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The Correlation of Aeroplane Loading and Accident Statistics

By
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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR)
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Summary.—The general problem is to predict the probable effect of a given change of structural strength upon the accident rate, the available data usually being in the form of rather meagre loading and accident statistics together with a knowledge of the strength of the structure concerned. A method of treating this problem is given and is illustrated by an application to undercarriages. The method is simple and quick and requires no specialist knowledge of statistical mathematics.

1. *Introduction.*—In a report[1] written in 1939, attention was drawn to the growing volume of statistical data on airworthiness matters and to the importance and potentialities of a proper analysis of this information. In particular, the possibility of correlating data on the loads coming upon aeroplanes, the strength of their structures and data on accident rates, was roughly demonstrated. Opportunities have been taken since then to apply and develop the preliminary work of the earlier report. This report describes the results of a return to the central problem—the correlation of loading and accident statics. A general method of treating this problem in practical terms is outlined and illustrated by a recent application to the difficult question of the influence of undercarriage strength upon landing accidents (an application foreshadowed in the earlier report).

2. *The General Problem.*—2.1. The usual form of the general problem is this: knowing the strength of an aeroplane structure and having some records of the loads coming upon that structure in service, together with information on the frequency of relevant structural failures in service, to predict the reduction or increase of that structural accident rate likely to arise from a given strengthening or weakening of the aeroplane structure. In practice, the question may relate to the whole structure of an aeroplane or to a component only, such as the undercarriage, and the loading and accident evidence must be sifted accordingly. And in practice also, over and above the data mentioned above, we may expect to have some relevant *ad hoc* data from general experience to help judge of the adequacy of any approximate solution of the problem.

2.2. Considering first the loading data available in any particular case, it is natural that these should be less extensive than one would like (thus in the undercarriage example discussed below only 134 accelerometer records were available), so that when the data are reviewed in relation to the aeroplane strength the highest recorded loads are much below the known failing loads. Yet to correlate the recorded loads with the known accident rate we must in effect *extrapolate* a frequency curve based on such meagre loading statistics to cover loads in the region of the failing loads. This question of plotting and extrapolation is of prime importance to the general problem and is the only point in its solution of general statistical interest.

2.3. The method of treatment adopted here and illustrated by an application to undercarriages is as follows. Consider the frequency curve ABC of Fig. 1, supposed based upon records of a

*R.A.E. Reports S.M.E. 3207.

certain specified kind of load arising in service. The highest recorded load at C is only about half the known failing load at D, yet in order to estimate the rate of change of accident rate with a change of the strength D, we want to extrapolate the information represented by ABC to the region of D. One way of doing this—and that which most naturally occurs to statisticians—is to fit some standard frequency curve to the tail BC of Fig. 1 and then extrapolate BC to D by direct plotting from the mathematical expression defining the standard curve. The Pearson standard curves are the most suitable for this purpose, but the work of fitting is very considerable and the resulting extrapolation is inconvenient graphically.

Instead, therefore, of following this procedure, we integrate the curve ABC from the end C to provide a basis for another curve $A_1B_1C_1$ (Fig. 2) giving the frequency with which a *given value of the load is reached or exceeded*, and then plot this second curve $A_1B_1C_1$ on a log-log scale to give curve abc of Fig. 3. Now if this process is applied to a standard normal frequency curve (Fig. 4), the log-log curve resulting is of the form yz of Fig. 5; so that provided the actual frequency curve we are concerned with is, in the shape of its tail, not very different from a normal one, we may expect the 'observed' curve abc of Fig. 3, were further data available, to continue to d along the almost straight curve shown dotted.

2.4. Before we accept this very considerable extrapolation, however—which has no strict logical foundation at all—we turn to accident statistics to check the level of the dotted curve at d. This can usually be done directly, for if the frequency curve ABC of Fig. 1 is drawn on the basis of loads recorded in 100 landings, for example, the anti-log of the log n at d in Fig. 3 should agree with the number of undercarriage structural failures per 100 landings. Thus for the extrapolation of abc we have both the general guidance of Fig. 5 (and other such curves) and of a single point at d representing the appropriate accident rate. The actual assessment of this accident rate is an accident investigation matter outside the scope of this report, but as will be seen from the example below it may in some cases be itself liable to considerable error, though commonly not an error of *order*. It is easy in any given case to check to what extent a given error in the accident rate affects the slope of the extrapolated curve of Fig. 3.

2.5. The above process, given the data, is simple and quick, and requires no special knowledge of statistical mathematics. Once the extrapolated curve through d is drawn its slope at d represents (on a log basis) the required information—the probable change of accident rate for a given change of structural strength.

