS with a number of cycles equal to ½ the number of cycles accumulated on the fatigue test article.

5. COMPLIANCE FOR OPERATORS

14 CFR part 121operators of transport category airplanes and foreign air carriers or foreign persons operating native transport category airplanes under 14 CFR part 129 should incorporate an LOV approved by the FAA Oversight Office into their maintenance programs. Under § 121.1115 and § 129.115, no one may operate an affected airplane unless it has an ALS with an LOV approved under Appendix H to part 25 or § 26.21.

The DAH must make the ALS available to operators for incorporation into their maintenance programs. Depending on the airplane's certification basis, a DAH would have either revised an ALS or established a new one to include the LOV for affected airplanes.

Operators may be faced with a situation where a LOV for a certain model airplane is not available for compliance with the operating rule. If the DAH has not provided an LOV on an airplane for which it was required, the operator may use the default LOV published in Table 1 of §121.1115 or § 129.115. If an operator intends to operate an airplane on the exclusion list of § 26.21, that operator may develop its own LOV or use the default LOV published in Table 2 of § 121.1115 or § 129.115.

6. CONCLUSIONS

The revisions of airworthiness regulations continuously have close relations with the improved knowledge of safety for aircraft structure. The concepts in safety for using aircrafts was initially from without regard to life, determination of limit life, the infinite life or economic life by inspections and maintenances to the LOV based on WFD evaluation by Amdt.25-132. Operation of aircrafts is not merely controlled by the economy of operation and market demands, but by more in-depth analysis and evaluation during certification by DHA. It is a milestone that necessary maintenances should be implemented before the LOV for aircrafts by issuing AD.

The compliance for § 25.571 by this new regulation before obtaining TC should be not only based on analysis and tests according to the current effective damage tolerance evaluation, but also based on assessing WFD. New direction of research is put forward in the current and future design and evaluation for damage tolerance especially for WFD.

More structural fatigue tests are required in the design phase for identifying WFD-susceptible structure, attention to the cumulating related service data for existed aircraft model.

Determining $WFD_{(average\ behavior)}$ includes determination of initial cracking mode and conservative damage limit for MSD/MED, analysis technique of multi-crack propagation and residual strength related to WFD and so on. At present, there is more research on the residual strength for MSD and less research for MED because of involving multiple structural components, complex reallocation of internal load and difficulties on analysis and tests. Determining $WFD_{(average\ behavior)}$ also includes statistical analysis of events causing WFD and related research reports and data have yet not been seen.

Good theoretical basis of statistical analysis of single crack development has been formed at present, but tests or theoretical study on statistical analysis of crack development for MSD and MED are insufficient because of lack of corresponding tests data and theoretical model. IWFD and determining SMP whose principle is minimizing size of cracking in WFD-susceptible structure depends on validity of inspection methods and instruments. Pertinent research should be placed on establishing maintenance program and policy for WFD in China [17].

References

[1] Federal Aviation Administration. Part 25-airworthiness standards: transport category airplanes[S]. [2011-04-26].

[2] Federal Aviation Administration. Advisory circular 25.571-1D “damage tolerance and fatigue evaluation of structure” [S]. [2011.1.13].

[3] Federal Aviation Administration. Advisory circular 120-104 “establishing and implementing limit of validity to prevent widespread fatigue damage” [S]. [2011.1.10]

[4] Federal Aviation Administration. Fatigue regulatory review program amendments, Amdt. No. 25-45[S]. 1978.

[5] Federal Aviation Administration. Fatigue evaluation of structures, Amdt. No. 25-96[S]. 1998.

[6] Fang Chang De. Aging Aircraft Program: Widespread Fatigue Damage: 75 FR 69746, November 15, 2010.

[7] Aging Airplane Safety: 70 FR 5518; February 2, 2005.

[8] Federal Aviation Administration. Aging Aircraft Program: Widespread Fatigue Damage, proposed rule [J]. Federal Register, 2006, 74(71): 19927-19951.

[9] Federal Aviation Administration. Part 26-airworthiness standards: continued airworthiness and safety improvements for transport category airplanes[S]. [2011-04-26].

[10] Federal Aviation Administration. Part 121-operating requirements: domestic, flag, and supplemental operations[S]. [2011-04-26].

[11] Federal Aviation Administration. Part 129-operations: foreign air carriers and foreign operators of U.S.-registered aircraft engaged in common carriage[S]. [2011-04-26].

[12] European Aviation Safety Agency. CS-25 certification specification for large airplanes[S]. 2005.

[13] Federal Aviation Administration. Advisory circular 120-93 "damage tolerance inspections for repairs and alterations" [S]. [2007.11.20].

[14] Recommendations for Regulatory Action to Prevent Widespread Fatigue Damage in the Commercial Airplane Fleet, Revision A, dated June 29, 1999 (a report of the Airworthiness Assurance Working Group for the Aviation Rulemaking Advisory Committee's Transport Aircraft and Engine Issues Group).

[15] Federal Aviation Administration. Advisory circular 120-73 "damage tolerance assessment of repairs to pressurized fuselages" [S]. [2000.12.14].

[16] Federal Aviation Administration. Advisory circular 91-56B "continuing structural integrity program for airplanes" [S]. [2008.03.07].

[17] Civil Aviation Administration of China. Part 25- airworthiness standards: transport category airplanes[S]. 2001.

[18] Federal Aviation Administration. Advisory circular 120-84 "aging airplane inspections and records reviews" [S]. [2009.08.20].