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MINISTRY OF TECHNOLOGY

AERONAUTICAL RESEARCH COUNCIL

Fatigue Test Results and Analysis of 42 Piston Provost Wings

by

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Summary.

The safe fatigue life of the Piston Provost was established by full-scale, programmed load, fatigue tests, the load spectrum being collected from 'in service' records.

Forty 'life-expired' wings and an appropriate number of fuselages were used to continue the programmed load tests to failure with the object of determining the degree of scatter.

A standard deviation of 0·087 and a coefficient of variation of 0·022 indicates less scatter than has been suggested in other literature. (Ref. 3.)

The estimated life obtained by using Miner's cumulative damage rule is compared with the mean of the experimental results.

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* Replaces B.A.C. S & T Memo 1/65—A.R.C. 27 089.

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1. *Introduction.*

The Piston Provost was designed for service with the Royal Air Force, as its primary trainer. Whilst being designed on fairly rugged principles, fatigue life was not, at that time, of primary concern. The Jet Provost, which superseded the Piston Provost, was designed from the outset to have a specified fatigue life and the results given in this memorandum have no bearing whatever on the fatigue characteristic of Jet Provost.

During the service life of the Piston Provost, data were collected to enable a fatigue load spectrum to be determined and full scale fatigue tests, under programmed loading, were made. These are reported in Ref. 1 and the results summarized in Table 1.

These tests were used as a basis for fixing a safe life in service for the aircraft at 2400 hours. After expiry of the safe life forty wings, mainly in pairs, and a convenient number of fuselages, were selected on the score of good condition, freedom from repairs etc. to be used as specimens for further fatigue tests in the form of complete airframes subjected all to the same programmed loading.

The thirty-nine results obtained, coupled with the original two results were intended to show the degree of scatter to be expected in programmed-load fatigue tests of nominally identical specimens.

2. *Discussion on Test Rig*

The later tests were made by restraining the fore and aft ends of the fuselage vertically and applying loads to the wing through a linkage from a hydraulic jack. Within each programme, the various load levels were controlled by pressure switches and the number of applications of each load level controlled by a suitably designed rotating drum, operating micro-switches.

Measurement of the load levels was made by a calibrated 'C' type load-measuring ring inserted between the hydraulic jack and its earth point.

In addition strain gauges were fixed to the upper and lower centre-section spar boom on the centreline of aircraft, the results being recorded under dynamic conditions on a Woodhill recorder.

The original wing test rig differed slightly, inasmuch as the wing loading linkage and the fuselage tail end were restrained vertically and loads applied to the engine mounting.

Similar means of load measurement were used with the addition of strain-gauged links in the wing-loading linkage.

3. *Programmed Test Load.*

Records were collected from Royal Air Force aircraft on pupil training which enabled the fatigue spectrum of Fig. 1 to be established. This spectrum was divided into six bands of acceleration, the total number of counts in each band was determined and gave the following test programme, representative of 25 flying hours :

Acceleration range in 'g'	*Cycles per 25 flying hours*
+2·0 to 0·4	195
+2·6 to 0	105
+3·3 to −0·5	65
+3·9 to −1·0	27
+4·6 to −1·5	7
+5.2 to −1.9	1

The programme was applied in a descending order of '*g*', i.e. starting with the high '*g*' range down to the low '*g*' then starting at the high '*g*' again.

4. *History and Analysis of Results*

So far as is known, the aircraft had been used on pupil training duties and Table 2 shows the service hours and the subsequent testing period, expressed in equivalent flying hours.

In Table 3 the lives of 16 aircraft which yielded both port and starboard results are given and an analysis shows that there is no significant difference between port and starboard wings.

The analysis of total hours is shown in Table 4 (i.e. equivalent test hours plus 'in-service' hours). From this, results are plotted in Fig. 2 on log/probability scales indicating the log normal distribution. The results from the pair of wings used in the original test have been included in this analysis, and it is worth noting that they provide the highest two values in the distribution, the mean life of the two being 2·1σ above the mean of the population.

5. *Points of failure.*

With the exception of one of the original wings (which failed in the lug) all failures occurred in the front spar lower boom at a point approximately 8 in. outboard of the wing root attachment pin.

