NLR TEST RESULTS AS A DATABASE TO BE USED IN A CHECK OF CRACK PROPAGATION PREDICTION MODELS

A GARTEUR ACTIVITY

BY

H.H. VAN DER LINDEN
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The report describes a joint Garteur activity in the field of the prediction of crack propagation under variable amplitude loading. Existing crack propagation models or models under development will be checked with NLR crack propagation data of 2024-T3 Alclad 2 mm sheet material under F-27 Spectrum flight simulation loading. After completion of model checking follow-on activities will be defined. The report includes also the NLR database, consisting of constant amplitude data, F-4 spectrum data and F-27 spectrum test results. Also given is the F-27 Spectrum load generation program.
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SUMMARY

At the GARTEUR meeting of the Group of Responsables for Structures 
and Materials at ONERA a joint GARTEUR activity has been proposed in the 
field of the prediction of crack propagation under variable amplitude 
loading.

It is intended to check existing crack propagation models with 
NLR crack propagation data of 2024-T3 alclad sheet material under F-27 
Spectrum flight simulation loading. After completion of model checking a 
possible follow-on activity could be discussed.

In this report the cooperative activity is described followed 
by the NLR data base.
INTRODUCTION

At the GARTEUR meeting of the Group of Responsables for Structures and Materials (ONERA, 13 and 14 September 1979) a joint GARTEUR activity has been proposed in the field of the prediction of crack propagation under variable amplitude loading. It was intended to check existing crack propagation models with a well-defined set of test data. NLR could provide such crack propagation data of light alloy specimens under flight simulation loading. After completion of model checking a possible follow-on activity could be discussed as a suitable topic for a new GARTEUR action group.

It was agreed upon to use the so-called F-27 Spectrum flight simulation test results on 2024-T3 Alclad 2 mm sheet material as reference; the material selection depended on the availability of sufficient 2024-T3 Alclad material of the same batch as used in flight simulation testing.

The crack propagation calculations will be performed and the results will be checked and compared to the database before summer 1980 in order to present the results and a possible follow-on activity to the fall 1980 meeting of the Group of Responsables of Structures and Materials. In this report the F-27 Spectrum and the test data package will be presented. Also given are Constant Amplitude test results and so-called F-4 Spectrum test results.

The crack propagation tests have been performed under contract for the Netherlands Agency for Aerospace Programmes.

FRAMEWORK OF THE ACTIVITIES

During 1979 a number of flight simulation fatigue tests have been carried out at the NLR. The effect of variation in the gust load severity and Ground-Air-Ground cycle on crack propagation behaviour was studied by means of crack growth tests on 2 mm sheet specimens of 2024-T3 Alclad material provided with a central saw cut. The basic spectrum is based on a calculated load spectrum which corresponds with the severest usage experienced so far by actual F-27 operators and is therefore denoted as F-27 Spectrum.
It was agreed upon to adjust the "participating" propagation models using constant amplitude data, also provided to some extent by the NLR, and the F-27 Spectrum normal gust/normal GAG test results. Material is available to the participants to run additional tests, i.e. constant amplitude tests or simple overload tests. The adjusted model will then be used to predict crack propagation and crack propagation life for four gust/GAG-cycle variations.

The predictions can be checked to the test results.

The results of the comparison will be discussed by the participants before summer 1980. Possible modifications can be proposed and checked for. It also will be decided whether or not to have a follow-on program, which had to be proposed in the fall 1980 meeting of the GARTEUR Group of Responsables of Structures and Materials.

3 DESCRIPTION OF THE LOAD SPECTRA

NLR carried out an extensive test series on sheet material under F-27 Spectrum loading. Gust severity and GAG-cycle were systematically varied. Also tests were carried out under different mean flight stress levels. A number of tests were performed under the F-4 loading: this loading consists of one flight type, build up from 10.5 constant amplitude gust cycles followed by a GAG-cycle; this flight is repeated continually. Constant amplitude data are available from the same material batch as the F-27 and F-4 Spectrum tests.

In the following the F-27 load spectrum, the load generation and checks of the load sequence will be given. Also the F-4 loading will be described.

3.1 Description of F-27 Spectrum

The derivation of the test load programme is fully described in reference 1.

The main features of the test programme may be summarized as follows:

a) One test load programme consists of a "block" of 2500 flights.

b) Nine different "flight types" are distinguished ranging from "very severe" to "nice weather"-flights.
c) The test load spectra pertaining to each flight type and the frequency of occurrence of each flight type in a block of 2500 flights are presented in table 1.

d) The "ground load level" is equal to $\frac{S_{\text{ground}}}{S_{m \text{ flight}}} = -0.234$

e) Figure 1 gives the stepped load spectrum pertaining to one block of 2500 flights. It may be noted that the average number of test load cycles per flight is approximately equal to 11.

The sequence of flights within one block of 2500 flights and the sequence of loads have been randomly selected for once and for all; after a flight block of 2500 flights, exactly the same load sequence is applied again in the next block, and so on.

Figure 2 and table 2 indicate the position of the relatively severe flights within the block of 2500 flights.

With regard to the sequence of loads within each flight, which is randomly chosen as said, the following may be noted:

a) Each flight phase starts with an upward gust load.
b) An upward gust load is immediately followed by a downward gust load.

3.2 Generation of load sequence - F-27 Spectrum

The F-27 Spectrum is generated by the same algorithm as the TWIST standard load sequence, which is described in reference 2. Both load sequences are based on the TWISTBASE-program which utilizes the following procedure:

i) Generation of a "block" of $N$ flights, consisting of $n$ "weather-types". Each weather type $i$ appears in $F(i)$ flights, therefore

$$\sum_{i=1}^{n} F(i) = N$$

ii) Within each flight the gust loads are generated with the following limitations

i) each flight phase starts with an upward gust load.

ii) an upward gust load is immediately followed by a downward gust load.

A total $m$ "gust load-severities" $j$ are distinguished. In flight type $j$ a total number of $R(ij)$ upward and $R(ij)$ downward gust loads of
Both flight sequence as gust load sequence are selected "at random" by independent random generators.

The following input data are required:

i \( N \)

ii \( F(i) \) \((i=1, \ldots, n)\)

iii \( R(ij) \) \((i=1, \ldots, n, j=1, \ldots, m)\)

iv Random generator start numbers \( r_1 \) and \( r_2 \)

The codes as used in the Algol and Fortran programs, as described in reference 2, are given in table 3.

Utilizing the TWISTBASE program for the generation of the F-27 load sequence the input data as given in table 4 and 5 must be used. In appendix A the Algol and Fortran programs, not including the F-27 Spectrum input data of table 4 and table 5, are given. In appendix B the NLR developed modified version of the F-27 Spectrum Fortran program is given: this generation procedure is about 40 times as fast as the original TWISTBASE program.

3.3 Checks of F-27 Spectrum load sequence

It is recommended to check the F-27 Spectrum load sequence using the following procedure:

i check sequence of load cycles in flight number 1 through flight number 6, as given in table 6.

ii check sequence of flight types and associated random numbers for flight 7 through 50, as given in table 7.

iii using examples of some flights:

- flight number 1 through 12
- flight number 85 through 95
- flight number 106 through 114, see figure 3.

iv check position of severe flights; given in table 2 and figure 2.

3.4 F-27 Spectrum variations

The basic F-27 load Spectrum refers to a specific aircraft usage and a specific F-27 wing station. A different usage may result in a different gust load experience; the severity of the GAG-cycle depends
on the wing location and mass distribution on the wing.

For the load programme, the following variations of the basic spectrum were applied in the database test series (Ref. 4)

a) Variation of the gust load spectrum

A light gust spectrum being three times as light as the basis spectrum and a severe gust spectrum which is three times as heavy as the standard spectrum are considered.

These factors of three imply that in a semi-logarithmic spectrum plot the "light" spectrum is shifted a constant factor 3 to the left, the heavy spectrum the same amount to the right with respect to the normal spectrum.

