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STATISTICAL LOAD DATA PROCESSING

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SUMMARY

In designing against fatigue the assessment of the loading environment still is a major problem. Especially with military trainer and fighter aircraft which may be used for a variety of duties, regular or continuous load recording programs have to be considered mandatory. Such load recording programs may serve either to assess the consumed fatigue life of operating aircraft or to select design spectra for future aircraft designs and a fatigue-test setup. Within this scope the National Aerospace Laboratory has carried out a tentative load monitoring program.

A recorder system has been installed on two operational fighter aircraft. Signal values from a c.g.-acceleration transducer and a strain-gage installation at the wing root were sampled and recorded in digital format on the recorder system. To analyse such load-time histories for fatigue evaluation purposes, a number of counting methods are available in which level crossings, peaks, or ranges are counted. Ten different existing counting principles are defined. The load-time histories are analysed to evaluate these counting methods.

For some of the described counting methods, the counting results might be affected by arbitrarily chosen parameters such as the magnitude of load ranges that will be neglected and other secondary counting restrictions. Such influences might invalidate the final counting results entirely. The evaluation shows that for the type of load-time histories associated with most counting methods, a sensible value of the parameters involved can be found at which the counting results are rather unique.

Besides assessing the influences of secondary parameter values, the different counting methods are compared with each other. The analysis shows that the counting results obtained by level-crossing count methods and peak count methods compare rather well. For most of these counting methods the differences actually turned out to be surprisingly small, especially for the c.g.-acceleration load-time history. The results of the range count methods exhibit larger differences. Also, with the range counting methods the differences appear to be larger for the strain-gage history. The comparison of the different counting methods with each other is concluded by comparing the level-crossing and peak count methods with the range count methods. Three different ways are used to convert level-crossing and peak countings into range countings. The results show that level-crossing and peak count methods do not compare well with range count methods.

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Finally, the described counting methods are evaluated from the fatigue point of view while bearing in mind the purposes they will have to serve. It is concluded that in assessing the life consumed by individual aircraft, a sophisticated range count method applied to strain-gage histories should be preferred. For the selection of design spectra of future aircraft or a fatigue-test setup, level-crossing and peak count methods may be suitable; in fact, they may even be preferred.

INTRODUCTION

A major question in designing against fatigue concerns the assessment of the loading environment to which the aircraft will be subjected during their service life. Civil and military transport aircraft generally appear to be fatigue sensitive with respect to gust loads. This gust loading environment is substantially independent of the aircraft itself. In the past, extensive measurement programs have been carried out which enabled the assessment of the quantitative rules determining this loading environment.

High-performance aircraft appear to be relatively insensitive to gust loads with respect to fatigue. With this type of aircraft, fatigue damage will be primarily due to maneuver loading. However, in contrast with gust loads the maneuver loading depends greatly on both the tasks to be carried out and the maneuverability of the aircraft and is substantially independent of external conditions. On the one hand, the maneuvering capabilities of the aircraft as well as the intended usage differ enormously from aircraft to aircraft. On the other hand, the way in which the intended composite tasks are carried out will be highly dependent on training philosophy, pilot experience, and such. Therefore, the resulting loading severity will be somewhat unknown and, in addition, will exhibit important differences from aircraft to aircraft. Consequently, to assure adequate structural integrity (especially with fighters and military trainer aircraft), load monitoring – either individual monitoring or sample monitoring – has to be considered mandatory. Such load monitoring will provide the means to assess the life consumed by the individual aircraft and will also provide information regarding load spectra to be used in future aircraft designs and fatigue testing. Within this scope the National Aerospace Laboratory has carried out a tentative load monitoring program under contract for the Royal Netherlands Air Force. Continuous load-time histories became available from both the c.g. acceleration and a wing-root-bending-moment strain-gage installation.

To analyse such load-time histories for fatigue evaluation purposes, a number of counting methods are available in which the number of certain load occurrences is counted. In the past, these counting methods were compared to each other with respect to gust loads. Bearing in mind the nature of a gust loading environment, the results of that evaluation are not self-evidently applicable to maneuver-induced load-time histories.

The main theme of the present paper is to evaluate the basic counting methods with respect to maneuver-type loading. The results will be discussed from the fatigue point of view while taking into account the purposes they might serve.

PRINCIPLES OF DATA ANALYSIS

Actual load-time histories will consist of a number of load excursions with an irregular pattern and in irregular random sequence. The analysis of load-time histories has to be such that the amount of damage caused by these load excursions is somehow quantitatively reflected in the final results. With all analysis procedures of present interest, the actual time scale is irrelevant. Actually, the assumption is made that for fatigue evaluation purposes load-time histories are fully characterized by all peak values in their actual sequence irrespective of the time elapsed between successive peaks.

A number of different counting methods do exist in which specific occurrences within such simplified load histories are counted. The occurrences of interest are the following:

(1) Crossings of fixed levels with either a positive or a negative slope

(2) Peak values (either maxima or minima)

(3) Load variations (either load increments or decrements)

With counting procedures of type (1) and type (2), the counting results usually do not provide any direct information about those load variations known to influence the fatigue process. Additional information about the load patterns that do occur will generally be needed. Thus, secondary counting principles should be applied to account for sequence effects.

The different counting methods will be described in the next section. The discussion of each method will comprise these two distinct elements:

(1) Uniqueness of the counting method

(2) Usefulness of the counting results

The aspect of uniqueness will be discussed in connection with the secondary counting principles. In applying these secondary counting principles arbitrary parameter values may have to be adopted which may influence the final counting results.

Self-evidently, such influence (if considerable) would reduce the validity of the counting method, and the results would no longer be unique.

The usefulness of a counting method is influenced by its application; this relationship forms the basis for the discussion of the counting methods. The basic purposes are as follows:

(1) Estimating the life consumed by individual aircraft

(2) Estimating load spectra for future aircraft designs

(3) Selecting the loads for fatigue testing

The discussion will take into account the state-of-the-art in realising these three purposes.

DEFINITION OF COUNTING PROCEDURES

Ten different counting procedures are considered in the present evaluation, enumeration of which can be found in table I. It should be noted that although all methods are derived from the literature (refs. 1 to 7), slightly different names have been adopted for some of the methods to emphasize the characteristic differences between them.

Simple Level-Crossing Count Method

The simple level-crossing count method is the simplest way of analysing load histories. A number of preset levels are chosen. Each time the load crosses one of these levels with positive (or negative) slope, a count is made. Obviously, it does not matter whether level crossings are counted with positive or negative slope. Both procedures will provide almost exactly the same results (maximum difference will be 1 count at each level for each load history analysed). With this method only momentary load values are of interest. Information regarding the actual load patterns is fully lost. In order to interpret the counting results for fatigue evaluation purposes, additional information will be needed regarding the expected load patterns. The insufficiency of this counting method is clearly demonstrated by figure 1. Although the load patterns shown on the left-hand and right-hand sides of this figure are highly different, the same counting results will be obtained. Small intermediate load variations, which virtually are of minor importance in the fatigue process, will give rise to additional countings. Generally, interpretation of the counting results will be such that the number of crossings of a level is assumed to equal the number of maxima above (or minima below) that level. Figure 1 also clearly demonstrates the incorrectness of this assumption. Obviously, small intermediate load variations seriously hamper the validity of this counting method. In practical applications a secondary restriction may be applied to compensate to some extent for this setback. It may be decided to neglect level crossings which are associated with load variations smaller than a certain range value. This decision would actually mean skipping all load variations which do not exceed that assumed range value. This range filtering may be carried out by means of a logical system or may be due to the type of load transducer used, as for example with scratch gages (ref. 8).

Restricted Level-Crossing Count Method

The restricted level-crossing count method applies the same primary counting principles as the simple level-crossing count method. Different secondary counting principles are applied, however. A crossing of a level with positive (or negative) slope is not made until the load also has crossed a second lower (or higher) preset level in opposite direction. This counting method is associated with the so-called "Fatiguemeter" developed at the British Royal Aircraft Establishment (RAE) and is normally referred to in the literature as the Fatiguemeter count method. Although the Fatiguemeter was developed to count acceleration occurrences, the method may also be used to monitor other parameters such as strains. The adjustment of the secondary counting levels generally is of arbitrary nature. The drop or rise required to satisfy the secondary counting condition may be the same for all counting levels or may be chosen in a progressive way. With the progressive adjustment, the higher (or lower) the primary counting level concerned, the larger is the drop (or rise) required to satisfy the secondary counting condition. Still, however, interpretation is hampered by intermediate load cycles as is clearly demonstrated by figure 2. Rather different load patterns are depicted on the left-hand and right-hand sides of this figure but, as in the simple level-crossing count method, they will produce equal counting results.

Simple Peak Count Method

With the simple peak count method all peak values are counted. The counting results are presented separately for the maxima and the minima. From the definition it is understood that with this counting method, as well as with all other peak count methods, the load patterns that actually occur are taken into account to some extent since application of this method implies a peak detection. However, the counting results will not provide any information regarding the sequence of the maxima and the minima themselves. It is not possible to tell whether a counted peak was actually associated with small or large load variations. Again interpretation is seriously hampered by the smaller intermediate load variations. Much the same as with the simple level-crossing count method, a secondary counting condition may be introduced to more or less compensate for this setback by disregarding peaks which are not associated with at least a certain load range. It sometimes is decided to count only maxima above a specified mean level and minima below that level. This simplification does not improve the validity of the counting results at all. For example, minima associated with minor load ranges are sometimes neglected whereas the adjacent maxima would still be counted.

Level-Restricted Peak Count Method

The principles of the level-restricted peak count method are very much the same as those of the restricted level-crossing count method (Fatiguemeter counting). In contrast, however, with the restricted level-crossing count method, only a count is made pertaining to the highest primary counting level that has been crossed before the secondary counting condition was met, after which all other previous crossings of primary counting levels are disregarded. Actually, the crossings of primary and secondary counting levels are considered merely to detect a peak associated with at least a certain load range. Figure 3 shows a comparison of this method (see fig. 3(b)) with the restricted level-crossing count method (see fig. 3(a)). The final counting results do not provide definite information regarding the actual sequence of the maxima and the minima. The method has been widely used in association with VGH recording programs (ref. 3).

Range-Restricted Peak Count Method

With the range-restricted peak count method, the intention is to count merely the more significant peaks. The method will merely count peaks that are associated with major load variations. The counting is restricted to peaks beyond mean threshold levels (e.g., minima below 0-g and maxima above 2-g). The peaks to be counted are those which are both preceded and followed by drops (or rises) of at least a certain magnitude (e.g., 1-g increment) or exceeding a fixed percentage of the incremental peak value (e.g., 50 percent), whichever is the greater. Here the incremental peak value is defined as the difference between the peak value itself and the mean load level. The counting conditions for a maximum count are illustrated in figure 4. From the definition it is understood that intermediate load fluctuations are disregarded rather rigorously by this method. The method also neglects some load fluctuations which are not truly insignificant. However, counts pertaining to the higher maxima and the lower minima have become more relevant. The method has been used extensively with VGH recording programs (ref. 6).

