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LOAD SEQUENCES FOR FATIGUE TESTING OF COMPONENTS AND FULL-SCALE AIRCRAFT STRUCTURES

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Abstract

A survey is given of testing methods and testing purposes. Relevant test data are summarized regarding the effects of load sequences, infrequently occurring high loads and large numbers of low-amplitude cycles. This information is required for the discussion of the question how testing methods can meet specific testing purposes. A proposal is made for exploring the usefulness of random flight-simulation tests for making life estimates.

1. Introduction

In the last decades fatigue testing procedures of aircraft structures and components have seen a steady evolution. New philosophies about fatigue of aircraft have been proposed while essentially new testing techniques were developed. Fatigue of aircraft includes such aspects as loads on aircraft, aero-elastic response, stress analysis, design concepts, life calculations, testing and last but not least aspects of safety and economics. It is evident that various disciplines have to contribute to the problem. This implies that there is a risk of unbalanced solutions.

Fatigue testing of components or a full-scale structure is now generally accepted as a necessity, but the way to do it is not always clear. Different opinions exist about:

1 Simplification versus sophistication of testing methods.
2 Significance and relevance of test results.

In fact both topics are intimately interwoven. In the present paper it is tried to analyse these questions.

The paper starts with a chapter on testing methods and testing purposes. The following chapter gives a summary on some relevant test data with respect to the effects of load sequences, infrequently occurring high loads and large numbers of low-amplitude cycles. The discussion in chapter 4 is concerned with the question whether the various testing methods can meet the specific testing purposes. In chapter 5 a proposal is made for an investigation on random flight-simulation tests. The paper is completed with a number of conclusions.

2. Testing methods and testing purposes

2.1 Testing methods

Four types of loading will be considered, see fig. 1

1 Constant-amplitude loading
2 Program loading
3 Random loading
4 Flight-simulation loading

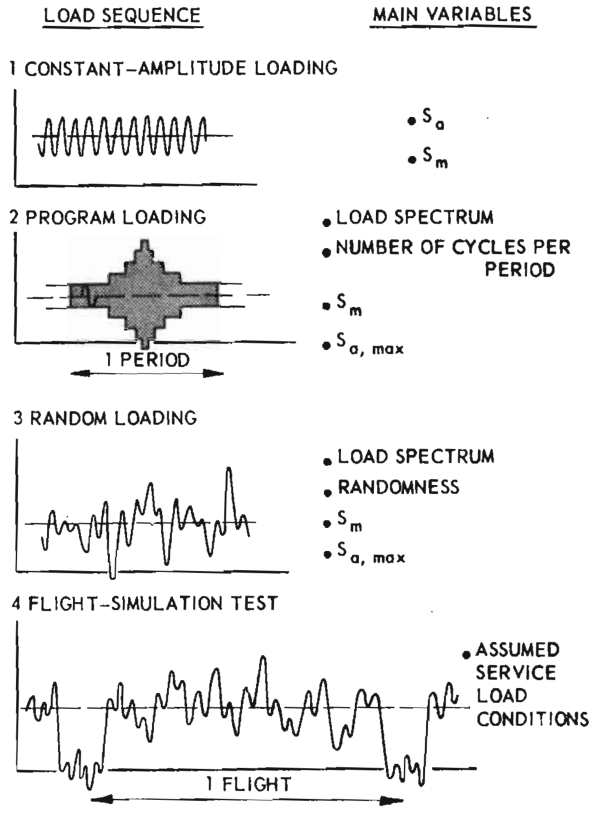


Fig.1 Testing methods

Constant-amplitude loading should be associated with the classical fatigue test. In the early days rotating bending and plane bending could be applied with simple fatigue machines.

In 1939 Gassner(1) proposed the program test. The basic idea was that load amplitudes in service are varying instead of being constant. The variation of the amplitude in a program test should then correspond to the statistical distribution of the amplitude in actual service.
Since program tests originally had to be carried out on resonance fatigue machine or conventional hydraulic machines the amplitude could be changed only slowly. Hence a program test implied a slow modulation of the amplitude which initially excluded the possibility of applying small numbers of high amplitude cycles.

Many fatigue loads in service are characterized by a random sequence rather than a programmed one. The need for fatigue testing with a random loading was recognized quite early but the difficulty was the fatigue machine. The first experiments were made with electro-dynamic shakers (2,3,4) loading a specimen in bending. The shaker was fed by random noise. A disadvantage is that the test set up may be acting as a filter, the output being a narrow band random loading. This problem can now be eliminated by electro-hydraulic load control in a closed loop system. In a random load test the statistical properties of the magnitude and the sequence of the loads are stationary. In general this will not be true in service and moreover well defined deterministic loads will occur. This has led to the flight-simulation test, which is aiming at a more or less realistic representation of the load-time history in service. Flight-simulation tests are well known as a testing method for full-scale structures. Originally this implied the application of ground-to-air cycles (GTAC) and gusts and manoever loads in a flight-by-flight pattern. The first tests of this nature were a crude representation of the actual load-time history since all flights were identical with a constant-amplitude gust loading, see fig.2. All gust cycles were reduced to the same amplitude by calculation employing the Palmgren-Miner rule.

