The Strategy of Widespread Fatigue Damage in FMP System

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Abstract: As is known, widespread fatigue damage (WFD) is a common phenomenon of aging aircraft being a negative impact on safety and reliability. The current FAR 25.571(b) requires that "An LOV (Limit of Validity) must be established, during which it is demonstrated that widespread fatigue damage will not occur in the aircraft structures". The FAA issued AC 91-82A in August 2011 providing guidance on developing and implementing a Fatigue Management Program (FMP) system to address in-service issues for metallic fatigue critical structures. This action brings new challenges to aircraft manufacturers in China. This paper introduces the problem of widespread fatigue damage including the MSD(multiple site damage) and MED(multiple element damage) and the differences between them and the steps to establish the LOV/ELOV(Extended limit of validity). Authors in this paper is also proposing some management indicators to control WFD during the design phase and maintenance. Developing and implementing the management indicators to address WFD which are involved in the FMP system may provide guidance on the estimation and management to address WFD for present and future aircraft. Finally, some suggestions are put forward to provide the theoretical basis for large civil aircraft design and airworthiness.

Key words: limit of validity; fatigue management program; widespread fatigue damage; airworthiness; fatigue

1 Introduction

WFD in metallic structures is recognized as a significant threat to the continued airworthiness of airplanes. Because of this, each country's airplane design department proposes requirements on monitoring the fatigue and these requirements have evolved over the years and changed as the relevant knowledge base has increased. This paper introduces the widespread fatigue damage which is becoming a common phenomenon in aging aircraft and evaluation; meanwhile we propose the definition and the steps to establish the LOV and ELOV. Then, some management indicators that are involved in the fatigue management program system (FMPS) are put forward to provide guidance on how to defence the WFD in the aircraft structure design. And with the challenge of the Chinese new big aircrafts, the management of WFD will get more and more attention.

2 WFD and evaluation

In this section, the sources of WFD and how to perform a WFD evaluation as part of the overall process for establishing the LOV are introduced. As described in the FAA regulations, the widespread fatigue damage (WFD) is the simultaneous presence of cracks at multiple structural locations that are of sufficient size and density such that the structure will no longer meet the residual strength requirements of section 25.571 (b) [1,2]. The evaluation of WFD is the basis of preventing aircraft structures from WFD and the establishment of LOV. The evaluation should be based on service history, test data, fatigue analyses, damage-tolerance analyses, teardown inspections of high-usage airplanes, or any combination of these. The evaluation of WFD has two objectives in the following:

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1) When WFD is likely to occur.

2) Establish the additional maintenance actions to ensure continued safe operation of the airplane.

2.1 MSD/MED

2.1.1 Definition

WFD comes from two multiple crack scenarios called MSD and MED. Multiple site damage (MSD) is a source of WFD characterized by the simultaneous presence of fatigue cracks in the same structural elements. And multiple element damage (MED) appears in similar adjacent structural elements. At the beginning, it´s difficult to perceive them only by simple detection, and if no corrective action is carried out, they will increase to the critical state.

2.1.2 The difference

As stated in the definition, the differences between MSD and MED are obvious. So we expect details of the approach used to characterize events leading up to WFD to be different. The differences will depend on whether you are considering MSD or MED. This is especially true for crack interaction.

1) Crack interaction. MSD has the potential for strong crack interaction, and the effect of multiple cracks on each other needs to be addressed. However, in most cases MED doesn´t have the same potential for strong crack interaction. The differences between interaction effects for MSD and MED are illustrated in Figure 1.

