NLR TR 79121 U

NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM

NATIONAL AEROSPACE LABORATORY NLR

THE NETHERLANDS

NLR TR 79121 U

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

A GARTEUR ACTIVITY

BY

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DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF.		SECURITY CLASS.
	NLR TR 79121 U		Unclassified

ORIGINATOR
National Aerospace Laboratory NLR
Amsterdam, The Netherlands

TITLE
NLR test results as a database to be used in a check of crack propagation prediction models
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PRESENTED AT

AUTHORS	DATE	pp	ref
H.H. van der Linden	Nov. 1979	72	5

DESCRIPTORS

Crack propagation	Data bases	Stress ratio
Aluminium alloys	Gust loads	
Flight simulation	Gust loads	
F-27 aircraft	Cyclic loads	
Metal sheets	Stress intensity factors	
Power spectra	Computer programs	
Load tests	Data base	
Amplitudes	Pseudo random sequences	

ABSTRACT

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.

Division: Structures and Materials
Prepared: HHvdL/ vdLi
Approved: JBdJ/ JdJ

Completed : November 1979
Ordernumber : 541.703
Typ. : MS

CONTENTS

(73 pages in total)

1 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 socalled 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.

2 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 varieed. 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 algoritm 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 gustloads 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 severity j are present.

Both flight sequence as gust load sequence are selected "at random" by independent random generators.

The following inputdata are required:

i N

ii F(i) (i=1,.....n)

iii R(ij) (i=i,.....n, j=1,......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 inputdata as given in table 4 and 5 must be used. In appendix A the Algol and Fortran programs, not including the F-27 Spectrum inputdata 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 flightnumber 1 through flightnumber 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:
- flightnumber 1 through 12
- flightnumber 85 through 95
- flightnumber 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-logaritmic 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 occurence 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 $S_{ground} = -0.234\ S_{m\ flight}$ 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 $S_{ground} = -0.5\ S_{m\ flight}$.
Also a high ground stress level, resulting in a light GAG-cycle was chosen: $S_{ground} = +0.125\ S_{m\ flight}$

3.5 F-4 load programme

A prototype of the F-27 has been subjected to a full-scale fatique 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 test have been carried out on an MTS electro-hydraulic fatigue testing machine with a capacity of 250 kN equiped 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 test 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 ΔK.

The stress intensity range ΔK is defined as followes:

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

where S_{max} = maximum stress of a cycle
S_{min} = minimum stress of a cycle
a = semi-crack length
β = 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 ΔK 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 ΔK_{rms} defined as:

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

The rms gust amplitude $S_{a\ rms}$ has been defined in table 8.

The term $\sqrt{\sec \frac{\pi a}{2b}}$ 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-4 test programme $S_{a\ rms}$ 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.

6 CONCLUDING REMARKS

In chapter 5 the NLR test results are presented, i.e. constant amplitude test results, F-27 Spectrum test results and F-4 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-4 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.

7 REFERENCES

1. Pennings, B.M.J., Jongebreur, A.A. — Load Program For Fatigue Test On F-27 Lower Wing Panels. Fokker VFW Report G 27-601.

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. NLR TR 73029 U, March 1973.

3. de Jonge, J.B., Nederveen, A. and Tromp, P.J. — Effect of Flight Load Spectrum Variations on Fatigue Life of Riveted Specimens and Crack Propagation in Sheet Made of Alclad 7075-T6. NLR TR 78071 U, July 1978.

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. — A Simple Analytical Model for Computation of Specimen Compliance and Effective Crack Extension Force in a Centrally Cracked Strip, Including Effect of Yoelding. 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

Flight type Code	Number of flights in one block	Gust amplitude S_a/S_m flight										Cycles per flight
		1.25	1.15	1.05	0.95	0.85	0.75	0.65	0.55	0.425	0.30	
10	1	1[x] 1[x]	0 0	1 1	0 0	2 2	0 0	3 3	5 5	7 7	28 28	47
9	1		1 1	0 0	1 1	0 0	2 2	2 2	4 4	7 7	27 27	44
8	2			1 2	0 0	1 2	1 2	2 4	3 6	7 14	25 50	40
7	4				1 4	0 0	1 4	2 8	2 8	6 24	24 96	36
6	11					1 11	1 11	0 0	3 33	4 44	23 253	32
5	27						1 27	1 27	2 54	4 108	20 540	28
4	70							1 70	1 70	2 140	18 1260	22
3	184								1 184	1 184	14 2576	16
2	2200									1 2200	9 19800	10
	Σ 2500	1	1	3	5	15	46	114	364	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 2

Position of heavy flights in the block of 2500 flights (F-27 Spectrum)

Flight type	position number(s)
10	1635 (1)
9	106 (1)
8	684, 2229 (2)
7	168, 1099, 2458, 2493 (4)
6	239, 965, 1071, 1121, 1211, 1378, 1465, 1851, 2324 2365, 2434 (11)
5	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)
4	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)

TABLE 3

Codes as used in the Algol and Fortran TWISTBASE program

	Algol	Fortran
N	SUMFLIGHT	SUMFL
F(i)	FREQ (/ /)	FLFREQ ((/ /))
R(ij)	LOAD (/ , /)	TABL 3 ((/ , /))
r_1	IA (1), IB (1)	IA (1), IB (1)
r_2	IA (2), IB (2)	IA (2), IB (2)
$\sum_{j=1}^{m} R(ij)$	-	SUMLD (j)

TABLE 4

Inputdata TWISTBASE for F-27 Spectrum

N	2500
n	9
IA (1) = IA (2) = 19934	
IB (1) = IB (2) = 47251	
A = 4	FLFREQ (A) = 1
B = 5	FLFREQ (B) = 1
C = 3	FLFREQ (C) = 2
D = 2	FLFREQ (D) = 4
E = 1	FLFREQ (E) = 11
F = 6	FLFREQ (F) = 27
G = 7	FLFREQ (G) = 70
H = 8	FLFREQ (H) = 184
I = 9	FLFREQ (I) = 2200

continue table 5

TABLE 5

continue Inputdata TWISTBASE for F-27 Spectrum

TABL3 (A,10) = 28 TABL3 (A, 9) = 7 TABL3 (A, 8) = 5 TABL3 (A, 7) = 3 TABL3 (A, 6) = 0 TABL3 (A, 5) = 2 TABL3 (A, 4) = 0 TABL3 (A, 3) = 1 TABL3 (A, 2) = 0 TABL3 (A, 1) = 1 SUMLD (A) = 47	TABL3 (B,10) = 27 TABL3 (B, 9) = 7 TABL3 (B, 8) = 4 TABL3 (B, 7) = 2 TABL3 (B, 6) = 2 TABL3 (B, 5) = 0 TABL3 (B, 4) = 1 TABL3 (B, 3) = 0 TABL3 (B, 2) = 1 SUMLD (B) = 44	TABL3 (C,10) = 25 TABL3 (C, 9) = 7 TABL3 (C, 8) = 3 TABL3 (C, 7) = 2 TABL3 (C, 6) = 1 TABL3 (C, 5) = 1 TABL3 (C, 4) = 0 TABL3 (C, 3) = 1 SUMLD (C) = 40
TABL3 (D,10) = 24 TABL3 (D, 9) = 6 TABL3 (D, 8) = 2 TABL3 (D, 7) = 2 TABL3 (D, 6) = 1 TABL3 (D, 5) = 0 TABL3 (D, 4) = 1 SUMLD (D) = 36	TABL3 (E,10) = 23 TABL3 (E, 9) = 4 TABL3 (E, 8) = 3 TABL3 (E, 7) = 0 TABL3 (E, 6) = 1 TABL3 (E, 5) = 1 SUMLD (E) = 32	TABL3 (F,10) = 20 TABL3 (F, 9) = 4 TABL3 (F, 8) = 2 TABL3 (F, 7) = 1 TABL3 (F, 6) = 1 SUMLD (F) = 28
TABL3 (G,10) = 18 TABL3 (G, 9) = 2 TABL3 (G, 8) = 1 TABL3 (G, 7) = 1 SUMLD (G) = 22	TABL3 (H,10) = 14 TABL3 (H, 9) = 1 TABL3 (H, 8) = 1 SUMLD (H) = 16	TABL3 (I,10) = 9 TABL3 (I, 9) = 1 SUMLD (I) = 10

TABLE 6

Sequence of load cycles (without GAG-cycle) in flight number 1 through 6

FLIGHTNUMBER 1 TYPE I RANDOM(A,B) = 10682 41519

10	-10	10	-10	9	-9	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10

FLIGHTNUMBER 2 TYPE I RANDOM(A,B) = 59022 8030

9	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-9	10	-10

FLIGHTNUMBER 3 TYPE I RANDOM(A,B) = 24092 54024

10	-10	9	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-9	10	-10

FLIGHTNUMBER 4 TYPE I RANDOM(A,B) = 31001 60766

10	-10	10	-9	9	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10

FLIGHTNUMBER 5 TYPE I RANDOM(A,B) = 51227 22699

10	-9	10	-10	10	-10	10	-10	10	-10	10	-10	10	-10	9	-10	10	-10	10	-10

FLIGHTNUMBER 6 TYPE G RANDOM(A,B) = 2563 45309

10	-10	10	-10	10	-7	10	-10	10	-10	10	-9	10	-10	10	-10	10	-9	10	-10
8	-10	10	-10	10	-10	9	-10	10	-10	10	-10	10	-8	9	-10	7	-10	10	-10
10	-10	10	-10																

TABLE 7

Flight types and associated random numbers for flight 7 through 50

FLIGHTNUMBER	7	TYPE	H	RANDOM(A,B) =	4856	53000
FLIGHTNUMBER	8	TYPE	I	RANDOM(A,B) =	27929	2034
FLIGHTNUMBER	9	TYPE	H	RANDOM(A,B) =	6103	20285
FLIGHTNUMBER	10	TYPE	I	RANDOM(A,B) =	60856	38594
FLIGHTNUMBER	11	TYPE	I	RANDOM(A,B) =	50248	24555
FLIGHTNUMBER	12	TYPE	I	RANDOM(A,B) =	8131	44228
FLIGHTNUMBER	13	TYPE	G	RANDOM(A,B) =	1613	3087
FLIGHTNUMBER	14	TYPE	I	RANDOM(A,B) =	9262	7926
FLIGHTNUMBER	15	TYPE	I	RANDOM(A,B) =	23779	35712
FLIGHTNUMBER	16	TYPE	I	RANDOM(A,B) =	41601	41514
FLIGHTNUMBER	17	TYPE	I	RANDOM(A,B) =	59008	35246
FLIGHTNUMBER	18	TYPE	I	RANDOM(A,B) =	40204	15663
FLIGHTNUMBER	19	TYPE	I	RANDOM(A,B) =	46991	5203
FLIGHTNUMBER	20	TYPE	I	RANDOM(A,B) =	15611	15104
FLIGHTNUMBER	21	TYPE	I	RANDOM(A,B) =	45313	61937
FLIGHTNUMBER	22	TYPE	I	RANDOM(A,B) =	54741	1270
FLIGHTNUMBER	23	TYPE	H	RANDOM(A,B) =	3812	34421
FLIGHTNUMBER	24	TYPE	I	RANDOM(A,B) =	37728	45858
FLIGHTNUMBER	25	TYPE	H	RANDOM(A,B) =	6504	27972
FLIGHTNUMBER	26	TYPE	I	RANDOM(A,B) =	18381	47485
FLIGHTNUMBER	27	TYPE	I	RANDOM(A,B) =	11384	37094
FLIGHTNUMBER	28	TYPE	I	RANDOM(A,B) =	45747	5711
FLIGHTNUMBER	29	TYPE	I	RANDOM(A,B) =	17135	11880
FLIGHTNUMBER	30	TYPE	I	RANDOM(A,B) =	35641	63285
FLIGHTNUMBER	31	TYPE	I	RANDOM(A,B) =	58785	39138
FLIGHTNUMBER	32	TYPE	I	RANDOM(A,B) =	51880	18886
FLIGHTNUMBER	33	TYPE	I	RANDOM(A,B) =	56660	43454
FLIGHTNUMBER	34	TYPE	I	RANDOM(A,B) =	64828	16827
FLIGHTNUMBER	35	TYPE	I	RANDOM(A,B) =	50483	14703
FLIGHTNUMBER	36	TYPE	I	RANDOM(A,B) =	44111	35080
FLIGHTNUMBER	37	TYPE	I	RANDOM(A,B) =	39706	36342
FLIGHTNUMBER	38	TYPE	I	RANDOM(A,B) =	43492	24389
FLIGHTNUMBER	39	TYPE	H	RANDOM(A,B) =	7633	23794
FLIGHTNUMBER	40	TYPE	H	RANDOM(A,B) =	5847	46694
FLIGHTNUMBER	41	TYPE	I	RANDOM(A,B) =	9011	64237
FLIGHTNUMBER	42	TYPE	I	RANDOM(A,B) =	61640	25736
FLIGHTNUMBER	43	TYPE	I	RANDOM(A,B) =	11674	14049
FLIGHTNUMBER	44	TYPE	I	RANDOM(A,B) =	42148	49071
FLIGHTNUMBER	45	TYPE	I	RANDOM(A,B) =	16143	44445
FLIGHTNUMBER	46	TYPE	G	RANDOM(A,B) =	2264	27340
FLIGHTNUMBER	47	TYPE	I	RANDOM(A,B) =	16485	34133
FLIGHTNUMBER	48	TYPE	I	RANDOM(A,B) =	36864	18053
FLIGHTNUMBER	49	TYPE	I	RANDOM(A,B) =	54161	63109
FLIGHTNUMBER	50	TYPE	I	RANDOM(A,B) =	58257	28986

TABLE 8

The gust amplitude levels for the basic programme and the derived severe gust and light gust versions - F-27 Spectrum

	gust amplitude S_a/S_{mf}		
Code	Basic-programme	Severe gust	Light gust
10	1.25	1.39	1.11
9	1.15	1.28	1.02
8	1.05	1.18	0.92
7	0.95	1.08	0.82
6	0.85	0.97	0.73
5	0.75	0.87	0.63
4	0.65	0.76	0.54
3	0.55	0.65	0.45
2	0.425	0.515	0.335
1	0.30	0.39	0.21
$\frac{S_{a\ r.m.s.}^{*}}{S_{mf}}$	0.3232	0.4126	0.2344

$$* \quad S_{a\ r.m.s.} = \sqrt{\frac{\sum_{1}^{10} n_i \, [S_{a_i}]^2}{\sum_{i=1}^{10} n_i}}$$

TABLE 9

Constant Amplitude Tests

test no.	R	S_{max} (MPa)	S_{min} (MPa)	S_m (MPa)	frequency (Hz)
1	.54	130	70	100	10
2	.54	91	49	70	15
3	.10	130	12.5	71.25	7
4	-.11	225	- 25	100	1
5	-.18	130	- 23.5	53.25	7
6	-.38	130	- 50	40	7
7	-1	130	-130	0	1

TABLE 10

Constant Amplitude Lives

test no.	R	upper specimen (cycles)	lower specimen (cycles)	mean life (cycles)
1	.54	116401	118657	117529
2	.54	362517	393442	377980
3	.10	21069	-	21069
4	-.11	1157	-	1157
5	-.18	14257	15303	14780
6	-.38	14190	10501	12346
7	- 1	-	-	-

TABLE 11

Average crack propagation rates

a (mm)	$\frac{\Delta K}{\Delta \sigma}$ 1) ($m^{\frac{1}{2}}$)	Crack propagation rates $\frac{da}{dn}$ per 1000 flights												
		basic program with S_{mf} =				variations on basic program with S_{mf} = 100								F-4 test with S_{mf} = 100
		70	90	100	110	LL	LN	LS	NL	NS	SL	SN	SS	
3.75	0.1887	0.10	0.33	0.41	0.72	0.11	0.28	0.41	0.20	0.83	0.33	0.71	1.2	0.39
4.5	0.1191	0.10	0.33	0.50	0.83	0.12	0.33	0.45	0.22	1.0	0.40	0.77	1.66	1.19
5.5	0.1318	0.11	0.32	0.53	0.91	0.15	0.33	0.5	0.22	1.0	0.40	0.91	1.83	1.55
6.5	0.1435	0.13	0.38	0.62	0.95	0.17	0.38	0.59	0.25	1.0	0.50	0.95	2.0	1.70
7.5	0.1544	0.15	0.36	0.62	1.00	0.17	0.42	0.63	0.26	1.0	0.50	1.0	2.2	2.22
8.5	0.1646	0.17	0.41	0.67	1.05	0.20	0.45	0.71	0.27	1.33	0.55	0.95	2.5	3.74
9.5	0.1743	0.16	0.41	0.77	1.11	0.22	0.45	0.83	0.35	1.43	0.67	1.43	2.5	3.0
11	0.1881	0.16	0.46	1.0	1.54	0.27	0.59	0.95	0.45	2.2	0.83	1.54	3.1	4.3
13	0.2055	0.16	0.55	1.43	2.36	0.31	0.65	1.33	0.52	2.3	1.0	2.1	4.4	5.4
15	0.2219	0.18	0.67	1.67	4.5	0.37	0.87	1.53	0.67	2.9	1.25	2.9	5.0	7.1
17	0.2377	0.22	0.96	2.5	5.8	0.45	1.18	2.0	0.74	4.0	1.67	3.6	8	8.8
19	0.2532	0.23	1.25	2.9	6.7	0.57	1.43	2.5	1.0	5.0	2.0	5.0	10	10.7
22.5	0.2796	0.26	1.92	4.5	11.1	0.90	2.3	4.2	2.0	9.1	3.6	7.2	20	16
27.5	0.3174	0.47	3.8	11.1	20	1.43	6.2	12.5	5.0	25	8.3	14.3	50	28
32.5	0.3565	0.83	8.3	16.7	50	5.0	16.7	25	8.3	50	33	50		47

1) $\frac{\Delta K}{\Delta \sigma} = \sqrt{\pi a} \quad \sqrt{\sec \frac{\pi a}{2b}}$

TABLE 12

Crack propagation lives (in flights) under variations of the F-27 Spectrum ($S_{m\ flight}$ = 100 MPa in all tests)

Ground Load Level	Gust load Spectrum		
	Light	Normal	Severe
Light: $\frac{S_g}{S_{mf}}$ = +0.125	Code LL 76662 73605 74159 83101 mean: 76792	Code NL .49153 52234 42613 41321 mean: 46111	Code SL 23970 24741 22955 24829 mean: 24112
Normal: $\frac{S_g}{S_{mf}}$ = -0.234	Code LN 33655 34013 29154 32610 mean: 32299	Code NN 18978 18429 21470 19699 20552 17462 mean: 19386	Code SN 11122 11582 11996 12953 mean: 11894
Severe: $\frac{S_g}{S_{mf}}$ = -0.500	Code LS 19348 17711 20342 21657 mean: 19711	Code NS 10969 9121 10832 11124 mean: 10478	Code SS 4964 6248 5370 5977 mean: 5616

