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Some Preliminary Results from V-g Recorders Installed in Military and Civil Aircraft

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Summary.—During the latter half of the 1939-45 war, V-g recorder slides were collected from a number of operational and training aircraft types, and about April, 1944, the scope was widened to include some commercial transport aircraft. A number of the results has been given limited circulation as Aeronautical Research Council papers, from heavy bombers in October, 1943, from fighters in January, 1944, and from twin-engined aircraft in April, 1944, and a summary of readings from commercial aircraft in 1946; this Report collects these scattered results into one body.

Part I outlines the method of collection of the slides, describes the nature of the readings obtained, and their method of presentation, and discusses the results. These are grouped roughly into classes, as heavy bombers, fighters, twin-engined aircraft, training aircraft and commercial transport aircraft, and the possibilities of comparison between different types performing the same role, and between different roles performed by the same basic type, are indicated.

Part II is a theoretical consideration of possible methods of analysis and extrapolation; it is pointed out that as the work has developed, first ideas have been enlarged or superseded, and finality is still far off. The advantages and disadvantages of several methods used up to 1946 are discussed, and suggestions are made for subsequent work.

Introduction.—In the determination of design loads for a new aircraft it is of great assistance to know not only the limiting accelerations which have been imposed on the current aircraft performing the same role, but also the approximate frequency of occurrence of all levels of acceleration, and the frequency of occurrence of high speeds. One instrument which goes some distance towards the provision of such data is the American-designed V-g recorder, a brief description of whose method of operation is given in Appendix I; a fuller account is contained in Ref. 6.

Collection of data has now proceeded for several years, and a considerable body of results has accumulated. A certain amount of this information has been given restricted publication[1 to 5]; final analysis of the rest has been delayed by shortage of staff. This report is intended to offer for wider publication those results which have previously been given a limited circulation, and which are of general application. Part I, therefore, consists of a rescript of the factual reports already mentioned. Part II concerns methods of analysis for purposes of extrapolation, and is based on Ref. 5. A list of the aircraft, readings from which are shown in the Report, is given in Table 1, together with some leading particulars.

* R.A.E. Report S.M.E. 3393, received 15th March, 1947. This report has been formed by combining the five following Tech. Notes :—

S.M.E. 188 (A.R.C. 7266), 204 (A.R.C. 7475), 232 (A.R.C. 7887), 368 (A.R.C. 9940), 303 (A.R.C. 8621).

PART I

1. *Method of Collection of Slides*.—1.1.—The records used in compiling this report have been obtained in two different ways. Those for all Service types were collected by the method now standardised in this country; as many instruments as could be made available were installed by the Royal Air Force (or in one case by the Royal Navy) in operational and training aircraft and the slides were regularly changed by squadron personnel. The flying period aimed at per slide was ten hours, but obviously this was subject to operational limitations, and on the average it worked out at rather more than this. (It is of course desirable from the statistical viewpoint that the flying time covered by each slide should be as nearly constant as possible.) Similarly, for results from commercial transport aircraft, the installation of the recorders and the changing of the slides were carried out by the staff of the airline concerned.

1.2. The slides from the Fortress, Liberator, Marauder, Lightning and Thunderbolt on the other hand were obtained by United States Army Air Force personnel from U.S.A.A.F. aircraft. The procedure adopted in this case was for two officers to service and maintain all the instruments, making periodic visits to the different stations to do so. The advantages of this method lay in the more uniform handling of slides, and in less work being required of squadron maintenance staff, but there was, of course, less control over the period covered by each slide. Photographs of these slides were kindly supplied to the Royal Aircraft Establishment by the American Army Air Corps and were analysed by Royal Aircraft Establishment staff.

2. *Nature of Readings Taken from the Slides and Method of Presentation*.—2.1. As described in the introduction, this report is a synthesis of Notes issued separately over a period of more than two years, and covering both military and civil aircraft. Ideas on the best method of presenting results changed slightly during that time; it happens, therefore, that the layout of the data for military aircraft involves the use of graphs, while for civil aircraft greater use is made of tables and histograms. The original method of presenting each class of results is retained here, as recasting would involve a considerable amount of work which would appreciably delay publication; it will be noticed that tables and diagrams which have been compiled at different times are not always in step with regard to the information they present.

2.2. Two types of reading are made, the first, which we may call Case I, being overall limiting values of acceleration and speed for the whole slide, and the second, Case II, being limiting values in a restricted area of the slide. These values are illustrated in Appendix II. It is to be noted that $1g$ represents level flight.

In Case I, the actual readings taken are:

(i) the highest acceleration shown on the slide;
(ii) the highest speed at which (i) occurs;
(iii) the algebraically lowest acceleration shown on the slide;
(iv) the highest speed at which (iii) occurs;
(v) the highest speed shown on the slide;
(vi) the highest acceleration associated with (v).

We have therefore three acceleration/speed combinations formed by (i) with (ii), (iii) with (iv) and (v) with (vi).

In Case II, the slide is divided into speed bands of a breadth of 50 m.p.h., such as 50 to 100 m.p.h.*, 100 to 150 m.p.h., etc., and the following readings are taken for each band:

(i) the highest acceleration shown;
(ii) the algebraically lowest acceleration shown.

* In the lower speed bands, up to 150 m.p.h. traces caused by landing accelerations are often mixed with those caused by flight accelerations. Care must be taken to read only the latter; because of this difficulty the 50 to 100 m.p.h. band was disregarded on many records.

2.3. Originally, for the military aircraft, the three acceleration/speed combinations defined in section 2.2, Case I, were plotted on a graph; these graphs are reproduced here as Figs. 1 to 10. As the numbers of slides received increased, multiple points became more frequent and the graphs became more confused and difficult to trace; a system of using different symbols to represent the number of times a point recurred proved clumsy and not very satisfactory. For civil aircraft, therefore, square tables were substituted for the graph, such that the figures in the body of the table showed the recurrences of each set of values of the acceleration/speed combinations defined in the previous paragraph; thus in Table 4(a) we see that a highest acceleration of $1 \cdot 6g$ occurs at a speed of 125 m.p.h. on 15 slides (combination (i) with (ii)). These tables are shown as Tables 4(a) to 4(e).

2.4. For Case II of section 2.2, graphical plotting was also used for military aircraft, these graphs being shown as Figs. 11 to 17. Owing to similar difficulties with large numbers of slides, a change to tabular presentation was again made for civil aircraft, the relevant tables being Tables 5(a) to 5(e). The same information is also given in histogram form in Figs. 18, 19.

2.5. A small amount of calculation has been performed on these results, to assist anyone who may wish to carry out further analysis. The mean m and the scatter, in the form of the standard deviation σ, have been listed in Table 2 for Case I, for all the quantities (i) to (v) in the case of civil aircraft, but for (i), (iii) and (v) only in the case of military aircraft; the total flying time represented, the number of slides used, and the overall highest or lowest value reached is also shown. Table 3 shows similar results for (i) and (ii) in Case II; in the case of high speed aircraft additional columns record the highest speeds occurring on every slide in each of a series of acceleration bands, namely 0 to $1g$, 1 to $2g$, 2 to $3g$ and 3 to $4g$, along with the flying times, m and σ.

2.6. For purposes of extrapolation, some log-log plots are reproduced (Figs. 20 to 27); the use of this is described in Part II, sections 1.1 and 2.6 to 2.9.

2.7. The acceleration readings are shown to the nearest $0 \cdot 1g$, and speeds to the nearest 5 m.p.h. (all speeds are A.S.I., no position error corrections being made, though figures are given in Table 1), but it is not claimed that results are accurate to this figure. With many different workers handling slides, it is not to be expected that uniformity of smoking will be reached, and if a slide is too heavily smoked, the trace may spread or the soot may flake, resulting in the reading being exaggerated. In addition, each instrument requires to be damped to suit the vibration characteristics of each particular aircraft. The response of an accelerometer depends on the damping coefficient, among other factors, and although it is believed that the degree of damping provided is such as to produce a reasonably true response over the whole range, it is possible that where excessive damping is required, as on the Typhoon, the accuracy of the response may be affected. In addition, vibration of the stylus broadens the trace, and leads to further inaccuracies in readings. There is also the difficulty of deciding on the zero setting of the calibration graticule. The practice has been followed of reading the limit of the trace, and not the centre; partly because a separate line may not be discernible, when there will be no indication of the thickness of the trace, and partly because the data obtained will be used for design purposes, in which case it is advisable for figures to err on the high side. In the calculations, more figures have been retained than are physically justifiable, to prevent the possibility of further errors creeping in.

3. *Discussion of Results.*—3.1. *General.*—3.1.1. In considering the V-g recorder results from a design point of view a difficulty arises owing to the fact that the accurate all-up weight of the aeroplane at the time of the recorded speeds and accelerations is usually unknown. One has, therefore, either to assume that the circumstances that led the pilot to execute a given manoeuvre might arise at any practicable all-up weight for the type, or to probe by enquiry the actual circumstances associated with, say, extreme recorded values of speeds or accelerations. Such

enquiries have been undertaken where possible as a routine and indicate generally that, for example, for heavy bombers the most violent manoeuvres commonly occur over the target area, but occasionally arise at any stage after crossing the enemy coast. It seems at present wise to assume in design that V-g records on operational bombers may apply to any practicable state of loading, including the case of full bomb and fuel load, though it will be realised that the frequency of occurrence of high V or g values at such high loadings must actually be substantially lower than this simple assumption implies. The figures of weights in Table I are for approximate maximum take-off weights at the time of collection of the slides.

3.2. *Heavy Bombers.*—3.2.1. Considering the Lancaster and Stirling, it is interesting to note from the Tables and Figures that the Lancaster seems rather more liable to high accelerations and speeds than the Stirling, but that peak accelerations on the latter tend to be associated with rather higher speeds. Except as regards the last point the Fortress and Liberator seem to be similarly related; (Table 2 and Fig. 2). The Liberator results are notable also for the curiously 'cramped' appearance of the plotted points on Fig. 2.

3.3. *Fast Single-Seat Aircraft.*—3.3.1. Turning to the fast single-seat aircraft, it must be realised that the tactical use is not identical. The Spitfire IX and Typhoon are a close parallel, although the question of operating altitude may affect the results; the Thunderbolt, which was at first the standard American fighter in this country, appeared to be largely limited to bomber escort duties, the Mustang version considered was a low-level reconnaissance and "train-busting" aircraft, which although armed evaded enemy fighters whenever possible, and the Lightning records are for the unarmed photographic reconnaissance version.

3.3.2. On examination of results, (Tables 2, 3, Figs. 3, 4, 5, 12, 13, 22, 23), it appears (Table 2) that although the Thunderbolt is represented by many more hours than any other type, both the overall limit and the mean positive acceleration and speed are lower than on either of the British fighters; only as far as average 'negative g' is concerned does the Thunderbolt show a slightly higher overall acceleration. The accelerations recorded on the Lightning are surprisingly close to those on the Thunderbolt, though the maximum and mean speeds are lower, the scatter of the speeds recorded is unusually small, and the scatter of the accelerations is also well below the average, suggesting that a routine tactic is followed fairly closely. Generally, the accelerations and speeds are the lowest of the five types considered. The Mustang appears as perhaps the most outstanding, the mean speed lying between that of the Spitfire and Typhoon, while the mean accelerations are by very little the highest. The overall maxima recorded in normal flying are not exceptional, compared with the other types.

3.3.3. When we examine the logarithmic frequency curves, (Figs. 22, 23), we see that the Spitfire shows a tendency to produce higher accelerations than the other types. The Thunderbolt shows much lower accelerations at the same frequencies, while the other three types lie somewhere in the middle with not very much to choose between them over the range 1 in 10^4 to 1 in 10^5 flying hours. The curves for the Typhoon, Mustang and Lightning pass reasonably smoothly through the points, but for both the Spitfire and Thunderbolt there are one or two isolated high accelerations, which appear to conflict with the main trend. This, of course, may be due to the high g's being due to appear only once or twice in a large number of hours, and having actually appeared early in their period; this then may be corrected as the flying time covered increases.

3.3.4. It is interesting to consider the Spitfire high acceleration figures in relation to Spitfire accidents. Total recorded flying hours, including both operational and non-operational, since the introduction of the Spitfire IX, to the date of writing of the original report[2], were about 66,000; five wing failures attributed to high accelerations had been reported, showing a rate of roughly 1 in 13,200 hours. This frequency, plotted on the graph, (Fig. 6), corresponds to a failing load of about $13\frac{3}{4}g$; alternatively, taking $10g$ as the known failing load, the frequency would be 1 in 800 hours. Both these figures assume that any record of such high accelerations arises only once on a given slide. There are, of course, two separate sources of error, one that given above concerning the plotting of the curve, and the other the fact that not all wing failures may be included in these statistics; correction for these two errors would decrease the estimated frequency of high accelerations, and increase the recorded frequency of accidents, thus bringing the figures closer together.

3.3.5. The logarithmic frequency curves for speed are generally more satisfactory than those for acceleration, although it is hoped that when more slides are available the smoothness will be further increased. The Mustang, Typhoon and Spitfire all show the same general tendency for the highest speeds to increase with increasing hours, while the curves for Thunderbolt and Lightning seem to indicate that there is a limiting speed which will not be exceeded no matter how many hours are recorded. This speed lies in the region of 530 m.p.h. for the Thunderbolt, and 480 m.p.h. for the Lightning. A possible cause may be that the then tactical use of these two machines did not fully utilise their potentialities.

For a frequency of 1 in 10^4 flying hours, the indicated speed of the Mustang is plotted as 650, the Typhoon as 680, and the Spitfire as 610 m.p.h. These speeds undoubtedly seem high, and the question arises whether the readings are dependable. It is known that on the Typhoon the A.S.I. reading is apt to contain a considerable error at speeds of Mach number higher than about 0·7 and it is possible that at speeds of 500 m.p.h. or over the figures used in the calculations were unduly high. This, however, would affect only the Typhoon to any great extent, and we should expect to see the slope of the curve greater than on the other two types; actually, the slope is practically the same for the three aircraft. In the majority of Typhoon slides, though the acceleration readings may be slightly open to question on the score of excessive vibration, as mentioned above, there appears no obvious reason to doubt the speeds.

3.3.6. There is one slide from a Typhoon which is worthy of notice on account of the speed shown. The main body of the record ends at a speed of about 450 m.p.h.; two separate traces extend beyond this, one up to just over 600 m.p.h. and back, the other up to 640 or 650 m.p.h. and back, one half of the latter trace lying between 0 and $-1g$, and the other half around $2g$. This might be caused by an inverted dive, followed by a gentle pull out, but the positive acceleration is so slight that the recovery must have been very gradual. The pilots who had flown the machine during the relevant period remembered no exceptional manoeuvres (on enquiry the highest speed reported was 450 m.p.h), and the aircraft showed no external evidence of damage. It appears fairly clear that the reading cannot be accepted as accurate (the slide was, of course, not included in the calculations), and a possible cause of the high reading would be a compressibility effect on position error—unfortunately there is no evidence on which any estimate of height can be based.

The highest acceleration recorded so far is about $10g$ on a Spitfire. The pilot was flying in formation with his Squadron, dived on some enemy, broke to port and pulled out hard to follow his No. 1, and so experienced the maximum acceleration while banked; he actually felt the load building up, so eased off, and then pulled back again. The speed was about 380 m.p.h. At the same time he was leaning far back in his seat, adjusting his reflector sight, so was in a good position to resist the effects of 'g'—he claimed not to have blacked out. Both mainplanes were severely buckled, with rivets pulled, and the upper skin of the port tailplane was crumpled under the effects of up-load, a buckle also being caused in the web of the tailplane rear spar.

Another outstanding acceleration was recorded on a Mustang. A pilot took up the aircraft with the intention of seeing how much g he could put on; he dived to under 1,000 feet and pulled out hard at about 400 m.p.h., going into a vertical climb before he levelled off; he then climbed and dived again, executing a series of tight turns. The record shows between 9 and $10g$ at about 400 m.p.h.; and again the pilot claimed not to have blacked out. The sole evidence of damage to the machine was some slight signs of incipient rivet pulling on stringers just outboard of the wheel wells. This slide was not included in the analysis, as it represented a flight of only ten minutes duration, in which a deliberate attempt was made to record high accelerations.

3.4. *Twin-engined Training Aircraft.*—3.4.1. The aircraft considered in this section can usefully be compared in a number of ways; for example, we can compare the Fighter and Coastal Command versions of the Beaufighter, the latter being a day-fighter, used mainly over the Bay of Biscay or in operations along the Norwegian coast, the former a night-fighter; we can compare the versions of the Mosquito unarmed bomber as against night-fighter, and then again we can compare the Beaufighter and Mosquito as two examples of a night-fighter. Such comparisons are interesting in investigations to determine whether it is necessary to design from the start for different functions, or whether one type can be adapted economically to fill different roles, and also from the tactical point of view. Detailed discussion of this sort will be reserved until larger numbers of slides have been obtained, when conclusions can be drawn with greater certainty, but some remarks concerning general trends are added.

3.4.2. For the Beaufighter, the day-fighter shows somewhat greater accelerations and speeds (Tables 2, 3, Figs. 6, 14, 24) than the night-fighter, as would be expected, although the latter includes day test and practice flying; the mean values are not markedly different, though such differences as exist are consistent, but the overall limits are appreciably more extreme, and extrapolated curves (Fig. 24) suggest that with increasing flying hours the differences will also increase. The two versions of the Mosquito (though as very few slides are available no definite tendency can be relied on) show on the whole no marked differences; the night-fighter shows more pronounced accelerations and higher speeds than the Beaufighter performing similar duties. (Tables 2, 3, Figs. 7, 15.)

3.4.3. Turning next to the class of light or medium bomber, we can compare as very close parallels the Boston, Mitchell and Marauder. (Tables 2, 3, Figs. 7, 8, 15, 25.) Air crews who have flown both regard the Boston as more manoeuvrable and more pleasant to fly than the Mitchell, though the only record showing corkscrew evasive action, which was obtained on a Mitchell, showed extremes of acceleration reached of $4g$ at 265 m.p.h., $3\frac{1}{2}g$ at 305 m.p.h., $-\frac{1}{2}g$ at 225 m.p.h. and 240 m.p.h., $0g$ at 170 m.p.h. and 280 m.p.h. The pilot said he handled the aircraft more violently than he would on operations. The figures quoted in Table 2 certainly suggest that the Boston is usually subjected to higher loads than either the Mitchell or the Marauder, and is also flown faster on the average than either of the others, though the Marauder has actually returned the highest speed so far recorded on any of these three types. While the Marauder averages a lower speed and acceleration than the other two, the extrapolated curves (Fig. 25) suggest that with increase of flying hours the peak values for this aircraft may become the highest of the three.

It may be remarked that three or four slides were obtained from an instrument placed near the tail of a Boston. A most pronounced increase in negative g was recorded, $-2g$ being fairly common at all points of the speed range, and $-3g$ being reached not infrequently.

