THE METHOD FOR DEVELOPING F-BY-F LOAD SPECTRA OF FIGHTER AIRCRAFT BASED ON MANOEUVERS

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Abstract

Fatigue loads of fighter aircraft in service are mainly caused by manoeuvers. Such loads occur with their inherent characters. According to these characters a way for developing F-by-F load spectra of aircraft is presented in this paper. Firstly manoeuvers are standardized by a series of typical load sequences based on all flight samples. Then different flight missions are formed by various manoeuvers in their correct order. Finally a complete F-by-F load spectrum can be created by connecting flight missions in a certain way. The most important step for developing such kind of load spectrum is how to determine standard manoeuvers. Two methods to do it are described comparatively in this paper .

For assesment of these two methods, several groups of specimens have been fatigue-tested under different load spectra. Conclusions and discussions about the test results are also included here.

1.Introduction

The development of a load spectrum is very important in determining fatigue life of aircraft structures . In order to predict the fatigue life , fatigue test and/or analysis must be carried out which requires the definition of load spectrum. The more accurately can the spectrum represent actual aircraft usage, the higher confidence we can have to the fatigue life. Many methods are availible for developing load spectra , but no matter how a spectrum is developed and how every detail is carefuly considered, one cannot expect that the developed fatigue spectrum would be eaxctly equal to the actual service load history experienced by aircraft. None of methods which are well-accepted has achieved this up to now. That is, there is always a difference between them . However, the difference of fatigue damages would be much smaller if all important factors affecting fatigue damage are properly considered. These factors include the magnitude, the frequency and the sequence of loads, as well as how the loads being distributed on aircraft structures.

It is a common practice in fatigue field now to adopt F-by-F load spectrum for aircraft, for example, the well known FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue evaluation)[1] . In a F-by-F load spectrum, the loads are usually randomly arranged within a flight misssion or a mission segment to imitate real load sequence. It is thought, by randomly arranging the loads the effect of load sequence on fatigue damage can be taken into account. This may hold true for transport type aircraft since the loads experienced by such type of aircraft are mainly gust loads whose occurence varies indeed in a random manner.

However, it may not be proper to sequence the loads in the same way for combat aircraft. The loads subjected by this type of aircraft are mainly from manoeuvers. With regard to the gust loads ,they have little or no effect on the fatigue/fracture life of high load factor type aircraft , which has been shown by past experience [2]. Since the occurence of manoeuver loads relate to the pilot's control actions, the load sequences have their inherent characters. It would be more reasonable to sequence the loads in accordance with these characters.

Furthermore, apart from the load factors at the center of gravity, each loading point must associate with some other parameters , such as attack angle, airspeed ,roll rate and so on, to constitute a set of loading condition in order to correctly distribute the total load among different parts of aircraft structures. It would be very difficult to properly match other parameters with load factors by random method.

In order to make a spectrum more representive in the above two aspects, the methods for developing F-by-F spectrum of fighter aircraft based on manoeuvers are presented below.

2. Structure of a load spectrum

The usage of an individual aircraft can be monitored. The recorded load history during a long period can be analysed and processed as following:

A flight period can be separated as a series of flight missions. A flight mission can be divided into a series of manoeuvers and each manoeuver is composed of several pairs of load peaks/valleys. In this way a recorded load spectrum can be well organized into a hierarchic structure of four different levels.

A load spectrum for fatigue test or analysis must be "typical" to represent a class of aircraft/ or a fleet group. The common practice is not to monitor all aircraft for very long period, limited by cost and time, but to collect data on a few aircraft in some sample flights during a short period instead. Then a representative load spectrum must be developed based on data of these sample flights. However, the developed spectrum will still have the hierarchic structure.

2.1 Flight missions within a flight period

Flight aircraft in peace time are mainly used in flight training practice, which are carried out in accordance with the Flight Training Progrom (FTP) The FTP specifices what kind of missions and how often they should be flown , hence it reflects the average usage of one type fighter aircraft during a flight period. This information will be represented by a mission utilization matrix (proportion factors).

Another point which should be considered in constructing a load spectrum is, in what order the different flight missions should be sequenced. The FTP does not mention this . The statistical investigation of service Log showed that there is no regularity and the sequence of all flight missions within a flight period for an individual aircraft is randomly ordered. Therefore in constructing load spectrum, the different flight missions are randomly arranged within a flight period according to the utilization matrix.

2.2 Characters of manoeuvers

Firstly, the occurence of manoeuvers within a flight mission is not arbitrary but rather strictly fixed. For example , taking off must always be the first manoeuver of a flight , and landing is the last one with other manoeuvers between them. This feature contradicts the common practice of randomly arranging loads within a flight mission.