Peak-Between-Mean-Crossings Count Method

The peak-between-mean-crossings count method is also intended to count only the more significant peaks. Only the highest maximum or the lowest minimum between two successive crossings of a specified mean level is counted. With this method intermediate load fluctuations are disregarded most rigorously. However, all counts are now known to be associated with major deviations from the steady-flight level. A further refinement of the counting procedure may be obtained by applying two mean threshold levels as references. The highest maximum will be counted between any two successive crossings of the upper threshold level, as well as the lowest minimum between any two successive crossings of the lower threshold level. The method is illustrated in figure 5. With this refinement, peaks associated with minor deviations from the steady-flight pattern will also be neglected. On the other hand, less high maxima and lower minima will be disregarded in applying this counting procedure. The method has been used extensively in evaluating VGH records (ref. 9).

Simple Range Count Method

With the simple range count method as well as with all other range count methods, the load fluctuations are of direct interest. The fluctuations are known to be a primary influence in the fatigue process. A range is defined as the difference between two successive peak values. With the simple range count method all ranges are counted. It should be noted here that counting ranges essentially implies a peak detection procedure. With this simple range count method the loading sequence is taken into account to some extent; that is, with each count two succeeding characteristic values of the load history are considered. However, information regarding the peak values themselves is completely lost.

In practical applications it may be decided to neglect small load fluctuations which are not of much importance for the fatigue process. As is illustrated in figure 6, disregarding such small load fluctuations does affect the final counting results seriously. Apparently, the final counting results will depend on the magnitude of the smallest load range that will be counted.

It may also be decided to count only ranges pertaining to load increments or load decrements. One should bear in mind, however, that the counting results for the positive ranges might differ appreciably from the counting results for the negative ranges. Consequently, such a simplification might yield less relevant results.

Range-Mean Count Method

The principles of the range-mean count method are very much the same as with the simple range count method. However, this counting method does provide additional information. Not merely the load ranges are counted. With each count the corresponding mean value of the load range counted will also be taken into account. So each count is now associated with two values which completely describe the load variation concerned.

As is clear from the definition, the counting results will again be sensitive to the smallest load range regarded.

Range-Pair Exceedance Count Method

The range-pair exceedance count method is intended to analyse load histories in terms of load cycles rather than load ranges (half cycles). Since fatigue properties are generally presented in terms of load cycles, this is of course a favourable property.

To accomplish a count two conditions must be met. Each count of a range-pair exceedance of a certain specified magnitude, say R, will have to be associated with a load increment (positive range) of at least R succeeded by a load decrement (negative range) of at least R. By proceeding as such and consecutively considering a number of different range values, the counting result will finally give the number of range pairs (load cycles) exceeding a certain range value R. The counting procedure is illustrated in figure 7. The Vickers-Armstrongs strain range counter (ref. 10) is an example of a counting device operating according to this counting method. In considering figure 7, it becomes clear that the method will primarily count the major load fluctuations. Small intermediate load fluctuations will be regarded as superpositions on the major load patterns. Obviously, this counting method does take into account the loading sequence. Fatigue test experience indicates that this characteristic feature is desirable. The counting procedure also has the advantage of being insensitive to the magnitude of the smallest load range regarded.

Another interesting feature of this counting method will become clear by considering the largest range-pair value that will be present in the final counting results. By nature, the range-pair exceedance count method will combine the largest load increment and load decrement that both occur in the load history concerned and will count them as one load cycle of that specific magnitude. Likewise, the counting procedure will also combine the next largest load increment with the next largest load decrement, and so on. From fatigue experience it is known that extreme negative load excursions do actually influence the damage caused by a succeeding extreme positive load excursion. So it may be stated that fatigue experience is indeed reflected in the counting principles. Nevertheless, this feature does imply a complication. It certainly is not relevant to combine a very low minimum with a very high maximum which occur at instances very much apart. In practical applications the method should be carried out separately on segments of the load history to avoid irrelevant countings. Treating each flight as such, a separate load-history segment seems to be a both obvious and rather practical approach.

Another example of a counting device operating according to this counting procedure is the Schenck range-pair counter (ref. 5). With this counting device, however, the starting procedure is not altogether in accordance with the basic counting principles. In starting the counting process the device will analyse the load history as if the starting point of the load history were an extreme minimum. This actually means that for the first count to be made, merely the second condition of the basic counting principles will have to be met. The effect is illustrated in figure 8 and demonstrates that the Schenck procedure will produce higher counting results than the basic procedure. In applying the counting procedure on a flight-by-flight basis, the effect on the final counting results might be significant.

Although the range-pair exceedance count method does apply rather sophisticated counting principles, the method is still hindered by two shortcomings:

(1) No information will be provided regarding the mean values of the load cycles counted.

(2) Not all load excursions will be fully counted (see fig. 9).

Both shortcomings are offset by the next counting method.

Range-Pair-Range Count Method

The range-pair-range count method is also intended to count load cycles. The counting procedure operates in two phases. In the first phase all intermediate load cycles are detected and counted in connection with the associated mean values. Each intermediate load cycle will be eliminated from the load history after being counted. The procedure is continued until the load history does not present any more intermediate load cycles. As may be easily verified, the residual load history will necessarily have a divergent-convergent envelope such as depicted in figure 9. In the second phase of the counting procedure, this residual load history is analysed according to the range-mean count method. These counting principles are illustrated in figure 10. The range-pair-range counting procedure is referred to in the literature as the NLR counting method (ref. 2) and the rain-flow counting method (ref. 4).

This range-pair-range counting method generally has the same advantages as the range-pair exceedance count method without being hindered by its previously mentioned shortcomings. It should be noted that this counting method also is intended to analyse load histories on a flight-by-flight basis.

NUMERICAL EVALUATION DATA

Under contract for the Royal Netherlands Air Force a tentative load monitoring program has been carried out. This load monitoring program was intended to serve the following primary purposes:

(1) To demonstrate the feasibility of a digital load recording system

(2) To demonstrate the feasibility of a strain gage as a load transducer in operational conditions for long-term load monitoring

(3) To emphasize the desirability of recording strain histories instead of acceleration histories

(4) To evaluate different counting methods

Two operational fighter aircraft have been equipped with both an accelerometer transducer at the aircraft c.g. and a bending-moment strain-gage installation in the wing root section. Signal values from both transducers were sampled at a scanning rate of 24/sec. After being digitised, the data were stored on a magnetic recorder medium with a 15-hour recording capacity. The beginning of each flight could be recognized by a series of marking numbers which were automatically entered on the recorder medium at the activation of the aircraft electrical power. Every 15 flight hours the recorder medium was removed for further processing on ground-based facilities. By means of a digital computer the data were checked for spurious readings after which a data compression was carried out.

The data compression reduced the enormous amount of data to a relatively small number of characteristic data resembling the peak values that did occur. The compressed load-time history still comprises all significant information for fatigue evaluation purposes. During the data compression phase more than just peak values are detected. Peaks which are not associated with at least a certain relatively small variation are disregarded to reduce the number of data and to remove data that are of less importance for the purposes concerned. The minimum load range thus left in the compressed load-time history amounted to approximately 7 percent of the aircraft limit load level. When applying the counting procedures just described, such a range filtering is either obligatory or does not significantly affect the counting results since other more stringent restrictions are applied. Consequently, the load histories resulting from the final data compression phase are still suited to evaluate the different statistical load counting procedures. A plot of such a compressed load-time history for a typical fighter mission is shown in figure 11. Such load histories – covering some 75 flight hours – were used to evaluate the different counting methods. The results of this numerical evaluation are presented in the next section.

NUMERICAL RESULTS

General Comments

The counting procedures which have been described herein were simulated by means of a digital computer to analyse the available load-time histories. The results obtained with the c.g.-acceleration history and the wing-root-bending-moment strain-gage history are presented separately. It should be noted that this paper is not intended to present a quantitative comparison of the counting results obtained for the acceleration history with those obtained for the strain-gage history.

The load data are presented in arbitrary units as a result of the digitisation process. In general, the counting results were calculated with an interval width of 8 units. The results have been plotted without any fairing.

Application of some counting methods did imply the definition of a mean level. For the c.g.-acceleration data the 1-g steady-flight level has been defined as such, although in terms of mathematical statistics this level is not actually the mean value but rather the most probable value. An "equivalent" 1-g level has been assessed to be used as mean reference level in the strain-gage data analysis. Actually, the equivalent 1-g strain-gage value is not a constant value. Nevertheless, the definition remains relevant since, on the one hand, merely a reference level has to be chosen while, on the other hand, with high-performance aircraft the variations in this 1-g strain-gage value are relatively small in comparison with the load fluctuations of general interest.

Before discussing the numerical results, it should be mentioned that the counting results obtained with different counting procedures are not all fully independent of each other. The following relations do exist which will all be easily understood by considering the definitions given for the various methods:

(1) Simple level-crossing counting results may be derived from the counting results obtained with the simple peak count method.

(2) Simple peak counting results may be derived from both the counting results obtained with the range-mean count method and those obtained with the range-pair-range count method.

(3) Simple range counting results may be derived from the range-mean counting results.

(4) The results obtained with the simple peak count method and the peak-between-mean-crossings count method will be the upper and lower limits of the counting results obtained with all other level-crossing and peak count methods described.

(5) Peak-between-mean-crossings counting results may be derived from the range-pair-range counting results.

Results From Level-Crossing and Peak Count Methods

The results obtained with the level-crossing and peak count methods are presented in figures 12 to 15 and table II.

As previously stated, parameter values associated with secondary counting principles may influence the final counting results. The effect is illustrated in figure 12, figure 13, figure 14, and table II for the counting results obtained with the simple level-crossing count method, simple peak count method, peak-between-mean-crossings count method, and restricted level-crossing count method, respectively.

In figures 12 and 13 it is shown that the value of the smallest load range regarded does indeed affect the counting results obtained with the simple level-crossing and simple peak count method. The effect of doubling the basic range-filter value (R_o) from 13 to 26 units does not seriously affect the counting results for the higher load values. Apparently the countings which were additionally disregarded were mainly associated with load cycles near the steady-flight level. Further increasing the range-filter value hardly changed the counting results for the higher load values. However, applying a smaller range-filter value yielded highly different counting results. The main conclusion to be drawn is that if a sensible range-filter value is adopted, the counting results for the higher load values are rather unique. It is nevertheless interesting to note that the counting results obtained by analysing the strain-gage history appear to be more sensitive to the adopted range-filter value than the results obtained by analysing the acceleration history. In considering both load histories in more detail, the major load excursions from the strain-gage history presented small intermediate load fluctuations more frequently than did the major load excursions from the acceleration history. This effect is most probably due to dynamic effects (dynamic overshoot and buffeting).

By definition it is clear that the restricted level-crossing count method, the level-restricted peak count method, and the range-restricted peak count method are intended to apply secondary counting principles which at least override the applied basic range filtering. From the preceding results the effect of the applied secondary parameter values may be expected to be rather limited. This limited effect is indeed confirmed by the data from table II, in which the restricted level-crossing counting results are tabulated by applying two different adjustments of the secondary counting levels. The counting results came out to be only slightly different. Similar results were obtained with the level-restricted and range-restricted count methods. Also with the peak-between-mean-crossings count method (fig. 14), the influence of the secondary parameter values (e.g., mean threshold levels) was rather limited. From these findings it may be concluded that the majority of the load fluctuations of interest were separate excursions from the steady-flight level.

