

AD-A096 539

AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA)  
FATIGUE PREDICTION USING STANDARDISED LOADING SEQUENCE DATA. (U)  
SEP 79 6 5 JOST

F/6 20/11

UNCLASSIFIED

ARL/STRUC NOTE-458

ML

| of |  
404  
088539

END
DATE
FILMED
4-81
DTIC

12

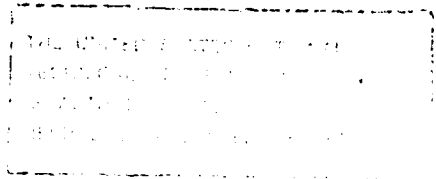


AD A 096539

DEPARTMENT OF DEFENCE  
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION  
AERONAUTICAL RESEARCH LABORATORIES  
MELBOURNE, VICTORIA

STRUCTURES NOTE 458

FATIGUE PREDICTION USING  
STANDARDISED LOADING SEQUENCE DATA



by

G. S. JOST

Approved for Public Release.



DTIC  
ELECTE  
MAR 19 1981  
S A

FILE COPY

© COMMONWEALTH OF AUSTRALIA 1979

COPY No 20

SEPTEMBER 1979

81 3 19 099

DEPARTMENT OF DEFENCE  
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION  
AERONAUTICAL RESEARCH LABORATORIES

STRUCTURES NOTE 458

(6) **FATIGUE PREDICTION USING  
STANDARDISED LOADING SEQUENCE DATA.**

by

(10) G. S. JOST

(12) / 22

(14) ARL/STRUCTURE NOTE-758

SUMMARY

*A new proposal for predicting pre-crack fatigue lives under service loading sequences is given. It is characterised by the replacement of fatigue data obtained under constant amplitude loading by that obtained under appropriate variable amplitude loading sequences.*

(11) S. f. 79

---

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories,  
Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

008650 1/21

**DOCUMENT CONTROL DATA SHEET**

Security classification of this page: Unclassified

- |   |  |
|---|--|
| 1. Document Numbers<br>(a) AR Number:<br>AR-001-807<br>(b) Document Series and Number:<br>Structures Note 458<br>(c) Report Number:<br>ARL-Struc-Note-458 | 2. Security Classification<br>(a) Complete document:<br>Unclassified<br>(b) Title in isolation:<br>Unclassified<br>(c) Summary in isolation:<br>Unclassified |
|---|--|

3. Title: **FATIGUE PREDICTION USING STANDARDISED LOADING SEQUENCE DATA**

- |                                       |                                      |
|---------------------------------------|--------------------------------------|
| 4. Personal Author:<br>Jost, G. S.    | 5. Document Date:<br>September, 1979 |
| 6. Type of Report and Period Covered: |                                      |

- |   |                                    |
|---|------------------------------------|
| 7. Corporate Author(s):<br>Aeronautical Research Laboratories | 8. Reference Numbers:<br>(a) Task: |
| 9. Cost Code:<br>27 7030                                      | (b) Sponsoring Agency:             |

- |  |  |
|--|--|
| 10. Imprint:<br>Aeronautical Research Laboratories,<br>Melbourne | 11. Computer Programs<br>(Titles and languages):<br>Not applicable |
|--|--|

12. Release Limitations (of the document): Approved for public release

12-0. Overseas:	N.O.	P.R.	I	A	B	C	D	E
-----------------	------	------	---	---	---	---	---	---

13. Announcement Limitations (of the information on this page): No limitation

- |  |                          |
|--|--------------------------|
| 14. Descriptors:<br>Fatigue life<br>Loads (forces)<br>Crack initiation | 15. Cosati Code:<br>1113 |
|--|--------------------------|

16. **ABSTRACT**  
*A new proposal for predicting pre-crack fatigue lives under service loading sequences is given. It is characterised by the replacement of fatigue data obtained under constant amplitude loading by that obtained under appropriate variable amplitude loading sequences.*

Preparation For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

## CONTENTS

	Page No.
NOTATION	
1. BACKGROUND	1
2. ACCUMULATION OF FATIGUE DAMAGE	1
3. BASIC FATIGUE DATA	2
4. FATIGUE TESTS UNDER REALISTIC LOADING SEQUENCES	2
5. PROPOSAL	2
5.1 Examples	4
5.2 Evaluation of $\beta_i$ and $\beta_j$	5
5.3 Numerical Examples	6
6. DISCUSSION	7
7. CONCLUSION	7
REFERENCES	
TABLES	
FIGURES	
DISTRIBUTION	

## NOTATION

$i$	load level index, standard spectrum
$j$	load level index, related spectrum
$l$	number of fatigue cycle levels, standard spectrum
$m$	number of fatigue cycle levels, related spectrum
$n$	number of cycles
$n_s$	number of pre-crack cycles at $i$ th level, standard spectrum
$n_r$	number of pre-crack cycles at $j$ th level, related spectrum
$r$	subscript, related spectrum
$s$	subscript, standard spectrum
$D$	(Miner) pre-crack fatigue damage
$N$	number of cycles to cracking (notional)
$N_s$	number of cycles to cracking at $i$ th level, standard spectrum
$N_r$	number of cycles to cracking at $j$ th level, related spectrum
$S_r$	characteristic stress, related spectrum
$S_s$	characteristic stress, standard spectrum
$\alpha_s$	ratio of number of cycles at $i$ th level to those at level $i = 1$ , standard spectrum
$\alpha_r$	ratio of number of cycles at $j$ th level to those at level $j = 1$ , related spectrum
$\beta_s$	ratio of notional cycles to cracking at $i$ th level to those at level $i = 1$ , standard spectrum
$\beta_r$	ratio of notional cycles to cracking at $j$ th level to those at level $j = 1$ , related spectrum

## 1. BACKGROUND

Attempts at predicting, with confidence, the fatigue lives of items undergoing typical service loadings have had a long and unsatisfactory history. Even today, it is rarely possible to predict, with acceptable accuracy, the fatigue life of a given component, specimen or structure subjected to a specified loading history (trivial examples excepted). The recent competition<sup>1</sup> advertised internationally by the Engineering Sciences Data Unit in which life predictions were sought for a notched specimen under given loading sequences highlights the fact that real difficulties still plague predictive fatigue.