3.4.4. The records obtained on the Wellington (Tables 2, 3, Figs. 9, 16, 26), cover three different uses, namely Coastal patrol, operational bomber, and gunnery training aircraft. (Results from the latter must be accepted with reserve, as the Mark III was not permitted to use full evasive action, and the attacking ' fighter ' being a Martinet, the speed also was limited.) The greatest number of flying hours was obtained on the Coastal Wellingtons, though a large proportion of the flying was probably routine patrol. The figures given by analysis of slides from the operational bomber are comparable with those obtained on the Lancaster and Stirling and as might be expected are more extreme than those appropriate to either of its other two functions. Extrapolation, however, (Fig. 26) shows that it is possible that the frequency of occurrence of high accelerations may in time be greatest for the Coastal Wellington, although the frequency of high speeds will be lower than that of the bomber. It is interesting to note that though the average flying time of a slide is much shorter on the gunnery training aircraft than on the other types, the curves produced are not materially different from the others, except of course at the low speed and low acceleration ends.

3.4.5. On the Master and Swordfish (Tables 2, 3, Figs. 10, 17), little need be said. Both are training aircraft, the first a general flying instruction type and the second used for torpedo-dropping practice. As might be expected, both show fairly close adherence to a mean value of acceleration, with a few points lying well away which bring up the value of the standard deviation; the Master also showed a fairly constant maximum speed.

3.4.6. An interesting feature which is apparent from the plots of the overall limiting accelerations and speeds (Figs. 6 to 10) and which is borne out by the plots for specified speed ranges (Figs. 14 to 17) is that for most aircraft, and particularly for Beaufighter and Mosquito, high acceleration tends to occur at speeds up to about the maximum level speed. Beyond this speed the peak accelerations fall away rapidly to about $1g$ at the maximum speeds recorded. This effect has been noticed in the majority of records from all aircraft and has led to the suggestion of designing for a lower g at diving speed than at maximum level speed.

3.5. *Commercial Transport Aircraft.*—3.5.1. The information sought from transport aircraft when analysing results may be either that obtained from the same type of aircraft operating on different routes, or that from different aircraft on the same route. The former is possible in the case of the Boeing Clipper, since the northern Atlantic route Poole–Foynes–Botwood–Baltimore was flown in the summer, and the southern Atlantic route Poole–Foynes–Lisbon–W. Africa–Brazil–Bahamas–Baltimore in the winter. The latter is not yet available though later it may be possible to compare Liberator and Boeing Clipper on the North Atlantic route.

3.5.2. Comparing the results from these two Atlantic routes (Tables 2, 3, 4, 4d), we find that as far as limiting accelerations per slide are concerned, both the average and the overall values are more extreme for the northern route in summer than for the southern route in winter; the average speed at which the highest and lowest accelerations occur is lower on the northern route, establishing that the pilots do in fact react to the gusty weather by reducing speed. The variation of highest speed from slide to slide is very similar for the two routes, but the histograms of limiting accelerations per slide in speed bands again show the tendency for more extreme accelerations to be more frequent on the northern route (Fig. 19).

3.5.3. Another comparison that can usefully be made is between the DH. 86 and the DH. 89A (Tables 2, 3, 4a, 4b, 18). These two aircraft are very similar, but the former is four-engined and the latter a twin. The routes they cover are rather similar—both the Speke to Belfast and mainland to Shetland runs can be fairly windy. We see first that the DH. 86 appears to operate normally at a higher speed, as mean highest speeds and speeds of extreme accelerations are higher than for the DH. 89A, although the latter aircraft has recorded a higher overall highest speed. Secondly, both positive and negative departures from the steady level flight acceleration are more extreme for the DH. 86 than for the DH. 89A. Gust calculations for each aircraft might show whether this difference is attributable to different cruising speeds or whether the gusts themselves are more intense on the Speke to Belfast route.

3.5.4. The most remarkable result obtained from the Dakota is the very low negative g recorded in many slides, accelerations of less than zero being quite frequent. (Table 2, 3, 4a, 19.)

3.5.5. Log-log curves (Fig. 27) were drawn only for Clipper on the northern Atlantic outer, D.H. 86 and D.H. 89A, as there were too few slides for the other types to determine a smooth curve. Even those which were drawn are not very precisely determined, and further information will very possibly alter appreciably the extrapolated values. A curious kink is seen in the points for the log-log curve for maximum accelerations for the D.H. 89A; a smooth curve has been drawn, but a large number of points lie well off it. These log-log curves are, therefore, included rather as an illustration of the method than as a serious attempt at extrapolation; many more readings are required before much reliance can be placed on any values obtained from these curves.

4. Further data from these and other types are in the process of being analysed, and it is intended later to publish a further report to include all the results available.

PART II

1. *Methods of Analysis.*—1.1. For the purpose of estimating the probable frequency of occurrence of speeds or accelerations higher than those actually recorded, the method adopted in this Report (Fig. 20 to 27) is the so-called 'log-log plot'. This involves plotting log (acceleration or speed) against log (reciprocal of frequency), this reciprocal being the total time covered by the slides divided by the number of occurrences of an acceleration or speed. The extrapolated part of the curve is usually a straight line or a smooth curve asymptotic to a horizontal straight line.

1.2. In one of the early reports[7] the main method of analysis suggested was to calculate $m + k\sigma$, where m is the mean of the readings (either acceleration, overall or in a band, or speed) and σ is the standard deviation; k is a constant. It can be shown that when the distribution of events being investigated follows the normal frequency or Gaussian law, k can be tabulated against n so that the frequency of $m + k\sigma$ is 1 in n, k depending only on n and not on m or σ; *i.e.*, a value of $m + k\sigma$ would appear once in n slides. It was assumed that the frequency distribution of acceleration and speed readings would be Gaussian, and values of k were accordingly taken from the standard tables. By analysing the speed bands in this way, an envelope can be drawn showing the highest and lowest accelerations expected in a certain number of hours flying time (equal to n times the average flying time per slide), and a third curve can be added to show the highest speed expected in each acceleration band. It may be noted that it was shown that the shape of the envelope depended on the value of k used, *i.e.*, on the expected frequency of occurrence of the accelerations. Difficulty arises, however, in fitting these three curves together, at the high-speed end of the stressing diagram, and it is precisely these corners at which information is required. Further objections are discussed later.

1.3. In an effort to present a complete picture of what happens in the areas of extreme high and low accelerations at high speeds, an attempt was made to extrapolate along lines of constant incidence, *i.e.*, along straight lines through the origin on the n vs. V^2 diagram. Great difficulty was experienced in reading, however, as the graticule for the V-g recorder slide is curvilinear, on a scale which lies between V and V^2; the preparation of direct-reading graticules would be difficult and complicated, and the labour of taking the necessary readings from the present graticules when several thousand slides were involved would be overwhelming.

2. *Theoretical Considerations.*—2.1. It is obviously important that when curves are drawn which purport to show frequencies of occurrence and acceleration larger than any yet recorded, that the method used should have a strong theoretical basis, and that the implications involved are logically sound. It is necessary therefore to examine all methods used to test their reliability.

2.2 Let us first discuss the methods described in sections 1.2 and 1.3, as the same fundamental idea lies behind both. The crucial point is the determination of k. It was pointed out that the values of k used were those derived from a Gaussian curve. Now a frequency distribution curve for accelerations is necessarily skew; in the case of a bomber, for example, $2g$ is an average maximum, a maximum reading lower than $1g$ obviously cannot be recorded, and figures of $3g$ and more have been shown on numerous occasions. The curve, therefore, is not symmetrical, the greatest discrepancy between it and a Gaussian curve lying in the region of high accelerations of low frequency, and it is precisely into these regions that we desire to extrapolate. To use this method, therefore, a frequency curve will have to be drawn for each band, a standard curve fitted to it, and the appropriate value of k chosen.

2.3. It has already been pointed out that a clear picture of the area of intersection of extrapolated curves is difficult to obtain. Using two separate curves for acceleration and speed, either a considerable distance has to be faired in with no points to guide the line, or there is a considerable overlap, and a decision has to be made which points to neglect. If the method of radial plotting is followed, a considerable number of lines has to be drawn (thus adding greatly to the labour) to ensure sufficient points are obtained to enable a reliable curve to be drawn.

2.4. There is another factor which creates difficulty at the high-speed end. It will be realised that when a band at the high-speed end is being analysed, not all the slides will show a reading in that band, and in particular the final band, which terminates at the maximum diving speed, will show comparatively few readings. If we have p slides, q of which show a reading, and r of these reach xg, the frequency of xg is r/p, but the method of extrapolation must realise the significance of q. The actual method proposed is to draw a frequency curve for the highest speed per slide, and determine the frequency with which a reading would be recorded in the required band, say $1/m$ (which may not be exactly q/p). If the ultimate frequency to which extrapolation is required is $1/n$, that value of k is taken which corresponds to m/n, *i.e.*, an acceleration which occurs once in n/m slides showing a reading will occur once in n total slides.

2.5. A further point arises in the extrapolation of $m + k\sigma$ in bands as to the exact meaning of the extrapolation. It has been pointed out that if we divide up the speed range into, say, ten bands, and extrapolate within each band to a frequency of one in ten, we can construct an envelope which will be reached in each band once in ten slides. In ten slides, therefore, the envelope will be reached somewhere ten times, several times on some slides, and not at all on others. From the table on page 62 of B.S. 600R[8], we see that out of ten slides the envelope will be reached on six, and will not be reached on four. We, therefore, when extrapolating to a frequency of one in ten in each of ten bands, actually produce a frequency of six in ten somewhere on the slide, and by increasing the number of bands further we increase the final frequency. (This point, about taking the frequency of slides on which an acceleration is reached and not the frequency of the acceleration will be discussed more fully later).

If, therefore, we desire to obtain a design envelope with different factors for different speeds, we need to extrapolate in each band to a much lower frequency than we require for the overall result. Since k is larger, therefore, it is all the more important that its value should be known exactly, and any inaccuracy due to taking it from a Gaussian frequency curve will be more pronounced.

2.6. The method of extrapolation by log-log curves remains to be considered. There are two main objections to this method, first that since the plotting is on a logarithmic scale, a slight variation in the 'best line' which can be drawn through a number of points will produce a considerable difference in the frequency corresponding to a fixed acceleration, and secondly, that the shape of the lower end of the curve is conditioned by the period for which the slide is left in the instrument. It is also argued that as the results obtained from a V-g recorder are only frequencies at which certain accelerations are the highest on its slide, and not their absolute frequencies, accident rates cannot accurately be collated with these results.

2.7. The first objection has a great deal of weight behind it. The only satisfactory way round is to collect sufficient slides to establish a fairly reliable line. The major snag is, of course, that if a failure is likely to occur once in a certain period, we will not know about it, as the chances are the loss will be put down to ordinary operational loss, and not to structural failure; the upper part of the line will therefore be based on incomplete information. There is one case of a slide being recovered from a Halifax which broke up in the air, but that should probably be regarded as an unusual stroke of luck.

2.8. There is not very much which can yet be done about the second objection. A method has been developed[9] to establish from the V-g records the absolute frequency of an acceleration. The fundamental assumption is made, however, that 'the occurrences of any load are not upset in their distribution by occurrences of any other load'; what is in effect a correction term is developed, to take account of accelerations which are masked by higher accelerations. The assumption is, however, in the present author's belief, totally unjustified. A number of Lancaster slides were examined at random, and every one which showed any acceleration above $2g$ showed at least two peaks above this value. It can be argued theoretically that the assumption will not hold; for if a fighter pilot makes a sortie without seeing the enemy, he will probably record not more than $4g$, possibly even $3g$; if he sees enemy vehicles on the ground to be attacked, he will almost invariably dive several times, pulling out each time, as the practice is to pick out one vehicle, and break away after that single attack, regaining height, and diving again on the next target. Similarly if a bomber pilot is forced to carry out evasive action (in the absence of which he rarely exceeds $2g$ or at least $2\frac{1}{2}g$) he will almost certainly perform more than one cycle of the corkscrew. Thus, if a high acceleration is recorded once, several accelerations of the same order will very probably be recorded on the same occasion.

In symbols, the assumption may be written that, if xg is the highest acceleration recorded on p slides out of n, and yg on q slides, x being greater than y; yg will also occur $q \, . \, p/(n-p)$ times along with xg, and the method effectively finds the value of $q(p/(n-p) + r/(n-r) + \ldots.)$, etc. for all accelerations higher than yg, adding a further theoretical correction to allow for repeated readings. In the writer's opinion, according to the reasoning given above, the correction term should be $kqp/(n-p)$, where k is an unknown constant, which may lie anywhere between $1\frac{1}{2}$ and 4.

A check on the result obtained in the Note[9] was obtained from 'flight analyser' records flown on a Fortress. It is unfortunate that this was the only check available, as the Fortress is the most likely aircraft to obey the assumption made, due to its tactical use; as the aircraft of a squadron or group fly in close formation, their ability to use evasive action is strictly limited when in the region of heavy flak defences. Also, the bombing run is much longer than that for British bombers, and once entered upon, it cannot be broken off and a second attempt made. Thus the comparison only suggests that the method may give reasonable results for an American heavy bomber, and no inference can be drawn as to fighters and British heavy bombers. It is probably significant that the correction shown is less than that required to fit the curve derived from flight analyser results.

It is suggested, that if the method be applied to analysis of each speed band individually, and the resulting frequencies added, the final result might be nearer the actual distribution, as so much more of the information from the V-g slide, which at the moment is not being used in the application of this method, would play its part in the calculations, and the fundamental assumption would be more likely to hold for a limited speed range (although in the case of ground strafing or corkscrewing, the speeds of successive manoeuvres would still be fairly close). The difficulty would arise, however, that the same manoeuvre frequently extends into two or more speed bands, and so would tend to be counted more than once.

2.9. There is one argument which seems to the author to have considerable bearing on the whole problem of extrapolation of results, which does not appear to have been put forward yet; it is suggested here only as a basis for further thought and discussion. It affects only extrapolation to frequencies of high acceleration in the region of proof or ultimate loads, or to frequencies of high speeds; the problem of fatigue loading (as an answer to which the method just discussed was devised) does not appear likely to be readily solvable by the use of the V-g recorder alone, and probably will have to await the collection of a body of results from some statistical accelerometer, which may be used in conjunction with a much larger amount of data obtained from V-g recorders on the same aircraft type.

It is suggested that what is important from the point of view of ultimate loads is not the frequency of actual accelerations, but the frequencies of periods of high acceleration, typified by the highest acceleration recorded during a period. In the later stages of the 1939–45 war, on bomber aircraft, there was a tendency for each slide to cover only one sortie; slides for one fighter aircraft usually covered more than one sortie. If a frequency curve was drawn showing the absolute acceleration frequency distribution, we might find, for example, that certain values might be expected three times in 30,000 flying hours; the conclusion would then be drawn that if this figure was used as the ultimate design factor, an accident rate of 1 in 10,000 hours might be expected. Actually, it is possible that owing to repetition of heavy loading during the same sortie, or on successive sorties, the acceleration might be due to appear twice on the same slide, and therefore from the failure point of view, the frequency would be 1 in 15,000 hours—a significant difference. For the aircraft does not know the limits of acceleration imposed by its own strength; the only limits it knows are aerodynamic ones, due to elevator power, etc. So we should calculate that three occurrences of the failing load were due to occur in 30,000 flying hours, and then actually only two would show up (assuming it was known at all that they occurred, *i.e.*, assuming the slides could be recovered), as the third would be statistically due to appear on an aircraft that had failed previously on the same flight. To counteract this, if extrapolations were made from absolute frequency curves, the suggested failure rates would have to be amended by performing auxiliary calculations on the probability of occurrence of two or more failing loads on the same flight. The results from direct plotting of overall maximum readings from V-g recorders would, however, already give the frequency of flights on which failure might be expected—which is the significant value from an accident point of view.

3. *Methods of Analysis to be Followed when more Slides are Available.*—3.1. So far only a limited number of slides has been available, insufficient to allow of any very definite conclusions being drawn. It was therefore thought desirable to publish results rather than elaborate analyses. Several curves have been drawn however, which might yield useful and interesting results when a greater number of slides can be included.

3.2. In section 2.3 of Part I it was said that results had been shown by plotting peak acceleration against corresponding speed, both overall and in bands and that difficulty was experienced when results from large numbers of slides had to be shown. A possible alternative method is to draw frequency curves of acceleration, maximum and minimum, overall and in bands, and of maximum speeds, overall and in acceleration bands where the range justifies it; from these curves the variation of most frequent acceleration with speed would be visible, which would show the pilot's tendency to limit his acceleration (or not to limit it!) as speed increases. Another curve could show the frequency distribution of the speed at which overall peak accelerations occur, independently of acceleration value, again showing whether a pilot tends to pull out most violently when travelling at high speed or not—the curves of course would also be affected by the aerodynamical limitations of the aircraft. Cross plots could also be drawn, showing the frequency distribution of a fixed acceleration at different speeds, and of a fixed speed at different accelerations.

3.3. It is also thought that this method of log-log curves should be extended to the accelerations in each speed band, and used to draw envelopes of accelerations to be expected at different speeds for various frequency levels. These could be compared with envelopes prepared from the $m + k\sigma$ formula, k being derived from the normal frequency curve; and if the actual frequency curves could be established, the correct k should be used as well, to illustrate the actual loss by assuming a normal frequency curve.

It may be found of course that some of these ideas are inapplicable in practice, but it is hoped that some curves at least can be presented to illustrate possible lines of development of analysis, and to suggest which of the different methods tried is the most likely to arrive at the desired result. Owing to shortage of staff, however, there is no prospect of immediate work along these lines.

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APPENDIX I

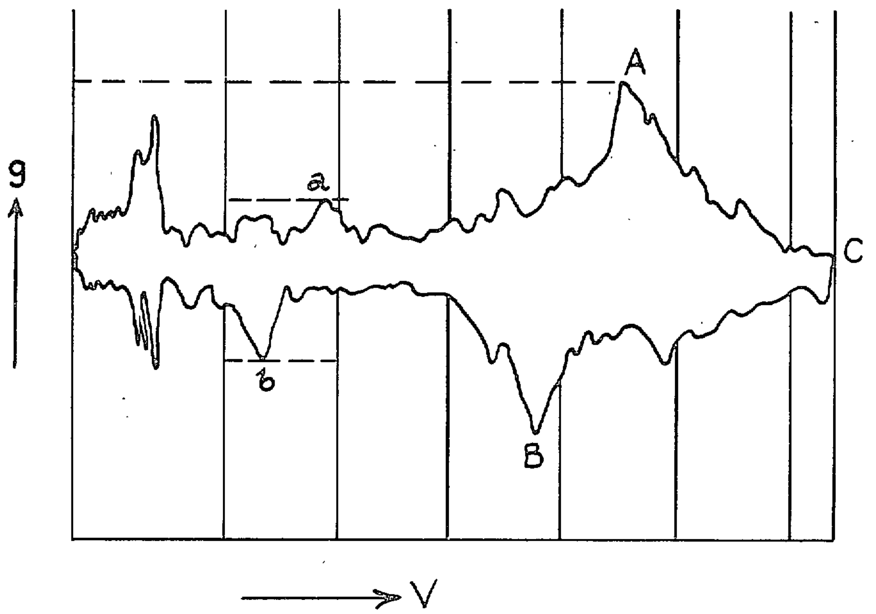
Description of the V-g *Recorder and its Use*

This instrument comprises a spring-controlled moving-weight recording accelerometer, together with an air speed system connected to the pitot static system of the aircraft. A stylus is moved in one direction by alterations of acceleration, and in a direction at right angles by alterations of air speed; this stylus inscribes a trace on a smoked glass plate or slide, in effect drawing a graph of g against speed. The slide is periodically removed, lacquered to prevent smudging of the trace, and the data read by superimposing on it a transparent graticule or calibration grid. Each instrument is individually calibrated and periodically checked. Readings are made to the nearest $0 \cdot 1g$ and 5 m.p.h., though it cannot be claimed that the accuracy is as high as this, due to possible maladjustment of the damping of the instrument or to spreading or flaking of the trace because of heavy or uneven smoking of the slide. The error should, however, lie within $\pm 0 \cdot 25g$ and calculations are made to $0 \cdot 1g$ to guard against additional loss of accuracy with large numbers of slides.