All the level-crossing and peak count methods described are compared in figure 15. As might be expected from the aforementioned findings, the differences are not large, although they are more pronounced with the strain-gage data than with the acceleration data. Nevertheless, when accurate data are required, the results obtained with different counting methods are not fully compatible (number of counts may differ by a factor of 2).

Results From Range Count Methods

The results obtained with the range count methods are depicted in figures 16 to 18. It should be noted that these results have been plotted without distinguishing between positive and negative ranges. This effect has been studied in connection with the simple range count method. Comparative results showed that when applying the basic range-filter value of 13 units, the number of positive and negative ranges counted did not differ very much. However, when applying a smaller range-filter value, the differences appeared to be much more pronounced. The counting results pertaining to the negative ranges appeared to be far more sensitive to the applied range-filter value than the counting results pertaining to the positive ranges. Apparently, small intermediate load fluctuations more frequently occurred after the load had reached a maximum. The overall effect of the applied range-filter value on the results obtained with the simple range count method is illustrated in figure 16. Doubling the basic range-filter value from 13 to 26 units does appreciably affect the counting results, especially the results obtained by analysing the strain-gage history. When applying a smaller range-filter value than the basic one, the differences were even more pronounced. It should be noted that further increasing the applied range-filter value (>26 units) still yielded appreciably different counting results. Consequently, it is stated that the results obtained by the simple range count method are not unique even when intermediate load fluctuations are disregarded.

The counting results from the various range count methods are compared in figure 17. The curves presented illustrate that the range-pair-range count method and both variants of the range-pair exceedance count method do not produce very different results. The simple range counting results, however, appear to be very different. It is interesting to note that with the strain-gage data, both variants of the range-pair exceedance count method coincide completely because of the presence of the Ground-Air-Ground (G-A-G) cycle (with every flight the strain-gage history will exhibit a relatively low starting value).

In comparing the mean countings as obtained by the range-mean count method and range-pair-range count method, the results have been averaged – that is, all mean countings pertaining to a specified range interval have been averaged while a corresponding standard-deviation value has been calculated. The averaged means thus derived are represented in figure 18. With the c.g.-acceleration data as well as with the strain-gage data, the range-pair-range count method yielded lower averaged mean values than did the range-mean count method. However, the differences are much more pronounced with the strain-gage data. This fact may be easily understood by considering the counting principles of the range-pair-range count method and bearing in mind that in every flight the strain-gage history will both start and end with a low minimum due to the G-A-G cycle. These results clearly demonstrate that with the range-pair-range count method the G-A-G cycle is certainly accounted for.

The calculated standard-deviation values corresponding to the averaged means are not plotted in figure 18. It is interesting to note, however, that these standard-deviation values were approximately equal for all range intervals considered and, besides, appeared to be relatively small (order of magnitude of 10 units). From this finding it may be concluded that most load fluctuations of equal magnitude apparently occurred between approximately the same levels.

Comparison of Range Count Methods With Peak Count Methods

By nature the results obtained by the range count methods are not directly comparable with the countings resulting from the level-crossing and peak count methods since different types of occurrences are counted. To enable a comparison the counting results have to be converted. The present comparison will be accomplished by applying different ways of converting simple peak countings into range countings. Reference will be made especially to the range-pair-range counting results since this method is believed to represent best the amount of fatigue damage caused by the load history concerned. The following three conversion procedures are considered (see fig. 19):

(A) Maxima and minima are supposed to occur in random sequence.

(B) Maxima and minima are supposed to occur in random sequence; however, maxima below a certain level (e.g., 115 units) and minima above a certain level (e.g., 95 units) are neglected. Although the additional assumption seems a curious one, the case is relevant since actually the data disregarded generally are not available.

(C) Maxima are to be combined with minima having the same probability of exceedance (equal cumulative frequency).

The results of these converted simple peak countings as well as the range-pair-range countings and simple range countings are plotted in figure 19. As is illustrated, the applied conversion procedures do produce highly different results. Again the strain-gage data reveal the largest differences. However, none of the applied conversion procedures produce counting results which approximately coincide with the range-pair-range countings. From these findings, it is concluded that a quantitative comparison of range countings with simple peak countings as well as with all other types of peak and level-crossing countings is hardly feasible for the type of load histories concerned.

DISCUSSION

Basically the counting methods as described herein are intended to interpret irregular load-time histories by counting the number of specific types of load occurrences. In the preceding sections the uniqueness of the information has already been discussed and illustrated. In discussing the usefulness of the counting results, one should primarily take into account the purposes these results are meant to serve – that is, the type of information required.

In assessing the life consumed by individual aircraft, reference has to be made to experimental fatigue data, either simple S-N data or full-scale fatigue test data. Accomplishing such life calculations, however, will be useful only if the final counting results are sufficiently accurate. Thus, in assessing the life consumed by individual aircraft, a counting method should be used which fully takes into account the actual load-time history and which does not need the application of additional assumptions to be interpreted. Besides, the fatigue damage caused by the actual load-time history should be reflected in the counting results (interaction effects). By considering its definition and bearing in mind the aforementioned requirements, it is felt that the range-pair-range count method is best suited for assessing the individual aircraft fatigue damage. Also, the range-pair exceedance count method may be rather useful; however, with this method the counting results are not definite since no information is provided about the means of the range pairs counted. Consequently, less accurate results are to be expected. It should be noted that the same remarks hold when the counting methods are meant to compare with any degree of accuracy the life consumed by individual aircraft of the same type. Here, however, the requirements perhaps could be less stringent since it may be known that the aircraft are operating according to the same type of load patterns. In this case, restricted level-crossing or restricted peak count methods may be suited as well.

In estimating load spectra for future aircraft designs or selecting the loads for fatigue testing of an aircraft type that possibly has not even been in service operation, the requirements are somewhat different. Here, great accuracy would be more apparent than real. The load patterns as well as the sequence in which they occur may be entirely different with different types of aircraft. In particular, the number of intermediate load fluctuations at the higher load levels may be expected to be strongly related to the aerodynamic performance capabilities, which may be highly different for different aircraft types. Estimating loading spectra as well as selecting loads for fatigue testing usually implies a mission analysis procedure. The number of exercises (during a mission) that will be carried out has to be estimated. The assumption made is that each separate exercise is associated with major load excursions from the steady-flight level ("characteristic events"). Small intermediate load fluctuations are considered of less or even irrelevant importance. A counting method should be chosen which will provide the number of such major load excursions and the peak levels they are associated with. As will be understood, the peak-between-mean-crossings count method is very well in accordance with these requirements. However, a restricted level-crossing or peak count method may be suited as well. To obtain a loading program for fatigue testing, the number of "events" counted may be arranged in a realistic sequence. Interaction effects will then be accounted for to some extent.

It can be concluded that the range-pair-range count method apparently has the best general validity. On the one hand, the method embodies some of the characteristics of the other counting methods mentioned (simple level-crossing countings, simple peak countings, and peak-between-mean-crossings countings may all be derived from the results of this range-pair-range count method). On the other hand, the load histories are taken into account by this method as much as possible from the fatigue point of view. Consequently, general application is recommended.

CONCLUSIONS

(1) Some counting methods require secondary counting restrictions involving the choice of an arbitrary parameter value which may influence the final counting results. With the exception of the simple range count method and the range-mean count method, a sensible parameter value can be found which will yield rather unique counting results for maneuver-type load histories.

(2) The restricted level-crossing and restricted peak count methods will yield approximately equal counting results, especially at the higher load levels. The simple level-crossing and simple peak count methods, however, will yield conservative counting results.

(3) Level-crossing and peak countings virtually do not compare very well with range countings.

(4) The range-pair-range count method and the range-pair exceedance count method will produce approximately equal range counting results.

(5) Both the simple range count method and the range-mean count method will provide irrelevant information since the counting results are very sensitive to the magnitude of the smallest load ranges regarded.

(6) Both the range-pair exceedance count method and the range-pair-range count method provide relevant information in assessing the life consumed by individual aircraft. However, the range-pair-range count method is to be preferred since this method provides additional information about mean values of the ranges.

(7) In comparing individual lives of aircraft that are of the same type and that operate according to the same kind of duties, a restricted level-crossing or restricted peak count method may be sufficiently relevant.

(8) In estimating spectra for future aircraft designs or in selecting load events for fatigue testing, the peak-between-mean-crossings peak count method will provide relevant data.

(9) The range-pair-range count method will have the best general validity. The results obtained by this method are unique as well as definite and do suit all purposes.

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TABLE I: COUNTING PROCEDURES

SIMPLE LEVEL-CROSSING COUNT METHOD RESTRICTED LEVEL-CROSSING COUNT METHOD
SIMPLE PEAK COUNT METHOD LEVEL-RESTRICTED PEAK COUNT METHOD RANGE-RESTRICTED " " " PEAK-BETWEEN-MEAN-CROSSINGS COUNT METHOD
SIMPLE RANGE COUNT METHOD RANGE-MEAN " " RANGE-PAIR EXCEEDANCE COUNT METHOD RANGE-PAIR-RANGE COUNT METHOD

TABLE II: RESULTS OF RESTRICTED LEVEL-CROSSING COUNT METHOD FOR C.G.-ACCELERATION HISTORY

PRIMARY COUNTING LEVEL (G)	SECOND. COUNTING LEVEL (G)		NUMBER OF COUNTS	
	EQUIDISTANT ADJUSTMENT	PROGRESSIVE ADJUSTMENT	EQUIDISTANT ADJUSTMENT	PROGRESSIVE ADJUSTMENT
-1.0	-0.5	0	-	-
0	0.5	0.5	17	17
2.0	1.5	1.5	1019	1019
3.0	2.5	1.5	402	343
3.5	3.0	2.0	194	180
4.0	3.5	2.0	76	70
4.5	4.0	2.5	29	27
5.0	4.5	3.0	10	9

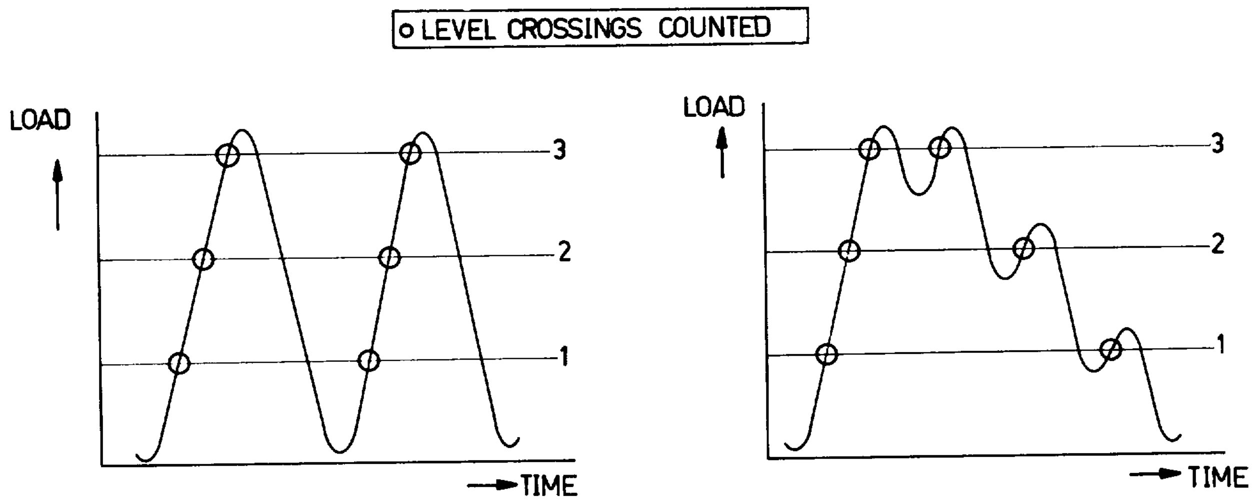


Figure 1.- Simple level-crossing count method.

