



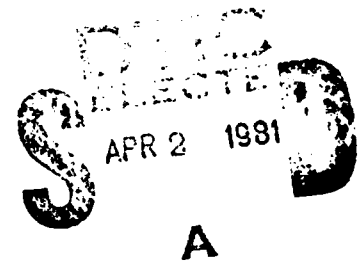
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MELBOURNE, VICTORIA**

STRUCTURES REPORT 381

**FATIGUE LIFE VARIABILITY IN
ALUMINIUM ALLOY AIRCRAFT STRUCTURES**

by

G. S. JOST and S. P. COSTOLLOE



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SUMMARY

A survey of variability in the fatigue lives of aluminium alloy aircraft structures tested under gust and manoeuvre loadings using programmed and random sequences has shown that scatter associated with gust loading is significantly higher than that for manoeuvre loading. By contrast, there appears to be no systematic effect of loading sequence.

The data have been treated both as lognormal and Weibull distributed.

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ABSTRACT

A survey of variability in the fatigue lives of aluminium alloy aircraft structures tested under gust and manoeuvre loadings using programmed and random sequences has shown that scatter associated with gust loading is significantly higher than that for manoeuvre loading. By contrast, there appears to be no systematic effect of loading sequence.

The data have been treated both as lognormal and Weibull distributed.

CONTENTS

	Page No.
NOTATION	
1. INTRODUCTION	1
2. DATA	1
3. ANALYSIS	1
4. CONCLUSIONS	2
REFERENCES	
APPENDIX	
TABLES	
FIGURE	
DISTRIBUTION	

NOTATION

f	function
i	failure number, $1 \leq i \leq n$
k	sample number, $1 \leq k \leq m$
n	number in the sample
m	number of sample
s	sample standard deviation of log life
x	fatigue life
y	$\log x$
α	dispersion parameter of Weibull distribution
β	location parameter of Weibull distribution
Γ	gamma function
ν_k	degrees of freedom of k^{th} sample = $n_k - 1$
Σ	sum
σ	standard deviation of log normal distribution
μ	mean of log normal distribution
$\hat{\sigma}$	pooled sample estimate of σ
$\hat{\alpha}$	pooled sample estimate of α .

1. INTRODUCTION

Since an earlier report on this subject was issued in 1971¹, additional data on fatigue life variability in aircraft structures have been published. In Reference 1 data on scatter arising from full scale fatigue tests on many aluminium alloy aircraft structures were analysed on the basis of the log normal distribution. Data pooling permitted the establishment of typical values for given types of loading and/or sequence. It was considered worthwhile repeating the exercise to include the additional data, and to treat the total body of data also in terms of the two parameter Weibull distribution.

2. DATA

The opportunity has been taken to make some improvements to the earlier report. First, neither the constant amplitude data nor the notched specimen data given there are included here. The relevance of such data to service sequence loading and to real structures, respectively, is now recognised as rather remote, and the present adequate and far more appropriately based data make their use unnecessary.

The variable amplitude data of the original report were classified into symmetric and asymmetric loadings, and those which included ground to air cycles. These categories have been retained but the first two have been retitled gust loading and manoeuvre loading respectively. Loadings in the former category are symmetrical about the 1 g level and are typical of civil or transport aircraft, whilst manoeuvre loadings are characterised by a marked asymmetry typical of, for example, fighter aircraft. All of the additional published data fall into the manoeuvre loading category which now contains over 160 individual test results.

Finally, the source data used for subsequent analysis were not included in the earlier report. That omission is rectified here in Tables 1, 2 and 3 where the details of the data from gust loading, manoeuvre loading and from loadings which included ground to air cycles are given.

It is to be noted that the data considered here have all been generated prior to the general introduction of closed loop servo (or load feedback) fatigue testing equipment with its inherent precision and long term stability. The indications from data obtained on specimens and components under more representative testing and/or more modern testing equipment are that the scatter associated with such tests results does, if anything, tend to decrease. The present scatter estimates may therefore be considered as representing upper variability bounds.