Success in any predictive situation requires two basic ingredients: relevant and appropriate fundamental or basic data, and an acceptable (and usually mathematical) model of the process with which to use it. Given the basic data and the model, reliable predictions may be expected only if both are appropriately adequate. Although there is, at least in principle, unlimited scope for reworking the mathematical model, the same cannot be said for the basic data. If this is fundamentally deficient, then nothing is likely to remedy the deficiency.

These two elements appear in all attempts to improve predicted fatigue life. Typically, basic fatigue data are represented by those obtained under constant amplitude loading, and the model of fatigue damage accumulation is represented by the Palmgren-Miner hypothesis or a variant.<sup>2</sup> Thus, when a predicted life fails to agree with that established experimentally, it is clear that either the basic data, or the damage accumulation model (including the manner in which the data are used in the model), or both, must be inadequate.

The present proposal has arisen out of difficulties associated with fatigue life prediction in aircraft structures. In this field the (highly) variable amplitude service loading sequences are typically quasi-random, quasi-deterministic flight-by-flight in nature. Several characteristically different flights may be identifiable, the numbers of fatigue cycles within a given flight ranging from some tens to several hundreds. Such sequences *might be considered very far removed* from constant amplitude sequences.

In this report fatigue life refers to the pre-crack stage, i.e. the number of cycles (or other appropriate units) to cause the initiation of a fatigue crack. Once this point is reached there are, of course, appropriate techniques for dealing with the crack growth phase, although they are not without their difficulties.

## 2. ACCUMULATION OF FATIGUE DAMAGE

Miner<sup>3</sup> proposed that, for the pre-crack stage, a linear accumulation of damage be assumed. His restriction to the pre-crack regime has not, however, prevented others from extending the notion to include the crack growth regime as well. Discrepancies arising from the use of this rule in conjunction with constant amplitude fatigue data have led to much research aimed at modifying Miner's rule and/or developing alternatives.<sup>2</sup> Excepting perhaps for an appreciation of the significance of residual stresses,<sup>4,5</sup> little headway has been made in improving the precision of these predictions.

The application of fracture mechanics to fatigue crack growth has focussed attention on the influence and extreme significance of load interaction or sequence effects on the rate of crack growth.<sup>6</sup> Because of these effects, crack growth predictions based upon the simple accumulation of crack growth increments on a cycle-by-cycle basis, making use of constant amplitude crack growth data, fail to tally with reality for variable amplitude sequences. Numerous crack growth models have been proposed to account for interaction effects, with mixed success.

It is not unreasonable to suspect that cycle interaction and/or analogous effects may operate also in the pre-crack or crack initiation stage. Should the magnitude of their influence even

distantly approach that of those in the crack growth stage, then it follows that the combination of a cumulative damage rule and data based on constant amplitude loading is inappropriate and is almost unlikely to result in consistently accurate predictions of the life to crack initiation. But it is possible that such a cumulative damage rule combined with more appropriate fatigue data might lead to more reliable life estimates.

### 3. BASIC FATIGUE DATA

Constant amplitude fatigue data and those described by the above heading have become, for practical purposes, almost synonymous. Yet the foregoing indicates that there are shortcomings of real consequence in them and their applications to variable amplitude sequences. It is suggested that the basic fatigue data to be used predictively must already include sequence and other significant effects *whether or not these effects are understood, quantified, or, for that matter, even identified.* At the present time, the fulfillment of this requirement may be approached only by the adoption of realistic loading sequence fatigue data in place of constant amplitude data. This leads immediately to the concept of the generation of fatigue data under standard spectra, each appropriate to a given type or class of loading action. The recently announced TWIST and FALSTAFF sequences, which represent the type of loading history occurring in the lower wing root region of civil<sup>7</sup> and military<sup>8</sup> aircraft, are perhaps the first examples of such specific standard spectra.

Having obtained appropriate loading sequence fatigue data under a standard spectrum, the problem remains as to how to use such data in predicting fatigue life under other similar or "related" spectra. One proposal is outlined in Section 5.

### 4. FATIGUE TESTS UNDER REALISTIC LOADING SEQUENCES

Realistic fatigue tests may now be carried out to any desired degree of sophistication. Service sequence tests usually aim to establish, amongst other things, crack growth characteristics and or fatigue life, from which inspection intervals and or safe lives may be estimated. Such tests are necessary, of course, only because *predicted crack growth rates and fatigue lives under specified sequences cannot be relied upon.*

The problem of transposing a fatigue life established by test under one spectrum to its equivalent under some other related spectrum is often solved by the relative Miner method.<sup>9</sup> This operates as follows:

- (a) For the test spectrum, 1 say, and using constant amplitude S-N data, the Miner damage is calculated. Thus the known fatigue life  $(\sum n)_1$  say has associated with it a calculated fatigue damage of  $(\sum (n/N))_1$ ;
- (b) The Miner damage for the related spectrum 2,  $(\sum (n/N))_2$  is also calculated.
- (c) Assuming that for both spectra the total Miner damage at failure is the same

$$(\sum n)_1 (\sum (n/N))_1 = (\sum n)_2 (\sum (n/N))_2$$

and

$$(\sum n)_2 = (\sum n)_1 (\sum (n/N))_1 / (\sum (n/N))_2$$

Provided the two service spectra do not differ significantly, some confidence is usually placed in the new life estimate. Certainly its basis is better founded than that from a direct Miner calculation in which  $\sum n/N$  is equated to unity at failure. Unfortunately, however since its application does not lead invariably to satisfactory results,<sup>9</sup> it cannot always be relied upon. Another application of the relative Miner rule, which uses fatigue data obtained under the original test spectrum and omits reference to constant amplitude fatigue data altogether, is discussed in the next Section.