To simulate the effect of load sequence, the order of different manoeuvers within a flight should be definitely predetermined. Through analyzing flight profiles for all different flight missions sampled, it is not difficult to obtain the correct order of manoeuvers within each flight . Thus the orders of manoeuvers obtained are kept fixed in the developed fighter load spectrum.

When dividing the flight data recorded in service into various manoeuvers and putting the data for an identical manoeuver into one group, we can notice that : the number and the order of the peaks and valleys of load factors are the same for all samples in one group , the magnitude of load factors at the same point is a random variable and follows a Normal distribution. An example for an acrobatic manoeuver is given in Table 1. Only 20 samples from flight are listed in this Table to show that the manoeuver consists of 2 pairs of valley/peak and the peaks in the first pair are higher than those of the second pair. The variations of load factors in second pair of valley/peak of this manoeuver (but with more samples) are shown in Fig 1 and Fig 2 respectively. The sample points are ranked first and then the accumulated ferquency of occurence are plotted on Normal probability paper. The sample

Table 1 Valley/peak load factors in 20 samples of an acrobatic manoeuver

	First pair		Second pair	
NO	Valley	Peak	Valley	Peak
1	1.51	4.00	1.18	3.19
2	1.19	3.74	1.16	3.17
3	1.69	4.24	1.11	2.98
4	1.00	3.77	1.05	3.18
5	2.06	4.29	1.16	3.52
6	1.54	4.16	1.53	2.87
7	1.90	4.16	1.60	3.72
8	2.39	4.77	1.52	3.63
9	1.37	4.39	1.54	3.46
10	2.08	4.12	0.90	2.76
11	2.14	4.25	1.19	2.53
12	2.48	4.34	1.31	3.87
13	1.56	4.73	1.58	4.45
14	1.64	4.24	1.33	3.41
15	2.64	4.23	1.33	3.52
16	1.94	4.33	1.35	3.60
17	1.56	4.66	1.18	3.58
18	1.42	4.24	1.27	3.55
19	1.98	3.88	1.16	3.86
20	1.79	4.12	1.29	3.55
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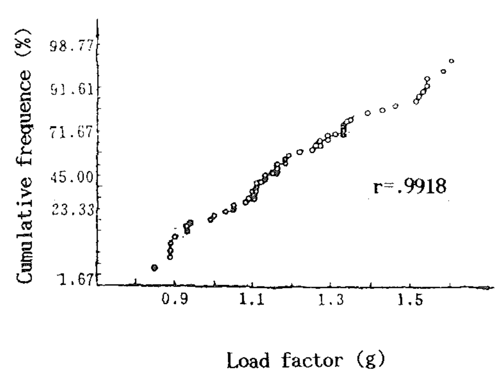

Figure 1 Distrubution of load factors for the second valley of an acrobatic manoeuver

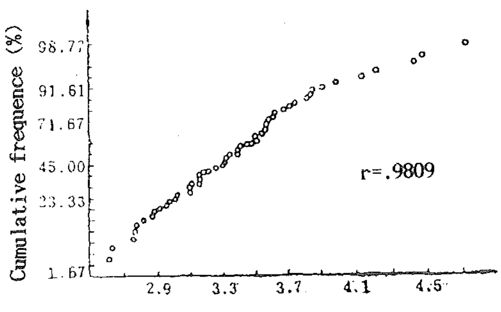

Figure 2 Distrubution of load factors for the second Peak of an acrobatic manoeuver

points can be well represented by straight lines on probability paper (correlation coefficients (r)$\geq$.98).

According to these characters, we can base the aircraft load spectra on manoeuvers: Firstly manoeuvers can be standardized by a set of typical load sequence from all samples . Then different flight missions are formed by various manoeuvers in their correct nature order. Finaly a complete F-by-F load spectrum for a flight period can be created by connecting flight missions in the way as described above.

3. Standardization of manoeuvers

How to determine standard manoeuver is the most important step in developing such kind of spectrum . Two diffent methods are described comparatively here in details , The two spectra developed by these two methods are called MA and MB respectively hereafter.