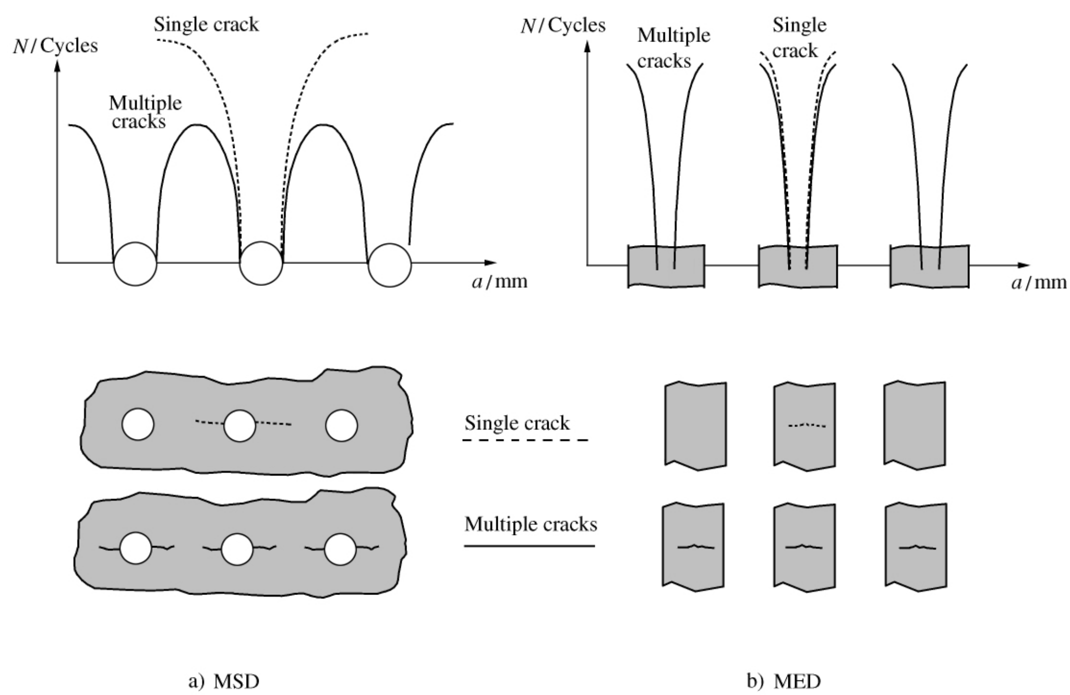

Figure 1 Differences between MSD and MED

2) MSD and MED interaction. Some structures are susceptible to both MSD and MED, and simultaneous occurrence of MSD and MED is possible, even though it´s not common. In this case, our evaluation should consider interaction between MSD and MED.

2.2 WFD evaluation

As discussed above, the evaluation of WFD has two objectives. Firstly, we must confirm the time when WFD will occur. Secondly, establish the maintenance actions.

2.2.1 WFD predicting

The fatigue process that leads to WFD is shown in Figure 2. This figure is applicable both to MSD and MED. Research shows that [3,4], for any susceptible structures, it´s not a question of whether WFD will occur but when it will occur. In Figure 2, the time point is illustrated by the line titled "WFD (average behavior)", which represents the time 50% of the airplanes in a fleet would have experienced WFD in the considered area. The process of WFD includes the crack initiation and crack growth phase. During the crack initiation phase, the curve in Figure 2 is flat, which means there is little or no change in the basic strength capability of the structure. However, after the first phase, the residual strength begins to degrade, and crack growth continues until the capability of the structure degrades to the point of the minimum strength required by 25.571(b).