The associated stepped test spectra were obtained in the way indicated in figure 4.

The frequency of occurrence of the various gust amplitudes is left unchanged, but the size of the amplitude level is adapted to obtain the right stepped approximation of the light spectrum and the severe spectrum respectively. The resulting amplitude levels are presented in table 8.

The size of the amplitude levels is the only thing that is varied: the sequence of flights within a block and the sequence of loads within a flight is unchanged.

b) Variation of Ground Load Level

The Ground Load Level $S_{\text{ground}} = -0.234 S_m \text{ flight}$ of the basic programme refers to a particular wing station.

To account for different wing stations and mass distributions and to allow a comparison with the TWIST Standard spectrum (Ref. 2) a lowest ground load level was chosen as $S_{\text{ground}} = -0.5 S_m \text{ flight}$.

Also a high ground stress level, resulting in a light GAG-cycle was chosen: $S_{\text{ground}} = +0.125 S_m \text{ flight}$

3.5 F-4 load programme

A prototype of the F-27 has been subjected to a full-scale fatigue test, known by insiders as the F-4 test.

This test, carried out in 1957-1958, was a flight simulation test in which a GAG-cycle was followed by 10.5 gust cycles of equal magnitude.
Thus all "flights" simulated were equal. The F-4 load sequence is depicted in figure 5. Referring to table 1, it may be noted that the F-4 flight contains half a gust cycle more than the lightest flight in the basic load programme (Flight code 2), but that otherwise the F-4 flight seems to be less severe in all respects: the $S_m$ level is lower, the gust amplitude is smaller and the Ground stress level is higher.

4

TEST METHODOLOGY

All tests have been carried out on an MTS electro-hydraulic fatigue testing machine with a capacity of 250 kN equipped with the NLR built control unit PAGE jr. This unit included a tape recorder with data storage capacity of ten thousand flights which made it possible to perform tests at night and during the weekends.

The constant amplitude tests were carried out using a signal generator instead of PAGE jr. Test frequency was primarily 7 cycles per second. However, test frequency was reduced when visual crack propagation became hard to perform accurately due to fast crack growth. The main test frequency per specimen is given in table 9. The test frequency for all flight simulation tests was 15 Hz for small amplitudes. In view of the pumping capacity the larger amplitudes and ground-air-ground cycle had to be reduced in frequency.

The load accuracy obtained in all tests is within one percent of the total load range. The test temperature was ambient (295 K) and the environment was normal air (40 - 60 % relative humidity). All tests have been performed using anti-buckling guides.

Two specimens in series were tested and both crack length histories were recorded simultaneously.

After final failure of one of the specimens testing of the second specimen was continued unless the crack length was more than 70 mm. Besides visual observations an electrical potential method was used in flight simulation tests to monitor crack growth.

The material used was 2 mm 2024-T3 Alclad sheet.

All specimens were cut from 2 sheets; rolling direction was parallel to the loading direction.
The width of the specimens was 160 mm. The specimens were provided with a central notch consisting of a saw cut with a total length of 7 mm (see Fig. 6).

More detailed information of the flight simulation tests is given in reference 4.

5 NLR TEST RESULTS

The NLR test results of the constant amplitude tests and flight simulation tests are presented.

These test results will act as database for the GARTEUR programme in which different crack propagation models will be checked.

5.1 Constant amplitude test results

A number of constant amplitude tests have been carried out under a range of stress ratios; an overview is given in table 9. Per test two specimens were tested in series.

The test frequency depended on the crack propagation, i.e. in order to monitor the crack propagation with sufficient accuracy it sometimes was necessary to reduce the test frequency.

The total life test results are given in table 10, except for some specimens which were not tested to failure.

The crack propagation data, i.e. total crack length versus number of cycles and the average crack propagation curve per test, are given in figures 7 through 12; no crack propagation data are available for test number 2. In figure 13 through 18 the crack propagation rates are given as function of $\Delta K$.

The stress intensity range $\Delta K$ is defined as follows:

$$\Delta K = (S_{\text{max}} - S_{\text{min}}) \sqrt{\pi a \beta}$$

where $S_{\text{max}}$ = maximum stress of a cycle

$S_{\text{min}}$ = minimum stress of a cycle

$a$ = semi-crack length

$\beta$ = finite width correction:

$$\beta = \frac{1}{\sqrt{1-(\frac{a}{b})^2}}$$

$b$ = half of specimen width.
In figure 19 all crack propagation rates, as function of the stress intensity range, are given, showing that $\Delta K$ as such is incapable in correlating the crack propagation rates pertaining to tests under a range of stress ratios.

5.2 F-27 and F-4 Spectrum test results

First, the influence of stress level on crack propagation has been investigated. The specimens were tested under the basic F-27 programme using four different mean flight levels. One of these mean stress levels was selected as standard for the subsequent tests with variation of the F-27 spectrum and the F-4 programme. The results of the tests using different stress levels $S_{mf}$ are shown in table 11 and figure 20.

On the basis of these results, a stress of $S_{mf} = 100$ MPa was selected for all further tests. The associated test loads were calculated based on the average measured cross-sectional area of two specimens tested in series.

Table 12 gives an overview of the tests done and crack propagation lives obtained under variations of the basic F-27 spectrum.

The average crack propagation curves are presented in figure 20 (variation of $S_{mf}$), figures 21 up to 23 (variation F-27 Spectrum) and figure 24 (F-4 test programme).

These mean curves were obtained as follows:

i. The individual potential method recorder traces were read out.
   In the case of a tensile overload extensions, a data point was obtained prior to the overload and some distance behind the overload extension.

ii. The data of the corresponding specimens were plotted in one figure and a mean curve drawn through the data points.

The mean crack propagation curves were read out and crack propagation rates were calculated. The results have been tabulated in table 11. These data have been plotted in the figures 25 up to 29 both versus half crack length $a$ and versus a mean stress intensity factor $\Delta K_{rms}$ defined as:

$$\Delta K_{rms} = S_{a rms} \sqrt{\frac{na}{\sqrt{\sec \frac{\pi a}{2b}}}}$$

The rms gust amplitude $S_{a rms}$ has been defined in table 8.
The term \( \sqrt{\frac{\pi a}{2b}} \) is the finite width correction; this factor is different from that as used with the constant amplitude data. In reference 5 both correction factors have been compared resulting in small differences in the results.

In the case of the F-U test programme \( S_{a \text{ rms}} \) is equal to 0.29 \( S_{mf} \) (see figure 5).

Test results on 2024-T3 clad material are reported and discussed upon in reference 4.

In reference 3 the test results of a previously carried out similar investigation on 7075-T6 clad material have been reported.

CONCLUDING REMARKS

In chapter 5 the NLR test results are presented, i.e. constant amplitude test results, F-27 Spectrum test results and F-U load programme test results.

It is intended to check existing crack propagation models using these test results.

The model under consideration should be adjusted, if necessary, using the constant amplitude data and the NN loading case of F-27 Spectrum tests; the F-U load programme test results also may be used. Each participant can perform additional testing.

It was agreed upon to predict the following F-27 Spectrum variation test results: NL, NS, LN and SN loading case.

Detailed information about the NN loading case test results and its variations are given in table 12 and figures 30 through 34; in these figures all test data points and the average crack propagation curves are given.

The results of the predictions will be discussed before summer of 1980.
REFERENCES

1. Pennings, B.M.J., Jongebreur, A.A.
   Load Program For Fatigue Test On F-27 Lower Wing Panels.

2. de Jonge, J.B., Schütz, D., Lowack, H. and Schijve, J.
   A Standardized Load Sequence For Flight Simulation Tests on Transport Aircraft Wing Structures.

3. de Jonge, J.B., Nederveen, A. and Tromp, P.J.