3. *Example : The Influence of Undercarriage Strength upon Landing Accidents*.—3.1. Certain accident statistics were recently examined in relation to undercarriage design, and the great difference between day and night landing records was noted. It was pointed out, however, that no evidence was there given 'on what a change of undercarriage strength or shock absorption requirements might be expected to do to the accident rates'. An attempt is made here to fill this gap by making a very rough estimate of the extent by which a specified increase of undercarriage strength would probably reduce the number of landing accidents. For this purpose, shock absorption properties are supposed unchanged and undercarriage strength is supposed 'uniformly' varied in the sense that strengths under vertical, drag and side forces are all changed together in the same proportion. On these assumptions undercarriage strength is expressed by the design vertical acceleration (at present $4g$) as a single representative parameter.

3.2. Records of peak accelerations observed in ordinary daylight landings at the R.A.E. and at Boscombe Down on various types of aircraft have been collected—134 peak values in all—and the numbers of readings falling into each of a series of acceleration intervals of $0.1g$ have been noted and plotted to give the frequency diagram of Fig. 6*. To assess the probable number of accidents likely to occur due to collapse of the undercarriage structure at $4g$ or above, it is necessary to extrapolate this diagram beyond the bounds of the experimental points. This is

*The form of this frequency diagram provides an answer to the suggestion sometimes made that aeroplanes either land gently or very violently. Actually the distribution of accelerations for daylight landings is a much more normal one. The suggestion, were it true, would involve a double-peaked frequency curve—a dimodal form rare in statistical experience and implying that a landing at an average acceleration would be remote from the most probable landing.

obviously difficult on the frequency diagram, but if we take the observed peak accelerations and *the numbers of times any given value is recorded or exceeded* and plot the logarithms of these as in Fig. 7 it is easy to extrapolate the resulting curve (as shown by the dotted line) on the lines of the normal log-log curve of Fig. 5.

3.3. Now we can turn to landing accident records for another guide to the curve in the extrapolated region. Accidents during ordinary landings (*i.e.*, not forced ones) are largely attributed by courts of enquiry, *etc.*, to errors of pilots' judgment, but in a small number of cases it is felt that the pilot landed in a way that the undercarriage would be expected to withstand and yet did not. This is very roughly equivalent to saying that the pilot landed with reasonable skill—as an R.A.E. or A.A.E.E. pilot might be expected to land—so that it seems fair to take accidents reported as of this 'structural failure' kind for comparison with the landing accelerometer results of Section 3.2. An analysis of undercarriage accident records for the Home Commands indicates a 'structural accident' rate for daylight landings of one in about 2×10^4 landings*. This corresponds to 0.0067 accidents in 134 landings—the number to which the records of Figs. 6 and 7 apply—and the point corresponding to ($\log 4$, $\log 0 \cdot 0067 = 0 \cdot 60, -2 \cdot 17$) is shown at X on Fig. 7. The dotted extrapolation of the curve given by the accelerometer records is taken through X.

3.4. The purpose of drawing Fig. 7 was to estimate the change of the accident rate represented by X for a given change of undercarriage strength. Assume an all round 10 per cent. increase of strength, corresponding to a change of the limit $4g$ to $4 \cdot 4g$. From our logarithm diagram this gives a change of $\log n$ from $-2 \cdot 17$ to $-2 \cdot 57$, corresponding to $n = 0 \cdot 0067$ and $n = 0 \cdot 0027$ respectively per 134 landings. Thus our rough diagram suggests that a 10 per cent. increase in undercarriage strength would probably rather more than halve ($0 \cdot 0027/0 \cdot 0067 = 1/2 \cdot 5$) the current number of structural accidents to undercarriages. This refers strictly to daylight landings; the reduction of accidents at night would probably be greater, but night landings naturally do not constitute a large proportion of *all* Service landings.

3.5. It is important to note that such a reduction, whilst appreciable, will have only a small effect on landing accidents as a whole. Of every hundred landing accidents, only four or five are attributed to structural failures of main or tail wheel units. It is this four or five that our analysis suggests would be more than halved by a 10 per cent. increase of strength. As usual with such strength changes, we are concerned with a small proportion of accidents only; but in this case it must be remembered that as there are some thousands of landing accidents per year the saving of two or three per hundred would be of considerable value. Moreover, any strength increase must somewhat reduce the large proportion of undercarriage failures attributed to pilots' errors of judgment. If these are reduced by only 5 per cent. as against the 50 per cent. reduction of structural failures, the saving of two or three accidents in a hundred would rise to a total saving of six or seven per hundred accidents.

4. *Conclusion.*—The foregoing example illustrates the application of the method to an example made difficult by the meagre loading data available and the uncertainty of the accident rate concerned. More important applications include the strength of the wings of aeroplanes of different types, where loading data is now being collected by means of V–g recorders and the relevant accident rate is better known.†

REFERENCE.