At the present time such simplifications are no longer necessary in view of the development of closed loop servo-hydraulic loading systems. A flight-simulation test now could be a realistic simulation of the actual load sequence in service. It may include both statistically varying loads (e.g. gust, maneuvers) and loads with a more deterministic character (e.g. GTAC, pressurisation cycles). The loads may be different from flight to flight.

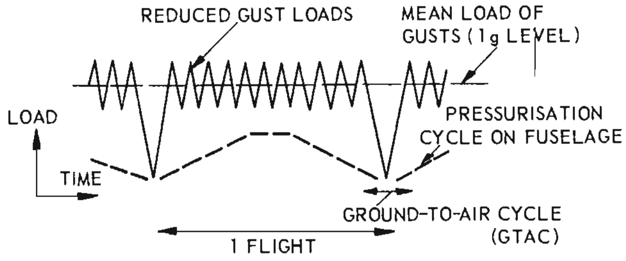


Fig.2 Load sequence in a simplified flight-simulation test

It is beyond any doubt that the development of experimental facilities has strongly affected the present state of the art. Testing machines were recently described by Jacoby(5) and random load testing was surveyed by Swanson(6). A problem not yet fully settled is the matching of testing methods to testing purposes. This requires some knowledge of fatigue damage accumulation and the question then boils down to the significance of:

a the load sequence

b load cycles with a very high amplitude and a very low probability of occurring in the target life

c load cycles with a very low amplitude occurring very frequently in service and if applied in a test covering the major part of the testing time.

These aspects are considered in chapters 3 and 4.

2.2 Testing purposes

Aircraft components or structures may be tested for a variety of reasons which usually fall in the following categories.

a Determination of fatigue data for life calculations. Usually such data are understood to be S-N curves or a complete fatigue diagram. Many tests are necessary unless some analytical relation between cyclic stress, mean stress and life is assumed. The utilization of the data for life calculations requires a cumulating damage rule, such as the Palmgren-Miner rule. Results of program tests(7) and random tests(8) have also been proposed as basic data for life calculations.

b Comparative fatigue tests. The purpose may be a comparison between alternative designs, production techniques, surface treatments, etc. Although constant-amplitude tests are frequently employed for this purpose, program loading, random loading and even flight-simulation loading can be used.

Another purpose of comparative testing is checking the fatigue quality of a new design. A fatigue test on a component is carried out in order to see whether the life compares favourably with data from a previous design. Frequently constant-amplitude tests have to be used for this purpose because the older data were also obtained with this type of loading.

c Direct determination of fatigue life or crack propagation data. Tests for this purpose can only be made if the load spectrum has been defined. It further requires that the loading in the test will give an accurate representation of the damage accumulation in service. One of the purposes of full-scale fatigue tests with a flight-simulation loading is indeed the determination of fatigue lives and crack growth data.

In order to see how the above goals can be achieved by the various testing methods the results of some relevant test series will be summarized in the following chapter.

3. Survey of some relevant test series

3.1 The effect of the sequence of the load cycles

The damage increment during a certain load cycle will depend on(9) :

a the intensity of the load cycle (its range and its maximum or mean value)

b the fatigue damage already present.

From microscopical evidence and theoretical considerations we know that fatigue damage should be associated with cracking, either on a micro or a macro scale. However, cracking alone is insufficient to describe fully the fatigue damage because it does not say anything about the conditions at the tip of the crack such as the geometry (crack front orientation, crack blunting, crack closure) and the state of the material (strain hardening, residual stress). These conditions will affect subsequent damage increments, which are incremental increases of the crack length. Since the conditions at the tip of the crack are a function of the preceding load history it should be expected that the sequence of the various load cycles will affect the rate of damage accumulation. Several examples will be shown below.

The classical example of the sequence effect is given by the two-step test, a fatigue test in which the stress amplitude is changed only once. The fatigue life (and also $\sum n/N$) depends on the condition whether the test starts with the higher amplitude or the lower one.

In a program test the amplitude is changed many times in some programmed sequence. The sequence may affect the fatigue life. As an illustration fig.3 shows the results of tests on riveted 2024-T3 joints. Sequence effects in program tests were shown in several investigations(10-18), which also indicated that the size of the period (number of cycles per period) could affect the life (see also fig.5).