APPENDIX II

Illustrations of Readings taken from a V-g *Recorder Slide*

The boundary described by the stylus of the recorder on a slide appears after a few hours flying in the typical form indicated below:



The highest and lowest accelerations recorded on the slide are at points A and B associated each with its particular speed. The highest speed is indicated by the point C associated with its appropriate acceleration. For a given speed range, say 100 to 150, the highest and lowest accelerations are typically as shown at a and b.

TABLE I

		TAKE-OFF (ROUGHLY AT TIME OF COLLECTION OF RECORDS)	WEIGHT (LB.) FOR STRESSING	WING AREA GROSS (SQ. FT)	WING LOADING LB./SQ.FT.	SPAN (FT)	ASPECT RATIO	THICKNESS / CHORD RATIO	$\frac{dC_L}{d\alpha}$ (PER DEGREE)	C_L MAX (FLAPS UP)	WING SECTION	LIMITING DIVING SPEED M.P.H.	POSITION ERROR CORRECTIONS * 100-150 M.P.H.	150-200 M.P.H.	200-250 M.P.H.	250-300 M.P.H	300-350 M.P.H	350-400 M.P.H
BEAUFIGHTER	(NIGHT FIGHTER) (COASTAL COMMAND) (FIGHTER)	21,340	22,000	503	42	57·8	6·6		0·075	1·4	RAF. 28	400 (AUG '44)	5	0	0	-5		
BOEING CLIPPER	COMMERCIAL TRANSPORT.	39,500																
BOSTON	MEDIUM BOMBER	20,490		465	44	61·0	8·1							-5	-10	-10		
D.H. 86	COMMERCIAL TRANSPORT.	10150																
D.H. 89A	COMMERCIAL TRANSPORT.	55,000		340	16	48	6·8											
DAKOTA	COMMERCIAL TRANSPORT.	28,000		989	28	95	9·1					200 (MAR '46)	6	5				
FORTRESS	HEAVY BOMBER (U.S.A. A.F.)	53,200	40,260	1430	37	104	7·6	18% ROOT										
LANCASTER	HEAVY BOMBER	63,000	60,000	1297	49	102	8·0	9% TIP	0·081	MORE THAN 1·6	NACA 23000 SERIES	360 (MAY '44)	10	10	5			
LIBERATOR	HEAVY BOMBER (U.S.A.A.F.)	56,000		1048	53	110	11·5						-5	-5	-5			
LIGHTNING	UNARMED PHOTO-RECONNAISSANCE (U.S.A.A.F.)	15,000	14,467	327	46	52·0	8·3		0·091	1·45								
MARAUDER	MEDIUM BOMBER (U.S.A.A.F.)	26,340		664	40	71·0	7·6						0	5	10	10		
MASTER	TRAINER	5,330		224	24	35·75	5·7					290 (JULY '44)	-5	-10				
MITCHELL	MEDIUM BOMBER (U.S.A.A.F.)	26,090		610	43	67·6	7·4						5	5	5	10		
MOSQUITO	(NIGHT FIGHTER (UNARMED BOMBER	19,780 20,800	17,000	454 450	42 46	54·2 54·2	6·5 6·5	14% ROOT 8·6% TIP	0·075	1·4	RAF. 34 MODIFIED		0 0	0 0	0 0	0 0		
MUSTANG	HIGH SPEED RECONNAISSANCE	8,620		233	37	37·0	5·9						5	5	0	-5	-5	-10
SPITFIRE IX	FIGHTER	7,240	6800	242	30	36·8	5·6	13·2% ROOT 6% TIP	0·077	1·4	NACA 2200 SERIES		5	0	0	-5	-5	
STIRLING	HEAVY BOMBER	70,000	54,000	1453	48	99·0	6·7	20% ROOT 9% TIP	0·074	1·5	GÖTTINGEN 436 MODIFIED	295-325 (JAN '44)	5	0	-5	-10		
SWORDFISH	TORPEDO-DROPPING TRAINER	9,250		356 273	15	45·5 43·75	5·8 7·0					237 (APRIL '44)	0	0				
THUNDERBOLT	FIGHTER (U.S.A.A.F.)	12.430		300	41	40·8	5·6							5	10	10		
TYPHOON	FIGHTER	10,960	10,500	279	39	41·5	6·2	19·3% ROOT 13% TIP		1·5	NACA 2200 SERIES	525 (MAY '45)	0	-5	-10	-15	-20	25
WELLINGTON	(BOMBER) (COASTAL COMMAND) (PATROL) (GUNNERY TRAINER)	34,520	33,000	840	41	86·4	8·9	17% ROOT 10% TIP			NACA 2400 SERIES	320 (JULY '44)	10	5	0	-5		

* + DENOTES ADD CORRECTION TO A.S.I.R

TABLE 2

AIRCRAFT TYPE	ROUTE	No. OF SLIDES	TOTAL FLYING HOURS	AVERAGE FLYING TIME PER SLIDE	UPPER LIMIT OF ACCLLERATION PER SLIDE			SPEED AT UPPER LIMIT OF ACCELERATION M.P.H. A.S.I.			LOWER LIMIT OF ACCELERATION PER SLIDE			SPEED AT LOWER LIMIT OF ACCELERATION M.P.H. A.S.I.			HIGHEST SPEED PER SLIDE M.P.H. A.S.I.		
					OVERALL	MEAN	σ	OVERALL	MEAN	σ	OVERALL	MEAN	σ	OVERALL	MEAN	σ	OVERALL	MEAN	σ
LANCASTER		34	450	13·2	3·0	2·1	0·47				-0·4	0·24	0·25				325	260	25
STIRLING		31	380	12·2	3·2	2·1	0·39				-0·5	0·25	0·32				315	250	27
FORTRESS		82	1700	20·7	3·0	1·9	0·34				-0·2	0·30	0·23				305	220	20
LIBERATOR		59	825	14·0	2·5	1·9	0·23				-0·3	0·17	0·28				265	238	14
SPITFIRE IX		48	552	11·5	10·0	4·9	1·47				-5·8	-0·3	1·01				490	410	39
TYPHOON		55	650	11·8	7·5	5·1	1·20				-3·3	-0·2	0·70				530	440	42
THUNDERBOLT		118	1654	14·0	6·6	3·7	0·84				-2·1	-0·5	0·52				485	390	44
LIGHTNING		34	345	10·1	6·6	3·6	1·07				-1·9	-0·4	0·35				415	370	26
MUSTANG		11	105	9·6	6·7	5·2	1·23				-2·0	-0·6	0·65				475	415	44
BEAUFIGHTER.F		13	208	16·0	3·4	2·5	0·43				0	0·3	0·21				340	290	20
BEAUFIGHTER.C		25	322	12·9	5·0	2·9	0·81				-0·6	0·1	0·24				385	300	32
MOSQUITO.F		11	111	10·1	3·9	3·1	0·50				-0·8	-0·1	0·40				395	350	25
MOSQUITO.B		6		10·	3·6	3·0	0·41				-1·0	-0·4	0·37				360	350	6
BOSTON IIIA		37	539	14·6	5·6	3·4	0·92				-2·4	-1·1	0·65				380	335	23
MITCHELL		30	600	20	4·0	3·2	0·64				-1·6	-0·4	0·47				360	295	34
MARAUDER		37	770	20·8	4·8	2·3	0·65				-2·4	-0·7	0·66				410	285	28
WELLINGTON.B		16	157	9·8	3·1	2·3	0·43				-0·2	0·1	0·28				285	250	20
WELLINGTON.C		20	279	14·0	2·6	1·7	0·38				0	0·5	0·25				275	230	17
WELLINGTON.T		26	52	2·0	2·4	1·7	0·28				0	0·4	0·18				245	200	20
MASTER		15	173	11·5	5·5	3·9	0·55				-1·7	-1·1	0·40				300	275	14
SWORDFISH		10	128	12·8	4·3	3·1	0·51				-0·8	-0·3	0·27				255	225	15
CLIPPER	NORTH ATLANTIC	43	763:00	17:45	2·3	1·62	0·22	175	144	18	-0·8	0·31	0·32	185	138	20	200	178	10
CLIPPER	SOUTH ATLANTIC	25	297:55	11:55	2·0	1·54	0·20	190	160	18	0	0·34	0·18	175	148	11	200	180	11
D.H.86	OVER BRITISH ISLES	255	867:05	3:24	2·2	1·64	0·18	165	134	11	-0·3	0·39	0·23	170	134	11	170	151	7
D.H.89A		89	367:25	4:08	2·3	1·40	0·20	175	125	14	0·1	0·73	0·15	160	120	17	185	144	9
DAKOTA	ENGLAND N.AFRICA	21	1234:35	58:46	2·4	1·96	0·27	175	150	21	-0·8	-0·13	0·49	210	145	26	225	198	17

NOTE:- (i) THROUGHOUT THESE TABLES 1g REPRESENTS LEVEL FLIGHT
(ii) ALL SPEEDS ARE M.P.H. A.S.I.

TABLE 3

Aircraft Types	Speed Band m.p.h. A.S.I.	No. of slides	Total flying time	Average flying time per slide	Upper limit of Acceleration per slide: Overall	Upper limit: Mean	Upper limit: σ	Lower limit of Acceleration per slide: Overall	Lower limit: Mean	Lower limit: σ	Highest Speeds: No. of slides	Highest Speeds: Total flying time	Highest Speeds: Average flying time per slide	Highest Speeds: Overall	Highest Speeds: Mean	Highest Speeds: σ	Highest Speeds: Acceleration range
Lancaster	100–150	34	450	13·2	2·8	1·7	0·41	—0·4	0·39	0·28							
	150–200	34	450	13·2	3·0	2·0	0·44	—0·3	0·33	0·30							
	200–250	34	450	13·2	2·9	1·9	0·40	0·2	0·49	0·17							
	250–300	18	210	11·7	2·0	1·3	0·22	0·4	0·72	0·15							
Stirling	100–150	31	380	12·3	2·6	1·7	0·30	—0·5	0·44	0·29							
	150–200	31	380	12·3	2·7	1·9	0·35	—0·4	0·40	0·32							
	200–250	31	380	12·3	3·2	2·0	0·45	—0·1	0·55	0·27							
	250–300	15	130	8·7	2·6	1·9	0·38	0	0·81	0·38							
Spitfire IX	100–150	46	531	11·5	3·6	2·25	0·60	—0·7	0·3	0·36	48	552	11·5	530	400	43	0–1g
	150–200	48	552	11·5	4·4	3·2	0·71	—1·0	0·1	0·36	48	552	11·5	530	405	39	1–2g
	200–250	48	552	11·5	6·0	3·9	0·89	—1·5	—0·1	0·50	48	552	11·5	530	395	47	2–3g
	250–300	48	552	11·5	7·2	4·3	1·14	—1·8	—0·1	0·55	46	527	11·5	490	365	61	3–4g
	300–350	48	552	11·5	8·3	4·2	1·40	—1·8	+0·1	0·52							
	350–400	47	538	11·4	10·0	3·6	1·59	—5·1	0·2	0·89							
	400–450	30	441	14·7	5·2	2·9	0·98	—5·8	0·4	0·60							
	450–500	6	75	12·5	7·1	3·05	1·91	—0·4	0·3	0·34							
Typhoon	100–150	49	587	12·0	3·0	2·0	0·41	—0·4	0·2	0·30	55	650	11·8	530	430	45	0–1g
	150–200	54	638	11·8	5·6	2·8	0·93	—1·8	0·1	0·48	55	650	11·8	530	440	42	1–2g
	200–250	54	638	11·8	5·6	3·9	0·90	—1·4	0·1	0·45	54	641	11·9	530	425	35	2–3g
	250–300	55	650	11·8	6·4	4·6	0·96	—3·2	0	0·70	53	628	11·8	525	405	48	3–4g
	300–350	55	650	11·8	7·2	4·8	1·54	—3·3	0	0·48							
	350–400	55	650	11·8	7·5	4·5	1·20	—3·2	0·2	0·43							
	400–450	42	485	11·5	7·3	4·1	1·50	—3·0	0·3	0·67							
	450–500	20	232	11·6	6·0	3·0	1·28	—0·5	0·6	0·40							
Beaufighter (Coastal)	100–150	25	322	12·9	2·6	1·5	0·28	0·1	0·5	0·28	25	332	12·9	365	285	34	0–1g
	150–200	25	322	12·9	3·4	1·9	0·43	0·2	0·5	0·16	25	332	12·9	385	295	32	1–2g
	200–250	25	322	12·9	4·1	2·6	0·64	—0·6	0·1	0·25	23	314	13·6	385	275	39	2–3g
	250–300	25	322	12·9	5·0	2·4	0·95	—0·5	0·4	0·30							
	300–350	9	124	13·8	4·5	2·4	1·03	0·5	0·8	0·25							

TABLE 3—*continued*

Aircraft Types	Speed Band m.p.h. A.S.I.	No. of slides	Total flying time	Average flying time per slide	Upper limit of acceleration per slide: Overall	Mean	σ	Lower limit of acceleration per slide: Overall	Mean	σ	Highest Speeds: No. of slides	Total flying time	Average flying time per slide	Overall	Mean	σ	Acceleration range
Beaufighter (Fighter)	100–150	13	208	16·0	2·2	1·8	0·25	0·3	0·6	0·15	13	208	16·0	315	290	15	0–1*g*
	150–200	13	208	16·0	3·0	2·4	0·39	0	0·4	0·22	13	208	16·0	340	290	20	1–2*g*
	200–250	13	208	16·0	3·4	2·5	0·44	0	0·3	0·26	11	187	17·0	340	255	32	2–3*g*
	250–300	13	208	16·0	2·9	2·0	0·42	0·1	0·6	0·21							
	300–350	3	98	32·7	2·8	2·1	0·50	0·8	0·9	0·09							
Marauder	150–200	26	448	17·2	4·5	2·2	0·72	−2·4	−0·6	0·71	26	448	17·2	400	290	30	0–1*g*
	200–250	26	448	17·2	4·8	2·2	0·68	−2·0	−0·6	0·67	26	448	17·2	410	290	31	1–2*g*
	250–300	26	448	17·2	3·8	2·0	0·51	−1·7	0·1	0·51	18	319	17·7	410	245	59	2–3*g*
	300–350	3	56	18·7	4·4	2·6	1·28	−1·3	0·0	0·40							
Mitchell	150–200	25	480	19·2	3·2	2·2	0·49	−1·6	−0·2	0·59	25	480	19·2	355	290	36	0–1*g*
	200–250	24	453	18·9	4·0	3·0	0·61	−1·6	−0·3	0·49	25	480	19·2	360	295	37	1–2*g*
	250–300	24	453	18·9	4·0	2·9	0·75	−1·2	0·2	0·50	24	453	18·9	350	270	39	2–3*g*
	300–350	9	254	28·2	3·5	2·3	0·75	−0·4	0·5	0·37							
Mosquito F	150–200	11	111	10·1	3·0	2·0	0·47	−0·3	0·3	0·30	11	111	10·1	360	340	20	0–1*g*
	200–250	11	111	10·1	3·5	2·6	0·43	−0·7	0·1	0·38	11	111	10·1	390	350	24	1–2*g*
	250–300	11	111	10·1	3·8	3·1	0·52	−0·8	0	0·35	11	111	10·1	395	330	37	2–3*g*
	300–350	11	111	10·1	3·9	2·5	0·72	0	0·4	0·33	6	57	9·5	335	300	24	3–4*g*
Mosquito B	100–150	6	63	10·5	2·1	1·8	0·19	−0·3	0·1	0·26	6	63	10·5	360	350	10	0–1*g*
	150–200	6	63	10·5	2·9	2·4	0·30	−0·2	0·2	0·32	6	63	10·5	360	350	6	1–2*g*
	200–250	6	63	10·5	3·5	2·9	0·37	−0·7	−0·3	0·34	6	63	10·5	360	330	32	2–3*g*
	250–300	6	63	10·5	3·6	2·7	0·64	−0·8	−0·2	0·33							
Boston IIIA	150–200	26	298	11·5	3·6	2·3	0·59	−1·5	−0·6	0·61	26	298	11·5	370	330	16	0–1*g*
	200–250	26	298	11·5	3·9	2·7	0·64	−2·2	−0·8	0·72	26	298	11·5	370	327	17	1–2*g*
	250–300	26	298	11·5	4·5	2·9	0·74	−2·4	−0·8	2·78	24	278	11·6	370	300	38	2–3*g*
	300–350	25	288	11·5	4·0	2·2	0·63	−2·2	−0·3	0·86	13	165	12·7	315	260	57	3–4*g*
Master	100–150	15	173	11·5	4·1	3·3	0·45	−1·4	−0·4	0·43	15	173	11·5	290	270	11	0–1*g*
	150–200	15	173	11·5	5·3	3·8	0·52	−1·7	−1·0	0·60	15	173	11·5	300	270	14	1–2*g*
	200–250	15	173	11·5	5·5	3·8	0·58	−1·5	−0·5	0·69	15	173	11·5	300	270	15	2–3*g*
	250–300	15	173	11·5	3·7	3·0	0·58	−1·0	0·3	0·44	15	173	11·5	270	250	16	3–4*g*

(96518)

TABLE 3—*continued*

Aircraft Types	Speed Band m.p.h. A.S.I.	No. of slides	Total flying time	Average flying time per slide	Upper limit of acceleration per slide: Overall	Upper limit: Mean	Upper limit: σ	Lower limit of acceleration per slide: Overall	Lower limit: Mean	Lower limit: σ	Highest Speeds: No. of slides	Highest Speeds: Total flying time	Highest Speeds: Average flying time per slide	Highest Speeds: Overall	Highest Speeds: Mean	Highest Speeds: σ	Highest Speeds: Acceleration range
Swordfish	100–150	10	128	12·8	3·0	2·4	0·27	−0·8	−0·3	0·28	8	94	11·8	195	165	25	−1–0g
	150–200	10	128	12·8	4·3	2·9	0·51	−0·8	−0·1	0·25	10	128	12·8	255	225	15	−0–1g
	200–250	9	107	11·9	3·6	2·7	0·50	0	+0·3	0·18	10	128	12·8	255	225	15	1–2g
											10	128	12·8	255	220	19	2–3g
Welling-ton C	100–150	20	279	14·0	2·3	1·5	0·31	0	0·6	0·20							
	150–200	20	279	14·0	2·6	1·6	0·40	0	0·5	0·28							
	200–250	19	269	14·2	2·3	1·5	0·34	0·6	0·8	0·12							
Welling-ton T	100–150	26	52	2·0	2·4	1·6	0·25	0	0·5	0·20							
	150–200	26	52	2·0	2·2	1·6	0·22	0	0·5	0·16							
	200–250	11	22	2·0	2·0	1·5	0·24	0·1	0·6	0·13							
Welling-ton B	100–150	16	157	9·8	2·6	1·8	0·40	−0·1	0·3	0·24							
	150–200	16	157	9·8	3·1	2·2	0·42	−0·2	0·1	0·28							
	200–250	16	157	9·8	2·7	1·9	0·42	0	0·4	0·27							