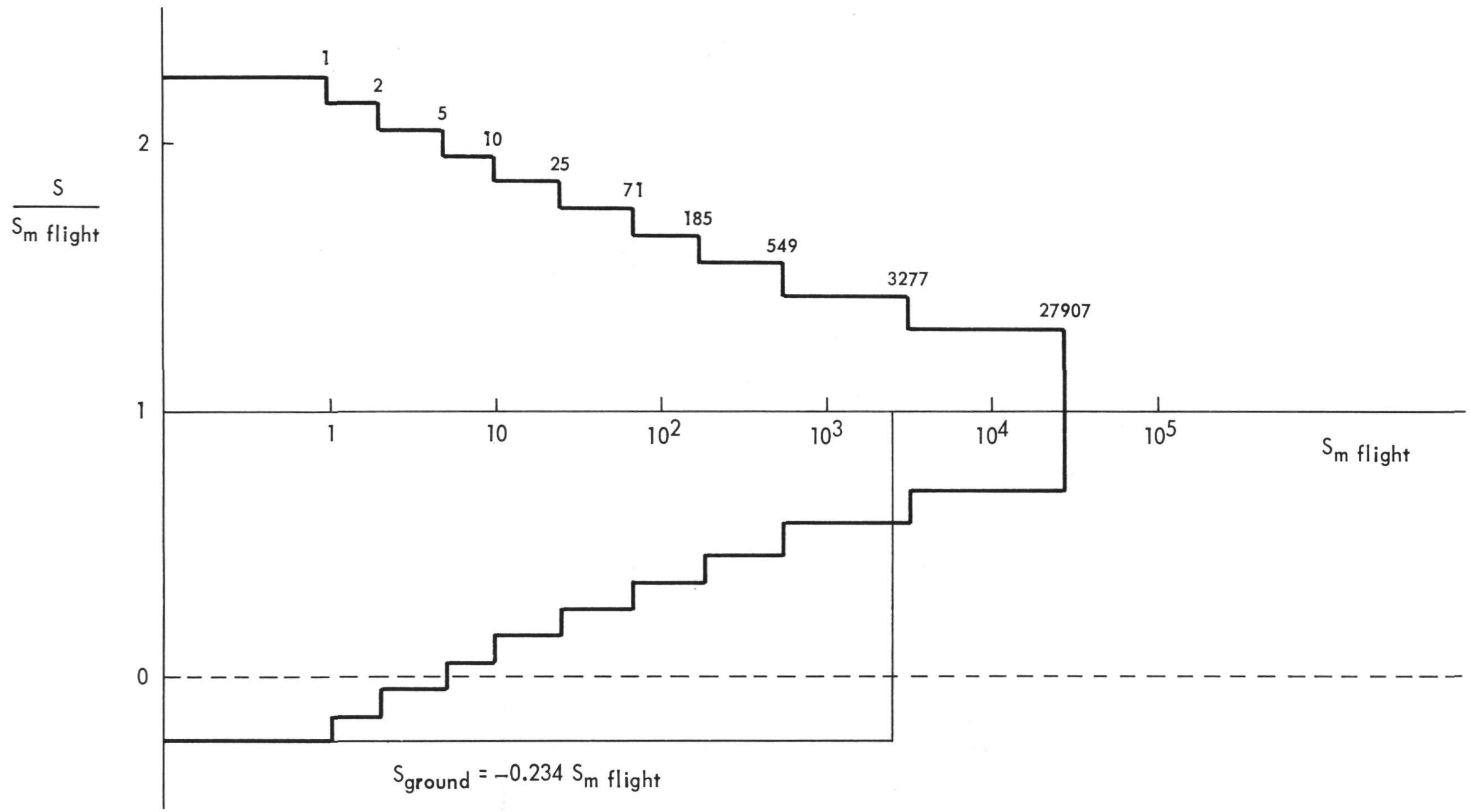


Fig. 1 Basic test load spectrum for 2500 flights - F-27 Spectrum

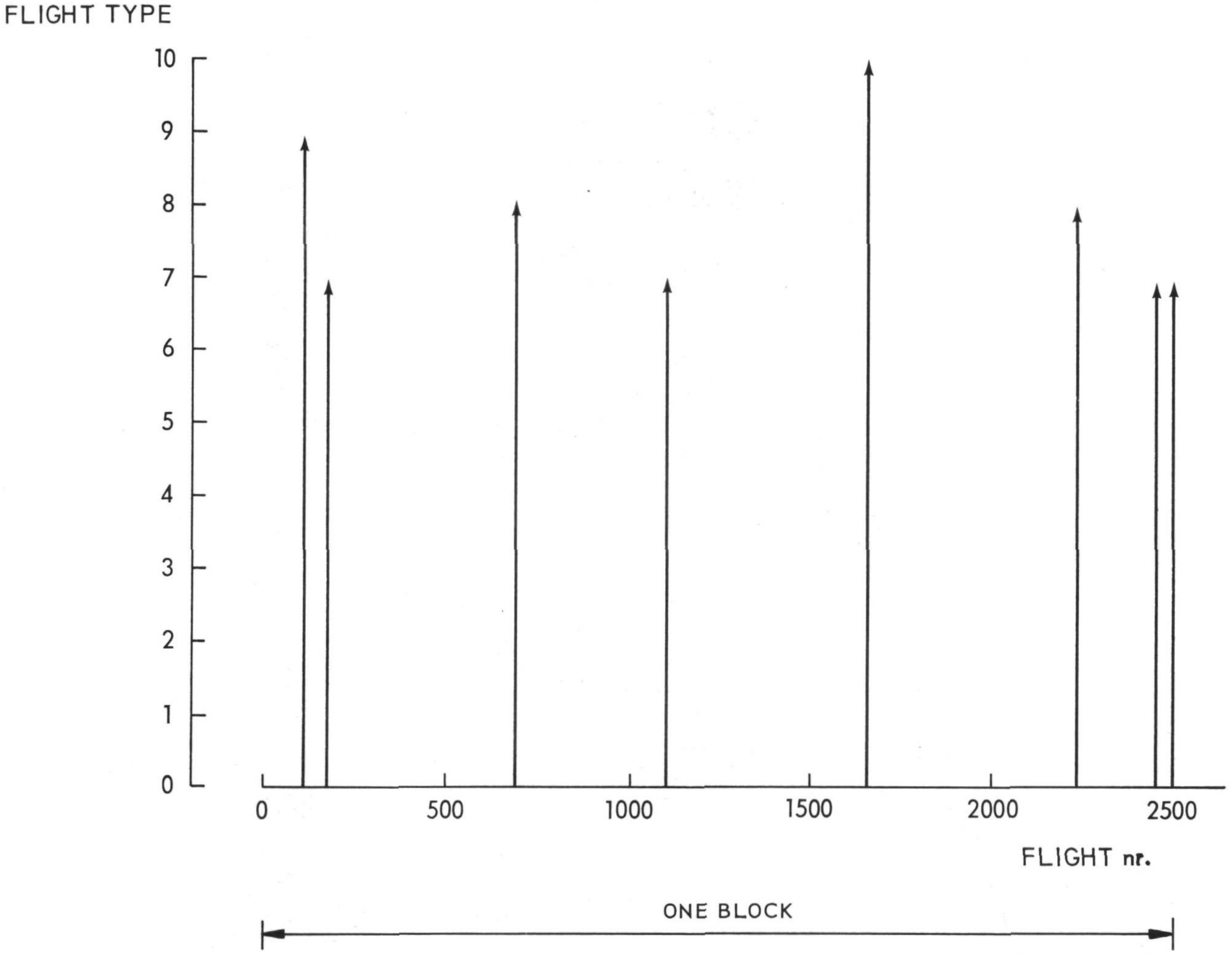


Fig. 2 Position of severe flights in a block - F-27 Spectrum

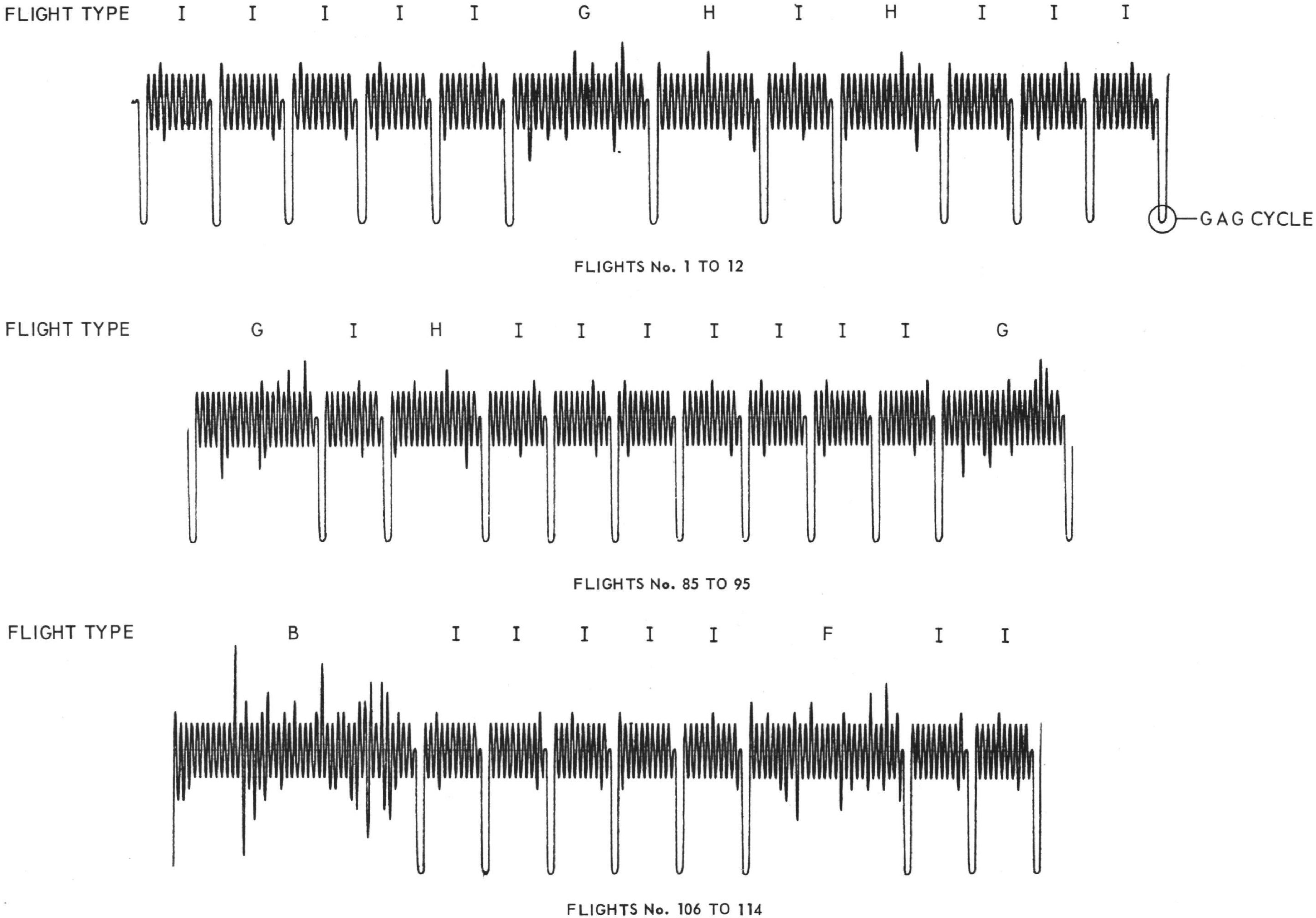


Fig. 3 Examples of different flight types of the F-27 spectrum

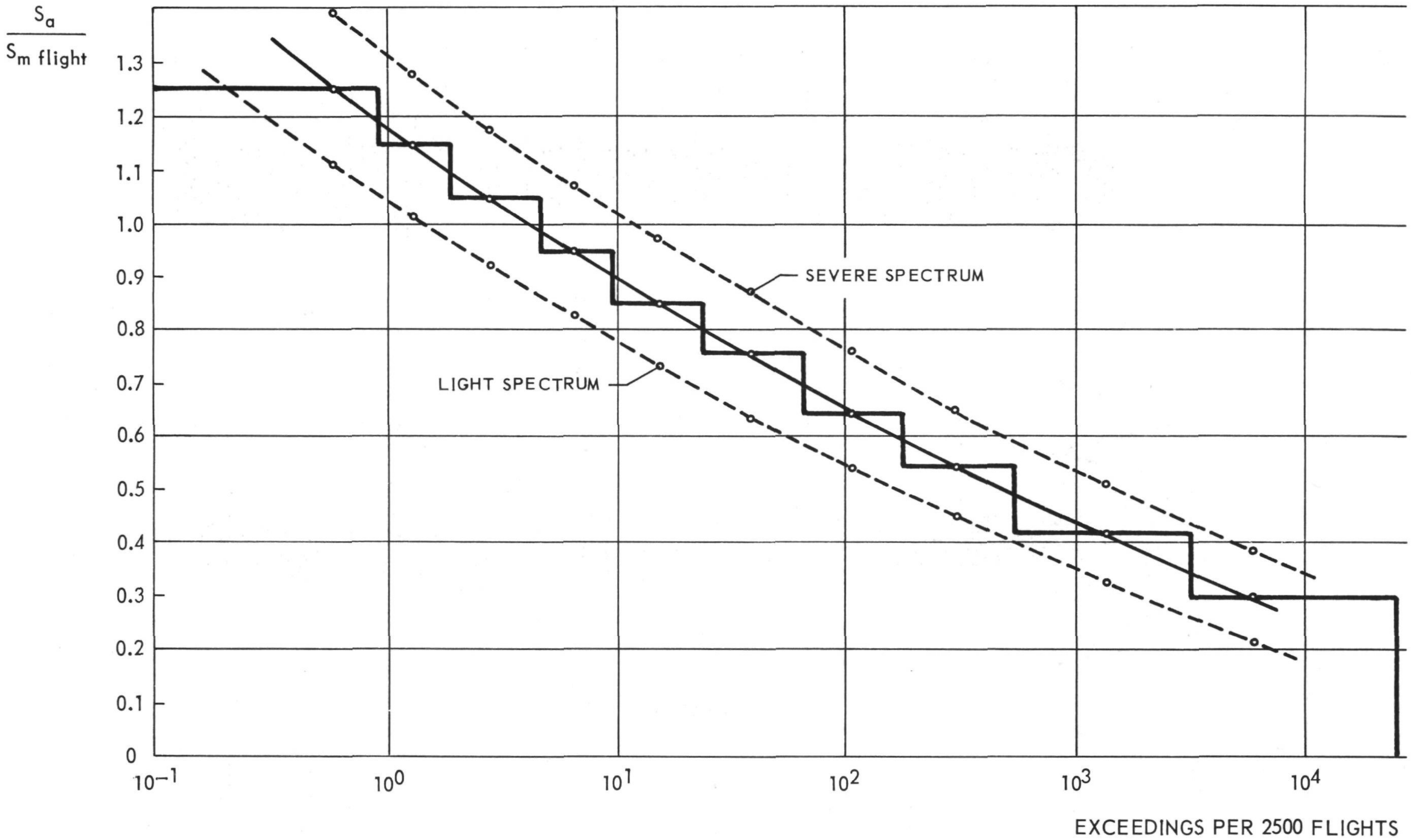
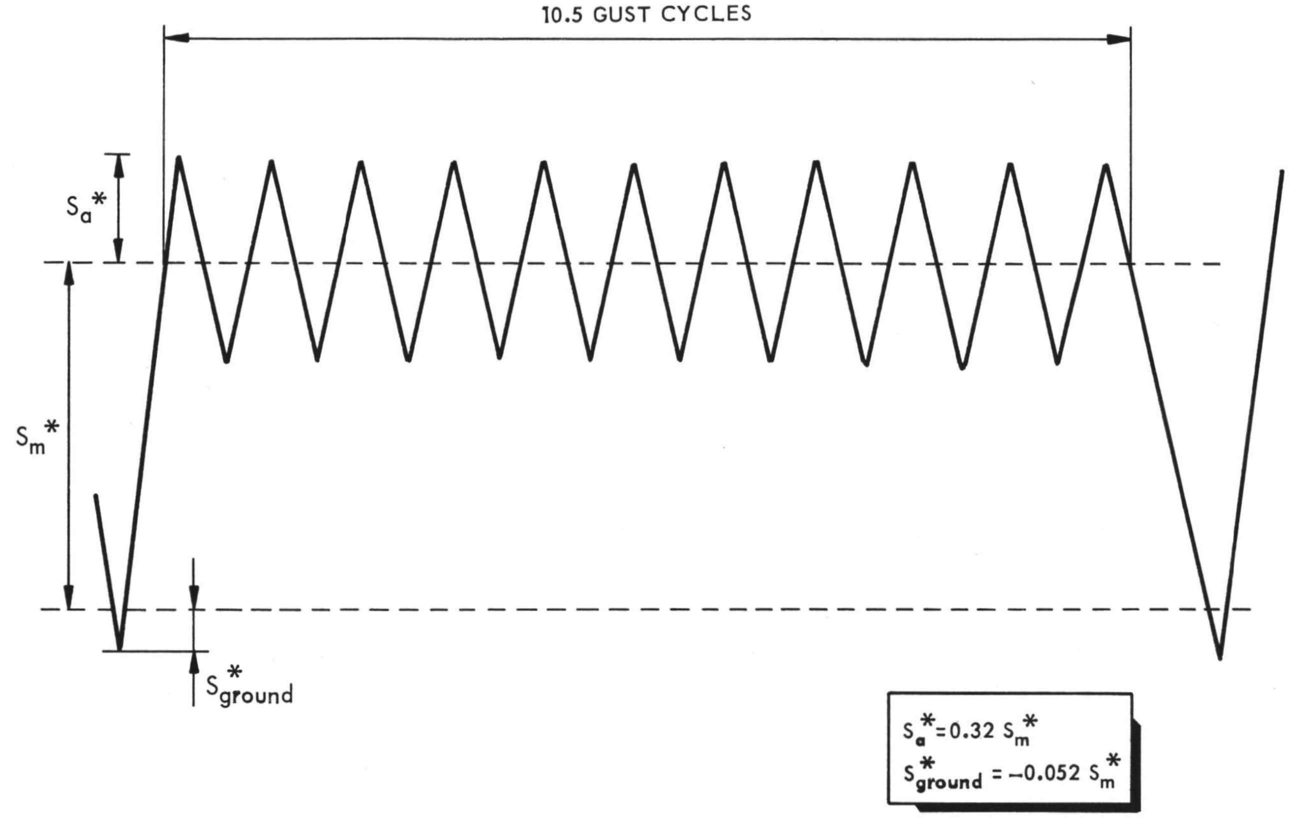


Fig. 4 Derivation of gust amplitude levels for severe and light gust spectra - F-27 Spectrum



S_m^*, S_a^* AND S^*_{ground} EXPRESSED IN S_m PERTAINING TO THE BASIC SPECTRUM :

(1)

$S_m^* = 0.91\ S_m$

$S_a^* = 0.29\ S_m$

$S^*_{ground} = -0.047\ S_m$

(1) RELATION BASED ON :