4. de Jonge, J.B., Nederveen, A. and Tromp, P.J.
   Effect of variations in gust spectrum and ground load level on fatigue life and crack propagation in 7075-T6 and 2024-T3 specimens.
   To be published.

5. de Koning, A.U.
   NLR TR 79062 L, June 1979.
**TABLE 1**

Distribution of load cycles per block of 2500 flights over the different flight types - F-27 Spectrum

<table>
<thead>
<tr>
<th>Flight type Code</th>
<th>Number of flights in one block</th>
<th>Gust amplitude S_a/S_m flight</th>
<th>Cycles per flight</th>
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<tr>
<td></td>
<td>1.25</td>
<td>1.15</td>
<td>1.05</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>0</td>
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<tr>
<td>9</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>1</td>
<td>2</td>
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<tr>
<td>7</td>
<td>4</td>
<td>1</td>
<td>4</td>
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<tr>
<td>6</td>
<td>11</td>
<td>1</td>
<td>1</td>
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<tr>
<td>5</td>
<td>27</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>184</td>
<td>1</td>
<td>184</td>
</tr>
<tr>
<td>2</td>
<td>2200</td>
<td>1</td>
<td>2200</td>
</tr>
</tbody>
</table>

| Σ 2500 | 1    | 1    | 3    | 5    | 15   | 46   | 114  | 367  | 2728  | 24630 | average: | 11.16 |
| Cumulative | 1    | 2    | 5    | 10   | 25   | 71   | 185  | 549  | 3277  | 27907 |

X first number is number of cycles per flight, second number is number of cycles within one block of 2500 flights.
<table>
<thead>
<tr>
<th>Flight type</th>
<th>position number(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1635 (1)</td>
</tr>
<tr>
<td>9</td>
<td>106 (1)</td>
</tr>
<tr>
<td>8</td>
<td>684, 2229 (2)</td>
</tr>
<tr>
<td>7</td>
<td>168, 1099, 2458, 2493 (4)</td>
</tr>
<tr>
<td>6</td>
<td>239, 965, 1071, 1121, 1211, 1378, 1465, 1851, 2324, 2365, 2434 (11)</td>
</tr>
<tr>
<td>5</td>
<td>112, 249, 412, 426, 463, 501, 737, 831, 1243, 1260, 1271, 1382, 1481, 1633, 1656, 1665, 1719, 2105, 2107, 2181, 2211, 2221, 2273, 2288, 2323, 2391, 2397 (27)</td>
</tr>
<tr>
<td>4</td>
<td>6, 13, 46, 69, 85, 95, 145, 202, 365, 427, 481, 514, 576, 604, 713, 742, 879, 897, 904, 921, 948, 986, 1007, 1008, 1031, 1034, 1129, 1170, 1184, 1185, 1197, 1225, 1278, 1281, 1286, 1316, 1374, 1377, 1384, 1461, 1490, 1498, 1579, 1581, 1593, 1606, 1681, 1751, 1820, 1908, 1931, 1955, 1967, 2073, 2092, 2097, 2147, 2165, 2196, 2262, 2277, 2290, 2306, 2317, 2334, 2339, 2377, 2415, 2437, 2496 (70)</td>
</tr>
</tbody>
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TABLE 3
Codes as used in the Algol and Fortran TWISTBASE program

<table>
<thead>
<tr>
<th></th>
<th>Algol</th>
<th>Fortran</th>
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<tr>
<td>N</td>
<td>SUMFLIGHT</td>
<td>SUMFL</td>
</tr>
<tr>
<td>F(i)</td>
<td>FREQ (/ /)</td>
<td>FLFREQ ((/ /))</td>
</tr>
<tr>
<td>R(ij)</td>
<td>LOAD (/ , /)</td>
<td>TABL 3 ((/ , /))</td>
</tr>
<tr>
<td>r_1</td>
<td>IA (1), IB (1)</td>
<td>IA (1), IB (1)</td>
</tr>
<tr>
<td>r_2</td>
<td>IA (2), IB (2)</td>
<td>IA (2), IB (2)</td>
</tr>
<tr>
<td>$\sum_{j=1}^{m} R(ij)$</td>
<td>-</td>
<td>SUMLD (j)</td>
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### TABLE 4
Inputdata TWISTBASE for F-27 Spectrum

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<th>N</th>
<th>2500</th>
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<tbody>
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<td>IA (1) = IA (2)</td>
<td>19934</td>
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<tr>
<td>IB (1) = IB (2)</td>
<td>47251</td>
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<tr>
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<td>C = 3</td>
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<tr>
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<tr>
<td>E = 1</td>
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<tr>
<td>F = 6</td>
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<td>G = 7</td>
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<td>H = 8</td>
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<td>I = 9</td>
<td>FLFREQ (I) = 2200</td>
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*continue table 5*
<table>
<thead>
<tr>
<th>TABLE 5</th>
<th>Inputdata TWISTBASE for F-27 Spectrum</th>
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<tbody>
<tr>
<td></td>
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<td>TABL3 (D, 6) = 1</td>
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<td></td>
<td>SUMLD (G) = 22</td>
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<td>Flight Number</td>
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<td>------</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
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TABLE 7  
Flight types and associated random numbers for  
flight 7 through 50

<table>
<thead>
<tr>
<th>FLIGHTNUMBER</th>
<th>TYPE</th>
<th>RANDOM(A,R)</th>
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<tbody>
<tr>
<td>7</td>
<td>F</td>
<td>4856</td>
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<td>J</td>
<td>39608</td>
</tr>
<tr>
<td>17</td>
<td>I</td>
<td>46991</td>
</tr>
<tr>
<td>18</td>
<td>J</td>
<td>15611</td>
</tr>
<tr>
<td>19</td>
<td>I</td>
<td>45313</td>
</tr>
<tr>
<td>20</td>
<td>J</td>
<td>54741</td>
</tr>
<tr>
<td>21</td>
<td>I</td>
<td>3812</td>
</tr>
<tr>
<td>22</td>
<td>J</td>
<td>37728</td>
</tr>
<tr>
<td>23</td>
<td>I</td>
<td>6504</td>
</tr>
<tr>
<td>24</td>
<td>J</td>
<td>18381</td>
</tr>
<tr>
<td>25</td>
<td>I</td>
<td>11384</td>
</tr>
<tr>
<td>26</td>
<td>J</td>
<td>45747</td>
</tr>
<tr>
<td>27</td>
<td>I</td>
<td>17135</td>
</tr>
<tr>
<td>28</td>
<td>J</td>
<td>35641</td>
</tr>
<tr>
<td>29</td>
<td>I</td>
<td>58785</td>
</tr>
<tr>
<td>30</td>
<td>J</td>
<td>51880</td>
</tr>
<tr>
<td>31</td>
<td>I</td>
<td>56666</td>
</tr>
<tr>
<td>32</td>
<td>J</td>
<td>64828</td>
</tr>
<tr>
<td>33</td>
<td>I</td>
<td>50843</td>
</tr>
<tr>
<td>34</td>
<td>J</td>
<td>44111</td>
</tr>
<tr>
<td>35</td>
<td>I</td>
<td>39706</td>
</tr>
<tr>
<td>36</td>
<td>J</td>
<td>43342</td>
</tr>
<tr>
<td>37</td>
<td>I</td>
<td>11768</td>
</tr>
<tr>
<td>38</td>
<td>J</td>
<td>9674</td>
</tr>
<tr>
<td>39</td>
<td>I</td>
<td>61640</td>
</tr>
<tr>
<td>40</td>
<td>J</td>
<td>9011</td>
</tr>
<tr>
<td>41</td>
<td>I</td>
<td>42149</td>
</tr>
<tr>
<td>42</td>
<td>J</td>
<td>16143</td>
</tr>
<tr>
<td>43</td>
<td>I</td>
<td>16495</td>
</tr>
<tr>
<td>44</td>
<td>J</td>
<td>36564</td>
</tr>
<tr>
<td>45</td>
<td>I</td>
<td>54161</td>
</tr>
<tr>
<td>46</td>
<td>J</td>
<td>58247</td>
</tr>
</tbody>
</table>