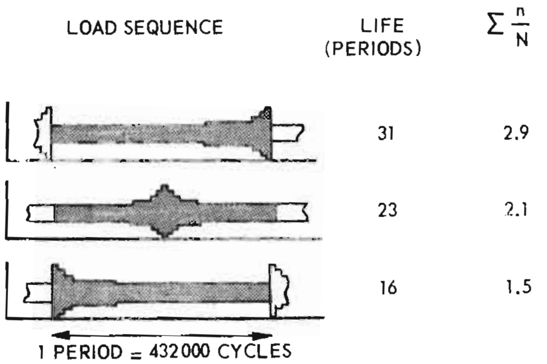


Fig.3 Three series of program tests with different load sequences. Tests on 2024-T3 Alclad riveted joints(10)

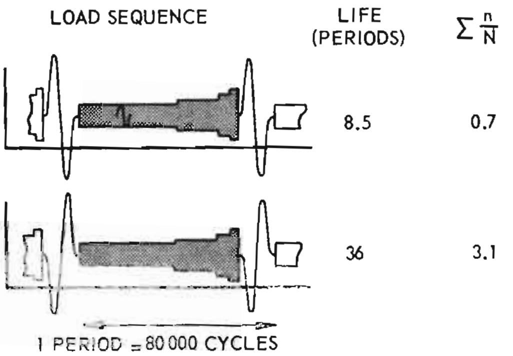


Fig.4 The effect of reversing the sequence of a high peak load cycle on the program fatigue life of a 7075-T6 Clad riveted joint(10)

A fairly dramatic sequence effect is shown in fig.4. In two comparative test series one high peak load cycle was added to each period of a program test. Reversing the sequence of only this cycle (neg.-pos. instead of pos.-neg.) increased the life more than four times. Assuming that a positive peak induces favorable residual stresses and that a negative peak eliminates such stresses the latter half of the peak load cycle apparently had a predominant effect.

An interesting topic is the comparison between the results of program tests and random tests if the same statistics of maxima and minima apply to both types of tests. Jacoby(19,20) has found that the life in a program test on a notched 2024-T4 bar could be six times larger than in a comparative random test. He also found large differences for a titanium alloy and a super alloy, but it appears that a generally valid correlation between the results of random loading and program loading does not exist. Fortunately data from Naumann,(21,22) Lipp(17) and Jacoby(18) suggest that the life does not depend so much on the sequence provided that it is random in some way or programmed with a short period. This is also illustrated by results of crack propagation tests recently carried out at the NLR(23), see fig.5.

The tests were carried out on 2024-T3 Alclad sheet specimens, thickness 2 mm, width 160 mm. Crack propagation started from a central notch and the propagation life in fig.5 is defined as the life for crack extension from 24 mm to 100 mm (tip to tip). In all tests complete load cycles were applied, that means each positive amplitude was followed by a negative amplitude of the same magnitude. An exception is the second series of random tests in which each cycle was applied in the reversed order (neg.peak-pos.peak). The distribution function of the stress amplitude was the same in all test series. It was derived from a gust spectrum. The sequence in the random tests was obtained by omitting the ground-to-air cycles from a random flight-simulation test, see later. In the program tests with the short periods each period corresponded to that which had been a flight in the random sequence. The minimum and the maximum stress amplitude were 1.1 and 7.7 kg/mm^2 respectively, the mean stress was 7.0 kg/mm^2. As fig.5 shows the fatigue lives for the random loading and the program loading with the short period exhibit small differences only. However, in the more conventional program test (long period, 40,000 cycles) the lives were considerably larger and moreover depending on the load sequence in the period.

Sequence effects were also studied in flight-simulation tests, namely by Naumann(21), Gassner and Jacoby(24), Jacoby(19), Imig and Illg(25), and the NLR(9,26). It turned out that the sequence of the loads in flight had only a small effect on the fatigue life or the crack propagation. One exception was reported by Gassner and Jacoby testing notched 2024-T4 bars with programmed flight loads. For a low-high-low amplitude sequence the life was 5800 flights as compared to 2800 flights for a

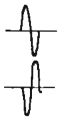
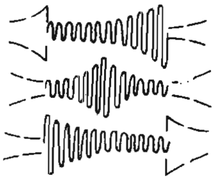
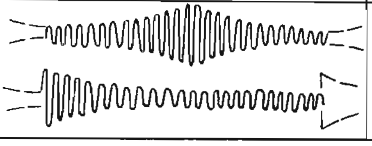
SEQUENCE			CRACK PROPAGATION LIFE (CYCLES)	RATIO
RANDOM			1 167 000 997 000	1 0.85
PROGRAMMED	SHORT PERIOD (av. 40 CYCLES)		1 113 000 1 197 000 1 333 000	0.95 1.03 1.14
	LONG PERIOD (40 000 CYCLES)		3 012 000 3 639 000	2.58 3.12

Fig.5 Comparative crack propagation tests with random and programmed load sequences (23)

high-low-high sequence. For two types of random sequences the lives were 3400 and 3660 flights. The number of gust cycles was 405 per flight and this large number may be responsible for the diverging result.