$M_{b_{n=1}}$ AT WS 5075 IN F – 4 TEST : 15400 kgf.m

IN "NEW SPECTRUM" : 16931 kgf.m

Fig. 5 The F-4 test load sequence

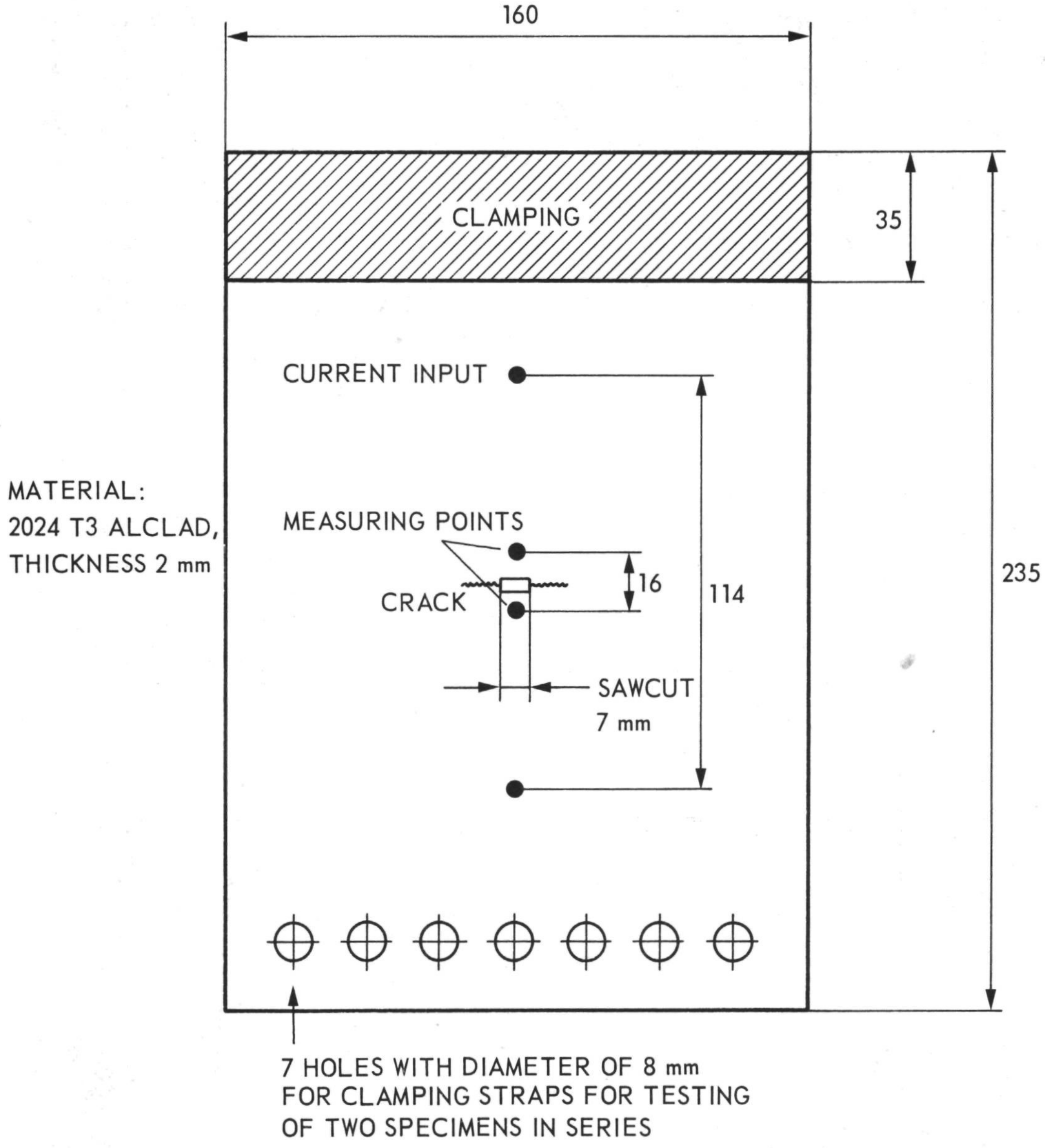


Fig. 6 Crack propagation specimen

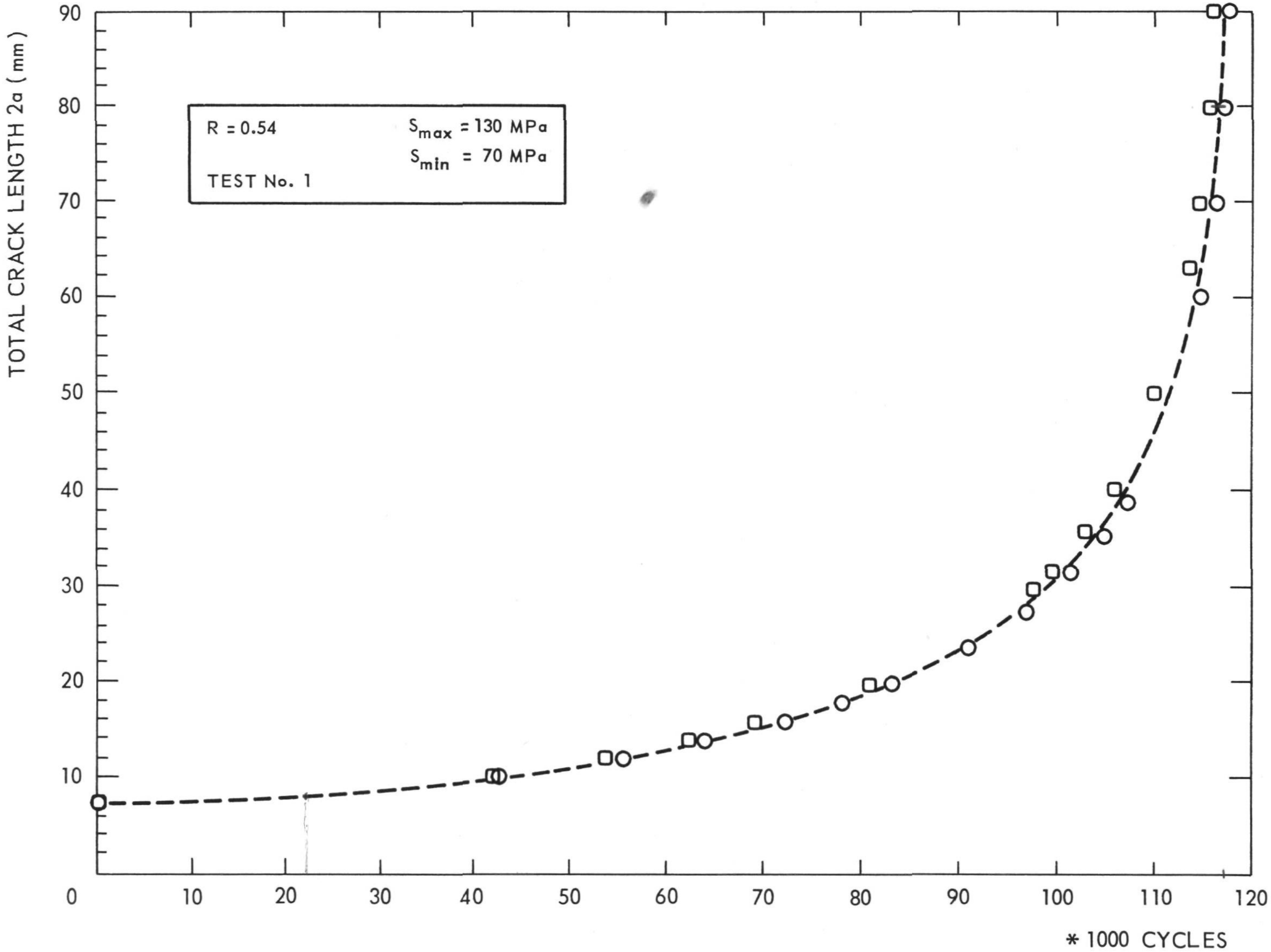


Fig. 7 Constant amplitude crack propagation data

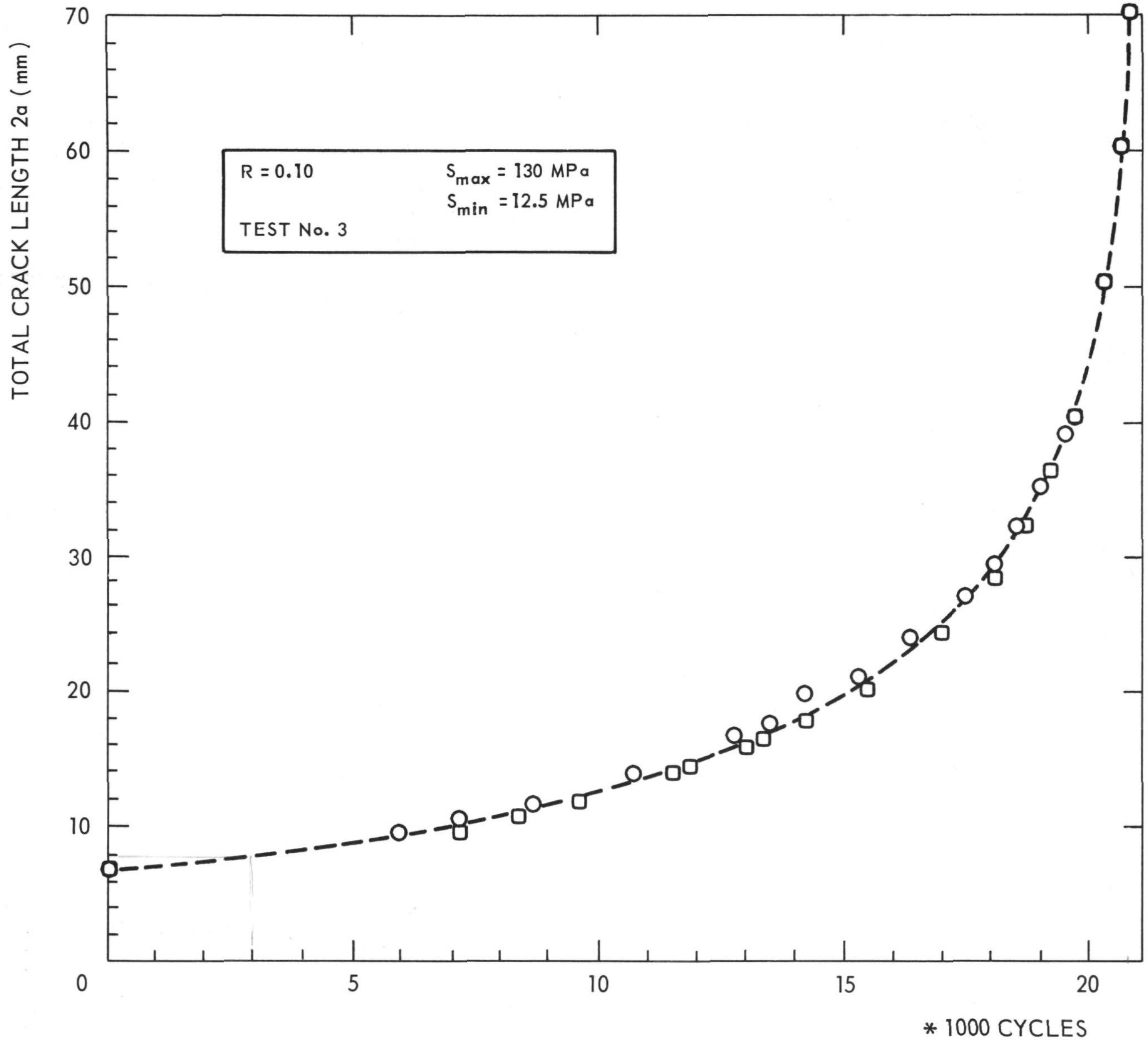


Fig. 8 Constant amplitude crack propagation data

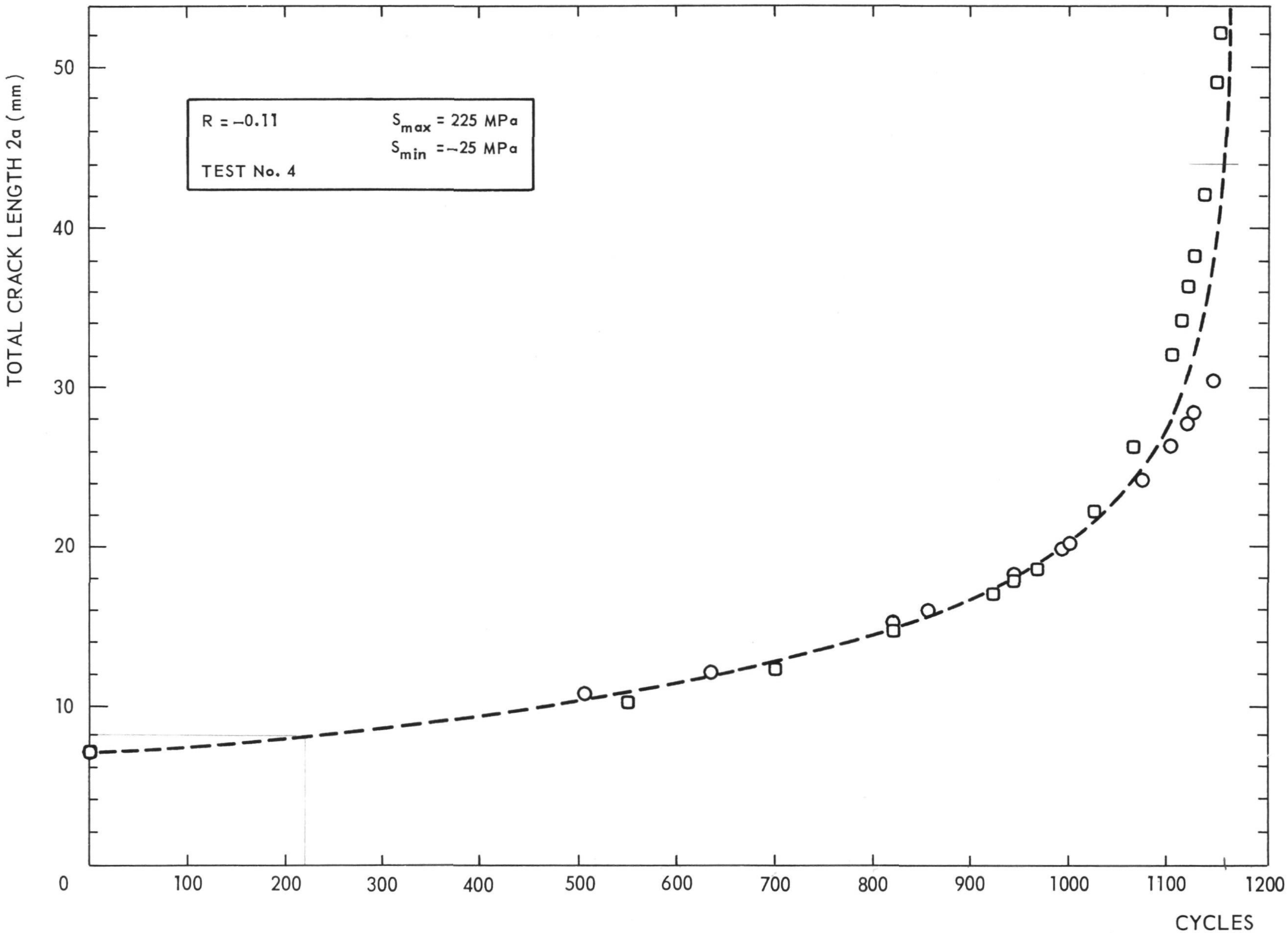


Fig. 9 Constant amplitude crack propagation data

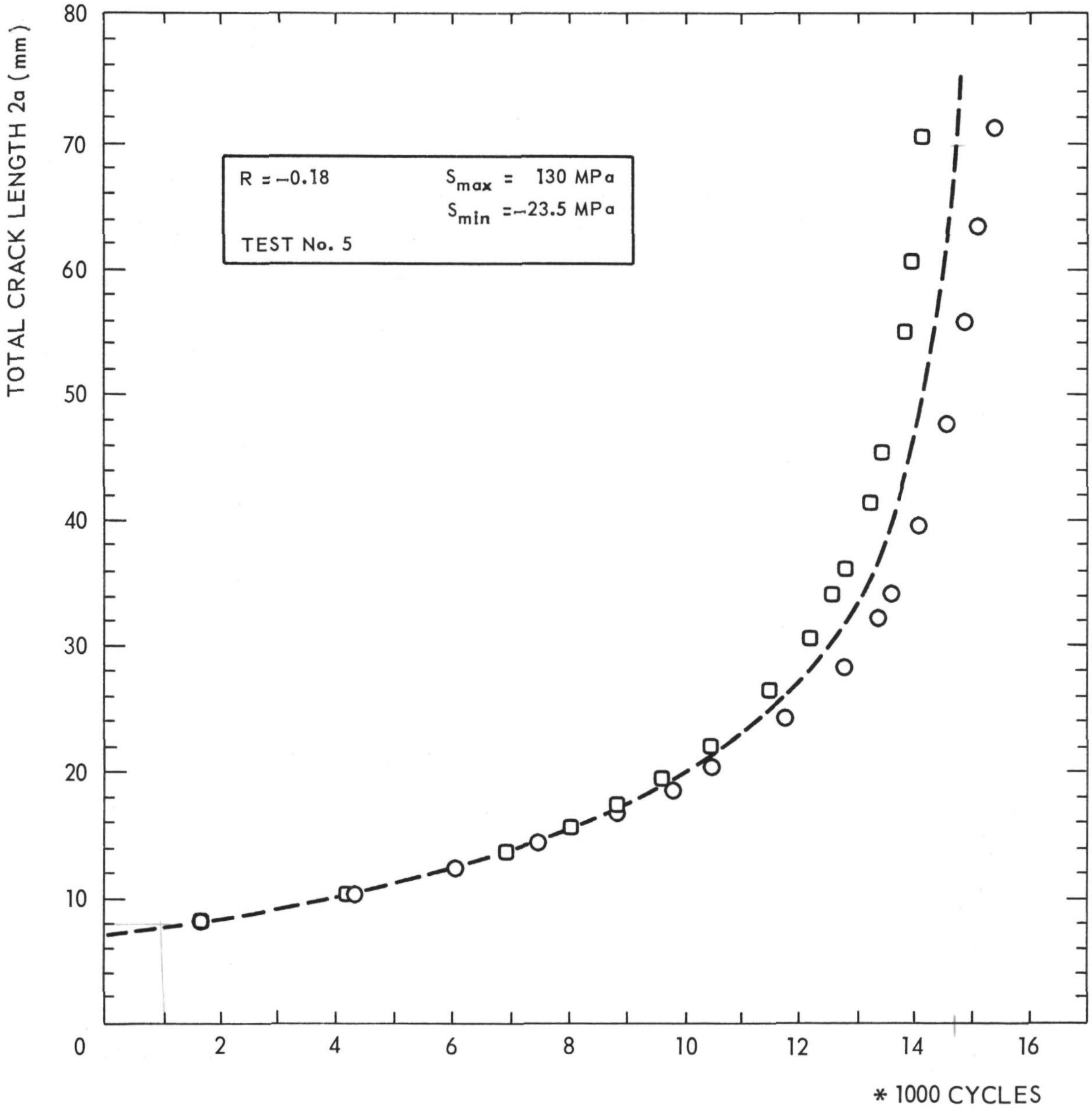


