C.P. No. 1318

C.P. No. 1318

PROCUREMENT EXECUTIVE, MINISTRY OF DEFENCE

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

The Effect of Load Dwells during Fatigue Crack Propagation

by

F. E. Kiddle

Structures Dept., R.A.E., Farnborough

LONDON: HER MAJESTY'S STATIONERY OFFICE

1975

PRICE *25p* NET

UDC 620.178.311.82 : 539.219.2 : 539.388.1

*CP No.1318
November, 1974

THE EFFECT OF LOAD DWELLS DURING FATIGUE CRACK PROPAGATION

by

F. E. Kiddle

SUMMARY

An investigation has been made into the influence of constant load dwells during fatigue tests on the crack growth rates in thin sheet Al 2% Cu specimens. The fatigue loading used was a simplified flight-by-flight load sequence and in tests including dwell periods, dwells were either at steady tension or at zero load. It is shown that dwells in fatigue loading significantly reduced crack growth rates; dwells at a steady load were possibly more beneficial than dwells at zero load. Possible mechanisms are discussed and further research programmes are outlined which should provide a better understanding of these mechanisms.

---

* Replaces RAE Technical Report 74163 - ARC 35906.

CONTENTS

1 INTRODUCTION

In aircraft service operation, periods of fatigue loading are interspersed with periods during which the loading is sensibly steady or is changing very slowly, e.g. when in steady flight in calm air and when standing on the ground. During these periods of steady load, stresses in different parts of the structure range from compressive to tensile values. In order to keep the duration of a fatigue test under representative loading in the laboratory within a reasonable time-scale, tests are usually shortened by eliminating dwell periods at steady load from the loading sequence. A number of investigations have been made to establisr the significance of dwell periods on fatigue endurance but these have mostly been concerned with low-cycle fatigue of notched specimens at elevated temperatures where overageing and creep occur during dwell periods and have an appreciable effect on endurance. Only a limited amount of evidence is available on the effect of dwell periods during room temperature fatigue, and this is primarily from work on steels containing free ferrite[1-3]. Work on aluminium alloys has been done by Day and Ballett[4] and Redfern[5]. Day and Ballett investigated the effect on the constant amplitude fatigue performance of notched specimens of interspersing zero load dwells at ambient temperature and found that endurance was significantly reduced. Redfern's work was on notched specimens and riveted joints tested under a flight-by-flight load sequence and indicated that in the former case endurance was reduced and in the latter case, endurance was increased by the inclusion of dwells, with and without applied load, in the load sequence. This limited information suggests that in specimens where the life is predominantly spent in initiating a crack (i.e. notched specimens), endurance is reduced by the inclusion of dwells in the loading sequence whereas in specimens where the life is predominantly spent in propagating a crack (i.e. riveted joint specimens) endurance is increased. In an attempt to substantiate this increase in endurance, a research programme has been undertaken which investigates the effect of dwells in fatigue loading on crack propagation rate. The results of this work are presented in this Report and it is shown that dwells both with and without applied load significantly reduced crack propagation rate.

2 MATERIAL AND SPECIMEN

The specimens were extracted from 1.6mm thick sheet of clad Al 2% Cu alloy to specification CM001-1F (clad RR58 material). Details of the chemical composition and tensile strength of this material are given in Table 1. The crack propagation specimens (see Fig.1) contained a central notch to facilitate crack initiation. This notch consisted of a 9.5mm drilled hole and 2.5mm slots, spark eroded each side of the hole. The length to width ratio of the sheet specimen was 3:1 in order to minimise end-loading effects[6].

3 FATIGUE TESTS

All specimens were tested in an electro-hydraulic rig in axial tension using a load sequence which was dictated by the requirements of an investigation of the effects of heat on fatigue[7]. The loading was a simplified flight-by-flight load sequence interrupted at intervals with a dwell at steady load or at zero load. The loading used for tests with no dwell is shown in Fig.2a and represents a possible loading sequence on fuselage structure, composed of pressurisation cycles and superimposed gust load cycles; the sequence shown was repeated until the crack had grown to a total length of 100 mm, i.e. 40% of the specimen width. In tests where dwells were included the same sequence of loads was used but dwells were inserted by holding the appropriate applied load for an extensive period (see Figs.2b and 2c).