### 5. PROPOSAL

For the purpose of estimating pre-crack fatigue lives under typical service loadings or spectra it is proposed that, as basic fatigue data, constant amplitude data be replaced with those from

appropriate standardised loading sequence fatigue tests.\* These data would then be used, at least initially, in Miner type calculations to predict lives to crack initiation under *related* spectra, i.e. under those deemed to be of the same general character or class as the source data spectrum.

The proposal provides nothing new by way of assessing the accumulation of fatigue damage; however the substitution for constant amplitude data of more realistic variable amplitude data is seen as crucial to the possibility of a significant improvement in Miner type fatigue life prediction. In principle, the proposal would work along the following lines:

- (a) Establish the (set of) characteristic stress versus pre-crack cycles curve(s) under the standard spectrum, Fig. 1. It may be useful here to think in terms of a sequence in which the characteristic stress  $S_i$  is designated as the maximum occurring in the sequence. Appropriate stress scaling about, for example, a given Ig level, and testing, will provide the required fatigue data for various stress levels. Corresponding data for different Ig levels will clearly require additional testing and may be required for full implementation of the proposal. The important point is that graphs such as Fig. 1 represent *actual* data obtained under the standard spectrum according to the magnitude of its characteristic stress.
- (b) For the standard spectrum (subscript  $s$ ) at any specified characteristic stress,  $S_i$ , say, a Miner damage model is set up.

$$n_{1s}/N_{1s} + n_{2s}/N_{2s} + \dots + n_{ls}/N_{ls} = \sum_{i=1}^l (n_{is}/N_{is}) = D_s \quad (1)$$

at the pre-crack life. The  $n_{is}$  here are the numbers of cycles occurring at each of the  $l$  stress levels in the standard sequence, and the  $N_{is}$  are, by analogy with those in a conventional Miner sum, the pre-crack cycles at corresponding stress levels, *but these cycles must be regarded as notional only*. They cannot be evaluated directly by test, since that would require a change in test sequence and hence the validity of their means of estimation. They must remain (at this stage) simply the unspecified dividers in the Miner damage equation (1).

- (c) For the related spectrum (subscript  $r$ ) at characteristic stress level,  $S_i$ , say, for which the life estimate is sought, the corresponding damage equation will be given by

$$\sum_{i=1}^m (n_{ir}/N_{ir}) = D_r \quad (2)$$

Assuming that  $D_s = D_r$  at the onset of cracking gives

$$\sum_{i=1}^l (n_{is}/N_{is}) = \sum_{i=1}^m (n_{ir}/N_{ir}) \quad (3)$$

- (d) For both standard and related spectra the relative numbers of cycles at each of the  $l$  and  $m$  stress levels respectively are presumed known. For the standard spectrum the total number of pre-crack cycles is

$$\sum_{i=1}^l n_{is} = n_{1s} + n_{2s} + \dots + n_{ls}$$

By expressing all cycles in terms of one of these,  $n_{1s}$ , say, the above may be expressed as

$$\begin{aligned} \sum_{i=1}^l n_{is} &= n_{1s} + \alpha_2 n_{1s} + \dots + \alpha_l n_{1s} \\ &= n_{1s} (1 + \alpha_2 + \dots + \alpha_l) \\ &= n_{1s} \sum_{i=1}^l \alpha_i \quad \alpha_1 = 1 \end{aligned} \quad (4)$$

\* Such a suggestion, in relation to narrow-band random loading, was made by Kirkby and Edwards.<sup>10</sup>

where  $\alpha_{is} = n_{is}/n_{1s}$ ,

Similarly, for the related spectrum

$$\sum_{i=1}^m n_{jr} = n_{1r} \sum_{i=1}^m \alpha_{ir}, \quad \alpha_{1r} = 1 \quad (5)$$

where  $\alpha_{jr} = n_{jr}/n_{1r}$ ,

The corresponding notional  $N_{is}$  and  $N_{jr}$  may be analogously expressed:\*

$$\sum_{i=1}^l N_{is} = N_{1s}, \quad \beta_{1s} = 1 \quad (6)$$

and

$$\sum_{j=1}^m N_{jr} = N_{1r}, \quad \beta_{1r} = 1 \quad (7)$$

Substituting from (4), (5), (6) and (7) in (3) and rearranging gives

$$\begin{aligned} n_{1r} &= N_{1r} \sum (\alpha_{is} \beta_{is}) \\ n_{1s} &= N_{1s} \sum (\alpha_{jr} \beta_{jr}) \end{aligned}$$

and resubstitution for  $n_{1r}$  and  $n_{1s}$  from (4) and (5) yields the required ratio of the fatigue life under the related spectrum to that under the standard

$$\frac{\sum n_{jr}}{\sum n_{is}} = \frac{N_{1r} \sum \alpha_{jr} \sum (\alpha_{is} \beta_{is})}{N_{1s} \sum \alpha_{is} \sum (\alpha_{jr} \beta_{jr})} \quad (8)$$

Further progress requires some tightening of relationships and definitions. First, in any practical application, the stress characterising the related spectrum,  $S_r$ , will be equal to that for the standard,  $S_s$ ; it would seem unreasonable to deliberately choose to estimate fatigue life under the related spectrum from that under the standard at a different  $S_s$ . Thus  $S_r = S_s$  in practice. Secondly, the  $N_{is}$  and  $N_{jr}$  above are expressed in terms of their values  $N_{1s}$  and  $N_{1r}$  each at one particular stress level. No loss of generality ensues from assigning this level to the characteristic stress level of the spectrum. Thus, when  $S_s$  and  $S_r$  are equal, the notional  $N_{1r}$  and  $N_{1s}$  will also be equal, and (8) becomes

$$\frac{\sum n_{jr}}{\sum n_{is}} = \frac{\sum \alpha_{jr} \sum \alpha_{is} \beta_{is}}{\sum \alpha_{is} \sum \alpha_{jr} \beta_{jr}} \quad S_r = S_s \quad (9)$$

Some simple examples will serve to clarify the application of (8) and (9).

## 5.1 Examples

### 5.1.1

Related spectrum is identical to the standard, at the same characteristic stress level,  $S_r = S_s$ . In this (trivial) example  $l = m$ , and for all  $i = j$ ,  $\alpha_{jr} = \alpha_{is}$  and  $\beta_{jr} = \beta_{is}$ . Thus all corresponding numerator and denominator terms in (9) are identical and  $\sum n_{jr} = \sum n_{is}$ , as required.