C

TABLE 3—*continued*

Aircraft Type	Speed band m.p.h. A.S.I.	No. of slides	Total flying time	Average time per slide hours	Upper limit of acceleration per slide			Lower limit of acceleration per slide		
					Overall	Mean	σ	Overall	Mean	σ
Clipper North Atlantic	100–150	43	763:00	17:45	2·3	1·60	0·21	—0·2	0·35	0·26
	150-200	43	763:00	17:45	2·3	1·55	0·23	—0·8	0·42	0·72
Clipper South Atlantic	100–150	25	297:55	11:55	2·0	1·48	0·19	0	0·38	0·20
	150–200	25	297:55	11:55	2·0	1·50	0·20	0	0·48	0·19
D.H. 86	50–100	249	849:50	3:25	2·1	1·35	0·15	0	0·70	0·18
	100–150	255	867:05	3:24	2·1	1·64	0·17	—0·2	0·39	0·22
	150–200	92	281:50	3:04	2·2	1·51	0·22	—0·3	0·61	0·27
D.H. 89A	50–100	89	367:25	4:08	1·7	1·21	0·13	0·3	0·84	0·14
	100–150	89	367:25	4:08	2·3	1·39	0·19	0·1	0·75	0·14
	150–200	9	39:15	4:21	2·1	1·36	0·32	0·1	0·74	0·32
Dakota	100–150	21	1,234:35	58:46	2·4	1·91	0·26	—0·8	0·03	0·16
	150–200	20	1,201:05	60:03	2·3	1·93	0·23	—0·8	0·07	0·48
	200·250	7	418:50	59:50	1·9	1·53	0·20	0·3	0·03	0·23

TABLE 4 (a)

D. H. 86

SPEED M.P.H. A.S.I.	HIGHEST ACCELERATION PER SLIDE										
	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	TOTAL
95				1							1
100					1			1	1		3
105					2	1					3
110				2			1	1			4
115			2	1	2						5
120		1	1	2	2						6
125	1	3	11	15	4	7	6	2	1		50
130	3	6	10	13	5	5	2			1	45
135		3	13	11	8	4		1	1		41
140	4	3	7	13	16	5				1	49
145		1	7	4	6		1	4	1		24
150		3	1	3	3	3	5			1	19
155					1						1
160			1		1		1				3
165				1							1
170											
TOTAL	8	20	53	66	51	25	16	9	4	3	255

SPEED M.P.H. A.S.I.	LOWEST ACCELERATION PER SLIDE													
	0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	-0·1	-0·2	-0·3	TOTAL
95														
100			1					1		2				4
105		1		1				1						3
110			1				2							3
115					5	3						1		9
120			1	2	1	2			1	1				8
125			3	7	5	11	8	4	1	2				41
130	1	1	2	11	8	11	7	3	2	3	1			50
135	1	1		8	8	7	5	2	2	4		1		39
140		2	6	7	5	12	8	5	1			1		47
145			1	5	2	6	2	1	2	7		1		27
150			1	3	2	1	1	3	2	3			1	17
155					1		1							2
160				1	1			1		1				4
165														
170				1										1
TOTAL	2	5	16	46	38	53	34	21	11	23	1	4	1	255

SPEED M.P.H. A.S.I.	HIGHEST SPEED PER SLIDE												
	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	TOTAL
95													
100													
105													
110													
115													
120													
125													
130										1			1
135								1					1
140				1	14	4	2			1	1		23
145					20	5	6	4	6	1		1	43
150	1				18	12	23	24	9	6	4	1	98
155					17	2	6	11	2	2			40
160			1		11	3	6	5	1	1	2		30
165					6	2	2	1	1	1	1		14
170					1	2	1		1				5
TOTAL	1		1	1	87	30	46	46	20	13	8	2	255

TABLE 4 (b)

D. H. 89 A.

SPEED M.P.H. A.S.I.	HIGHEST ACCELERATION PER SLIDE														LOWEST ACCELERATION PER SLIDE										HIGHEST SPEED PER SLIDE						
	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3	TOTAL	0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	TOTAL	1·0	1·1	1·2	1·3	1·4	1·5	TOTAL
75					1									1				1						1							
80		1												1		1								1							
85																1	1	1	2					5							
90			1											1																	
95																	2		1					3							
100		1	1											2	1	1	1	1	1					5							
105		1	1	2	1									5	1		4							5							
110			1	1										2	1	2	1							4							
115		3		3	1					1				8		1	2	1						4							
120		1	1	2	3									7	1	6	3	1				1		12							
125			9	9	1	1		1	1	1				23	2	7	5	1						15		1		1			2
130		2	10	3	3	1								19	10	4	2	2	1					19	4	1					5
135		1	2	1		2								6	2	4	1	2						9	7	2	1	1			11
140	1		1	2	2								1	7	1	1								2	14	1	4	1			20
145		1	1	1										3					1					1	13	2	3			1	19
150			1	1	1									3		1							1	2	18	1	4				23
155																									3						3
160																				1				1	2			1			3
165																									1						1
170																															0
175											1			1													1				1
180																															0
185																									1						1
TOTAL	1	11	29	25	13	4	0	1	1	2	1	0	1	89	19	29	22	10	6	1		1	1	89	63	8	13	4	0	1	89

TABLE 4 (c)

CLIPPER—NORTH ROUTE.

SPEED M.P.H. A.S.I.	HIGHEST ACCELERATION PER SLIDE												
	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3	TOTAL
85													
90								1					1
95													
100								1					1
105						1							1
110													
115													
120													
125				2		2							4
130						1							1
135				1		1							2
140			3	1	1	3						1	9
145		1				1		1					3
150			2	2	3	1							8
155	1					1						1	3
160			1			3							4
165			1	1		1							3
170					1	1							2
175				1									1
180													
185													
190													
195													
200													
TOTAL	1	1	7	8	5	16	0	3	0	0	0	2	43

SPEED M.P.H. A.S.I.	LOWEST ACCELERATION PER SLIDE												
	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	-0·1	-0·2	-0·8	TOTAL
85						1							1
90													
95													
100						1							1
105											1		1
110							1						1
115													
120						1			1	1			3
125			1	1	2	1	1						6
130	1			1	2								4
135		1				1		1	1	1			5
140				1		1	1		1				4
145	1		2										3
150		1	1	1	1			1					5
155								1				1	2
160			2				1						3
165						1							1
170													
175			1			1							2
180					1								1
185													
190													
195													
200													
TOTAL	2	2	7	4	6	8	4	3	3	2	1	1	43

SPEED M.P.H. A.S.I.	HIGHEST SPEED PER SLIDE									
	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	TOTAL
85										
90										
95										
100										
105										
110										
115										
120										
125										
130										
135										
140								1		1
145										0
150										0
155					1					1
160										0
165					1					1
170				1	2	1		2		6
175				1	4	3	3	1	1	13
180					4	1		2		7
185		1	1		3	1	2	1		9
190			1	1				1		3
195		1								1
200	1									1
TOTAL	1	2	2	3	15	6	5	8	1	43

TABLE 4 (d)

CLIPPER – SOUTH ATLANTIC ROUTE.

SPEED M.P.H.	HIGHEST ACCELERATION PER SLIDE									LOWEST ACCELERATION PER SLIDE									HIGHEST SPEED PER SLIDE								
	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	TOTAL	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	TOTAL	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	TOTAL
130		1							1				1					1									
135					1	1			2					1	1			2									
140	1				1				2	1			2	1	3	1		8									
145	1								1					1				1									
150		2	2		1			1	6			1		2	1		1	5				1					1
155															1			1									
160						1			1	1		1	1	2				5									
165	2		1	1					4	1								1						1			1
170																								1	1		2
175	1		1	1	1				4				1					1				4		1		1	6
180				1					1										1			6					7
185	1								1													3			1		4
190			1			1			2																		
195																						2					2
200																						1		1			2
TOTAL	6	3	5	3	4	3		1	25	3		2	5	7	6	1	1	25	1			17		4	2	1	25

TABLE 4 (e)

DAKOTA.

SPEED M.P.H.	HIGHEST ACCELERATION PER SLIDE 1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3	2·4	TOTAL
100							1							1
105														
110														
115														
120					1									1
125	1													1
130							1					1		2
135								1						1
140							1							1
145													1	1
150								1			1			2
155								1	1	1				3
160									1			1		2
165											1			1
170						1				1				2
175								1		1				2
180									1					1
185														
190														
195														
200														
205														
210														
215														
220														
225														
TOTAL	1				1	1	3	4	3	3	2	2	1	21

SPEED M.P.H.	LOWEST ACCELERATION PER SLIDE 0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	-0·1	-0·2	-0·3	-0·4	-0·5	-0·6	-0·7	-0·8	TOTAL
100						1												1
105							1											1
110																		
115																		
120													1					1
125												3						3
130							1		1									2
135																		
140				1													1	2
145															1		1	2
150										1								1
155														1				1
160	1				1									1				3
165																		
170																		
175		1			1		1											3
180																		
185																		
190																		
195																		
200																		
205																		
210			1															1
215																		
220																		
225																		
TOTAL	1	1	1	1	2	1	3		1	1		3	1	2	1		2	21

SPEED M.P.H.	HIGHEST SPEED PER SLIDE 0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	TOTAL
100												
105												
110												
115												
120												
125												
130												
135												
140												
145												
150						1						1
155												
160												
165												
170												
175							1					1
180			1									1
185												
190		1		2	1							4
195						1					1	2
200				1	1	2	1	1				6
205	1											1
210				1								1
215				1								1
220				1	1							2
225							1					1
TOTAL	1	1	1	6	3	4	3	1			1	21

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TABLE 5(a)
DH. 86

Speed band m.p.h. A.S.I.	Highest acceleration in speed band											
	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2
50–100	4	54	100	40	32	11	4	1		1	2	
100–150			7	22	55	65	51	28	14	6	4	3
150–200	1	7	17	13	21	9	8	9	6			1

Speed band m.p.h. A.S.I.	Lowest acceleration in speed band													
	1·0	0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	—0·1	—0·2	—0·3
50–100		44	78	62	25	17	11	5	3	1	3			
100–150		2	5	18	45	37	54	35	20	11	22	1	5	
150–200	5	12	18	15	9	11	7	5	4	1	4			1

TABLE 5(b)
DH. 89A

Speed band m.p.h. A.S.I.	Highest acceleration in speed band													
	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3
50-100	7	23	32	17	6	3		1						
100–150		3	10	30	25	12	4		1	1	2			1
150-200	1	1	2	1	1	2						1		

Speed band m.p.h. A.S.I.	Lowest acceleration in speed band										
	1·1	1·0	0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1
50–100		18	30	24	10	3	3		1		
100–150			21	31	20	11	4			1	1
150-200	1	1	3	1		1		1			1

TABLE 5(c)

Clipper—North Atlantic Route

Speed band m.p.h. A.S.I.	Highest acceleration in speed band											
	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3
50–100	1	3	5	4	1	1		2				
100–150	1	2	8	6	9	13		2			1	1
150–200	2	4	11	6	8	8	1			2		1

Speed band m.p.h. A.S.I.	Lowest acceleration in speed band											
	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	—0·1	—0·2	—0·8
50–100	1	1	3		3	5	1		1	1	1	
100–150	1	4	6	5	7	7	4	2	3	2	2	
150–200	2	7	10	5	6	3	2	5	1		1	1

TABLE 5(d)

Clipper—South Atlantic Route

Speed band m.p.h. A.S.I.	Highest acceleration in speed band									
	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0
50–100	1	1	3							
100–150			8	5	5	1	4	1		1
150–200		1	7	2	6	4	2	2		1

Speed band m.p.h. A.S.I.	Lowest acceleration in speed band								
	0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8
50–100					1		2	2	
100–150	1	1	5	4	6	4.		3	1
150–200	1		2	2	6	6	2	5	1

TABLE 5(e)

Dakota

Speed band m.p.h. A.S.I.	Highest acceleration in speed band												
	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·2	2·3	2·4
50–100	1			1			1	1					
100–150	1				1	1	6	3	4	1	2	1	1
150–200				1	2	3		4	3	4	2	1	
200–250		1	2	1	2			1					

Speed band m.p.h. A.S.I.	Lowest acceleration in speed band																		
	1·0	0·9	0·8	0·7	0·6	0·5	0·4	0·3	0·2	0·1	0	−0·1	−0·2	−0·3	−0·4	−0·5	−0·6	−0·7	−0·8
50–100			1					1			2								
100–150			2	2		2		2	2		1	1		4	1	1	1	1	1
150–200			2	1		1	3	1	1	1	2	2	1			3	1		1
200–250	1			1	2	1	1	1											

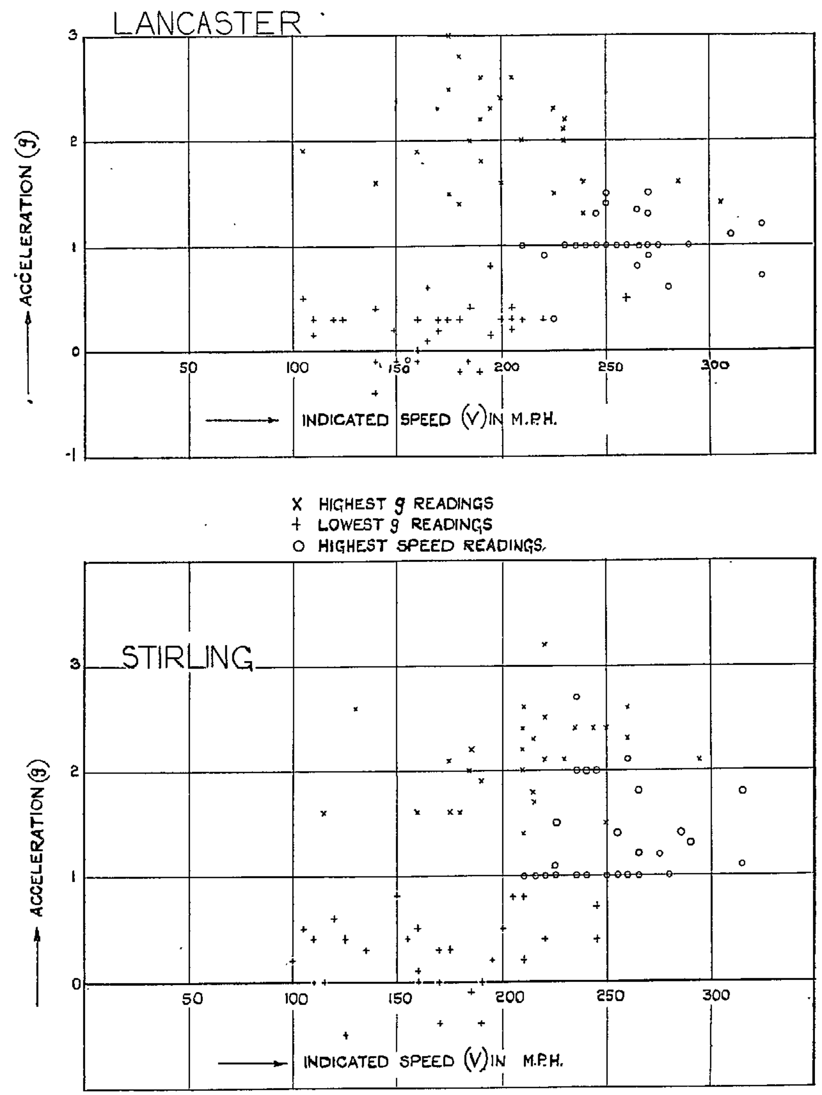


FIG. 1. Highest and lowest acceleration and speed records for R.A.F. bombers.

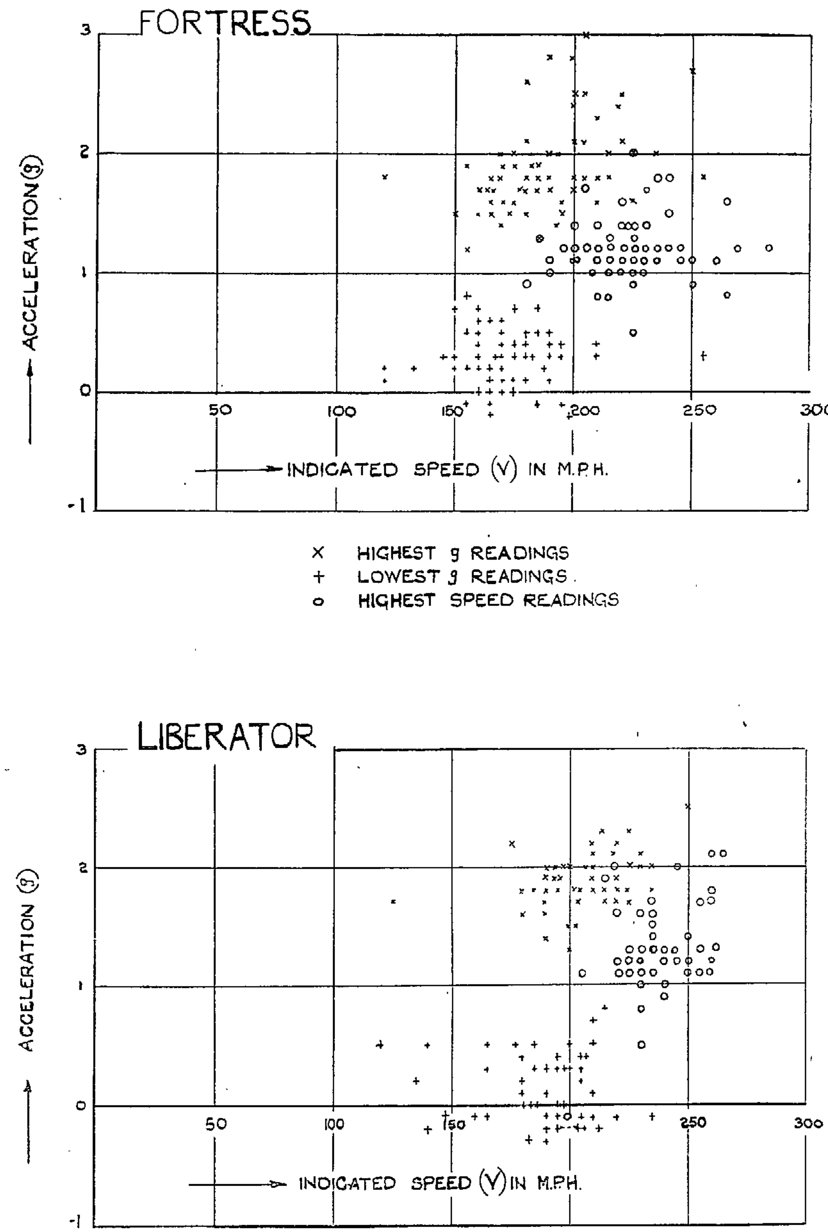


FIG. 2. Highest and lowest acceleration and speed records for U.S.A.A.F. bombers.