Fatigue crack growth was measured using a replica technique[8]. The method was to obtain an impression of the specimen surface on a cellulose acetate sheet for examination by an optical microscope. The impression was obtained by first softening the surface of the acetate sheet with acetone and applying it to the specimen surface under light pressure. After about 3 minutes the surface of the acetate hardened to form a replica of the specimen surface from which the length of the crack could be measured to within 0.05 mm. Replicas were taken of the crack during test at intervals short enough to ensure a minimum of 40 readings; whilst replicas were being taken the test was suspended with the specimen under load.

4 RESULTS AND ANALYSIS

The results for each test in terms of crack length and number of 'load sequences' are presented graphically in Fig.3. Crack growth rates were computed using a programme developed by McCartney and Cooper[9]; this method uses spline functions to fit a curve to the data and hence calculate the growth rate curves. Computed crack rates are presented graphically against crack length in Fig.4.

5 DISCUSSION

From Fig.3 it is seen that the inclusion of dwells in the load sequence significantly reduced crack growth rates. The magnitude of these reductions is better appreciated if lives to 100mm crack are expressed as a ratio to the mean life for the tests without dwell, i.e. life ratio in the following table.

Testing condition	Life ratio
no dwell	1.0
dwell with load	1.40
dwell without load	1.34

These figures indicate that dwells are beneficial, slightly more so if load is applied. This result is in line with the work of Redfern[5]. Turning to Fig.4, it is seen that the crack growth rate is reduced at most crack lengths, the biggest reductions being in the mid-range of crack lengths.

No evidence has been obtained on the mechanisms of dwell effects but it is worthwhile speculating on phenomena which could induce these effects. The metallurgical state of the material at the tip of the crack undergoes change during fatigue cycling. Some of these metallurgical changes are time dependent, e.g. diffusion, generation of dislocations, dislocation movement, etc. and thus it is probable that changes in the state of the material at the crack tip will differ in fatigue loading with and without dwell periods. Another time dependent phenomenon which occurs is corrosion at the crack tip. It is possible that when dwells are included in the load sequence, sufficient corrosion can take place to affect subsequent crack growth.

Further work is in progress to investigate the effect of load dwell. The influence of dwell periods on the progress of the crack through the material is being deduced by examining the striations on the fracture surface using an optical microscope. Also the effect of the number of dwells included in the fatigue test of notched and riveted joint specimens is being investigated[10] and further information is being obtained on the effect of load level during the dwell period[5,10].

6 CONCLUDING REMARKS

Crack propagation tests have been carried out on clad aluminium alloy sheet under a simple form of flight-by-flight loading to investigate the effect of dwell periods at regular intervals during the test.

It was shown that the inclusion of dwells at steady tension or at zero load significantly reduced the crack propagation rate. The effect of dwells at load was slightly more beneficial than dwells at zero load. Further work is in progress to investigate the general applicability of this result.

Table 1

CHEMICAL COMPOSITION AND TENSILE PROPERTIES OF CM001-1F

Chemical composition

Core material

Element	% by weight	
	Min	Max
Cu	1.8	2.7
Mg	1.2	1.8
Si	0.15	0.25
Fe	0.9	1.4
Mn	-	0.2
Ni	0.8	1.4
Zn	-	0.1
Pb	-	0.05
Sn	-	0.05
Ti	-	0.2
Aluminium	-	Remainder