Fig. 10 Constant amplitude crack propagation data

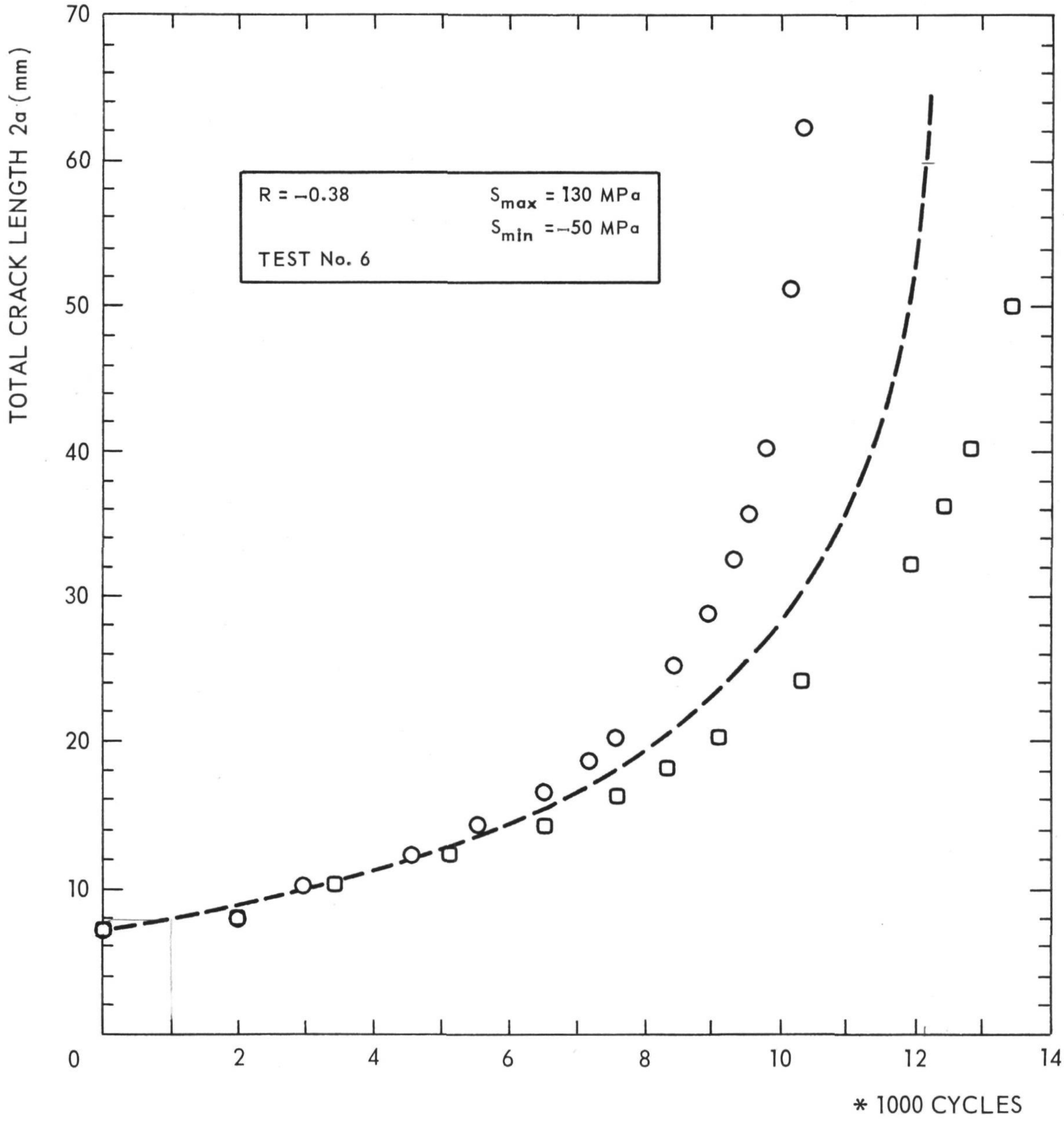


Fig. 11 Constant amplitude crack propagation data

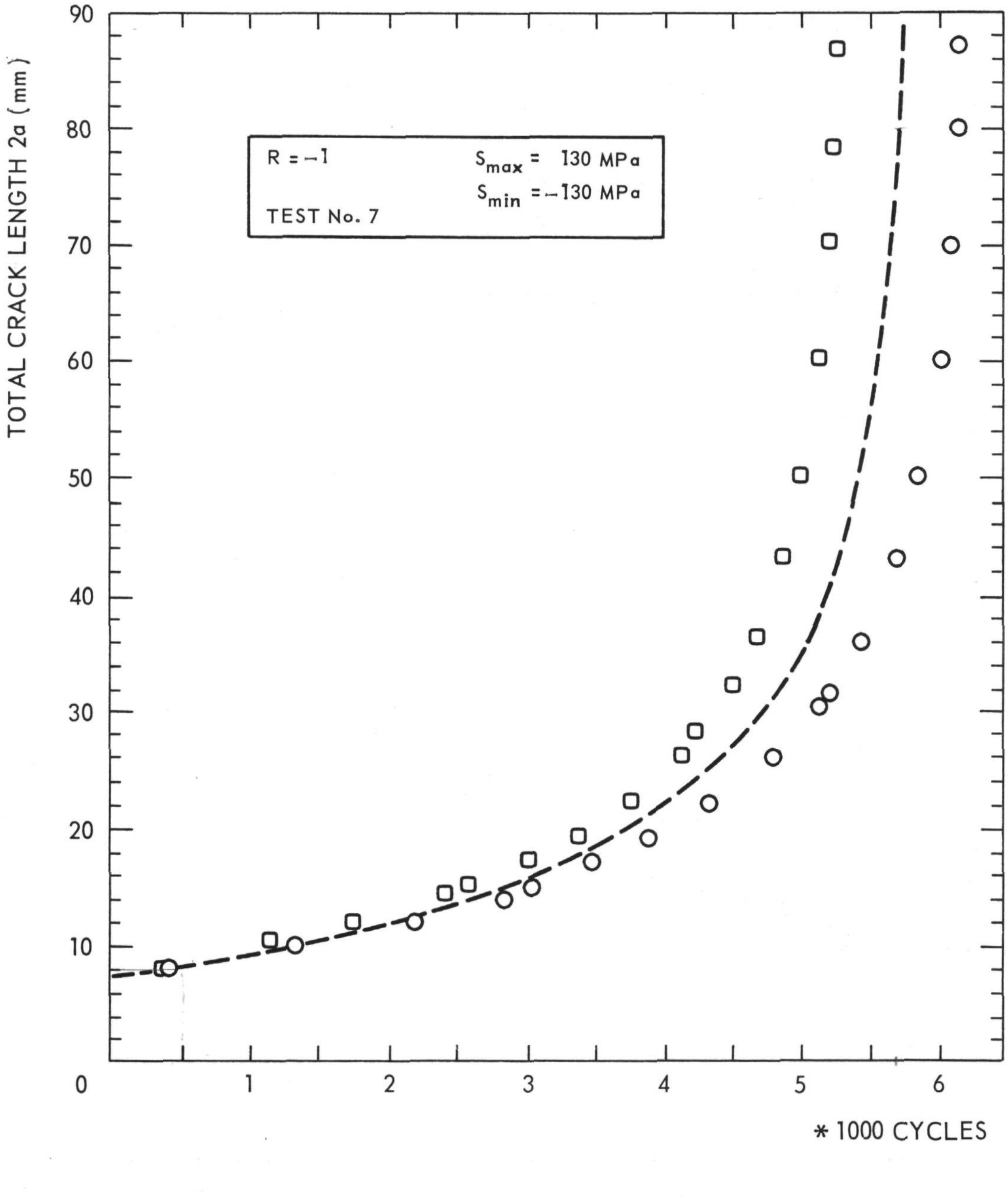


Fig. 12 Constant amplitude crack propagation data

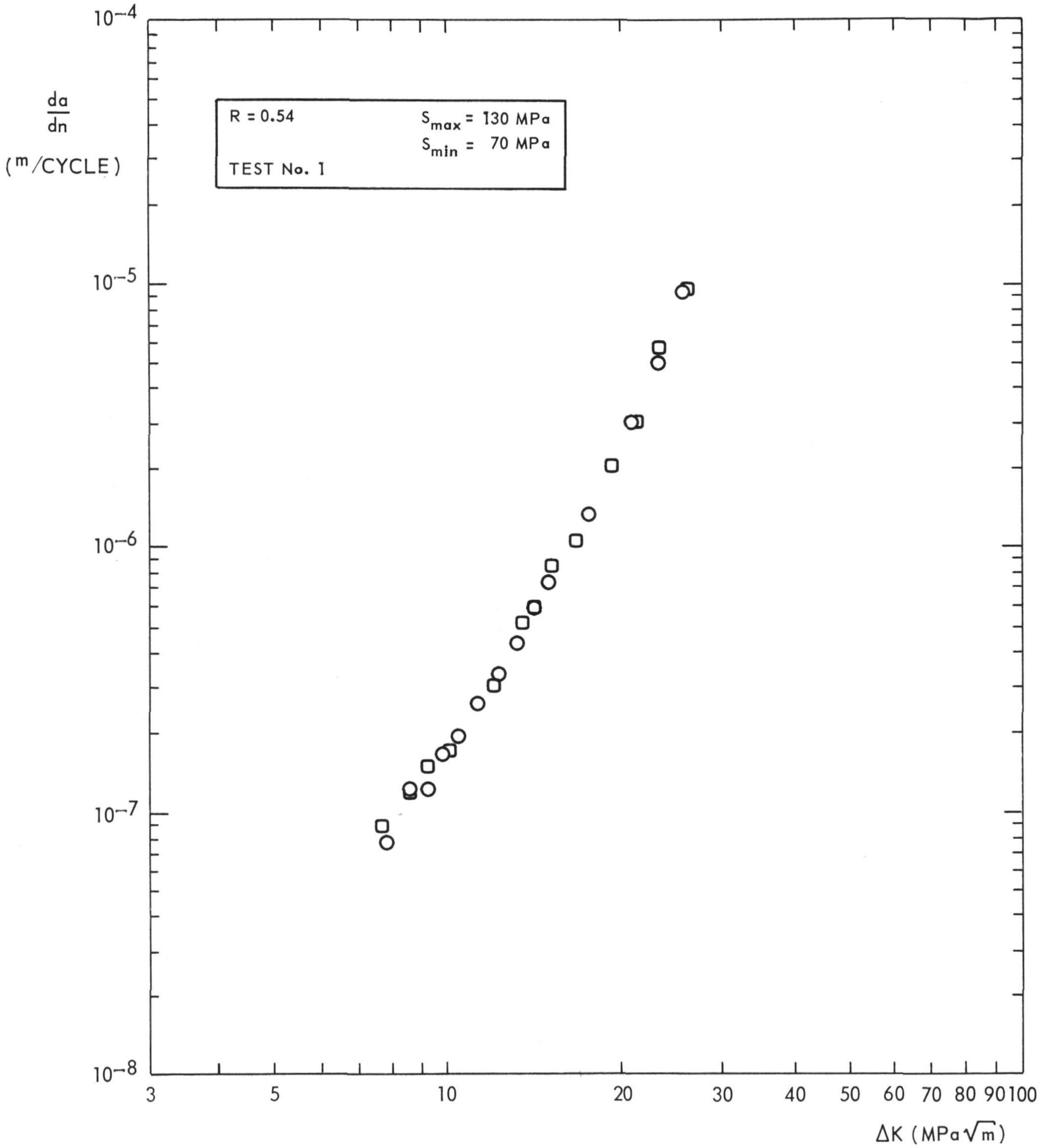


Fig. 13 Constant amplitude crack propagation rates

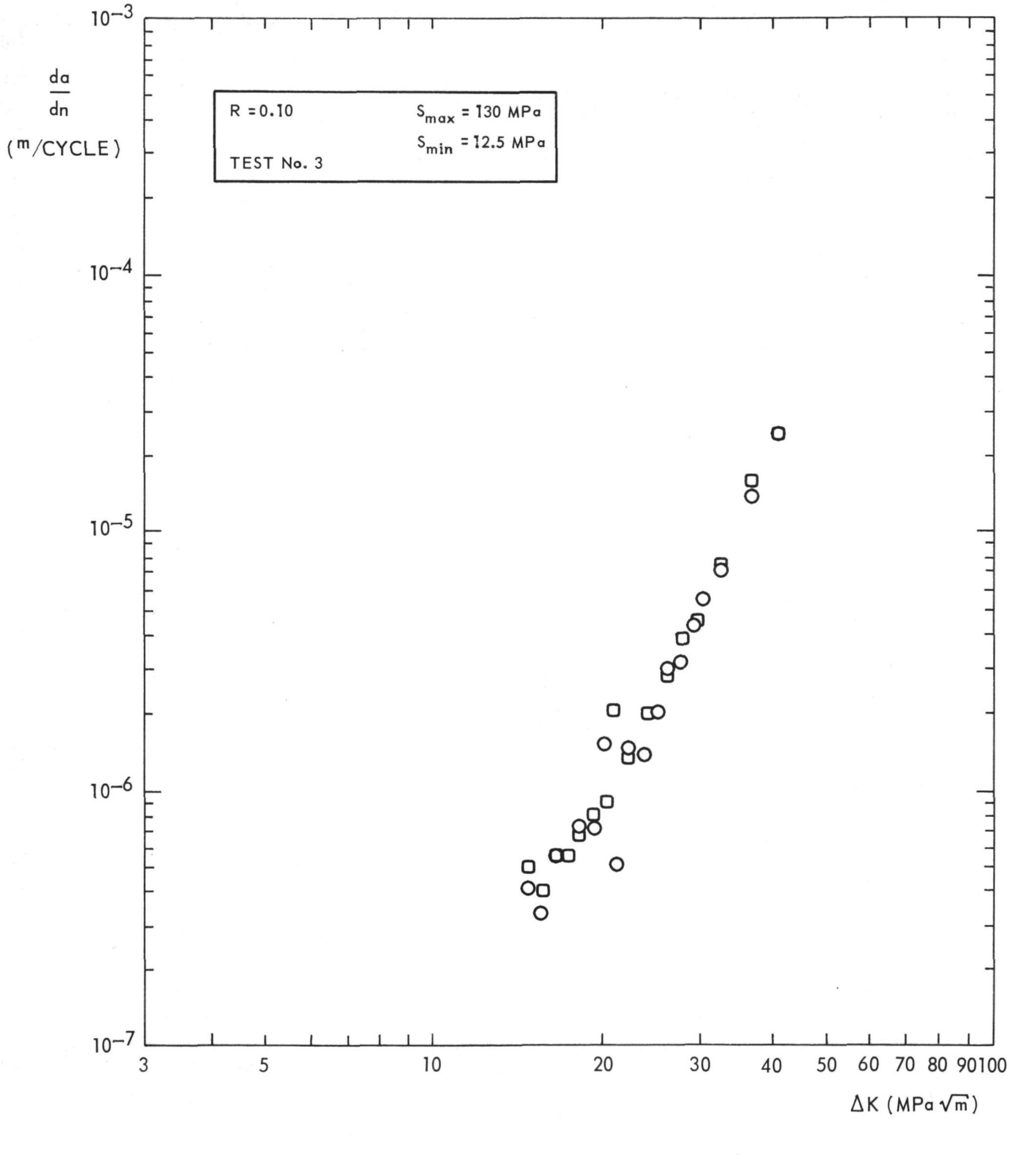


Fig. 14 Constant amplitude crack propagation rates

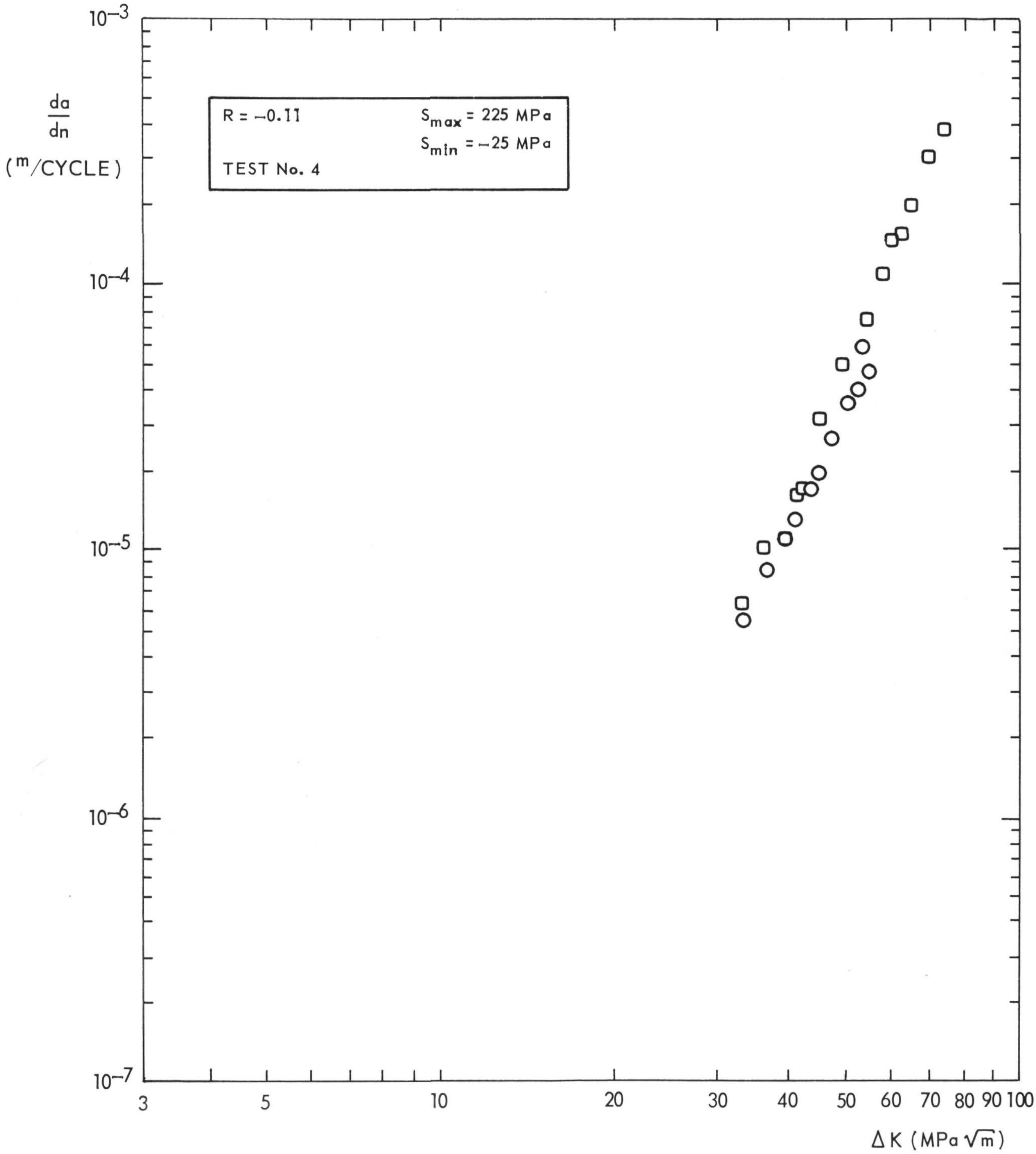


Fig. 15 Constant amplitude crack propagation rates