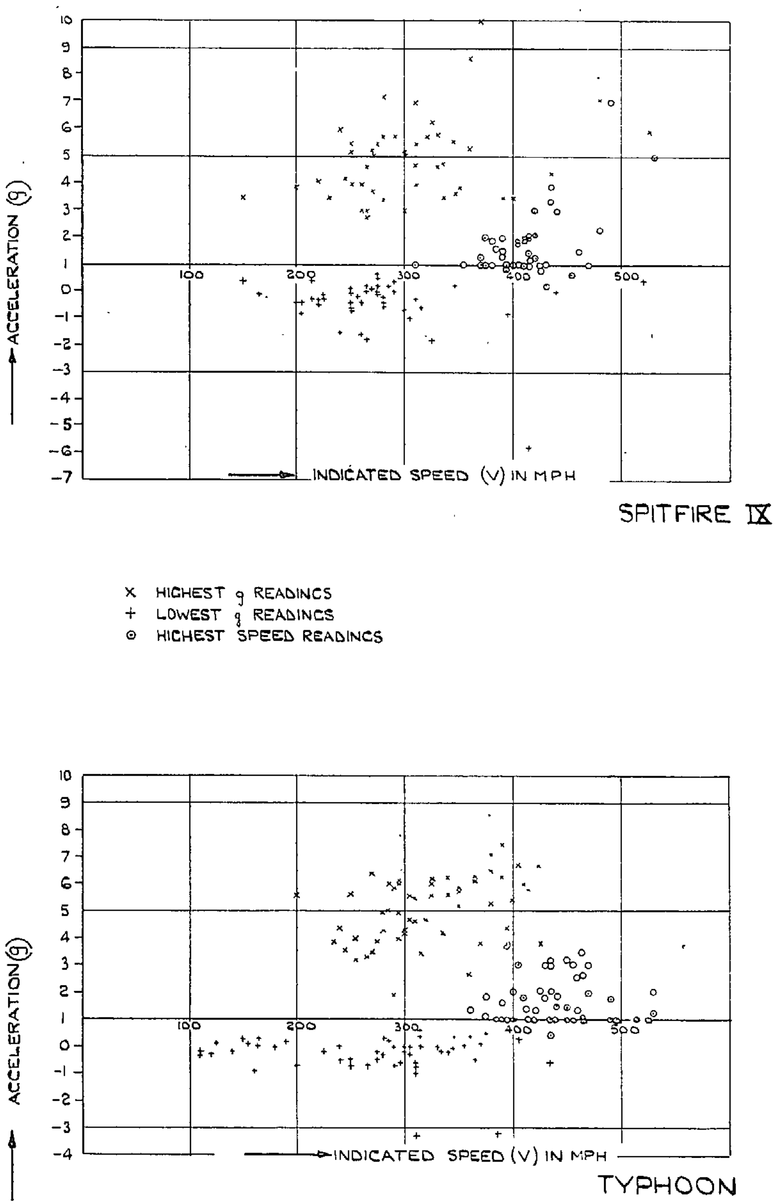


FIG. 3. Highest and lowest acceleration and speed records.

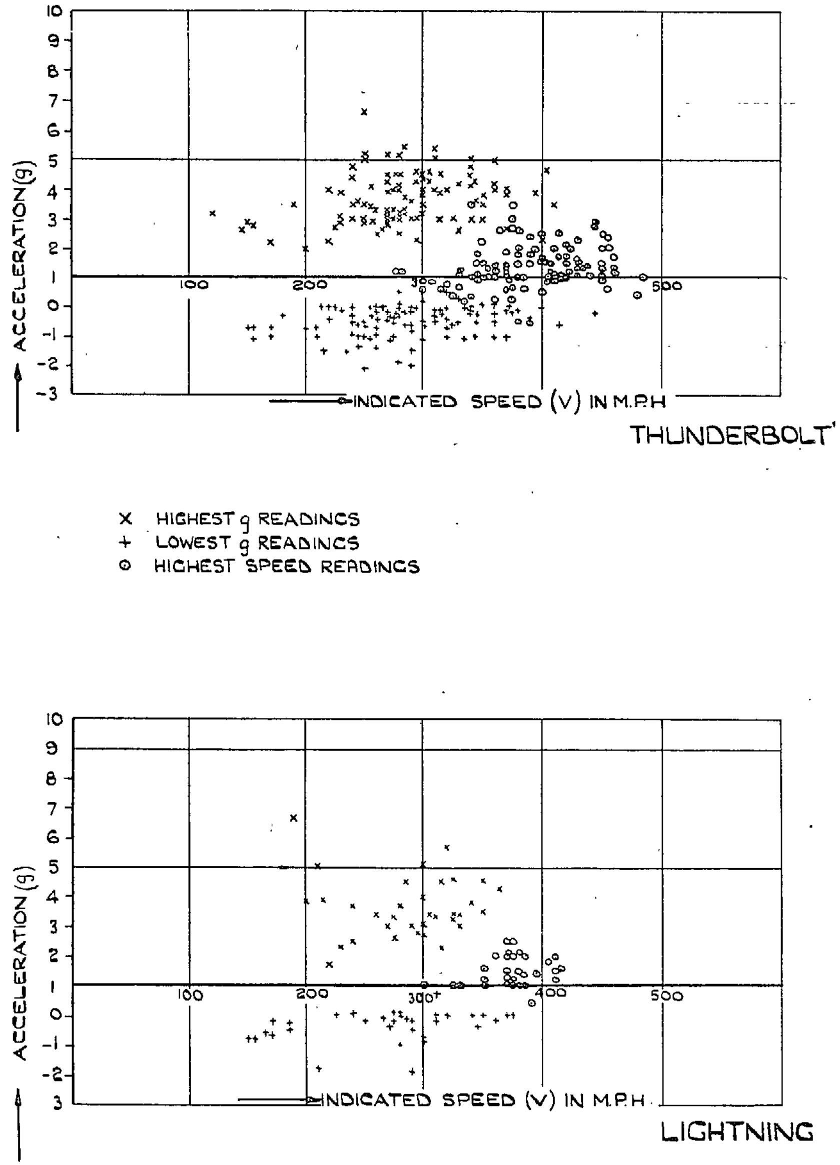


FIG. 4. Highest and lowest acceleration and speed records.

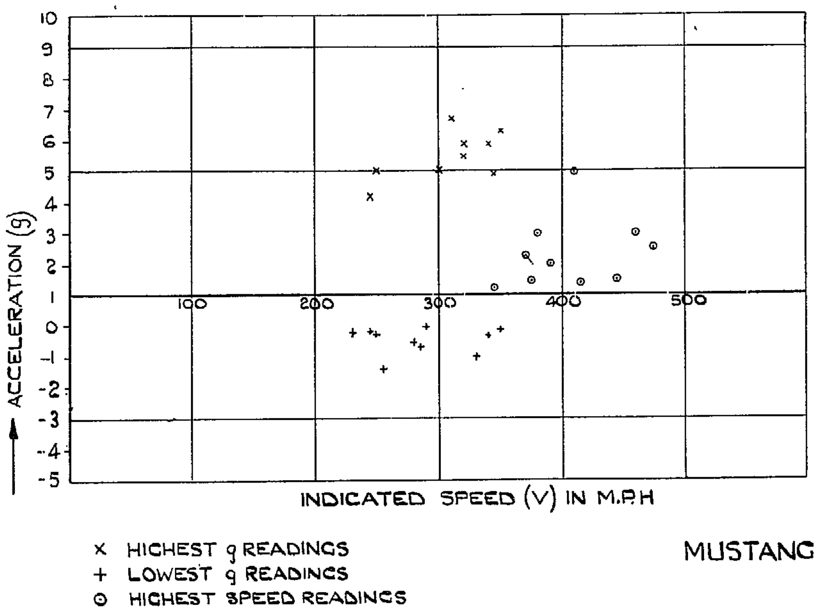


FIG. 5. Highest and lowest acceleration and speed records.

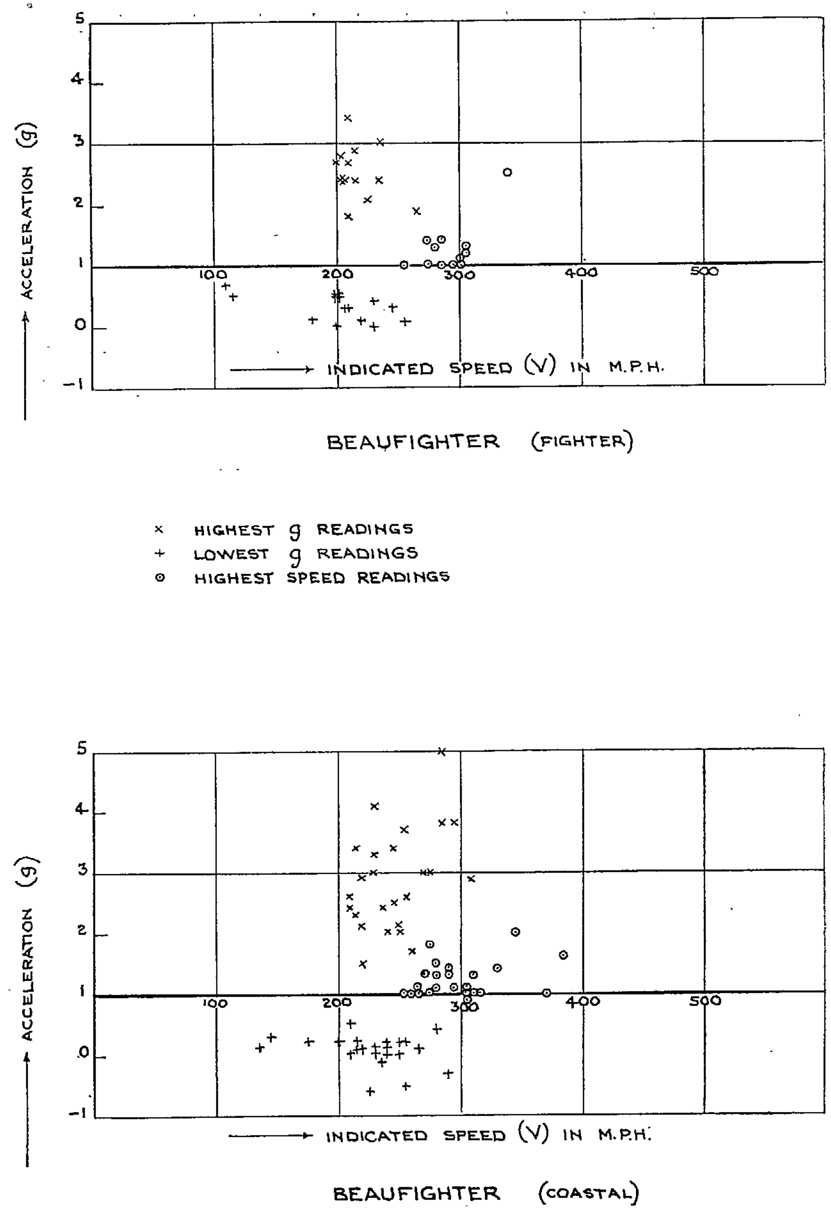


FIG. 6. Highest and lowest acceleration and speed records.

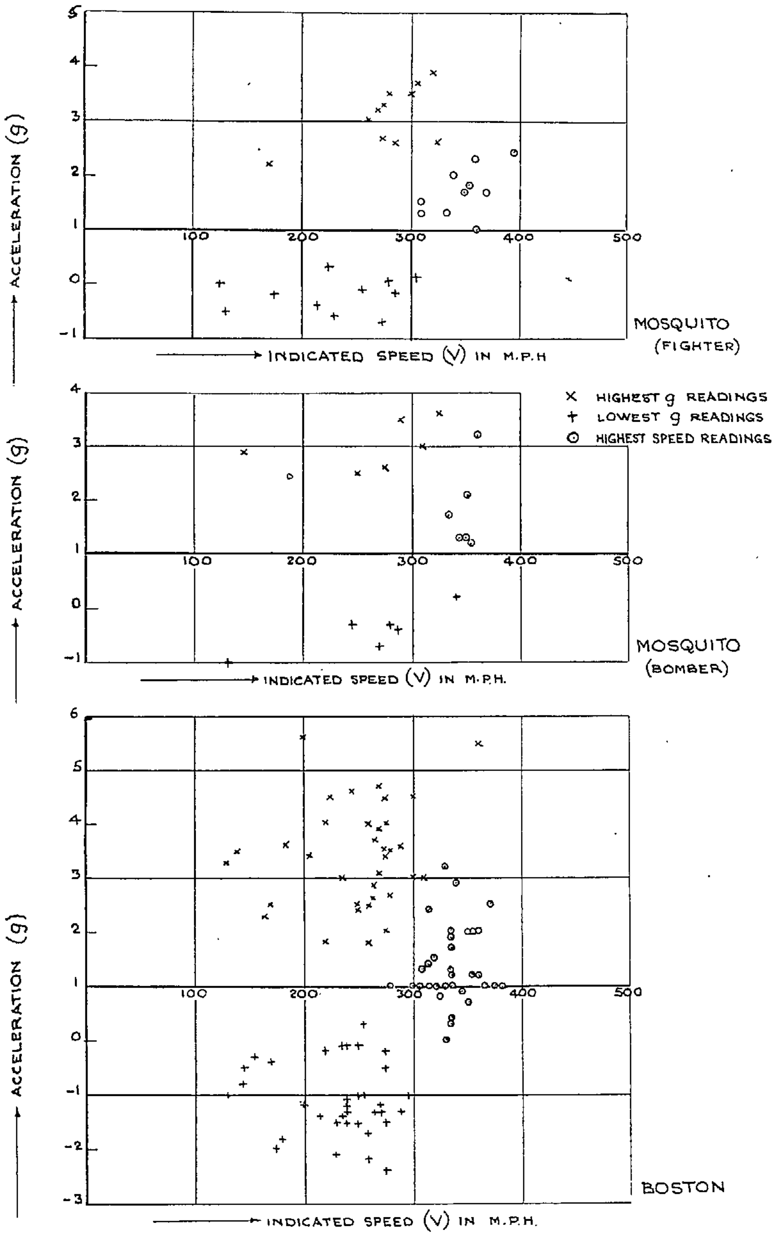


FIG. 7. Highest and lowest acceleration and speed records.

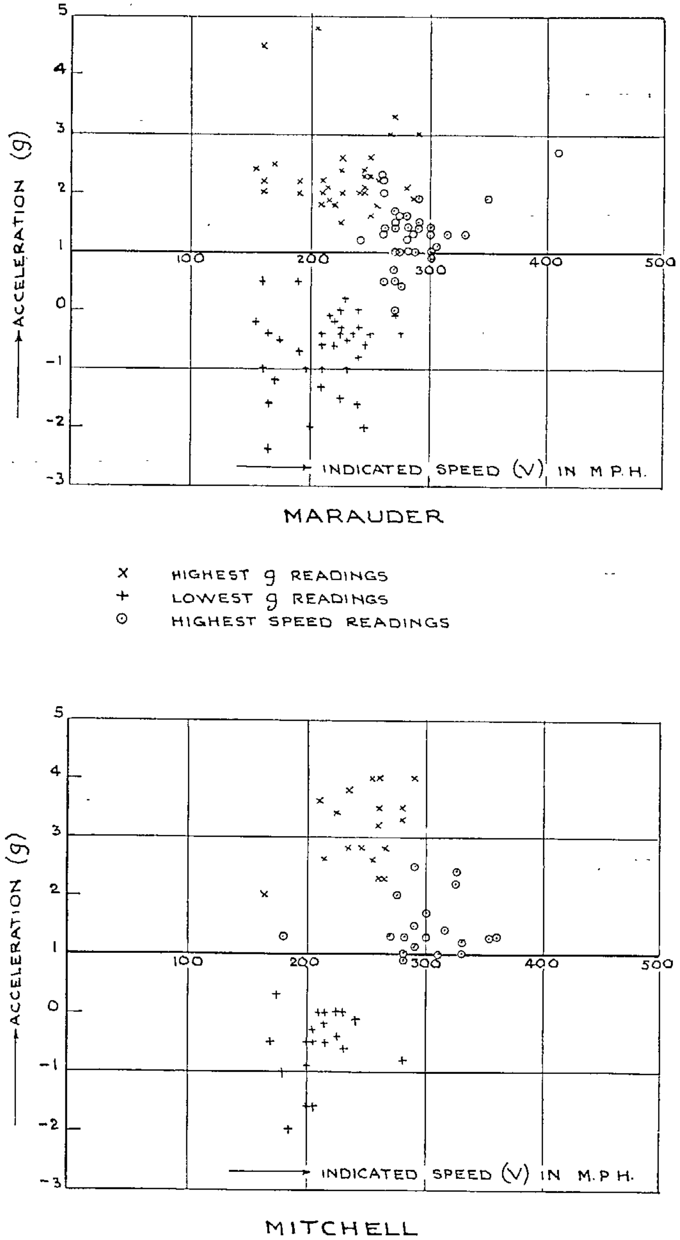


FIG. 8. Highest and lowest acceleration and speed records.

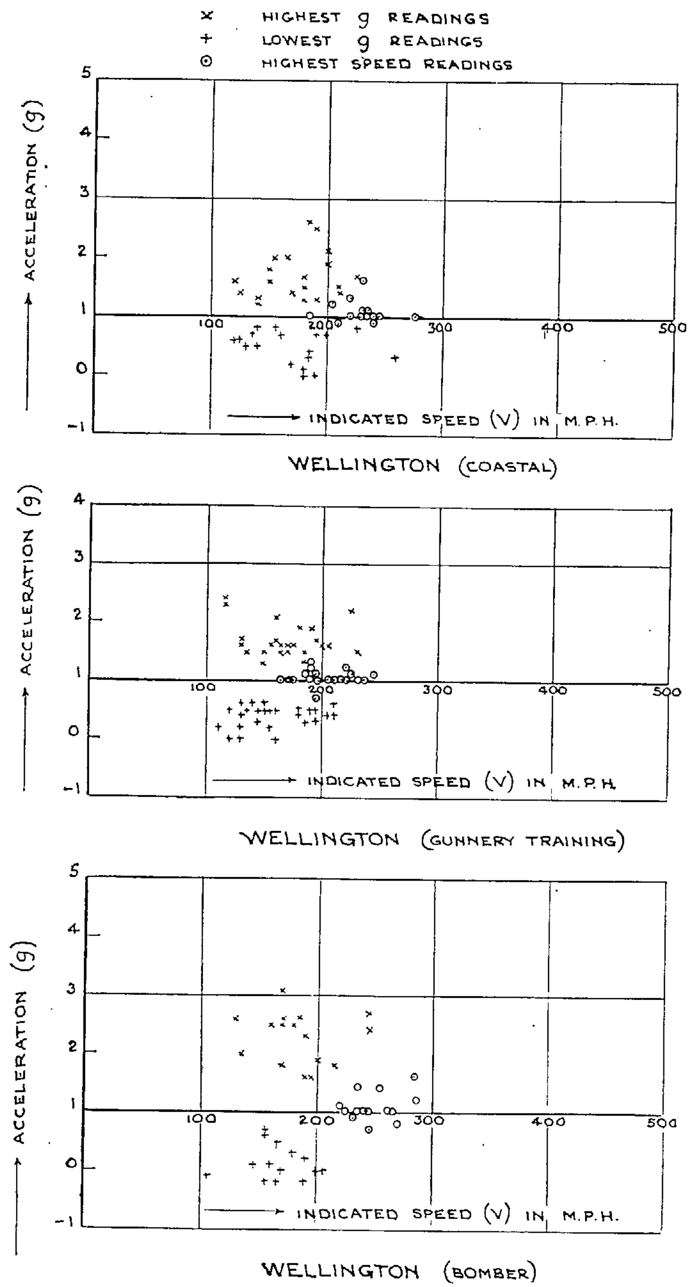


FIG. 9. Highest and lowest acceleration and speed records.

