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AGARD ADVISORY REPORT No. 28

on

Fatigue Load Monitoring of Military Aircraft

NORTH ATLANTIC TREATY ORGANIZATION

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

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FATIGUE LOAD MONITORING OF MILITARY AIRCRAFT

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SUMMARY

The present report has been prepared for the benefit of the NATO Military Committee by the Netherlands National Aerospace Laboratory on behalf of the Structures and Materials Panel of AGARD.

This document is the result of a study conducted by AGARD on the topic "Fatigue Level Control of Tactical Aircraft" which was submitted by the Military Committee to the AGARD Steering Committee in September 1968.

In this short advisory report the NATO Military Authorities will find the summarized views of the AGARD Structures and Materials Panel on the subject and precise recommendations for further cooperative action within NATO.

SOMMAIRE

Le présent rapport a été préparé pour le compte du Comité Militaire de l'OTAN par le Laboratoire National Aérospatial des Pays-Bas au nom de la commission Structures et Matériaux de l'AGARD.

Ce document est le résultat d'une étude faite par l'AGARD sur le sujet "Contrôle du Niveau d'Endommagement en Fatigue des Avions Tactiques" qui avait été soumis par le Comité Militaire à l'AGARD en Septembre 1968.

Les autorités militaires de l'OTAN trouveront dans ce court rapport un résumé des vues sur la question de la commission Structures et Matériaux de l'AGARD ainsi que des recommendations précises pour de futures actions en coopération à l'intérieur de l'OTAN.

CONTENTS

1. Conclusions and Recommendations

1. For present-day combat or tactical aircraft the monitoring of fatigue loads experienced in service appears to be mandatory.

2. The monitoring systems used at present measure and record movement parameters like the c.g. acceleration.

3. The conversion of these parameter records to structural loads or stresses may be difficult for more complex aircraft, like those capable of variable wing sweep and wise ranges of speed and store-carrying.

4. Vertical c.g. acceleration records give little or no direct information with regard to the load experience of various aircraft components such as empennage, landing gear and control surfaces.

   Recommendation

   It is recommended that efforts to establish statistical relations between movement parameters and structural loads should be promoted and coordinated.

5. The monitoring of strains instead of c.g. acceleration should be preferred in those cases, where no consistent relation between acceleration and structural load can be taken to exist. However, sufficiently simple and reliable strain recording systems are not available as yet.

   Recommendation

   Present efforts in the NATO community to develop a simple strain recording system should be promoted and coordinated.

6. Within the NATO countries with relatively large air forces, well-established techniques for fatigue life monitoring exist, which are adapted to their specific demands and problems. This situation does not occur in the smaller NATO countries.

   Recommendation

   It is therefore recommended that those countries which do not have a well-established procedure should coordinate their efforts to arrive at a solution which suits their joint requirements.

2. Introduction

It was suggested to the NATO Military Committee at its meeting of 5 September 1968 that "Fatigue Load Monitoring of Tactical Aircraft" was a problem in need of study.

The Netherlands Military Authorities, who made the suggestion, emphasized the importance of load monitoring especially with regard to aircraft that are used for missions other than those they were designed for.

The Military Committee approved the topic being submitted for consideration by the AGARD Steering Committee.

The Chairman of the Steering Committee brought the topic to the attention of the AGARD National Delegates Board at its 25th Meeting in September 1968. The National Delegates Board decided that the problem should be handled by the appropriate AGARD Panels and that a high priority should be assigned to it.

It turned out that the Structures and Materials Panel was the best qualified to deal with the subject. As a result of actions taken by the Panel Chairman, introductory presentations were made by delegates from the United Kingdom and the Netherlands at the 28th Meeting of the Structures and Materials Panel in April 1969. The Netherlands delegation was given the task to make a compilation of the opinions as regards solving the problem, held by various officials in those NATO countries actively engaged in pertinent research and development efforts. This led to a report called "Fatigue Load Monitoring of Tactical Aircraft", issued as NLR Technical Report 69063 and presented by its author to the 29th Meeting of the Structures and Materials Panel.