3.2 Truncation of the load spectrum

Usually fatigue in aircraft structures is associated with geometrical notches inducing stress concentrations. Secondly in most cases a positive mean stress is involved. As a consequence a positive fatigue load with a high amplitude will easily cause local plastic yielding at the root of the notch. This will introduce compressive residual stresses which are favorable for fatigue resistance. The same arguments apply to cracks. An illustration was already presented in fig.4. A second one(27) concerning crack propagation is shown in fig.6. Three high loads had a highly delaying effect on the propagation of the fatigue crack. The figure also shows that a subsequent downward load greatly reduced this effect, but nevertheless it is still clearly noticeable.

The effect of high loads on the fatigue life under constant amplitude loading has been known for a long time from the work of Heywood(28). He also showed that repeating such high loads considerably increased the effect.

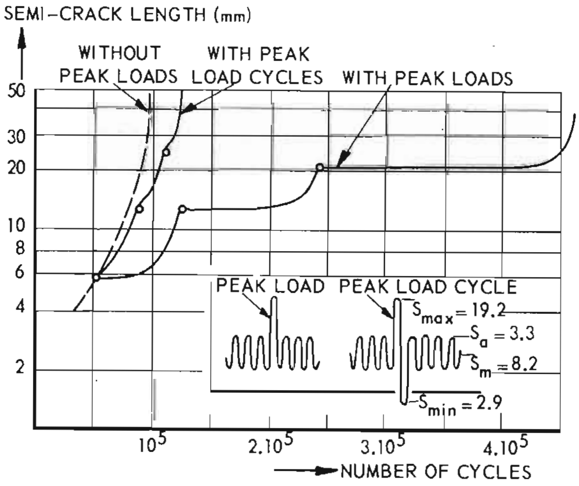


Fig.6 The delaying effect of peak loads and peak load cycles on the fatigue crack propagation in 2024-T3 Alclad sheet specimens.(27) Stress values in kg/mm^2, 0 = moment of application of peak load or peak load cycle.

With the above information in mind it will be clear that the selection of the highest load to be applied in a program test, a random test (clipping ratio) or a flight-simulation test will be a critical issue. Data in the literature for program tests are not abundant because changing the maximum load was usually coupled with changing all load levels proportionally. Available results(13,39,45) confirm the significance of the maximum load.

With respect to flight-simulation loading Gassner and Jacoby(24) found a small increase of the fatigue life of a notched 2024-T4 specimen if the maximum amplitude was reduced from 2.1 S_m to 1.55 S_m. In these tests the gust loads in each flight were applied in a programmed sequence.

Recently the NLR carried out an extensive test series on crack propagation in 2024 and 7075 sheet specimens(9,26,29). The type of loading history is shown in fig.9. One of the variables studied was the truncation level as defined in fig.7. The amplitudes of the gust cycles exceeding the truncation levels were reduced to that level. The test results clearly indicated that a higher truncation level increased the life. As an illustration some results are presented in fig.8 from a test series which included the pre-crack life. The figure shows that increasing the truncation level from 4.4 to 8.8 kg/mm^2 increased the pre-crack life 1.5 times, the crack propagation life almost 4 times and the total life 2.2 times. For 7075 specimens the effect on the crack propagation life was even larger, the ratio being almost 6 !

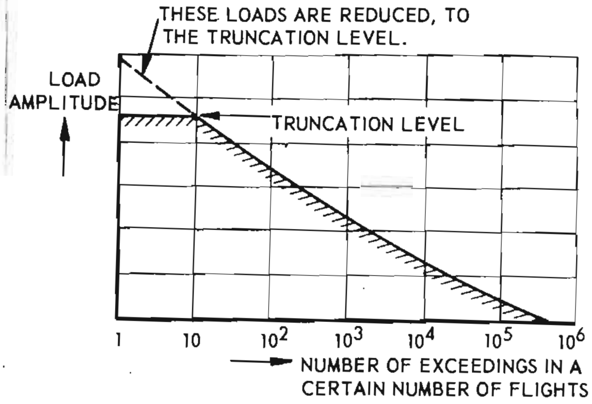


Fig.7 Example of truncating the infrequently occurring high amplitudes of a load spectrum