Cladding

Element	% by weight	
	Min	Max
Zinc	0.8	1.2
Aluminium	-	Remainder

Minimum tensile properties

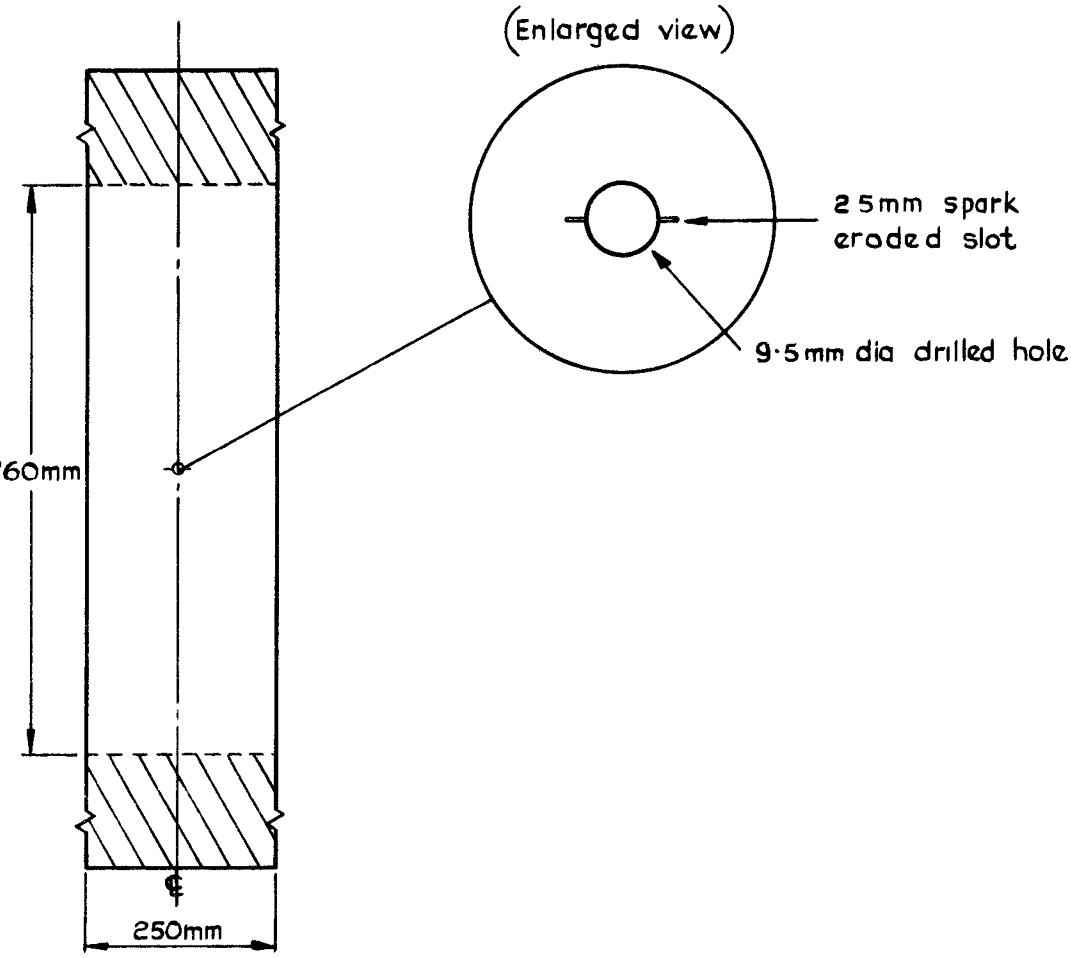
0.2% proof stress = 338 MN/m^2

UTS = 410 MN/m^2

Elongation (on 50mm gauge length) = 7%

REFERENCES

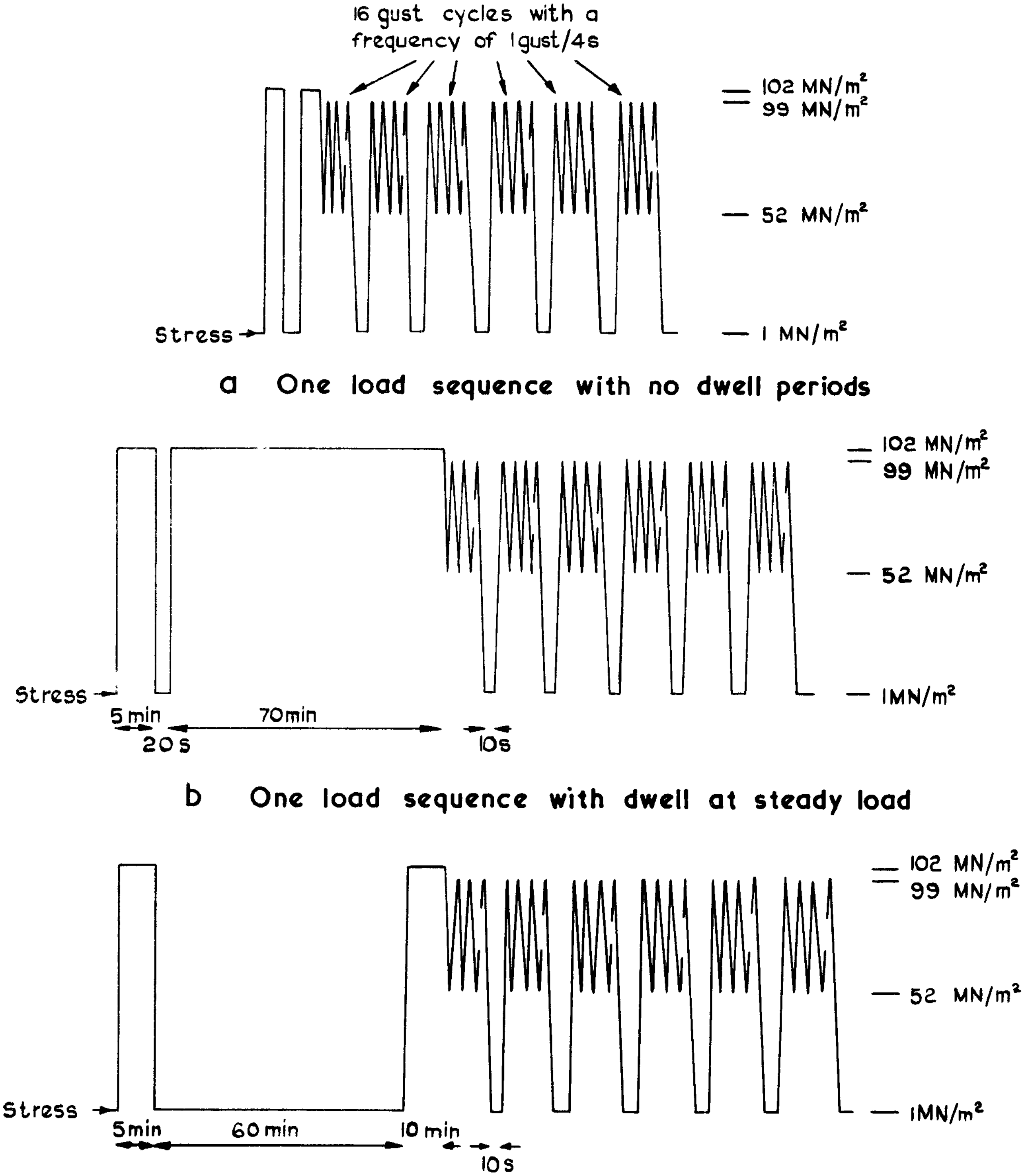
No.	Author	Title, etc.
1	A. Karius	Thesis, Carola Wilhelmina, Technische Universitat, Braunschweig
2	K. Daeves E. Gerold E.H. Schulz	Stahl und Eisen, 60, pp.100-103 (1940)
3	J.G. Whitman	Repeated rest periods in the fatigue of a mild steel bar. M.E.X.E. Technical Note 4/60 (1960)
4	M.F. Day J.T. Ballett	Reduction in notched fatigue life of CM001-1C sheet caused by interspersed periods of heating at 120°C and 150°C - investigation of mechanisms. Unpublished MOD(PE) report
5	A.K. Redfern	Creep testing for Concorde - recent results from the HSA Creep/Fatigue testing machines. HSA Ltd., Manchester. Report No. SM/MISC/220 (1974)
6	T.J. Carter	Crack propagation tests on 2024-T3 unstiffened aluminium alloy panels of various length/width ratios. RAE Technical Report 66366 (1966)
7	F.E. Kiddle	Test schedule for heat-fatigue interaction experiments in thin sheet specimens. RAE Test Note Structures 1772 (1973)
8	A.W. Cardrick R.W. Gardiner	A replica method for recording the surface growth of fatigue microcracks. RAE Technical Report 72210 (1973)
9	L.N. McCartney Mrs. P. Cooper	Computerised processing of fatigue crack propagation data. NPL Report Mat App, 23 (1972)
10	-	Supersonic Transport Co-ordinated Avro Rig Test Schedule. BAC Ltd. (Filton Division) SST/B74S-5/TS/2.4.11.0 Issue 7 (1974)