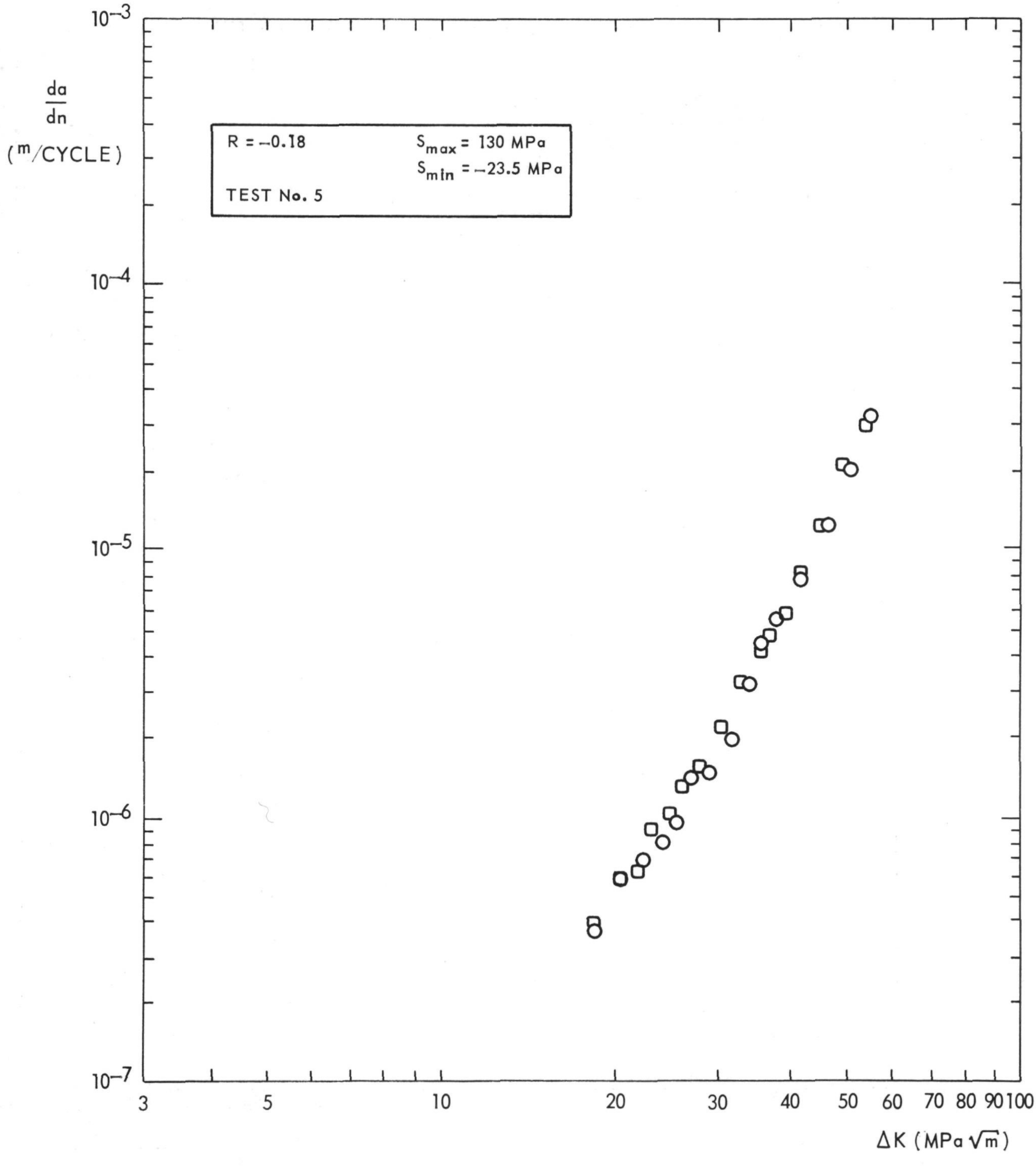


Fig. 16 Constant amplitude crack propagation rates

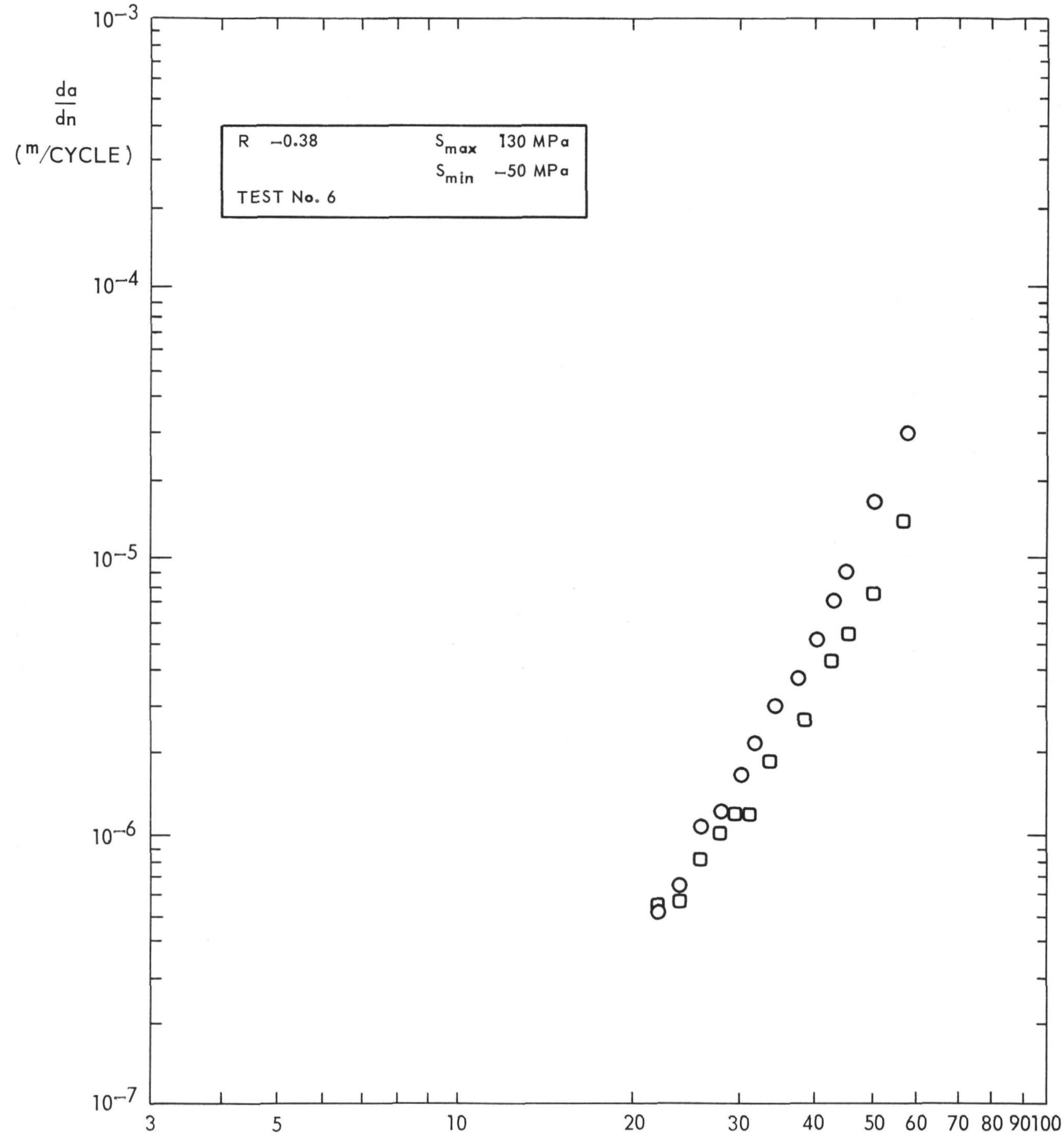


Fig. 17 Constant amplitude crack propagation rates

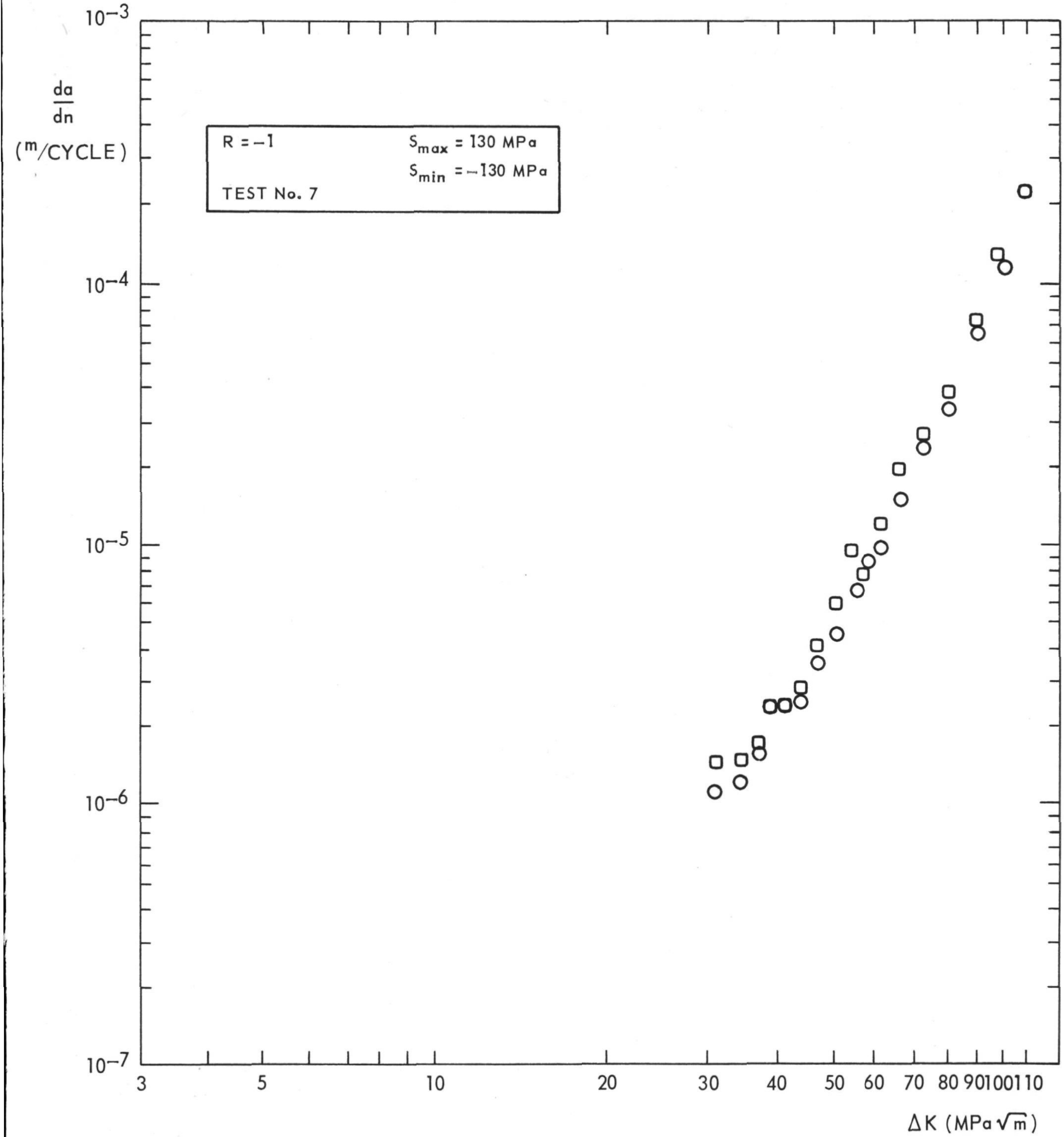


Fig. 18 Constant amplitude crack propagation rates

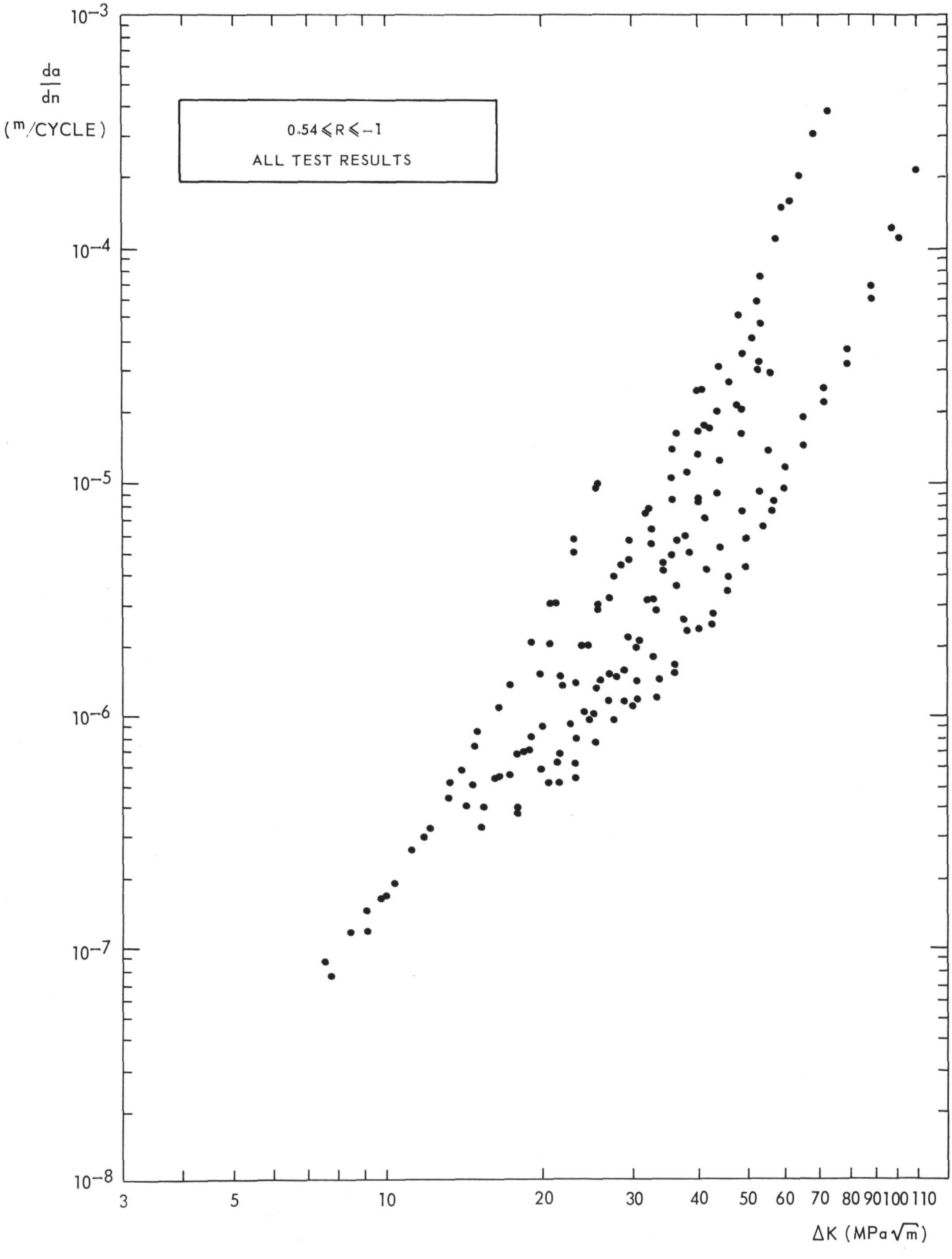


Fig. 19 Constant amplitude crack propagation rates.
All test results

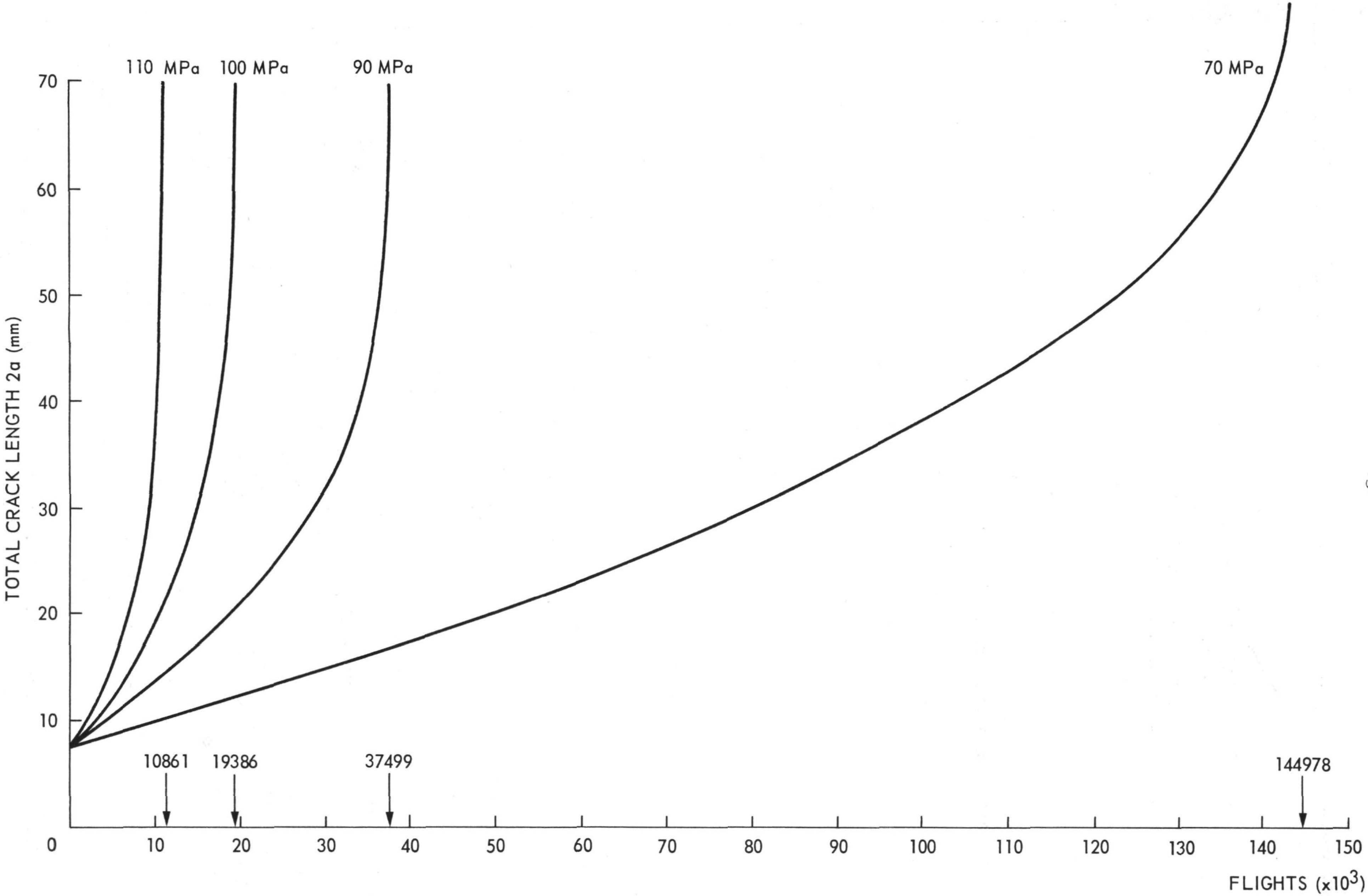


Fig. 20 Average crack propagation curves for different S_{mf} values - F-27 Spectrum