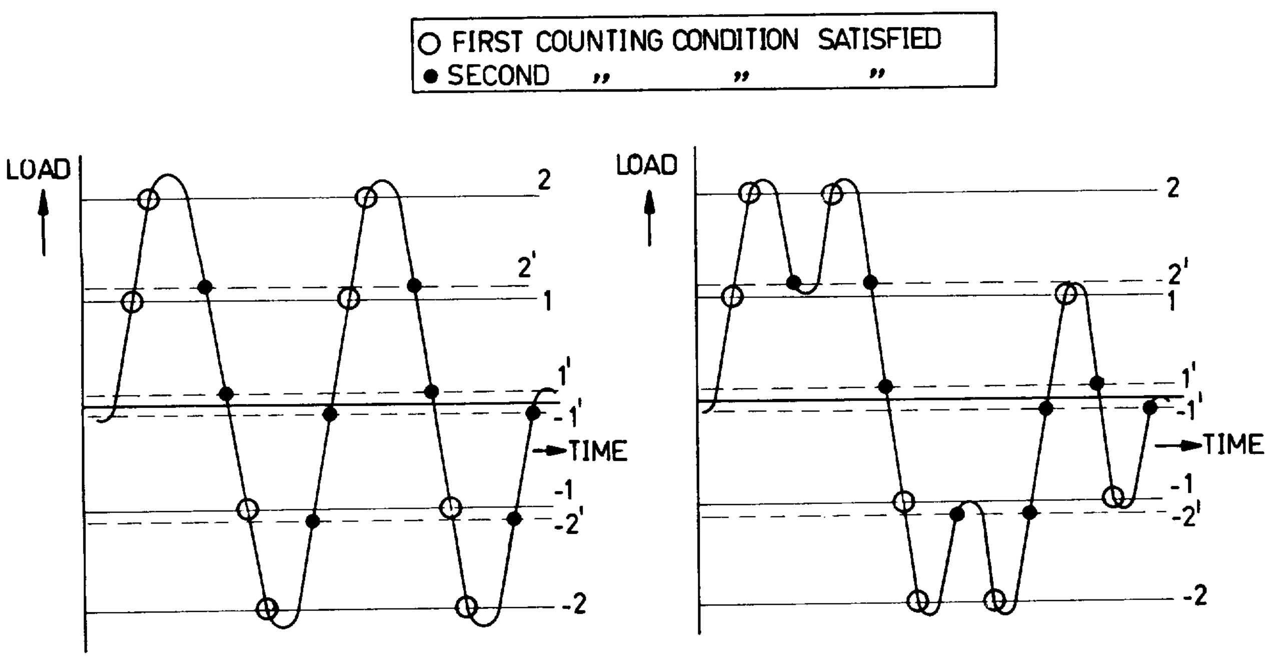


Figure 2.- Restricted level-crossing count method.

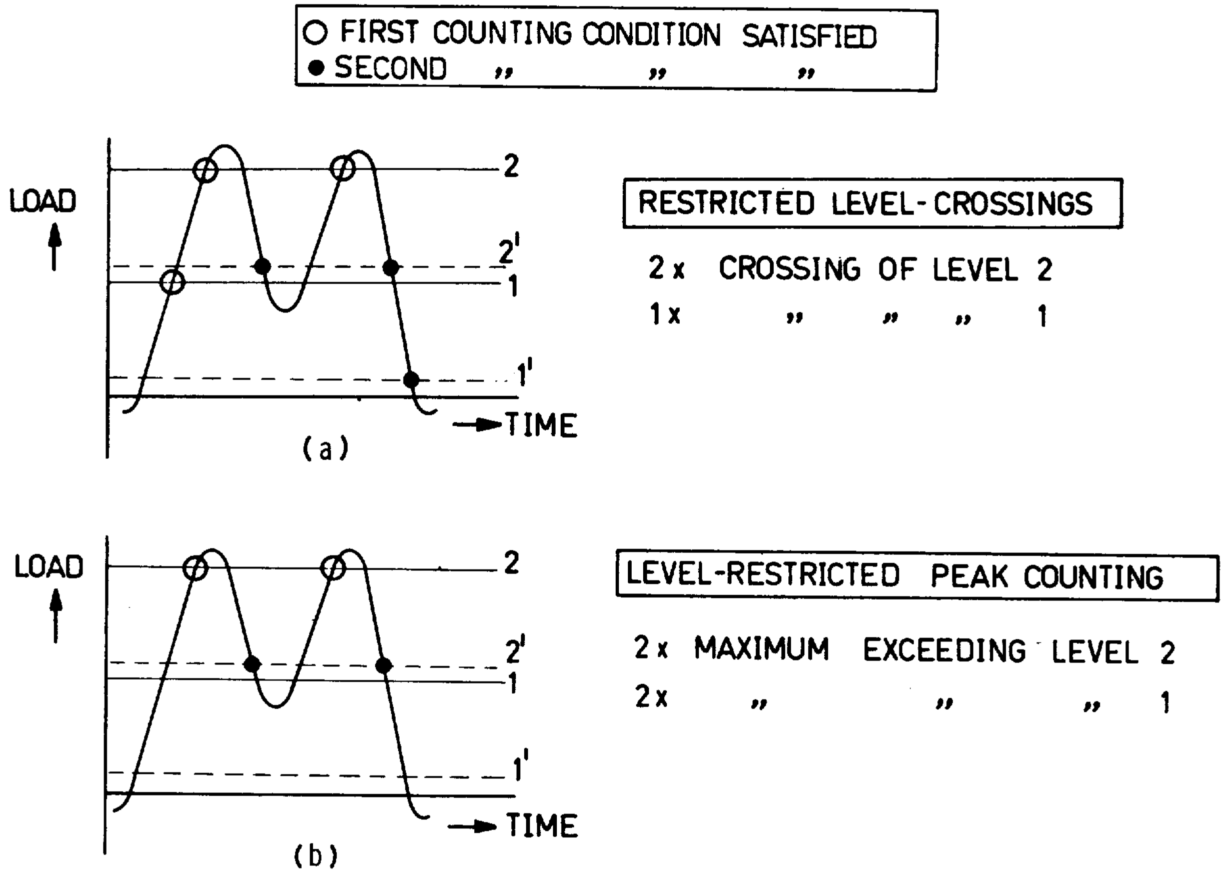


Figure 3.- Comparison of level-restricted peak count method with restricted level-crossing count method.

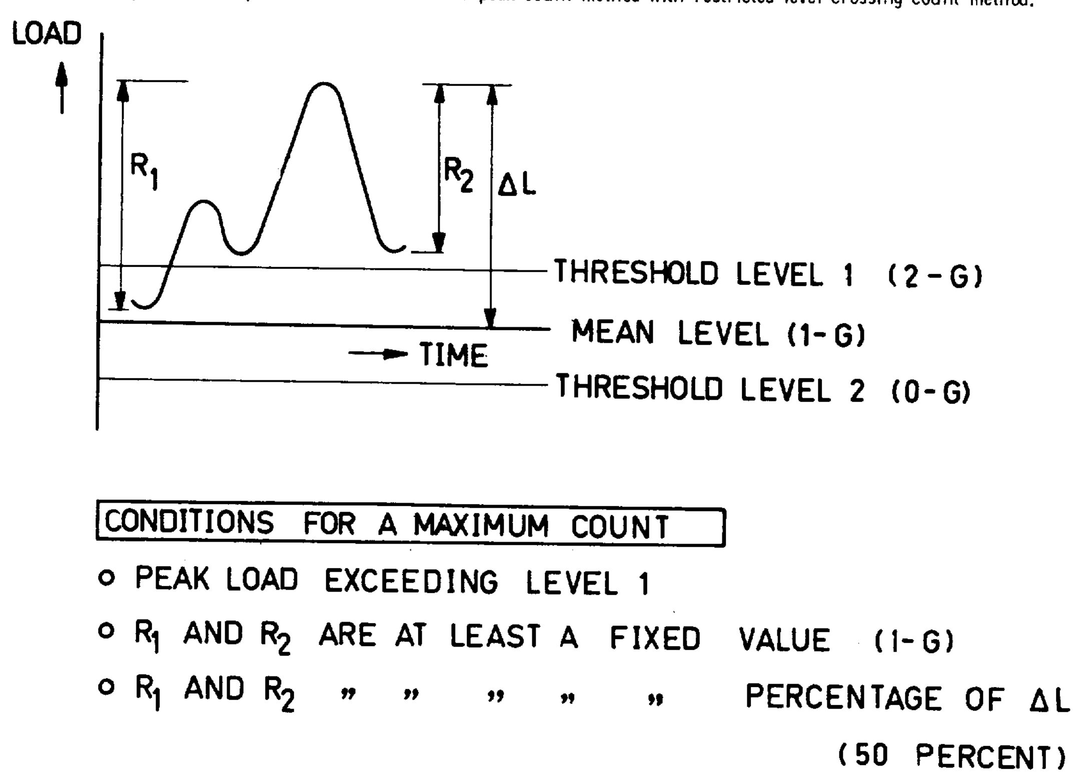


Figure 4.- Range-restricted peak count method.

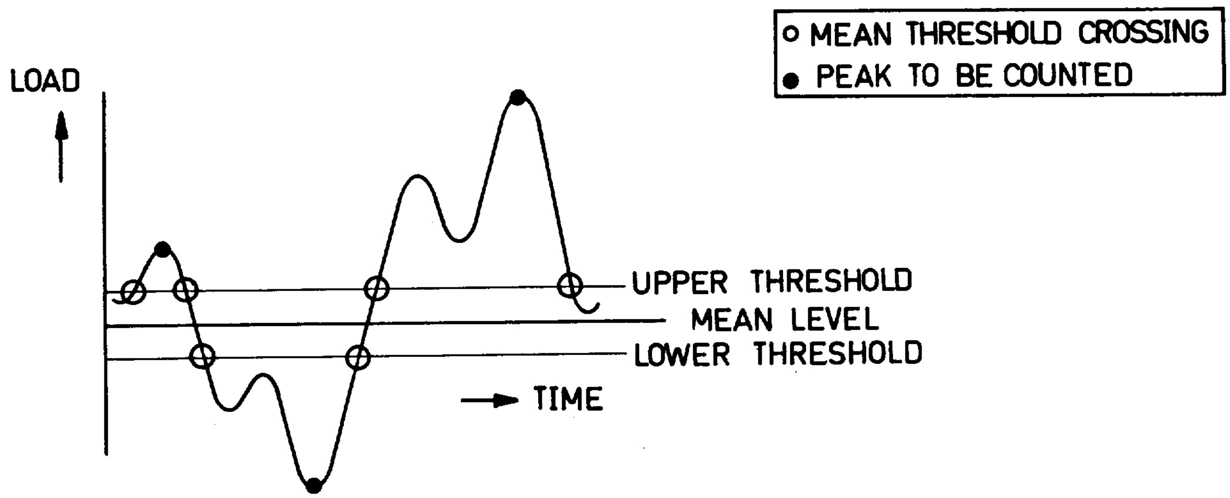


Figure 5.- Peak-between-mean-crossings count method.