3. ANALYSIS

The data have been fitted to the log normal and Weibull distributions. Defining $y = \log x$, where x represents fatigue life in cycles or hours, the normal distribution of y is given by

$$f(y) = (\sigma\sqrt{2\pi})^{-1} \exp \left[-\frac{1}{2} \left(\frac{y - \mu}{\sigma} \right)^2 \right]$$

where μ and σ^2 are the mean and variance respectively, their estimators from a sample of size n being given by

$$\bar{y} = \sum_{i=1}^n y_i / n$$
$$s^2 = \sum_{i=1}^n (y_i - \bar{y})^2 / (n - 1)$$

For the Weibull distribution

$$f(x) = (\alpha/\beta) (x/\beta)^{\alpha-1} \exp \left[-(x/\beta)^\alpha \right]$$

where α and β are the dispersion and location parameters of x respectively, their maximum likelihood estimators being given by

$$\hat{\alpha} = n \sum_{i=1}^n x_i \hat{\alpha} / \left[n \sum_{i=1}^n x_i \hat{\alpha} \ln x_i - \left(\sum_{i=1}^n \ln x_i \right) / \sum_{i=1}^n x_i \hat{\alpha} \right]$$

and

$$n \hat{\beta}^2 = \sum_{i=1}^n x_i \hat{\alpha}$$

Estimates of μ and σ and of α and β for the data of Tables 1, 2 and 3 are given in Tables 4, 5 and 6. In these latter, program loading data have been separated from random loading data.

The final steps are taken in Table 7 for the lognormal analysis, and in Table 8 for the Weibull analysis where the results of pooling of variabilities of like groups of test data are presented*. The data have been pooled as follows: For the data treated as log normal

$$\hat{\sigma}^2 = \sum_k v_k S_k^2 / \sum_k v_k,$$

and as Weibull (see Appendix)

$$\hat{\alpha} = \frac{\sum_k n_k / \sum_k \left[n_k (\sum_i x_{ik} \hat{\alpha} \ln x_{ik}) / (\sum_i x_{ik} \hat{\alpha}) - \sum_i \ln x_{ik} \right]}{}$$

Considering first the lognormal analysis, Table 7, the additional data confirm the values previously established:

- (1) for gust loading, $\hat{\sigma} = 0.14$
- (2) for manoeuvre loading $\hat{\sigma} = 0.09$
- (3) the ground to air cycle data are too limited to permit generalised conclusions: their inclusion in the earlier categories does not significantly alter the above values, and
- (4) loading sequence (program versus random) has no significant effect upon *variability* in fatigue life.

The corresponding Weibull analysis gives, for estimates of typical dispersion parameters:

- (1) for gust loading $\hat{\alpha} = 3.9$, and
- (2) for manoeuvre loading $\hat{\alpha} = 6.2$.

Rounding these to the nearest whole numbers, $\hat{\alpha} = 4$ for civil flying and $\hat{\alpha} = 6$ for military fighter flying. The former is in agreement with another estimate for civil aircraft¹⁷.

It is of interest to contrast the $\hat{\alpha}$ and $\hat{\sigma}$ estimates for the various groups of data of Tables 4, 5 and 6. This is shown in Figure 1. On average a straight line relationship between $1/\hat{\alpha}$ and $\hat{\sigma}$ fits the data points well, and is given by

$$\hat{\alpha} \hat{\sigma} = 0.6.$$

4. CONCLUSIONS

Analysis of the fatigue lives of over 200 variable amplitude fatigue tests on aluminium alloy aircraft structures indicates that

- (1) Variability in fatigue life may be characterised by the following typical values of dispersion parameter:

* In Reference 1, the question of whether scatter in fatigue life varied with life was examined. It was concluded there that the life range of the data was too limited to allow resolution of this point. The additional data included here do not alter this conclusion.

Loading Sequence	Data treated as	
	Log Normal $\hat{\sigma}$	Weibull \hat{a}
Gust	0.14	3.9
Manoeuvre	0.09	6.2

- (2) These values are statistically independent of whether the loading sequence was program or random.
- (3) These results are not significantly altered by the inclusion of the very limited available data from sequences which included the ground to air cycle.