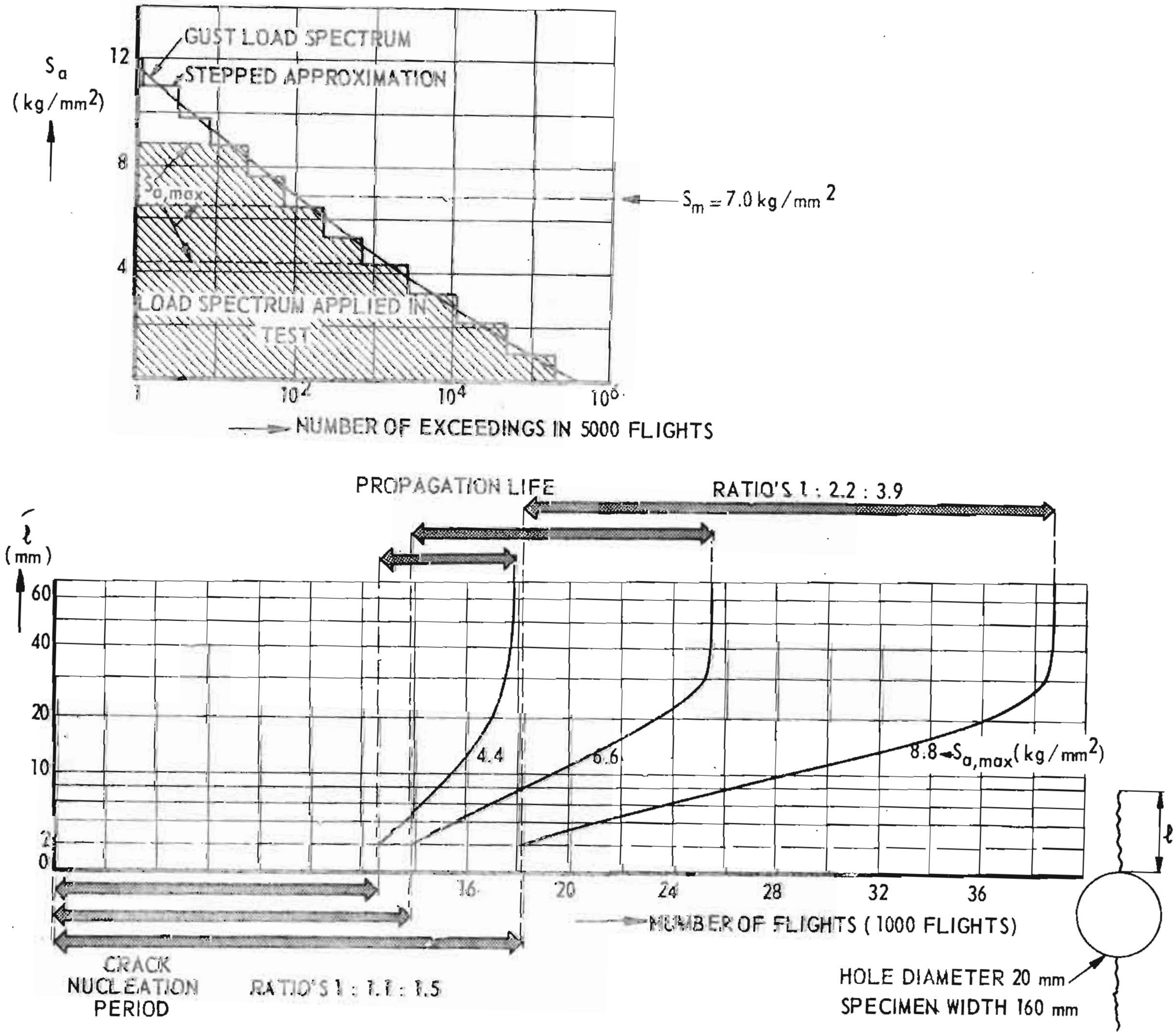


Fig.8 Crack propagation curves for 2024-T3 Alclad sheet specimens with a central hole. Effect of truncation level ($S_{a,max}$) on the crack nucleation period (to $l = 2$ mm) and the crack propagation life(9,26)

An indirect but very important proof of the significance of the maximum load applied in a test is obtained from test series on full-scale structures. Results found for a variety of fatigue load histories have been reported for Mustang wings(30,31) Commando wings(32), Dakota wings(33), a swept back wing(34) and wing center sections(35). As a general trend it turned out that the picture of fatigue-critical elements in a structure and the indication of the most fatigue critical component of the structure both depend on the load-time history applied. In reference 35 it was concluded that the maximum load applied in the test was mainly responsible for this result.

