Widespread Fatigue Damage Evaluation for Multi Elements based on Probabilistic Approach

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Introduction

In order to obtain a Type Certificate for civil transport category aircraft the Applicant must to comply with some design rules - airworthiness requirements. Among those, the one associated with structural fatigue (§25.571[1, 2]), whose main objective is related to prevent a catastrophic event, from structural damage, during the operational life of the aircraft. That section requires special attention for Widespread Fatigue Damage (WFD). For that, the design approval holder (DAH) must establish a Limit of Validity (LOV)[3] of the engineering data that supports the structural maintenance program. Up to the LOV, DAH must demonstrate that the aircraft will be free from WFD. A Widespread Fatigue condition can be originated from: Multi Site Damage (MSD), Multi Element Damage (MED) or a combination of both. The objective of this work is to propose a probabilistic approach to define maintenance actions to prevent widespread fatigue damage condition from Multi Element Damage up to the LOV.

To support establishment of the LOV, the DAH must demonstrate by test evidence and analysis at a minimum and, if available, service experience or by service experience plus teardown inspection results of high-time airplanes, that WFD will not occur in that airplane up to the LOV.

For any susceptible structural area, it is not a question of whether WFD will occur, but when it will occur. This “when” is called WFD Average Behavior (WFD_{AVE}), which is the point when, without intervention, half of the airplanes in a fleet would have experienced WFD in the considered area.

The main sources of engineering data to support the WFD_{AVE} are laboratory fatigue tests (full-scale fatigue tests, components tests, and teardown) and service experience. This work intends to propose an approach to establish the WFD_{AVE} for a MED scenario for a WFD_{SS} based on these sources of data.

Once WFD_{AVE} is determined, the maintenance actions (ISP- Inspection Start Point and/or SMP-Structural Modification Point) are established based on this value:

Methodology

In order to define the WFD_{AVE} is necessary to know when (in Flight Cycles, FC or Flight Hours, FH) the structure achieve the minimum residual strength - as per §25.571(b). This is an important step for MED, i.e. to evaluate the size of simultaneous cracks in its elements the structure can withstand. For the sake of clarity, a typical frame construction of five elements is considered herein, which WFD condition is established when three of these five frames are failed, independent of position.

The typical fatigue life, considered as 50% unreliability, of each frame is typically obtained from Full-Scale Fatigue Tests or Service Experience findings. In case there is no findings for one or more frames, the total cycles of FSFT is considered as the typical life for it. It is considered the fatigue behavior of elements follow a 2-parameter Weibull Distribution.

For each element, from its typical life it is generated random values based on Weibull distribution for that shape (β) and characteristic life (η).

In the assumed example (five frames), the WFD condition is established when three of this five frames are failed, independent of position. For each random set of lives, one WFD_{AVE}^{i} is determined at the moment of three frames are failed. The WFD_{AVE} for the WFD_{SS} is defined as the moment when 50% of the airplanes in a fleet would have experienced WFD in the considered area, i.e. the moment of the fleet (in our case, the distribution of WFD_{AVE}^{i}) reaches 50% of unreliability.

The resulting distribution of WFD_{AVE} does not necessarily follow Weibull with knowledge β as single fatigue behavior of each element. Therefore, ISP and SMP will not be defined as 1/3 and 1/2 of WFD_{AVE}, but by reliability of 1% and 5% respectively.

Results

It is assumed, arbitrary, typical lives from five elements (five frames in a row). These values may come from any source of Engineering data (Testing or Service Experience), and are assumed to already have considered any kind of adjustment. In resume, it is the time to failure of each structure.

It was considered in this example 3,000 simulations. The Table 1 shows the first five for better comprehension – the three first failed frames, that indicates the WFD condition, are highlighted.