The failures ranged over seven bolt hole positions and their distribution is shown in Table 5. Fig. 3 shows the bolt hole positions and a typical boom section. Variance analysis indicates that the variation in the position of failure is without significance.

The lower boom was strain-gauged to obtain stress levels. (See Fig. 4.) Using this information in conjunction with Miner's hypothesis and an appropriate S/N curve (Fig. 5), a cumulative damage calculation was performed to compare the predicted life with the test result. This is commented upon in Appendix.

6. *Comments on Analysis of Results.*

(1) The overall standard deviation of log endurance for total hours is shown to be 0·087. This is lower than the values of 0·2 suggested in Ref. 3 and 0·176 given in design requirements.

(2) The coefficient of variation for total hours is 0·022. This is lower than the typical value of 0·03 given in Ref. 4 for light alloy structures based on static testing.

All analysis has been done on the basis of total hours since the in-service period cannot be ignored. The uncertainties associated with the 'in-service' period of damage are

(a) that the loading would be random

(b) whether the loading spectrum was as used on test.

(The collected records from fatigue meters fitted in all Jet Provost aircraft indicate a reasonably consistent spectrum of loading in pupil training.)

7. *Proposal for further Work.*

With this considerable amount of fatigue test data available, the effect on endurance of order of loading can be readily assessed. Work is being undertaken to test additional wings with the order of loading reversed.

REFERENCES

No.	*Author(s)*	*Title, etc.*
1	Hunting Aircraft Ltd.	Fatigue investigations on a Provost T. Mk. 1 aircraft. Report 1464/P56/171.
2	J. L. Kepert and A. O. Payne ..	Fatigue characteristics of a typical metal wing. A.R.L. Report SM.207.
3	Messrs. Ford, Graff and Payne ..	*Proceedings of ICAF/AGARD Fatigue Symposium*—Paris, 1961. Pergamon Press.
4	R. J. Atkinson	Permissible design values and variability test factors. A.R.C. R & M 2877. July, 1950.

APPENDIX

Comments on Fatigue Life Calculations

It was decided to strain-gauge the lower boom in the region of the bolt holes where failure occurred. The stress on the skin face was virtually constant in the spanwise direction and Fig. 4 shows the stress level against 'g' at bolt position 5.

Using these stress levels, a *S/N* curve derived from the 'Mustang' tests of Ref. 2 and carrying out a cumulative damage calculation, a mean life to failure of 4760 hours is predicted. Fig. 5 shows the *S/N* curve. The difference between this result, using Miner's hypothesis and the test result mean, is attributed to the residual compressive stress that is induced around the bolt holes after applying the higher loadings.

TABLE 1

Original Piston Provost—Fatigue Test Results and History

Aircraft No.	Port			Starboard		
	Service Hours	Test Hours	Total Hours	Service Hours	Test Hours	Total Hours
WV 639	1647	11775	13422	1647	13700	15347

TABLE 2

Piston Provost Fatigue—Test Results and History of 40 Wings

Aircraft No.	Port			Starboard		
	Service Hours	Test Hours	Total Hours	Service Hours	Test Hours	Total Hours
WV.566	2400	4387	6787	2400	3125	5525
WV.578	2381	6200	8581	2495	5812	8307
WV.628	2499	6337	8836	2499	8962	11461
WV.685	2401	8637	11038	2401	6637	9038
WV.625	2401	4612	7013	2401	6975	9376
WV.683	1885	9212	11097	1885	9287	11172
WV.643	2467	7587	10054	2467	6437	8904
WV.630	2497	7987	10484	2497	6762	9259
WV.621	2398	4387	6785	2398	6262	8660
WV.663	2397	7750	10147	2397	7150	9547
WV.636	2485	7087	9573	2485	5687	8173
WV.601	2500	7200	9700	2500	7125	9625
WV.605	2513	7387	9900	2271	9612	11883
WV.666	2489	7925	10414	2493	5137	7630
WV.616	427	9937	10364	595	9300	9895
WW.381	2233	8175	10408	2233	9600	11833
WV.619	2456	5237	7693			
WV.672				2360	5237	7597
WV.611				2469	8475	10944
WV.424	2400	9487	11887			
XF.681				2400	4987	7387
WV.635			Unbroken	2401	8387	11088
WV.669	2400	5962	8362			
WV.680	2400	5825	8225			