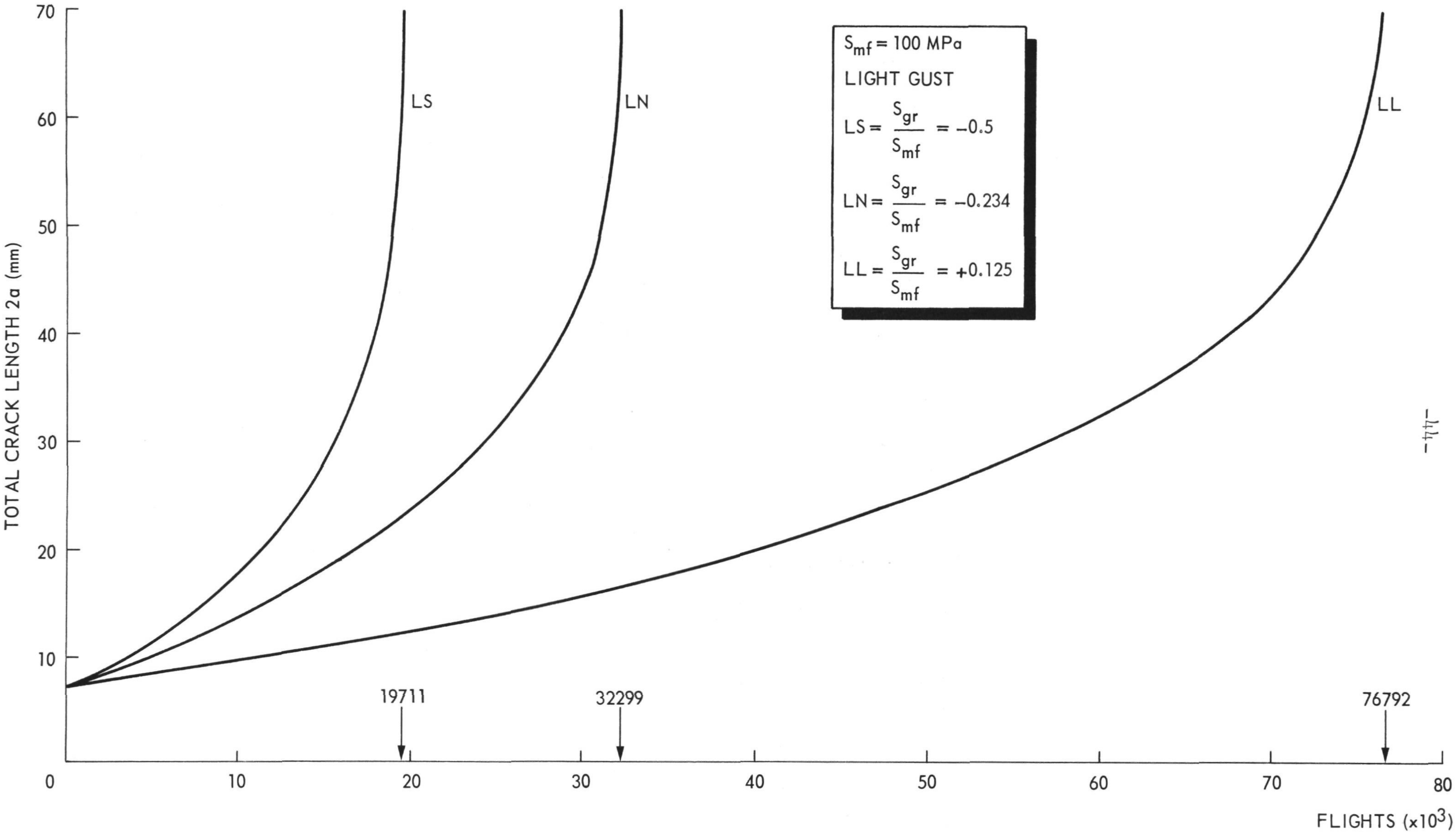


Fig. 21 Average crack propagation curves with light gust spectrum

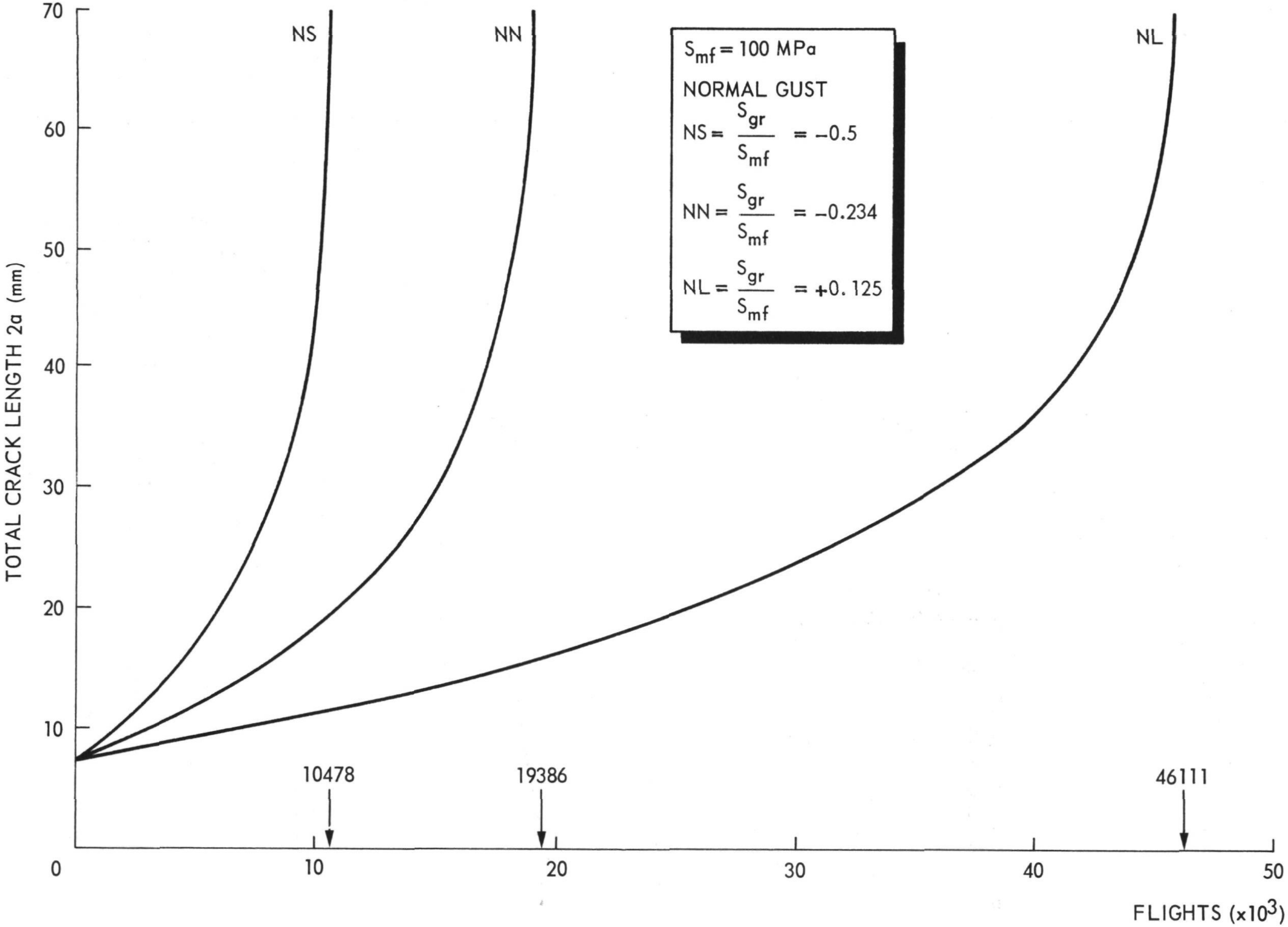


Fig. 22 Average crack propagation curves with normal gust spectrum

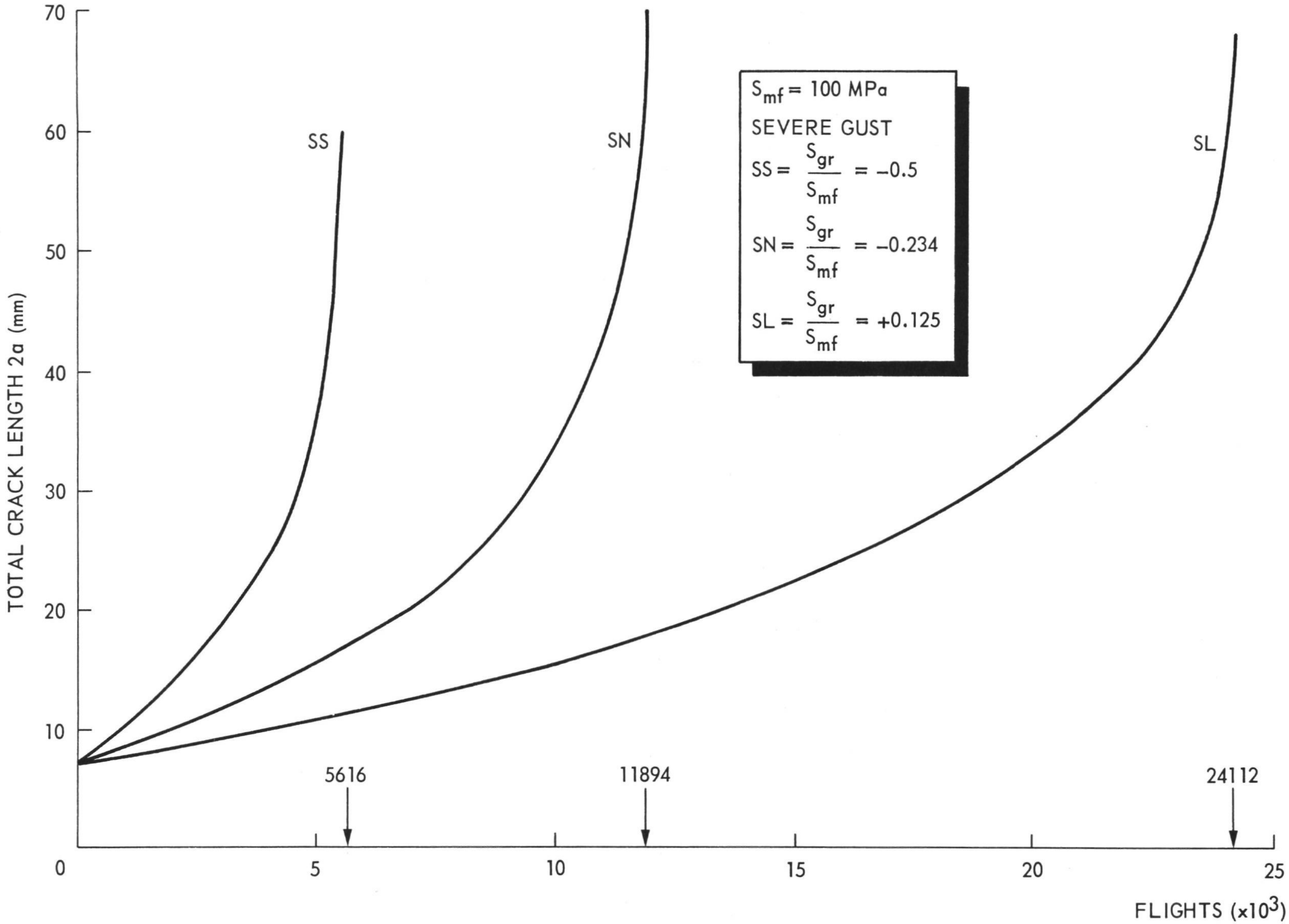


Fig. 23 Average crack propagation curves with severe gust spectrum

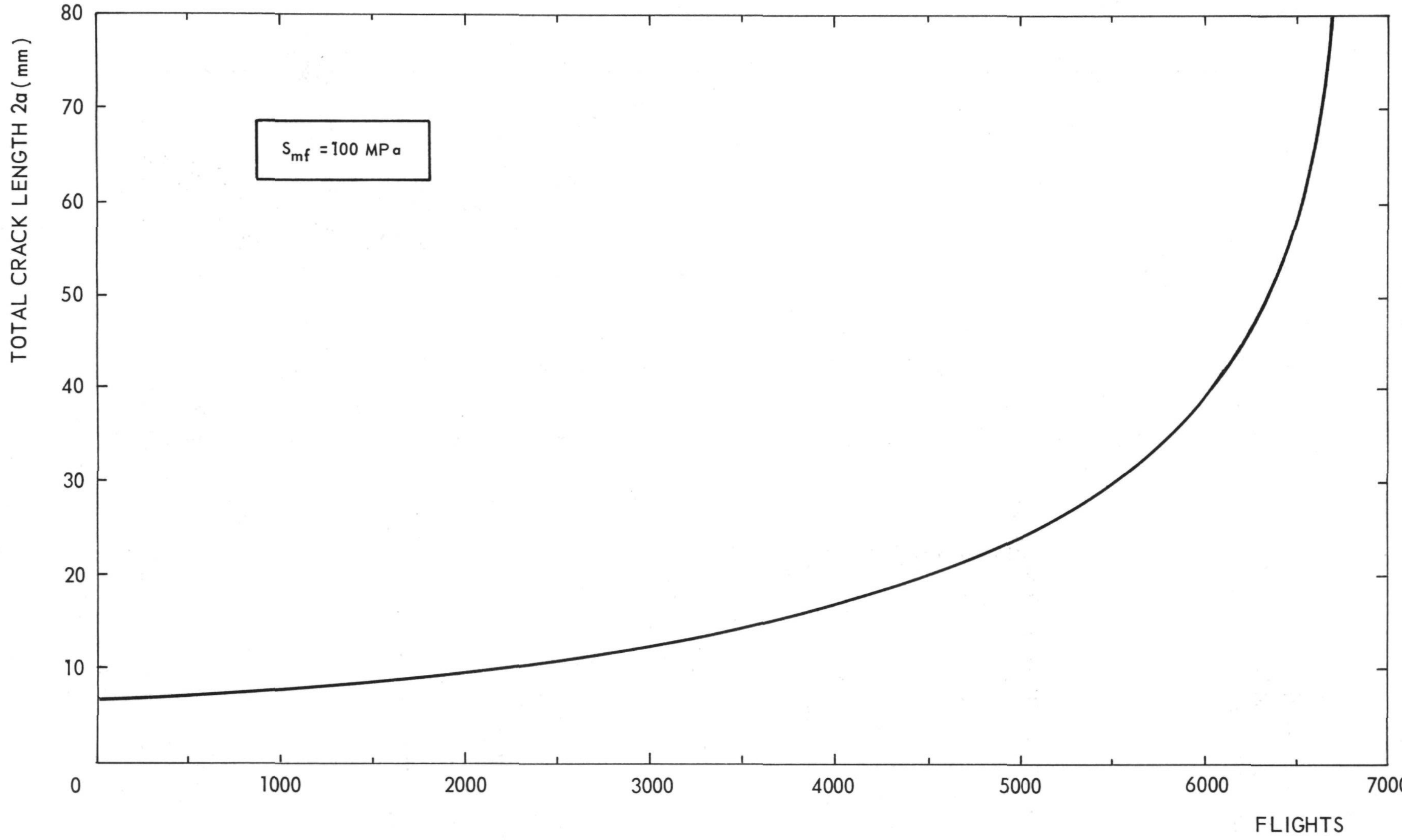


Fig. 24 Average crack propagation curve for F-4 test programme

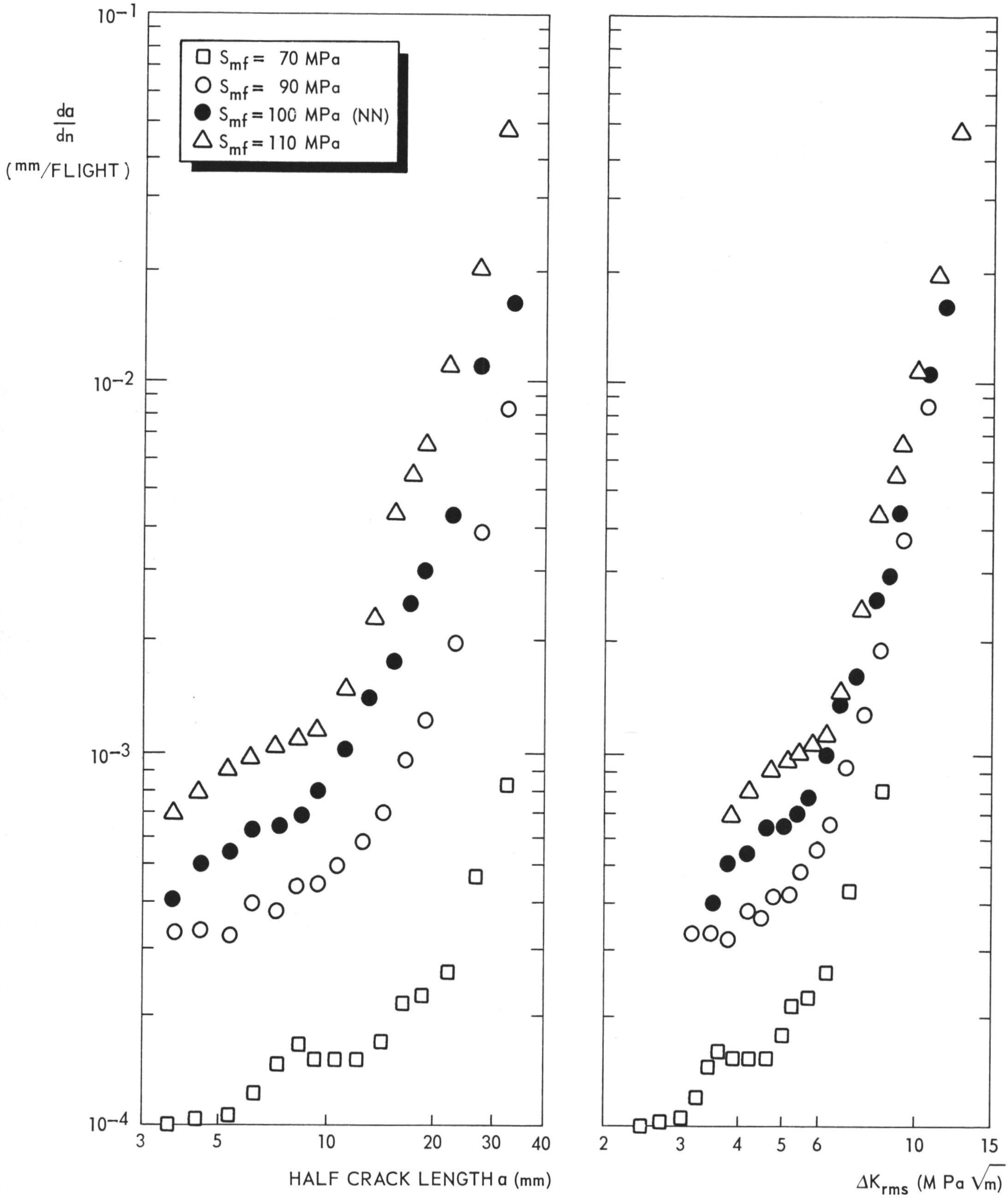


Fig. 25 Crack propagation rates as a function of stress level

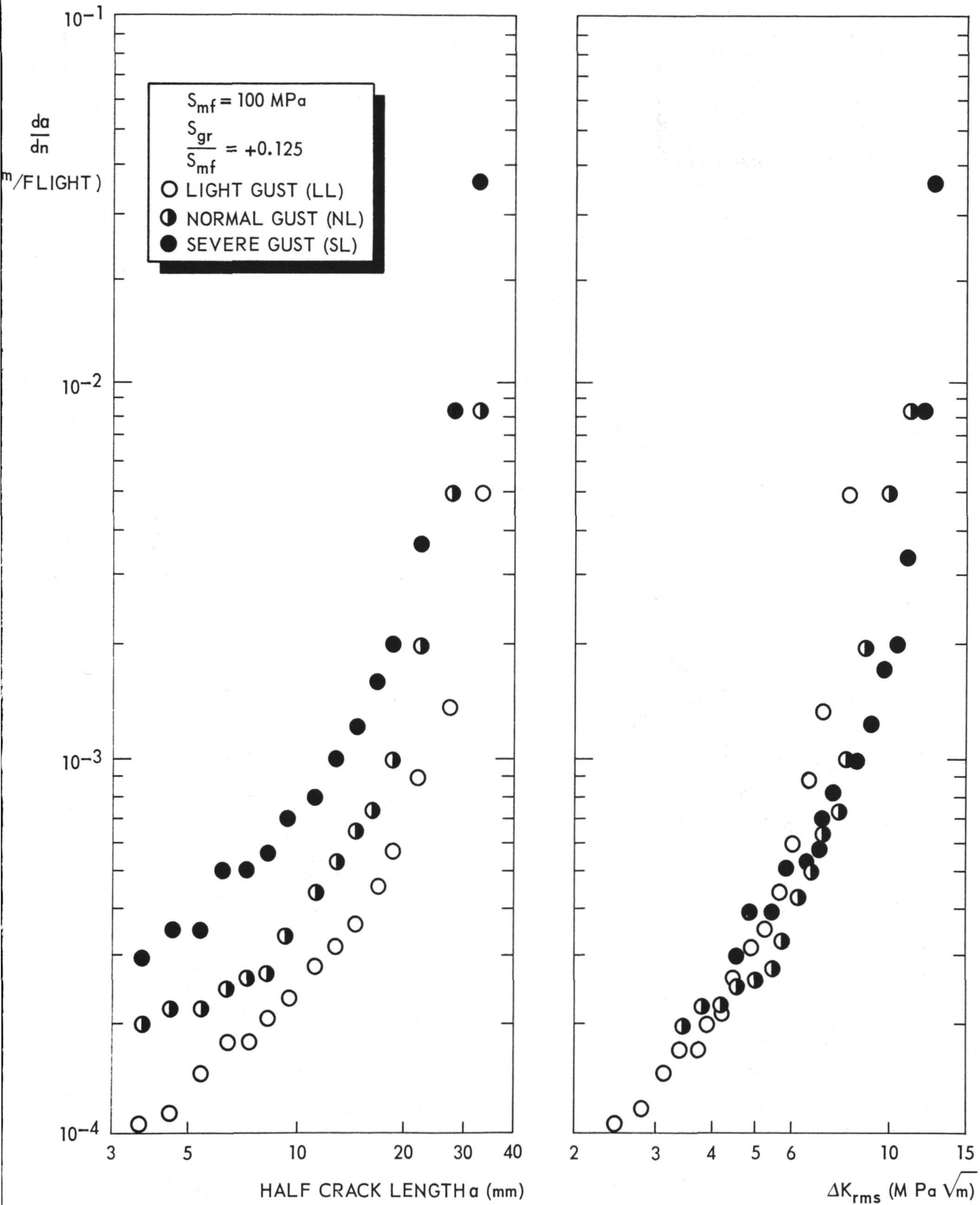


Fig. 26 Crack propagation rates for light, normal and severe gust spectra with light ground load level

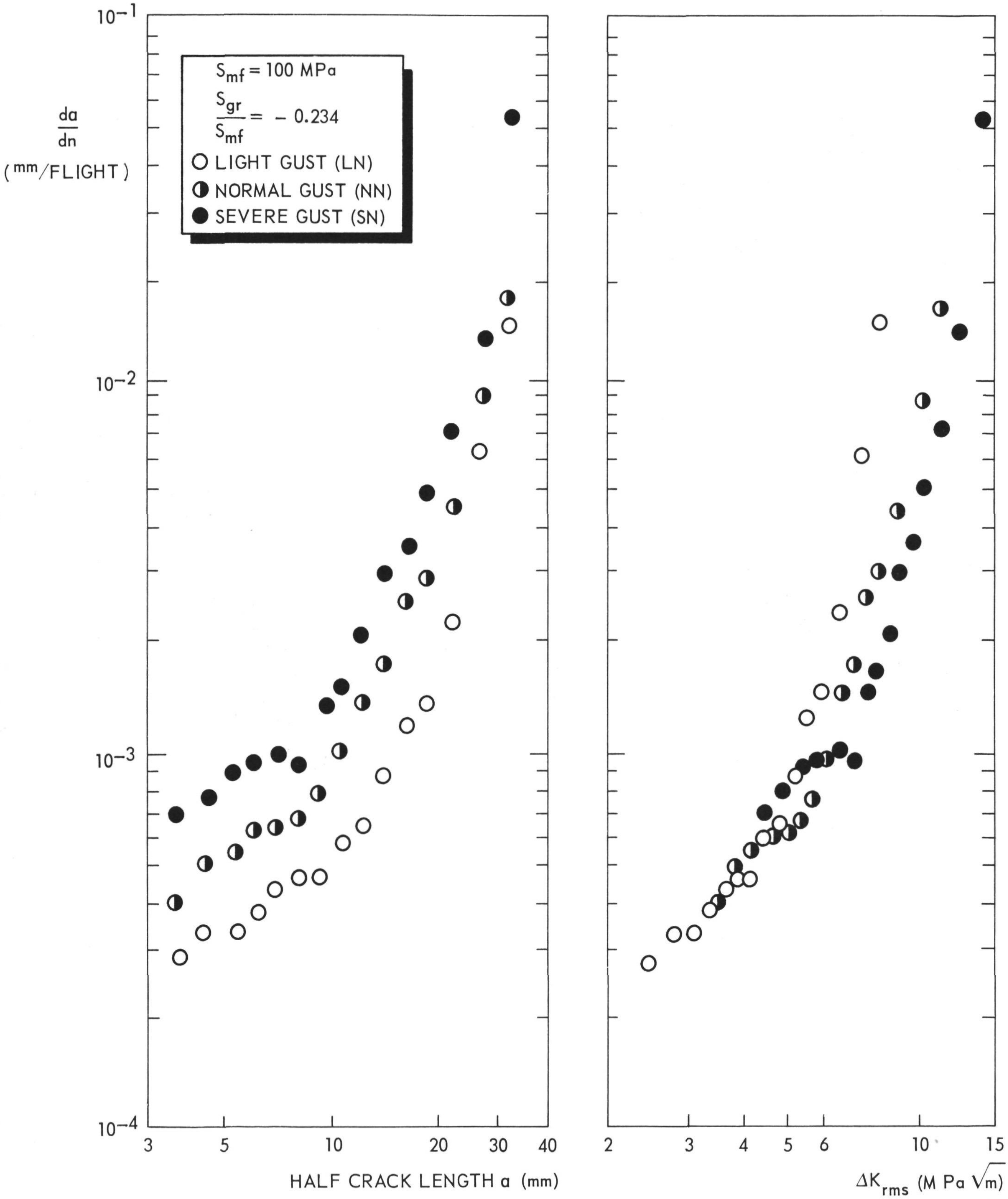


Fig. 27 Crack propagation rates for light, normal and severe gust spectra with normal ground load level

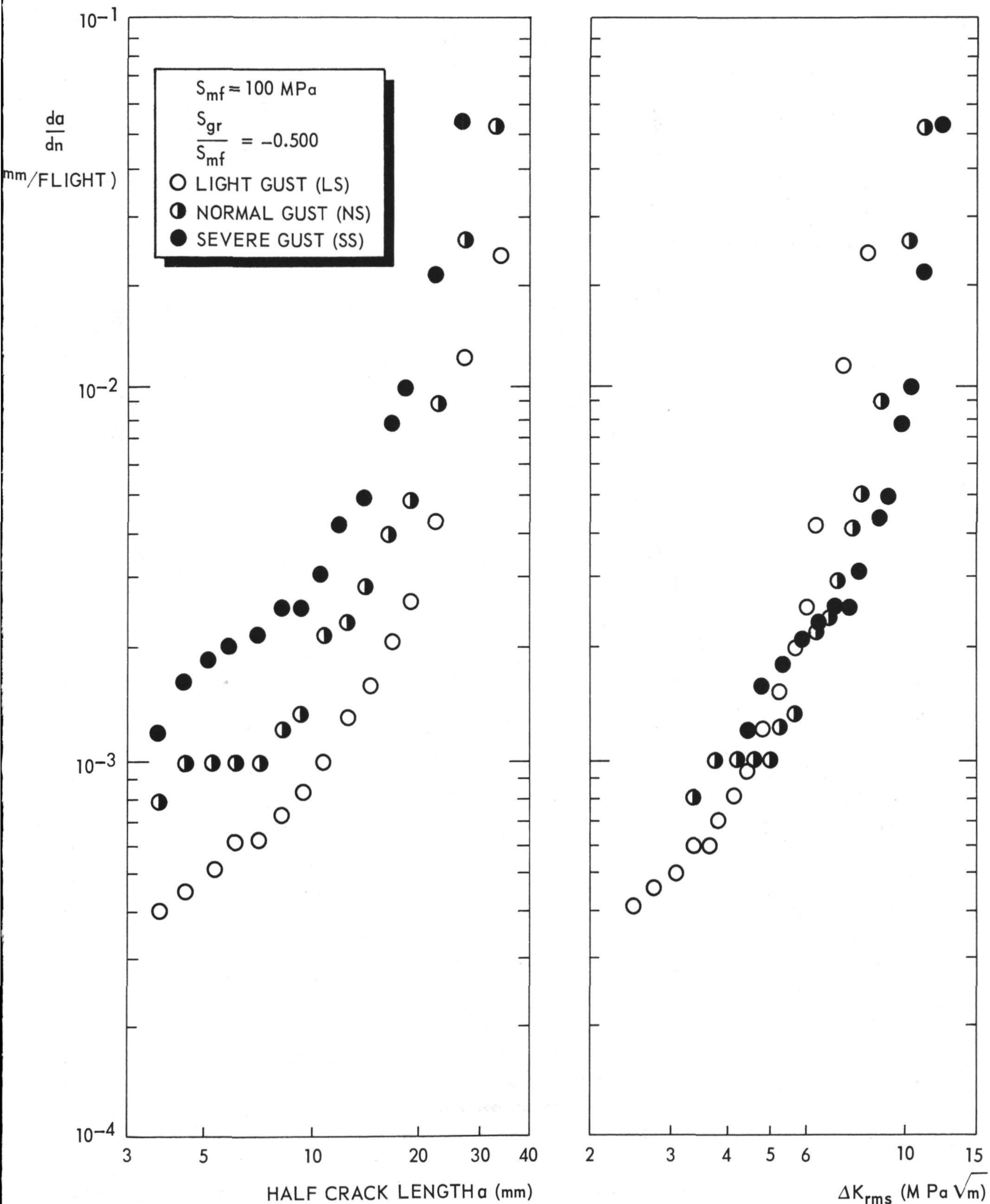


Fig. 28 Crack propagation rates for light, normal and severe gust spectra with severe ground load level

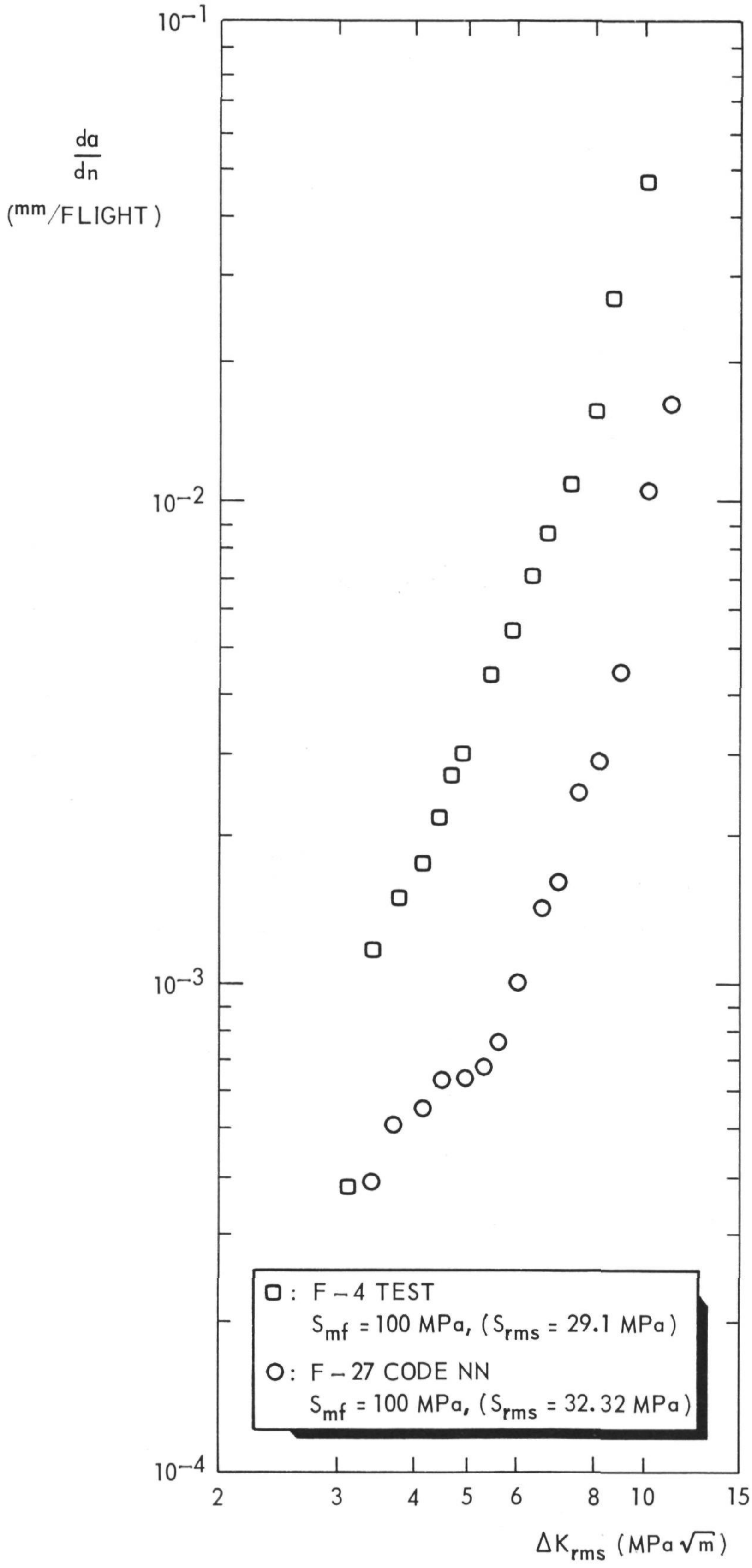


Fig. 29 Crack propagation rates for the F-4 test spectrum compared with the basic F-27 test spectrum