REFERENCES

1. Jost, G. S., Verinder, F. E.—A Survey of Fatigue Life Variability in Aluminium Alloy Aircraft Structures. A.R.L. Dept. of Supply, Report SM329, February, 1971.
2. Whaley, R. E.—*Fatigue Investigation of Full-Scale Transport-airplane Wings*. N.A.C.A. Tech. Note 4132, November 1957.
3. Foster, L. R., Whaley, R. E.—*Fatigue Investigation of Full-Scale Transport-airplane Wings*. N.A.S.A. Tech. Note D-547, October 1960.
4. Rosenfeld, M. S.—*Aircraft Structural Fatigue Research in the Navy*. A.S.T.M. Special Technical Publication No. 338, p. 216, 1963.
5. Haas, T.—*Spectrum Fatigue Tests on Typical Wing Joints*. Materialprüfung Bd. 2, p. 1, 1960. (I.C.A.F. Document No. 147).
6. Deneff, G. V.—*Fatigue Prediction Study*. Wright-Patterson Air Force Base, Ohio, Tech. Report No. WADD, TR61-153, January 1962.
7. Crichlow, W. J., McCulloch, A. J., Young, L., and Melcon, M. A.—*An Engineering Evaluation of Methods for the Prediction of Fatigue Life in Airframe Structures*. Wright-Patterson Air Force Base, Ohio, Tech. Report No. ASD-TR-61-434, March 1962.
8. Jost, G. S., and Lewis, Jeanette A.—*A Comparison of Experimental and Predicted Fatigue Lives of Mustang Wings under Programmed and Random Loading*. A.R.L. Dept. of Supply, Report SM.300, December 1964.
9. Schijve, J., and de Rijk, P.—*Fatigue Lives obtained in Random and Program Tests on Full-scale Wing Centre Sections*. N.L.R. TM S.611, December 1963.
10. Parish, H. E.—*Fatigue Test Results and Analysis of 42 Piston Provost Wings*. Ministry of Aviation, S. and T. Memo. 1/65, April 1965.
11. Parish, H. E.—*Fatigue Test Results and Analysis of four Piston Provost Wings tested in Ascending order of Loading*. Ministry of Technology S. and T. Memo 1/68, March 1968.
12. Parish, H. E.—*Fatigue Test Results and Analysis of 11 Piston Provost Wings to Determine the Effect of Order of Programmed Load*. Ministry of Technology S. and T. Memo 5/67, January 1968.
13. Ward, A. P., and Parish, H. E.—*Fatigue Test Results and Analysis of 16 Piston Provost Wings tested under Random Loading and their Comparison with Block Programming Results from Similar Specimens*. Ministry of Defence S. and T. Memo. 5/74, October 1974.
14. North American Aviation, Inc.—*F-86F Structural Integrity Engineering Investigation Phase II Fatigue Test Program Final Report NA-63-844, Volume II*. May 1965.
15. Patching, C. A., and Mann, J. Y.—*Comparison of an Aluminium Alloy Structure with Notched Specimens under Programme and Random Fatigue Loading Sequences*. *Fatigue Design Procedures* (eds. E. Gassner and W. Schutz) London. Pergamon Press, 1969, pp. 395-432.
16. Mordfin, L., and Halsey, N.—*Programmed Manoeuvre-Spectrum Fatigue Tests of Aircraft Beam Specimens*. A.S.T.M. Special Technical Publication No. 338, p. 251, 1963.
17. Thompson, P. A.—*A Procedure for Estimating the Demonstrated Fatigue Life of Airplane Structure from Fleet Service Experience*. Document No. D6-41246TN, The Boeing Company, 1973.

APPENDIX

Pooling of Weibull Dispersion Estimates

By D. G. Ford

Suppose there are m samples each of size n_k , $k = 1$ to m , from different Weibull populations with location parameter β_k but a common dispersion parameter, α , then

$$f(x_k) = (\alpha/\beta_k) (x_k/\beta_k)^{\alpha-1} \exp [-(x_k/\beta_k)^\alpha]$$

and the likelihood function is

$$\prod_k \left\{ \prod_{i=1}^{n_k} (\alpha/\beta_k) (x_{ik}/\beta_k)^{\alpha-1} \exp [-(x_{ik}/\beta_k)^\alpha] \right\} = e^L \text{ say.}$$

Then

$$L = \sum_k n_k \ln \alpha - \alpha \sum_k n_k \ln \beta_k + (\alpha - 1) \sum_k \sum_i \ln x_{ik} - \sum_k \sum_i (x_{ik}/\beta_k)^\alpha \quad (1)$$