TABLE 3

Comparison of Port and Starboard Results

Aircraft No.	Port		Starboard	
	Total Hours x_p	Log x_p	Total Hours x_s	Log x_s
WV.566	6787	3·8317	5525	3·7423
WV.578	8581	3·9335	8307	3·9194
628	8836	3·9462	11461	4·0592
685	11038	4·0429	9038	3·9561
625	7013	3·8459	9376	3·9720
683	11097	4·0453	11172	4·0480
643	10054	4·0021	8904	3·9496
630	10484	4·0204	9259	3·9666
621	6785	3·8316	8660	3·9375
663	10147	4·0064	9547	3·9799
636	9573	3·9811	8173	3·9124
601	9700	3·9868	9625	3·9834
605	9900	3·9956	11883	4·0748
666	10414	4·0174	7630	3·8825
616	10364	4·0154	9895	3·9954
WW.381	10408	4·0175	11833	4·0730

$\bar{x}_p = 3{\cdot}970 \qquad \bar{x}_s = 3{\cdot}9658$

$S_p = 0{\cdot}0703 \qquad S_s = 0{\cdot}0804$

$F = \frac{{\cdot}00645}{{\cdot}00495} = 1{\cdot}3$ Not significant

Pooled $S = 0{\cdot}0753$

$$t = \frac{\bar{x}_p - \bar{x}_s}{s\sqrt{\frac{1}{16}+\frac{1}{16}}} = 0{\cdot}158 \text{ for 30 d.f.}$$

Not significant.

TABLE 4

Analysis of Total Hours

Aircraft No.	Total Hours	log x	log $x-\bar{x}$	$(\log x-\bar{x})^2$
WV.566	6787	3·83168	−0·143818	·020684
566	5525	3·74233	−0·233168	·054367
578	8581	3·93354	−0·041958	·001760
578	8307	3·91944	−0·056058	·003142
628	8836	3·94625	—0·029248	·000855
628	11461	4·05922	0·083722	·007009
685	11038	4·04293	0·067432	·004547
685	9038	3·95607	−0·019428	·000377
625	7013	3·84591	−0·129588	·016793
625	9376	3·97202	−0·003478	·000012
683	11097	4·04532	0·069822	·004875
683	11172	4·04802	0·072522	·005259
643	10054	4·00212	0·026622	·000709
643	8904	3·94958	—0·025918	·000672
630	10484	4·02042	0·044922	·002018
630	9259	3·96656	−0·008938	·000080
621	6785	3·83155	−0·143948	·020721
621	8660	3·93752	−0·037978	·001442
663	10147	4·00644	0·030942	·000957
663	9547	3·97987	0·004372	·000019
636	9573	3·98105	0·005552	·000031
636	8173	3·91238	−0·063118	·003984
601	9700	3·98677	0·011272	·000127
601	9625	3·98341	0·007912	·000063
605	9900	3·99564	0·020142	·000406
605	11883	4·07484	0·099342	·009869
666	10414	4·01745	0·041952	·001760
666	7630	3·88252	−0·092978	·008645
616	10364	4·01538	0·039882	·001591
616	9895	3·99542	0·019922	·000397
WW.381	10408	4·01745	0·041952	·001760
381	11833	4·07299	0·097492	·009505
WV.672	7597	3·88065	−0·094848	·008996
611	10944	4·03905	0·063552	·004039
XF.681	7387	3·86847	−0·107028	·011455
WV.635	11088	4·04487	0·069372	·004812
680	8225	3·91514	−0·060358	·003643
424	11887	4·07521	0·099712	·009942
619	7693	3·88610	−0·089398	·007992
639	13422	4·12776	0·152262	·023184
639	15347	4·18611	0·210612	·044357