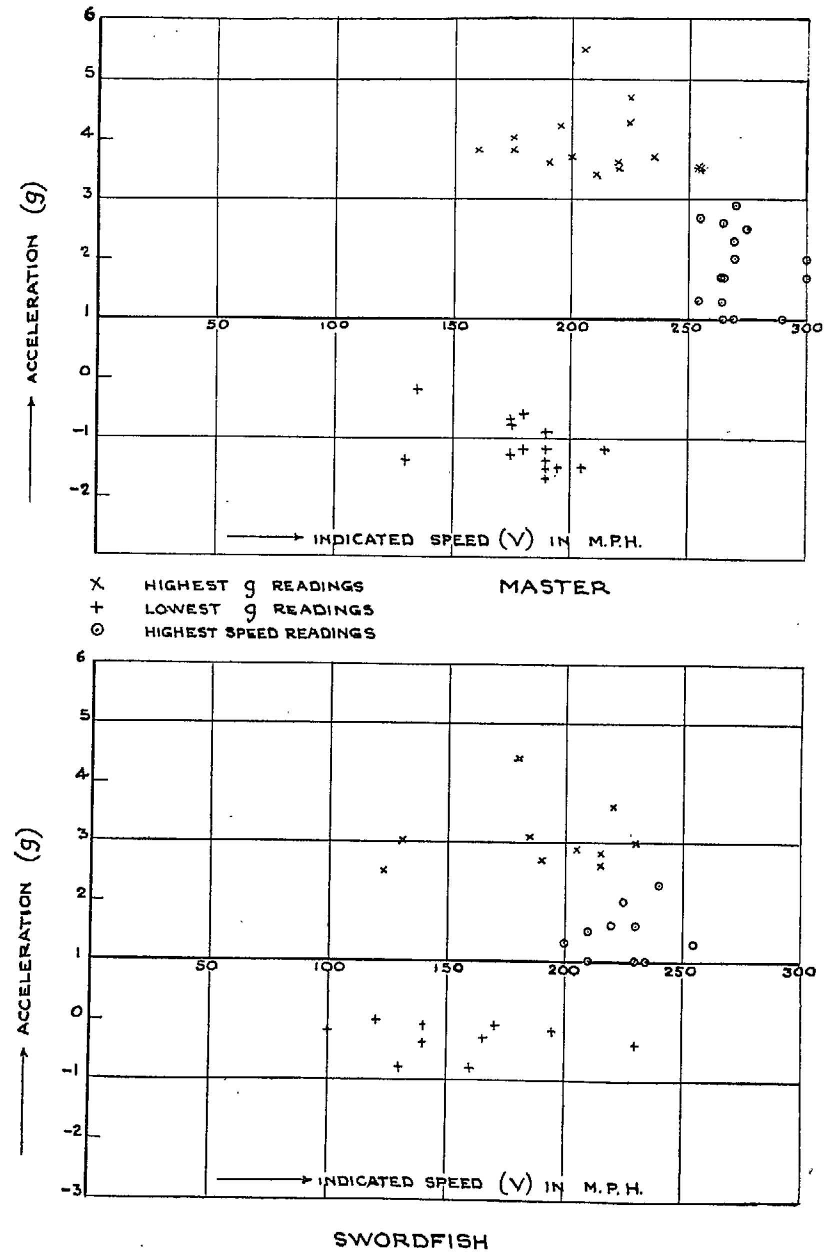


FIG. 10. Highest and lowest acceleration and speed records.

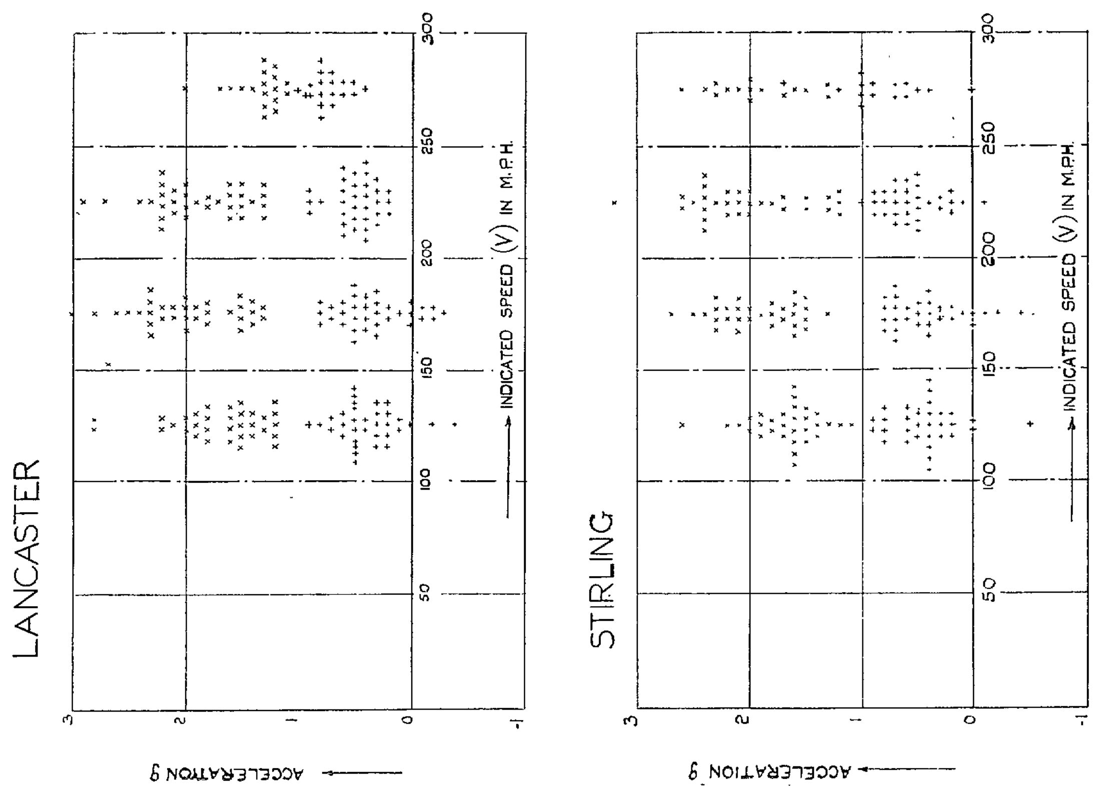
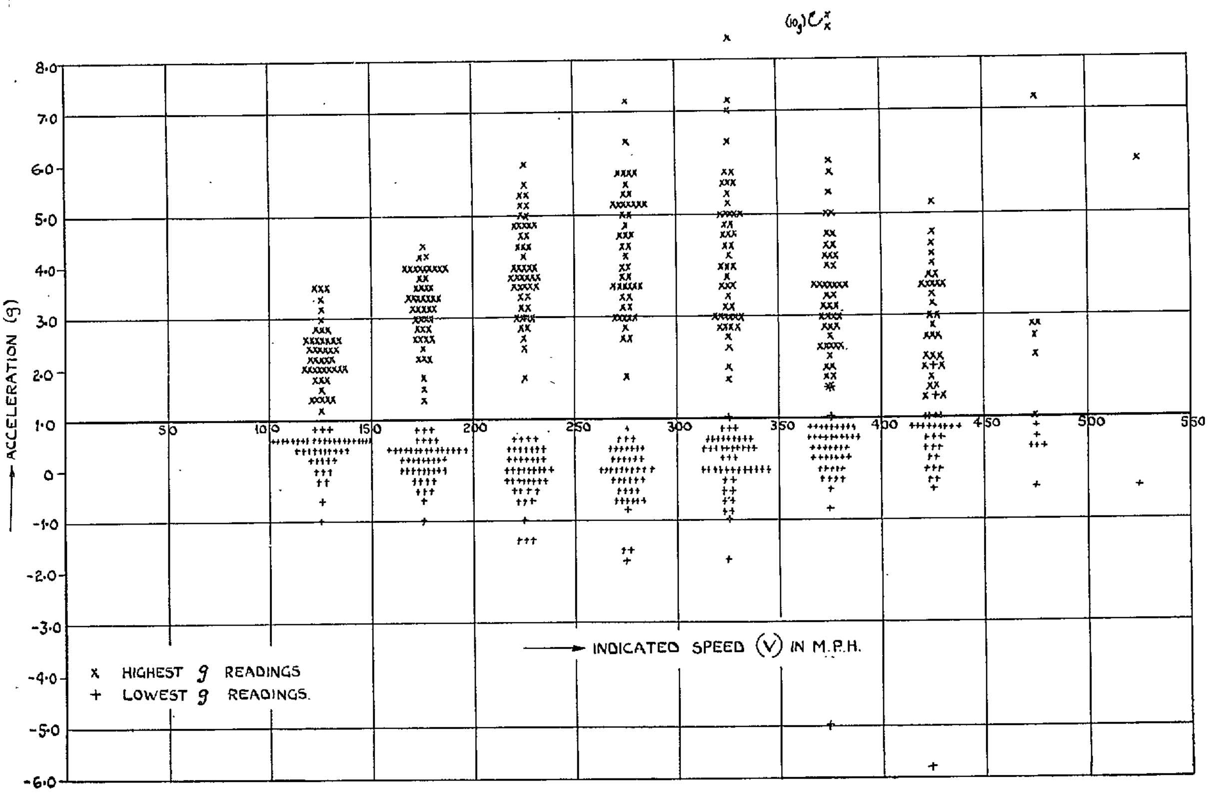


FIG. 11. Highest and lowest accelerations for specified speed ranges.



SPITFIRE IX

FIG. 12. Highest and lowest accelerations for specified speed ranges.

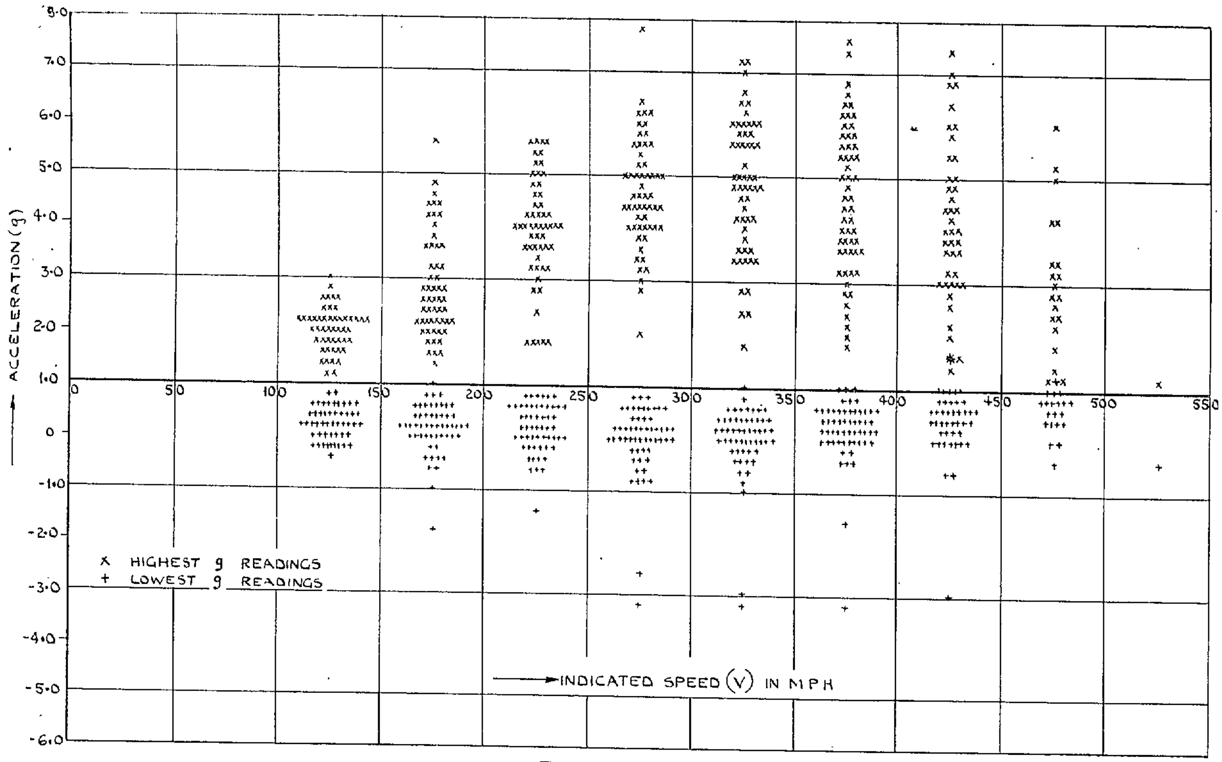


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FIG. 13. Highest and lowest accelerations for specified speed ranges.

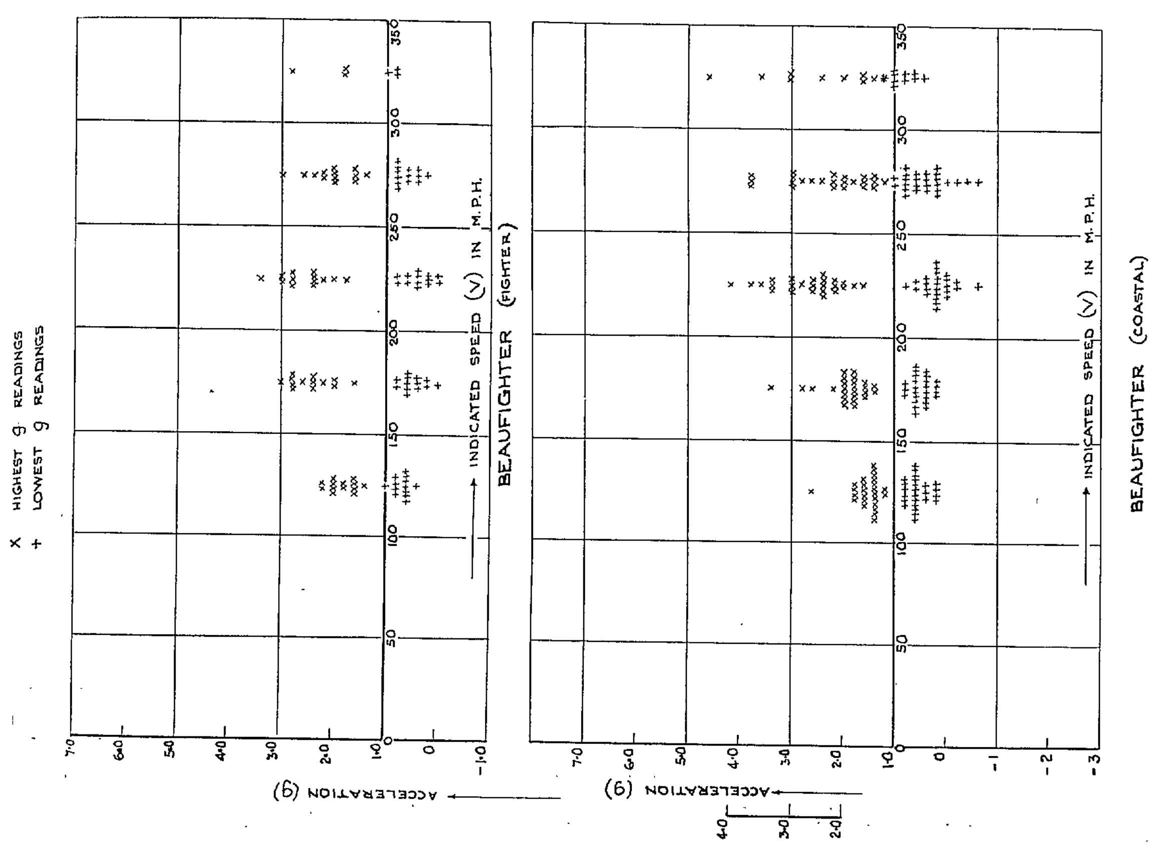


FIG. 14. Highest and lowest accelerations for specified speed ranges.

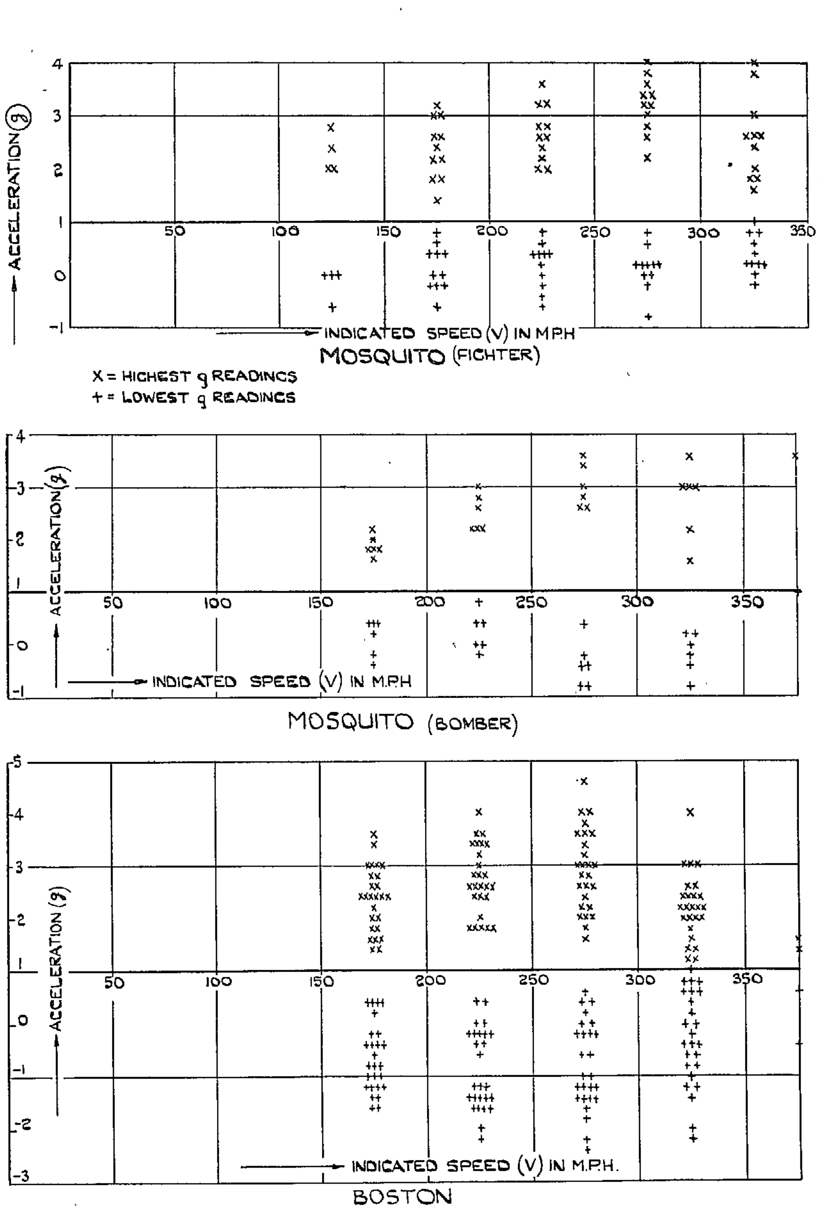


FIG. 15. Highest and lowest accelerations for specified speed ranges.