### 5.1.2

Related spectrum is identical to the standard, but at a different characteristic stress level,  $S_r \neq S_s$ .

In this case only the  $\alpha$  summations are identical, and (8) simplifies to

$$\frac{\sum n_{jr}}{\sum n_{is}} = \frac{N_{1r} \sum \alpha_{is} \beta_{is}}{N_{1s} \sum \alpha_{jr} \beta_{jr}}$$

This reduces to the above when  $S_r = S_s$ .

\* Quantification of the  $N_i$  and  $N_j$  is considered in Section 5.2.

### 5.1.3

Related spectrum is constant amplitude loading at level  $j$ ,  $S_r = S_j$ .

Here  $m = 1$ , so that

$$\begin{aligned}\sum \alpha_{jr} &= \alpha_{1r} = 1, \\ \sum \alpha_{jr}/\beta_{jr} &= \alpha_{1r}/\beta_{1r} = 1, \\ \sum n_{jr} &= n_{1r},\end{aligned}$$

and (8) gives

$$n_{1r}/\sum n_{is} = (N_{1r}/N_{1s})[\sum (\alpha_{is}/\beta_{is})]/\sum \alpha_{is}.$$

When  $S_r = S_s$ ,  $N_{1r} = N_{1s}$ , and the above simplifies to

$$n_{1r}/\sum n_{is} = [\sum (\alpha_{is}/\beta_{is})]/\sum \alpha_{is}.$$

The same result follows directly from (9).

Finally, for the limiting case of the multi-load level standard spectrum degenerating to the same single  $j$ th load level as the (constant amplitude) related spectrum, i.e. for the standard spectrum becoming a constant amplitude one

$$\begin{aligned}l &= 1 \\ \sum \alpha_{is} &= \alpha_{1s} = 1 \\ \sum (\alpha_{is}/\beta_{is}) &= \alpha_{1s}/\beta_{1s} = 1 \\ \sum n_{is} &= n_{1s},\end{aligned}$$

and the above gives

$$n_{1r} = n_{1s}$$

as required.

### 5.2 Evaluation of $\beta_i$ and $\beta_j$

An appropriate quantification of  $\beta_i$  and  $\beta_j$  is indicated by application 5.1.2; predicted lives at different characteristic stresses when both related and standard spectra are otherwise identical must clearly agree with the test data, Fig. 1.

Consider the equation at 5.1.2.

$$\frac{\sum n_{jr}}{\sum n_{is}} = \frac{N_{1r} \sum \alpha_{is} \beta_{is}}{N_{1s} \sum \alpha_{jr} \beta_{jr}}$$

Suppose now that  $\beta_{is} = \beta_{jr}$ , i.e.  $N_{1s}/N_{1r} = N_{jr}/N_{1r}$ . This is a possibility, at least over a limited range of the variables, and follows from a linear log stress - log notional  $N$  relationship.

In that case, and since  $\alpha_{is} = \alpha_{jr}$  here, the  $\alpha/\beta$  summation terms above cancel, and there remains

$$\sum n_{jr}/\sum n_{is} = N_{1r}/N_{1s}.$$

This equation is satisfied automatically for all  $i, j$  combinations by adopting the relationship of Fig. 1 as corresponding to the cycle stress - notional  $N$  relationship for both standard and related spectra, Fig. 2. According to this proposal

$$\sum n_{is} \propto N_{1s}$$

and

$$\sum n_{jr} \propto N_{1r}$$

here, and in general

$$\sum n_{is} \propto N_{1s}$$

and

$$\sum n_r \propto N_r.$$

Thus

$$\beta_{is} = N_{ir} / N_{is} = \sum n_{ir} / \sum n_{is} \quad (10a)$$

$$\beta_{jr} = N_{jr} / N_{ir} = \sum n_{jr} / \sum n_{ir} \quad (10b)$$

The proposal amounts to assigning to the characteristic stress and cycles to failure scales of Fig. 1 cycle stress and corresponding notational cycles to failure, Fig. 2. The notional  $N_i$  and  $N_j$  then become the dummy variables in the fatigue life calculation. Because they appear in equations (8), (9) and (10) only as ratios, i.e. as  $N_{ir}/N_{is}$ ,  $\beta_{is}$  and  $\beta_{jr}$ , their actual magnitudes are of no consequence. The ratios combine to form, in (8) and (9), the weighting factors to modify the known fatigue life under the standard spectrum to that under the related spectrum.

### 5.3 Numerical Examples

Fig. 3. shows a linear log stress - log life relationship plotted on conventional semi-log axes. Suppose that it had arisen from tests using a stress scaled standard spectrum of five levels having the characteristics listed in Table 1. The spectrum is "typical" in that smaller loads occur more frequently than do larger loads. For all examples here the characteristic stress is chosen at level  $i = 1$ , i.e. the maximum occurring in the sequence.\* Fig. 3. shows that when the characteristic stress of the spectrum is, for example, 40 units, the fatigue life is 6 cycle units: when  $S_{char} = 20$ ,  $\sum n_{is} = 30$ .