$\bar{x} = 3{\cdot}9755 \qquad \hat{\sigma} = 0{\cdot}087$

TABLE 5

Bolt Position of Boom Failure—Log of Total Hours and Variance Analysis

Bolt 2	Bolt 3	Bolt 4	Bolt 5	Bolt 6	Bolt 7	Bolt 8
3·9834	3·8685	4·0748	4·0480	4·0391	3·7423	3·9720
3·9868	3·9195	3·8807	3·9666	3·9375		4·0175
4·0453	4·0592	4·0449	3·9496	4·0204		
	3·9124	3·9799	3·9561	3·9810		
	4·1861	3·8825	3·9954			
		3·8861	3·9335			
		4·0064	3·8317			
		3·9151	3·9956			
		4·0174	3·8316			
		4·0154	3·8460			
		4·0730	3·9462			
			4·0021			
			4·0429			
			4·0752			

Between samples sum of squares 0·0637 for 6 d.f.
Within samples sum of squares 0·2153 for 33 d.f.
$F = 1{\cdot}63$ Not significant.

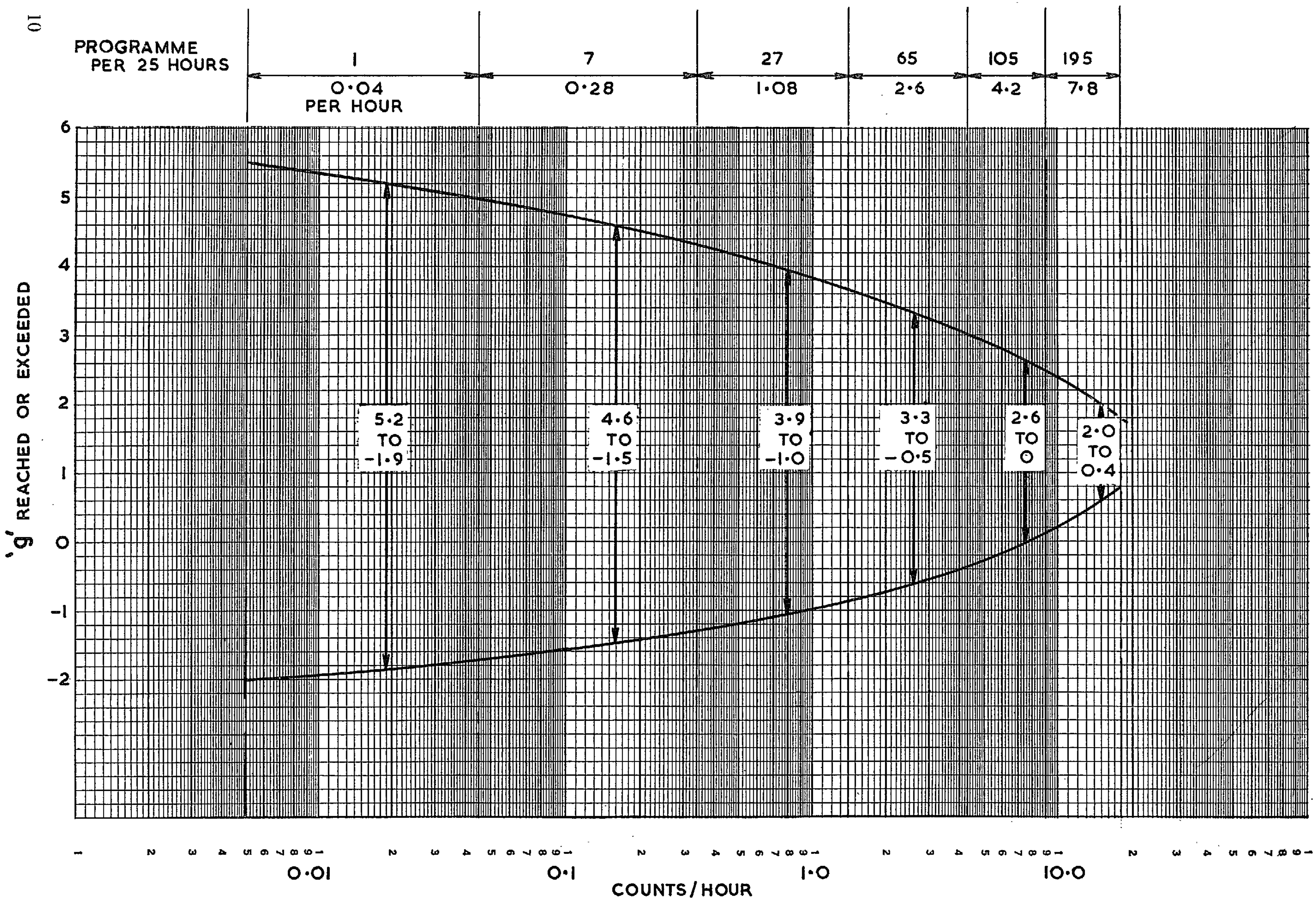

FIG. 1. Fatigue spectrum and programmed loads.

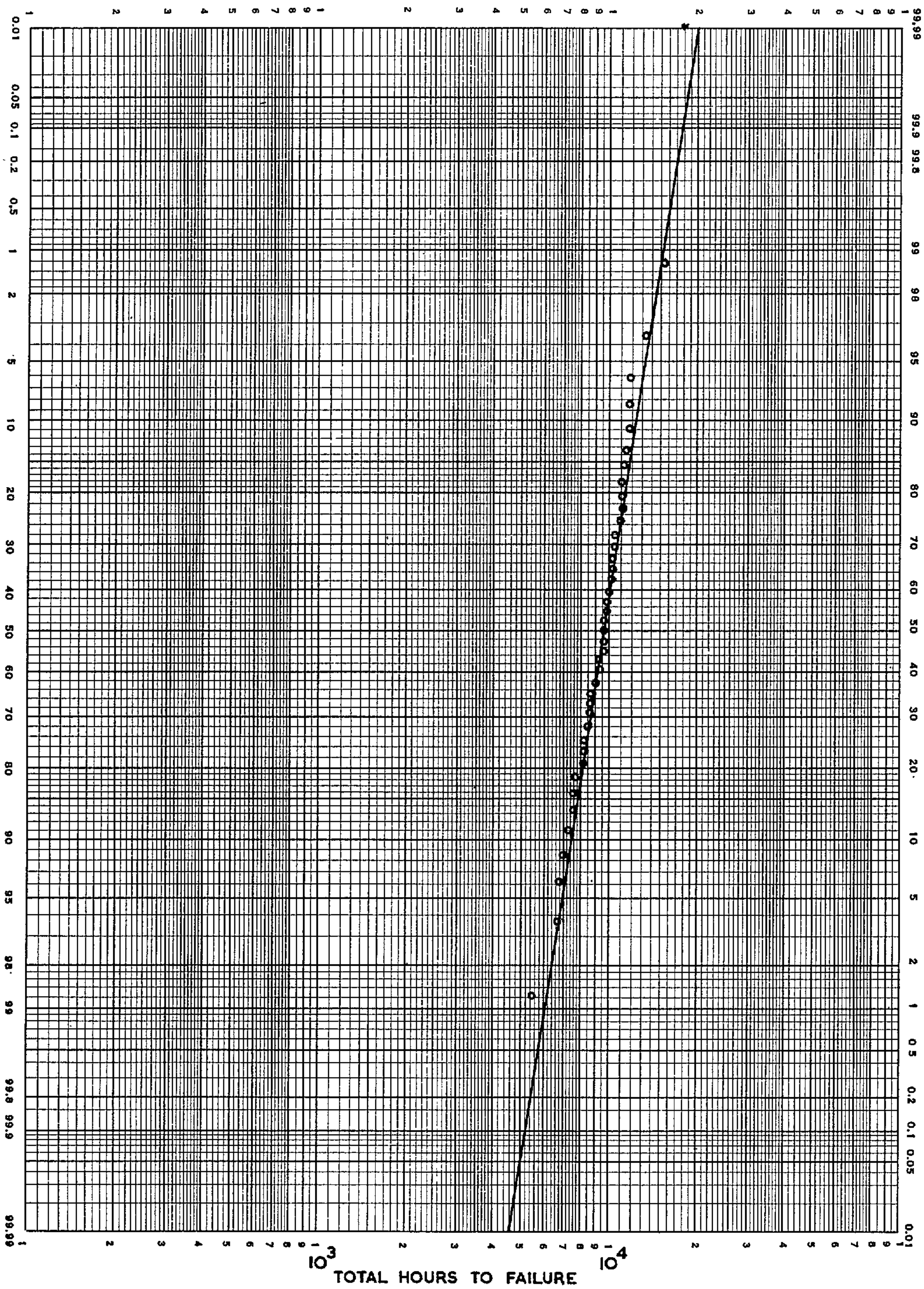

FIG. 2. Probability of total hours endurance.