Sheet thickness = 1·6 mm
Hatched areas covered by end plates

TR74163

Fig. 1 Test specimen



Note. All load sequences are repeated to end of test

Fig. 2 a-c Load sequences

TR 74163

TR 74163

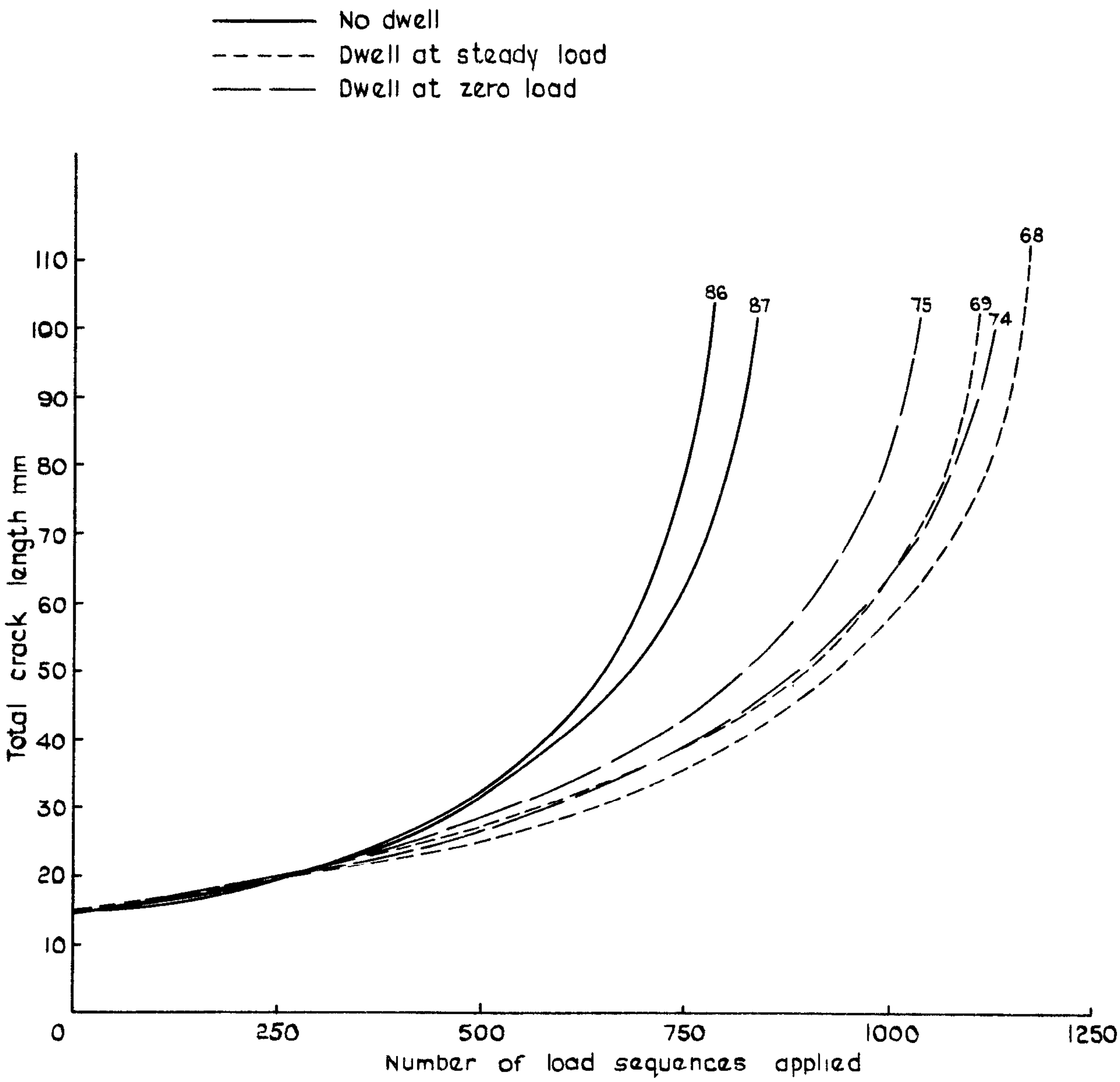


Fig. 3 Effect of dwell periods on crack growth

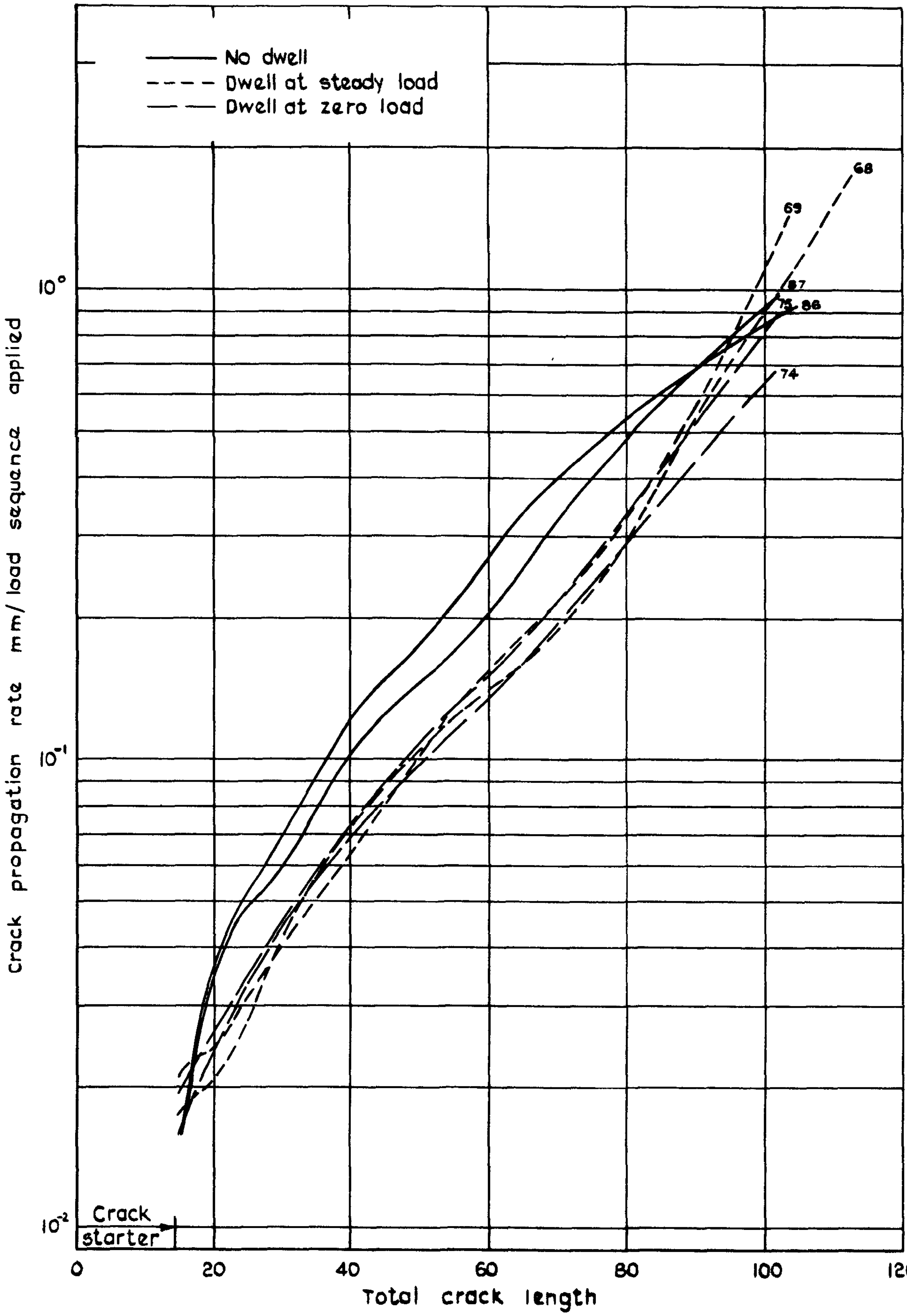


Fig. 4 Effect of dwell periods on crack propagation rate

Produced in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. Dd. 505376 K4 4/75.

1975

Published by
HER MAJESTY'S STATIONERY OFFICE

Government Bookshops
49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government Publications are also available through booksellers

C.P. No. 1318

ISBN 011 470928 9