Maximum likelihood estimators of α and β_k are found by putting $\partial L/\partial \alpha = 0$ and $\partial L/\partial \beta_k = 0$. For the location parameter

$$\frac{\partial L}{\partial \beta_k} = -\alpha n_k / \beta_k + \alpha \sum_{i=1}^{n_k} x_{ik}^\alpha / \beta_k^{\alpha+1} = 0$$

and

$$\hat{\beta}_k^{\hat{\alpha}} = \frac{\sum_{i=1}^{n_k} x_{ik}^{\hat{\alpha}}}{n_k}. \quad (2)$$

For the dispersion parameter

$$\frac{\partial L}{\partial \alpha} = \sum_k n_k / \alpha - \sum_k n_k \ln \beta_k + \sum_k \sum_{i=1}^{n_k} \ln x_{ik} - \sum_k \sum_{i=1}^{n_k} (x_{ik}/\beta_k)^{\hat{\alpha}} \ln (x_{ik}/\beta_k) = 0$$

which, after simplifying and substituting for β_k from (2) becomes

$$\hat{\alpha} = \frac{\sum_k n_k / \sum_k \left[n_k \left(\sum_{i=1}^{n_k} x_{ik}^{\hat{\alpha}} \ln x_{ik} \right) \right]}{\left(\sum_{i=1}^{n_k} x_{ik}^{\hat{\alpha}} \right) - \sum_{i=1}^{n_k} \ln x_{ik}}. \quad (3)$$

For its solution Equation (3) requires iterative substitution for $\hat{\alpha}$: the process is programmed at A.R.L.

TABLE 1
Fatigue Life Data—Gust Loading

Group No.	Reference	Structure	Cycles	Group No.	Reference	Structure	Cycles			
1	8 Table VII	Mustang Wing (24S-T)	2418000	5	7 Table 98	Bultup Panel (7075-T6)	880000			
			1000000				1008000			
			1485000				6	7 Table 98	Bultup Panel (7075-T6)	904000
			1400000						776000	928000
2	8 Table VII	Mustang Wing (24S-T)	1082000	7	9 Table 2	Friendship Wing (7075-T6)	195182			
			1016000				247360			
			820000				8	8 Table VIII	Mustang Wing (24S-T)	5344000
			801000							2751000
			1951000	1626000						
			1994000	3707000						
1396000	3	2 Table 3	Commando Wing (24S-T)	8950350	4060000					
8652005				2423000						
10322737				2340000						
7160280				3598000						
3	2 Table 3	Commando Wing (24S-T)	13067511	9	9 Table 2	Friendship Wing (7075-T6)	2249000			
			10919427				1390000			
			531063				208710			
			722007				146870			
			584766							
733941										
4	3 Table V	Commando Wing (24S-T)	531063	9	9 Table 2	Friendship Wing (7075-T6)	208710			
			722007				146870			
			584766							
			733941							

TABLE 2
Fatigue Life Data—Manoeuvre Loading

Group No.	Reference	Structure	Cycles	Group No.	Reference	Structure	Cycles
1	6 Table 15	Builtup Structure (7075)	63300	12	10 Table 4	Piston Provost Wing	108592
			62272				88400
			85958				137296
			52805				132912
2	6 Table 16	Builtup Structure (7075)	63128				141376
			75936				183376
			68408				176608
			47288				144608
3	7 Table 98	Builtup Panel (7075-T6)	480000				112208
			736000				150016
			960000				177552
							178752
4	4 Table VI	Fighter Wing	52170				160864
			40348				142464
			38549				167744
							148144
5	4 Table VI	Fighter Wing	82332				108560
			77291				138560
							162352
							152752
6	4 Table V	Fighter Tail	22682				153168
			38629				130768
			33992				155200
							154000
7	4 Table V	Fighter Tail	113209				158400
			93770				190128
			67309				166624
							122080
8	4 Table V	Fighter Tail	107560				165824
			74536				158320
			109572				166528
							189328
9	4 Table V	Fighter Tail	45459				121552
			50883				175104
			35256				118192
							177408
10	4 Table V	Fighter Tail	31680				131600
			37020				190192
			40160				123088
							214752
11	4 Table V	Fighter Tail	55019	13	14 pp. B-88 B-89	F86-F Horizontal Stabilizer	84591
			64833				131586
			68430				150384