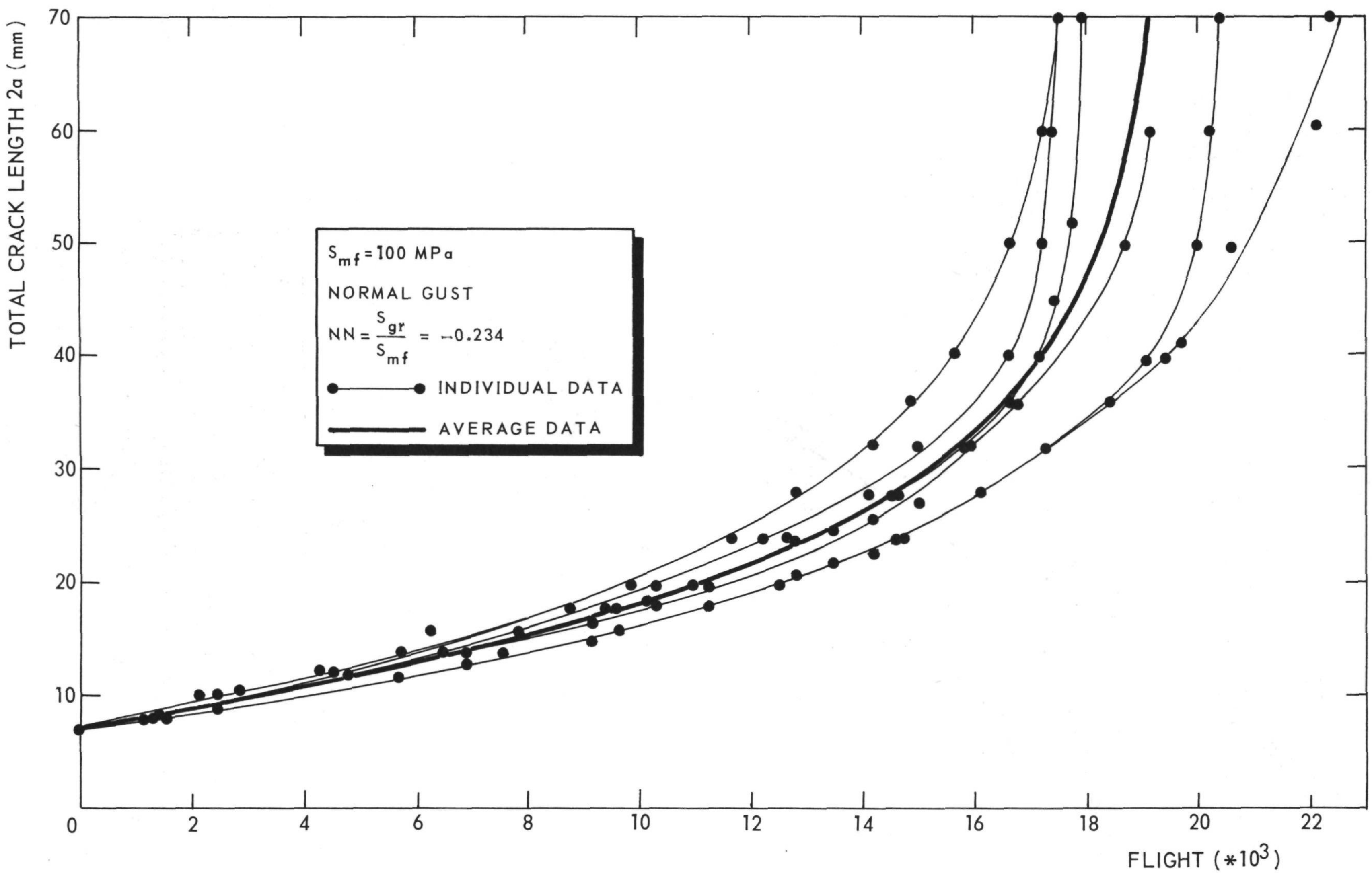


Fig. 30 F-27 spectrum crack propagation data (NN)

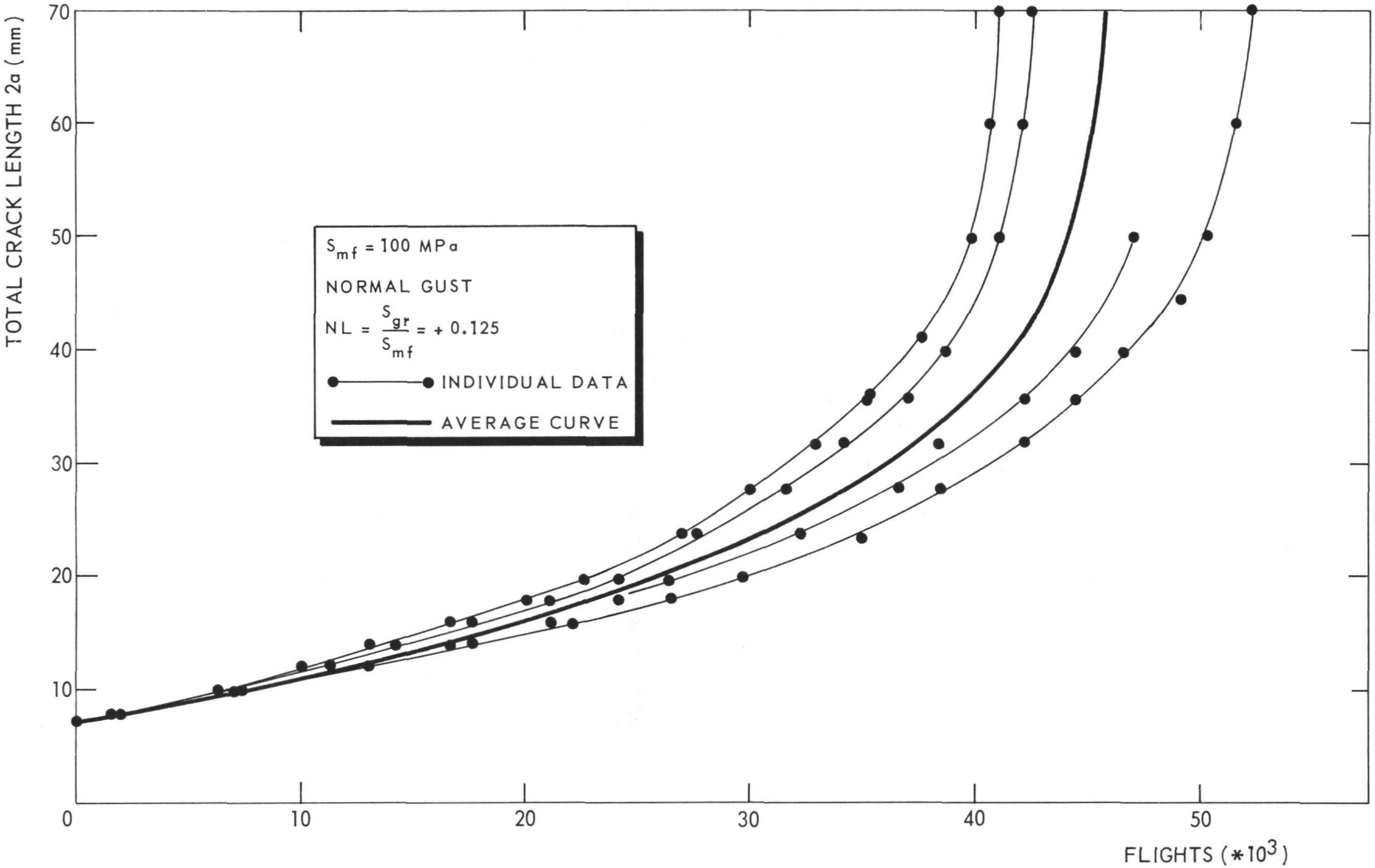


Fig. 31 F-27 spectrum crack propagation data (NL)

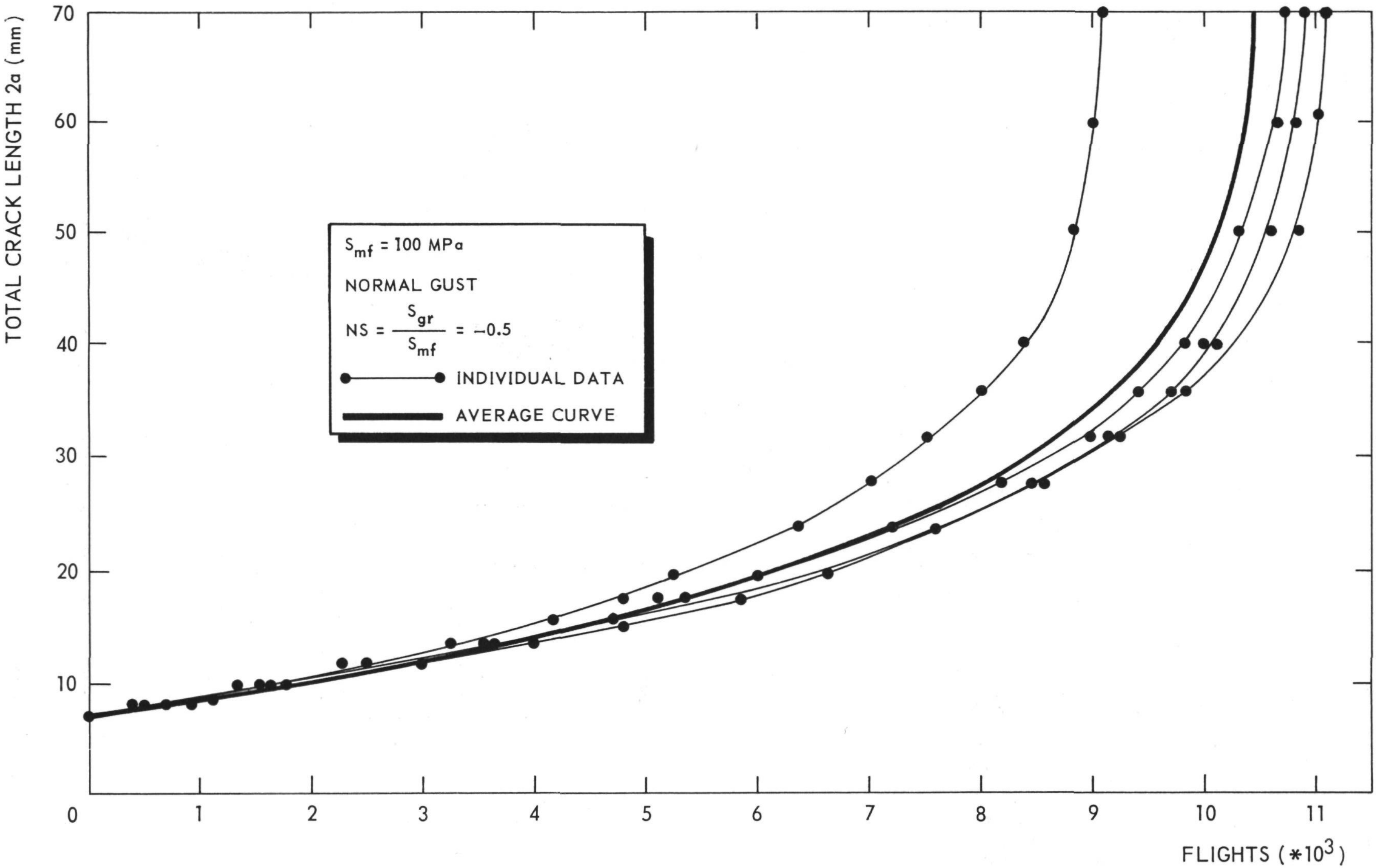


Fig. 32 F-27 spectrum crack propagation data (NS)

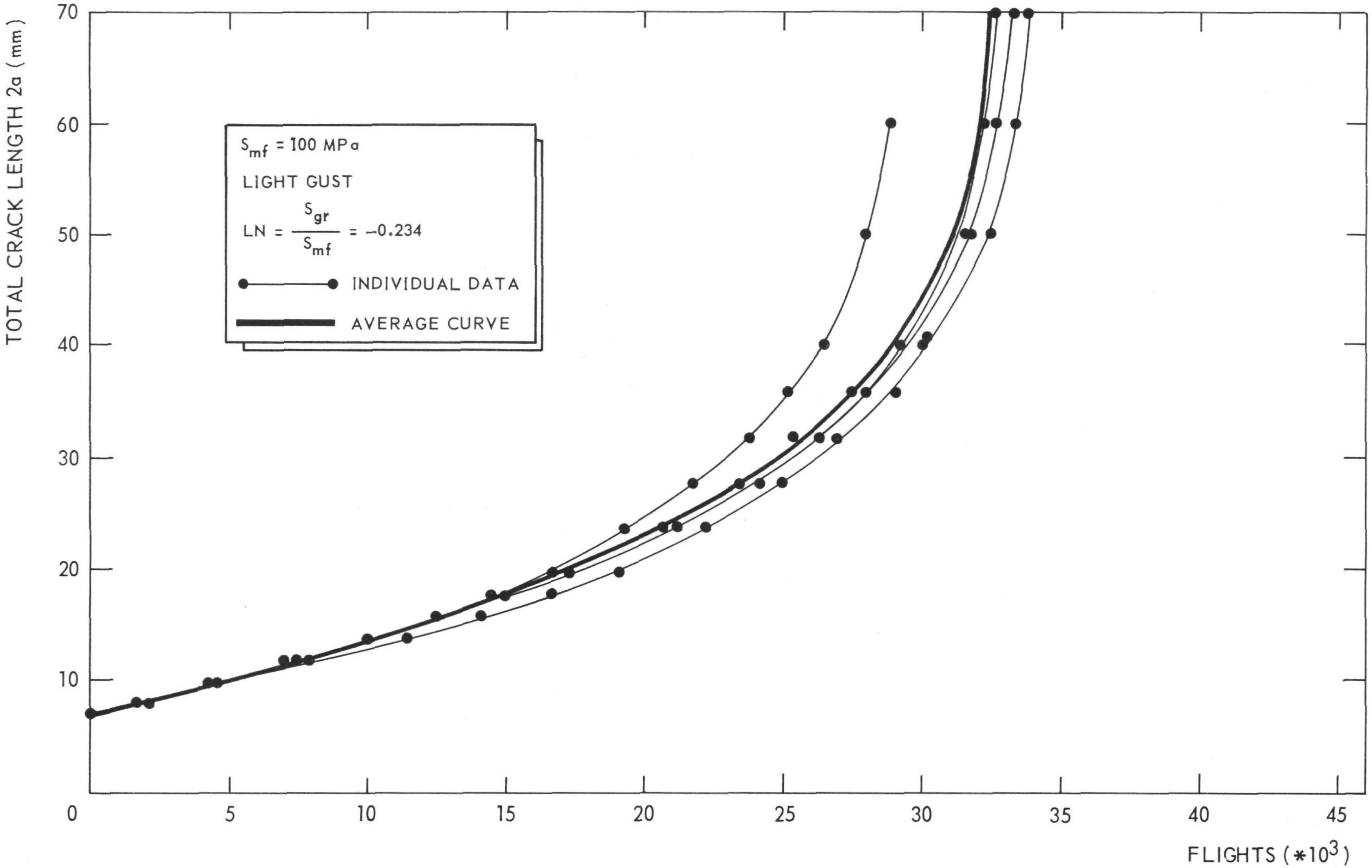


Fig. 33 F-27 spectrum crack propagation data (LN)

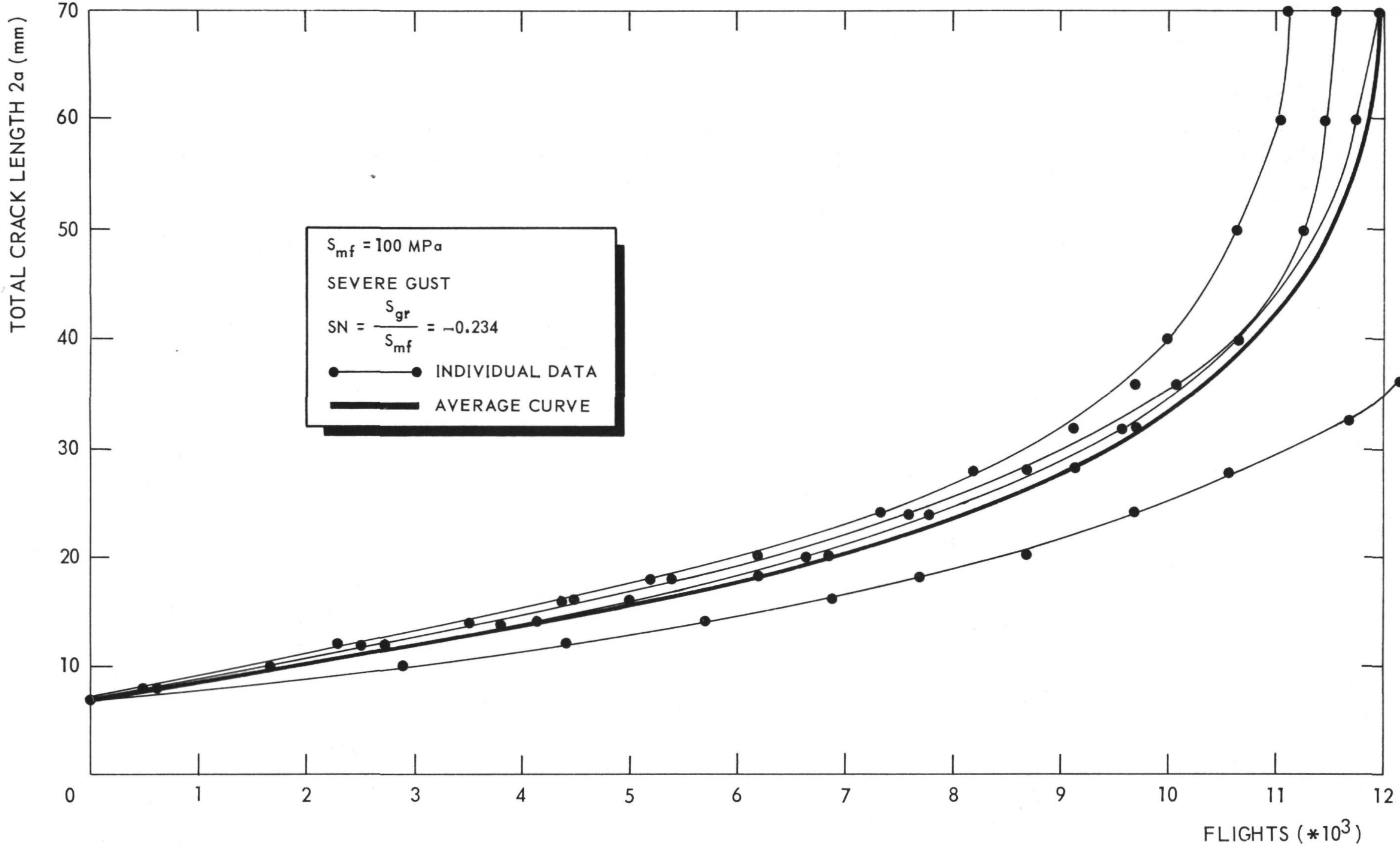


Fig. 34 F-27 spectrum crack propagation data (SN)

```
FLISIM
        ≠BEGIN≠ ≠COMMENT≠
        RANDOM SELECTION OF FLIGHTTYPES AND LOADS.
        IN ACTUAL APPLICATONS 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,E,F,G,H,I,J,L,M,IFL,ILN,ILP,
        SFL,SLN,SLP,RFL,RLN,RLP,SUMFLIGHT,SUMLOAD.,
        ≠INTEGER≠≠ARRAY≠ LOAD(/1..10,1..11/),
        FREQ,AMPLN,AMPLP(/1..10/),IA,IB(/1..2/).,


        ≠INTEGER≠≠PROCEDURE≠ RANDOMN(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/)+1+IA(/N/)≠DIV≠32768.,
          P.=S≠DIV≠65536.,
          T.=3*IA(/N/)+IB(/N/)+P.,
          IA(/N/).=S-P*65536.,
          IB(/N/).=T-(T≠DIV≠65536)*65536.,
          RANDOMN.=IA(/N/)≠DIV≠2.,
        ≠END≠      RANDOMN.,

        ≠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≠)≠,
            3ZD4B,≠(≠TYPE≠)≠,BB≠)≠,INR).,
            OUTCHARACTER(41,≠(≠EDCABFGHIJ≠)≠,IFL).,
            OUTPUT(41,≠(≠4B,≠(≠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≠
  ≠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,≠(≠/≠)≠).,
  OUTPUT(41,≠(≠+ZD3B≠)≠,I).,
  ≠IF≠ J=20 ≠THEN≠ J.=0.,
  FINISH..
≠END≠      PUTLOAD.,

≠COMMENT≠ FLIGHTTYPE AND NUMBER OF FLIGHTS.,
A.= 4.,  FREQ(/A/).=    1.,
B.= 5.,  FREQ(/B/).=    1.,
C.= 3.,  FREQ(/C/).=    3.,
D.= 2.,  FREQ(/D/).=    9.,
E.= 1.,  FREQ(/E/).=   24.,
F.= 6.,  FREQ(/F/).=   60.,
G.= 7.,  FREQ(/G/).=  181.,
H.= 8.,  FREQ(/H/).=  420.,
I.= 9.,  FREQ(/I/).= 1090.,
J.=10.,  FREQ(/J/).= 2211.,


≠COMMENT≠ LOADS.,
≠FOR≠ L.=1 ≠STEP≠ 1 ≠UNTIL≠ 10 ≠DO≠
≠FOR≠ M.=1 ≠STEP≠ 1 ≠UNTIL≠ 11 ≠DO≠
LOAD(/L,M/).=0.,

LOAD(/A,10/).= 900.,
LOAD(/A, 9/).= 391.,
LOAD(/A, 8/).= 112.,
LOAD(/A, 7/).=  64.,
LOAD(/A, 6/).=  18.,
LOAD(/A, 5/).=   8.,
LOAD(/A, 4/).=   4.,
LOAD(/A, 3/).=   1.,
LOAD(/A, 2/).=   1.,
LOAD(/A, 1/).=   1.,

LOAD(/B,10/).= 899.,
LOAD(/B, 9/).= 366.,
LOAD(/B, 8/).=  76.,
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)