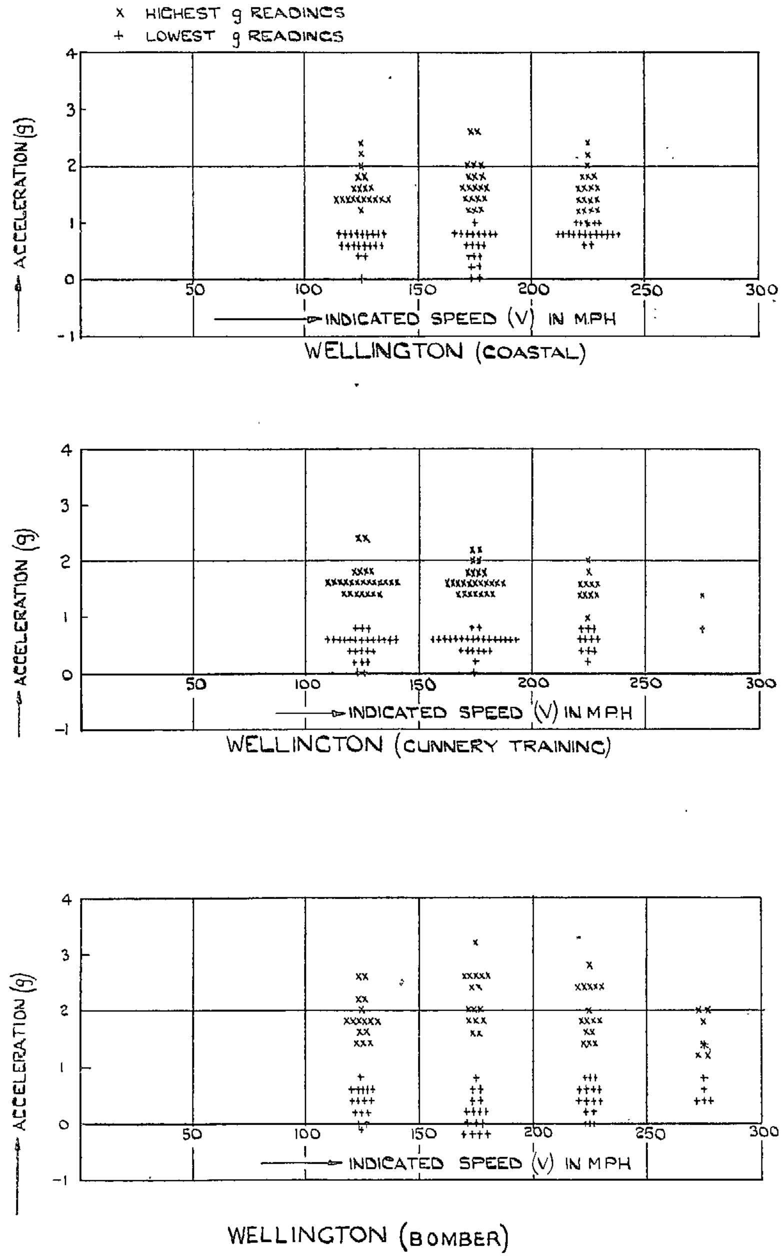


FIG. 16. Highest and lowest accelerations for specified speed ranges.

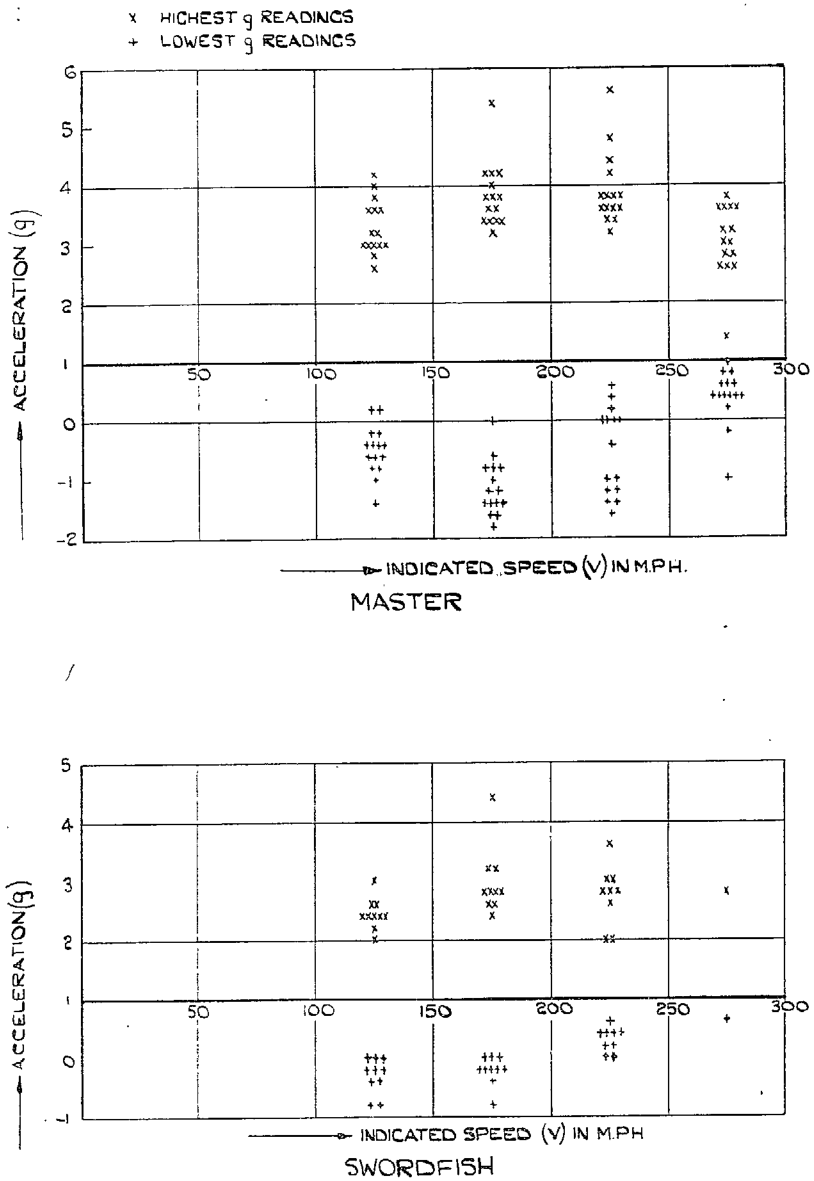


FIG. 17. Highest and lowest accelerations for specified speed ranges.

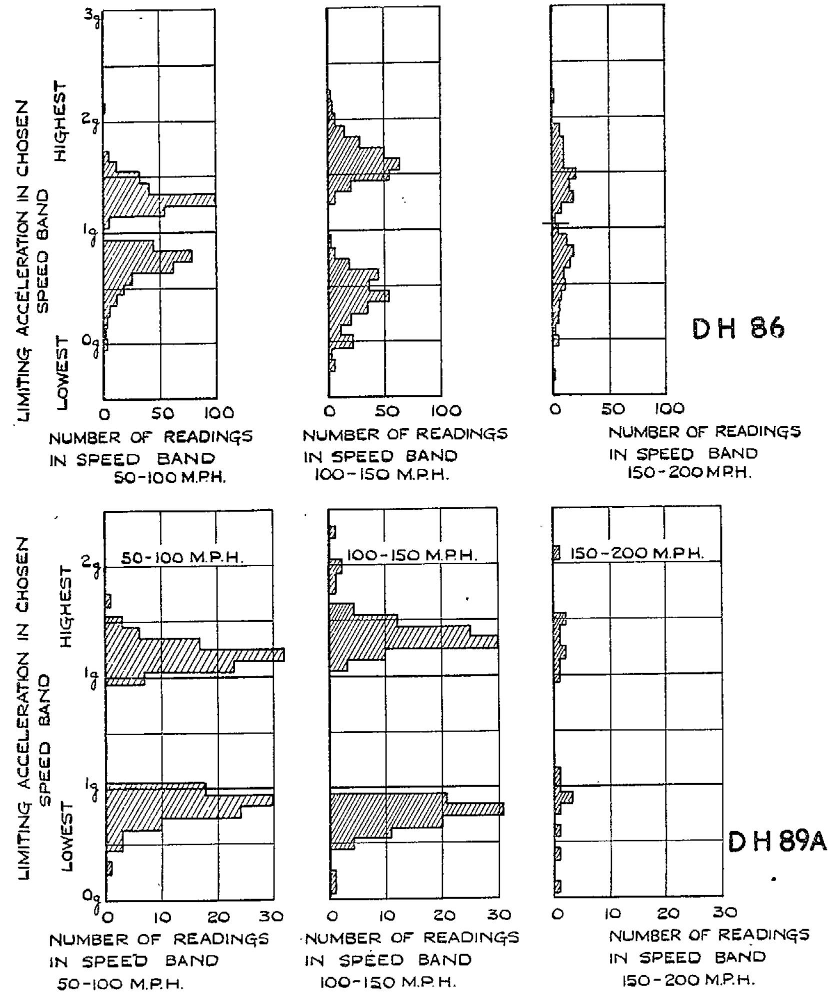


FIG. 18. Histograms of limiting accelerations.

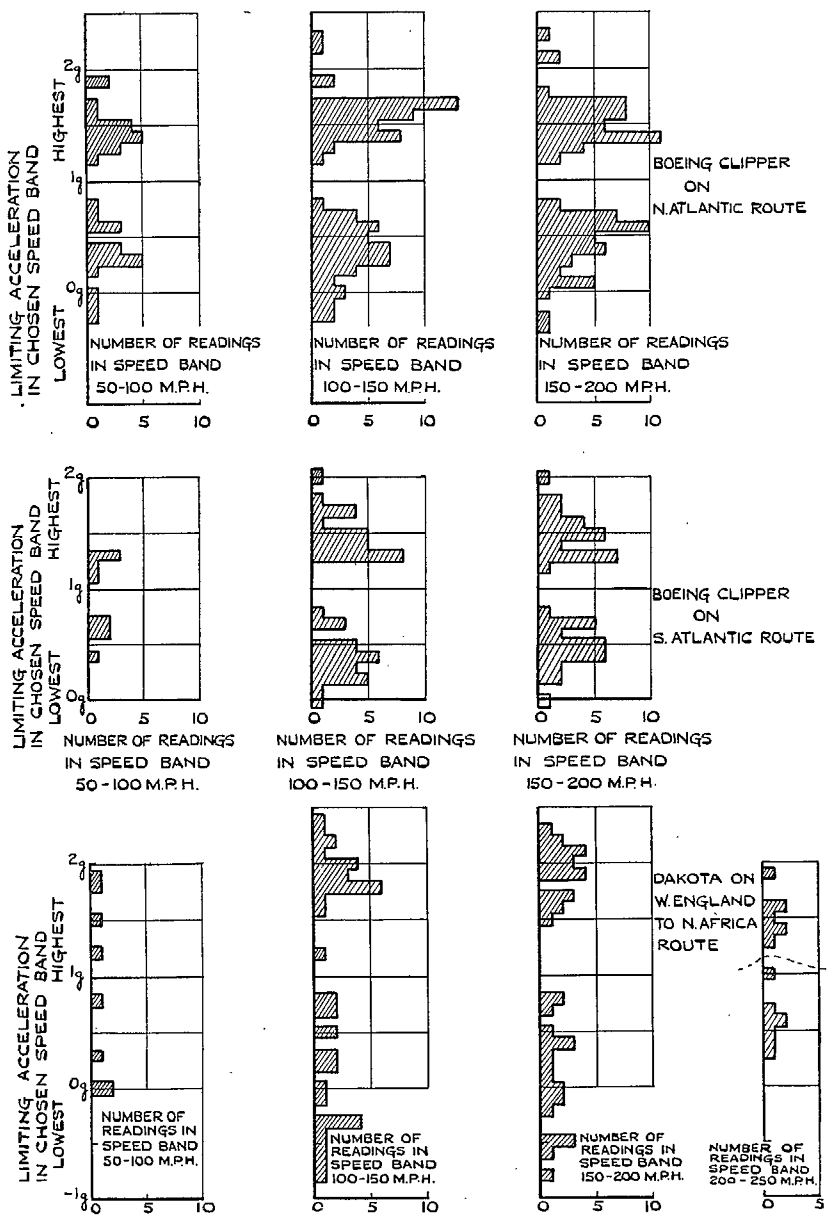


FIG. 19. Histograms of limiting accelerations.

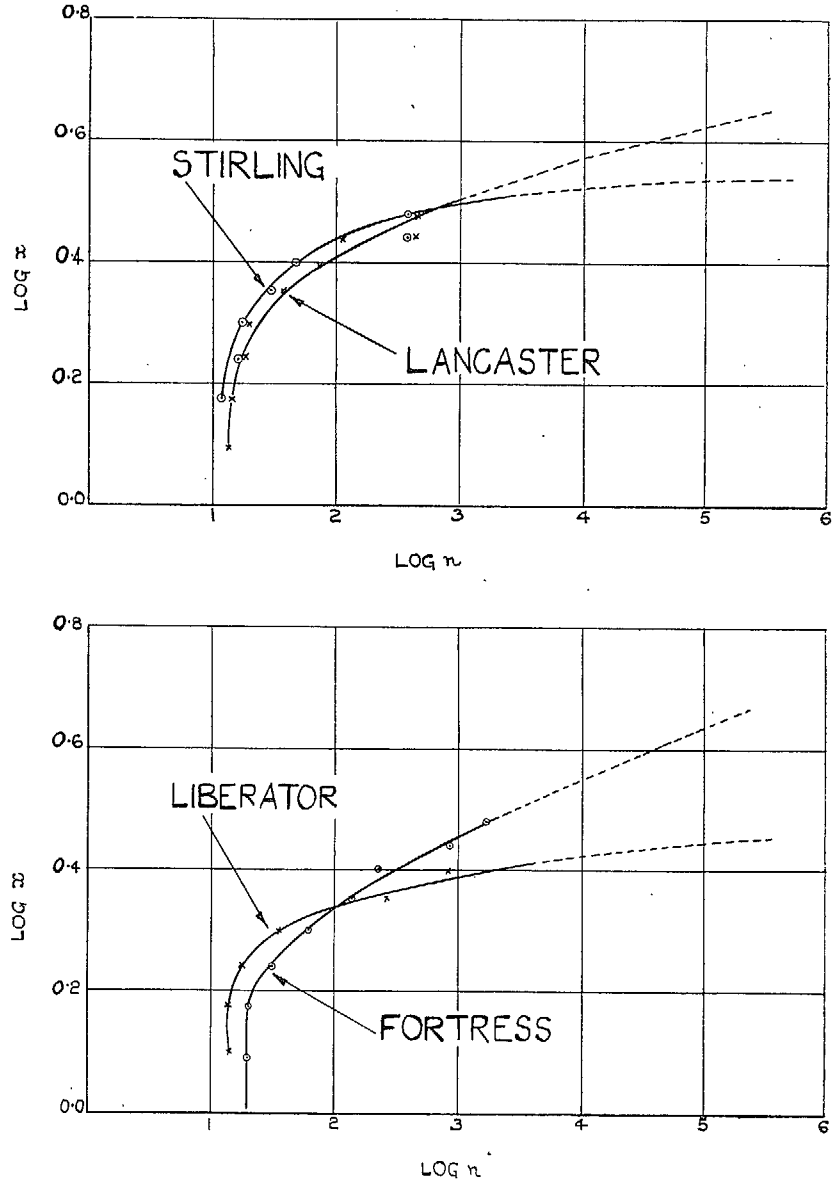


FIG. 20. Log-log diagrams for highest accelerations.

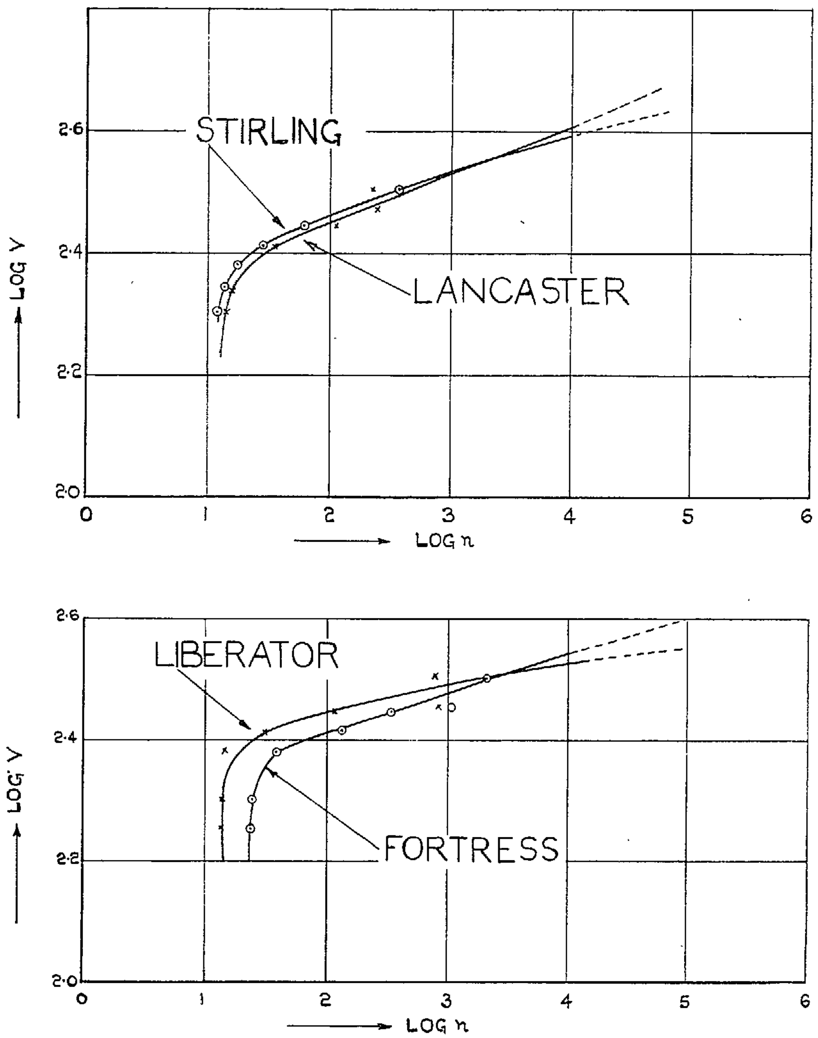


FIG. 21. Log-log diagrams for highest speeds.