3.3 The effect of low-amplitude cycles

In aircraft structures fatigue cycles with a low amplitude usually occur in relatively large numbers. Consequently if such cycles could be omitted from a test a large proportion of testing time would be saved. There are two theoretical arguments why low-amplitude cycles could be significant.

a Due to the large numbers they may induce fretting corrosion damage and thus enhance crack nucleation.

b Low-amplitude cycles may be damaging as soon as cracks have been created by load cycles with a higher amplitude.

Program tests carried out by Gassner(36) on 2024-T4 notched specimens with and without fretting indicated a life ratio of 1:2. Although this is much less than expected from S-N data it is not negligible. Hence low-amplitude cycles should not be omitted from a test if they can induce fretting corrosion damage, at least not from the first part of the test.

With respect to aspect b results from program tests as reported in the literature (10,11,37-39) generally indicate a noticeable increase of life if the low-amplitude cycles are omitted from the test. However, it has been said earlier(35) that a program test may be the best opportunity for low-amplitude cycles to be damaging, because they are applied in blocks of large numbers. In a random test the low-amplitude cycles are more evenly dispersed between cycles with higher amplitudes. This implies that the information from program tests is not necessarily relevant.

Similar data from random tests are not known, but the omission of low-amplitude cycles from flight-simulation tests has been studied. Naumann(21) reported a 16 and a 7 percent life increase when omitting gust cycles with S_a=1.05 kg/mm^2 from random flight-simulation tests on edge notched 7075-T6 specimens. Gassner and Jacoby(24) found a 2.5 times longer fatigue life in programmed flight simulation tests after omitting cycles with S_a = 1.3 kg/mm^2 (2024-T4 notched specimens).

Crack propagation tests of the NLR(9,26) yielded the data as shown in fig.9. In these tests 10 different types of weather conditions were simulated in each test in a random sequence. The loading history was similar to that shown in fig.11. As figure 9 shows omitting small gust cycles apparently increased th crack propagation life.

Figure 9 also shows that the omission of taxiing loads during the ground-to-air cycle did not have a systematic effect on the life. Similar observations were made by Gassner and Jacoby (24) and by Imig and Illg(25). It is expected that this trend is applicable only if the mean stress of the taxiing loads is either small or negative.

4. Discussion

In chapter 2 testing methods and testing purposes were briefly outlined. In chapter 3 the effects of the load sequence and of high and low-amplitude cycles on the fatigue life and crack propagation were illustrated by test results. These effects will first be summarized after which a discussion follows on the question how testing methods can meet testing purposes.

The results in section 3.1 clearly illustrate that the life in a fatigue test may be significantly affected by the sequence of the loads applied. From theoretical arguments about fatigue damage accumulation such effects are to be expected. In view of sequence effects a random load and a programmed load with a long period may be quite different types of loading. In a random load sequence the amplitude is changing from cycle to cycle while in a program test it is changed rather infrequently. Large differences in fatigue lives have indeed been noticed. Fortunately sequence effects become less significant if the variability of the load amplitude is large (different types of randomness, programmed sequences with a short period). For flight-simulation loading with periodic ground-to-air cycles the trend is that sequence effects become even less.

High loads occurring very infrequently may have a most predominant effect on the fatigue life. The higher these loads are, the longer the life may be.

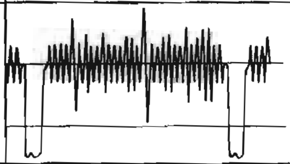
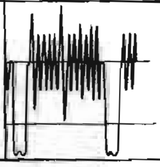
Low-amplitude cycles occurring very frequently may contribute to crack nucleation by fretting and to crack growth and thus be damaging.

Some comments will now be made on how to meet the test purposes.

a Determination of fatigue data for life calculations.

If we understand this type of data to serve as basic information for design purposes the problem to be solved is a very complex one. It includes the utilisation of a cumulative damage rule. However, if a reliable rule were available this does not mean that realistic life calculations could then be made. Two other uncertainties have to be considered which are differences between laboratory specimens and the aotual structure and secondly the validity of the assumed load spectrum. It is not sure whether the damage rule will be the weakest link. The conclusion has to be that only rough life estimates can be made.

It has been proposed by Gassner and Schutz(7) to use data from program tests as basic data for making life estimates. A similar proposal was made by Kirkby and Edwards(8) for random loading. There are some indications that life estimates may be improved in this way. In view of possible differences between random loading and program loading the first type of loading should probably be preferred (6,40). Nevertheless uncertainties about the

	LOAD SEQUENCE	REMARKS	CRACK PROPAGATION (a) LIFE (FLIGHTS)	
			2024 – T3 ALLOY	7075 – T6 ALLOY
A		RANDOM FLIGHT SIMULATION	10 900	5900
B		TAXIING LOADS OMITTED	11 800	5 100
D		SMALL GUST CYCLES OMITTED	13 900	7 000
E		MORE SMALL GUST CYCLES OMITTED	20 800	9 800

(a) THE CRACK PROPAGATION LIFE COVERS PROPAGATION FROM $2\ell = 20$ mm TO COMPLETE FAILURE OF THE SHEET SPECIMENS, WIDTH 160 mm. THE CRACKS WERE STARTED BY A SHARP CENTRAL NOTCH.