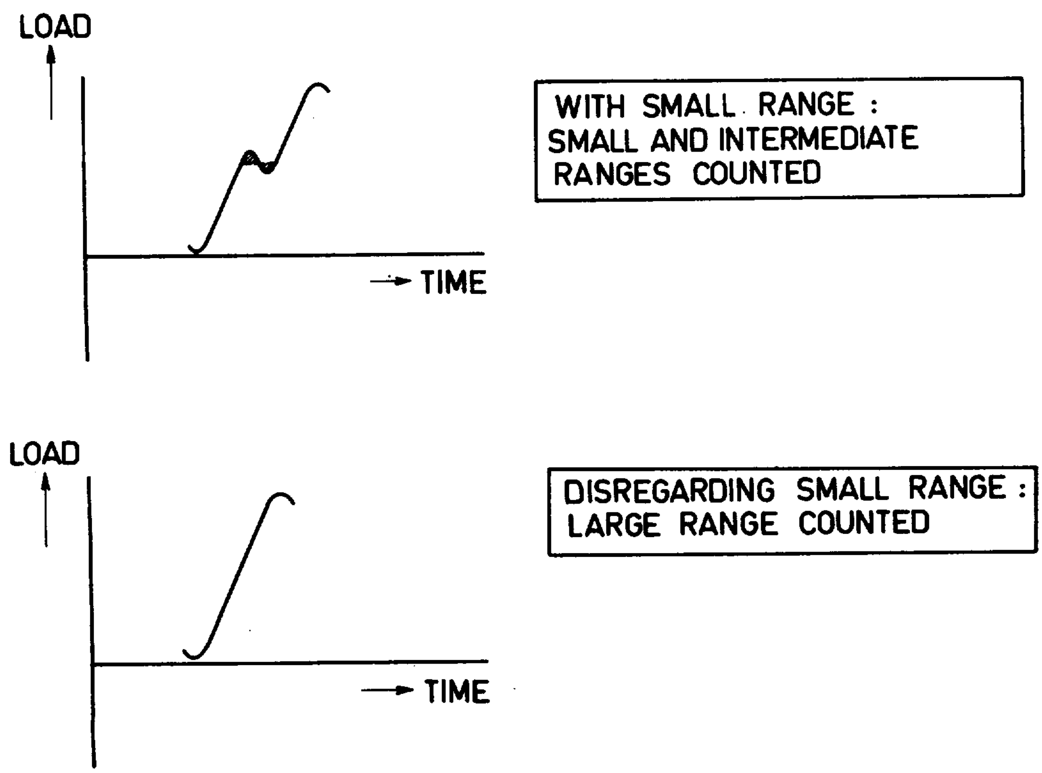


Figure 6.- Effect of disregarding small ranges with the simple range count method.

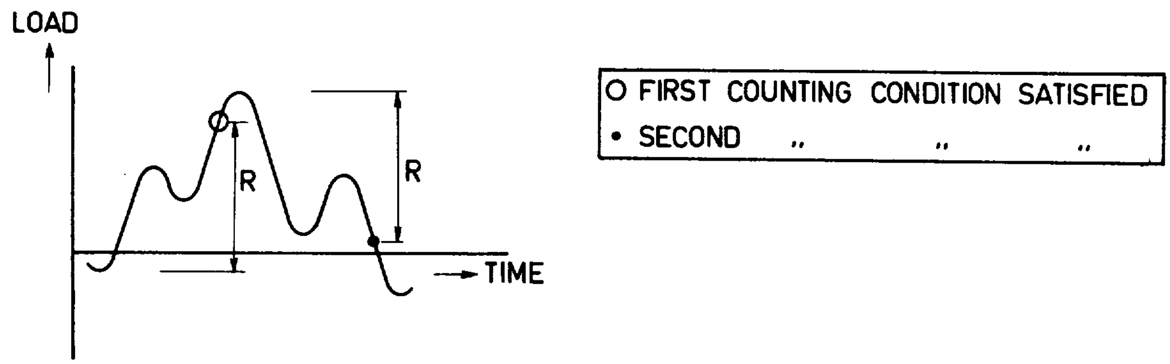


Figure 7.- Range-pair exceedance count method.

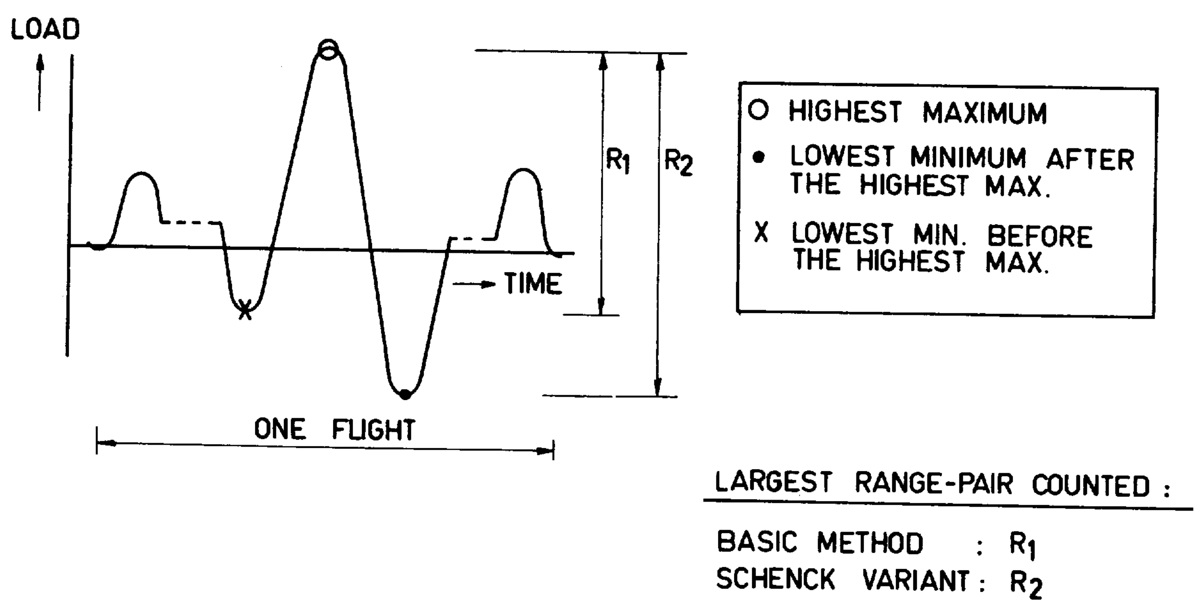


Figure 8.- Comparison of basic range-pair exceedance count method with Schenck variant.

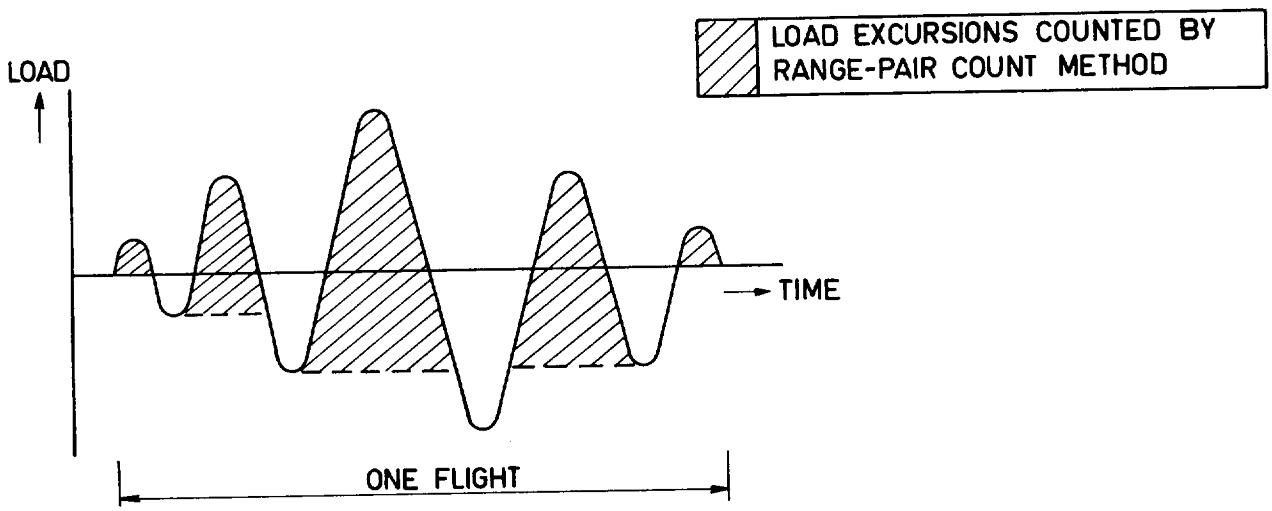


Figure 9.- Flight record with omission of intermediate load cycles.

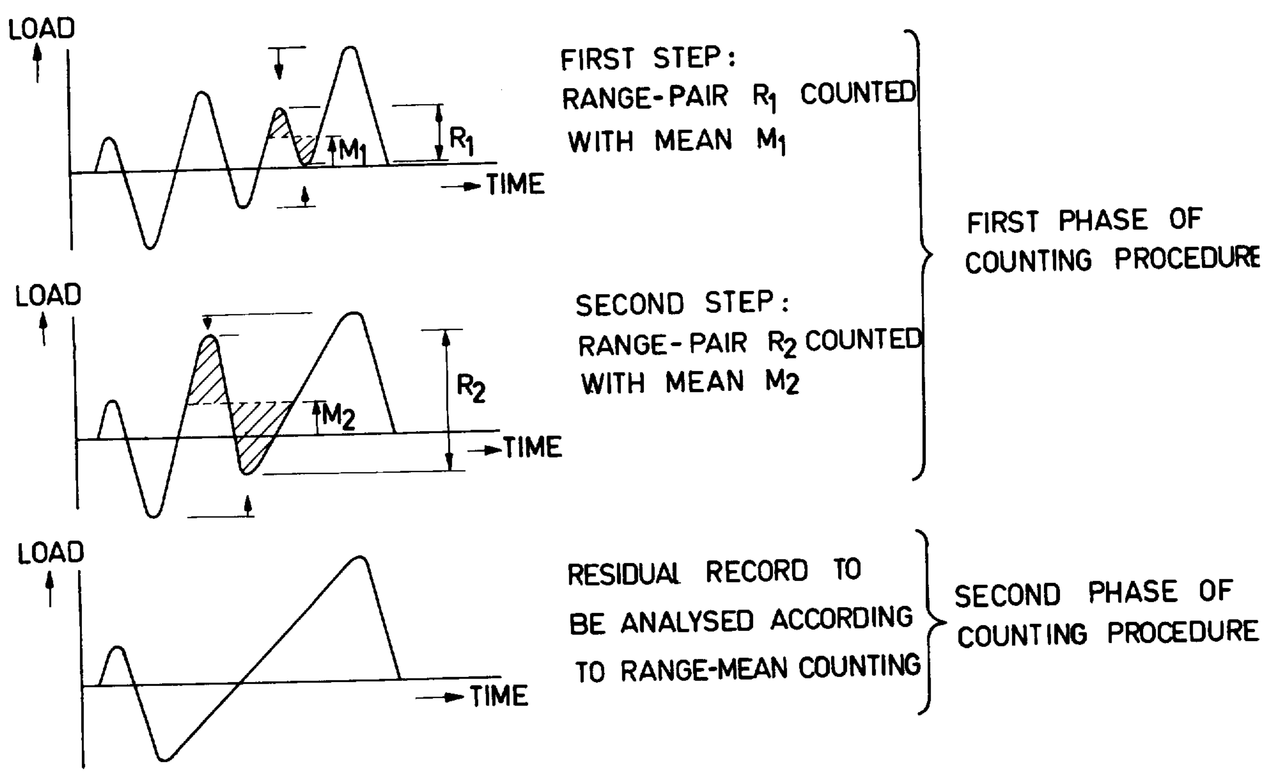


Figure 10.- Illustration of range-pair-range count method.