Given the fatigue data of Fig. 3 under the standard spectrum of Table 1, it is desired to calculate fatigue life under related spectra. These may differ from the standard in two basic ways: the number of cycles at each stress level may differ, or the stresses themselves may differ in level and/or number. An example of each follows:

*Example 1.* Suppose first that the related spectrum differs from the standard only in its cycle ratios, Column 4, Table 2(a). Thus, the  $\alpha_{is}$  and  $\alpha_{jr}$  are given, and the  $\beta_{is}$  (which are identical to the  $\beta_{jr}$  here since the cycle stress levels are common to both spectra) are calculated from (10a) and (10b) and Fig. 3. The full procedure is shown in Table 2(a), and the outcome is that

$$\sum n_{jr} / \sum n_{is} = 0.97$$

If the fatigue cycles applied are thought of in terms of groups or blocks (of 31 standard cycles and 37 related cycles in this example), then

$$\begin{aligned} \text{related blocks} / \text{standard blocks} &= (\sum \alpha_{is} \beta_{is}) / (\sum \alpha_{jr} \beta_{jr}) \\ &= 0.81. \end{aligned}$$

*Example 2.* In the second example, the number of stress levels and their magnitudes are changed, Table 2(b). For this case

$$\sum n_{jr} / \sum n_{is} = 0.81$$

and

$$\text{related blocks} / \text{standard blocks} = 2.28$$

These examples serve to illustrate the application of the proposal in practice. The sense of the predictions seem reasonable: in the first example, the number of intermediate load level occurrences is increased a little, compared with the standard, and relatively fewer blocks to pre-crack life are predicted. For the second case, omission of some load cycles per block results in a greater predicted number of pre-crack blocks. The efficacy or otherwise of such predictions can, of course, be judged only on the basis of appropriate test data.

\* The combination of a stress scaled spectrum and a linear log stress - log life relationship provides the satisfying result that  $\sum n_{jr} / \sum n_{is}$  is independent of the characteristic stress level chosen as the basis for performing the calculations.

## 6. DISCUSSION

It has been argued above that, for life prediction purposes, constant amplitude data might with profit be replaced by appropriate (standardised) fatigue data. These could then be used, initially at least, in Miner calculations for predicting fatigue lives under similar, or related, spectra. Since the basic fatigue data result from realistic testing, any discrepancies between predicted and actual fatigue lives under related spectra would then be forcefully attributable to shortcomings in either the Miner rule or the manner in which it is applied. The proposal still leaves open, for example, the question of the specification of fatigue cycles. Clearly, the sensitivity of actual and predicted lives to cycle definition will need to be an early area for investigation.

Although the present suggestion has been made on the basis of pre-crack life, it would be tempting, when the data are available, to apply the procedure to final fatigue lives as well. Further, given fracture surfaces for which striation counting between repeating identifiable events is possible, crack growth rate data under standard and related spectra should indicate whether data obtained under the standard spectrum better predict crack growth rates, and hence crack growth lives, for related spectra than do constant amplitude data.

*It is considered that the proposal is likely to give an accuracy at least equivalent to that of current procedures and it may prove significantly better.*

Tests are being planned to make a first practical evaluation of the proposal using a standardized loading sequence and others which might be deemed, on physical and statistical grounds, to be related to it. The FALSTAFF sequence is to be adopted as the standard in these tests.

## 7. CONCLUSION

A proposal for estimating pre-crack fatigue lives has been made in which standardised fatigue loading data become the basic or fundamental data to be used in place of constant amplitude fatigue data. It is argued that the adoption of representative data may well result in better fatigue predictions; the hypothesis is to be tested by experiment.

## REFERENCES

1. Engineering Sciences Data Unit. How long will this last? Leaflet on a fatigue competition in conjunction with the Society of Environmental Engineers, 1976.
2. Schijve, J. The Accumulation of Fatigue Damage in Aircraft Materials and Structures. Agardograph No. 157, January 1972.
3. Miner, M. A. Cumulative Damage in Fatigue. *J. Appl. Mech.* **12**, No. 1, September 1945.
4. Edwards, P. R. Cumulative Damage in Fatigue with Particular Reference to the Effects of Residual Stress. RAE TN 69237, November 1969.
5. Engineering Sciences Data Unit. Fatigue Life Estimation under Variable Amplitude Loading. ESDU Data Sheets Item No. 77004, March 1977.
6. Wei, R. P. and Stephens, R. I. (eds.). Fatigue Crack Growth under Spectrum Loads. A.S.T.M. Special Technical Publication 595, May 1976.
7. de Jonge, J. B., Schutz, D., Lowak, H. and Schijve, J. A Standardised Load Sequence for Flight Simulation Tests on Transport Aircraft Wing Structures. NLR TR 73029U, March 1973.
8. ---, FALSTAFF. Description of a Fighter Aircraft Loading Standard For Fatigue Evaluation. ICAF Document No. 839, March 1976.
9. Schutz, D. and Lowak, H. The Application of the Standardised Test Program for the Fatigue Life Estimation of Fighter Wing Components. (FALSTAFF, Part IV). Problems with Fatigue in Aircraft. Proceedings of the Eighth ICAF Symposium, 2-5 June 1975. ICAF Doc. No. 801, Swiss Federal Aircraft Establishment, 1976.
10. Kirkby, W. T. and Edwards, P. R. Constant Amplitude or Variable Amplitude Tests as a Basis for Design Studies. *Fatigue Design Procedures*. Proceedings of the Fourth ICAF Symposium, Munich, 1965 (eds. Gassner and Schutz). Pergamon Press, 1969.

**TABLE 1**  
**Standard Spectrum and Derived Data for  $S_{char} = 40$**   
**Characteristic Stress Level: 1**

Stress Level $i$	Stress Ratio $S_i/S_{char}$	Cycle Ratio $\alpha_{is}$	$S_{char} = 40$			
			Stress $S_i$	$N_{is}$	$\beta_{is}$	$\alpha_{is}$ $\beta_{is}$ (7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1	1	40	6	1	1
2	0.9	2	36	7.66	1.28	1.57
3	0.8	4	32	10.08	1.68	2.38
4	0.7	8	28	13.76	2.29	3.49
5	0.6	16	24	19.71	3.29	4.87
<b>TOTALS</b>		31				13.31

- (1): given
- (2): given
- (3): given
- (4): (2)  $\times S_{char}$
- (5): Data from Fig. 3 using (4)
- (6):  $\beta_{is} = N_{is}/N_{1s}$  (from (5))

**TABLE 2**  
**Calculation of Predicted Lives**

(a) First Example:  $S_{char} = 40$

$j$	$S_j/S_{char}$	$\alpha_{jr}$	$S_j$	$N_{jr}$	$\beta_{jr}$	$\alpha_{jr}$ $\beta_{jr}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1	1	40	6	1	1
2	0.9	3	36	7.66	1.28	2.34
3	0.8	5	32	10.88	1.68	2.98
4	0.7	12	28	13.76	2.29	5.24
5	0.6	16	24	19.71	3.29	4.86
<b>TOTALS</b>		<b>37</b>				<b>16.42</b>