In view of the obligation to report back to Military Authorities it was decided that a report had to be written expressing the views of the Panel as a single body rather than those of a number of individuals. The representatives of the nations most heavily involved (i.e. Canada, France, Germany, Netherlands, United Kingdom and United States of America) were requested to prepare statements that could serve as the basis for the Panel report. The Netherlands was assigned the task to assemble these statements into the present report.

3. Current Practices and Philosophies in Monitoring the Loads Experienced by Aircraft

The systems used presently within the NATO Community for the establishment of the operational load experience of military aircraft may be roughly divided into two groups:

1. A limited number of aircraft of each type are equipped with relatively complicated monitoring equipment. Parameters recorded are e.g. accelerations and angular velocities with respect to three axes, speed, altitude, etc. The records obtained, together with flight logs giving mission parameter data, are evaluated in order to obtain representative load spectra pertaining to each mission type or mission segment. The information obtained can be used to calculate (on a statistical base) the load experience of an individual aircraft, supposing its mission usage is known.

   Moreover, the "mission spectra" are used to define design load spectra for future aircraft.

2. Either a high percentage or all aircraft of the fleet are equipped with a relatively simple and inexpensive load monitoring device, a counting accelerometer. This meter is read after each flight and the data are recorded together with information on the type of sortie, take-off and fuel-weight etc. This information is processed to obtain the load experience for each aircraft. Also from these records, average "mission spectra" can be obtained. The relatively limited sophistication of the measurements, and hence the inaccuracy, compared to the techniques previously mentioned, may be compensated for by the fact that data are obtained on a much higher number of flights.

Although the two techniques are presented here as separate and alternative solutions, in practice they are often used in combination. This is done e.g. by the USAF and the GAF.

On the one hand, the variation in load experience among individual aircraft of the same type is too large to calculate the load experience of individual aircraft with sufficient accuracy from the measurements of type 1 alone. On the other hand the information obtained from measurements of type 2 alone is too limited to allow fatigue life calculations, especially for aircraft where the weight, load distribution and configuration change considerably during one flight.

The basic advantage of the load monitoring systems used nowadays is, that use can be made of available recording equipment with proven reliability. Moreover, the equipment can easily be mounted and is interchangeable from aircraft to aircraft.

The disadvantages, or rather the problems associated with the present monitoring systems have to do with the analysis of the results and the interpretation of the recorded loads in terms of fatigue damage. They will be discussed in the next section.

4. Measurement and Analysis Techniques

The magnitude and complexity of the recording equipment for the "type 1" measurements depends heavily on the complexity of the specific aircraft type and the missions performed. For example, according to USAF experience, in one type of aircraft it may be sufficient to record only velocity, altitude and normal load factor. On another, current fighter, however, a total of 24 parameters is being recorded.

Oscillograph recorders have been, and are being used extensively. The records obtained require manual processing to transcribe the data into a medium suitable for automatic processing on computers. For this reason the oscillograph recorders are replaced more and more by magnetic tape recorders.

As mentioned previously, the load records obtained can be processed to obtain load spectra pertaining to specific mission types or mission segments. In order to calculate fatigue damage, these load spectra, expressed in "parameter-variations", have to be converted to "stress-spectra", for critical locations of the aircraft structure. In other words, the relations between the measured parameters and the stresses in the aircraft structure have to be known.

This information may be obtained from:

a. Analytical calculations

b. Strain measurements obtained in previous flight load survey tests

c. Simultaneous measurement of "movement-parameters" and strain within the structure (German Air Force).

It will be clear from the previous lines that even in the case of fully automatic processing of the recorded data, the analysis of the recorded data of type 1 measurements is a complicated matter, for which a relatively large computer capacity and specialized personnel with good judgement are needed.