No.	*Author.*	*Title, etc.*
1	A. G. Pugsley and R. A. Fairthorne.	Note on Airworthiness Statistics. R. & M. 2224, 1939.

* It is of interest to note that an extrapolation of the flying boat alighting and take-off data given in R. & M. 2224[1], when done by a smooth log-log curve on the lines of this report, suggests the occurrence of $4g$ or over about once in 10^4 cases.

†At the time of printing, 1951, this work has greatly developed. In particular, it has become customary to plot the $\log (P)$, $\log (n)$ curves of this report as $\log P$, log (Time) curves.

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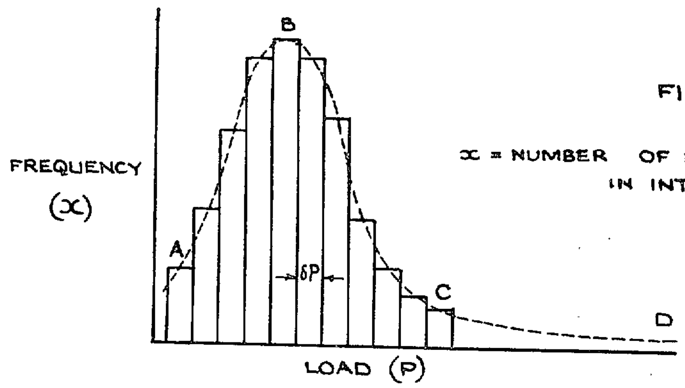

FIG. 1

x = NUMBER OF LOAD RECORDS IN INTERVAL δP

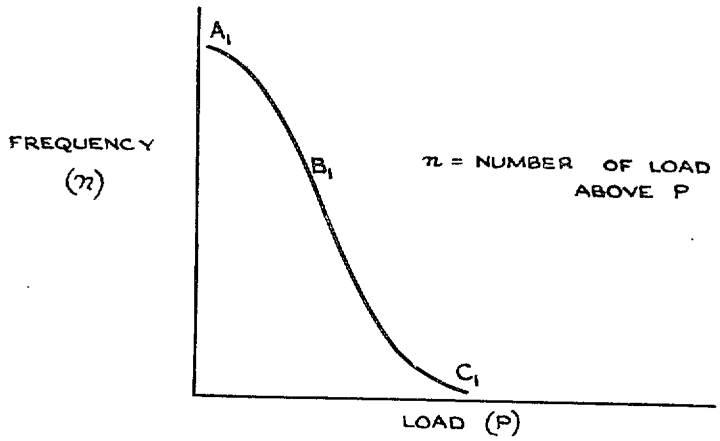

FIG. 2

n = NUMBER OF LOAD RECORDS ABOVE P

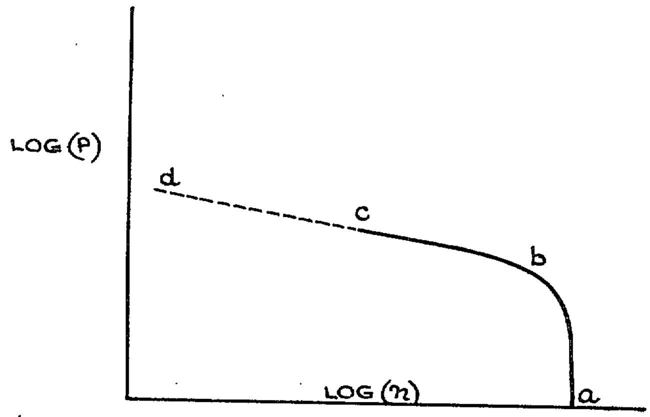

FIG. 3

(86756) Wt. 14/655 K.5 6/51 Hw.

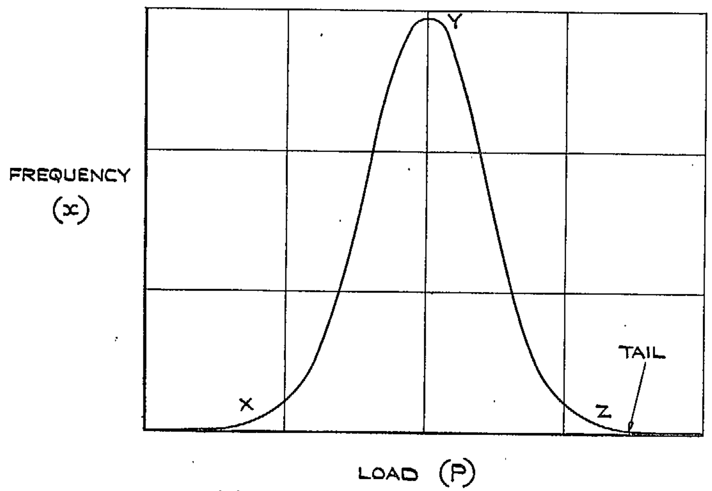

Fig. 4. Normal Frequency Curve.