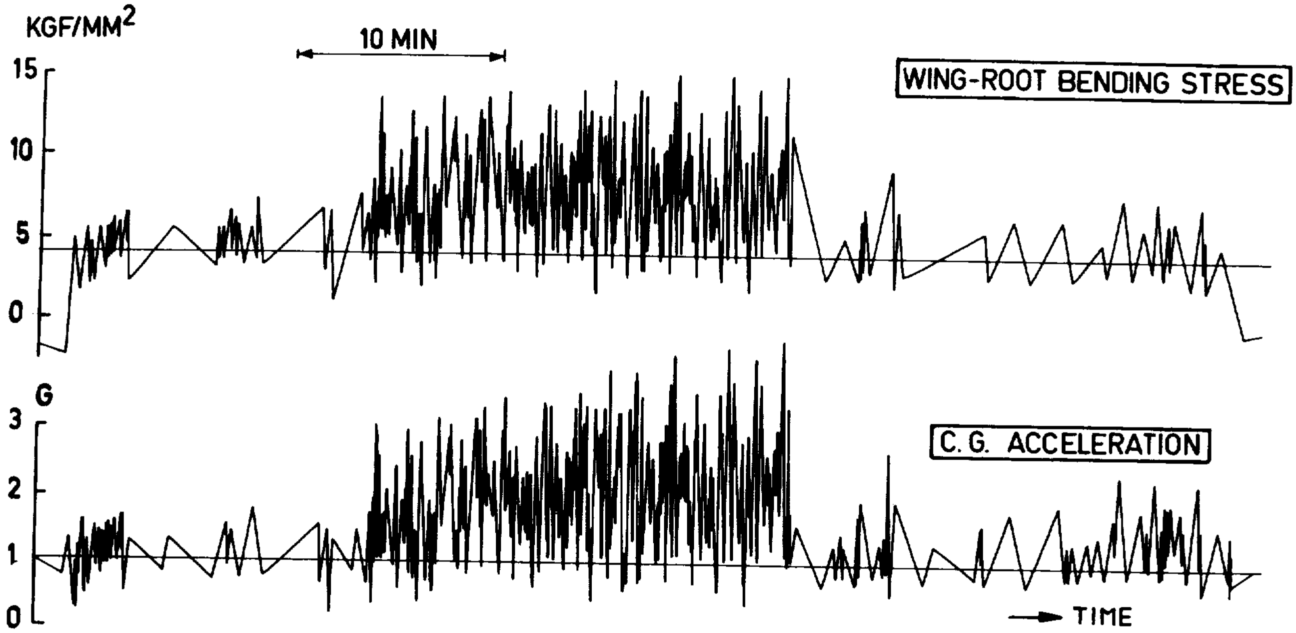
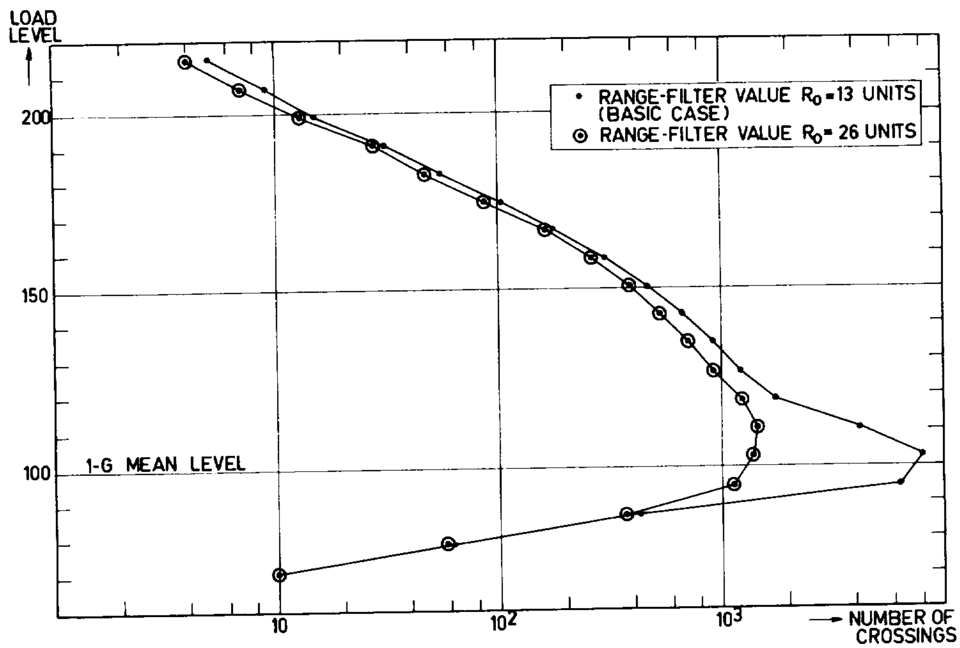
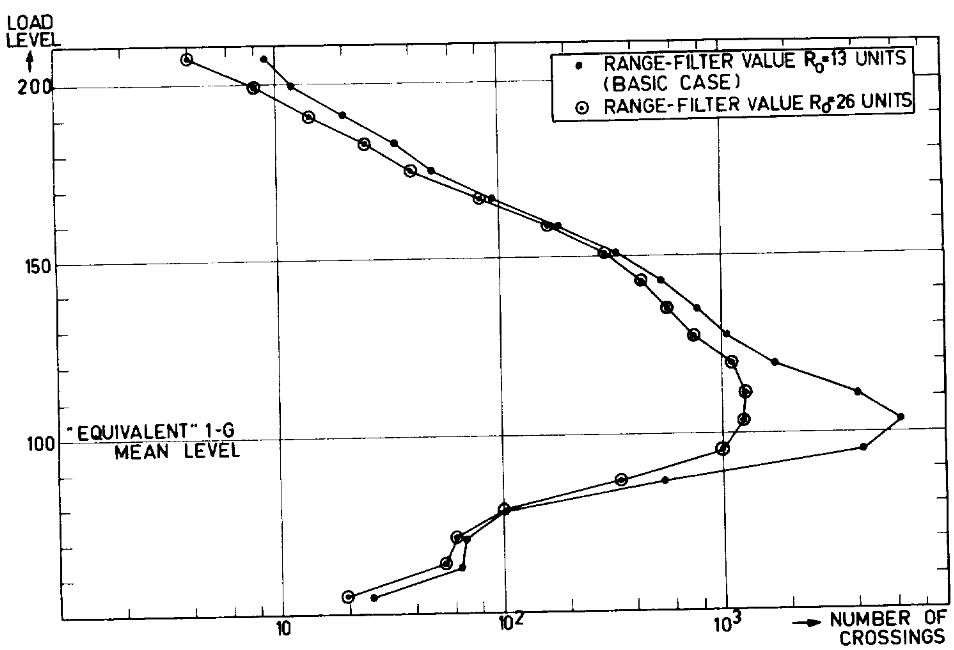


Figure 11.- Compressed load-time history of a typical fighter mission.



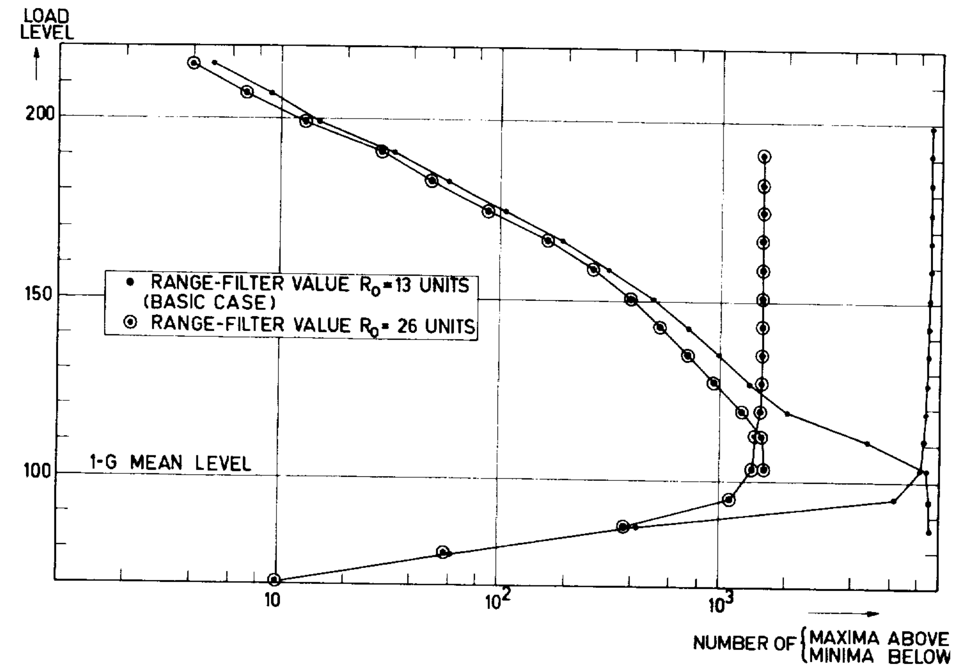
(a) Results for c.g. acceleration.

Figure 12.- Simple level-crossing counting results.