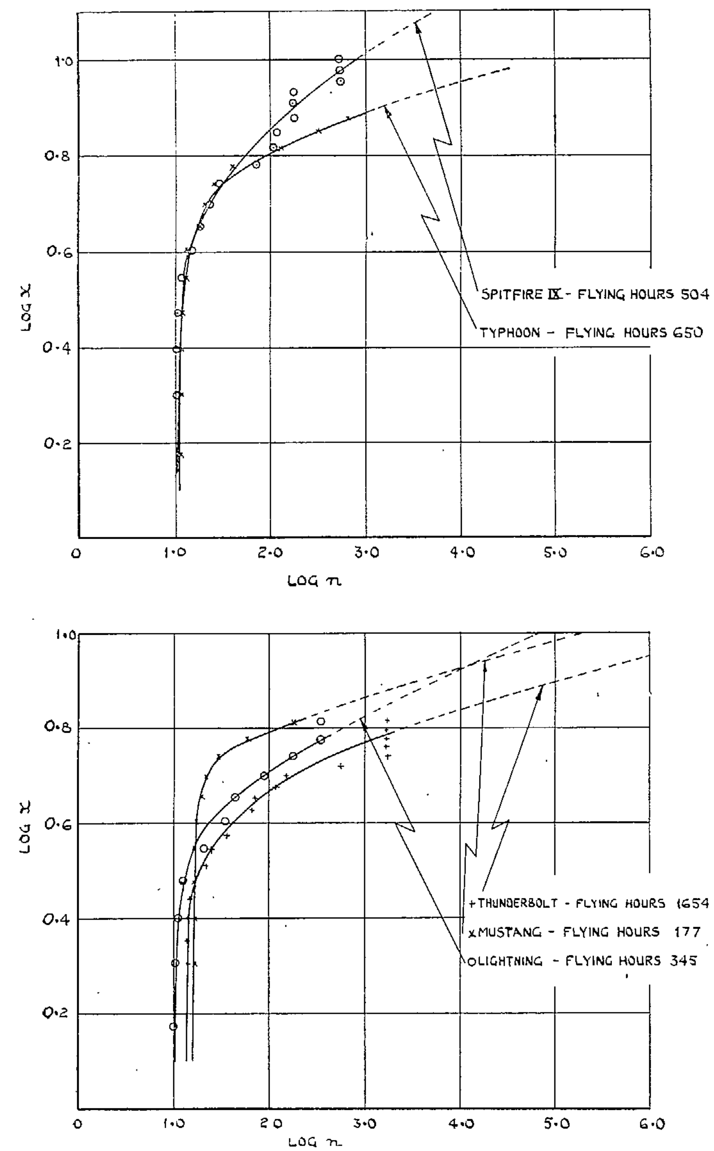


FIG. 22. Log-log diagrams for highest accelerations.
(xg is acceleration reached once in n hours.)

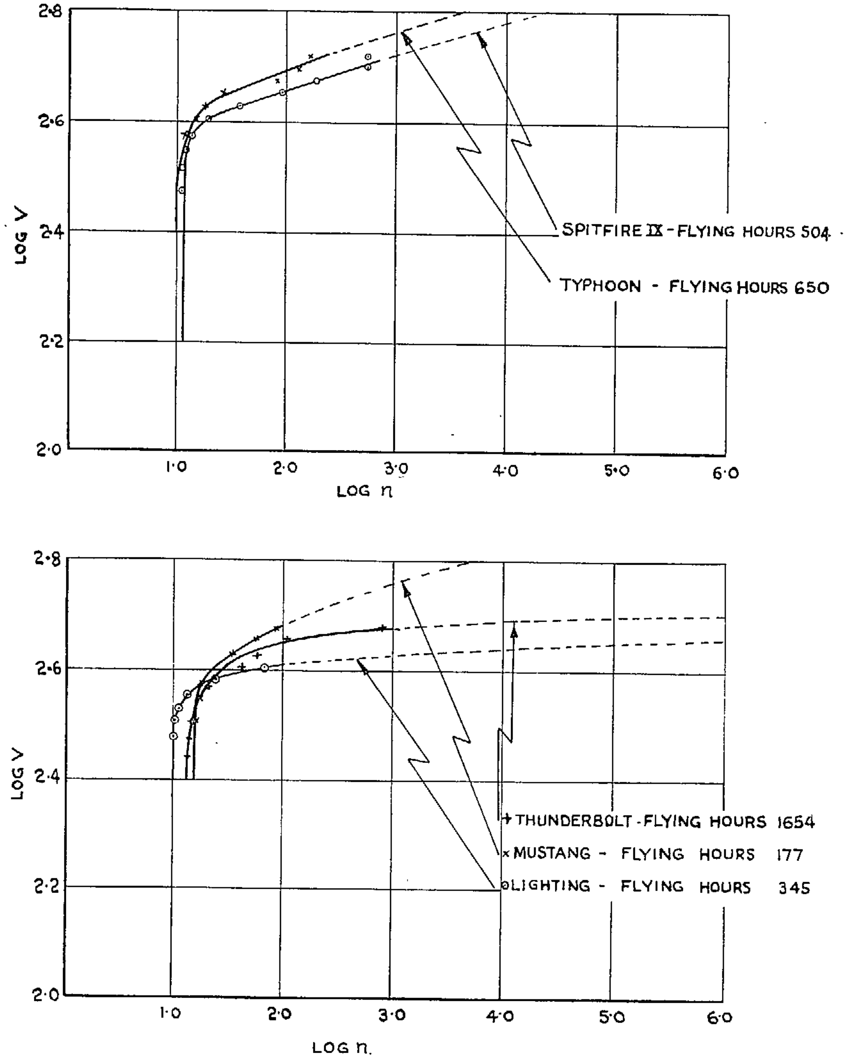


FIG. 23. Log-log diagrams for highest speeds. (V is speed reached once in n hours.)

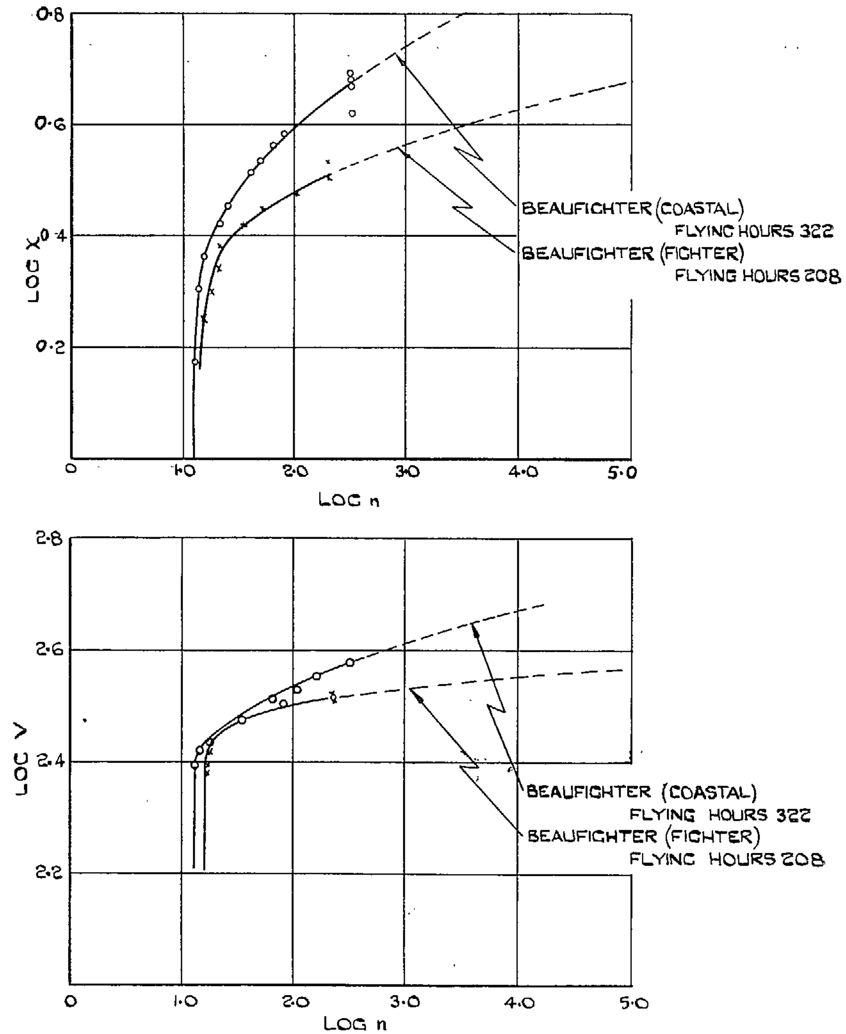


FIG. 24. Log-log diagrams for highest accelerations and speeds. (xg and V are the accelerations and speeds occurring once in n hours.)

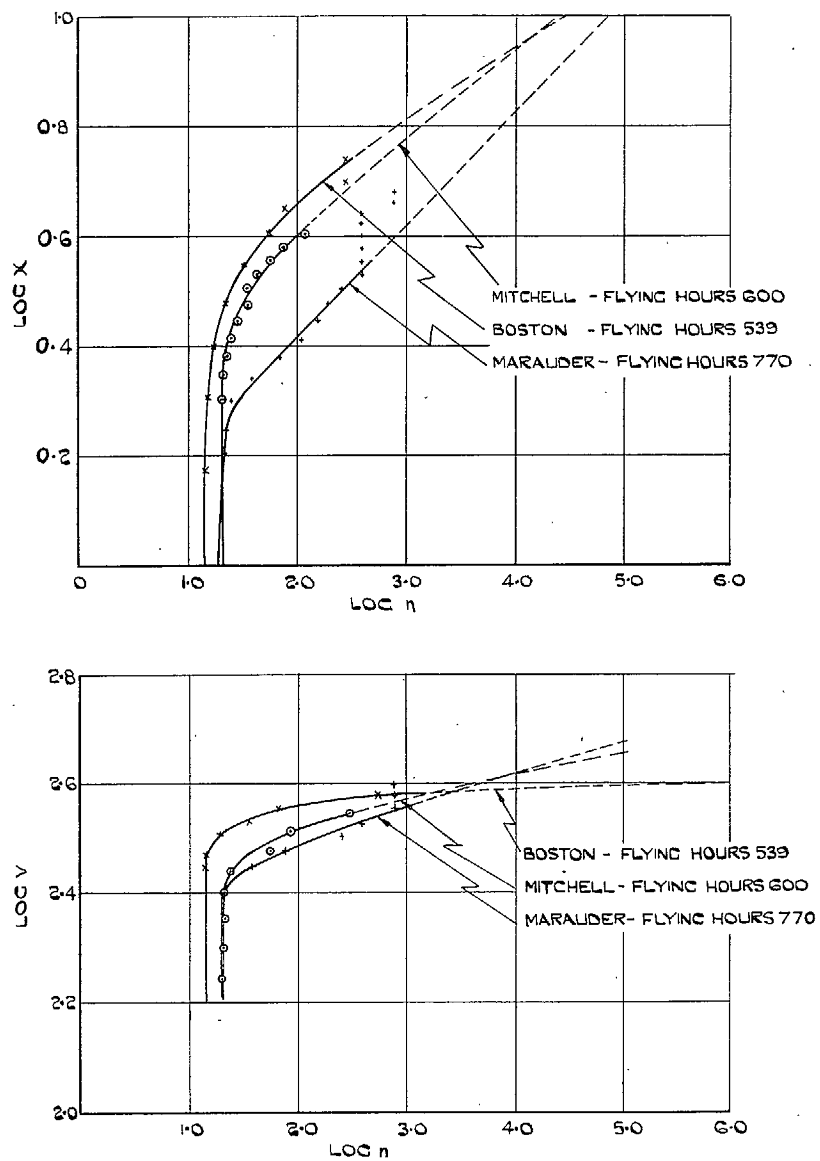


FIG. 25. Log-log diagrams for highest accelerations and speeds. (xg and V are the accelerations and speeds occurring once in n hours.)

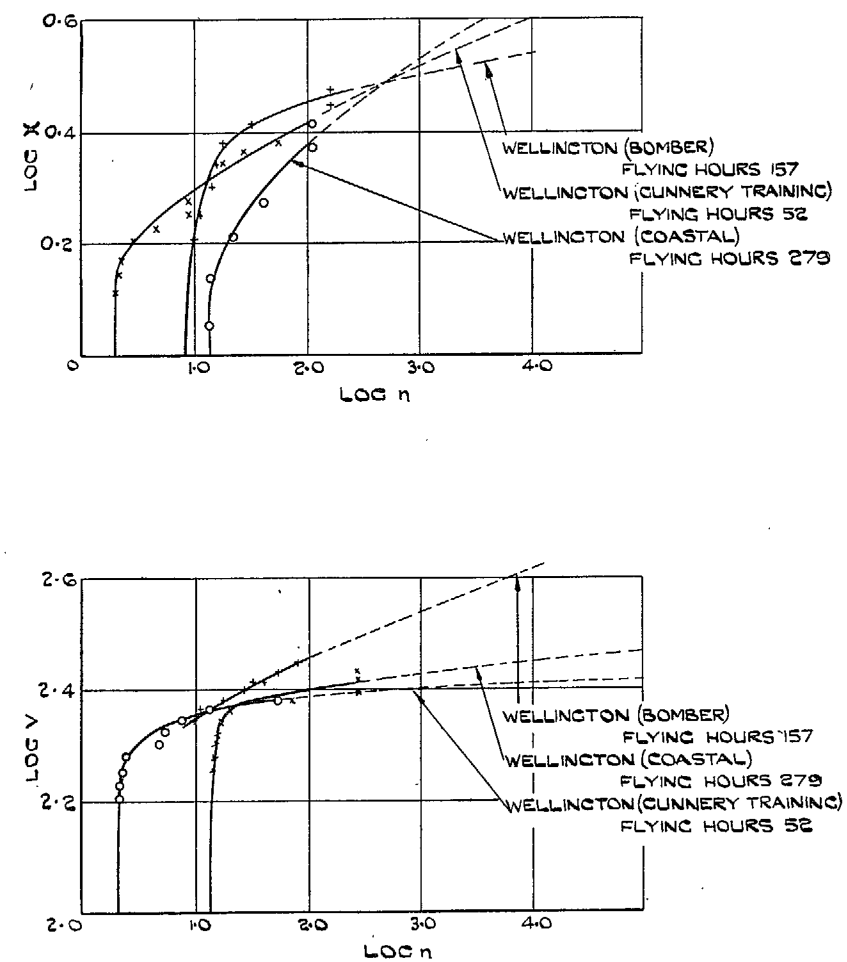
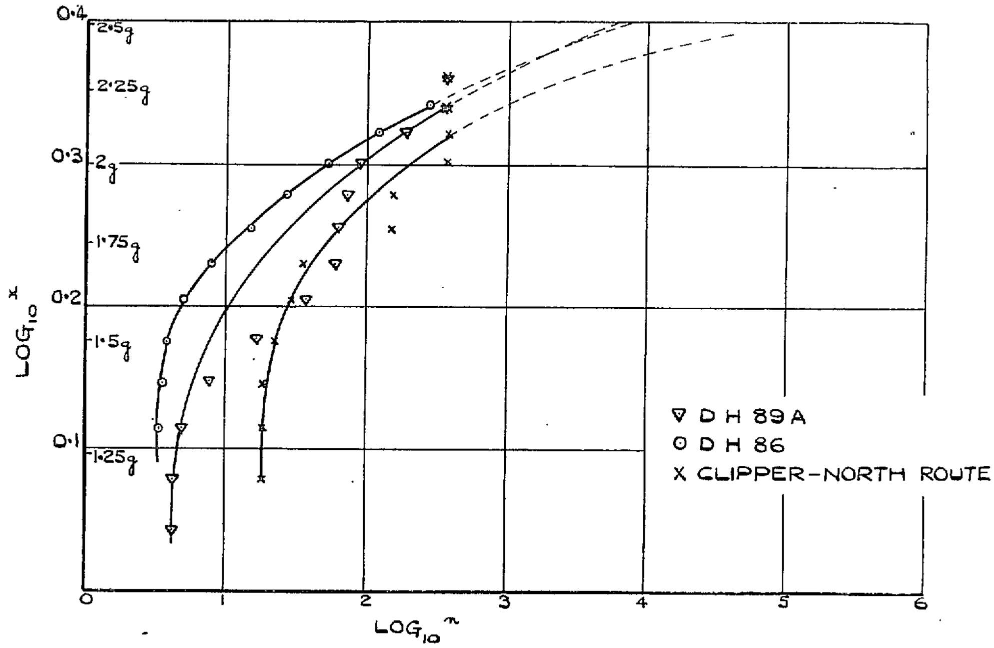


FIG. 26. Log-log diagrams for highest accelerations and speeds. (xg and V are the accelerations and speeds occurring once in n hours.)



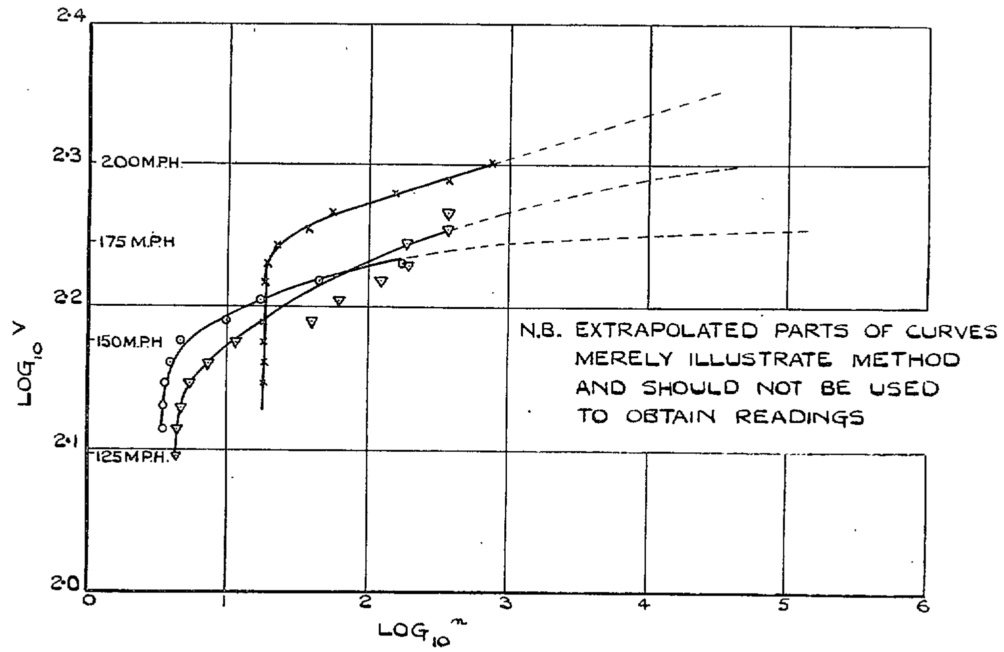


FIG. 27. Log-log diagrams for highest accelerations and speeds.
(xg and V are the accelerations and speeds occurring once in n hours.)

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