In order to calculate fatigue damage from the accelerometer counts obtained in type 2 measurements, the accelerometer counts for each flight can be multiplied by certain "weighing factors", which account for the average weight, speed and configuration during that specific flight. Due to fuel consumption the "stress per g" may vary considerably throughout one flight. In that case, the acceleration spectrum per flight has to be distributed statistically over a number of flight segments, each segment pertaining to an approximately constant "stress per g" - value. (German Fatigue Test Program)

When the stress per g variation is relatively small, which may be the case with wings and fuselages of fighters, simplifying assumptions can be made, for example that the maneuver activity takes place at half-mission weight. (UK practice)

(According to Dutch experience, this last assumption is certainly not true for peace-time operations, but it might be true for war-time operations).

The problems brought about by marked changes in load distribution due to supersonic flight or wing sweep position can be and are being tackled by accelerometers with more than one bank of counters which can be switched to read only in certain flight regimes, e.g. at specified speed, Mach number or wing sweep angle.

Obviously, this results in more complex instrumentation systems for type 2 measurements and more complex analysis problems.

Yet it has to be recognized that still accelerometer readings provide little or no information with regard to the fatigue damage of structural components whose loading condition is poorly or not at all defined by the load factor, such a tailplane, fin, undercarriage and control surfaces.

5. Problems and Needs

In the previous sections, current practices and techniques for the monitoring and analysis of loads on aircraft were discussed.

During these discussions, the major problems associated with the present systems came forward. These problems may be summarized as follows:

a. To define the load environment of relatively complex aircraft (e.g. variable sweep) with a wide range of store-configurations and mission-capabilities, the simultaneous measurement of many parameters may be necessary. The measuring equipment needed and the amount of data to be processed may become very large.

b. Due to the large scatter in load experience the "type 1" measurements are insufficient for the definition of fatigue load experience of individual aircraft. These measurements have to be supplemented by accelerometer-counts on individual aircraft.

c. Load factor counts give little or no direct information about the load experience of several aircraft components, such as empennage, undercarriage and control surfaces.

It will be obvious that the severity of these problems depends on the specific properties of the aircraft used and the missions performed by them.

Still it can be said that the problems mentioned have been recognized by all parties engaged in fatigue load monitoring, and several Research and Development Projects have been initiated to tackle them.

In the first place, attempts are being made to assess the statistical relations between movement parameters and structural loads. The idea may be illustrated by the following thoughts with regard to maneuver loads on the vertical fin. Obviously, no direct relation exists between c.g. vertical acceleration and fin load. Probably a statistical relation could be developed between fin load and aircraft c.g. lateral acceleration and angular rotation about the vertical axis.

Apart from this one might even argue that relatively heavy fin-maneuver loads occur in flights which are generally characterized by a severe maneuver activity which is reflected by the c.g. vertical accelerometer readings. In other words, it might be possible that a statistical correlation between c.g. vertical acceleration and fin maneuver loads can be derived.

It is our opinion that a further development of this statistical approach may give very useful results; the exchange of ideas on this matter and the exchange of results of statistical evaluations should be promoted.

In the second place the advantages of measuring directly the structural loads, viz. strains, instead of acceleration have been generally recognized. Several groups are investigating the feasibility of a simple recording device that would monitor strains in one or more critical locations of the aircraft. The U.S. and French thinking goes out to a "strain counter" device, comparable with the present counting accelerometer. The Netherlands and the U.K. propose a slightly more complicated system, using magnetic tape recording.

The development of a simple and reliable strain recording device has to be seen as a relatively long-term project.

In the meantime, the presently available systems may continue to "do the job" in many cases in the future. However, it is our conviction that the availability of a simple strain recording system might offer a solution for many of the problems inherent in a system that uses accelerations as a measure of loads, as discussed in the present report.

Hence, we feel that the efforts in the NATO nations to develop a strain recording system should be promoted and coordinated.

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