TABLE 2 [Continued]

Group No.	Reference	Structure	Cycles	Group No.	Reference	Structure	Cycles
14	11 Table 3	Piston Provost Wing	177200 142192 124800 122192	22	16 Table VIII	Box Beam (7075-T6)	69660 36720 55080
15	12 Table 3	Piston Provost Wing	125248 130448 127984 80384 127760 120960 140800 140400 144400 100400 165600	23	16 Table VIII	Box Beam (7075-T6)	72756 52116 49794
				24	13 Table 1 (i)	Piston Provost Wing	129200 155600 127600 148400 131200
				25	8 Table VIII	Mustang Wing (24S-T)	1147000 912000 720000 924000 907000 751000
16	15 Table 6	Vampire Wing (2L65)	430760 396940 590782 520472 459952 406552 354576 452476	26	4 Table VI	Fighter Wing	45963 51299 44765
17	15 Table 7	Vampire Wing (2L65)	383590 379318 406445 414028 370062 400856 380564 317196	27	15 Table VIII	Vampire Wing (2L65)	466716 366324
				28	13 Table 1 (ii)	Piston Provost Wing	140400 104272 145120 114160 132000
18	16 Table VIII	Box Beam (7075-T6)	92777 56540 62190	29	13 Table 1 (iii)	Piston Provost Wing	145600 191200 215680 150000 267792
19	16 Table VIII	Box Beam (7075-T6)	76140 83700 105840	30	13 Table 1 (iv), (v) (vi)	Piston Provost Wing	130640 160000 132640 114432 155760 102880 87360 117600 179264 149440 201344
20	16 Table VIII	Box Beam (7075-T6)	194040 212520				
21	16 Table VIII	Box Beam (7075-T6)	261290 132182				

TABLE 3

Fatigue Life Data—Loading Including Ground to Air Cycles

Group No.	Reference	Structure	Cycles	Group No.	Reference	Structure	Cycles
1	5 Table 2	Britania Wing Joint	981205 987440 1294976 1082724 1083724	7	7 Table 104 (Fig. 27)	Builtup panel	218881 394309
2	7 Table 103 (Fig. 26)	Builtup panel	638764 765582				
3	9 Table 2	Friendship Wing	124121 115706				
4	9 Table 2	Friendship Wing	100707 79726				
5	8 Table VIII	Mustang Wing	485000 1053000 668000 272000 542000 979000 961000 1101000 775000 855000				
6	4 Table VI	Fighter Wing	37575 58338				

TABLE 4
Gust Loading Data—Analysis

Group No.	Numbers of load Levels	Loading Sequence	No. of Specs.	Lognormal		Weibull	
	Up/Down			\bar{x} Log Cycles	s	β Cycles	α
1	3/3	Program	4	6.175	0.158	1761000	3.238
2	3/3	„	7	6.085	0.165	1455000	3.027
3	16/16	„	6	6.985	0.091	10635000	5.641
4	16/16	„	4	5.804	0.069	681000	8.954
5	36/36	„	2	5.974	0.042	974000	17.668
6	19/19	„	3	5.938	0.042	898000	18.343
7	15/15	„	2	5.342	0.073	233000	10.128
8	11/11	Random	10	6.436	0.182	3323000	2.754
9	15/15	„	2	5.243	0.108	191000	6.828