SOURCES:  
1. [19]
TABLE 8
The gust amplitude levels for the basic programme and the derived severe gust and light gust versions - P-27 Spectrum

<table>
<thead>
<tr>
<th>Code</th>
<th>Basic-programme</th>
<th>Severe gust</th>
<th>Light gust</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.25</td>
<td>1.39</td>
<td>1.11</td>
</tr>
<tr>
<td>9</td>
<td>1.15</td>
<td>1.28</td>
<td>1.02</td>
</tr>
<tr>
<td>8</td>
<td>1.05</td>
<td>1.18</td>
<td>0.92</td>
</tr>
<tr>
<td>7</td>
<td>0.95</td>
<td>1.08</td>
<td>0.82</td>
</tr>
<tr>
<td>6</td>
<td>0.85</td>
<td>0.97</td>
<td>0.73</td>
</tr>
<tr>
<td>5</td>
<td>0.75</td>
<td>0.87</td>
<td>0.63</td>
</tr>
<tr>
<td>4</td>
<td>0.65</td>
<td>0.76</td>
<td>0.54</td>
</tr>
<tr>
<td>3</td>
<td>0.55</td>
<td>0.65</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>0.425</td>
<td>0.515</td>
<td>0.335</td>
</tr>
<tr>
<td>1</td>
<td>0.30</td>
<td>0.39</td>
<td>0.21</td>
</tr>
</tbody>
</table>

\[
\frac{S_{a \text{ r.m.s.}}}{S_{mf}} = \sqrt{\frac{\sum_{i=1}^{10} n_i [S_{a_i}]^2}{\sum_{i=1}^{10} n_i}}
\]
TABLE 9
Constant Amplitude Tests

<table>
<thead>
<tr>
<th>test no.</th>
<th>R</th>
<th>$S_{\text{max}}$ (MPa)</th>
<th>$S_{\text{min}}$ (MPa)</th>
<th>$S_{\text{m}}$ (MPa)</th>
<th>frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.54</td>
<td>130</td>
<td>70</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>.54</td>
<td>91</td>
<td>49</td>
<td>70</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>.10</td>
<td>130</td>
<td>12.5</td>
<td>71.25</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>-.11</td>
<td>225</td>
<td>-25</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>-.18</td>
<td>130</td>
<td>-23.5</td>
<td>53.25</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>-.38</td>
<td>130</td>
<td>-50</td>
<td>40</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>-1</td>
<td>130</td>
<td>-130</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

TABLE 10
Constant Amplitude Lives

<table>
<thead>
<tr>
<th>test no.</th>
<th>R</th>
<th>upper specimen (cycles)</th>
<th>lower specimen (cycles)</th>
<th>mean life (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.54</td>
<td>116401</td>
<td>118657</td>
<td>117529</td>
</tr>
<tr>
<td>2</td>
<td>.54</td>
<td>362517</td>
<td>393442</td>
<td>377980</td>
</tr>
<tr>
<td>3</td>
<td>.10</td>
<td>21069</td>
<td>-</td>
<td>21069</td>
</tr>
<tr>
<td>4</td>
<td>-.11</td>
<td>1157</td>
<td>-</td>
<td>1157</td>
</tr>
<tr>
<td>5</td>
<td>-.18</td>
<td>14257</td>
<td>15303</td>
<td>14780</td>
</tr>
<tr>
<td>6</td>
<td>-.38</td>
<td>14190</td>
<td>10501</td>
<td>12346</td>
</tr>
<tr>
<td>7</td>
<td>-1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Table 11
Average crack propagation rates

<table>
<thead>
<tr>
<th>a (mm)</th>
<th>$\frac{dK}{d\sigma}$</th>
<th>Crack propagation rates $\frac{da}{dn}$ per 1000 flights</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma$ (m)</td>
<td>basic program with $S_{mf} = 70$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>3.75</td>
<td>0.1887</td>
<td>0.10</td>
</tr>
<tr>
<td>4.5</td>
<td>0.1191</td>
<td>0.10</td>
</tr>
<tr>
<td>5.5</td>
<td>0.1318</td>
<td>0.11</td>
</tr>
<tr>
<td>6.5</td>
<td>0.1435</td>
<td>0.13</td>
</tr>
<tr>
<td>7.5</td>
<td>0.1544</td>
<td>0.15</td>
</tr>
<tr>
<td>8.5</td>
<td>0.1646</td>
<td>0.17</td>
</tr>
<tr>
<td>9.5</td>
<td>0.1743</td>
<td>0.16</td>
</tr>
<tr>
<td>11</td>
<td>0.1881</td>
<td>0.16</td>
</tr>
<tr>
<td>13</td>
<td>0.2055</td>
<td>0.16</td>
</tr>
<tr>
<td>15</td>
<td>0.2219</td>
<td>0.18</td>
</tr>
<tr>
<td>17</td>
<td>0.2377</td>
<td>0.22</td>
</tr>
<tr>
<td>19</td>
<td>0.2532</td>
<td>0.23</td>
</tr>
<tr>
<td>22.5</td>
<td>0.2796</td>
<td>0.26</td>
</tr>
<tr>
<td>27.5</td>
<td>0.3174</td>
<td>0.47</td>
</tr>
<tr>
<td>32.5</td>
<td>0.3565</td>
<td>0.83</td>
</tr>
</tbody>
</table>

1) $\frac{dK}{d\sigma} = \sqrt{\pi a} \sqrt{\frac{\sigma}{2b}}$
<table>
<thead>
<tr>
<th>Ground Load Level</th>
<th>Gust load Spectrum</th>
<th>Light</th>
<th>Normal</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Code LL</td>
<td>76662</td>
<td>52234</td>
<td>23970</td>
</tr>
<tr>
<td></td>
<td>Code NL</td>
<td>49153</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light:</td>
<td>Code SL</td>
<td>23970</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{E}$ = +0.125 S_{mf}</td>
<td>mean: 76792</td>
<td></td>
<td>46111</td>
<td>24112</td>
</tr>
<tr>
<td></td>
<td>Code LN</td>
<td>33655</td>
<td>18978</td>
<td>11122</td>
</tr>
<tr>
<td></td>
<td>Code NN</td>
<td>18429</td>
<td></td>
<td>11582</td>
</tr>
<tr>
<td>Normal:</td>
<td>Code SN</td>
<td>19386</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{E}$ = -0.234 S_{mf}</td>
<td>mean: 32299</td>
<td>20552</td>
<td></td>
<td>11894</td>
</tr>
<tr>
<td></td>
<td>Code LS</td>
<td>19348</td>
<td>10969</td>
<td>4964</td>
</tr>
<tr>
<td></td>
<td>Code NS</td>
<td>17711</td>
<td>9121</td>
<td>6248</td>
</tr>
<tr>
<td>Severe:</td>
<td>Code SS</td>
<td>20342</td>
<td>10832</td>
<td>5370</td>
</tr>
<tr>
<td>$S_{E}$ = -0.500 S_{mf}</td>
<td>mean: 21657</td>
<td>11124</td>
<td></td>
<td>5977</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19711</td>
<td>10478</td>
<td>5616</td>
</tr>
</tbody>
</table>
Fig. 1 Basic test load spectrum for 2500 flights - F-27 Spectrum

\[
\frac{S}{S_{m \text{ flight}}} = -0.234 \frac{S_{\text{ground}}}{S_{m \text{ flight}}}
\]
Fig. 2 Position of severe flights in a block - F-27 Spectrum
Fig. 3 Examples of different flight types of the F-27 spectrum
Fig. 4 Derivation of gust amplitude levels for severe and light gust spectra - F-27 Spectrum.
10.5 GUST CYCLES

\[ S_a^* = 0.32 \, \, S_m^* \]
\[ S_{\text{ground}} = -0.052 \, \, S_m^* \]

\[ S_m^*, \, S_a^*, \, \text{and} \, S_{\text{ground}} \] expressed in \( S_m \) pertaining to the basic spectrum:

\[ S_m^* = 0.91 \, S_m \]
\[ S_a^* = 0.29 \, S_m \]
\[ S_{\text{ground}} = -0.047 \, S_m \]