Eqn. (9)  $\rightarrow \sum n_{jr} / \sum n_{is} = (37/31)(13.31/16.42) = 0.97$

(standard data from Table 1)

or related blocks/standard blocks =  $13.31/16.43 = 0.81$

(b) Second Example:  $S_{char} = 40$

$j$	$S_j/S_{char}$	$\alpha_{jr}$	$S_j$	$N_{jr}$	$\beta_{jr}$	$\alpha_{jr}$ $\beta_{jr}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1	1	40	6	1	1
2	0.8	3	32	10.08	1.68	1.79
3	0.7	7	28	13.76	2.29	3.06
<b>TOTALS</b>		<b>11</b>				<b>5.85</b>

Eqn. (9)  $\rightarrow \sum n_{jr} / \sum n_{is} = (11/31)(13.31/5.85) = 0.81$

(standard data from Table 1)

or related blocks/standard blocks =  $13.31/5.85 = 2.28$

(1), (2), (3): given

(4): (2)  $\times S_{char}$

(5): Data from Fig. 3 using (4)

(6):  $\beta_{jr} = N_{jr}/N_{1r}$  (from (5))

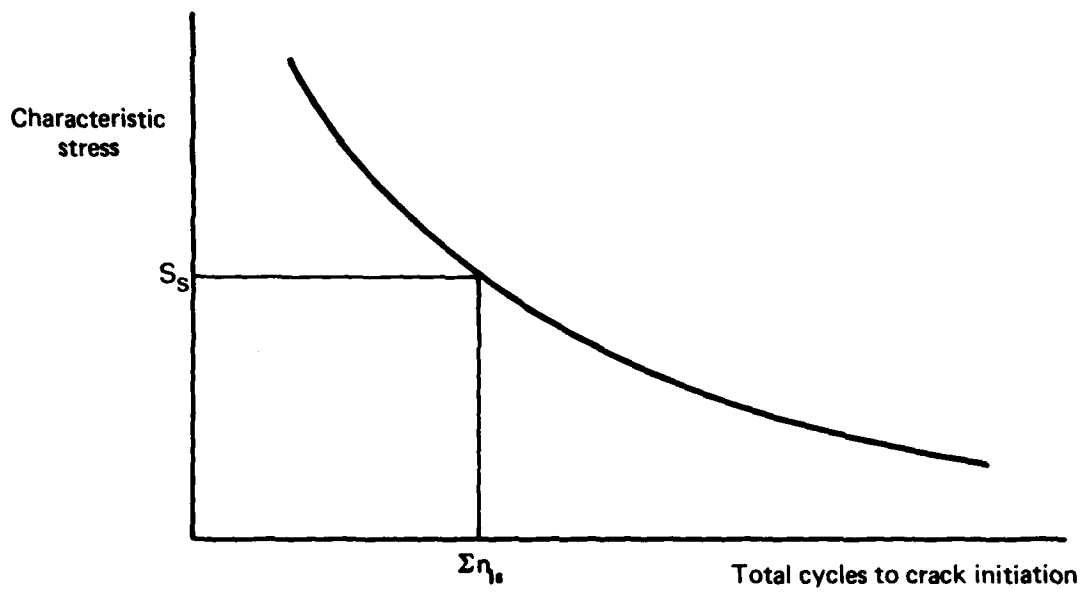


FIG. 1 FATIGUE DATA FOR STANDARD SPECTRUM

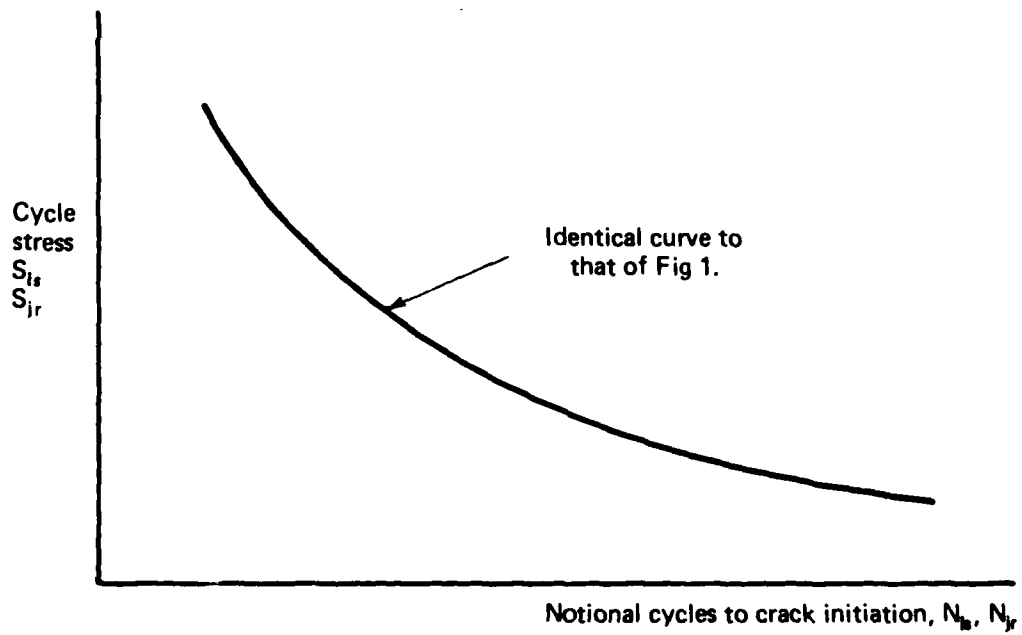


FIG. 2 NOTIONAL FATIGUE DATA

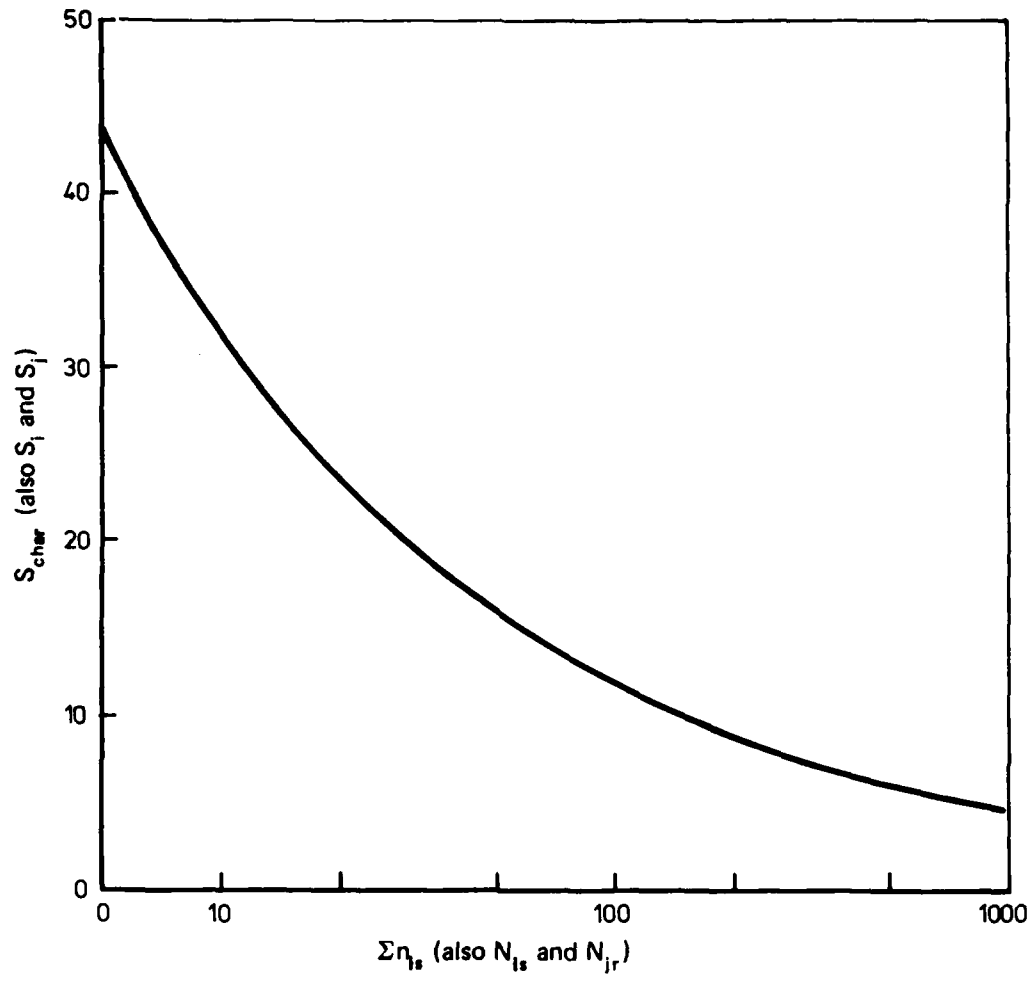


FIG. 3 FATIGUE DATA FOR EXAMPLES

## DISTRIBUTION

	Copy No.
<b>AUSTRALIA</b>	
<b>Department of Defence</b>	
<b>Central Office</b>	
Chief Defence Scientist	1
Deputy Chief Defence Scientist	2
Superintendent, Science and Technology Programs	3
Australian Defence Scientific and Technical Representative (U.K.)	—
Counsellor, Defence Science	—
Joint Intelligence Organisation	4
Defence Library	5
Document Exchange Centre, D.I.S.B.	6-22
<b>Aeronautical Research Laboratories</b>	
Chief Superintendent	23
Library	24
Superintendent Division—Structures	25
Divisional File—Structures	26
Author: G. S. Jost	27
<b>Materials Research Laboratories</b>	
Library	28
<b>Defence Research Centre, Salisbury</b>	
Library	29
<b>Central Studies Establishment</b>	
Information Centre	30
<b>Engineering Development Establishment</b>	