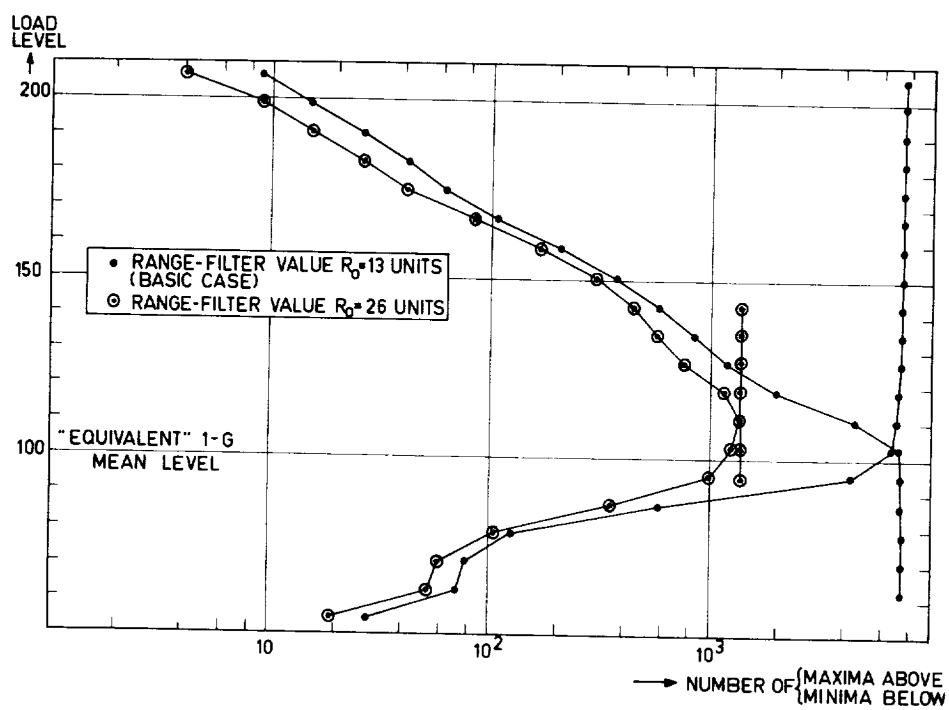
(b) Results for wing-root bending stress.

Figure 12.- Concluded.



(a) Results for c.g. acceleration.

Figure 13.- Simple peak counting results.



(b) Results for wing-root bending stress.

Figure 13.- Concluded.

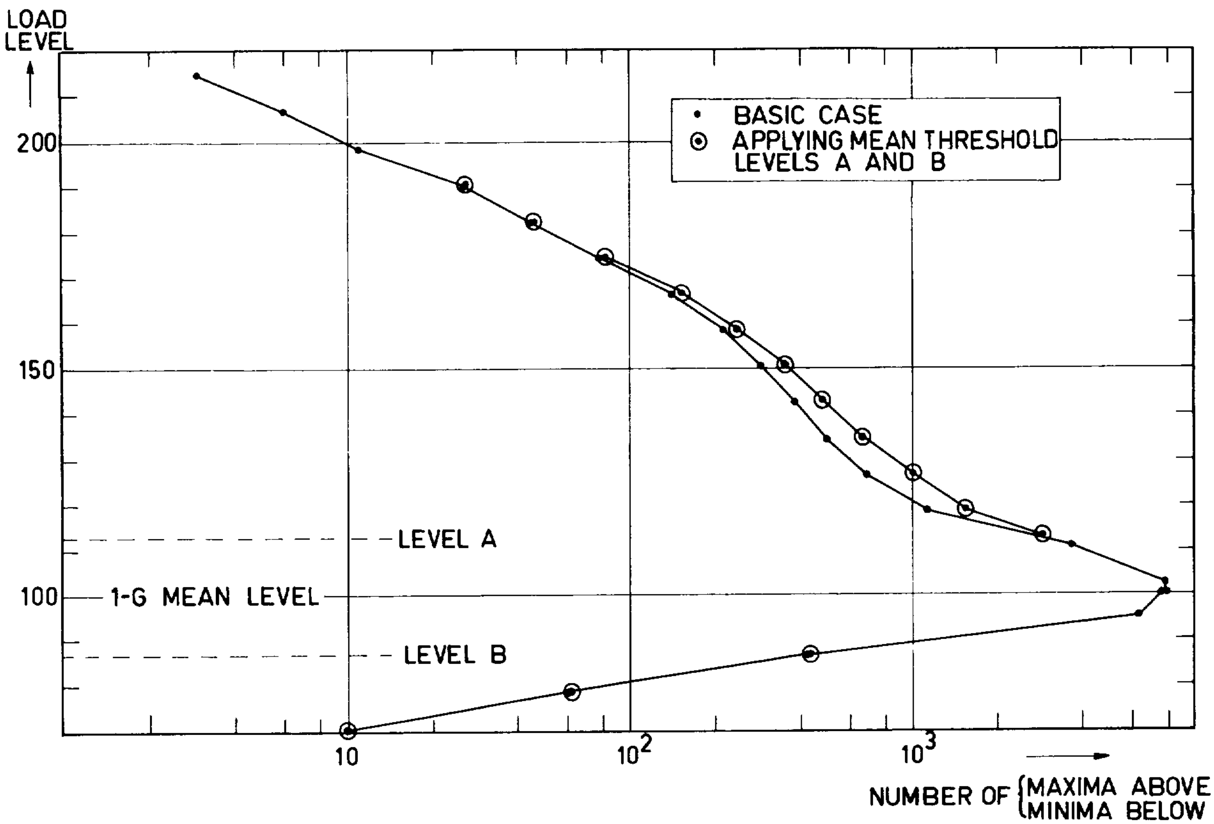
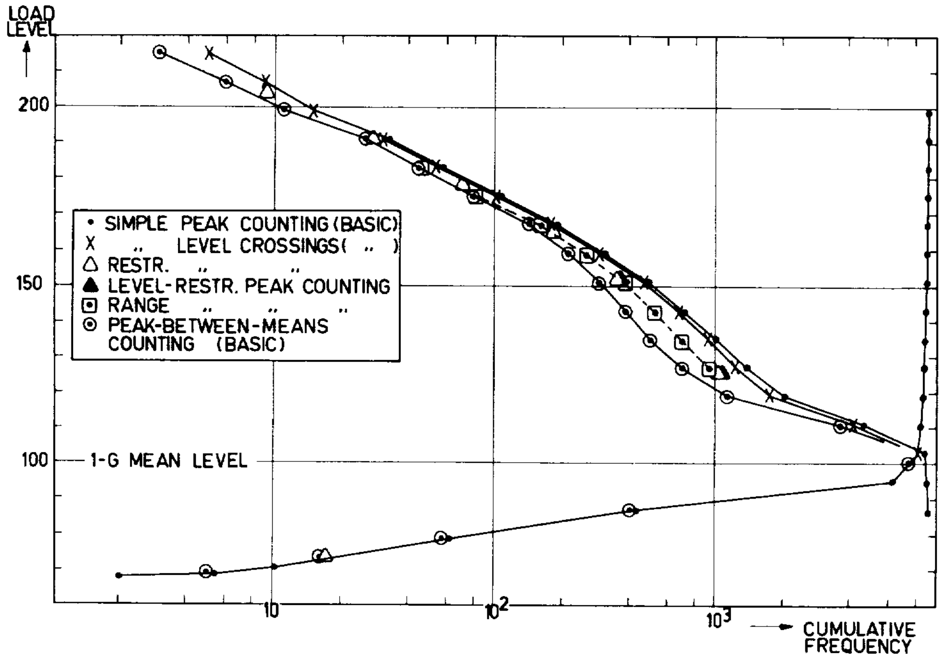
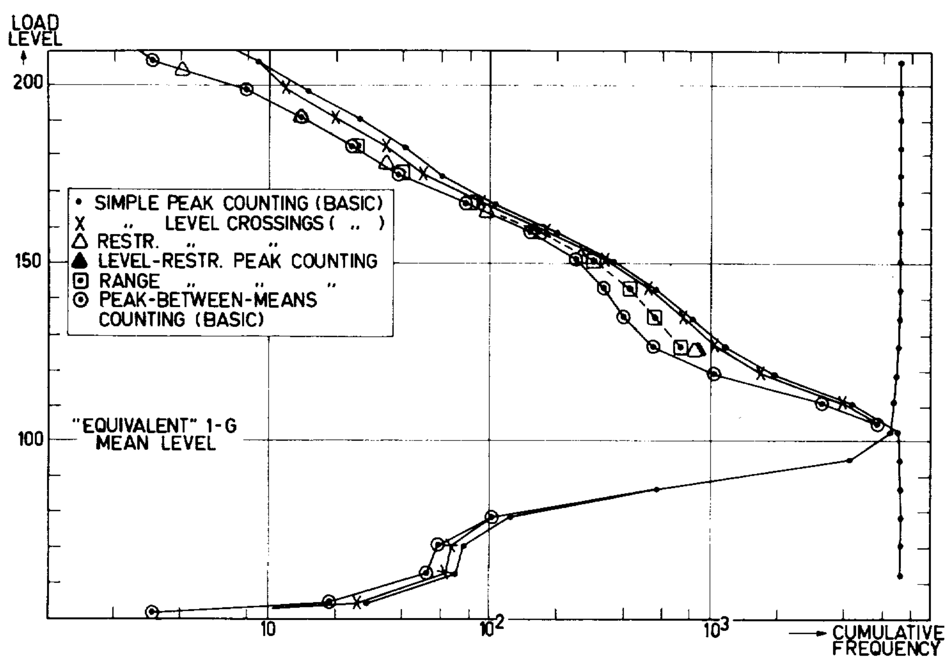


Figure 14.- Peak-between-mean-crossings counting results for c.g. acceleration.



(a) Results for c.g. acceleration.

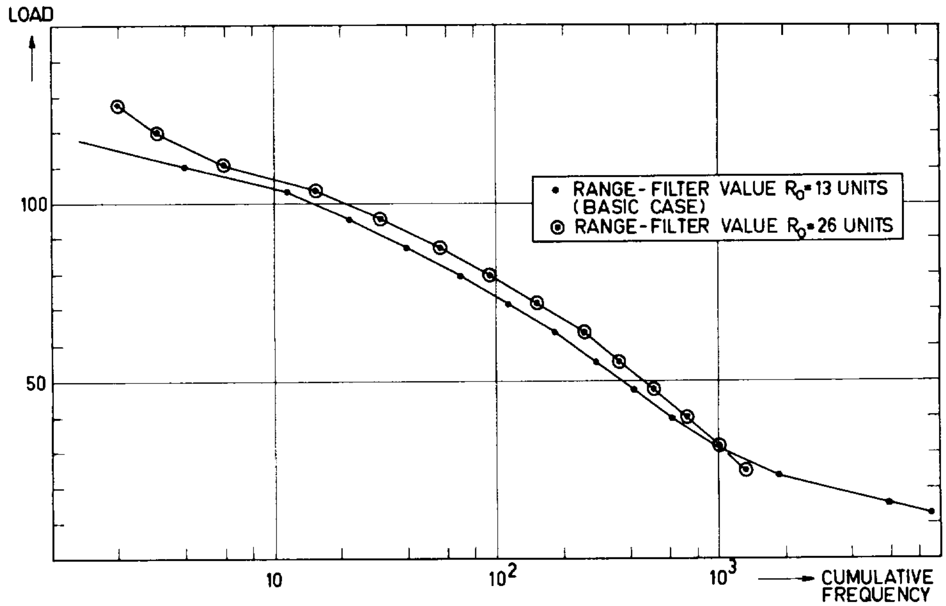
Figure 15.- Comparison of level-crossing and peak count methods.



(b) Results for wing-root bending moment.