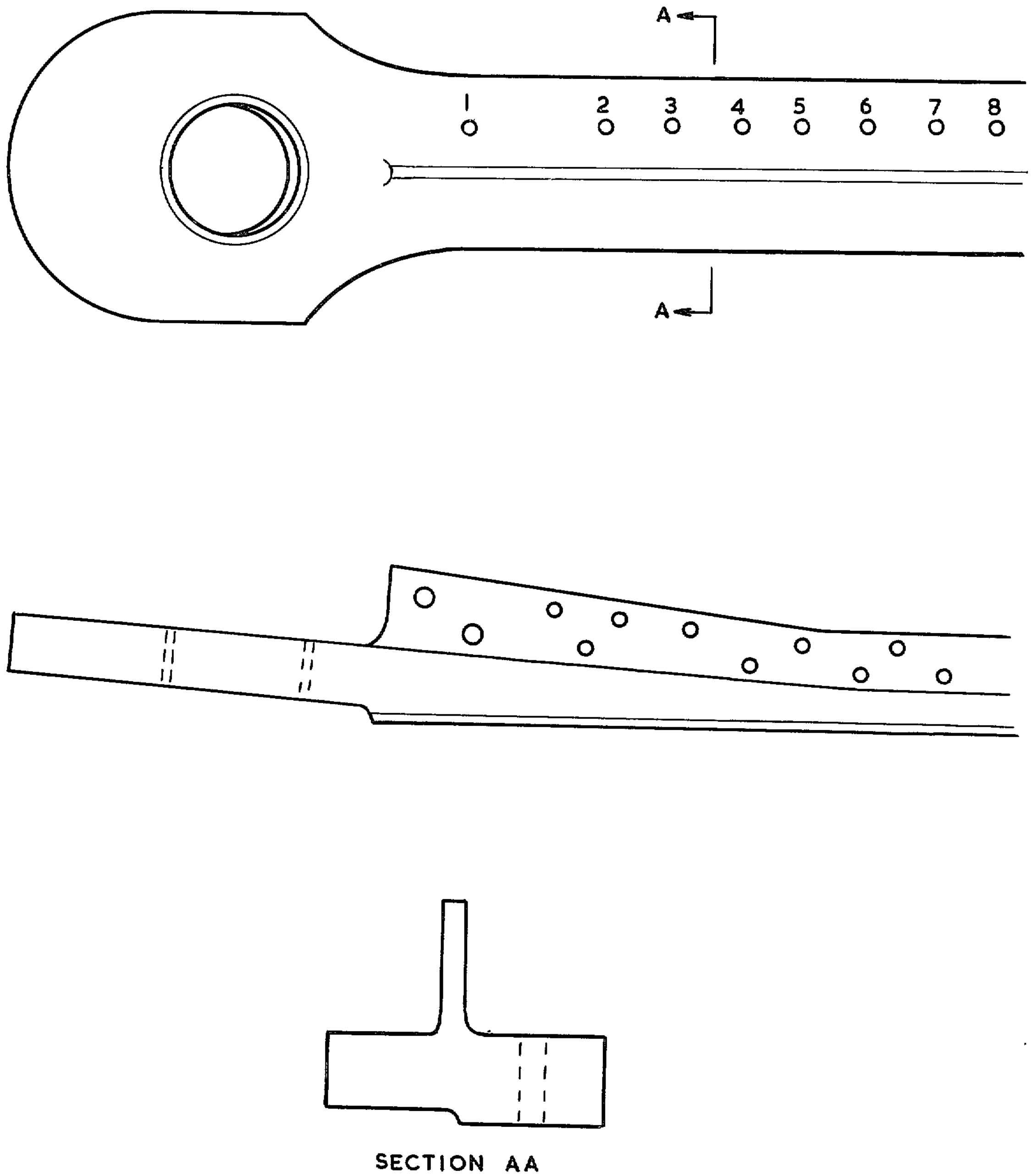

Fig. 3. Bolt positions and lower boom detail.