TABLE 5

Manoeuvre Loading Data—Analysis

Group No.	No. of Load Levels		Loading Sequence	No. of Specs.	Lognormal		Weibull	
	Up/Down	Lower Bound			\bar{x} Log Cycles	s	β Cycles	α
1	5/1	Constant	Program	4	4.813	0.088	71300	5.582
2	5/1	"	"	4	4.798	0.088	68000	7.684
3	11/1	"	"	3	5.843	0.152	800000	4.306
4	4/1	"	"	3	4.636	0.071	46400	7.561
5	10/1	"	"	2	4.902	0.019	81000	37.975
6	4/1	"	"	3	4.491	0.121	34400	6.013
7	5/1	"	"	3	4.951	0.114	99000	5.808
8	5/1	"	"	3	4.981	0.094	104000	8.447
9	4/1	"	"	3	4.637	0.082	46600	8.471
10	5/1	"	"	3	4.558	0.052	37800	12.863
11	5/1	"	"	3	4.796	0.049	65200	14.636
12	6/6	Gust	"	41	5.180	0.087	167000	5.237
13	5/1	Constant	"	3	5.075	0.131	133000	5.582
14	6/6	Gust	"	4	5.146	0.074	151000	6.580
15	6/6	"	"	11	5.099	0.084	136000	7.042
16	6/6	"	"	8	5.650	0.070	483000	6.537
17	6/6	"	"	8	5.580	0.036	393000	19.073
18	4/1	Constant	"	3	4.838	0.114	77000	4.724
19	5/1	"	"	3	4.943	0.074	94200	7.487
20	6/1	"	"	2	5.308	0.028	208000	26.375
21	6/1	"	"	2	5.269	0.209	220000	3.521
22	6/1	"	"	3	4.716	0.141	59100	4.705
23	5/1	"	"	3	4.759	0.090	62700	5.936
24	6/6	Gust	"	5	5.140	0.039	144000	12.826
25	12/9	Gust	Random	6	5.946	0.073	955000	6.651
26	4/1	Constant	"	3	4.674	0.031	48700	17.185
27	6/6	Gust	"	2	5.616	0.074	439000	9.906
28	6/6	"	"	5	5.101	0.061	134000	10.185
29	6/6	"	"	5	5.276	0.111	212000	4.632
30	6/6	"	"	11	5.132	0.107	152000	4.688

TABLE 6
Data Including Ground to Air Cycles—Analysis

Group No.	Type of Loading	Loading History				No. of Specs	Lognormal		Weibull	
		No. Load Levels		Loading Sequence	Cycles per GA Cycle		\bar{x} Log Cycles	s	β Cycles	α
		Up/Down	Lower Bound							
1	Gust	7/7	Gust	Program	64	5	6.034	0.049	1140000	9.228
2	..	19/19	..	..	Complex	2	5.845	0.056	731000	13.249
3	..	15/15	..	..	12.5	2	5.079	0.022	122000	34.177
4	..	15/15	..	Random	12	2	4.952	0.072	94900	10.270
5	..	11/11	..	..	≈ 36	10	5.854	0.190	857000	3.495
6	Man-oeuvre	4/1	Constant	Program	13	2	4.670	0.135	52200	5.454
7	..	11/1	..	Random	Complex	2	5.468	0.181	340000	4.076

TABLE 7
Structural Fatigue Life Variability—Lognormal Analysis

(a) Gust Loading

Loading Spectrum		Loading Sequence		Pooled
Upper	Lower	Program	Random	
Gust	Gust	0.120 (28, 21)	N.S. → 0.176 (12, 10)	0.141 (40, 31)

(b) Manoeuvre Loading

Loading Spectrum		Loading Sequence		Pooled
Upper	Lower	Program	Random	
Manoeuvre	Gust	0.079 (77, 71) ↓ N.S.	N.S. → 0.094 (29, 24) ↑ N.S.	0.083 (106, 95) ↑ N.S.
Manoeuvre	Constant	0.103 (53, 35)	N.S. → 0.031 (3, 2)	0.100 (56, 37)
Pooled		0.087 (130, 106)	N.S. → 0.090 (32, 26)	0.088 (162, 132)

(c) Loading including Ground Air Cycles

Loading Spectrum			Loading Sequence		Pooled
Upper	Lower	Ground Air Cycle	Program	Random	
Gust	Gust	Simple	0.045 (7, 5) ↑ N.S.	→ 0.182 (12, 10) ← Sig	0.147 (21, 16)
Gust	Gust	Complex	0.056 (2, 1)		
Manoeuvre	Constant	Simple	0.135 (2, 1)	N.S.	0.160 (4, 2)
Manoeuvre	Constant	Complex				→ 0.181 (2, 1)

Entries show standard deviation of log life, with number of test specimens and degrees of freedom, respectively, in parentheses.

N.S.: F test comparison of variances not significant at 5% level.

Sig.: F test comparison of variances significant at 5% level.