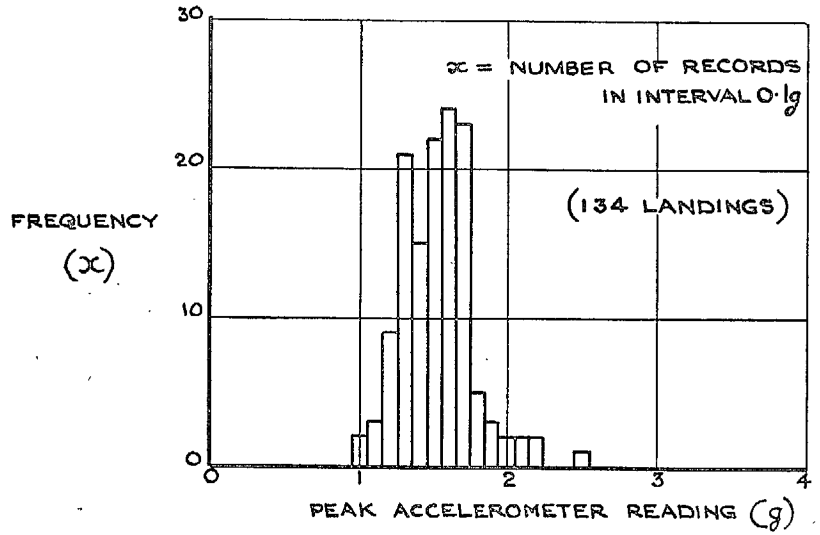

Fig. 6. Frequency Diagram.

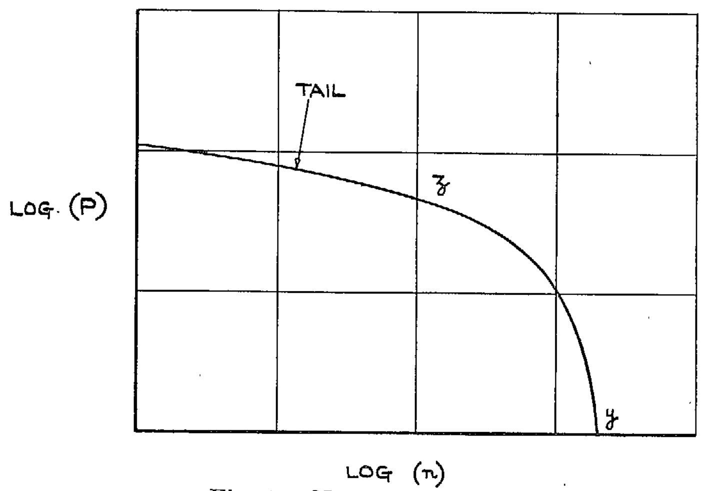

Fig. 5. Normal Logarithm Curve.

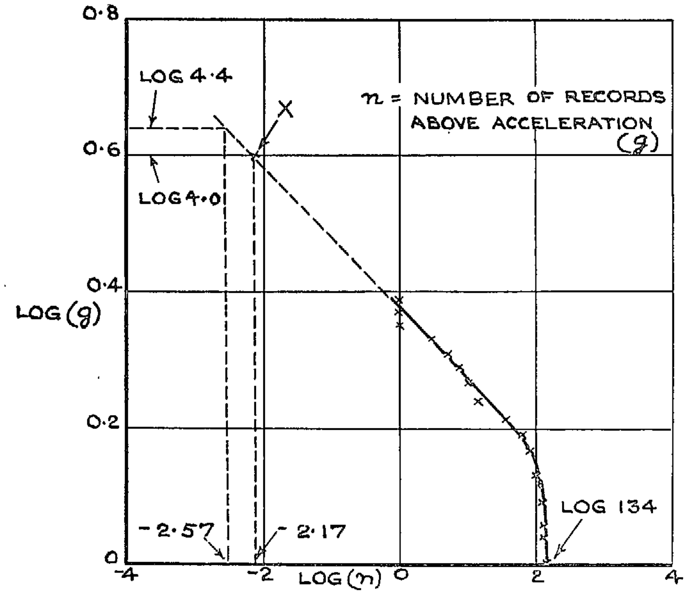

Fig. 7. Logarithm Diagram. Landings at Farnborough and Boscombe Down.

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