(1) Relation based on:

\[ M_{b_m} = 1 \]

AT WS 5075 IN F-4 TEST: 15400 kgf.m

IN "NEW SPECTRUM": 16931 kgf.m

Fig. 5 The F-4 test load sequence
MATERIAL:
2024 T3 ALCLAD, THICKNESS 2 mm

CURRENT INPUT •-
MEASURING POINTS •
CRACK •
SAWCUT 7 mm

7 HOLES WITH DIAMETER OF 8 mm
FOR CLAMPING STRAPS FOR TESTING
OF TWO SPECIMENS IN SERIES

Fig. 6 Crack propagation specimen
Fig. 8 Constant amplitude crack propagation data
Fig. 9 Constant amplitude crack propagation data
Fig. 10 Constant amplitude crack propagation data
Fig. 11 Constant amplitude crack propagation data
Fig. 12 Constant amplitude crack propagation data
Fig. 13 Constant amplitude crack propagation rates

\[ \frac{da}{dn} \text{ (m/CYCLE)} \]

-36-
Fig. 14 Constant amplitude crack propagation rates

\[ \frac{da}{dn} \quad (\text{m/CYCLE}) \]

\[ \Delta K \quad (\text{MPa} \sqrt{\text{m}}) \]

\[ \begin{align*}
R &= 0.10 \\
S_{\text{max}} &= 130 \text{ MPa} \\
S_{\text{min}} &= 12.5 \text{ MPa} \\
\text{TEST No. 3} 
\end{align*} \]
Fig. 15 Constant amplitude crack propagation rates
Fig. 16 Constant amplitude crack propagation rates
Fig. 17 Constant amplitude crack propagation rates

R = 0.38

$S_{\text{max}} = 130\ \text{MPa}$

$S_{\text{min}} = -50\ \text{MPa}$

TEST No. 6
Fig. 18 Constant amplitude crack propagation rates
Fig. 19 Constant amplitude crack propagation rates.
All test results
Fig. 20 Average crack propagation curves for different $S_{mf}$ values - F-27 Spectrum
Fig. 21 Average crack propagation curves with light gust spectrum
Fig. 22 Average crack propagation curves with normal gust spectrum

\[ S_{mf} = 100 \text{ MPa} \]

NORMAL GUST

\[ \text{NS} = \frac{S_{gr}}{S_{mf}} = -0.5 \]

\[ \text{NN} = \frac{S_{gr}}{S_{mf}} = -0.234 \]

\[ \text{NL} = \frac{S_{gr}}{S_{mf}} = 0.125 \]
Fig. 23 Average crack propagation curves with severe gust spectrum
Fig. 24  Average crack propagation curve for F-4 test programme
Fig. 25 Crack propagation rates as a function of stress level
Fig. 26 Crack propagation rates for light, normal and severe gust spectra with light ground load level
Fig. 27 Crack propagation rates for light, normal and severe gust spectra with normal ground load level
Fig. 28 Crack propagation rates for light, normal and severe gust spectra with severe ground load level
Fig. 29 Crack propagation rates for the F-4 test spectrum compared with the basic F-27 test spectrum
Fig. 30 F-27 spectrum crack propagation data (NN)
$S_{mf} = 100 \text{ MPa}$

NORMAL GUST

$NL = \frac{S_{nf}}{S_{mf}} = 0.125$

Fig. 31 F-27 spectrum crack propagation data (NL)
Fig. 32 F-27 spectrum crack propagation data (NS)
Fig. 33 F-27 spectrum crack propagation data (IN)
Fig. 34 F-27 spectrum crack propagation data (SN)
RANDOM SELECTION OF FLIGHT TYPES AND LOADS. IN ACTUAL APPLICATIONS THE FOLLOWING TWO PROCEDURES PUTGTAC AND PUTLOAD SHOULD BE REPLACED BY OTHER PROCEDURES FOR OUTPUT OF LOAD CODINGS TO AN INTERMEDIATE DEVICE OR DIRECTLY TO THE FATIGUE TESTING MACHINE. EACH FLIGHT IS STARTED BY A CALL OF PUTGTAC, WHICH IS THEN GENERATING OUTPUT FOR THE GROUND-TO-AIR CYCLE, CONSISTING OF A NUMBER OF LOADS IN A FIXED SEQUENCE. THE PROCEDURE PUTLOAD IS CALLED AFTER THE RANDOM- SELECTION OF EACH LOAD. IN THE PRESENT VERSION THE PROCEDURES ARE PRODUCING SYMBOLIC OUTPUT FOR TESTING THE PROGRAM.

INTEGER A, B, C, D, F, G, H, I, J, L, M, IFL, IILN, ILP, SFL, SLN, SLP, RFL, RLN, RLP, SUMFLIGHT, SUMLOAD,
INTEGER# ARRAY# LOAD(/1..10,1..11/),
FREQ, AMPLN, AMPLP(/1..10/,1..2/).

PROCEDURE RANDOM(N),
COMMENT
N=USED TO GENERATE THE NEXT RANDOM INTEGER IN THE FIRST (N=1) OR IN THE SECOND (N=2) ROW,
VALUE= N,
INTEGER N,
BEGIN
INTEGER S, P, T,
S=3*IB(/N/)+IA(/N/)#DIV#32768,
P=5#DIV#65536,
T=3*IA(/N/)+IB(/N/)+P,
IA(/N/)=S-P*65536,
IB(/N/)=T-(T#DIV#65536)*65536,
RANDOM=IA(/N/)#DIV#2,
END RANDOM,

PROCEDURE PUTGTAC,
COMMENT
OUTPUT OF FLIGHTTYPE AND THE RANDOM NUMBERS SELECTING IT, DURING THE FIRST 50 FLIGHTS,
BEGIN
INTEGER INR,
INR=4000-SUMFLIGHT,
IF# INR #LESS# 51 #THEN#
BEGIN
IF# INR=7 #THEN# OUTPUT(41,*(##*##)*),
IF# INR #LESS# 7 #AND# INR #NOTEQUAL# 1 #THEN#
OUTPUT(41,*(///*)),
OUTPUT(41,*(##(*FLIGHTNUMBER*)##),
32DB,*(##(TYPE*)##,BBF),INR),
OUTCHARACTER(41,*(##EDCABFGHIL##)*,IFL),
OUTPUT(41,*(###RANDOM(A,B)##)),
2*(5ZDBB),*,IA(/1/),IB(/1/)),
COMMENT# SET POINTER J FOR PUTLOAD,
J=0,
END# ELSE# SUMFLIGHT=0,
END# PUTGTAC,

ALGOL programme (to be continued)
#PROCEDURE# PUTLOAD(I),
#COMMENT#
OUTPUT OF LOADS CODED ACCORDING TO THE ROMAN FIGURES
OF TABLE 3, DURING THE FIRST 6 FLIGHTS.,
#VALUE# I,
#INTEGER# I,
#BEGIN#

70**
#INTEGER# INR,
INR. = 4000 - SUMFLIGHT,
#IF# INR #GREATER# 6 #THEN# #GOTO# FINISH,
#COMMENT# VALUE OF J INITIALIZED IN PROCEDURE PUTGTAC,
J. = J + 1,
#IF# J = 1 #THEN# OUTPUT(41, ((#3#), I),
OUTPUT(41, (#303B#), I),
#IF# J = 20 #THEN# J. = 0,
FINISH,
#END# PUTLOAD,

#COMMENT# FLIGHT TYPE AND NUMBER OF FLIGHTS,
A. = 4.
B. = 5.
C. = 3.
D. = 7.
E. = 1.
F. = 6.
G. = 7.
H. = 8.
I. = 9.
J. = 10.