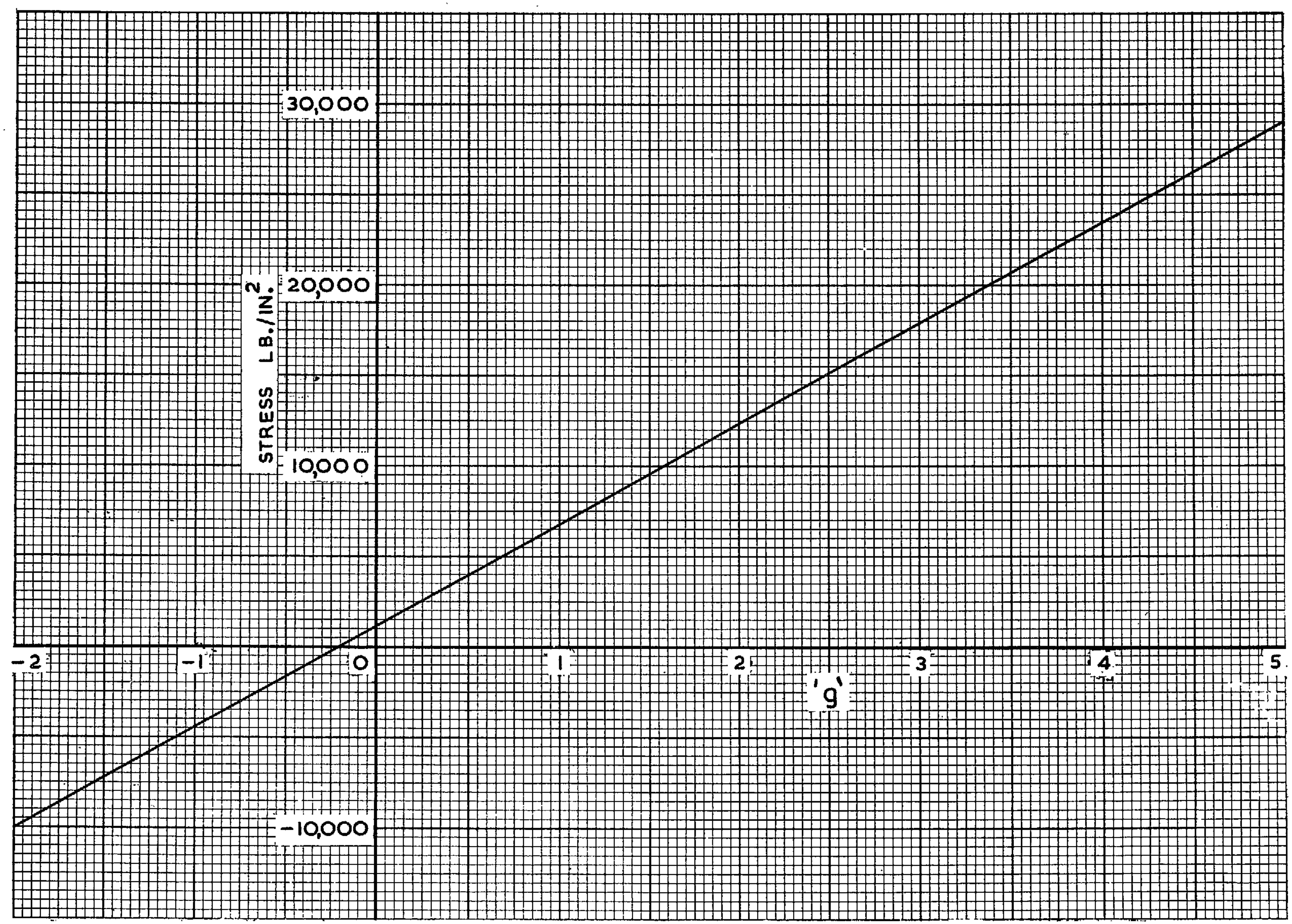

FIG. 4. Stress levels at point of failure—bolt 5.