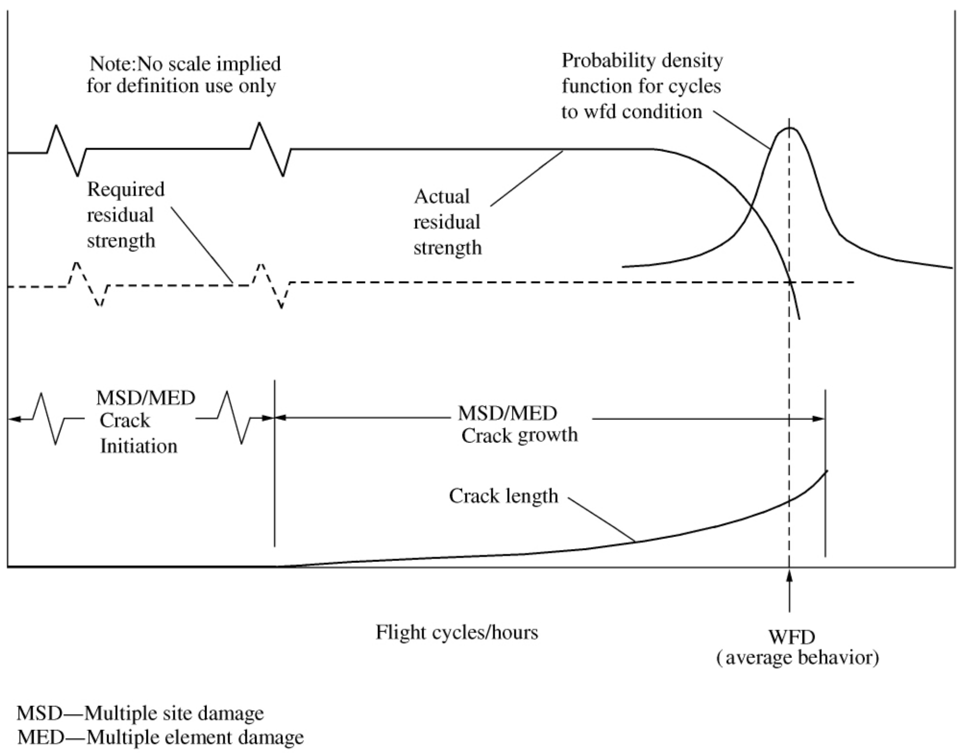

Figure 2 The sources of WFD

2.2.2 Maintenance actions

Fatigue damage is the gradual deterioration of a material subjected to repeated loads, and can be quantified. Thus, as the higher level fatigue damage, the WFD can also be quantified. As the mentioned above, WFD can never be absolutely precluded because there is always some probability, no matter how small, that it will occur. So, at a given time to replace or modify the structures is the most effective way.

The time when a modification is undertaken is referred to as the "structural modification point" (SMP). If inspections for the MSD/MED are effective, they must be implemented before the SMP, the inspection start time called "inspection start point" (ISP). However, if the inspection is proved to be ineffective, the SMP should be reset to ISP.

3 LOV/ELOV

3.1 Definition and establishment

1) LOV

In the year 2010, FAA issued the Amendment Nos. 25-132 and 26-5 [5] when the FAA revised §25.571 and added §26.21 and § 26.23. After that, the FAA issued the "aging aircraft program: widespread fatigue damage; final rule [6]". The regulation requires the design approval holders establish a limit of validity based on the evaluation of airplanes, and demonstrate that the WFD will not occur before the LOV. In FAA's advisory circular 25.571-1D [7], some guidance is proposed for the evaluation of the WFD, and provide the basis of establishing the LOV/ELOV. The steps of establishing the LOV are as follows:

Identifying a candidate LOV.

Identifying the WFD-susceptible structures as shown in Table 1.

Table 1 WFD-susceptible structures

Structural area
Longitudinal skin joints, frames, and tear straps (MSD/MED)
Circumferential joints and stringers (MSD/MED)
Lap joints with milled, chem-milled or bonded radius (MSD)
Fuselage frames (MED)
Stringer to frame attachments (MED)
Shear clip end fasteners on shear tied fuselage frames (MSD/MED)
Aft pressure dome outer ring and dome web splices (MSD/MED)
Skin splice at aft pressure bulkhead (MSD)
Abrupt changes in web or skin thickness-pressurized or unpressurized structure (MSD/MED)
Window surround structure (MSD,MED)
Over-wing fuselage attachments (MED)
Latches and hinges of non-plug doors (MSD/MED)
Skin at runout of large doubler (MSD) -fuselage, wing or empennage
Wing or empennage chordwise splices (MSD/MED)
Rib-to-skin attachments (MSD/MED)
Typical wing and empennage construction (MSD/MED)

Performing the WFD evaluation of each WFD-susceptible structure.

Finalizing the LOV, and establish the maintenance actions.

2) ELOV

On November 2010, FAA issued the Amendment 26-5, and proposed the concept of ELOV in §26.23. Any person may apply to extend an existing LOV established under §25.571, §26.21and §26.23 [8,9]. However, the applicant must demonstrate that the WFD will not occur before the new ELOV. An extended LOV is a major change to the type design of the aircraft, so the applicant must use the processes for an amended type certificate. The requirements on establishing the LOV and ELOV are almost the same, but some differences exist, which can be found in Table 2.

Table 2 The differences between LOV/ELOV

	§ 26. 21 (Initial LOV-required)	§ 25. 571 (Initial LOV-required)	§ 26. 23 (Extend LOV-optional)
Establisher	DAH	Applicant	Any person
Affected airplanes	> 75000 lbs	All transport airplane	Airplanes with LOV
Considered configuration	Configuration at effective rule date	Configuration of production airplane	Configuration at approval date of ELOV
Maintenance actions	Airworthiness directive	Placement in airworthiness limitations section	Placement in airworthiness limitations section
When is unpublished service information 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, whichever occurs latest	By date of approval of the extension
Is compliance plan required	Yes per § 26. 21(d)	Not required by § 25. 571 but recommended as part of the normal certification process per part 21	Not required by § 26. 23 but recommended as part of the normal certification process per part 21

4 Management indicators in FMP

The FAA issued the AC 91-82A [10] in 2011 providing guidance on developing and implementing the fatigue management program (FMP). And this brings new challenge to the large Chinese airplanes' airworthiness and design. In 2010, the FAA issued Amendment 25-132 [11] for aging airplanes and then issued the related regulation AC 120-104 [3], these two provide guidance for the WFD evaluation, maintenance, and the foundation of a replacement/modification program.