#COMMENT# LOADS,
#FOR# L. = 1 #STEP# 10 #UNTIL# 10 #DO#
#FOR# M. = 1 #STEP# 1 #UNTIL# 10 #DO#
LOAD(/L, M/). = 0,

100**
LOAD(/A, 10/). = 900,
LOAD(/A, 9/). = 391,
LOAD(/A, 8/). = 112,
LOAD(/A, 7/). = 64,
LOAD(/A, 6/). = 19,
LOAD(/A, 5/). = 9,
LOAD(/A, 4/). = 4,
LOAD(/A, 3/). = 1,
LOAD(/A, 2/). = 1,
LOAD(/A, 1/). = 1,

110**
LOAD(/R, 10/). = 899,
LOAD(/B, 9/). = 366,
LOAD(/B, 8/). = 75,
LOAD(/B, 7/). = 39,
LOAD(/B, 6/). = 11,
LOAD(/B, 5/). = 5,
LOAD(/B, 4/). = 2,
LOAD(/B, 3/). = 1,
LOAD(/B, 2/). = 1,

ALGOL programme (continuation)
120**
  LOAD(/C,10/) = 879,
  LOAD(/C, 9/) = 277,
  LOAD(/C, 8/) = 61,
  LOAD(/C, 7/) = 22,
  LOAD(/C, 6/) = 7,*
  LOAD(/C, 5/) = 2,*
  LOAD(/C, 4/) = 1,*
  LOAD(/C, 3/) = 1,*

130**
  LOAD(/D,10/) = 680, *
  LOAD(/D, 9/) = 208, *
  LOAD(/D, 8/) = 44, *
  LOAD(/D, 7/) = 14, *
  LOAD(/D, 6/) = 7, *
  LOAD(/D, 5/) = 1, *
  LOAD(/D, 4/) = 1, *
  LOAD(/E,10/) = 603, *
  LOAD(/E, 9/) = 165, *
  LOAD(/E, 8/) = 24, *
  LOAD(/E, 7/) = 6, *
  LOAD(/E, 6/) = 1, *
  LOAD(/E, 5/) = 1, *

140**
  LOAD(/F,10/) = 512, *
  LOAD(/F, 9/) = 115, *
  LOAD(/F, 8/) = 19, *
  LOAD(/F, 7/) = 3, *
  LOAD(/F, 6/) = 1, *

150**
  LOAD(/G,10/) = 412, *
  LOAD(/G, 9/) = 70, *
  LOAD(/G, 8/) = 7, *
  LOAD(/G, 7/) = 1, *
  LOAD(/H,10/) = 233, *
  LOAD(/H, 9/) = 16, *
  LOAD(/H, 8/) = 1, *

160**
  LOAD(/I,10/) = 69, *
  LOAD(/I, 9/) = 1,*
  LOAD(/J,10/) = 25,*

#COMMENT# CALCULATE SUMLOADS AND START RANDOMNUMBERS,*
#FOR# L=1 #STEP# 1 #UNTIL# 10 #DO#
#FOR# M=1 #STEP# 1 #UNTIL# 10 #DO#
  LOAD(/L+11/) = LOAD(/L+11/) + LOAD(/L*M/) *,
170**
  IA(/1/) = IA(/2/) = 1934,*
  IB(/1/) = IB(/2/) = 47251,*
180** #COMMENT# RANDOM NUMBER FOR NEXT FLIGHT.,
SUMFLIGHT.*=4000.,

L1.. RFL.=(RANDOMN(1)*SUMFLIGHT)/DIV#32768.,
RANDOMN(2),. #COMMENT# SHIFT ONE PLACE IN SECOND RANDOM ROW.,

#COMMENT# SELECT FLIGHT NUMBER.,
IFL.*=SFL.*=0.,

L2.. IFL. = IFL + 1.,
SFL.*=SFL.*+FREQ(/IFL/),

#IF# RFL NOTLESS# SFL #THEN# #GOTO# L2.,
FREQ(/IFL/).* = FREQ(/IFL/)-1.,
SUMFLIGHT.* = SUMFLIGHT-1.,

#COMMENT# FETCH THE CORRESPONDING LOADS.,
SUMLOAD.*, = LOAD(/IFL,11/),

#FOR# L=1 #STEP# 1 #UNTIL# 10 #DO# AMPLN(/L/)., = AMPLP(/L/). = LOAD(/IFL,L/),

200** PUTGTAC.,

#COMMENT# RANDOM NUMBER FOR NEXT POSITIVE LOAD.,
RLP.*=(RANDOMN(2)*SUMLOAD*/DIV#32768.,

#COMMENT# SELECT POSITIVE LOAD.,
ILP.* = SLP.* = 0.,

L3.. ILP. = ILP + 1.,
SLP.* = SLP.* + AMPLP(/ILP/),

#IF# RLP NOTLESS# SLP #THEN# #GOTO# L4.,
AMPLP(/ILP/). = AMPLP(/ILP/)-1.,
PUTLOAD(ILP),

#COMMENT# RANDOM NUMBER FOR NEXT NEGATIVE LOAD.,
RLN.*=(RANDOMN(2)*SUMLOAD*/DIV#32768.,

#COMMENT# SELECT NEGATIVE LOAD.,
ILN.* = SLN.* = 0.,

L4.. ILN.* = ILN + 1.,
SLN.* = SLN.* + AMPLN(/ILN/),

#IF# RLN NOTLESS# SLN #THEN# #GOTO# L5.,
AMPLN(/ILN/). = AMPLN(/ILN/)-1.,
SUMLOAD.* = SUMLOAD-1.,
PUTLOAD(-ILN),

#IF# SUMLOAD #GREATER# 0 #THEN# #GOTO# L3.,

220** #COMMENT# READY LOAD.,

#IF# SUMFLIGHT #GREATER# 0 #THEN# #GOTO# L1.,

#END.,

ALGOL programme (concluded)
PROGRAM FLISIM

RANDOM SELECTION OF FLIGHT TYPES AND LOAD LEVELS.

IN ACTUAL APPLICATIONS BOTH SUBROUTINES PRGTAC AND PRLOAD SHOULD

BE REPLACED BY OTHER ROUTINES FOR OUTPUT OF LOAD CODINGS TO AN

INTERMEDIATE DEVICE OR DIRECTLY TO THE FATIGUE TESTING MACHINE.

EACH FLIGHT HAS TO START BY A CALL OF PRGTAC FOR GENERATING THE

GROUND TO AIR CYCLE, CONSISTING OF A NUMBER OF LOADS IN A FIXED

SEQUENCE.

THE ROUTINE PRLOAD MUST BE CALLED AFTER THE RANDOM SELECTION OF EACH LOAD.

IN THE PRESENT VERSION THESE SUBROUTINES ARE PRODUCING SYMBOLIC OUTPUT

FOR TESTING THE PROGRAM.