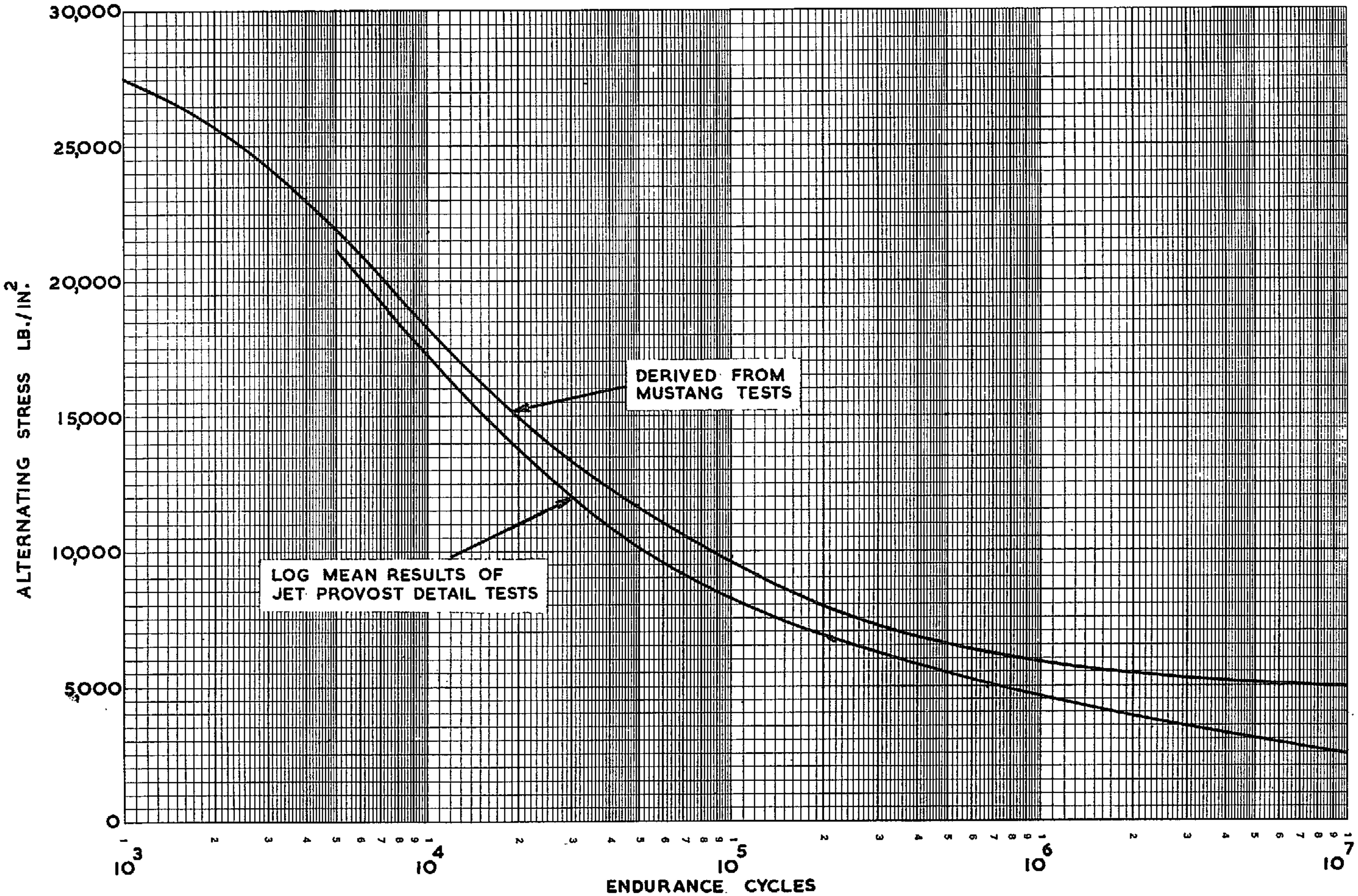

FIG. 5. *S/N* curves.

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