3.1 Spectrum MA

The standard manoeuvers in spectrum MA are determined through statistical approach which can be briefly described by following steps (More information about this method can be seen in reference [3]):

a) Picking out peak/valley load factors and all other flight parameters related to each point of load factor peak/valley from corresponding sample data recorded in the actual flight .

b) Dividing recorded flight data into various manoeuvers within each flight landing by considering all flight parameter simultaneously.

c) Drawing data for identical manoeuver from all landings and putting them into one sample group.

d) For each group, calculating the statistical mean values for all peak/valley load factors from samples. Using these values as typical load peaks/valleys.

e) Arranging all these typical values in origin order to form a standand manoeuver.

f) Similarly, all other parameters related to a typical load factor ,such as attack angle, airspeed etc, are represented by their statistic mean values of the samples to define a set of load condition which is needed in calculating detail load distribution.

Repeating step c) ~ step f) until all standard manoeuvers are determined.

3.2 spectrum MB

The method used in MB is much different from that of MA. After dividing recorded flight data into various manoeuvers and putting identical manoeuvers into the same group, the fatigue damage was calculated firstly, the standard manoeuvers are then determined according to the results of fatigue damage calculation. The additional steps to replace steps (d~f) in MA are as following:

a) Deriving the transfer function between load factor and strain at the most critical location by statistic regression of parameters measured in the flight.

b) Using S~N curve of the specimen which represents the geometry configuration of the critical location.

c) Calculating the fatigue damage of a manoeuver for all samples based on the linear fatigue damage accumulation law.

d) Determination of standard manoeuver. Once fatigue damage (D_i) for every sample is calculated , then the mean damage ($\bar{D}$) is easily found out. The sample manoeuver whose D_i is most close to $\bar{D}$ is selected as standard manoeuver and the load condition corresponding to each load point of the standard manoeuver is naturally the combination of all parameters recorded during that sample flight.

Some fluctuations of peak/valley load factors may be found during standardization of manoeuvers , which are not belong to any normal manoeuvers, but can not be ommited from raw flight data. In order to consider the effect on fatigue damage caused by such loads , several special transition manoeuvers are set up and added between some standard manoeuvers.

4. Comparative test of specimens

In order to evaluate different methods , several groups of specimens have been fatigue-tested [4] .

The whole process is briefly summed up as following:

Fristly , a "realistic spectrum " (named PA) was created by arranging actual recorded flight data randomly according to the Mission Utilization . Then spectra MA and MB as well as FALSTAFF-like spectrum (FA)[5] were developed on the basis of PA . After all these load factor spectra were converted into stress spectra at the critical location , a group of 6 specimens were fatigue-tested under each spectrum . The spectrum difference factors were calculated by using the result of PA as the reference spectrum. Finally, all the methods for developing load spectrum of fighter aircraft were evaluated by comparing these factors. More details about the test can be found in reference [4]. The test results are shown in the Table 2 .

5. Conclusion and discussion

The main conclusions derived from the study are:

There is no significant difference between the manoeuver-based MA and a FALSTAFF-like spectrum FA, when compared with the fatigue life under a realistic reference spectrum(PA). That is, the method based on manoeuvers represented by statistical means and that used in developing FALSTAFF have the same reliability.

By considering fatigue damage,the spectrum MB using the mean damage sample as the standard manoeuver results in a spectrum difference factor close to 1. That is, the fatigue life under MB is much closer to that under the relistical reference spectrum than those under other spectra. It clearly demonstrates that the fatigue damage equivalence rule should be followed in the development of the spectrum.

To develope manoeuver-based spectra needs special effort to divide recorded flight data into various manoeuvers, but it has two major advantages over FALSTAFF spectrum:

a) All other parameters necessary to determine load detailed distribution are given at the same time as the peak and valley load facters are standardized for a manoeuver. That enables the load conditions being considered more realistically.

b) If the aircraft is put into different usage or the FTP is revised (such thing can be met frequenly in service), a new load spectrum is offen required. Once all manoeuvers are standardized, it is very easy to reconstruct a new load spectrum without recording flight data again.

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Table 2 Comparion of test results under different spectra

Name of spectrum	cycles in 200hrs	crack initiation stage				crack growth stage				total life			
		MLL*	ML**	SD†	SDF‡	LML	GML	SD	SDF	LML	GML	SD	SDF
PA	12414	3.9344	8598	.01758	1.	3.3333	2154.4	.07679	1.	4.0322	10771	.02519	1.
MA	9780	4.0317	10758	.02461	1.251	3.4569	2863.7	.09038	1.329	4.1331	13587	.02966	1.261
MB	8790	3.9662	9252	.02915	1.076	3.3215	2096.3	.06275	.973	4.0814	12052	.04994	1.119
FA	8200	4.0551	11352	.06366	1.32	3.4094	2567.1	.12434	1.192	4.1465	14011	.05192	1.301

* MLL: Mean value of Log-life
** ML: Mean life
† SD: Standard deviation
‡SSD: Spectrum difference factor