COMMON IA(2), IB(2), J, SUMFL, IFL

DIMENSION FLFREQ(10), PLFREQ(10), NLFREQ(10), SUMLD(10), TABL3(10,10)

INTEGER A, R, C, D, E, F, G, H,

1 SUMFL, RFL, FLFREQ,

2 SUMPL, RPL, PLFREQ,

3 SUMNL, RNL,

4 TABL3, SUMLD

A= 4 $ FLFREQ(A)= 1
B= 5 $ FLFREQ(B)= 1
C= 3 $ FLFREQ(C)= 3
D= 2 $ FLFREQ(D)= 9
E= 1 $ FLFREQ(E)= 24
F= 6 $ FLFREQ(F)= 60
G= 7 $ FLFREQ(G)= 181
H= 8 $ FLFREQ(H)= 420
I= 9 $ FLFREQ(I)= 1090
J=10 $ FLFREQ(J)= 2211

SUMFL=4000

STORE LOAD FREQUENCIES OF TABLE 3

DO 10 L=1,10
DO 10 M=1,10
TABL3(L,M)=0
CONTINUE

TABL3(A,10)= 900
TABL3(A, 9)= 391
TABL3(A, 8)= 112
TABL3(A, 7)= 64
TABL3(A, 6)= 18
TABL3(A, 5)= 8
TABL3(A, 4)= 4
TABL3(A, 3)= 1
TABL3(A, 2)= 1
TABL3(A, 1)= 1
SUMLD(A) =1500

TABL3(B,10)= 899
TABL3(B, 9)= 366
TABL3(B, 8)= 76
TABL3(B, 7)= 39
TABL3(B, 6)= 11
TABL3(B, 5)= 5
TABL3(B, 4)= 2
TABL3(B, 3)= 1
TABL3(B, 2)= 1
SUMLD(B) =1400

FORTRAN programme (to be continued)
TABL3(C, 10) = 879
TABL3(C, 9) = 277
TABL3(C, 8) = 61
TABL3(C, 7) = 22
TABL3(C, 6) = 7
TABL3(C, 5) = 2
TABL3(C, 4) = 1
TABL3(C, 3) = 1
SUMLD(C) = 1250

TABL3(D, 10) = 680
TABL3(D, 9) = 208
TABL3(D, 8) = 44
TABL3(D, 7) = 14
TABL3(D, 6) = 2
TABL3(D, 5) = 1
TABL3(D, 4) = 1
SUMLD(D) = 950

TABL3(E, 10) = 603
TABL3(E, 9) = 165
TABL3(E, 8) = 24
TABL3(E, 7) = 6
TABL3(E, 6) = 1
TABL3(E, 5) = 1
SUMLD(E) = 800

TABL3(F, 10) = 512
TABL3(F, 9) = 115
TABL3(F, 8) = 19
TABL3(F, 7) = 3
TABL3(F, 6) = 1
SUMLD(F) = 650

TABL3(G, 10) = 412
TABL3(G, 9) = 70
TABL3(G, 8) = 7
TABL3(G, 7) = 1
SUMLD(G) = 490

TABL3(H, 10) = 233
TABL3(H, 9) = 16
TABL3(H, 8) = 1
SUMLD(H) = 250

TABL3(I, 10) = 69
TABL3(I, 9) = 1
SUMLD(I) = 70

TABL3(J, 10) = 25
SUMLD(J) = 25

SET STARTING VALUES FOR RANDOM GENERATORS
IA(1) = 19934 $ IA(2) = 19934
IB(1) = 47251 $ IB(2) = 47251

FORTRAN programme (continuation)
C NEXT FLIGHT
C SHIFT ONE PLACE IN SECOND RANDOM ROW
 20 IR=NRANDM(2)  
    IR=NRANDM(1)  
    RFL=IPROD(IR, SUMFL)  
    CALL SELECT(FLFREQ, SUMFL, RFL, IFL)  
    SUMPL=SULMD(IFL)  
    SUMNL=SUMPL  
C FETCH LOAD DISTRIBUTION FROM TABLE 3  
  DO 30 L=1,10  
    PLFREQ(L)=TABL3(IFL,L)  
  30 NLFREQ(L)=PLFREQ(L)  
C CALL PRGTAC  
C C NEXT POSITIVE LOAD  
  40 IR=NRANDM(2)  
    RPL=IPROD(IR, SUMPL)  
    CALL SELECT(PLFREQ, SUMPL, RPL, IPL)  
C CALL PRLOAD(IPL,1)  
C C NEXT NEGATIVE LOAD  
  IR=NRANDM(2)  
    RNL=IPROD(IR, SUMNL)  
    CALL SELECT(NLFREQ, SUMNL, RNL, INL)  
C CALL PRLOAD(-INL,1)  
C IF (SUMNL .GT. 0) GOTO 40  
C IF (J .GT. 0) CALL PRLOAD(0,0)  
C IF (SUMFL .GT. 0) GOTO 20  
END

FORTRAN programme (continuation)
FUNCTION NRANDM(N)
COMMON IA(2),IB(2)
C N=1 IS USED FOR FLIGHT TYPE SELECTION
C N=2 IS USED FOR LOAD LEVEL SELECTION
NS=3*IB(N)+1+IA(N)/32768
NP=NS/65536
NT=3*IA(N)*IB(N)*NP
IA(N)=NS-NP*65536
IB(N)=NT-(NT/65536)*65536
NRANDM=IA(N)/2
END

FUNCTION IPROD(NR,NSUM)
C (NR*NSUM)/2**15 HAS TO BE CORRECTLY TRUNCATED
C WHILE AT MOST 20 RITS MAY BE USED
IP=NR/128
IQ=NR-IP*128
IPROD=(IP*NSUM*(10**NSUM)/128)/256
END

SUBROUTINE SELECT(IFREQ,ISUM,IR,ISEL)
DIMENSION IFREQ(IO)
I=0
IF=0
100 I=I+1
IF=IF*IFREQ(I)
IF(IR.GE.IF) GOTO 100
IFREQ(I)=IFREQ(I)-1
ISUM=ISUM-1
ISFL=I
END

SUBROUTINE PRLOAD(I,K)
COMMON IH(4),J,JSUM
DIMENSION IBUF(20)
C OUTPUT OF LOADS CODED ACCORDING TO THE ROMAN FIGURES
C OF TABLE 3, DURING THE FIRST 6 FLIGHTS
IF(K.EQ.0) GOTO 100
NP=4000-JSUM
IF(NR.GT.6) RETURN
J=J*1
C VALUE OF J INITIALIZED IN PROCEDURE PRGTAC
IBUF(J)=I
IF(J.LT.20) RETURN
100 PRINT 1,(IBUF(N),N=1,J)
J=n
1 FORMAT(1H,20(I3,3X))
END

FORTRAN programme (continuation)
SUBROUTINE PRGTAC
COMMON IA(2),IB(2),J,JSUM,IFL
C OUTPUT OF FLIGHT TYPE AND THE RANDOM NUMBERS SELECTING IT.
C DURING THE FIRST 50 FLIGHTS
NR=4000-JSUM
IF(NR-51) 200,100,100
170 JSUM=0
RETURN
200 IF(NR.EQ.6 .OR. NR.EQ.7) PRINT 1
  1 FORMAT(1H1)
  IF(NR.GT.1 .AND. NR.LT.6) PRINT 4
  4 FORMAT(/)
  PRINT 2*NR:
  2 FORMAT(1H*,12HFLIGHTNUMBER,I4,4X,4HTYPF,2X)
  GOTO(11,12,13,14,15,16,17,18,19,20),IFL
11 PRINT 21 $ GOTO 300
12 FORMAT(1H*,26X,1HF)
13 PRINT 22 $ GOTO 300
14 FORMAT(1H*,26X,1HN)
15 PRINT 23 $ GOTO 300
16 FORMAT(1H*,26X,1HC)
17 PRINT 24 $ GOTO 300
18 FORMAT(1H*,26X,1HA)
19 PRINT 25 $ GOTO 300
20 FORMAT(1H*,26X,1HR)
21 PRINT 26 $ GOTO 300
22 FORMAT(1H*,26X,1HF)
23 PRINT 27 $ GOTO 300
24 FORMAT(1H*,26X,1HG)
25 PRINT 28 $ GOTO 300
26 FORMAT(1H*,26X,1HH)
27 PRINT 29 $ GOTO 300
28 FORMAT(1H*,26X,1HI)
29 PRINT 30 $ GOTO 300
30 FORMAT(1H*,26X,1HJ)
30C PRINT 3*IA(1),IB(n
3 FORMAT(1H*,31X,13HRANDOM(A,B) =I6*2X,I6/) 
C SET POINTER J FOR UROAD
J=0 
END