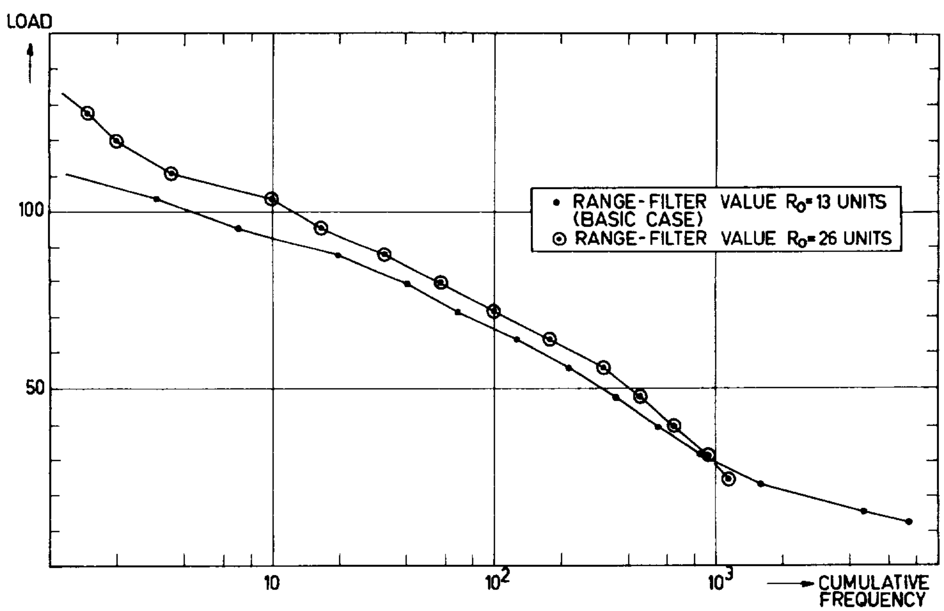
Figure 15.- Concluded.

C, 11



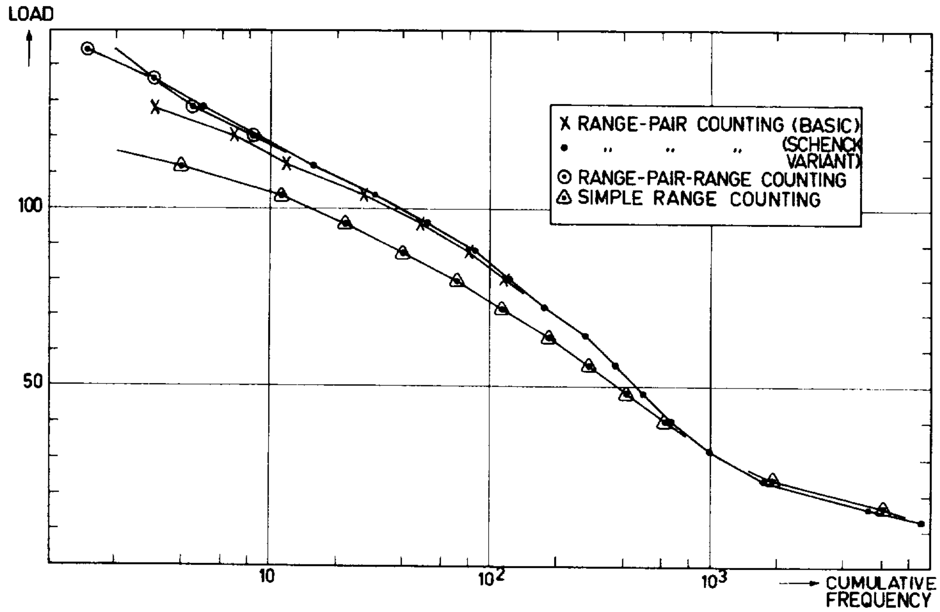
(a) Results for c.g. acceleration.

Figure 16.- Results of simple range counting.



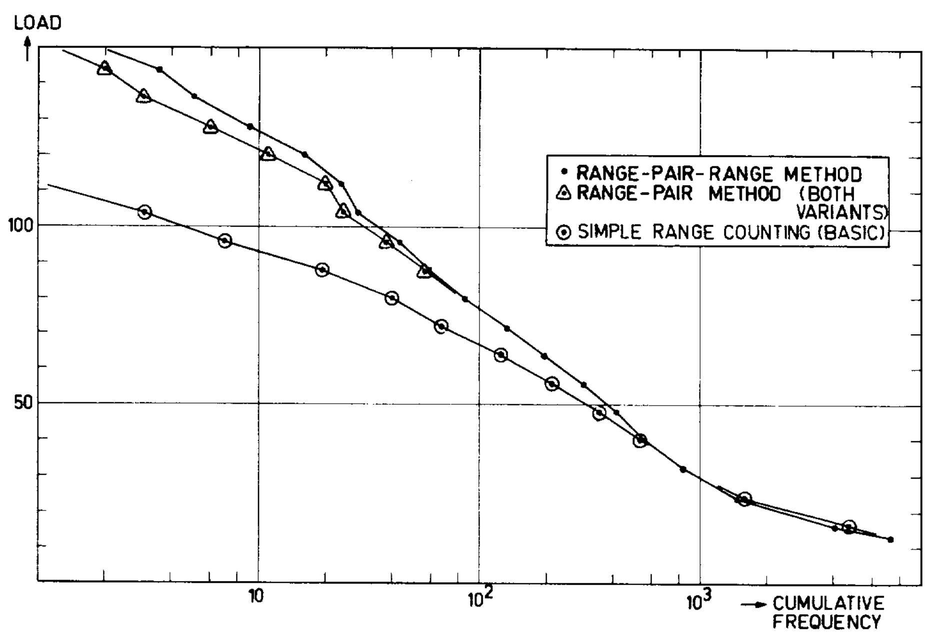
(b) Results for wing-root bending stress.

Figure 16.- Concluded.



(a) Results for c.g. acceleration.

Figure 17.- Range countings.



(b) Results for wing-root bending stress.

Figure 17.- Concluded.

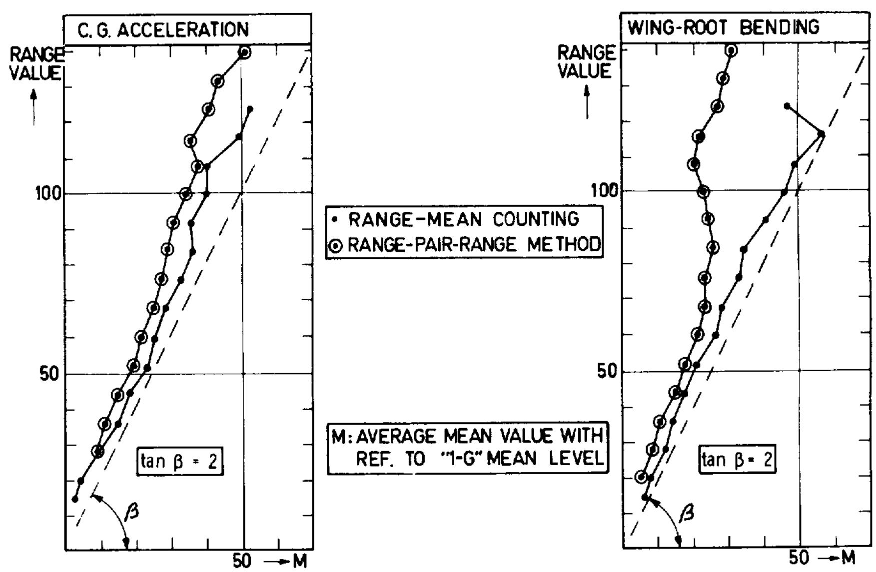
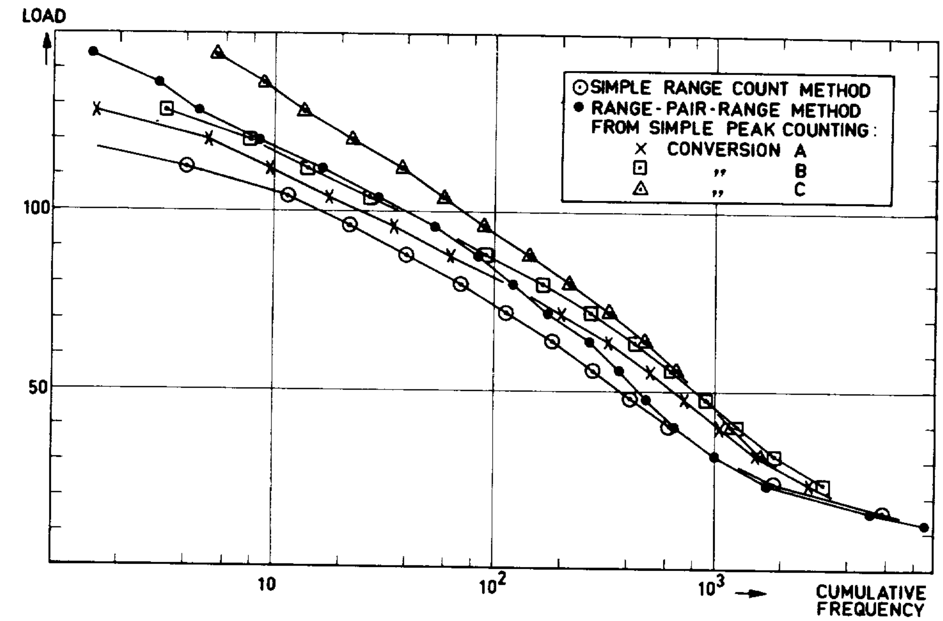
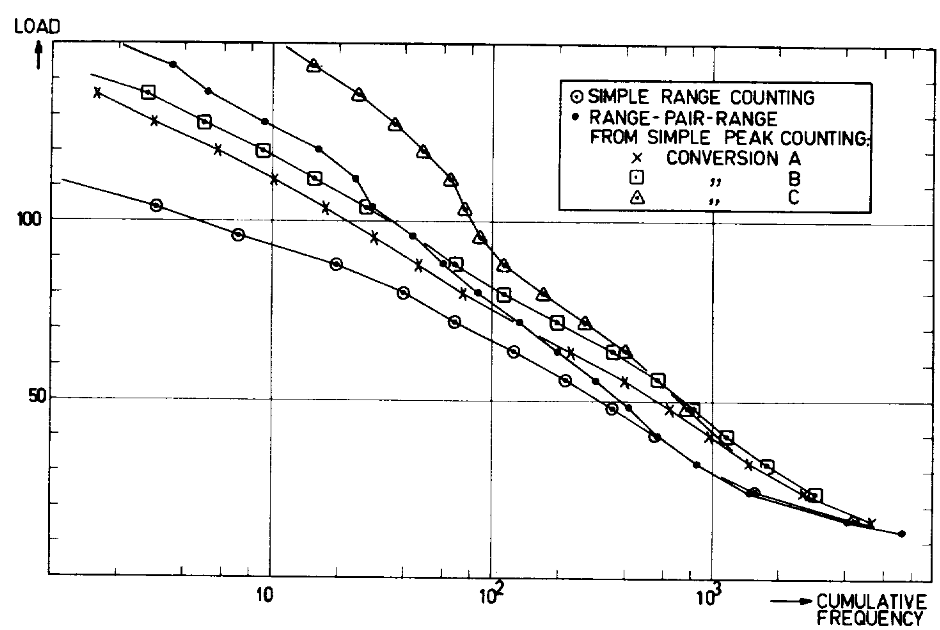


Figure 18.- Comparison of averaged means.



(a) Results for c.g. acceleration.

Figure 19.- Peak countings compared with range countings.



(b) Results for wing-root bending stress.

Figure 19.- Concluded.