Fig.9 The omission of low-amplitude cycles from a flight-simulation test and its influence on the crack propagation life in sheet specimens(9,26)

damage rule and the relevance of the specimens remain. This question will be touched upon again in chapter 5.

b Comparative fatigue tests

Many people still feel that constant-amplitude tests are a good means for comparing alternative designs, production techniques, etc. However, the possibility of intersecting or non-parallel S-N curves is making this very dubious. In figure 10 comparative tests at stress level S_{a1} would indicate design A to be superior to design B. At stress level S_{a3} the reverse would apply, whereas at S_{a2} both designs would be approximately equivalent.

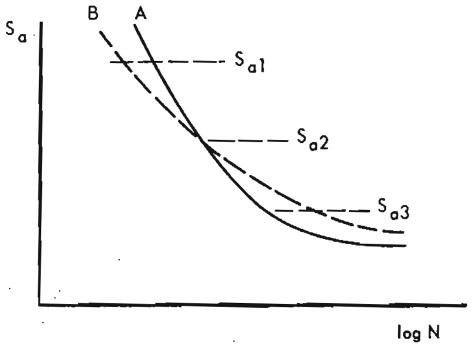


Fig.10 Two intersecting S-N curves

The numerous test series with program loading carried out by Gassner and his co-workers (41) indicate that the risk of a mis-judgement would be much smaller if program loading were adopted for comparative testing. This will apply also to random loading (42). Nevertheless if flight-simulation loading can be adopted it appears that it is the most preferable solution. Real problems should be tackled with realistic testing methods if possible. Recently Branger and Ronay(43) adopted random flight-simulation loading for exploring the fatigue behavior of a high-strength steel. Imig and Illg(25) adopted this test method for studying the effect of temperature on the endurance of notched Ti-alloy specimens. At the NLR as part of an ad-hoc problem we compared two alternative types of joints with random flight-simulation loading.

As an illustration of different answers to the same question a recent investigation(9) indicated that the crack propagation in 7075-T6 was four times faster than in 2024-T3 according to constant-amplitude loading. However, under flight-simulation loading it was only twice as fast.

c Direct determination of fatigue life and crack propagation data

This goal can only be reached if the damage rate in the test is representative for service conditions. In view of sequence effects a flight-simulation test is then required(44). An exact simulation of the load-time history in service appears to be the preferable solution, but this is not a feasible one for several reasons(9) such as testing time. A representative damage rate can still be obtained if the predominant features of the service loading are retained. The most important one is the variability of the fatigue loading. Fortunately the sequence of the loads in a flight will probably have a minor effect. Taxiing loads may be omitted in certain cases. However, a major problem is the assessment of the highest load level to be applied in such a test. As discussed before this level may have a predominant effect on the life and the crack propagation. If the load level that will be reached (or exceeded) once in the target life of the aircraft is applied in a test we know that it may have a favorable effect on the fatigue life. It then should be realized that this load level is subject to statistical variations, that means some aircraft will meet this load more than once in the target life, whereas other aircraft will never see it. In view of this aspect and the flattering effect of high loads it was proposed elsewhere(35) that the load spectrum should be truncated at the load level exceeded ten times in the target life (see fig.7 for illustration).

Limitations of the flight-simulation test(9) are associated with the assumed load spectrum and possible effects of loading rate and environment. Nevertheless it is thought that the most realistic information can be obtained only in a representatibe flight-simulation test.

The development of hydraulic loading systems with closed-loop load control has considerably affected the present state of the art. By now it seems inadmissable to simplify the loading program in a full-scale test for experimental reasons. As an example of what is thought to be representative flight-simulation testing figure 11 shows a sample of a wing loading record of the fatigue test on the F-28 Fellowship wing. The test set-up is shown in fig.12. Ten different types of weather conditions varying from good weather to storm conditions were simulated. In addition to gusts, flap loads and ground reaction loads were applied. After 150,000 flights the test was recently completed with a series of fail-safe tests.

A more extensive discussion on the usefulness of full-scale fatigue testing was presented in refs 9 and 26.