Library	31
<b>RAN Research Laboratory</b>	
Library	32
<b>Defence Regional Office</b>	
Library	33
<b>Navy Office</b>	
Naval Scientific Adviser	34
<b>Army Office</b>	
Army Scientific Adviser	35
Royal Military College Library	36
U.S. Army Standardisation Group	37
<b>Air Force Office</b>	
Aircraft Research and Development Unit, Scientific Flight Group	38
Air Force Scientific Adviser	39
Technical Division Library	40
D. Air Eng.—AF	41
H.Q. Support Command (SENGSO)	42
RAAF Academy, Point Cook	43

## Department of Productivity

### Government Aircraft Factories

Manager	44
Library	45

## Department of Transport

Secretary	46
Library	47
Airworthiness Group: Mr. K. O'Brien	48
Mr. C. Torkington	49

## Statutory, State Authorities and Industry

CSIRO, Central Library	50
CSIRO, Mechanical Engineering Division, Chief	51
CSIRO, National Measurement Laboratory, Chief	52
CSIRO, Materials Science Division, Director	53
Qantas, Library	54
Trans Australia Airlines, Library	55
SEC of Victoria, Herman Research Laboratory, Librarian	56
SEC of Queensland, Library	57
Ansett Airlines of Australia, Library	58
BHP, Melbourne Research Laboratories	59
Commonwealth Aircraft Corporation:	
Manager	60
Manager of Engineering	61
Hawker de Havilland Pty. Ltd.:	
Librarian, Bankstown	62
Manager, Lidcombe	63
ICI Australia Ltd., Library	64
Rolls Royce of Australia Pty. Ltd., Mr. Mosley	65

## Universities and Colleges

Adelaide	Barr Smith Library	66
Flinders	Library	67
James Cook	Library	68
Latrobe	Library	69
Melbourne	Engineering Library	70
Monash	Library	71
Newcastle	Library	72
New England	Library	73
Sydney	Engineering Library	74
N.S.W.	Prof. R. A. A. Bryant	75
Queensland	Library	76
Tasmania	Library	77
Western Australia	Library	78
R.M.I.T.	Library	79
	Mr. H. Millicer	80