FORTRAN programme (concluded)
INPUT DATA
9 Flighttypes i; frequency of type i = F[i]
10 Load amplitudes j; frequency of Ampl. j in flighttype i = N[i,j]

\[ \text{Sumf} = \sum_{i=1}^{9} F[i] = 2500; \text{Suml.} = \sum_{i,j} N[i,j] \]

Generate next Random number \( r_f \)
\((0 \leq r_f \leq 2^{15} - 1)\)

\[ \text{RFL} = \text{ENTIER} \left( \frac{r_f \times \text{Sumf}}{2^{15}} \right) \]
\((0 \leq \text{RFL} \leq \text{Sumf} - 1)\)

- \( p = 0 \)
- \( p = p + 1 \)

\[ \text{F}[p] = \text{F}[p] - 1 \]
\[ \text{Sumf} = \text{Sumf} - 1 \]

PUT GTAC

\[ \text{Suml} = \sum_{i,j} N[P,j] \]
\[ \text{APC} = \text{AN}[j] = \text{N}[P,j] \]

Generate next Random number \( r_l \)
\((0 \leq r_l \leq 2^{15} - 1)\)

\[ \text{RLP} = \text{ENTIER} \left( \frac{r_l \times \text{Suml}}{2^{15}} \right) \]
\((0 \leq \text{RLP} \leq \text{Suml} - 1)\)

Fig. A1 Flow diagram of computer programme. (part 1)
Fig. A2 Continued (part 2)
***PROGRAM F-27***

*GENERATION OF F-27 SPECTRUM LOAD SEQUENCE*
*INCLUDING THE GROUND-AIR-GROUND CYCLE.*

1. The load sequence is stored in array BLOCK.
2. The smallest load cycle in the program is from LEVEL -1 to LEVEL -1.
3. The largest load cycle is from LEVEL 10 to LEVEL -10.
4. Specific output statements must be defined in the program.

---

**PROGRAM FAST**

*COMMON* SLUP, FT, NFIB, NFP, NP, JL, LRN, NFLE, FL, FIELDS(1)

**DIMENSION** LOAD(50:10), SUM(50), FREQ(50), AMPLN(10), AMPLP(10)

**INTEGER** SLU, PL, JL, TM, FN, SFR, SF, SLNP, SLPL, RLP, TL, SUM, SUML, A1, A2, B1, B2, TS, F, T, SUM, FREQ, AMPLN, AMPLP, FIELDS

**COMMON** SELECTED FLIGHT TYPES AND LOADS

READ *(NFT, NFIB, NFP)
READ *(FREQ(TI), TI=1, NFT)

**COMMON** LOADS

READ *(FLD, TI, TJ, TJ=1:10), TI=1, NFT

**COMMON** CALCULATE SUM LOADS AND START RANDOM NUMBERS

SL0=10
REWIND SL0
DO 10 TI=1, NFT
   SUM(TI)=0
10 CONTINUE
DO 20 TI=1, NFT
   DO 15 TM=1, 10
      SUM(TL)=SUM(TL) + LOAD(TL, TM)
   15 CONTINUE
20 CONTINUE
A1=A2=14934
B1=B2=472

**COMMON** RANDOM NUMBER FOR NEXT FLIGHT

SUMFL=NFIB
TI=NFIB/NFP
IF(TI*NFIB+NF, NFIB) TI=TI+1

---

Modified version of the F-27 FORTRAN programme (to be continued)
Fields(1) = T1
REWIND SLO

60  BUFREGUT(SLO,1)(FIELDS(1),FIELDS(1))
    CF = UNIT(SLO)
    FN = NCFP = 0
25  TS = 3*B1 + A1/32768
    P = TS/65536
65  T = 3*A1 + P1 + P
    A1 = TS - P*65536
    B1 = -T - (T/65536)*65536
    RFL = (R1/2)*SUMFL/32768

COMMENT: SHIFT ON LEAST SIGNIFICANT ROW:

70  TS = 3*R2 + A2/32768
    P = TS/65536
75  T = 3*A2 + P2 + P
    A2 = TS - P*65536
    B2 = T - (T/65536)*65536

COMMENT: SELECT FLIGHT NUMBER

80  IFN = NFT + 1
85  SFL = SUMFL
50  IFL = IFN + 1
    SFL = SFL - FREQ(IFN)
    IF(ISFL.LT.SFL) GOTO 50
    FREQ(IFN) = FREQ(IFN) - 1
    SUMFL = SUMFL - 1

COMMENT: FETCH THE CORRESPONDING LOADS

90  SUMLO = SUM(IFN)
    DO 10 TL = 1, 10
        AMPL(TL) = AMPLP(TL) * LOAD(IFN, TL)
      END
    CONTINUE
      NCFP = NCFP + 1
95  C ********************************************************************************
      C THE FOLLOWING STATEMENT DEFINES THE GROUND-AIR-GROUND CYCLE.
      C THE GROUND LEVEL IS LEVE = -11.
      C ********************************************************************************
      BLK(NCFP) = -11

100  FN = FN + 1

COMMENT: RANDOM NUMBER FOR NEXT POSITIVE LOAD

105  TO TS = 3*B2 + A2/32768
    P = TS/65536
    T = 3*A2 + B2 + P
110  A2 = TS - P*65536
    B2 = T - (T/65536)*65536
    RLP = (A2/2)*SUMLO/32768

COMMENT: SELECT POSITIVE LOAD

Modified version of the F-27 FORTRAN programme (continuation)
ILP=0
SLP=SUMLO

70 ILP=ILP+1
SLF=SLF-AMPLP(ILP)
IF(RLP.LT.SLP) GOTO 70
AMPLP(ILP)=AMPLP(ILP)-1
NCPR=NCPR+1
FLDP(NCPR)=ILP

125 COMMENT RANDOM NUMBER FOR NEXT NEGATIVE LOAD
TS=3*B2+1+A2/32768
P=TS/65536
T=3*A2+R2+P
A2=TS-F*65536
B2=T-(1/65536)*65536
RLN=((A2/2)*SUMLO)/32768

130 COMMENT SELECT NEGATIVE LOAD
ILN=0
SLN=SUMLO
80 ILN=ILN+1
SLN=SLN-AMPLN(ILN)
IF(RLN.LT.SLN) GOTO 80
AMPLN(ILN)=AMPLN(ILN)-1
SUMLO=SUMLO-1
NCPR=NCPR+1
BLDP(NCPF)=ILN

140 COMMENT STORE ON SLC
IF(SUMLO.GT.0) GOTO 60
IF(FN.LT.NCPF.AND.SUMFL.NE.0) GOTO 90
FIELDS(1)=NCPP
BUFFOUT(SLC,1)(FIELDS(1),FIELDS(1))
DUMMY=UNIT(SLC)
FIELDS(1)=FN
BUFFOUT(SLC,1)(FIELDS(1),FIELDS(1))
DUMMY=UNIT(SLC)
FN=NFIB-SUMFL
NCPP=NCPP+1
DO 85 TK=NCPR1,2500
BLDP(TK)=0
85 CONTINUE

C THE LOAD SEQUENCE IS STORED ON ARRAY BLDP.
C USING THE FOLLOWING TWO STATMENTS THE TOTAL LOAD
C SEQUENCE, INCLUDING THE GROUND-AIR-GROUND CYCLE,
C IS PRINTERED.
C IF NECESSARY AN APPROPRIATE OUTPUT STATEMENT SHOULD BE ADDED
C
170 PRINT 1002,(BLDP(1),I=1,2500)
1002 FORMAT(1H,20(13,3X))

Modified version of the F-27 FORTRAN programme (continuation)
THE FOLLOWING COMPUTER CARDS ARE REQUIRED AS INPUT:

CARD NO.

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Modified version of the F-27 FORTRAN programme (concluded)