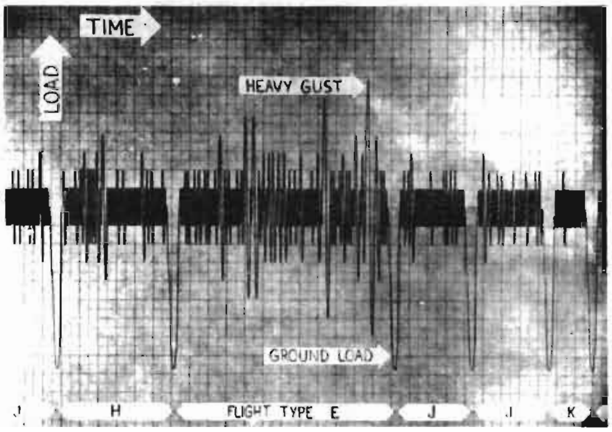


Fig.11 Sample of a load record, illustrating the load sequence applied in the F-28 wing fatigue test. Ten different types of weather condition are simulated, flight type E corresponds to a fairly severe storm, while flight type K is flown in good weather.

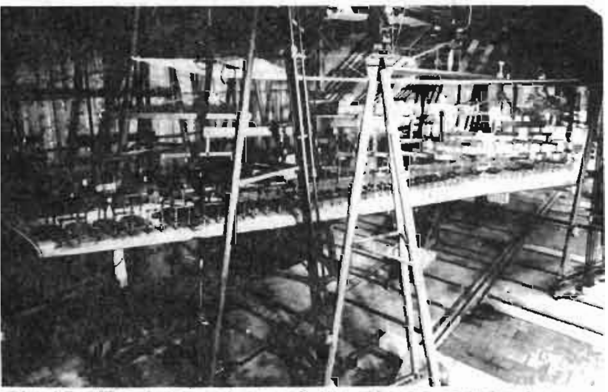


Fig.12 The test set-up of the flight-simulation fatigue test on the Fokker F-28 wing.

5. Outlook

It may well be expected that flight-simulation loading will be applied more and more in the future. The main problem is how to arrive at a representative load-time history, but it is thought that scrutinous mission analysis can solve this question. Also for comparative testing flight-simulation loading should be preferred, but availability of equipment may be a problem.

Estimation of fatigue lives in the design stage is a problem of its own. It is possible that improved cumulative damage rules including the effect of residual stresses(45) may turn out to be more reliable than the Palmgren-Miner rule. At the same time it is thought that there is a need for more realistic basic data. In fact S-N data from simply notched specimens are a fairly primitive basis for an extrapolation to obtain life estimates for a real structure. In order to make the extrapolation as small as possible the following test program is proposed.

Random flight-simulation tests should be carried out adopting variables such as:

a Specimens. Representative riveted and bolted joints could be used.
b Shape of load spectrum. Some typical shapes could be used, for instance representing gust spectra and manoever spectra.
c Design stress level. Some values should be adopted in order to study the effect of the stress level in a similar way as Gassner has done it for program tests.
d Ground-to-air cycle. The number and the magnitude may be varied.

Taking for example four cases for each item a-d this would imply $4^4 = 256$ test conditions if all possible combination would have to be made. Evidently it is a very large test program, but it would serve more than one purpose. Firstly the data could indeed be used in the design stage for making life estimates. Secondly the results would reveal the effects of several variables under flight-simulation conditions, which are not well known up to now. Thirdly without actually having to design a standardized test one could use the data as a standard for comparison when checking the fatigue quality of a new component. A handbook with this type of data could be extended from time to time.

6. Conclusions

In a discussion on fatigue problems it is difficult to make statements having a general validity. Nevertheless it will be tried below to summarize some trends of the previous chapter. Although the discussion was mainly illustrated by test results pertaining to fatigue of wing structures it is thought that the conclusions can be conveyed to other parts of the aircraft structure as well.

1. In a fatigue test with a varying load amplitude the sequence of the load cycles will affect the fatigue life and the crack propagation. A multitude of sequence effects have been reported. A qualitative understanding of these effects is possible in several cases, but a quantitative prediction is impossible as yet.
2. For comparative fatigue tests of alternative designs, production techniques materials, etc. flight-simulation testing should be preferred to random load and program testing. The latter two test methods should be preferred to constant-amplitude testing.
3. The fatigue life and crack propagation may be significantly different under random-loading and equivalent program loading if the program period is long. For a short period the differences may be small.
4. The fatigue life and crack propagation in flight-simulation tests have shown a low sensitivity to changes of the load sequence in flight.
5. In a full-scale test care should be taken to arrive at a representative flight-simulation loading in view of the relevance of the data to be obtained.
6. A proposal has been made for a program of flight simulation tests aiming amongst other things at basic data for making life estimates in the design stage of an aircraft.

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