Therefore, some management indicators are proposed in this section, and by means of these indicators we can make a prediction of WFD and ensure the evaluation of WFD is effective.

1) Material selection

During the process of the aircraft design, how to select the proper material can also be an effective way to prevent WFD occurrence. In the design phase, using more material that can play a better role in resistance fatigue may provide a better defence on WFD. For some WFD-susceptible structures, more crack resistant material should be incorporated to slow crack growth rates; also heat treatments could be applied to the material in advance and the forming method of the material and so on.

2) SMP/ISP

The SMP should minimize the extent of cracking in the susceptible structural area in a fleet of affected airplanes. And if the time point can be appropriately determined, a high percentage of airplanes will not have any WFD problems by the time the SMP is reached. Generally speaking, the SMP is determined by dividing the number which means timing of the WFD (average behavior)'s occurrence by a factor. If the inspection is effective, the factor equals 2, or the factor equals 3 if the inspection is ineffective. However, at some time, the DAH may have to adjust the SMP when the following situation appears:

(1) Any fatigue critical areas of the airplane in the fleet have exceeded the SMP. In that case, DAH must evaluate these areas of the high-time aging aircraft to determine their structural condition and notify the airworthiness department and propose the appropriate maintenance actions.

(2) Extension of SMP. You can extend the SMP if you can demonstrate freedom from WFD up to the new SMP. The work to extend the SMP may be as follows: Additional fatigue or residual strength tests or the full-scale fatigue analyses; teardown inspections on aging aircraft structures; analysis of in-service data from a number of aging airplanes.

(3) Reduction of SMP. If cracks are found in an inspection or a modification, the SMP should be revalued. If the result of the evaluation can not demonstrate the SMP is sufficiently reliable, the SMP must be shortened, and revise the existing service information.

If the inspection of MSD/MED is effective, it should be carried out before the SMP; the inspection start time is the ISP. It is determined by the analysis of crack initiation based on fatigue testing, teardown inspections, and in-service experience. The ISP is regarded to be equivalent to a lower-bound value with a specific probability in the statistical distribution of cracking events.

3) IWFD

The inspection interval is the time from the accomplishment of one inspection to another new one´s beginning. IWFD should be based on the effectiveness of the inspections, and its determination depends on the detectable crack size and the inspection method.

4) LOV/ELOV

In the process of aircraft maintenance, the modifications of the structures are matured along with the In-service history. As a maintenance indicator of the WFD, LOV can be regarded as the time point when a WFD inspection program should be implemented for the aging aircraft structures. Before proposing the concept of LOV, there is no more guidance on how to treat the aircraft structures after they had a WFD. If the aircrafts are out of service, there is no doubt that it will go against the economical goal. However, if the aging airplanes continue a high-usage operation, the probability of having a catastrophic accident will increase a lot. So, in this paper we regard the LOV/ELOV as the management indicator of the WFD, and if the structures reach the LOV, the inspection must be carried out according to the predicted WFD inspection program.

5 Conclusions and Suggestions

This paper introduces the sources and requirements of the WFD, the WFD´s evaluation and the steps on how to establish the LOV/ELOV according to the related regulations. And then, the authors propose the management indicators on the WFD to provide suggestions in the aircraft design phase. At present, better theoretical basis is established for single crack analysis, but inspections or theoretical basis for multiple cracks are insufficient because of less theoretical models and test data. And the LOV which represents the indicator of maintenance must be established to ensure the safety of the aircraft.

The management system of WFD can not be established in a short period. From the last century, many researchers began to study the multiple crack problems, but there is no integral system for the WFD until now. With the proposal of the Chinese big airplanes, there are more challenges in the defense of WFD for lack of experiment data, in-service history and so on. Thus, there are some suggestions as follows:

1) On the existing bases, we should implement more intensive inspections on WFD-susceptible structures, and this asks us to have further study on the initial crack and the crack growth.

2) The research of inspection and analysis methods on two sources of WFD (MSD/MED). Until

now, the research on MSD are much more than the MED because more structures are involved in the analysis of MED and the stress redistribution is much more complicated.

3) The prevention manual of the WFD must be established as quickly as possible, and the maintenance manual also should be developed as early as possible.

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Brief Biographies

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