TABLE 8

Structural Fatigue Life Variability—Weibull Analysis

(a) Gust Loading

Loading Spectrum		Loading Sequence		Pooled
Upper	Lower	Program	Random	
Gust	Gust	4.708 (28)	2.987 (12)	3.934 (40)

(b) Manoeuvre Loading

Loading Spectrum		Loading Sequence		Pooled
Upper	Lower	Program	Random	
Manoeuvre	Gust	6.092 (77)	5.620 (29)	5.966 (106)
Manoeuvre	Constant	6.529 (53)	17.185 (3)	6.740 (56)
Pooled		6.233 (130)	5.918 (32)	6.171 (162)

(c) Loading Including Ground Air Cycles

Loading Spectrum			Loading Sequence		Pooled
Upper	Lower	Ground Air Cycle	Program	Random	
Gust	Gust	Simple	10.844 (7)	3.893 (12)	5.441 (21)
Gust	Gust	Complex	13.25 (2)	—	
Manoeuvre	Constant	Simple	5.454 (2)	—	4.665 (4)
Manoeuvre	Constant	Complex	—	4.076 (2)	

Entries show dispersion parameter of fatigue life, with number of test specimens in parentheses.

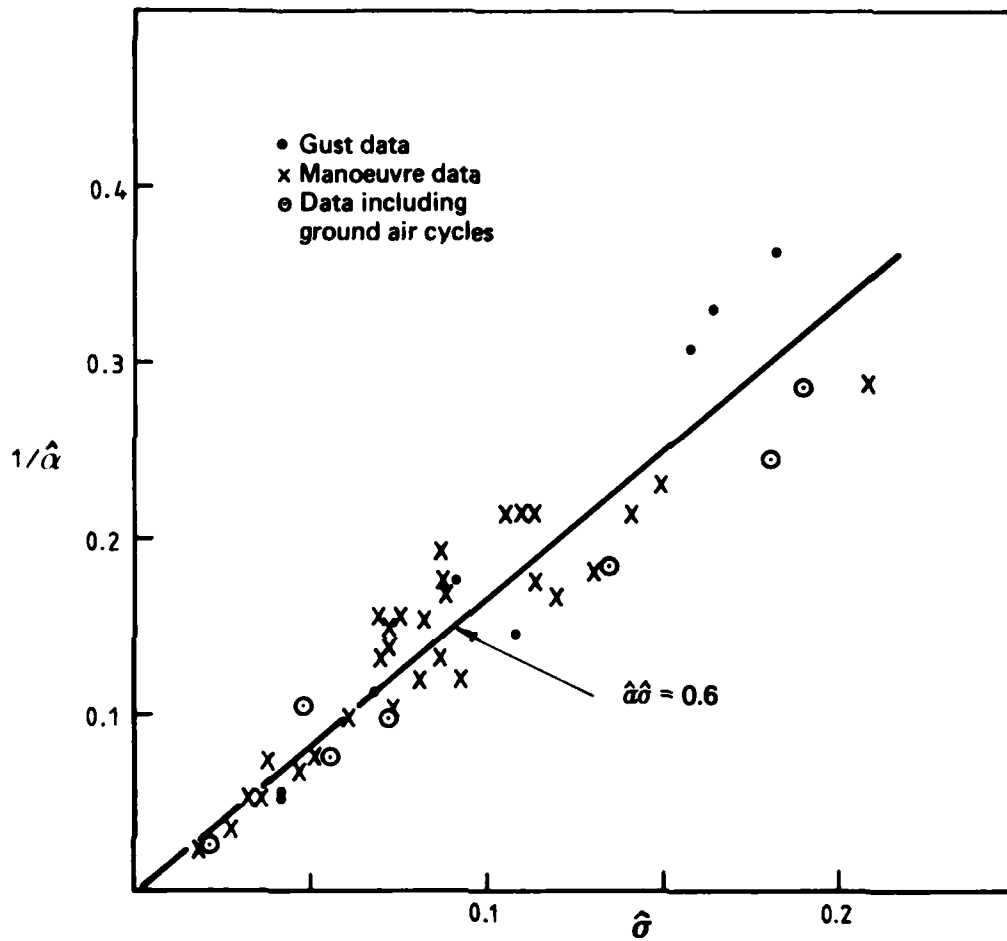


FIG. 1 RELATION BETWEEN LOGNORMAL STANDARD DEVIATION, $\hat{\sigma}$, AND RECIPROCAL OF WEIBULL DISPERSION PARAMETER, $\hat{\alpha}$

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