## CANADA

Aluminium Laboratories Ltd., Library	81
CAARC Co-ordinator Structures	82
International Civil Aviation Organization, Library	83
Physics and Metallurgy Research Laboratories, Dr. A. Williams, Director	84
NRC, National Aeronautical Establishment, Library	85
NRC, Division of Mechanical Engineering, Director	86

<b>Universities and Colleges</b>		
McGill	Library	87
Toronto	Institute for Aerospace Studies	88
<b>FRANCE</b>		
	AGARD, Library	89
	ONERA, Library	90
	Service de Documentation, Technique de l'Aeronautique	91
<b>GERMANY</b>		
	ZLDI	92
<b>INDIA</b>		
	CAARC Co-ordinator Materials	93
	CAARC Co-ordinator Structures	94
	Civil Aviation Department, Director	95
	Defence Ministry, Aero Development Establishment, Library	96
	Hindustan Aeronautics Ltd., Library	97
	Indian Institute of Science, Library	98
	Indian Institute of Technology, Library	99
	National Aeronautical Laboratory, Director	100
<b>ISRAEL</b>		
	Technion—Israel Institute of Technology, Prof. J. Singer	101
<b>ITALY</b>		
	Associazione Italiana di Aeronautica e Astronautica	102
	Fiat Co., Dr. G. Gabrielli	103
	University of Pisa, Dr. G. Salvetti	104
<b>JAPAN</b>		
	National Aerospace Laboratory, Library	105
<b>Universities</b>		
	Tohoku (Sendai) Library	106
	Tokyo Institute of Space and Aeroscience	107
<b>NETHERLANDS</b>		
	Central Organisation for Applied Science Research TNO, Library	108
	National Aerospace Laboratory (NLR), Library	109
<b>NEW ZEALAND</b>		
	Librarian, Defence Scientific Establishment	110
	Transport Ministry, Civil Aviation Division, Library	111
<b>Universities</b>		
	Canterbury Library	112
	Professor D. Stevenson, Mech. Eng.	113
<b>SWEDEN</b>		
	Aeronautical Research Institute	114
	SAAB-Scania, Library	115
<b>SWITZERLAND</b>		
	Swiss Federal Aircraft Factories (F · W)	116
<b>UNITED KINGDOM</b>		
	Aeronautical Research Council, Secretary	117

CAARC, Secretary	118
Royal Aircraft Establishment:	
Farnborough, Library	119
Bedford, Library	120
Royal Armament Research and Development Establishment	121
Commonwealth Air Transport Council Secretariat	122
Aircraft and Armament Experimental Establishment	123
National Engineering Laboratories, Superintendent	124
National Physical Laboratories, Library	125
British Library, Science Reference Library	126
British Library, Lending Division	127
CAARC, Co-ordinator, Structures	128
Aircraft Research Association, Library	129
C.A. Parsons, Gas Turbine Department, Library	130
English Electric Co. Ltd, Gas Turbine Department, Dr. W. Rizk	131
Motor Industries Research Association, Director	132
Rolls-Royce (1971) Ltd.:	
Aeronautics Division, Chief Librarian	133
Bristol Siddeley Division T. R. & I. Library Services	134
Science Museum Library	135
Welding Institute, Library	136
British Aerospace Corporation:	
Aircraft Group, Kingston-Brough Division	137
Aircraft Group, Manchester Division	138
Aircraft Group, Headquarters Library, Kingston-upon-Thames	139
Dynamics Group, Hatfield-Lostock Division	140
Aircraft Group, Weybridge-Bristol Division	141
Aircraft Group, Warton Division	142
British Hovercraft Corporation Ltd., Library	143
Short Brothers Harland	144
Westland Helicopters Ltd.	145

#### Universities and Colleges

Bristol	Library, Engineering Department	146
	Prof. L. Howarth, Engineering Department	147
Cambridge	Library, Engineering Department	148
	Sir W. Hawthorne, Engineering Dept.	149
London	Prof. A. D. Young, Aero. Engineering	150
Belfast	Dr. A. Q. Chapleo, Dept. of Aeron. Eng.	151
Manchester	Prof. Applied Mathematics	152
Nottingham	Library	153
Southampton	Library	154
Strathclyde	Library	155
Cranfield Institute	Library	156
of Technology	Prof. Lefebvre	157
Imperial College	The Head	158
	Prof. of Mech. Engineering	159
	Prof. B. G. Neal, Struc. Eng.	160
	Dept. of Aeronautics	161

#### UNITED STATES OF AMERICA

NASA Scientific and Technical Information Facility	162
Sandia Group Research Organisation	163
American Institute of Aeronautics and Astronautics	164
Applied Mechanics Review	165
The John Crerar Library	166
Allis Chalmers Inc., Director	167

Bell Helicopter Textron		168
Boeing Co.:		
Head Office, Mr. R. Watson		169
Industrial Production Division		170
Cessna Aircraft Co., Executive Engineer		171
General Electric, Aircraft Engine Group		172
Lockheed California Company		173
Lockheed-Georgia Company		174
McDonnell Douglas Corporation, Director		175
Westinghouse Laboratories, Director		176
Calspan Corporation (formerly Cornell Aero. Labs.)		177
United Technologies Corporation, Pratt & Whitney Aircraft Group		178
Battelle Memorial Institute, Library		179
<b>Universities and Colleges</b>		
Brown	Prof. R. E. Meyer	180
Florida	Aero. Engineering Dept.	181
Harvard	Prof. G. F. Carrier, Applied Mathematics	182
	Dr. S. Goldstein	183
Johns Hopkins	Prof. S. Corrsin	184
Iowa State	Dr. G. K. Serory, Mechanical Eng.	185
Princeton	Prof. G. L. Mellor, Mechanics	186
Stanford	Dept. of Aeronautics Library	187
Polytechnic Inst. of New York	Aeronautics Labs. Library	188
California Inst. of Technology	Graduate Aeronautical Labs. Library	189
Massachusetts Inst. of Technology	Library	190
Spares		191-200

LATE  
L MED  
-8