From the cumulative distribution it is possible to determine the WFD_{AVE}, and then the necessary maintenance actions ($ISP=N_{01}$ and $SMP=N_{05}$, in case structure is inspectable) - see Fig. 1. The WFD_{AVE}, ISP, and SMP are defined considering the point in time immediately below the thresholds (50%, 1%, 5% for WFD_{AVE}, ISP, and SMP respectively).

Table 1. Determination of WFD_{AVE}^{i}.

Simulation #	Random Lives for element *i*					**WFD_{AVE}^{i}**
	1	**2**	**3**	**4**	**5**	
1	102873	77094	226756	126598	**103691**	**103691**
2	61808	27824	167482	120718	77168	**77168**
3	73971	58339	**111873**	164892	120340	**111873**
4	29930	51749	235489	101060	134871	**101060**
5	105485	65053	225997	**141707**	147155	**141707**

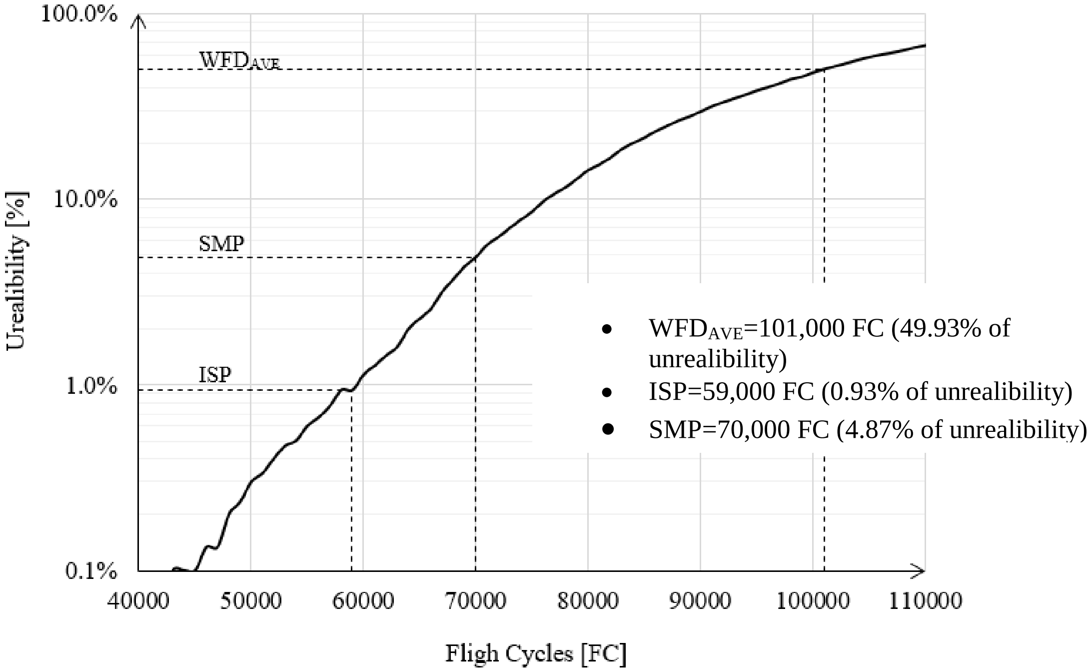

Figure 1. Cumulative distribution of WFD_{AVE}^{i}.

Conclusions

A simple probabilistic approach for definition of WFD average behavior for MED scenarios was proposed. The probabilistic fatigue behavior of MED scenario (herein, considered three of five frames failed) is not the same of individual one. The results demonstrate that the shape factor (for MED Weibull) is strongly dependent on the variability of the individual fatigue lives – the more variability in individual fatigue lives, the lower the shape factor. The principal effect of this is that to define maintenance actions using guidance of AC 120-104[3] usually results in conservative values – however in case of high dispersion this behavior might not be true.

It was not considered interaction between cracks in different elements. In case this influence cannot be neglected some reductions factors at individual lives must be considered.

Keywords

Reliability, Structure integrity, Fatigue, Damage tolerance, Widespread Fatigue Damage

References

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