```
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.,

LOAD(/D,10/).= 680.,
LOAD(/D, 9/).= 208.,
LOAD(/D, 8/).=  44.,
LOAD(/D, 7/).=  14.,
LOAD(/D, 6/).=   2.,
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.,

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

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.,

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/).,
IA(/1/).=IA(/2/).=19934.,
IB(/1/).=IB(/2/).=47251.,
```

ALGOL programme (continuation)

```
        ≠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 FLIGHTNUMBER.,
        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/).,
        PUTGTAC.,


        ≠COMMENT≠ RANDOM NUMBER FOR NEXT POSITIVE LOAD.,
   L3..
        RLP.=(RANDOMN(2)*SUMLOAD)≠DIV≠32768.,

        ≠COMMENT≠ SELECT POSITIVE LOAD.,
        ILP.=SLP.=0.,
   L4..
        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.,
   L5..
        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.,

        ≠COMMENT≠ READY LOAD.,
        ≠IF≠ SUMFLIGHT ≠GREATER≠ 0 ≠THEN≠ ≠GOTO≠ L1.,

        ≠END≠.,
           ≠EOP≠
           FINIS
```

ALGOL programme (concluded)

```
      PROGRAM FLISIM
C     RANDOM SELECTION OF FLIGHT TYPES AND LOAD LEVELS.
C     IN ACTUAL APPLICATIONS BOTH SUBROUTINES PRGTAC AND PRLOAD SHOULD
C     BE REPLACED BY OTHER ROUTINES FOR OUTPUT OF LOAD CODINGS TO AN
C     INTERMEDIATE DEVICE OR DIRECTLY TO THE FATIQUE TESTING MACHINE.
C     EACH FLIGHT HAS TO START BY A CALL OF PRGTAC FOR GENERATING THE
C     GROUND TO AIR CYCLE, CONSISTING OF A NUMBER OF LOADS IN A FIXED
C     SEQUENCE.
C     THE ROUTINE PRLOAD MUST BE CALLED AFTER THE RANDOM SELECTION OF EACH LOAD.
C     IN THE PRESENT VERSION THESE SUBROUTINES ARE PRODUCING SYMBOLIC OUTPUT
C     FOR TESTING THE PROGRAM.
C
      COMMON IA(2),IB(2),J,SUMFL,IFL
      DIMENSION FLFREQ(10),PLFREQ(10),NLFREQ(10),SUMLD(10),TABL3(10,10)
      INTEGER        A, B, C, D, E, F, G, H,
     1          SUMFL,   RFL, FLFREQ,
     2          SUMPL,   RPL, PLFREQ,
     3          SUMNL,   RNL,
     4          TABL3, SUMLD
C
      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
C
C     STORE LOAD FREQUENCIES OF TABLE 3
      DO 10 L=1,10
      DO 10 M=1,10
      TABL3(L,M)=0
   10 CONTINUE
C
      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
C
      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)

```
C
      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
C
      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
C
      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
C
      TABL3(F,10)= 512
      TABL3(F, 9)= 115
      TABL3(F, 8)=  19
      TABL3(F, 7)=   3
      TABL3(F, 6)=   1
      SUMLD(F)   = 650
C
      TABL3(G,10)= 412
      TABL3(G, 9)=  70
      TABL3(G, 8)=   7
      TABL3(G, 7)=   1
      SUMLD(G)   = 490
C
      TABL3(H,10)= 233
      TABL3(H, 9)=  16
      TABL3(H, 8)=   1
      SUMLD(H)   = 250
C
      TABL3(I,10)=  69
      TABL3(I, 9)=   1
      SUMLD(I)   =  70
C
      TABL3(J,10)=  25
      SUMLD(J)   =  25
C
C     SET STARTING VALUES FOR RANDOM GENERATORS
      IA(1)=19934 $ IA(2)=19934
      IB(1)=47251 $ IB(2)=47251
C
```

FORTRAN programme (continuation)

```
C      NEXT FLIGHT
C
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=SUMLD(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 BITS MAY BE USED
      IP=NR/128
      IQ=NR-IP*128
      IPROD=(IP*NSUM+(IQ*NSUM)/128)/256
      END


      SUBROUTINE SELECT(IFREQ,ISUM,IR,ISEL)
      DIMENSION IFREQ(10)
      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
      ISEL=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
      NR=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=0
    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
  100 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,4HTYPE,2X)
      GOTO(11,12,13,14,15,16,17,18,19,20),IFL
   11 PRINT 21  $ GOTO 300
   21 FORMAT(1H+,26X,1HE)
   12 PRINT 22  $ GOTO 300
   22 FORMAT(1H+,26X,1HD)
   13 PRINT 23  $ GOTO 300
   23 FORMAT(1H+,26X,1HC)
   14 PRINT 24  $ GOTO 300
   24 FORMAT(1H+,26X,1HA)
   15 PRINT 25  $ GOTO 300
   25 FORMAT(1H+,26X,1HB)
   16 PRINT 26  $ GOTO 300
   26 FORMAT(1H+,26X,1HF)
   17 PRINT 27  $ GOTO 300
   27 FORMAT(1H+,26X,1HG)
   18 PRINT 28  $ GOTO 300
   28 FORMAT(1H+,26X,1HH)
   19 PRINT 29  $ GOTO 300
   29 FORMAT(1H+,26X,1HI)
   20 PRINT 30  $ GOTO 300
   30 FORMAT(1H+,26X,1HJ)
  300 PRINT 3,IA(1),IB(1)
    3 FORMAT(1H+,31X,13HRANDOM(A,B) =,I6,2X,I6/)
C     SET POINTER J FOR PRLOAD
      J=0
      END
```

FORTRAN programme (concluded)

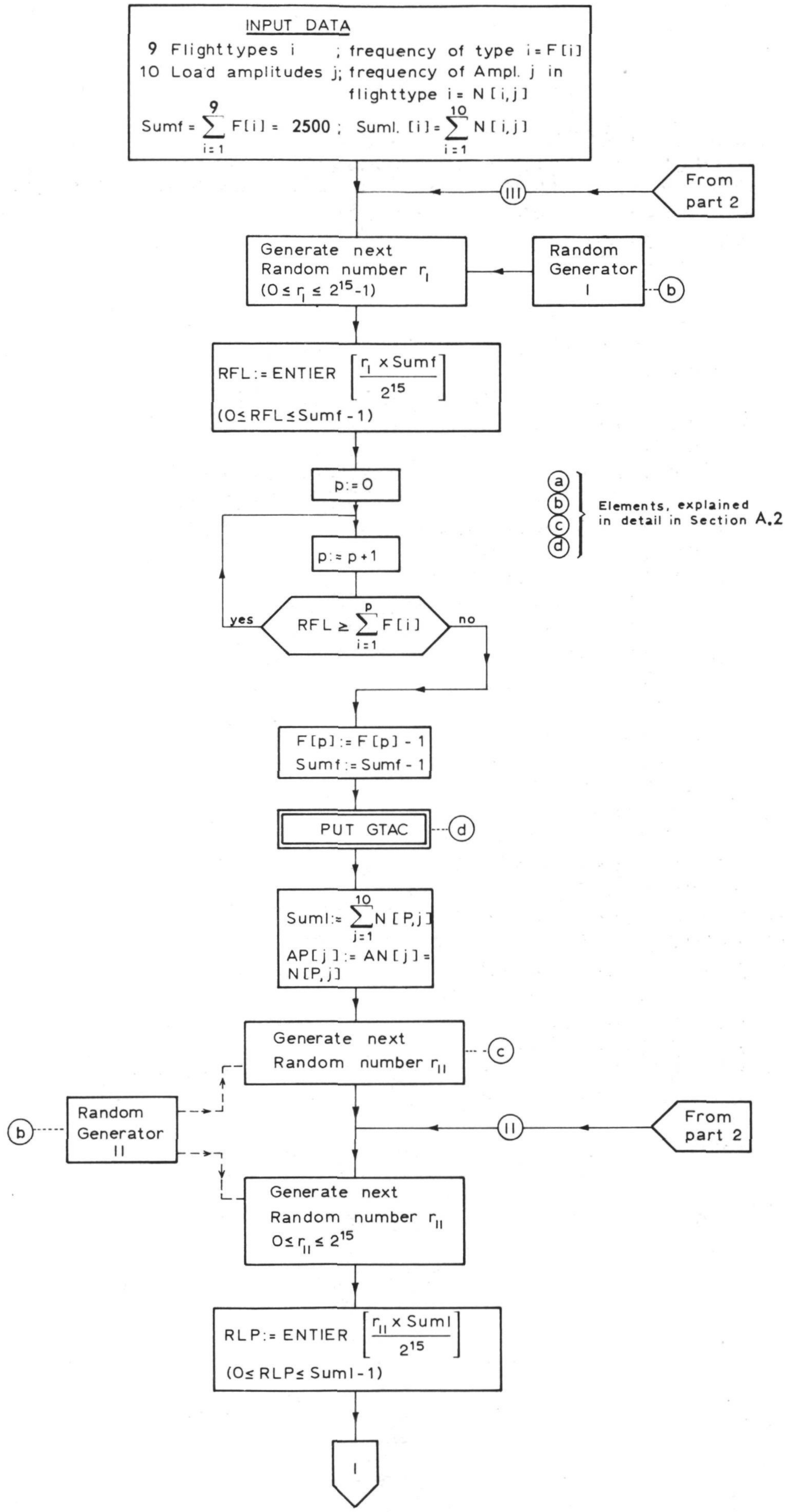


Fig. A1 Flow diagram of computer programme. (part 1)

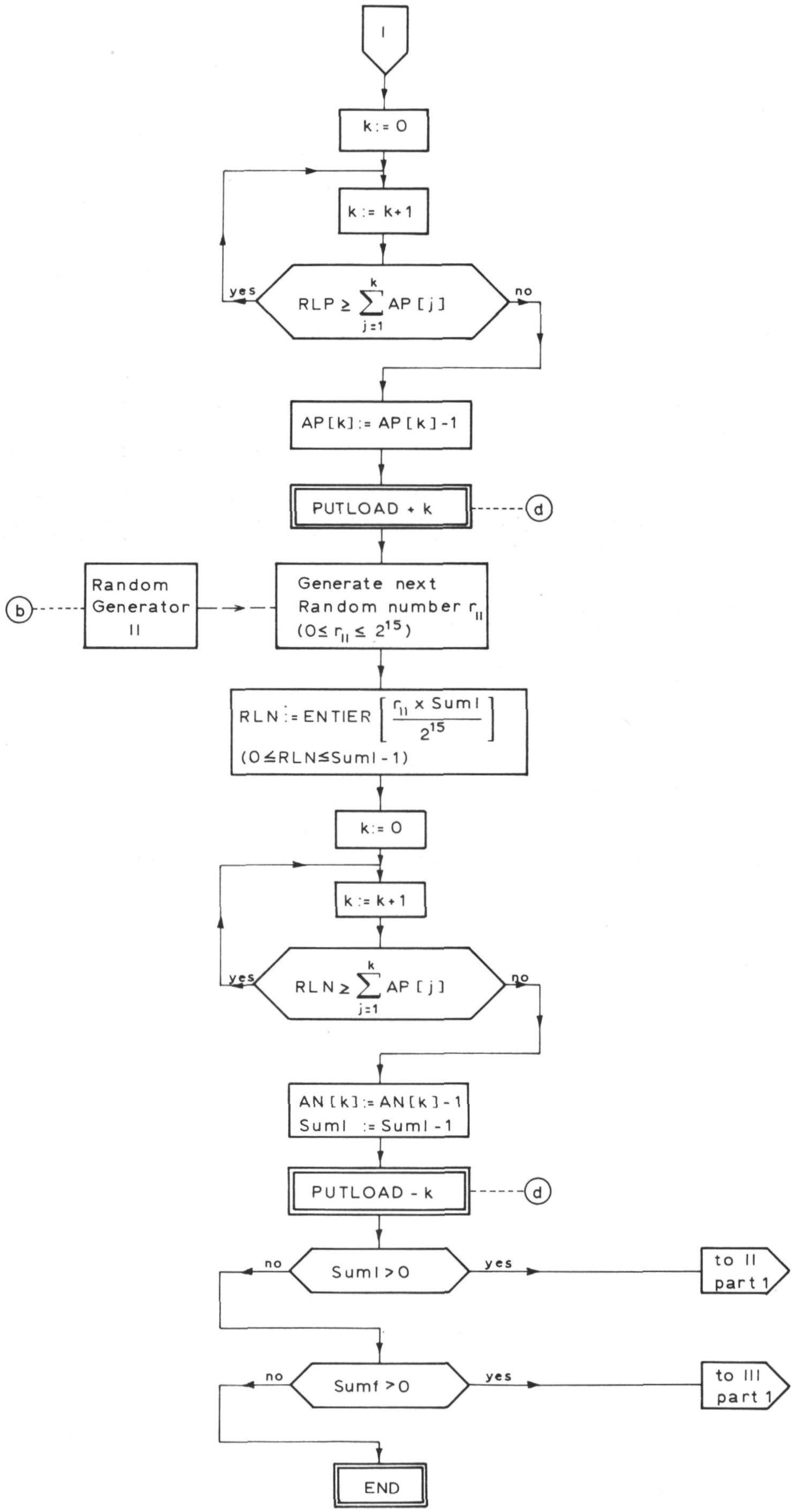


Fig. A2 Continued (part 2)

```
C       ******************************************
COMMENT PROGRAM FAST
C           GENERATION OF F-27 SPECTRUM LOAD SEQUENCE,
C           INCLUDING THE GROUND-AIR-GROUND CYCLE.
C           THE LOAD SEQUENCE IS STORED ON ARRAY BLOK.
C           THE SMALLEST LOAD CYCLE IN THE PROGRAM IS FROM
C           LEVEL 1 TO LEVEL -1..
C            THE LARGEST LOAD  CYCLE IS FROM LEVEL 10 TO LEVEL -10.
C           SPECIFIC OUTPUT STATEMENTS MUST BE DEFINED IN THE PROGRAM

C       ******************************************

        PROGRAM FAST(INPUT,OUTPUT,TAPE10=0)

COMMENT RANDOM SELECTION OF FLIGHTTYPES AND LOADS

        COMMON SLO,NFT,NFIB,NFPR,NCPR,J,K,L,NR,NPLE1,FIELDS(1),
       1BLOK(2500)
        DIMENSION LOAD(50,10),SUM(50),FREQ(50),AMPLN(10),AMPLP(10)
        INTEGER SLO,BLOK,TI,TJ,TK,TM,TN,FN,SFL,SLN,SLP,RFL,RLN,RLP,TL,
       1SUMFL,SUMLO,A1,A2,B1,B2,TS,P,T,SUM,FREQ,AMPLN,AMPLP,FIELDS


COMMENT FLIGHT TYPE AND NUMBER OF FLIGHTS

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


COMMENT LOADS

        READ *,((LOAD(TI,TJ),TJ=1,10),TI=1,NFT)


COMMENT CALCULATE SUMLOADS AND START RANDOM NUMBERS

        SLO=10
        REWIND SLO
        DO 10 TL=1,NFT
            SUM(TL)=0
     10 CONTINUE
        DO 20 TL=1,NFT
            DO 15 TM=1,10
                SUM(TL)=SUM(TL)+LOAD(TL,TM)
     15     CONTINUE
     20 CONTINUE
        A1=A2=19934
        B1=B2=47251


COMMENT RANDOM NUMBER FOR NEXT FLIGHT

        SUMFL=NFIB
        TI=NFIB/NFPR
        IF(TI*NFPR.NE.NFIB) TI=TI+1
```

Modified version of the F-27 FORTRAN programme (to be continued)

```
      FIELDS(1)=TI
      REWIND SLO
      BUFFEROUT(SLO,1)(FIELDS(1),FIELDS(1))
      DUMMY=UNIT(SLO)
      FN=NCPR=0
   25 TS=3*B1+1+A1/32768
      P=TS/65536
      T=3*A1+B1+P
      A1=TS-P*65536
      B1=T-(T/65536)*65536
      RFL=((A1/2)*SUMFL)/32768
COMMENT SHIFT ONE PLACE IN SECOND RANDOM ROW
      TS=3*B2+1+A2/32768
      P=TS/65536
      T=3*A2+B2+P
      A2=TS-P*65536
      B2=T-(T/65536)*65536


COMMENT SELECT FLIGHT NUMBER

      IFL=NFT+1
      SFL=SUMFL
   50 IFL=IFL-1
      SFL=SFL-FREQ(IFL)
      IF(RFL.LT.SFL) GOTO 50
      FREQ(IFL)=FREQ(IFL)-1
      SUMFL=SUMFL-1


COMMENT FETCH THE CORRESPONDING LOADS

      SUMLO=SUM(IFL)
      DO 55 TL=1,10
         AMPLN(TL)=AMPLP(TL)=LOAD(IFL,TL)
   55 CONTINUE
      NCPR=NCPR+1
C     ********************************************
C       THE FOLLOWING STATEMENT DEFINES THE GROUND-AIR-GROUND CYCLE.
C       THE GROUND LEVEL IS LEVEL -11.
C     ********************************************
      BLOK(NCPR)=-11
      FN=FN+1


COMMENT RANDOM NUMBER FOR NEXT POSITIVE LOAD

   60 TS=3*B2+1+A2/32768
      P=TS/65536
      T=3*A2+B2+P
      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
          SLP=SLP-AMPLP(ILP)
          IF(RLP.LT.SLP) GOTO 70
          AMPLP(ILP)=AMPLP(ILP)-1
          NCPR=NCPR+1
          BLOK(NCPR)=ILP


COMMENT RANDOM NUMBER FOR NEXT NEGATIVE LOAD

          TS=3*B2+1+A2/32768
          P=TS/65536
          T=3*A2+B2+P
          A2=TS-P*65536
          B2=T-(T/65536)*65536
          RLN=((A2/2)*SUMLO)/32768


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
          BLOK(NCPR)=-ILN


COMMENT STORE ON SLO

          IF(SUMLO.GT.0) GOTO 60
          IF(FN.LT.NFPR.AND.SUMFL.NE.0) GOTO 90
          FIELDS(1)=NCPR
          BUFFEROUT(SLO,1)(FIELDS(1),FIELDS(1))
          DUMMY=UNIT(SLO)
          FIELDS(1)=FN
          BUFFEROUT(SLO,1)(FIELDS(1),FIELDS(1))
          DUMMY=UNIT(SLO)
          FN=NFIB-SUMFL
          NCPR1=NCPR+1
          DO 85 IK=NCPR1,2500
             BLOK(IK)=0
       85 CONTINUE
C         *********************************************
C           THE LOAD SEQUENCE IS STORED ON ARRAY BLOK.
C           USING THE FOLLOWING TWO STATEMENTS THE TOTAL LOAD
C           SEQUENCE, INCLUDING THE GROUND-AIR-GROUND CYCLE,
C           IS PRINTED.
C           IF NECESSARY AN APPROPRIATE OUTPUT STATEMENTSHOULD BE ADDED
C         *********************************************
          PRINT 1002,(BLOK(I),I=1,2500)
     1002 FORMAT(1H,20(I3,3X))
```

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

```
      BUFFEROUT(SLO,1)(BLOK(1),BLOK(2500))
      DUMMY=UNIT(SLO)
      FN=NCPR=0
      REWIND SLO

COMMENT READY LOAD
   90 IF(SUMFL.GT.0) GOTO 25
      END
```

THE FOLLOWING COMPUTER CARDS ARE REQUIRED AS INPUT:

CARD NO.

1	9	2500	100								
2	11	4	2	1	1	27	70			184	2200
3	23	4	3	0	1	1	0	0		0	0
4	24	6	2	2	1	0	1	0		0	0
5	25	7	3	2	1	1	0	1		0	0
6	28	7	5	3	0	2	0	1		0	1
7	27	7	4	2	2	0	1	0		1	0
8	20	4	2	1	1	0	0	0		0	0
9	18	2	1	1	0	0	0	0		0	0
10	14	1	1	0	0	0	0	0		0	0
11	9	1	0	0	0	0	0	0		0	0

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